Cambridge Checkpoints VCE 2024

Physics Units 3&4

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Preface

This book is a collection of over 1000 practice/review questions for the VCE Physics written examinations to be held in 2024. The examination covers content in the areas of Newtonian mechanics, field models of gravitation, magnetism and electrostatics, generation and transmission of electric power, mechanical waves, light modelled as both waves and particles, wave properties of matter, special relativity, and principles of practical investigation.

This book is designed to serve as a comprehensive source of practice questions in the same style as the VCAA Units 3 and 4 examination questions. As such, it contains the combined wisdom of many Physics educators over a long period.

The examination is out of 120 marks and is of two and a half hours duration with an extra quarter of an hour reading time. The examination contains a block of 20 multiple-choice questions, each worth one mark. Short answer questions (normally worth between 1 and 18 marks) make up the rest of the paper and total 100 marks. Each chapter mirrors this general format, including almost all the past VCAA questions from 2016 to 2023. A copy of the examination data sheet is included as well.

In addition to past VCAA Victorian End of Year and NHT (Northern Hemisphere Timetable) examination questions, there are about 500 original questions in the same range of formats and styles, covering all examinable concepts in the study design. Some teachers and students have found these questions a useful first step before past exam questions are tackled.

The questions have been grouped into 20 chapters. The chapter titles do not correspond exactly to study design headings, but they have been arranged for an effective and reasonably logical approach to teaching and learning the content. Teachers will no doubt arrange their own courses in a variety of ways.

Answers and short solutions have been provided to all questions.

Marks have been attached to all the questions to indicate the weighting (or likely weighting) each question or question part have had or would have in the actual examination.

About the authors

Dr Syd Boydell has had a long association with university and Years 11 and 12 Physics, including involvement in course design, teacher preparation and evaluation, classroom teaching, together with setting, vetting and marking examinations.

Dr Eddy de Jong has been involved with science and physics education at the secondary and tertiary level for many years. He has taught science at all levels, senior HSC/VCE Physics and university physics. He was involved in the Victorian Gifted Students Physics Network, has had a long association with Year 12 Physics, including involvement in course design; classroom teaching; and setting, vetting and marking the examinations. He is a successful author of numerous science and physics texts, including *Cambridge Victorian Science Years 7–10*, *Cambridge Senior Science Physics Units 1&2* and *Cambridge Senior Science Physics Units 3&4*.

Contents

Chapter 1 Motion basics

Question 1/ 11

Which one of the following is closest to the final speed and distance travelled of a ball dropped from a height on the surface of Mars and falls for 3.5 s?

(*g* on $\mathrm{Mars} = 3.7\ \mathrm{m\ s^{-2}}$)

A $\mathrm{Final\ speed} = 35\ \mathrm{m\ s^{-1}};\ \mathrm{distance} = 61\ \mathrm{m}$

B $\mathrm{Final\ speed} = 35\ \mathrm{m\ s^{-1}};\ \mathrm{distance} = 123\ \mathrm{m}$

C $\mathrm{Final\ speed} = 13\ \mathrm{m\ s^{-1}};\ \mathrm{distance} = 46\ \mathrm{m}$

D $\mathrm{Final\ speed} = 13\ \mathrm{m\ s^{-1}};\ \mathrm{distance} = 23\ \mathrm{m}$

Question 2/ 11

$25\ \mathrm{km\ h^{-1}}$ is closest to which one of the following?

A $6.9\ \mathrm{m\ s^{-1}}$

B $69\ \mathrm{m\ s^{-1}}$

C $90\ \mathrm{m\ s^{-1}}$

D $250\ \mathrm{m\ s^{-1}}$

Question 3/ 11

A car accelerates at $2.0\ \mathrm{m\ s^{-2}}$ for 5.0 s, and at the end of this time is moving at $30\ \mathrm{m\ s^{-1}}$. Which one of the following is closest to the distance covered in this time?

A 20 m

B 125 m

C 150 m

D 175 m

Question 4/ 11

Which one of the following is the closest to the speed of the car at the start of the 5.0 s period?

A 5 m s^{-1}

B 10 m s^{-1}

C 15 m s^{-1}

D 20 m s^{-1}

Question 5/ 11

A ball is thrown directly upwards with an initial speed of 25 m s^{-1}. (Neglect air resistance in the following three questions.)

Question 6/ 11

Which of the following best describes the minimum speed of the ball during its flight and the time it occurs?

A $\text{Minimum speed} = 0 \text{ m s}^{-1} \text{ at } t = 2.6 \text{ s}$

B Minimum speed $= 0 \text{ m s}^{-1}$ at $t = 4.9 \text{ s}$

C Minimum speed $= 10 \text{ m s}^{-1}$ at $t = 2.6 \text{ s}$

D Minimum speed $= 10 \text{ m s}^{-1}$ at $t = 4.9 \text{ s}$

Question 7/ 11

Which of the following best describes the distance and displacement of the ball during its flight?

A Distance $= 0 \text{ m}$ and displacement $= 0 \text{ m}$

B Distance $= 31 \text{ m}$ and displacement $= 32 \text{ m}$

C Distance $= 64 \text{ m}$ and displacement $= 32 \text{ m}$

D Distance $= 64 \text{ m}$ and displacement $= 0 \text{ m}$

Question 8/ 11

Which one of the following best describes the acceleration of the ball during its flight?

A The acceleration direction reverses halfway through the flight.

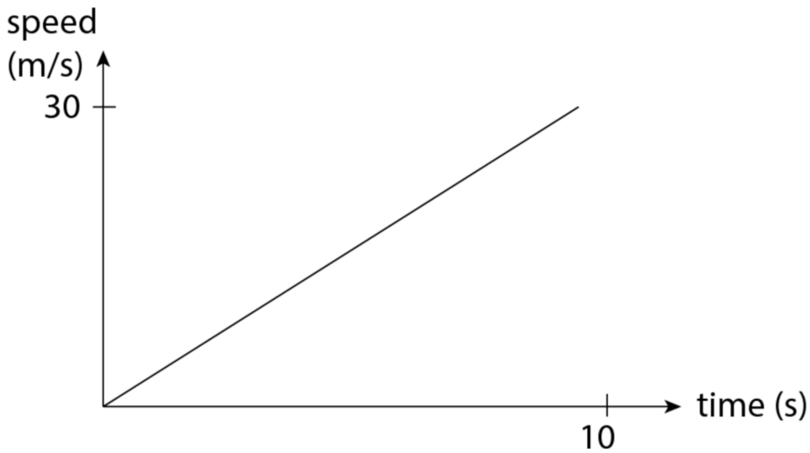
B The acceleration direction is constant throughout the flight.

C The acceleration magnitude decreases during the flight.

D The acceleration magnitude increases during the flight.

Question 9/ 11

The speed–time graph below describes the motion of an object.



Question 10/ 11

Which one of the following best describes the motion of the object at $t = 5$ s?

A $\text{Speed} = 15 \text{ m s}^{-1}$; acceleration increasing; $\text{distance travelled} = 150 \text{ m}$

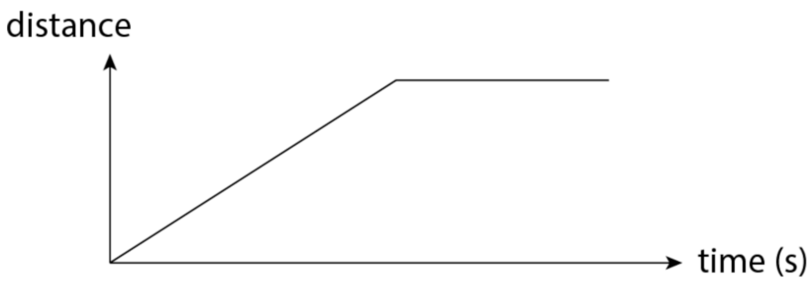
B $\text{Speed} = 15 \text{ m s}^{-1}$; acceleration constant; $\text{distance travelled} = 38 \text{ m}$

C $\text{Speed} = 10 \text{ m s}^{-1}$; acceleration constant; $\text{distance travelled} = 38 \text{ m}$

D $\text{Speed} = 15 \text{ m s}^{-1}$; acceleration constant; $\text{distance travelled} = 75 \text{ m}$

Question 11/ 11

The distance-time graph below describes the motion of an object.



Question 12/ 11

Which one of the following best describes this motion?

A Constant speed followed by no motion

B Increasing speed followed by constant speed

C Increasing acceleration followed by constant acceleration

D Increasing distance followed by constant speed

Question 13/ 11

Two trains travel along the same track at $40\ \mathrm{m\ s^{-1}}$ towards each other. At a separation of 1 km, they start to brake, each with a constant deceleration of $1.7\ \mathrm{m\ s^{-2}}$. Which one of the following describes what happens?

A The two trains collide.

B The two trains stop with less than 1 m between them.

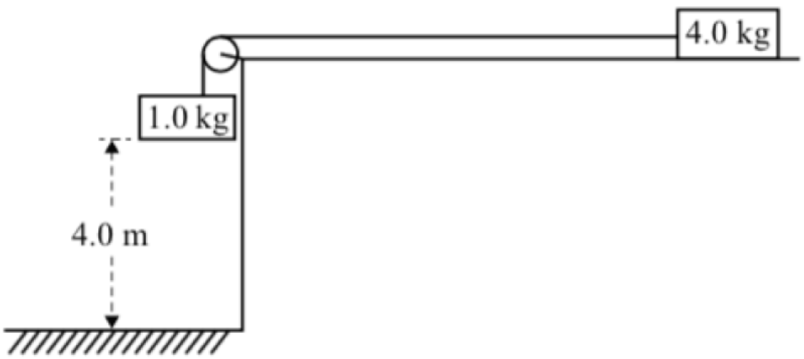
C The two trains stop with about 30 m between them.

D The two trains stop with about 60 m between them.

Question 14/ 11

[Adapted VCAA 2018 NHT SA Q8]

A 1.0 kg mass attached to a string hangs 4.0 m from the ground. The string is massless. The string is connected to a 4.0 kg mass on a horizontal frictionless table. The masses are released from rest and accelerate at 1.96 m s^{-2}.



Which one of the following best gives the speed of the 4.0 kg mass when the 1.0 kg mass strikes the ground after falling 4.0 m?

A 2.0 m s^{-1}

B 4.0 m s^{-1}

C 8.0 m s^{-1}

D 16 m s^{-1}

Question 1/ 22

A speeding motorbike travels past a stationary police car at a speed of 35 m s^{-1}. The police car starts accelerating immediately at 4.0 m s^{-2}, and it keeps accelerating at this rate until it has passed the bike.

a. At what time does the police car overtake the motorbike?

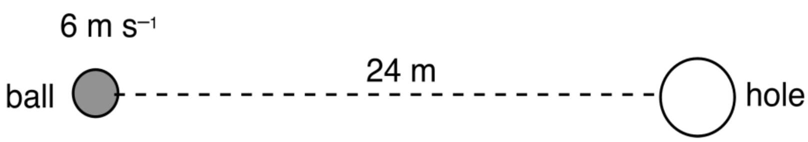
(2 marks)

b. How far does the police car travel before it overtakes the motorbike?

(2 marks)

Question 2/ 22

A golf ball rolls across a smooth grass ‘green’ towards a hole. It is heading straight for the hole. The hole is 24 m distant from the ball, as shown below.



The aim is to make the ball fall in the hole. If it is travelling faster than $2 \mathrm{~m} \mathrm{~s}^{-1}$ when it reaches the hole, it will not fall in. If the ball is slowing down at $0.7 \mathrm{~m} \mathrm{~s}^{-2}$, will it fall in the hole?

(3 marks)

Question 3/ 22

A baseball player slides across the ground towards third base. There is considerable friction; he slows down quickly. He slides a distance of 4 m and then stops. Before the slide, he was moving at $9 \mathrm{~m} \mathrm{~s}^{-1}$.

a. What was his average deceleration during the slide?

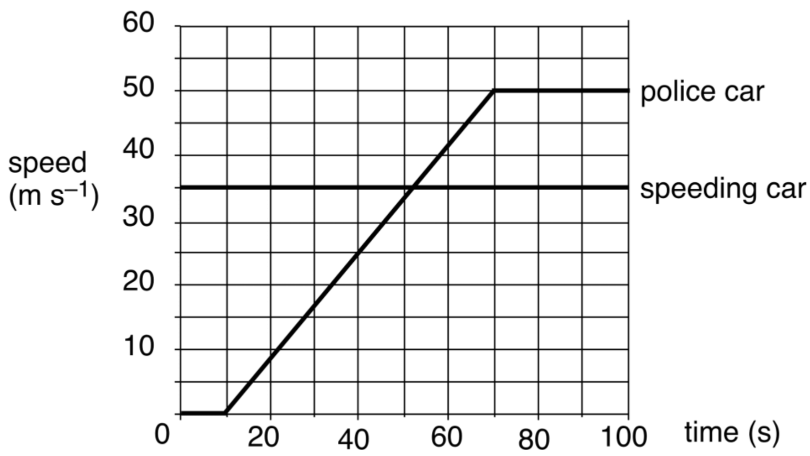
(2 marks)

b. How long (in time) did the slide last?

(2 marks)

Question 4/ 22

The graph shows the speed of two cars. The local speed limit is $90 \mathrm{~km} \mathrm{~h}^{-1}$.



a. By how much is the speeding car exceeding the speed limit?

(2 marks)

b. The police car gives chase to the speeding car 10 s after it passes. What is the acceleration of the police car at time $t = 45 \text{ s}$ s on the graph?

(2 marks)

c. Using the graph, calculate whether the police car has passed the speeding car by the time of 100 s.

(4 marks)

Question 5/ 22

A cyclist accelerates constantly from rest for 10 s at 2.5 m s^{-2}. In the next 20 s she rides at constant speed, and then slows to rest in the next 5 s, at a uniform rate.

a. Sketch a graph of her speed against time.

(3 marks)

b. What is the magnitude of her braking deceleration?

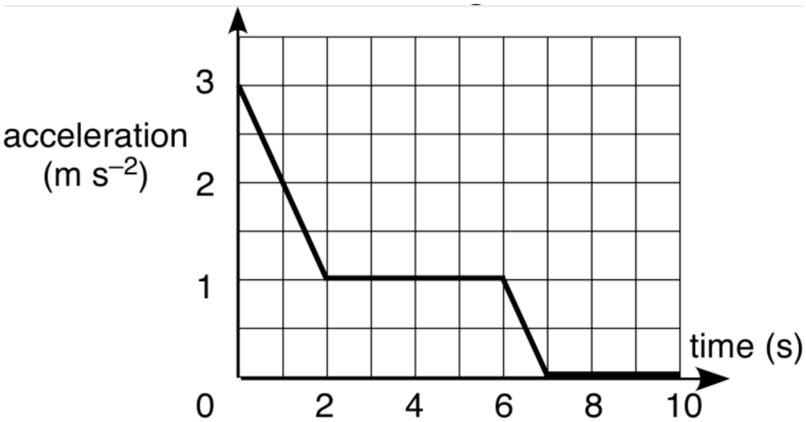
(2 marks)

c. What distance does she cover in the total time interval of 35 s?

(2 marks)

Question 6/ 22

The graph models the motion of a runner during a race. She starts from rest.



a. Calculate the speed of the runner at time $t = 2$ s.

(2 marks)

b. During which time interval is the runner travelling at constant speed?

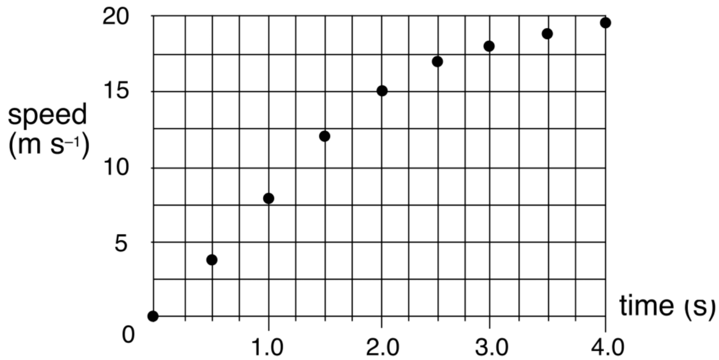
(2 marks)

c. Calculate the speed of the runner at time $t = 10$ s.

(2 marks)

Question 7/ 22

Cyril’s new car accelerates away from rest. Its speed-time graph is shown.



a. Estimate when he first breaks the suburban speed limit of $60\ \mathrm{km\ h^{-1}}$.

(2 marks)

b. Estimate the distance travelled in the first 4.0 s.

(2 marks)

c. What was the car's *initial* acceleration?

(2 marks)

Question 8/ 22

At a dragster race, the winner finishes at $40\ \mathrm{m\ s^{-1}}$. She was accelerating at $10\ \mathrm{m\ s^{-2}}$ for the last second. How much distance did the dragster cover in this last second?

(2 marks)

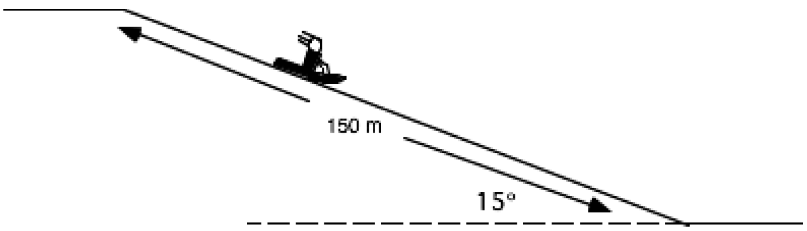
Question 9/ 22

During a golf shot, the ball rolls across a flat green, gradually slowing down on account of rolling friction. Ashley strikes the ball 32 m from the hole. The ball just reaches the hole. The rolling friction decelerates the ball at $1\ \mathrm{m\ s^{-2}}$. What speed did Ashley give the ball at the start of the shot?

(2 marks)

Question 10/ 22

Oscarina slides down a snow slope on a toboggan. The total mass of Oscarina and the toboggan is 40 kg. The slope makes an angle of 15° to the horizontal.



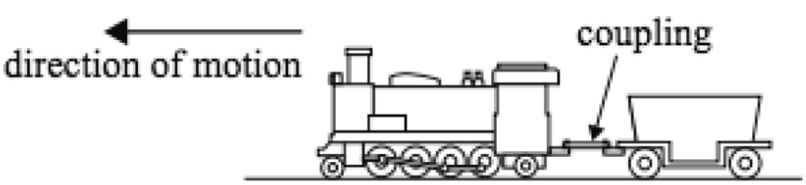
The toboggan starts from rest and takes 17 s to reach the bottom of the slope. Calculate the acceleration of the toboggan from these numbers.

(2 marks)

Question 11/ 22

[Adapted VCAA 2016 SA Q1]

A train consists of an engine of mass 20 tonnes (20 000 kg) towing one wagon of mass 10 tonnes (10 000 kg), as shown in the diagram.



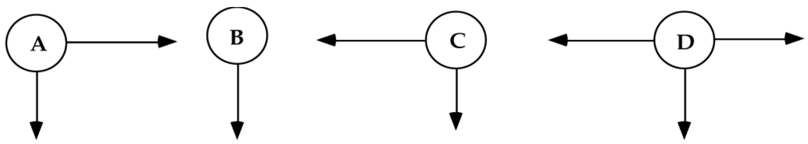
The train accelerates from rest with a constant acceleration of 0.10 m s^{-2}. Calculate the speed of the train after it has moved 20 m.

(2 marks)

Chapter 2 Forces

Question 1/ 22

The diagrams following show possible *forces* acting on a cricket ball, after leaving a bat, by means of arrows. The ball is moving to the *right*.



Question 2/ 22

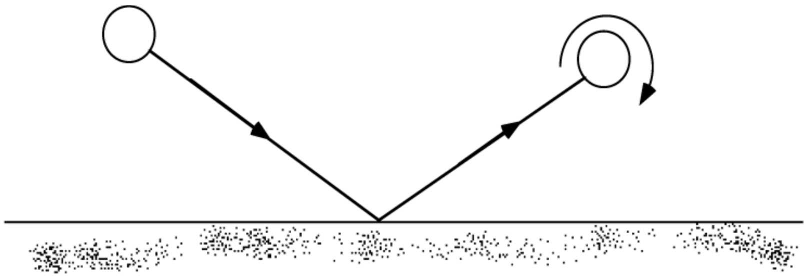
Which diagram best describes a cricket ball moving with very little air resistance?

Question 3/ 22

Which diagram best describes a cricket ball moving with substantial air resistance?

Question 4/ 22

The tennis ball shown is striking the ground. Before it strikes the ground, it is not spinning, but afterwards it is.



Which is the best reason why the ball is spinning after hitting the ground?

A The friction exerts a force on the ball towards the right.

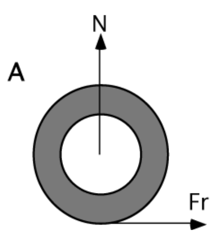
B The normal reaction exerts a force on the ball towards the right.

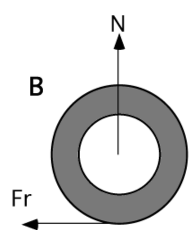
C The friction exerts a force on the ball towards the left.

D The normal reaction exerts a force on the ball towards the left.

Question 5/ 22

The wheel of a car is shown in the diagrams. The wheel is connected to the car's engine through an axle. The arrows indicate the main forces acting on the wheel from the road. 'N' stands for normal reaction, 'Fr' stands for friction. (The rolling friction is negligible.) The car is moving to the right.





Which of the following is correct? Give a reason for your answer.

A **A** shows the car accelerating. **B** shows the car braking.

B **A** shows the car braking. **B** shows the car accelerating.

C **A** shows the car accelerating hard. **B** shows the car accelerating.

D **A** shows the car braking hard. **B** shows the car braking gently.

Question 6/ 22

John and Betty are riding in a 'dodgem' car at a fair. A car behind them bumps into them. (They are not injured.) Which *one or more* of the following best describes what they feel at the start of the collision? Give your reasons.

A John and Betty felt the seatbelts pushing them more strongly.

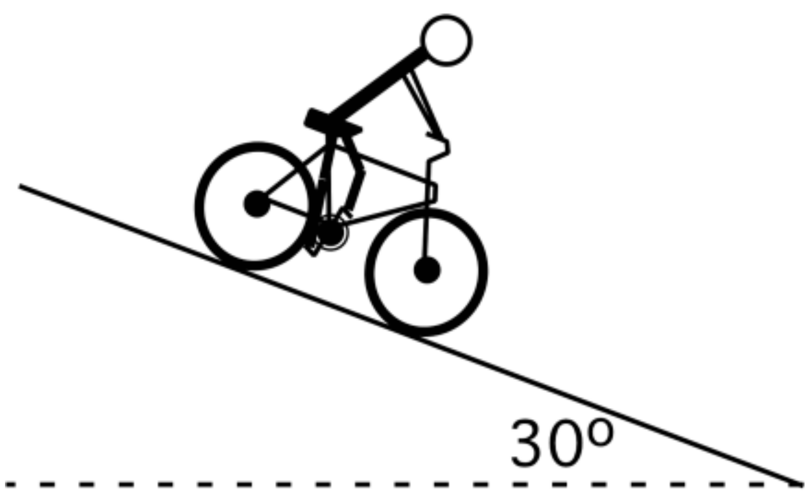
B John and Betty felt the seatbelts pushing them less strongly.

C John and Betty felt the seats pushing them more strongly.

D John and Betty felt the seats pushing them less strongly.

Question 7/ 22

Theo is riding down a hill on his bike. It is a steep hill, and he has the brakes of the bike on so that he does not accelerate.



Theo suddenly removes the brakes and accelerates downhill. Which of the following gives the best estimate of his initial acceleration?

A 100% of *g*

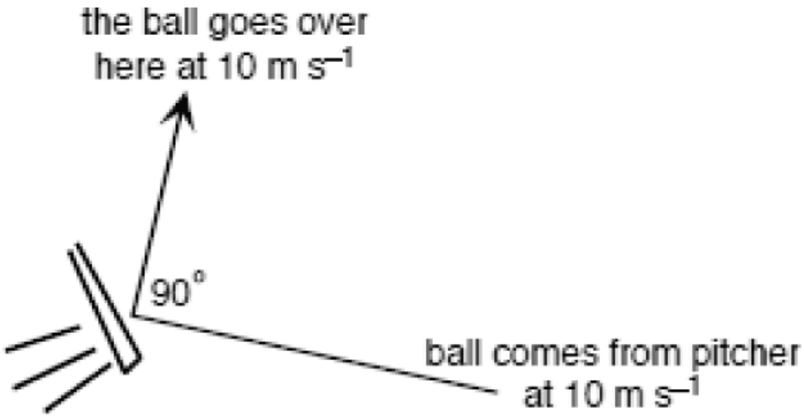
B 75% of *g*

C 50% of *g*

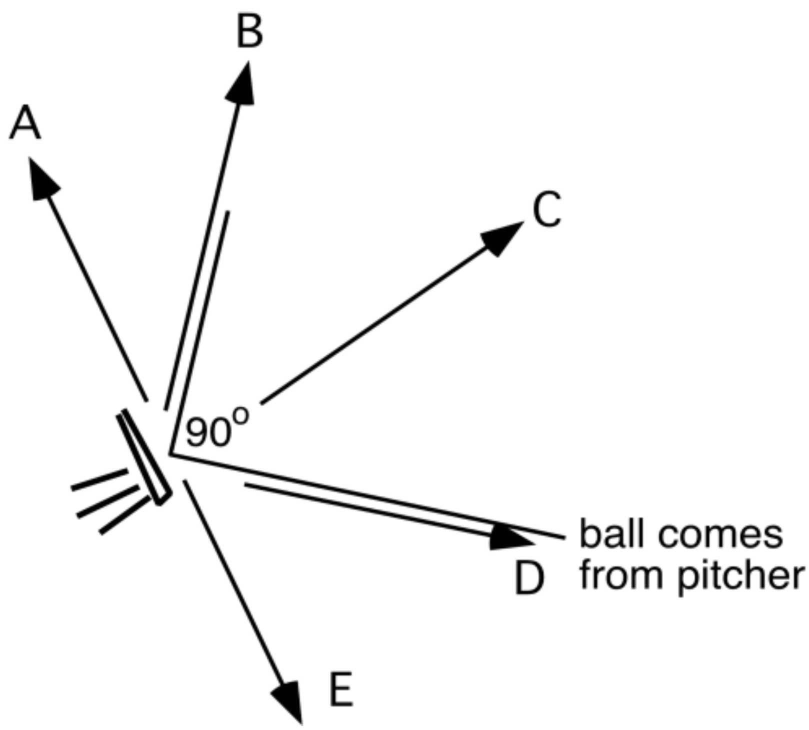
D 25% of *g*

Question 8/ 22

A player swings hard at a baseball and sends it a long way. This is a picture of what happened, as seen by a passing bird high overhead.



Which one of the arrows in the diagram best describes the direction of the change in the velocity of the ball?



Question 9/ 22

A ball falls vertically from few metres and bounces up. The ‘bounce time’ is small. Select the best statement about forces on the ball during the bounce.

A During the bounce, the weight of the ball is equal to the normal reaction from the ground.

B During the bounce, the weight of the ball is larger than the normal reaction from the ground.

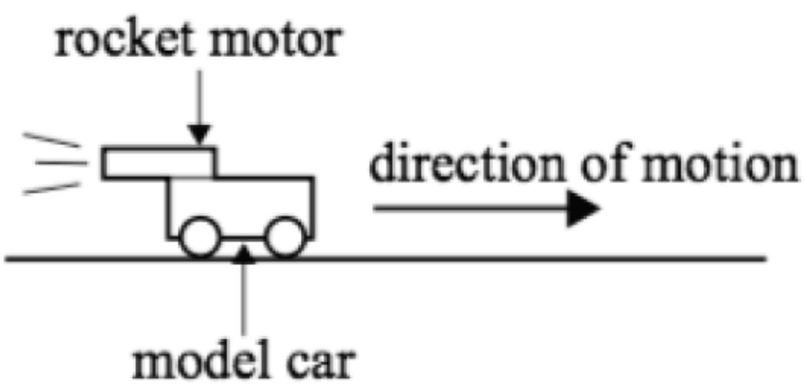
C During the bounce, the weight of the ball is less than the normal reaction from the ground.

D During the bounce, the normal reaction from the ground increases with the length of the bounce time, but is always less than the ball’s weight.

Question 10/ 22

[VCAA 2017 SA Q7]

A model car of mass 2.0 kg is propelled from rest by a rocket motor that applies a constant horizontal force of 4.0 N, as shown below. Assume that friction is negligible. Which one of the following best gives the magnitude of the acceleration of the model car?



A 0.50 m s^{-2}

B 1.0 m s^{-2}

C 2.0 m s^{-2}

D 4.0 m s^{-2}

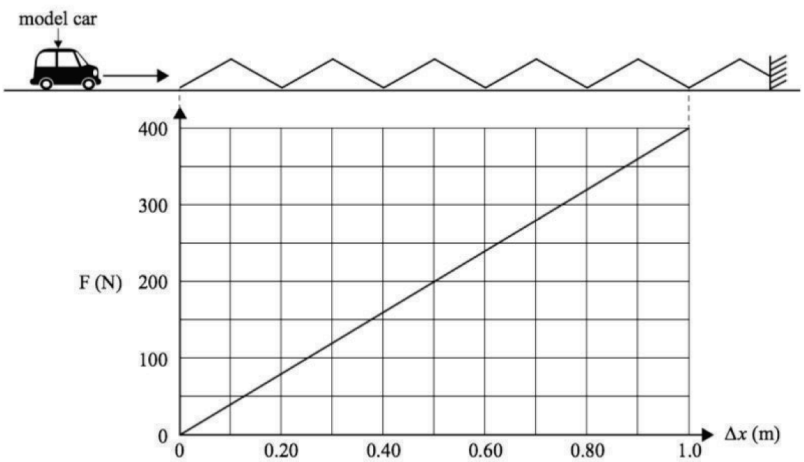
Question 11/ 22

[VCAA 2017 SA Q12]

A model car is on a track and moving to the right. It collides with and compresses a spring that is considered ideal, as shown in the diagram below.

The car compresses the spring to 0.50 m when the car comes to rest. The force-distance graph for the spring is also shown below.

Assume that friction is negligible.



Based on the graph above, what is the best estimate of the spring constant, *k*?

A 100 N m^{-1}

B 200 N m^{-1}

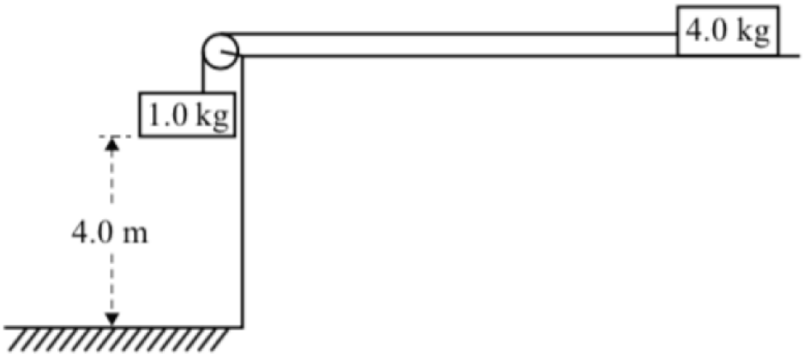
C 400 N m^{-1}

D 800 N m^{-1}

Question 12/ 22

[Adapted VCAA 2018 NHT SA Q8]

A 1.0 kg mass attached to a string hangs 4.0 m from the ground. The string is massless. The string is connected to a 4.0 kg mass on a horizontal frictionless table. The masses are released from rest and accelerate at $1.96 \mathrm{~m~s}^{-2}$.



The tension in the string is closest to

A 19.6 N

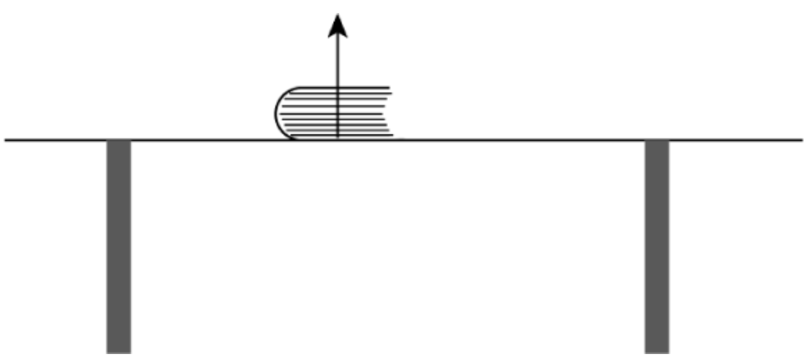
B 15.6 N

C 9.8 N

D 7.8 N

Question 13/ 22

A book rests on a table. A normal reaction force from the table pushes vertically upward on the book.



The action-reaction force pair to this force (according to Newton's third law) is

A the force of gravity acting downwards on the book.

B a normal reaction force on the table from the book.

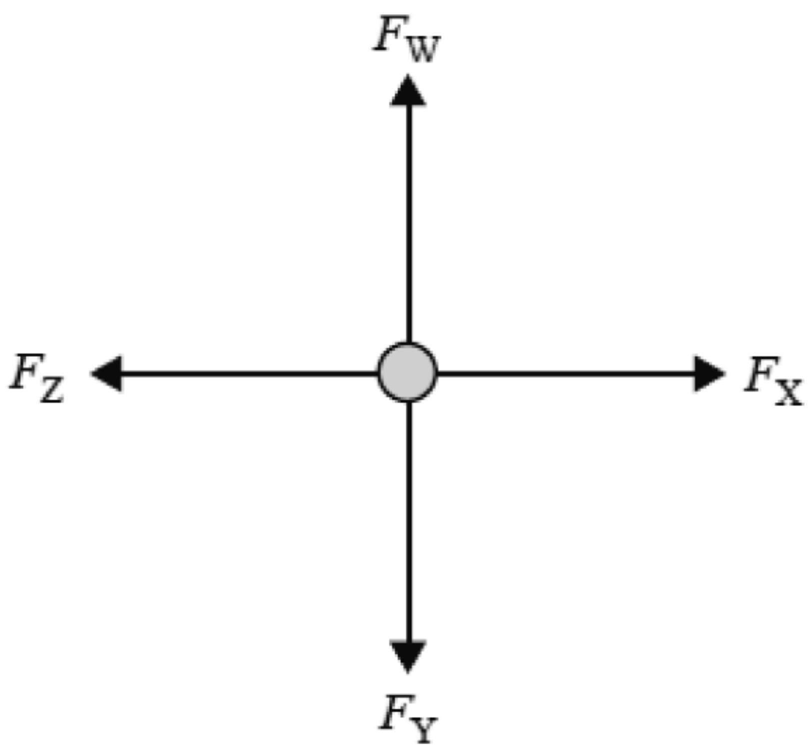
C a $F = mg$ force acting on the book.

D a compression force on the book pushing the pages together.

Question 14/ 22

[VCAA 2018 SA Q5]

Four students are pulling on ropes in a four-person tug of war. The relative sizes of the forces acting on the various ropes are $F_{\mathrm{W}} = 200\ \mathrm{N}$, $F_{\mathrm{X}} = 240\ \mathrm{N}$, $F_{\mathrm{Y}} = 180\ \mathrm{N}$ and $F_{\mathrm{Z}} = 210\ \mathrm{N}$. The situation is shown in the diagram below.



Which one of the following **best** gives the magnitude of the resultant force acting at the centre of the tug-of-war ropes?

A 28.3 N

B 30.0 N

C 36.1 N

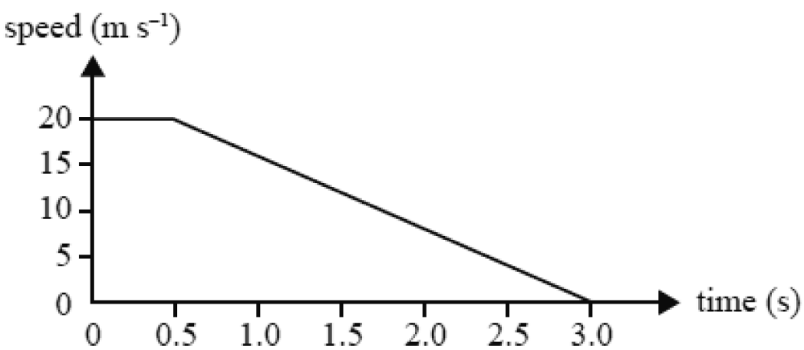
D 50.0 N

Question 15/ 22

[VCAA 2018 SA Q6]

Lisa is driving a car of mass 1000 kg at 20 m s^{-1} when she sees a dog in the middle of the road ahead of her. She takes 0.50 s to react and then brakes to a stop with a constant braking force. Her speed is shown in the graph below.

Lisa stops before she hits the dog.



Which one of the following is closest to the magnitude of the braking force acting on Lisa's car during her braking time?

A 6.7 N

B 6.7 kN

C 8.0 kN

D 20.0 kN

Question 16/ 22

[VCAA 2019 SA Q11]

An ultralight aeroplane of mass 500 kg flies in a horizontal straight line at a constant speed of 100 m s^{-1}. The horizontal resistance force acting on the aeroplane is 1500 N. Which one of the following best describes the magnitude of the forward horizontal thrust on the aeroplane?

A 1500 N

B slightly less than 1500 N

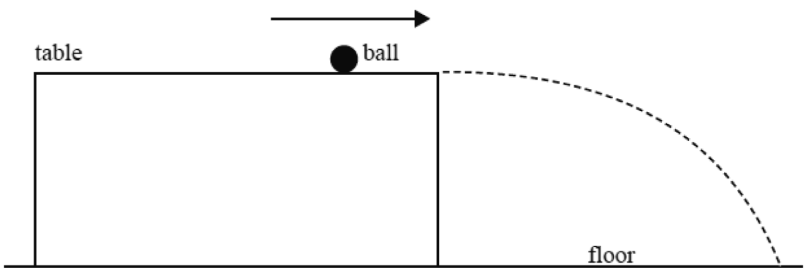
C slightly more than 1500 N

D 5000 N

Question 17/ 22

[VCAA 2019 SA Q12]

A small ball is rolling at constant speed along a horizontal table. It rolls off the edge of the table and follows the parabolic path shown in the diagram below. Ignore air resistance.



Which one of the following statements about the motion of the ball as it falls is correct?

A The ball’s speed increases at a constant rate.

B The momentum of the ball is conserved.

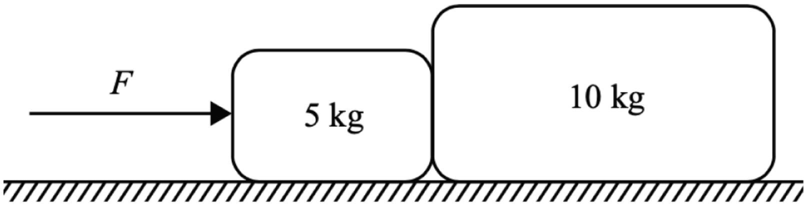
C The acceleration of the ball is constant.

D The ball travels at constant speed.

Question 18/ 22

[VCAA 2020 SA Q9]

Two blocks of mass 5 kg and 10 kg are placed in contact on a frictionless horizontal surface, as shown in the diagram below. A constant horizontal force, *F*, is applied to the 5 kg block.



Which one of the following statements is correct?

A The net force on each block is the same.

B The acceleration experienced by the 5 kg block is twice the acceleration experienced by the 10 kg block.

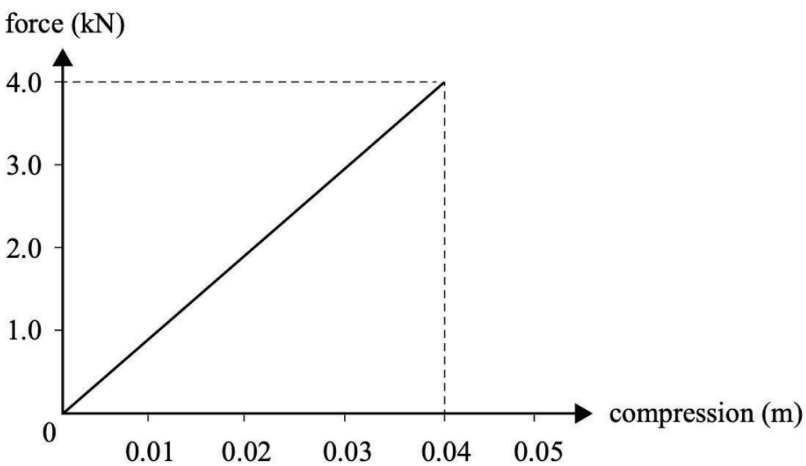
C The magnitude of the net force on the 5 kg block is half the magnitude of the net force on the 10 kg block.

D The magnitude of the net force on the 5 kg block is twice the magnitude of the net force on the 10 kg block.

Question 19/ 22

[VCAA 2021 SA Q11]

A force versus compression graph for a suspension spring is shown below.



Which one of the following is closest to the spring constant of the spring?

A 0.16 N m^{-1}

B $1.0 \times 10^2 \text{ N m}^{-1}$

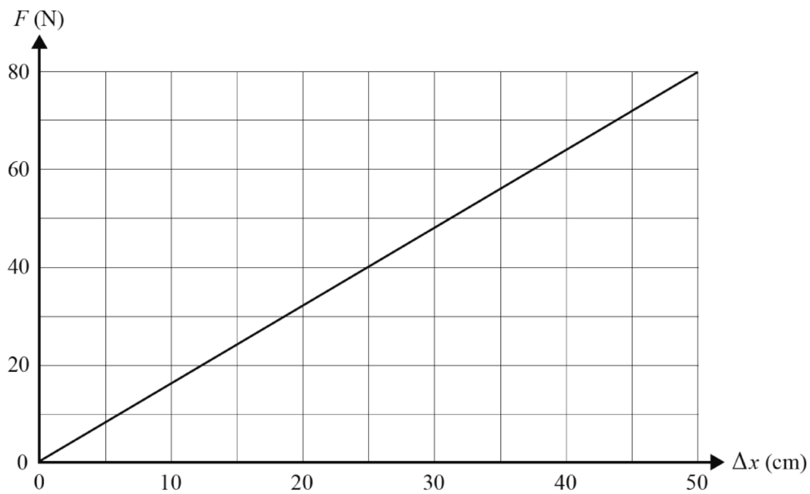
C $1.6 \times 10^2 \text{ N m}^{-1}$

D $1.0 \times 10^5\ \mathrm{N\ m^{-1}}$

Question 20/ 22

[VCAA 2022 NHT SA Q8]

Maya is given a light spring with an unstretched length of 20 cm. The force versus extension graph for the spring is shown below. Maya hangs the spring vertically and attaches a mass to it so that the new length of the spring is 30 cm.



The spring constant, *k*, of Maya's spring is closest to

A $1.6\ \mathrm{N\ m^{-1}}$

B $40\ \mathrm{N\ m^{-1}}$

C $160\ \mathrm{N\ m^{-1}}$

D $4000\ \mathrm{N\ m^{-1}}$

Question 21/ 22

[VCAA 2022 NHT SA Q9]

Assuming that the spring has no mass, the value of the mass Maya attached to it is closest to

A 1.6 kg

B 4.9 kg

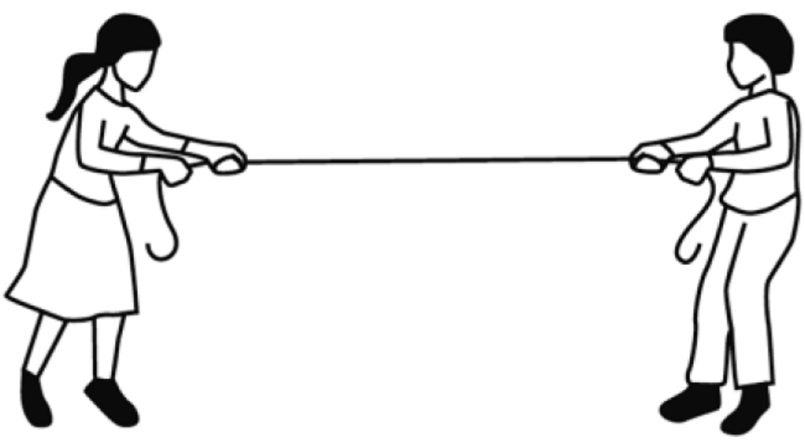
C 6.6 kg

D 8.2 kg

Question 22/ 22

[VCAA 2022 SA Q9]

Two students pull on opposite ends of a rope, as shown in the diagram below. Each student pulls with a force of 400 N. Which one of the following is closest to the magnitude of the force of the rope on each student?



A 0 N

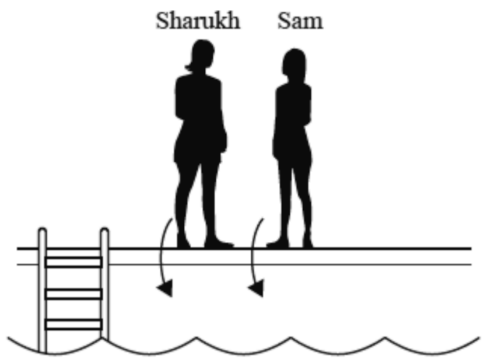
B 400 N

C 600 N

D 800 N

Question 23/ 22

At a swimming pool, Sharukh and Sam, shown below, step off the low diving board at the same time. Over the small distance they fall, air resistance may be ignored. Sharukh and Sam have masses of 80 kg and 60 kg respectively.



Which one of the following best explains what happens to Sharukh and Sam as they drop straight down into the water?

A Sharukh reaches the surface first because she has a larger mass.

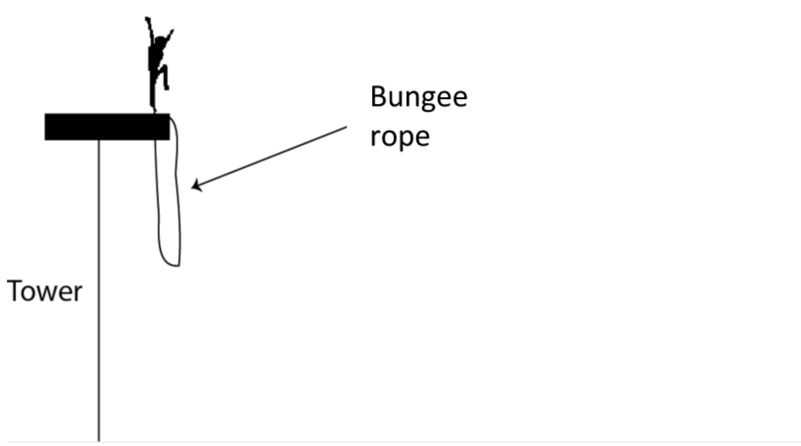
B The net force on Sharukh is larger than that on Sam, so Sharukh reaches the surface first.

C They both reach the surface together because they both experience the same downward force.

D They both reach the surface together because they both experience the same downward acceleration.

Question 1/ 49

Jemima is planning a 'bungee jump'. She will jump off a high tower, attached to her starting position by a strong elastic cord, with $k = 147 \text{ N m}^{-1}$. Before she hits the ground, the cord will stop her downwards motion.



Where the bungee cord stops her downwards motion, there are two forces acting on her, one up, and one down. Identify these two forces and calculate their magnitudes. Include units in your answer.

(3 marks)

Question 2/ 49

Read the following.

Crash barriers on freeways are designed to 'absorb the force' of cars crashing into them. To do this, they should not be too strong, and must be designed to crumple slowly under impact. This reduces the average force exerted on the car during a crash.

Use Newton's second law to explain why a crash barrier that 'crumples slowly' will reduce the average force exerted on a car during a crash.

(4 marks)

Question 3/ 49

The makers of a 1200 kg car claim it has an acceleration of 9.0 m s^{-2}.

a. Calculate the size of the friction between the car tyres and the road if the car accelerates at this rate. (Assume air resistance and rolling resistance are both very small.)

(2 marks)

b. Calculate the ratio:

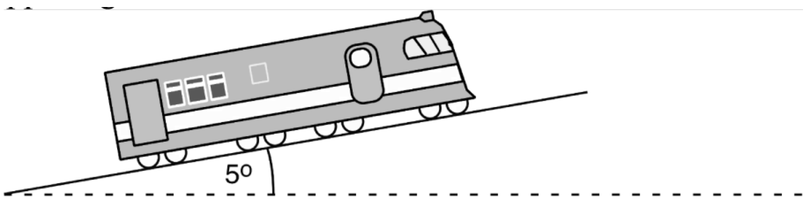
$$\frac{\text{frictional force whilst accelerating at } 9.0 \text{ m s}^{-2}}{\text{ormal reaction force}}$$

(2 marks)

(Total 4 marks)

Question 4/ 49

A train of mass 600 kg travels up a hill at a constant speed of 10 m s^{-1}. There is very little friction opposing the motion.

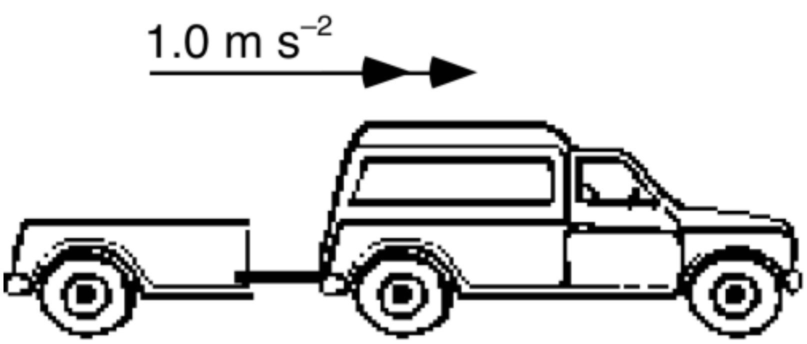


Identify the driving force that the wheels of the train are exerting on the track to keep the train travelling up the hill.

(1 mark)

Question 5/ 49

A car towing a trailer along a road is accelerating at 1.0 m s^{-2}. Take opposing friction as zero. The tension in the coupling is 1000 N.



a. What is the mass of the trailer?

(2 marks)

b. If the mass of the car is 1500 kg, what is the driving force that the wheels are exerting on the road?

(2 marks)

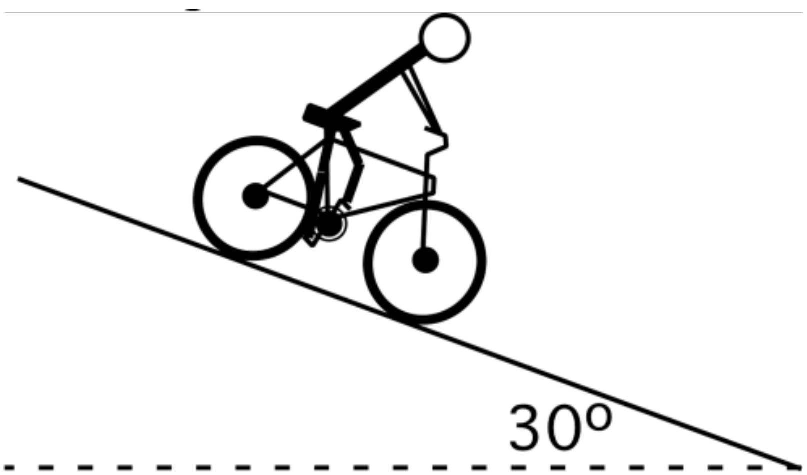
c. What is the frictional force that the road is exerting on the driving wheels of the car?

(2 marks)

(Total 6 marks)

Question 6/ 49

Theo is riding down a hill on his bike. It is a steep hill, and he has the brakes of the bike on so that he does not accelerate. Ignore air resistance and rolling resistance.



a. Draw arrows representing these three forces on Theo and his bike: weight (*mg*); normal reaction (*N*); braking friction between the tyres and the road (*Fr*).

(3 marks)

b. What is the vector sum of these three forces?

(1 mark)

c. Theo will feel 'lighter' than normal while he is accelerating with his brakes off. Explain.

(4 marks)

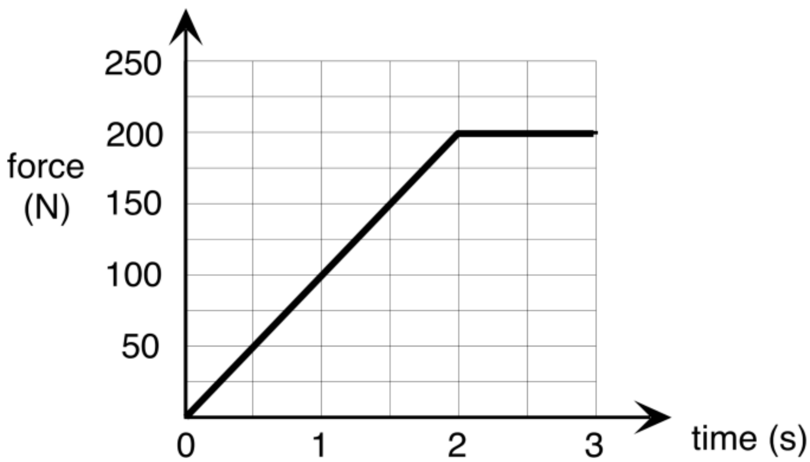
d. If the hill was a *long* one, his acceleration would decrease as he travelled further down the hill with his brakes off. Explain.

(3 marks)

(Total 11 marks)

Question 7/ 49

Julia accelerates on her bike. The mass of Julia and her bike is 80 kg. The net force acting on her and her bike for the first 3 seconds is shown in the graph.

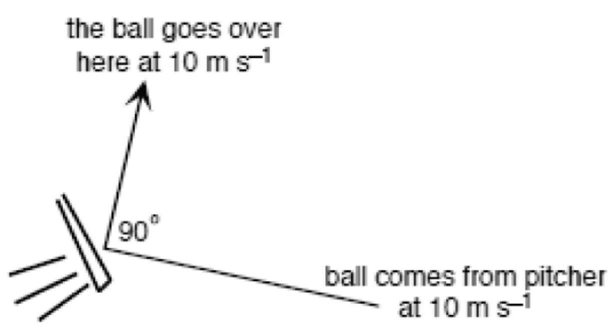


What is her acceleration at $t = 2.5$ s?

(2 marks)

Question 8/ 49

A player swings hard at a baseball and sends it a long way. This is a picture of what happened, as seen by a passing bird high overhead.



a. What is the size of the magnitude of the change in velocity?

(2 marks)

b. The ball mass is 250 g. Calculate the size of the impulse on the ball.

(2 marks)

c. Calculate the size of the impulse on the bat. Describe the direction of this impulse.

(2 marks)

Question 9/ 49

Jacinta is rollerblading along a straight flat road at a steady speed of 15 m s^{-1}. The average force of rolling friction from the wheels is around 5.0 N, and the total air resistance force is around 55 N.

a. What is the net force acting on her?

(2 marks)

b. What is the average force the ground is exerting on her rollerblades, in the same direction that she is travelling?

(2 marks)

Question 10/ 49

A bike accelerates from rest, covering 16 m in 4 s. The total mass of the bike and its rider is 90 kg.

a. What is its average acceleration?

(2 marks)

b. What is the average net force acting on the bicycle and its rider?

(2 marks)

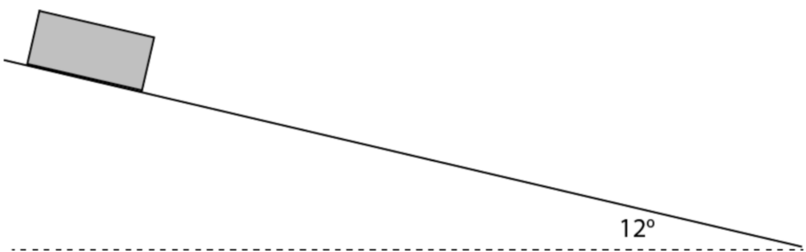
The bike and rider have three external friction forces on them *while accelerating*: rolling friction, air resistance, and static friction between the tyres and the road.

c. Rolling friction and air resistance are very small. Estimate the size of the static friction between the tyres and the road.

(3 marks)

Question 11/ 49

A 500 g block slides down a plane surface inclined at 12° to the horizontal, as shown. It accelerates at a constant rate of 1.5 m s^{-2}.

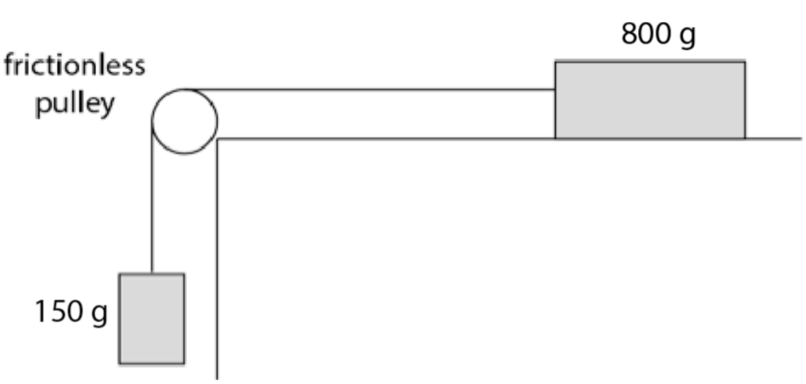


Calculate the size of the friction acting on the block as it slides.

(3 marks)

Question 12/ 49

Two masses are connected by a light non-extensible string as shown in the diagram below. There is no friction in the pulley or the surface of the table under the 800 g mass. The local gravitational field is found to be 9.81 N kg^{-1}.



a. Calculate the gravitational force acting on the 150 g mass, to three significant figures.

(1 mark)

b. Calculate the acceleration of the two masses, to three significant figures.

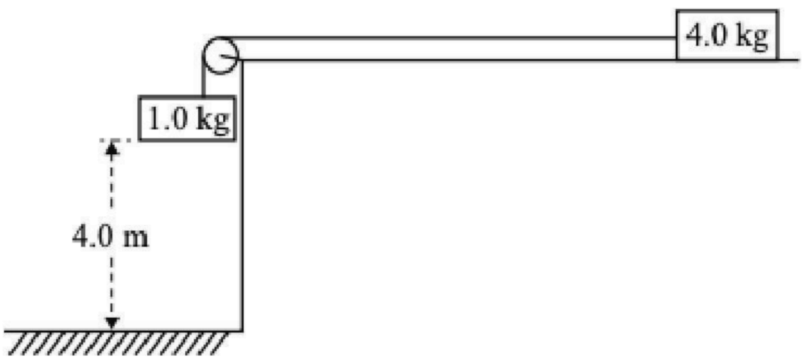
(3 marks)

c. Calculate the net force acting on the 150 g mass as it falls.

(3 marks)

Question 13/ 49

Two masses are connected by a light strong string in a frictionless situation shown in the diagram below. The 1.0 kg mass is released from rest.

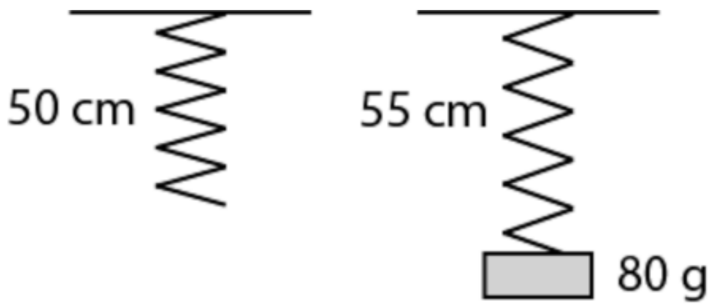


Calculate the time it takes for the 1.0 kg mass to fall 4.0 m. Show all the steps of your working.

(3 marks)

Question 14/ 49

An ideal spring has an unstretched length of 50 cm. A mass of 80 g stretches it to a length of 55 cm.



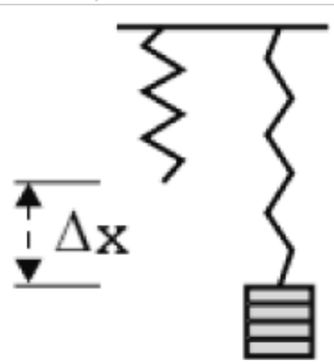
Calculate the mass required to stretch the spring to a length of 70 cm.

(2 marks)

Question 15/ 49

[Adapted VCAA 2016 SA Q3]

To determine the spring constant, *k*, of a spring, students attach 50 g masses to it consecutively and measure the extension, Δx. This is shown below.



The students' results are shown in the table below.

Number of masses	Extension from unstretched length, Δx
0	0 cm
1	25 cm
2	50 cm
3	75 cm

Calculate the value of the spring constant, *k*, to two significant figures.

(2 marks)

Question 16/ 49

[Adapted VCAA 2016 SA Q4]

A small model car of mass 4.0 kg is propelled by a compressed spring.

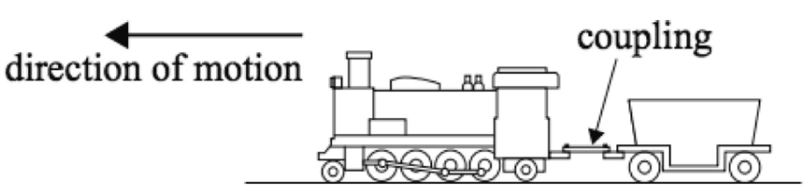
It leaves the spring with a speed of 2.0 m s^{-1} and travels along a flat surface that has a frictional resistance of 2.0 N. Calculate how far the car travels before it stops. Show your working.

(3 marks)

Question 17/ 49

[Adapted VCAA 2016 SA Q1]

An engine of mass 20 t, moving at 3.0 m s^{-1}, is towing a wagon of mass 10 t, as shown. It is accelerating with a constant acceleration of 0.10 m s^{-2}.



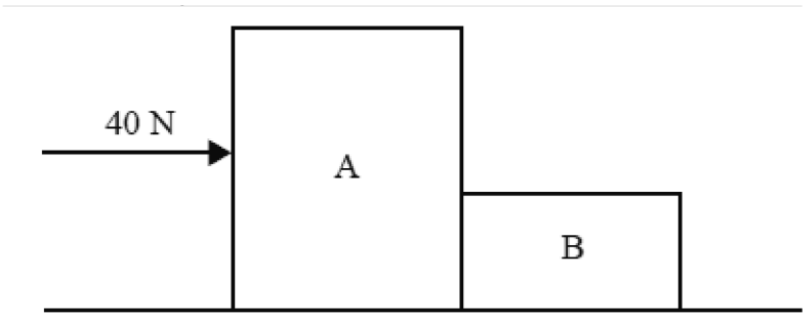
Calculate the tension in the coupling between the engine and the wagon.

(2 marks)

Question 18/ 49

[VCAA 2018 SB Q8]

Two blocks, A of mass 4.0 kg and B of mass 1.0 kg, are being pushed to the right on a smooth, frictionless surface by a 40 N force, as shown below.



a. Calculate the magnitude of the force on block B by block A ($F_{\text{on B by A}}$). Show your working.

(2 marks)

b. State the magnitude and the direction of the force on block A by block B ($F_{\text{on B by A}}$).

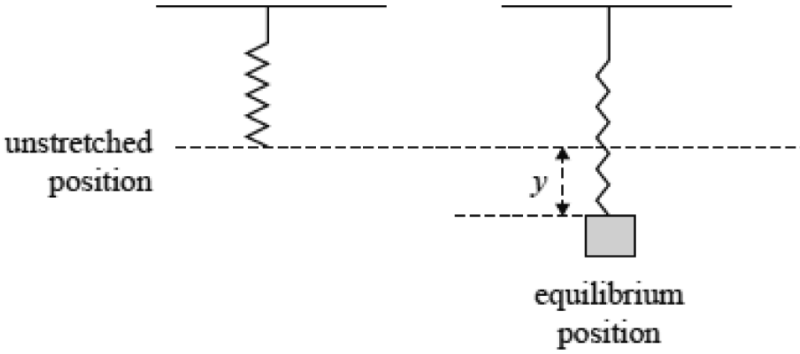
(2 marks)

Question 19/ 49

[Adapted VCAA 2019 NHT SB Q5]

Students conduct an experiment in which a mass of 2.0 kg is suspended from a spring with a spring constant $k = 100 \text{ N m}^{-1}$. Ignore the mass of the spring.

Take the gravitational field, *g*, to be 10 N kg^{-1}. Take the zero of gravitational potential energy when the mass is at its lowest point. The experimental arrangement is shown in the diagram below.



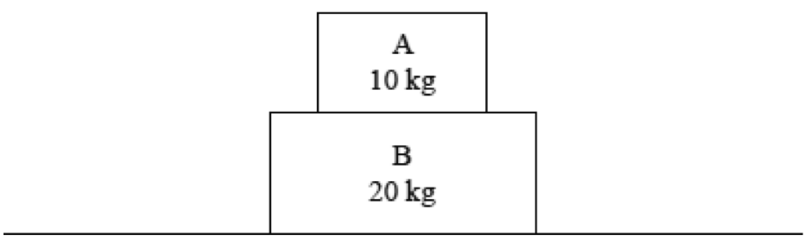
The mass is attached to the spring and slowly lowered to its equilibrium position. Calculate the extension, *y*, of the spring from its unstretched position to its equilibrium position. Show your working.

(2 marks)

Question 20/ 49

[VCAA 2019 NHT SB Q9]

The diagram below shows two masses. Mass A has a mass of 10 kg. It rests on top of Mass B, which has a mass of 20 kg.



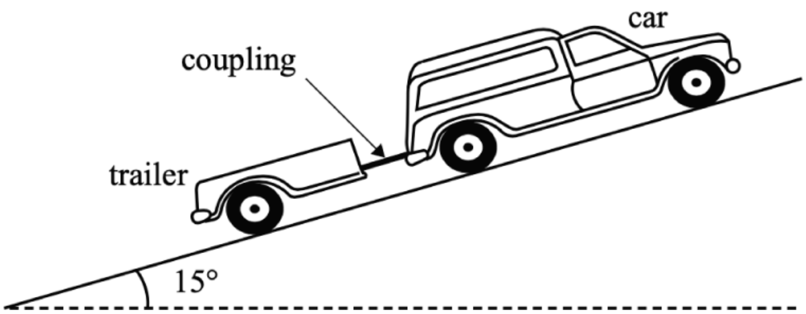
Calculate the magnitude and direction of the force on Mass A by Mass B. Take $g = 9.8 \text{ N kg}^{-1}$.

(2 marks)

Question 21/ 49

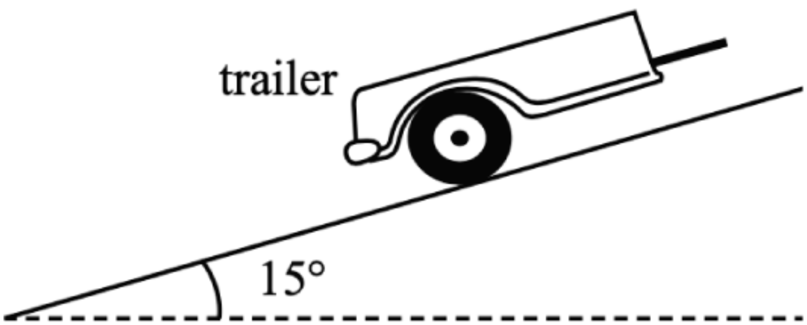
[VCAA 2021 NHT SB Q8]

A car is driving up a uniform slope with a trailer attached, as shown below. The slope is angled at 15° to the horizontal. The trailer has a mass of 200 kg and the car has a mass of 750 kg. Ignore all retarding friction forces down the slope.



a. On the diagram below, draw labelled arrows to indicate the direction of the forces acting on the trailer. The labels should also indicate the kind of force that each arrow represents.

(3 marks)



b. The car and trailer are travelling at a constant speed of $8 \mathrm{~m} \mathrm{~s}^{-1}$ up the slope. Calculate the magnitude of the force that the car exerts on the trailer. Show your working.

(2 marks)

(Total 5 marks)

Question 22/ 49

[Adapted VCAA 2021 NHT SB Q18]

A small rubber ball of mass 50 g falls vertically from a given height and rebounds from a hard floor. The ball's speed immediately before impact is $3.6 \mathrm{~m} \mathrm{~s}^{-1}$. The ball rebounds upward at a speed of $3.3 \mathrm{~m} \mathrm{~s}^{-1}$ immediately after it leaves the floor. The ball is in contact with the floor for 40 ms.

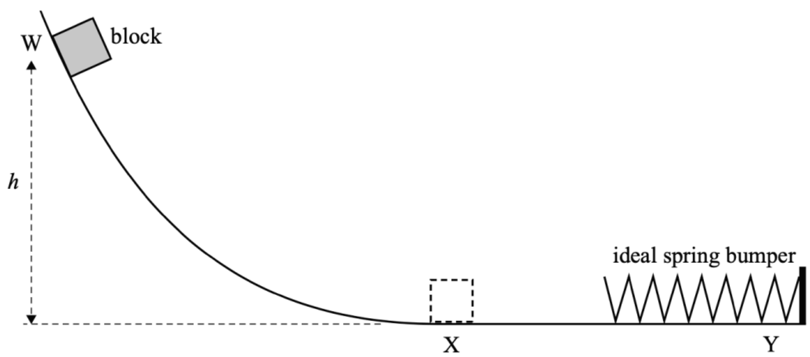
Calculate the magnitude and direction of the net average force acting on the 50 g ball while it is in contact with the floor. Show your working.

(4 marks)

Question 23/ 49

[Adapted VCAA 2021 NHT SB Q9]

In a model of a proposed ride at a theme park, a 5.0 kg smooth block slides down a ramp from point W and into an ideal spring bumper without any friction or air resistance, as shown below. The final section of the ramp, between points X and Y, is horizontal. The block comes to an instantaneous stop at point Y.



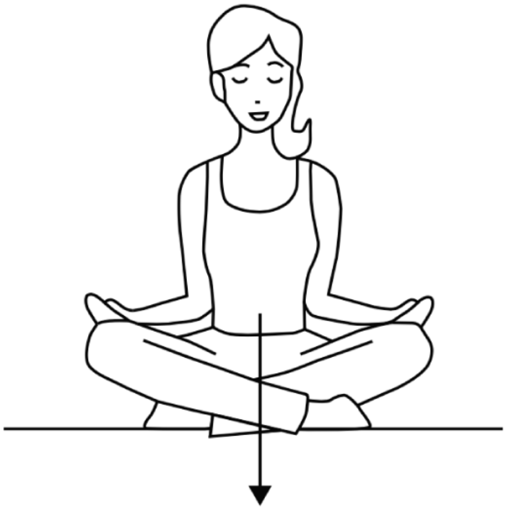
Describe the acceleration of the block at points W, X and Y.

(4 marks)

Question 24/ 49

[VCAA 2021 SB Q4]

Liesel, a student of yoga, sits on the floor in the lotus pose, as shown below. The action force, F_g, on Liesel due to gravity is 500 N down.



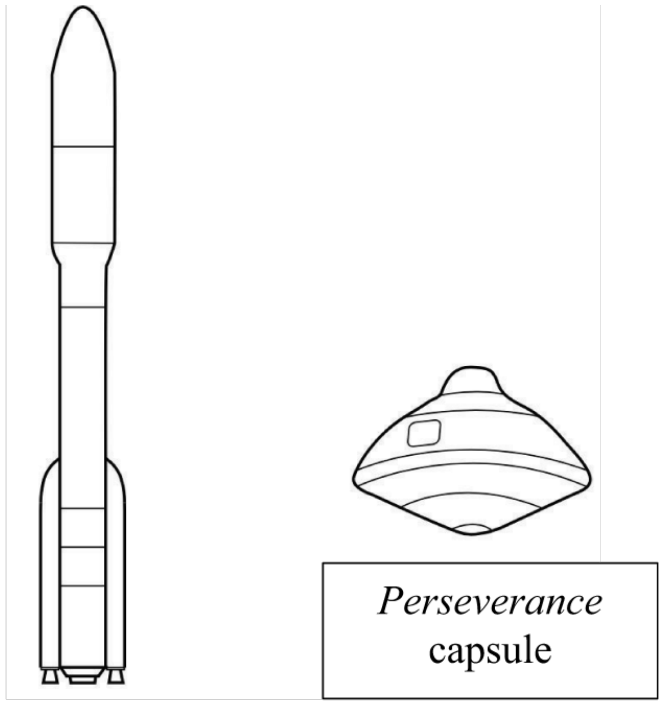
Identify and explain what the reaction force is to the action force, F_g, shown above.

(2 marks)

Question 25/ 49

[Adapted VCAA 2021 SB Q8]

On 30 July 2020, the National Aeronautics and Space Administration (NASA) launched an Atlas rocket containing the *Perseverance* rover space capsule on a scientific mission to explore the geology and climate of Mars, and search for signs of ancient microbial life.



Atlas rocket

At lift-off from launch, the acceleration of the rocket was 7.20 m s^{-2}. The total mass of the rocket and capsule at launch was 531 tonnes.

Calculate the magnitude and the direction of the thrust force on the rocket at launch. Take the gravitational field strength at the launch site to be $g = 9.80 \text{ N kg}^{-1}$. Give your answer in meganewtons. Show your working.

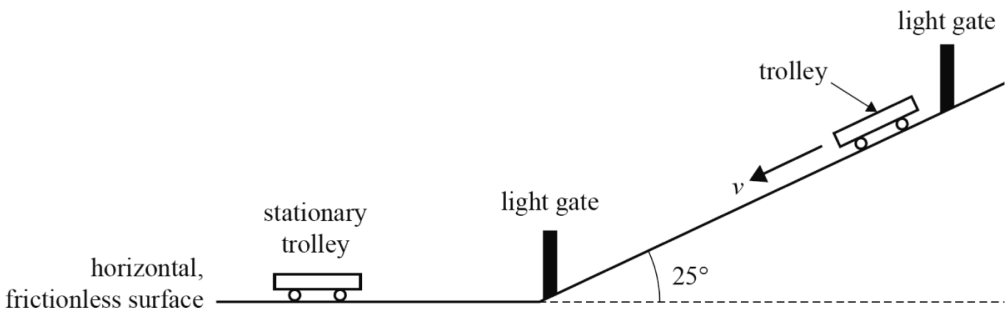
(3 marks)

Question 26/ 49

[Adapted VCAA 2022 SB Q7]

Kym and Kelly are experimenting with trolleys on a ramp inclined at 25°, as shown below. They release a trolley with a mass of 2.0 kg from the top of the ramp.

The trolley moves down the ramp, through two light gates and onto a horizontal, frictionless surface. Kym and Kelly calculate the acceleration of the trolley to be 3.2 m s^{-2} using the information from the light gates.



a. Show that the component of the gravitational force of the trolley down the slope is 8.3 N. Use $g = 9.8 \text{ m s}^{-2}$.

(2 marks)

b. Assume that on the ramp there is a constant frictional force acting on the trolley and opposing its motion. Calculate the magnitude of the constant frictional force acting on the trolley.

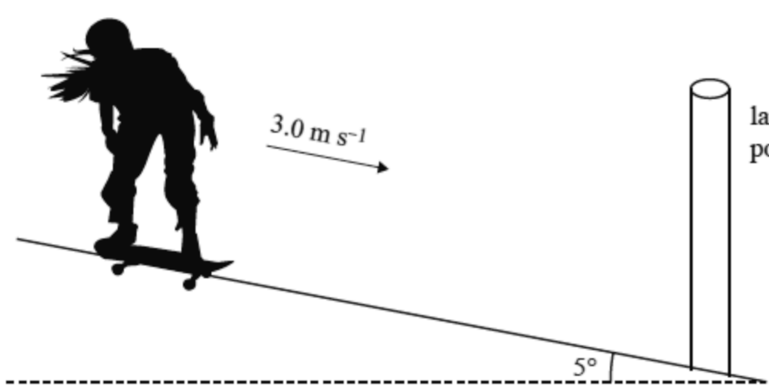
(2 marks)

Question 27/ 49

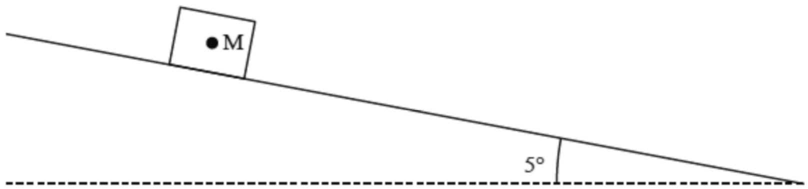
[Adapted VCAA 2023 SB Q8]

Maia is at a skatepark. She stands on her skateboard as it rolls in a straight line down a gentle slope at a constant speed of 3.0 m s^{-1}, as shown. The slope is 5° to the horizontal.

The combined mass of Maia and the skateboard is 65 kg.



a. The combined system of Maia and the skateboard is modelled as a small box with point M at the centre of mass as shown below.



Draw and label arrows to represent each of the forces acting on the system – that is, Maia and skateboard, as they roll down the slope.

(3 marks)

b. Calculate the magnitude of the total frictional forces acting on Maia and the skateboard.

(2 marks)

Chapter 3 Energy

Question 1/ 19

A climber ascends a mountain of height 4300 m, starting at a height of 1300 m. She has a mass (including her pack) of 66 kg. Which one of the following is closest to the gravitational potential energy she gains during this climb?

A 130 kJ

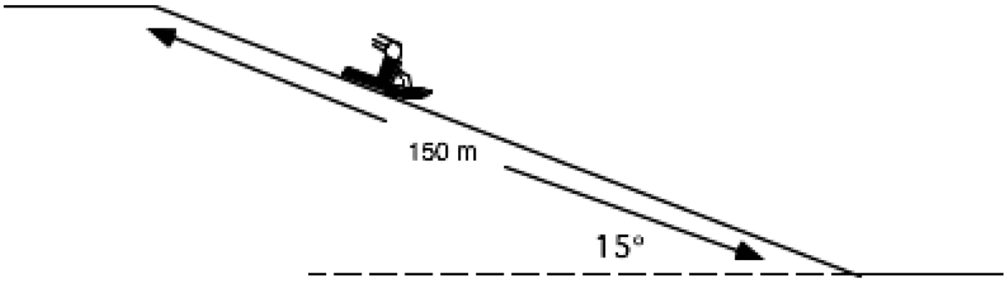
B 280 kJ

C 1.95 MJ

D 2.80 MJ

Question 2/ 19

Lucy slides down a snow slope on a toboggan. She has a mass of 35 kg.



Question 3/ 19

The gravitational potential energy she loses as she moves from the top of the slide to the bottom is closest to

A 1.3 kJ

B 13 kJ

C 5.2 kJ

D 52 kJ

Question 4/ 19

She reaches the bottom of the slide with a speed of 20 m s^{-1}. The thermal energy generated during her slide is closest to

A 1.3 kJ

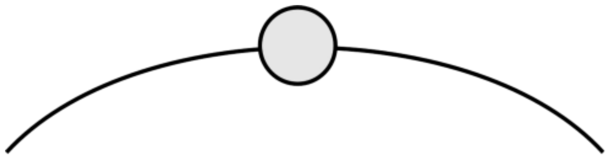
B 6.3 kJ

C 7.0 kJ

D 13 kJ

Question 5/ 19

A netball is thrown towards the net. It is shown below at the highest point of its flight. Air resistance is negligible.



Which *one or more* of the following best describes the ball at its highest point?

A At this point its kinetic energy is a minimum.

B At this point its kinetic energy is a maximum.

C At this point its potential energy is zero.

D At this point its potential energy increasing.

Question 6/ 19

Frankie drops from a height of several metres onto a trampoline. When he makes contact with the trampoline, he is travelling at $10 \mathrm{~m} \mathrm{~s}^{-1}$. The trampoline then stops his motion momentarily. Which of the following best describes his energy changes throughout this process?

A His initial potential energy has been changed into kinetic energy.

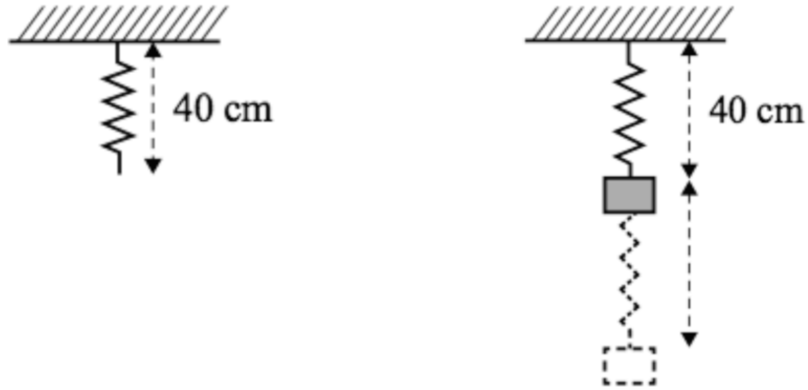
B His initial potential energy has been changed directly into elastic potential energy.

C He has gained extra energy from the trampoline.

D His initial potential energy has been changed into kinetic energy and then into elastic energy.

Question 7/ 19

A mass is attached to the end of a spring of unstretched length 40 cm, and then it is released. It oscillates up and down elastically.



Question 8/ 19

Which of the following best describes the energy changes?

A The sum of the initial potential energy and the kinetic energy is constant.

B The sum of the initial potential energy, the elastic energy and the kinetic energy varies during the oscillation.

C The kinetic energy is a maximum in the centre of the motion.

D The sum of the initial potential energy and the elastic energy is constant.

Question 9/ 19

The spring constant is $20\ \mathrm{N\ m^{-1}}$. The mass is 1.2 kg. The amplitude of the oscillation is closest to

A 0.12 m

B 0.6 m

C 1.2 m

D 1.4 m

Question 10/ 19

In real life, the mass would come to rest eventually. At this point, the extension of the spring would be closest to

A 0.12 m

B 0.6 m

C 0.7 m

D 1.2 m

Question 11/ 19

At this final rest point, the total energy dissipated to the environment would be closest to

A 3.5 J

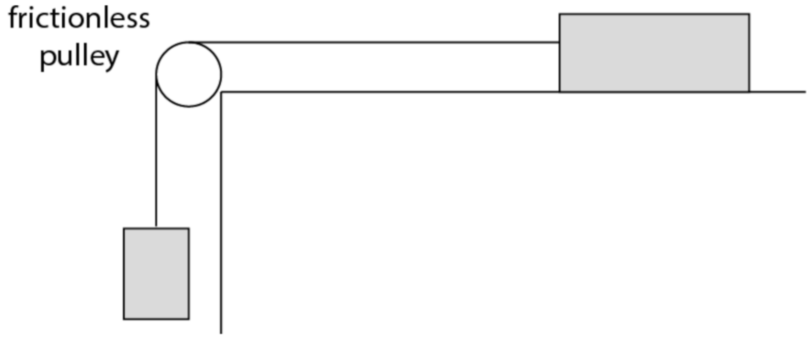
B 6.9 J

C 11 J

D 14 J

Question 12/ 19

Students conduct an experiment in which two blocks of equal mass are attached and placed as shown in the diagram. The surface has some friction, but the string does not stretch. The blocks are then released.



After a short time, both blocks have gained kinetic energy. Which of the following statements best describes the situation?

A The kinetic energy of the falling mass is equal to the kinetic energy of the sliding mass.

B The kinetic energy of the falling mass is less than the kinetic energy of the sliding mass.

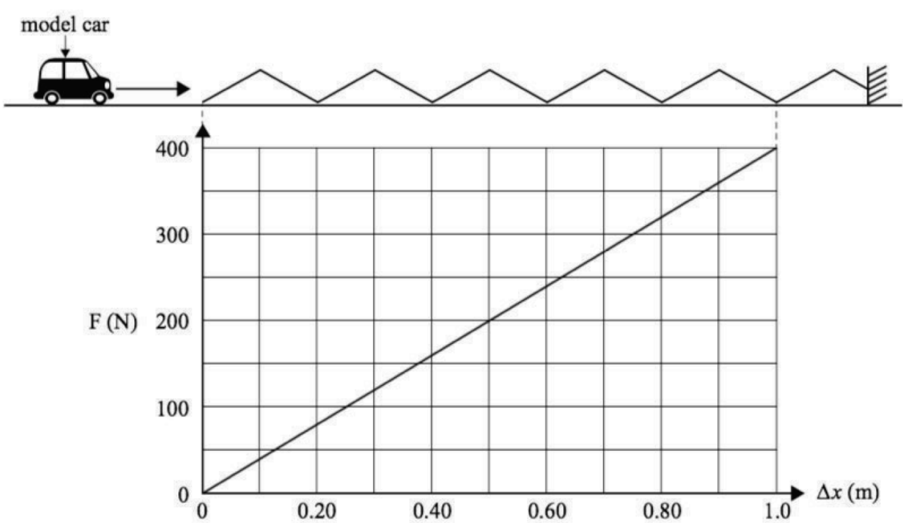
C The kinetic energy of the falling mass is greater than the kinetic energy of the sliding mass.

D The kinetic energy of the falling mass increases more quickly than the kinetic energy of the falling mass.

Question 13/ 19

[VCAA 2017 SA Q13]

A model car is on a track and moving to the right. It collides with and compresses a spring that is considered ideal, as shown in the diagram. The car compresses the spring to 0.50 m when the car comes to rest. The force-distance graph for the spring is also shown. Assume that friction is negligible.



What is the initial kinetic energy of the car?

A 25 J

B 50 J

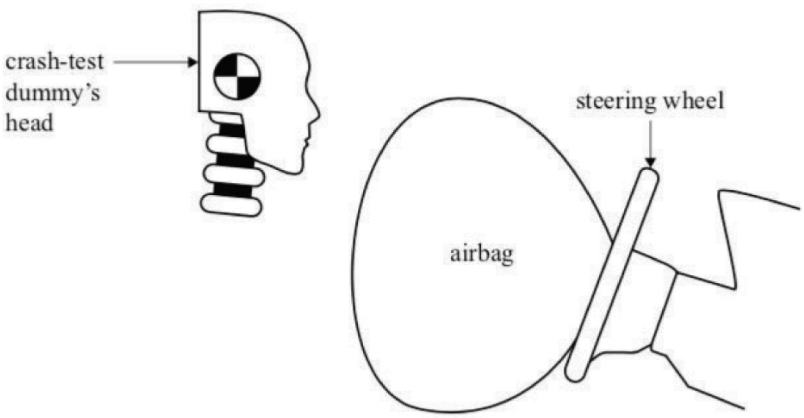
C 100 J

D 200 J

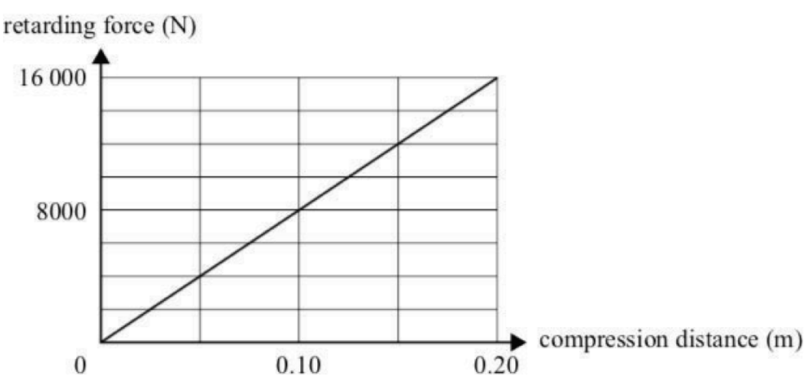
Question 14/ 19

[VCAA 2017 Sample SA Q11]

A test car is equipped with a crash-test dummy and an airbag. The car comes to a sudden stop when it collides with a solid wall, causing the airbag to inflate. The airbag then compresses by 0.10 m when the crash-test dummy hits the airbag. The diagram below shows the relative position of the crash-test dummy's head to the airbag and steering wheel.



The graph of retarding force on the crash-test dummy's head versus compression distance is shown below.



Which one of the following best gives the work done on the airbag in this collision?

A 80 J

B 400 J

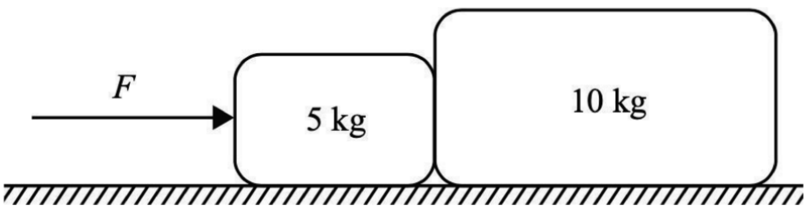
C 800 J

D 8000 J

Question 15/ 19

[VCAA 2020 SA Q10]

Two blocks of mass 5 kg and 10 kg are placed in contact on a frictionless horizontal surface, as shown in the diagram below. A constant horizontal force, *F*, is applied to the 5 kg block.



If the force *F* has a magnitude of 250 N, what is the work done by the force in moving the blocks in a straight line for a distance of 20 m?

A 5 kJ

B 25 kJ

C 50 kJ

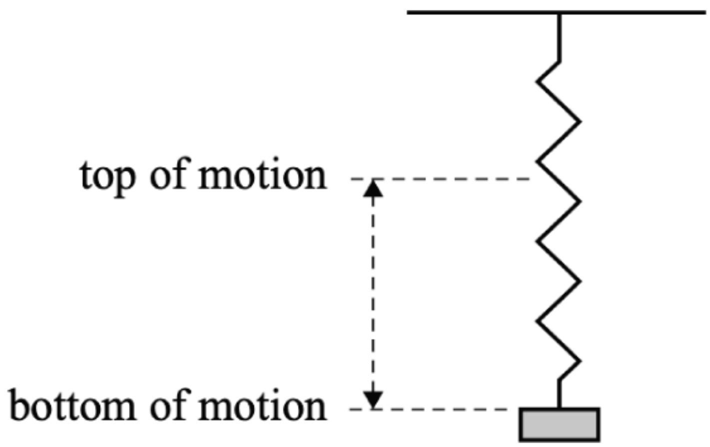
D 500 kJ

Question 16/ 19

[VCAA 2021 NHT SA Q11]

A mass at the end of an ideal spring is oscillating freely up and down.

Which one of the following best describes the motion of this oscillating mass?



A Its speed is a minimum only at the top of the motion.

B Its speed is a maximum when its acceleration is a maximum.

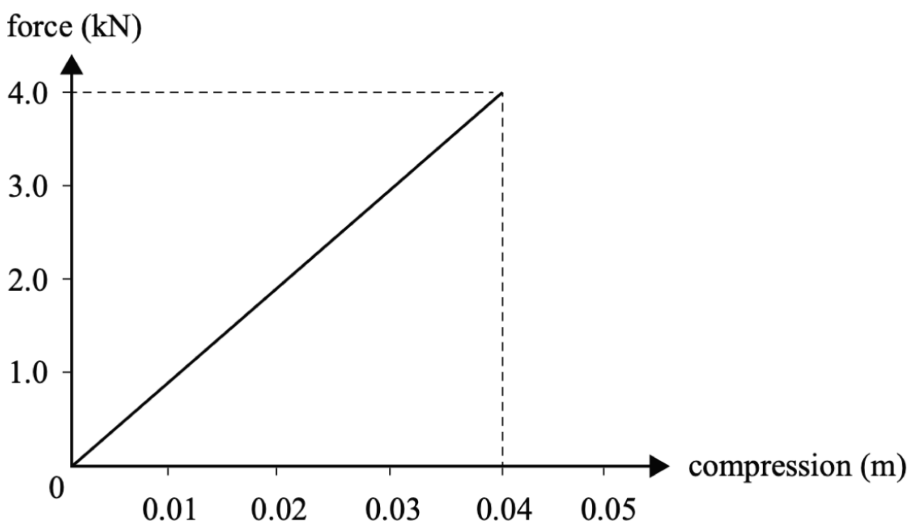
C Its acceleration has a minimum value at both the top and the bottom of the motion.

D Its acceleration has a maximum value upward when the mass is stationary at the bottom.

Question 17/ 19

[VCAA 2021 SA Q12]

A force versus compression graph for a suspension spring is shown below.



The spring is compressed to 0.02 m. Which one of the following is closest to the potential energy stored in the spring?

A 0.04 J

B 0.20 J

C 20 J

D 40 J

Question 18/ 19

[VCAA 2022 NHT SA Q7]

A car travelling at 60 km h^{-1} brakes to a complete stop of a distance of 18 m under a constant braking force. Which one of the following is closest to the braking distance required for the same car to come to a complete stop when travelling at $40 \text{ km h}^{-1}$and braking with the same constant braking force?

A 8 m

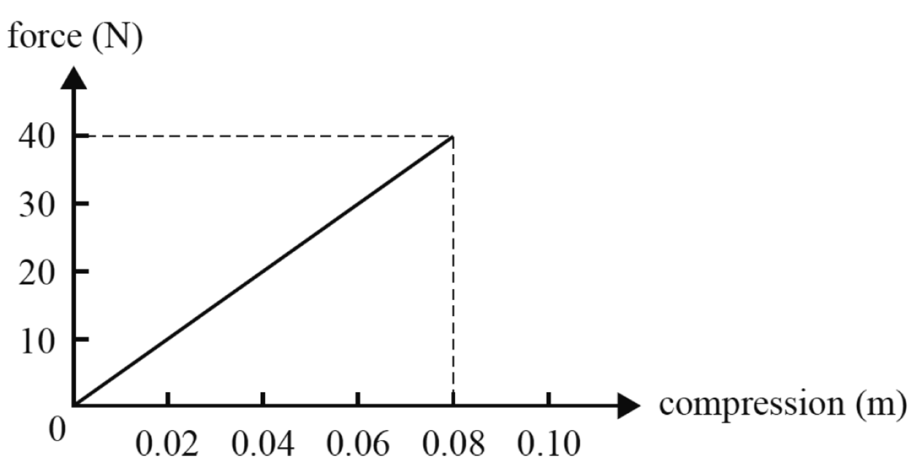
B 9 m

C 12 m

D 15 m

Question 19/ 19

The graph below shows force versus compression for a spring used in a Physics investigation.



Which one of the following is closest to the compression required to store 0.9 J of potential energy in the spring?

A 0.05 m

B 0.06 m

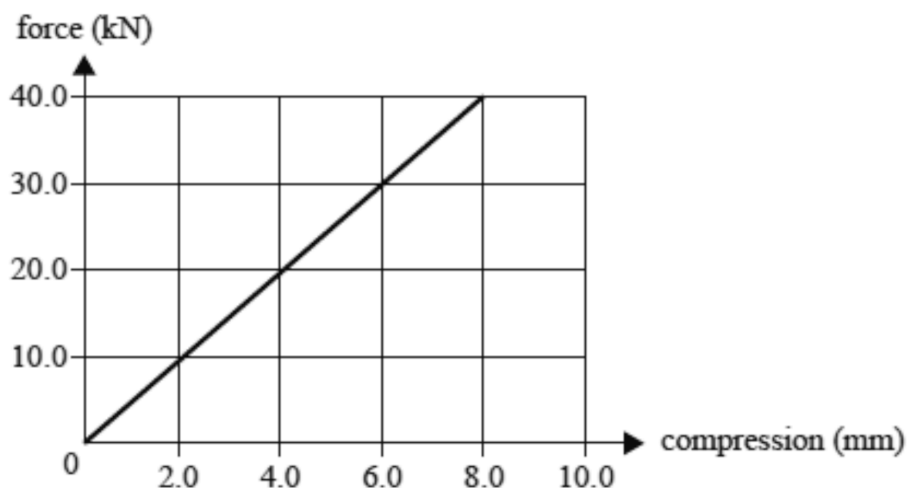
C 0.07 m

D 0.08 m

Question 20/ 19

[VCAA 2023 SA Q10]

A force versus compression graph for a car spring is shown below.



Which one of the following is closest to the spring constant of the car spring?

A $5.0\ \text{N m}^{-1}$.

B $5.0 \times 10^3\ \text{N m}^{-1}$.

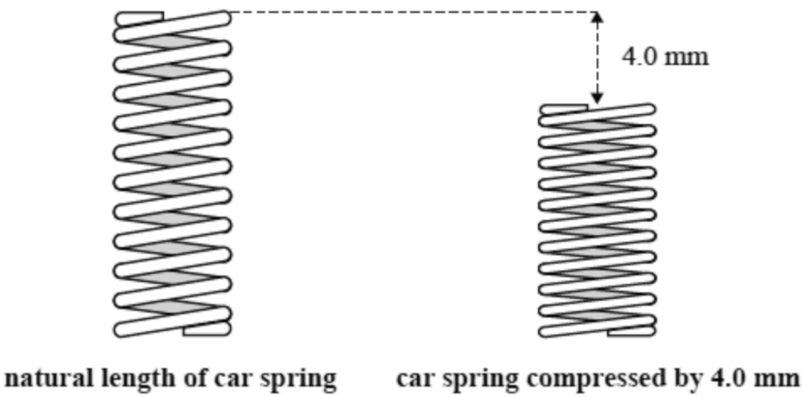
C $5.0 \times 10^5\ \text{N m}^{-1}$.

D $5.0 \times 10^6\ \text{N m}^{-1}$

Question 21/ 19

[VCAA 2023 SA Q11]

When the car is sitting on a level surface, the car spring is compressed by 4.0 mm from its natural length, as shown below.



As the car goes over a bump in the road, the car spring compresses an additional 4.0 mm from the initial compression of 4.0 mm, to a total compression of 8.0 mm.

Which one of the following is closest to the additional potential energy stored in the car spring when the car goes over the bump?

A $4.0 \times 10^1 \mathrm{J}$

B $1.2 \times 10^2 \mathrm{J}$

C $1.6 \times 10^2 \mathrm{J}$

D $3.2 \times 10^2 \mathrm{J}$

Question 1/ 52

A car (mass 900 kg) brakes steadily from $20 \mathrm{~m} \mathrm{~s}^{-1}$ to rest in 4.0 s. It is on a level road, and its brakes are the cause of its decrease in speed.

a. What is the braking distance?

(2 marks)

b. At what rate is thermal energy being dissipated in the brakes?

(2 marks)

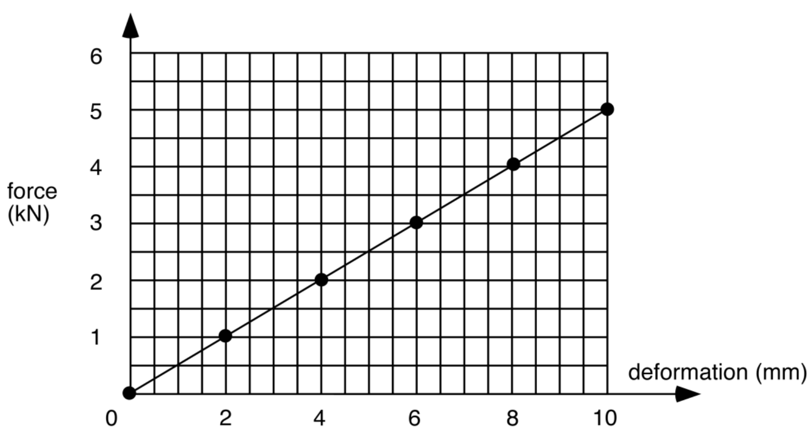
Question 2/ 52

A 500 kg car moving at 5.0 m s^{-1} runs into the back of a stationary truck of mass 3.0 t. The truck moves forward at 1.0 m s^{-1}; the car rebounds backwards at 1.0 m s^{-1}. Show that the combined KE of the car and truck after the collision is less than the combined KE of the car and truck beforehand.

(2 marks)

Question 3/ 52

During a golf drive, the ball changes speed very rapidly. The forces involved deform the ball considerably. The graph below shows the force on a 50 g golf ball as a function of its deformation.



In a particular drive, Georgia strikes the ball so that it deforms by 8.0 mm during the collision with the club head. Assume that this deformation is elastic.

a. What is the force constant of the golf ball?

(2 marks)

b. How much work has been done in deforming the ball?

(2 marks)

c. How much elastic potential energy is stored in the deformed ball?

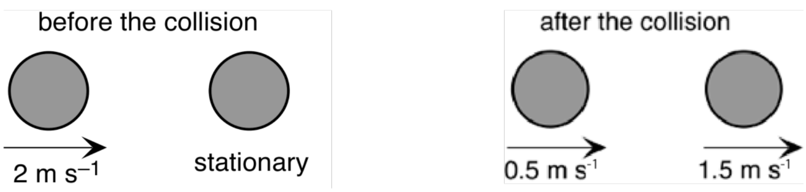
(2 marks)

d. Estimate the speed of the ball as it leaves the club head.

(3 marks)

Question 4/ 52

The collision between two snooker balls can be modelled by two isolated masses colliding.



a. Show that this collision is not elastic.

(2 marks)

b. Calculate the ratio:

$$\frac{kinetic\ energy\ before\ the\ collision}{kinetic\ energy\ after\ the\ collision}$$

(3 marks)

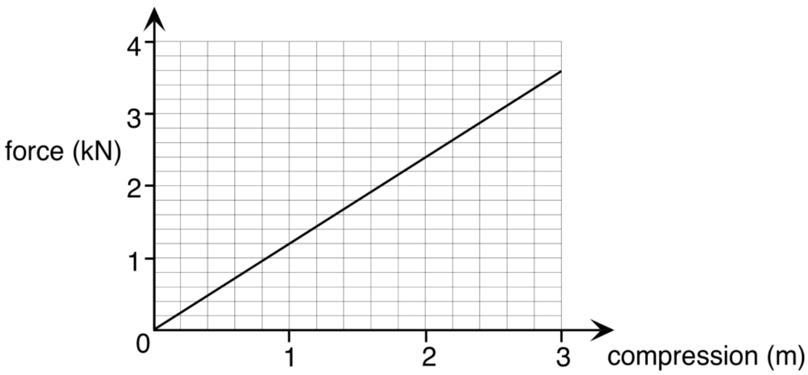
Question 5/ 52

A pole-vaulter achieves much of her height by converting stored elastic energy in the pole into gravitational potential energy. Her mass is 60 kg. She needs to raise her centre of mass by 7.0 m to vault a bar. 90% of her potential energy needs to be supplied from the elastic potential energy in the pole.

a. How much elastic potential energy needs to be stored in the pole?

(2 marks)

After a successful vault, she falls onto a pile of mats to cushion her fall. The compression-force graph for the pile of mats is shown below.



b. Estimate the maximum compression she causes in the mats.

(3 marks)

Question 6/ 52

A basketball player bounces a 450 g ball on the court floor. Just before the ball hits the ground, it is travelling at 8 m s^{-1}. After it bounces, it leaves the floor at 6 m s^{-1}.

a. How much kinetic energy has been converted into other forms of energy during the bounce?

(2 marks)

b. 'Energy cannot be created or destroyed.' Account for the 'missing' kinetic energy in terms of this statement.

(3 marks)

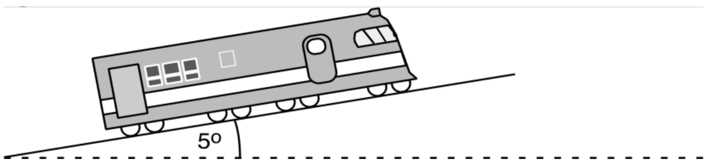
Question 7/ 52

Explain what is meant by the statement that 'a collision is *elastic*'.

(2 marks)

Question 8/ 52

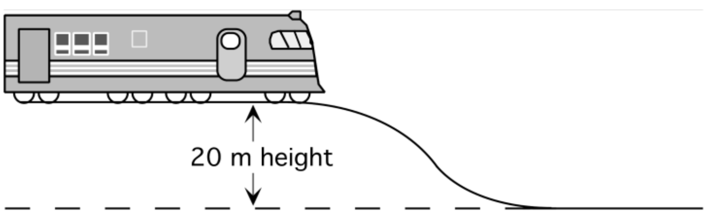
A train of mass 600 kg travels up a hill at a constant speed of 10 m s^{-1}. The only friction is between the track and the driving wheels. Give all your answers to this question to two significant figures.



a. The train reaches the top of the hill at 10 m s^{-1}. What is its kinetic energy?

(2 marks)

The train coasts down the hill on the other side into a valley.



b. If there was no opposing friction, what would its speed have been at the bottom of the hill?

(2 marks)

c. In fact, its speed was only 18 m s^{-1}. How much energy has been transformed into thermal energy?

(2 marks)

d. Later, the train travels up a slope slowly. It gains 4.0 MJ of gravitational PE. The efficiency of its engines is 20%. How much chemical energy (in MJ) did it transform from its fuel in climbing the hill?

(3 marks)

Question 9/ 52

Going up a hill, Sally's car generates a power of 35 kW (35 kJ s^{-1}).

a. How much mechanical energy does it generate every minute?

(2 marks)

b. The car uses 3 litres of petrol every 10 minutes. Each litre of petrol contains 30 MJ of energy. Estimate the car's efficiency.

(3 marks)

Question 10/ 52

Two cars travel at 5 m s^{-1}, collide head on and lock together. Straight after the collision they travel at 1.5 m s^{-1}. What percentage of the KE before the collision transforms into other forms during the collision? Show your working.

(3 marks)

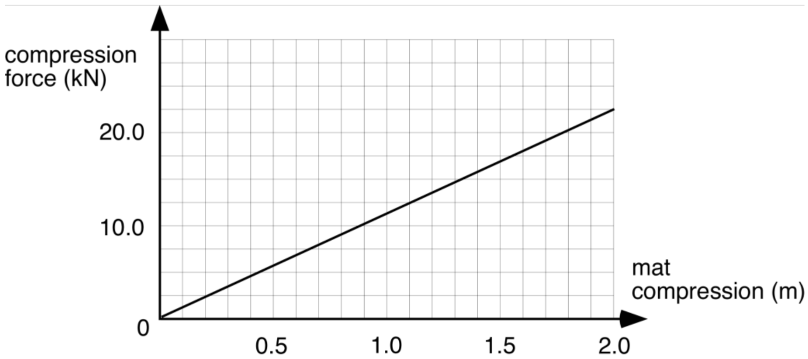
Question 11/ 52

Pole-vaulters use mats to absorb their kinetic energy (KE) when they fall.

a. How much KE would need to be absorbed by a mat under an 80 kg pole-vaulter whose centre of mass has fallen a distance of 7.0 m?

(2 marks)

The compression graph of a proposed pole-vault mat is shown below.



b. What is the force constant of this mat?

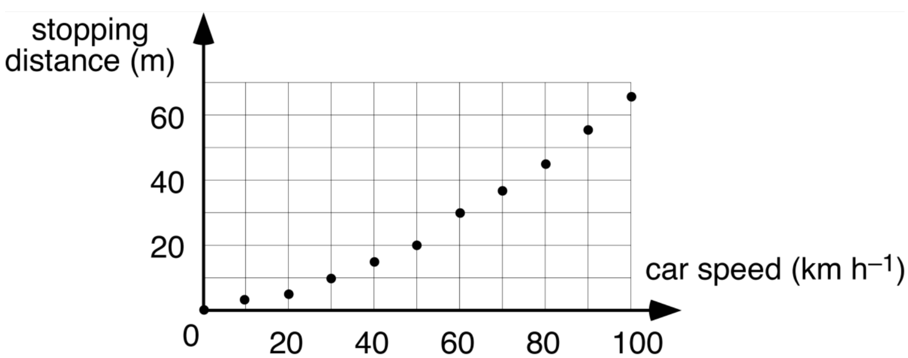
(2 marks)

c. Estimate the compression of this mat when it absorbs 6000 J of KE.

(2 marks)

Question 12/ 52

The graph below shows how the stopping distance of a car varies with its speed in good conditions. The car brakes are in good condition.

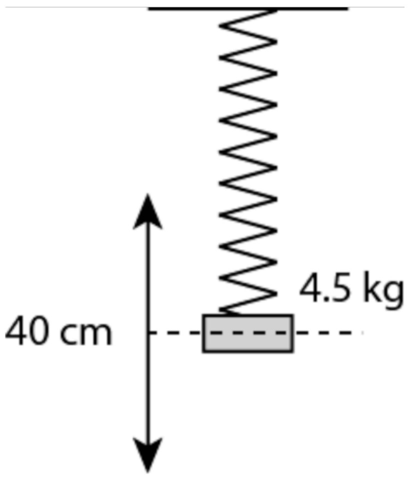


When the speed doubles (e.g. from 40 to 80 km h^{-1}), the stopping distance increases by much more than a factor of two. Outline how physics principles apply to this situation.

(3 marks)

Question 13/ 52

A mass of 4.5 kg is oscillating on the end of an ideal spring, as shown in the diagram. The amplitude of the oscillation is 40 cm. The spring constant is equal to 90 N m^{-1}.



a. Show that the stretch of the spring at the centre of the oscillation is equal to 49 cm.

(2 marks)

b. Take the lowest point of the oscillation as the zero of gravitational potential energy (GPE). Calculate the GPE at the top of the oscillation.

(1 mark)

c. Calculate the elastic potential energy stored in the system at the centre of the oscillation.

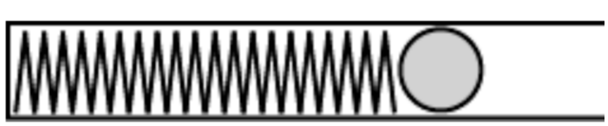
(2 marks)

d. Calculate the maximum elastic potential energy of the system.

(3 marks)

Question 14/ 52

A horizontal spring launcher is used to fire ball bearings along a frictionless tube, as shown in the diagram, with the spring compressed and ready to fire. The spring is ideal.



The speed and acceleration of the ball bearing change as the spring expands.

a. Describe when the acceleration of the ball bearing is a maximum.

(1 mark)

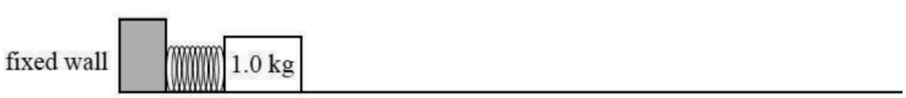
b. Describe when the speed of the ball bearing is a maximum.

(1 mark)

c. A launcher of this design propels a 10 g ball bearing to a maximum speed of 1.5 m s^{-1} when the maximum compression of the spring is 9.0 cm. Calculate the spring constant. Include a unit in your answer. (3 marks)

Question 15/ 52

A spring is resting against a fixed wall. The spring is compressed by a distance of 10.0 cm from its uncompressed length. A block of mass 1.0 kg is placed against the compressed spring as shown in the diagram and then released. The block leaves the spring with a kinetic energy of 6.0 J and slides along a frictionless surface at a constant speed.



a. Calculate the speed of the block as it slides along the frictionless surface.

(2 marks)

b. Calculate the spring constant, *k*, of the spring. Assume that the spring obeys Hooke's law.

(2 marks)

Question 16/ 52

A car has a braking distance of 18 m when travelling at 60 km h^{-1}.

Determine the braking distance for the same car under the same braking conditions and the same road conditions if the car is travelling at 40 km h^{-1}.

(2 marks)

Question 17/ 52

[Adapted VCAA 2016 SB Q3]

Students investigate masses oscillating on the end of a spring. They add masses and the spring extends, as shown in Diagram 1. Then they lift the masses up and release them from the spring's unstretched length, as shown in Diagram 2.

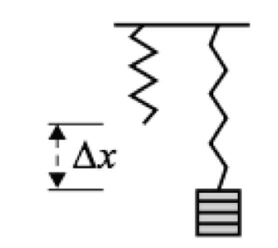


Diagram 1

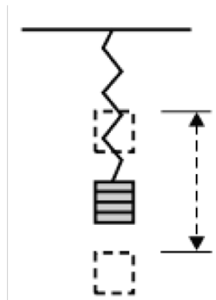
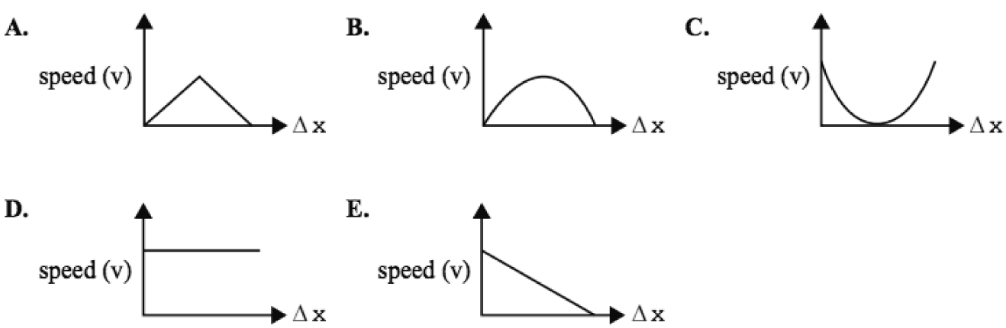


Diagram 2

Which of the graphs on the next page best shows the speed as a function of extension Δx as the masses move from top to bottom? Explain your answer.

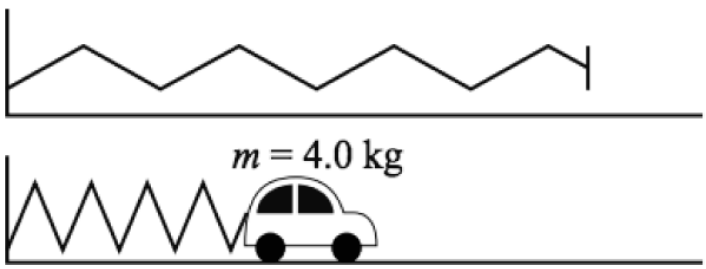


(2 marks)

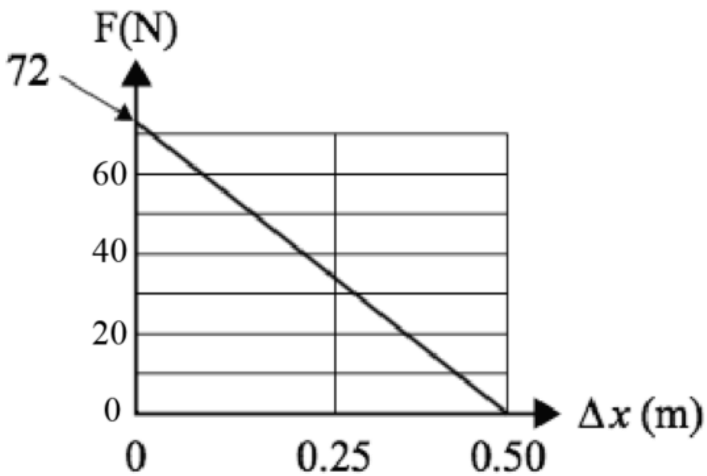
Question 18/ 52

[Adapted VCAA 2016 SB Q4]

In a test, an unpowered toy car of mass 4.0 kg is held against a spring, compressing the spring by 0.50 m, and then released, as shown below. There is negligible friction while the car is in contact with the spring.



The diagram below shows the force–extension graph for the spring.



a. Determine the energy stored in the spring before release.

(2 marks)

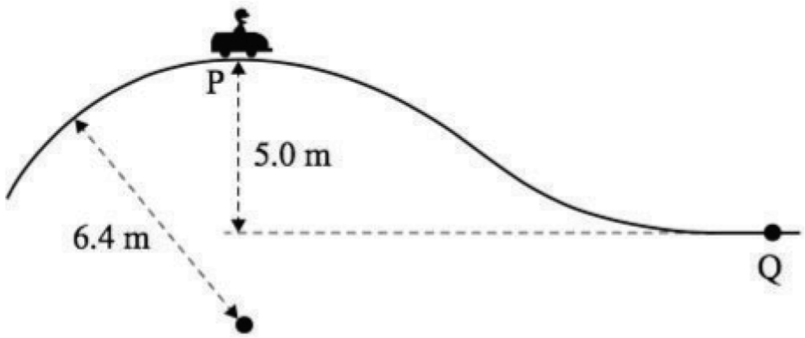
b. Calculate the speed of the car as it leaves the spring. Ignore any frictional forces.

(2 marks)

Question 19/ 52

[Adapted VCAA 2017 SB Q8]

A roller-coaster is arranged so that the car at point P, shown below, is travelling at 4.0 m s^{-1}.



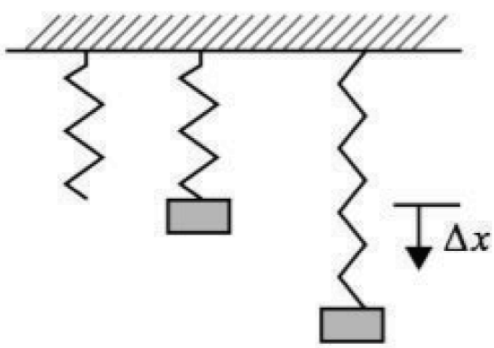
Calculate how fast the car would be moving when it reaches the bottom at point Q, 5.0 m below point P. Assume that there is no friction and no driving force on the car.

(2 marks)

Question 20/ 52

[VCAA 2017 SB Q13]

Pat and Robin hang a mass of 2.00 kg on the end of a spring with spring constant $k = 20.0 \text{ N m}^{-1}$. They hold the mass at the unstretched length of the spring and release it, allowing it to fall, as shown in the diagram.



a. Determine how far the spring stretches before the mass comes momentarily to rest at the bottom. Show your working.

(3 marks)

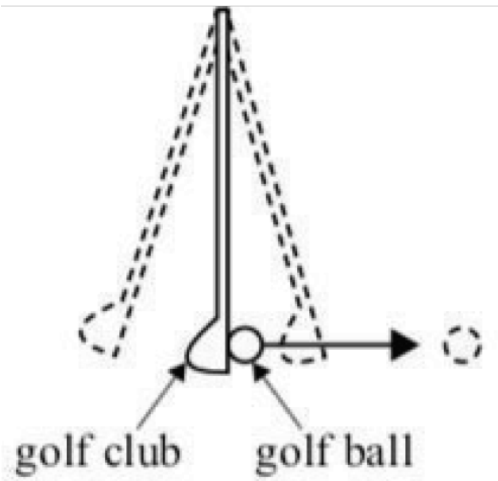
b. Explain how the three energies involved and the total energy of the system vary as the mass falls from the top to the bottom. Calculations are *not* required.

(4 marks)

Question 21/ 52

[VCAA 2018 SB Q7]

Students study the behaviour of a golf club hitting a golf ball. They treat it as a collision between the head of the golf club and the golf ball only, as shown.



The students take the following measurements.

mass of head of golf club	0.50 kg
mass of golf ball	0.040 kg
initial speed of golf club	$45 \mathrm{~m} \mathrm{~s}^{-1}$
final speed of golf club after hitting golf ball	$40 \mathrm{~m} \mathrm{~s}^{-1}$

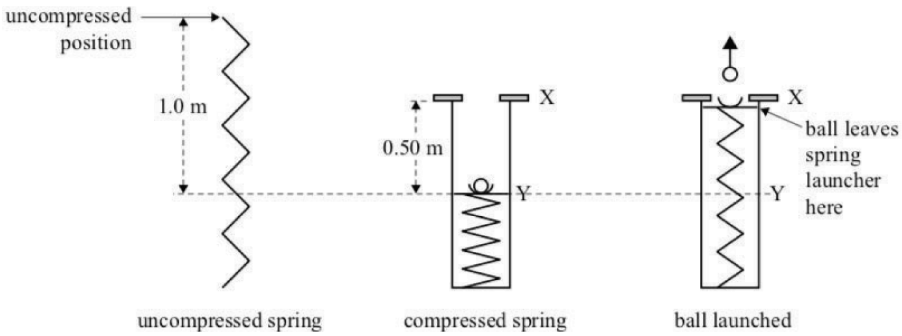
The golf ball is stationary before being hit. The ball's speed immediately after being hit is $63 \mathrm{~m} \mathrm{~s}^{-1}$. Use calculations to determine whether the collision is elastic or inelastic. Show your working.

(3 marks)

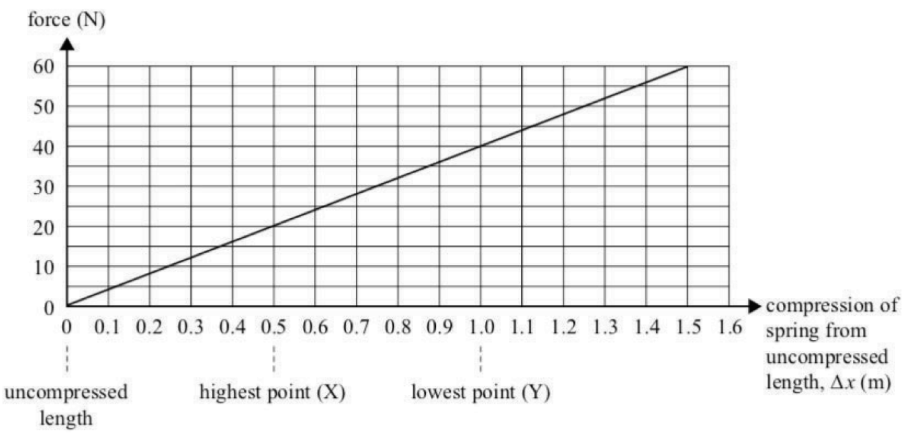
Question 22/ 52

[VCAA 2018 SB Q9]

A spring launcher is used to project a rubber ball of mass 2.0 kg vertically upwards. The arrangement is shown below. The ball is driven by a spring, which is compressed and released. When the spring reaches the top, point X, it is held stationary, but is still partly compressed as the ball leaves the launcher. Assume the spring has no mass.



The force–distance graph of the spring is below, on which the lower and upper positions of the spring in the spring launcher are marked.



a. Calculate the spring constant, k, of the spring.

(2 marks)

b. Calculate the change in spring potential energy of the spring as it goes from the lowest point, Y, to the highest point, X.

(3 marks)

c. The spring, with a ball in place, is released from Y. It moves up to X, where it is stopped and the ball is launched. Calculate the speed of the ball when it leaves the spring launcher. Show the steps in your working.

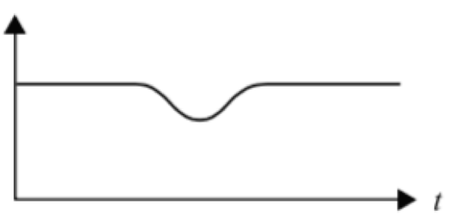
(4 marks)

Question 23/ 52

(Adapted VCAA 2017 Sample SB Q11)

Students observe two trolleys collide elastically on a horizontal surface.

They know that the collision is elastic but are unsure how the kinetic energy varies with time. One student, Pat, thinks that it will vary as shown in the left-hand graph below. Another student, Alex, thinks that it will vary as shown in the right-hand graph below. Who is correct? Explain your answer.

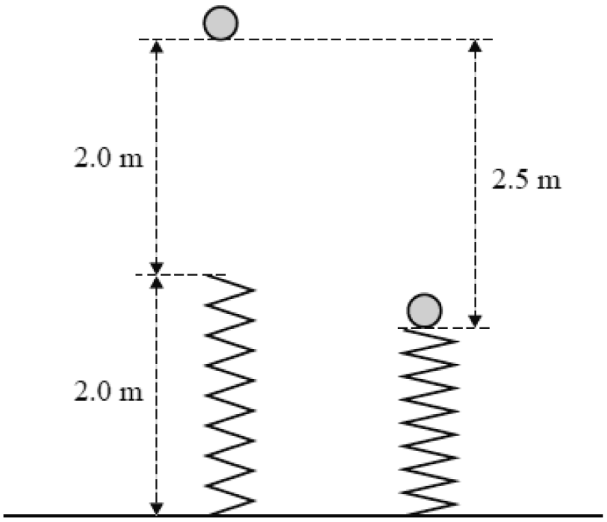


(2 marks)

Question 24/ 52

[VCAA 2018 SB Q6]

A ball of mass 2.0 kg is dropped from a height of 2.0 m above a spring, as shown below. The spring has an uncompressed length of 2.0 m. The ball and the spring come to rest when they are at a distance of 0.50 m below the uncompressed position of the spring.



a. Use $g = 9.8 \text{ N kg}^{-1}$ to show the spring constant, *k*, is equal to 392 N m^{-1}. Show your working.

(3 marks)

b. Determine the acceleration of the ball when it reaches its maximum speed. Explain your answer.

(2 marks)

c. Calculate the compression of the spring when the ball reaches its maximum speed. Show your working.

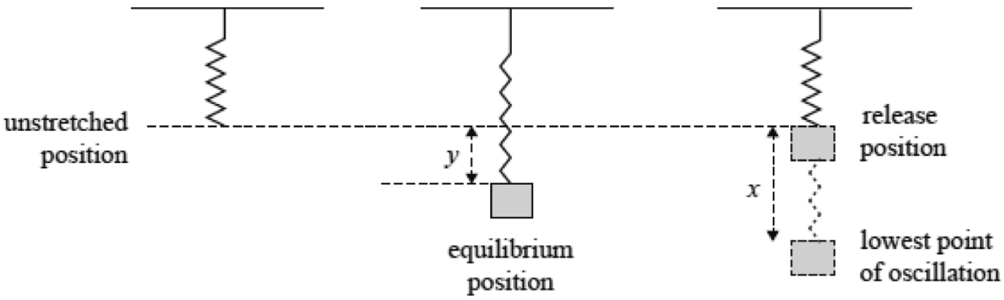
(2 marks)

Question 25/ 52

[Adapted VCAA 2019 SB Q5]

Students conduct an experiment in which a mass of 2.0 kg is suspended from a spring with spring constant $k = 100 \text{ N m}^{-1}$. Ignore the mass of the spring.

Take the gravitational field, *g*, to be 10 N kg^{-1}. Take the zero of gravitational potential energy when the mass is at its lowest point. The experimental arrangement is shown below.



The mass is raised to the unstretched length of the spring and released so that it oscillates vertically.

a. Determine the distance, *x*, from the release position to the point at which the mass momentarily comes to rest at the lowest point of oscillation. Ignore frictional losses. Show your working.

(2 marks)

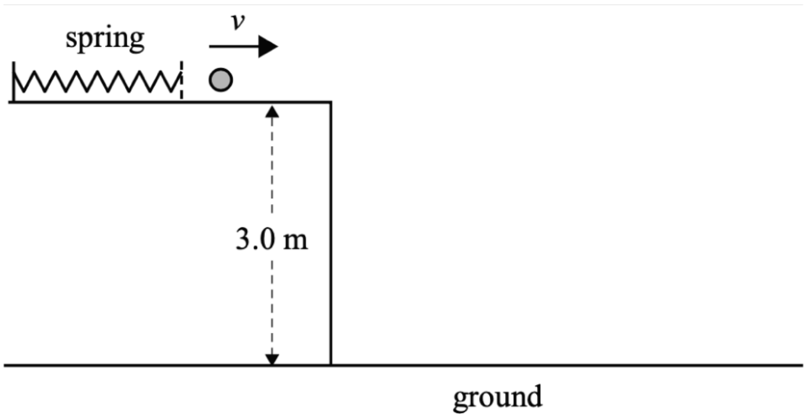
b. Calculate the maximum speed of the mass. Show your working.

(4 marks)

Question 26/ 52

[Adapted VCAA 2020 SB Q9]

An ideal spring is compressed by 0.15 m. A ball of mass 0.20 kg is placed in contact with the compressed spring. The spring is then released, causing the ball to move horizontally, with a velocity of *v*, across a smooth surface, as shown below.



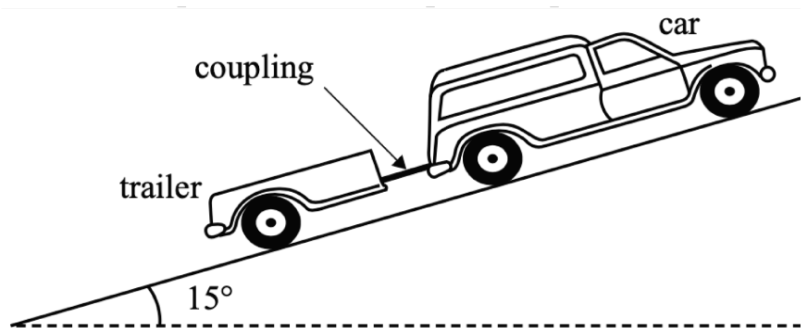
If the spring constant is 1250 N m^{-1}, show that the magnitude of the initial velocity, *v*, of the ball is 12 m s^{-1}, correct to two significant figures. Show your working.

(2 marks)

Question 27/ 52

[Adapted VCAA 2021 NHT SB Q8]

A car is driving up a uniform slope with a trailer attached, as shown below. The slope is angled at 15° to the horizontal. The trailer has a mass of 200 kg and the car has a mass of 750 kg. Ignore all retarding friction forces down the slope. The car and trailer are travelling at a constant speed of 8 m s^{-1} up the slope.



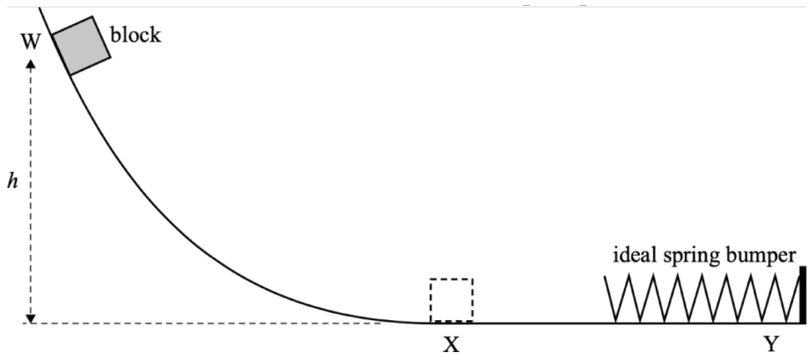
Calculate the gravitational potential energy gained by the car and trailer when they have travelled 100 m along the slope. Show your working.

(3 marks)

Question 28/ 52

[VCAA 2021 SB Q9]

In a model of a proposed ride at a theme park, a 5.0 kg smooth block slides down a ramp from point W and into an ideal spring bumper without any friction or air resistance, as shown below. The final section of the ramp, between points X and Y, is horizontal. The block comes to an instantaneous stop at point Y.



The maximum compression of the spring is measured as 3.0 m and its spring constant, *k*, is $100\ \mathrm{N\ m^{-1}}$. Calculate the release height, *h*. Show your working.

(3 marks)

Question 29/ 52

[Adapted VCAA 2021 SB Q18]

A small rubber ball of mass 50 g falls vertically from a given height and rebounds from a hard floor. Just before the ball hits the floor, it has a certain amount of kinetic energy, E_k. The ball's speed immediately before impact is $3.6\ \mathrm{m\ s^{-1}}$ and it rebounds upward at a speed of $3.3\ \mathrm{m\ s^{-1}}$. At one instant when the ball is in contact with the floor, it is stationary before it rebounds. Explain what has happened to the kinetic energy, E_k, of the ball when it is stationary.

(2 marks)

Question 30/ 52

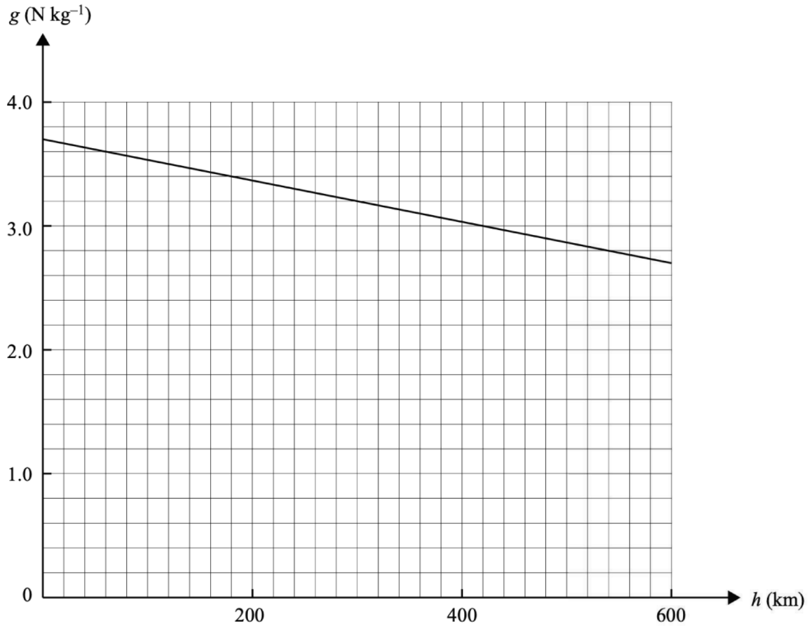
[Adapted VCAA 2021 SB Q8]

On 18 February 2021, the Perseverance rover space capsule, travelling at $20000\ \mathrm{km\ h^{-1}}$, entered Mars's atmosphere at an altitude of 300 km above the surface of Mars. The mass of the capsule was 1000 kg.

a. Calculate the kinetic energy of the capsule at this point. Show your working.

(2 marks)

The graph below shows the gravitational field strength of Mars (g) versus altitude (h).



b. Calculate the gravitational potential energy of the capsule relative to the surface of Mars at an altitude of 300 km. Show your working.

(3 marks)

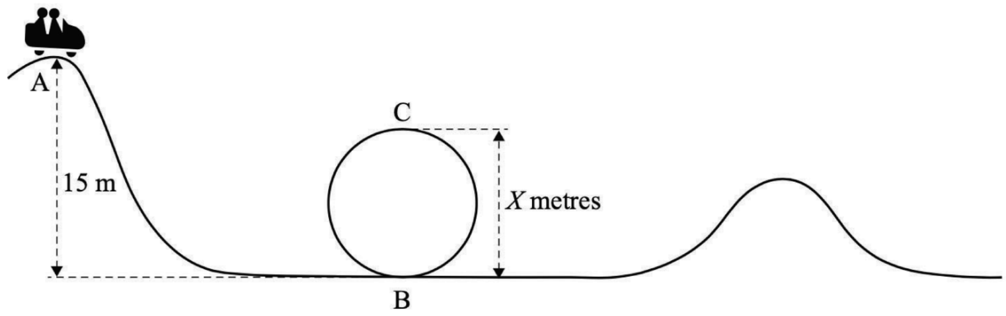
c. The capsule used aerodynamic braking as it descended through Mars's atmosphere to reduce its speed from 20000 km h^{-1} to 1600 km h^{-1}. The capsule was then at an altitude of 10 km above the surface of Mars and had ~1% of its original combined gravitational potential energy and kinetic energy remaining. Describe how ~99% of the gravitational potential energy and kinetic energy of the capsule was transformed and dissipated as the capsule descended from an altitude of 300 km above the surface of Mars to an altitude of 10 km above the surface of Mars. No calculations are required.

(3 marks)

Question 31/ 52

[Adapted VCAA 2021 SB Q9]

Abbie and Brian are about to go on their first loop-the-loop roller-coaster ride.



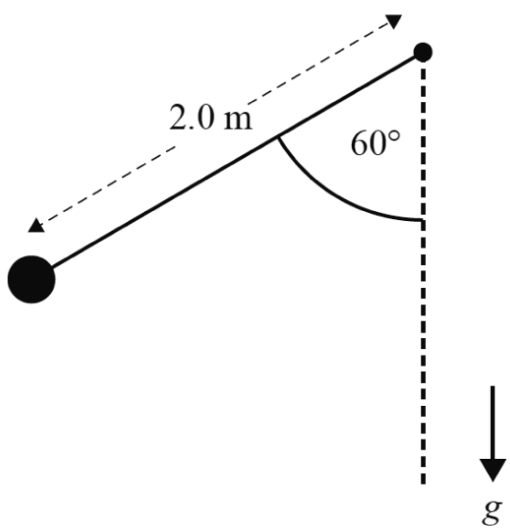
The highest point of the roller-coaster (point A) is 15 m above point B and the car starts at rest from point A. Assume that there is negligible friction between the car and the track. What is the speed of the car at point B? Show your working.

(2 marks)

Question 32/ 52

[VCAA 2022 NHT SB Q7]

A spherical mass of 2.0 kg is attached to a piece of string with length of 2.0 m. The spherical mass is pulled back until it makes an angle of 60° with the vertical, as shown below. The spherical mass is then released. Ignore the mass of the string.



a. Show that the maximum speed of the spherical mass is $4.4\ \mathrm{m\ s^{-1}}$.

(2 marks)

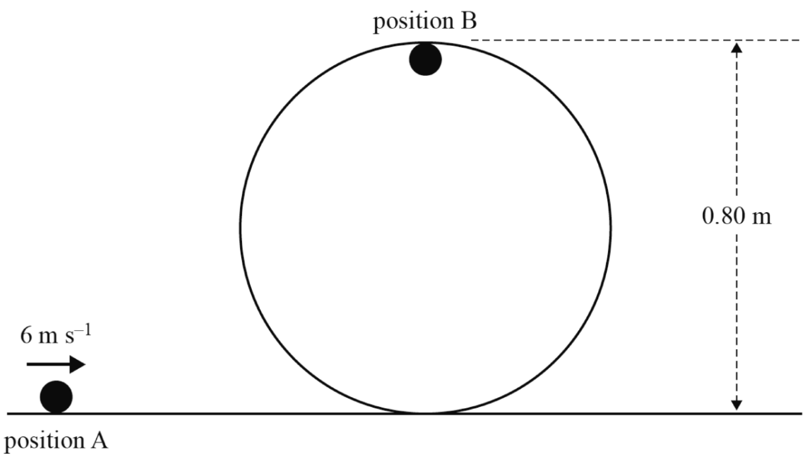
b. At what part of its path is the spherical mass at its maximum speed? Explain your reasoning.

(2 marks)

Question 33/ 52

[Adapted VCAA 2022 NHT SB Q9]

A small ball of mass 0.30 kg travels horizontally at a speed of 6 m s^{-1}. It enters a vertical circular loop of diameter 0.80 m, as shown below. Assume that the radius of the ball and that the frictional forces are negligible.



Show that the kinetic energy of the ball at position A is 5.4 J.

(1 mark)

Chapter 4 Momentum and collisions

Question 1/ 20

Two rollerbladers (Jack and Jill) are skating with very little frictional resistance to their motion. Jack rolls up to Jill, who is skating more slowly in the same direction. They join hands and roll on in the same direction, without accelerating.

Which of the following describes the physics of this ‘collision’ best?

A The combined momentum and KE has not changed.

B The combined KE has remained constant.

C The combined momentum has remained constant.

D Both the combined momentum and KE have changed.

Question 2/ 20

Two snooker balls of unknown quality travel directly towards each other, as shown below. They have the same mass.

Which one of the combinations in the table below is *impossible* immediately after the collision? Take right as positive.

Velocity of ball A (ms^{-1})	Velocity of ball B (ms^{-1})
$+4$	-1.0
-3.0	0.0
-1.5	-1.5
-5.5	$+2.5$

Question 3/ 20

Two blocks have a collision on a frictionless surface.

Question 4/ 20

In one instance, the blocks stick together after the collision, due to (very) quick-acting glue. Their speed after the collision is closest to

A $1.0\ \mathrm{m\ s^{-1}}$

B $1.2\ \mathrm{m\ s^{-1}}$

C $1.5\ \mathrm{m\ s^{-1}}$

D $1.8\ \mathrm{m\ s^{-1}}$

Question 5/ 20

On another occasion, the blocks collide elastically. The speed of the two blocks is closest to the following speeds (the 1.2 kg block speed is written first; the units are $\mathrm{m\ s^{-1}}$).

A (2, 1)

B (1, 2)

C (1.5, 1.5)

D (0, 1.5)

Question 6/ 20

A golf club head (mass 250 g) travelling at $30 \mathrm{~m~s^{-1}}$ strikes a stationary golf ball (mass 50 g). During the collision, the golf club head slows to $22 \mathrm{~m~s^{-1}}$. Which of the following is closest to the impulse acting on the golf ball during the collision?

A 0.2 N s

B 0.4 N s

C 2 N s

D 4 N s

Question 7/ 20

The speed of the golf ball after the collision is closest to

A $22 \mathrm{~m~s^{-1}}$

B $28 \mathrm{~m~s^{-1}}$

C $40 \mathrm{~m~s^{-1}}$

D $240 \mathrm{~m~s^{-1}}$

Question 8/ 20

The collision could best be described as

A elastic, with no loss of KE.

B inelastic, with a loss of 12 J.

C inelastic, with a loss of 40 J.

D inelastic, with a loss of 60 J.

Question 9/ 20

In a collision between two objects, where they stick together after the collision, it is true to say that

A all the KE is always lost to other forms.

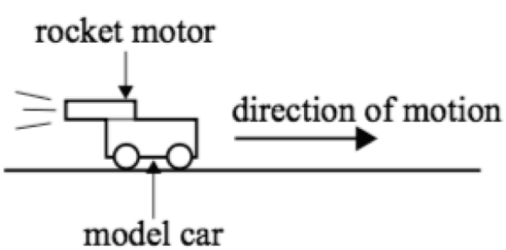
B sometimes all the KE is lost to other forms.

C sometimes the collision is elastic.

D sometimes some of the momentum is changed to other forms.

Question 10/ 20

A model car of mass 2.0 kg is propelled from rest by a rocket motor that applies a constant horizontal force of 4.0 N, as shown below. Assume that friction is negligible.



Question 11/ 20

[VCAA 2017 SA Q7]

Which of the following best gives the magnitude of the impulse given to the car by the rocket motor in the first 5.0 s?

A 4.0 N s

B 8.0 N s

C 20 N s

D 40 N s

Question 12/ 20

[VCAA 2017 SA Q9]

With the same rocket motor, the car accelerates from rest for 10 s. Which one of the following best gives the final speed?

A 6.3 m s^{-1}

B 10 m s^{-1}

C 20 m s^{-1}

D 40 m s^{-1}

Question 13/ 20

An X-ray photon with a momentum of $6.0 \times 10^{-23} \text{ N s}$ collides with a stationary electron. The electron's momentum gain is $1.0 \times 10^{-22} \text{ N s}$, and it is in the same direction as the X-ray photon. Which of the following is closest to the magnitude of the momentum of the scattered photon?

A $4 \times 10^{-11} \text{ N s}$

B $4 \times 10^{-17} \text{ N s}$

C $4 \times 10^{-23} \text{ N s}$

D $4 \times 10^{-30} \text{ N s}$

Question 14/ 20

Two atoms travelling at the same speed towards each other collide and bounce off at the same speed, going in opposite directions. Which of the following statements is correct?

A The collision increases the total amount of energy.

B Kinetic energy is conserved throughout the collision.

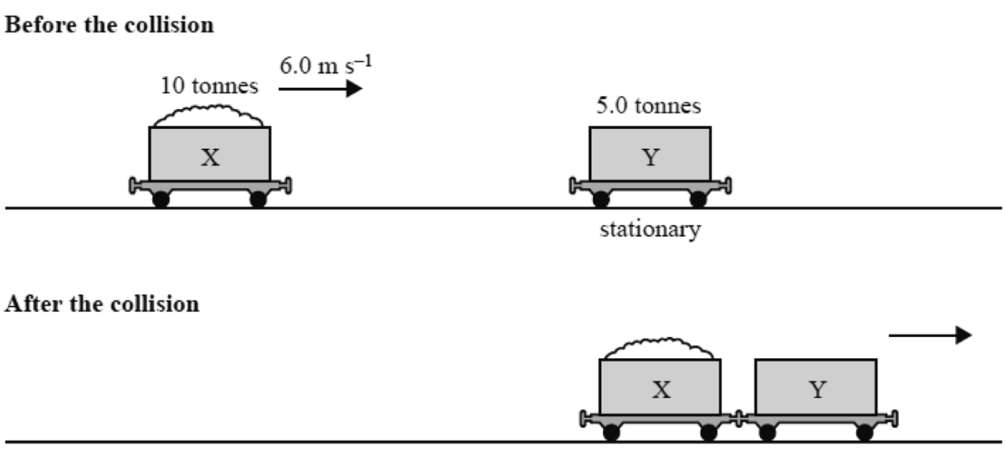
C The collision reduces the total momentum.

D The total momentum before the collision is zero.

Question 15/ 20

[VCAA 2018 SA Q8]

A railway truck X of mass 10 tonnes, moving at $6.0 \mathrm{~m} \mathrm{~s}^{-1}$, collides with a stationary railway truck Y of mass 5.0 tonnes. After the collision, the trucks are joined together and move off as one. The situation is shown below.



The final speed of the joined railway trucks after the collision is closest to

A $2.0 \mathrm{~m} \mathrm{~s}^{-1}$

B $3.0 \mathrm{~m} \mathrm{~s}^{-1}$

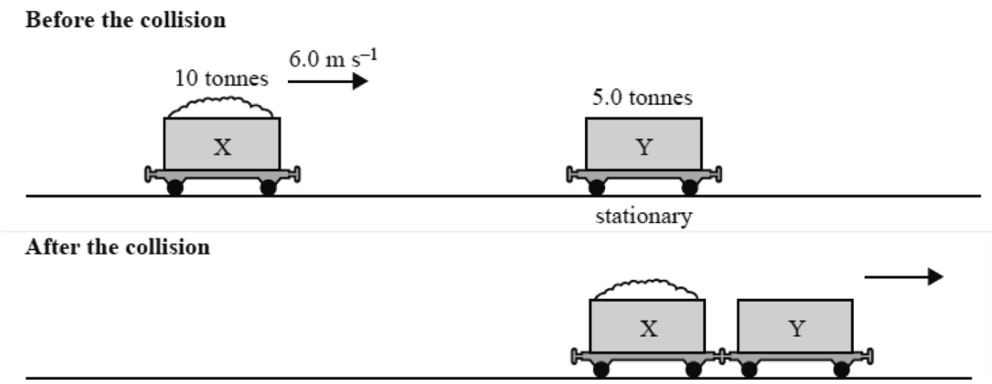
C $4.0 \mathrm{~m} \mathrm{~s}^{-1}$

D 6.0 m s^{-1}

Question 16/ 20

[VCAA 2018 SA Q9]

A railway truck X of mass 10 tonnes, moving at 6.0 m s^{-1}, collides with a stationary railway truck Y of mass 5.0 tonnes. After the collision, the trucks are joined together and move off as one. The situation is shown below.



The collision of the railway trucks is best described as one where

A kinetic energy is conserved but momentum is not conserved.

B kinetic energy is not conserved but momentum is conserved.

C neither kinetic energy nor momentum is conserved.

D both kinetic energy and momentum are conserved.

Question 17/ 20

[VCAA 2019 SA Q20]

As part of their Physics course, Anna, Bianca, Chris and Danshirou investigate the physics of car crashes. On an internet site that describes what happens during car crashes, they find the following statement.

It happens in a flash: your car goes from driving to impacting … As the vehicle crashes into something, it stops or slows very abruptly, and at the point of impact the car's structure will bend or break. That crumpling action works to absorb some of the initial crash forces, protecting the passenger compartment to some degree.

Source: Kathleen Poling, 'Crash Dynamics for Dummies', Car Seats for the Littles, 3 January 2018, www.csftl.org/crash-dynamics-dummies/

The students disagree about the use of the word 'forces' in the statement,

'That crumpling action works to absorb some of the initial crash forces, protecting the passenger compartment to some degree'.

Which one of the following students best identifies the physics of how the crumpling action protects the passengers?

A Anna '*to absorb some of the initial crash speed, protecting …*'

B Bianca '*to absorb some of the initial crash kinetic energy, protecting …*'

C Chris '*to absorb some of the initial crash momentum, protecting …*'

D Danshirou '*to absorb some of the initial crash forces, protecting …*'

Question 18/ 20

[VCAA 2021 SA Q3]

A 45 g golf ball, initially at rest, is hit by a golf club. The contact time between the club and the ball is 0.50 ms. The magnitude of the final velocity of the ball is 41 m s^{-1}. Which one of the following is closest to the average force experienced by the golf ball?

A 0.18 kN

B 0.37 kN

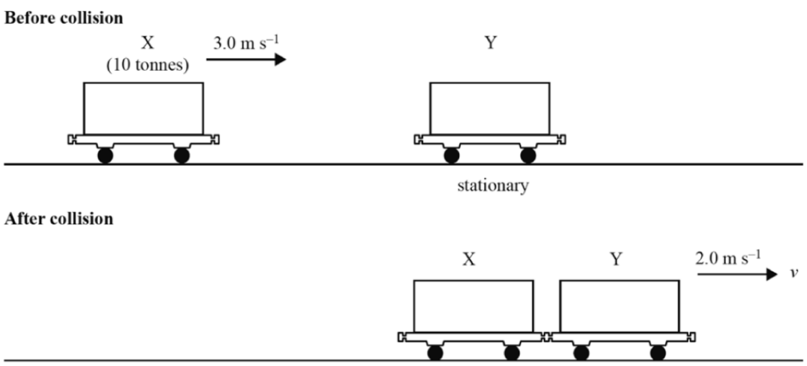
C 1.8 kN

D 3.7 kN

Question 19/ 20

[VCAA 2022 SA Q6]

A railway truck (X) of mass 10 tonnes, moving at $3.0 \mathrm{~m} \mathrm{~s}^{-1}$, collides with a stationary railway truck (Y), as shown in the diagram below. After the collision, they are joined together and move off at speed $v = 2.0 \mathrm{~m} \mathrm{~s}^{-1}$.



Which one of the following is closest to the mass of railway truck Y?

A 3 tonnes

B 5 tonnes

C 6.7 tonnes

D 15 tonnes

Question 20/ 20

[VCAA 2022 SA Q7]

Which one of the following best describes the force exerted by the railway truck X on the railway truck $\mathrm{Y}\left(F_{X \text{ on } Y}\right)$ and the force exerted by the railway truck Y on the railway truck $\mathrm{X}\left(F_{Y \text{ on } X}\right)$ at the instant of collision?

A $F_{\mathrm{X \text{ on } Y}} < F_{\mathrm{Y \text{ on } X}}$

B $F_{\mathrm{X \text{ on } Y}} = F_{\mathrm{Y \text{ on } X}}$

C $F_{\text{X on Y}} = -F_{\text{Y on X}}$

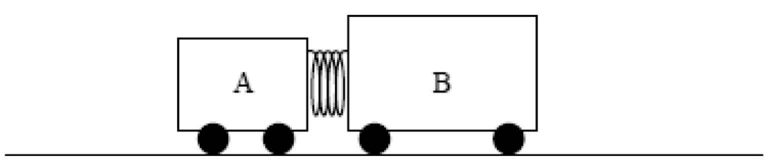
D $F_{\text{X on Y}} > F_{\text{Y on X}}$

Question 21/ 20

[Adapted VCAA NHT 2023 SA Q9]

The diagram below shows two stationary trolleys on a smooth surface, with an ideal spring compressed between them. Trolley A has mass of 1.0 kg and Trolley B has mass of 2.5 kg. The spring is released and the trolleys move off in opposite directions. The spring falls straight down.

Trolley A moves to the left at 0.80 m s^{-1}.



Which one of the following is closest to the speed of Trolley B?

A 0.32 m s^{-1}

B 0.80 m s^{-1}

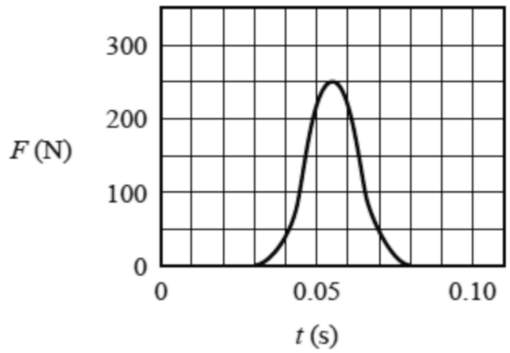
C 2.0 m s^{-1}

D 3.1 m s^{-1}

Question 22/ 20

[VCAA 2023 SA Q4]

The diagram below shows the force versus time graph of the force on a tennis ball when it is hit by a tennis racquet. The tennis ball is stationary when the tennis racquet first comes into contact with the ball.



Which one of the following is closest to the impulse experienced by the tennis ball as it is hit by the tennis racquet?

A 0.50 N s

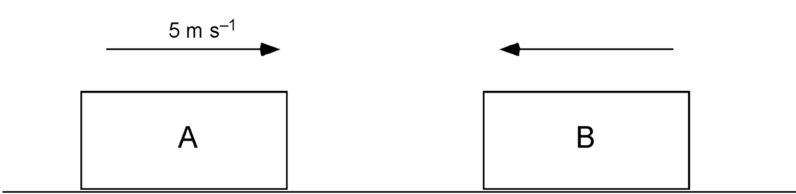
B 5.0 N s

C 10 N s

D 50 N s

Question 1/ 46

Students are studying collisions between blocks of wood on a flat frictionless table. The blocks slide towards each other as shown in the diagram.



Block A is travelling to the right at $5\ \mathrm{m\ s^{-1}}$; block B is moving to the left. Block A has a mass of 4 kg, and block B has a mass of 8 kg. After they collide, block A moves to the *left* with a speed of $5\ \mathrm{m\ s^{-1}}$, and block B is stationary.

a. Calculate the speed of block B *before* the collision. Show your reasoning.

(2 marks)

b. Does this collision conserve kinetic energy? You must justify your conclusion with calculations.

(2 marks)

Question 2/ 46

A 500 kg car travelling at $5\ \mathrm{m\ s^{-1}}$ runs into a stationary truck of mass 3.0 t. The truck moves forward at $1.0\ \mathrm{m\ s^{-1}}$, and the car rebounds in the opposite direction. What is the speed of the car straight after the collision? (Ignore external forces during the collision.)

(3 marks)

Question 3/ 46

The collision between two snooker balls can be modelled by two isolated masses colliding.

Show that momentum is conserved in this collision.

(2 marks)

Question 4/ 46

Two rollerbladers (Jack and Jill) are skating with good skates on a surface that has virtually no frictional resistance to their rolling. Jack has a mass of 55 kg. He rolls up to Jill at $5\ \mathrm{m\ s^{-1}}$. Jill has a mass of 45 kg, and she is rolling at $1\ \mathrm{m\ s^{-1}}$ in the same direction as Jack.

a. They join hands and roll on in the same direction. They do not skate. How fast will they be moving?

(2 marks)

b. Without pushing or pulling, Jack and Jill let go of each other. Describe what happens immediately after they let go. Justify your description with relevant physics.

(3 marks)

Question 5/ 46

A car travelling at $6\ \mathrm{m\ s^{-1}}$ crashes into two stationary cars. All the cars have the same mass (150 kg). They stick together and travel in the same direction as before. There is very little friction and no injuries.

a. How fast are they all travelling after the crash?

(2 marks)

b. How much momentum has the first car lost in the crash?

(2 marks)

c. What impulse did the first car exert on the other two cars?

(2 marks)

Question 6/ 46

Two cars, both travelling at $U\ \mathrm{m\ s^{-1}}$, collide head on and lock together. The right-hand car has mass *M* and the left-hand car has mass *m*.

Straight after the collision, the wreckage travels *left* at $V\ \mathrm{m\ s^{-1}}$.

a. What is the magnitude of the total momentum before the collision? (Give your answer in terms of *M*, *m*, and *U*.) (2 marks)

b. Derive an expression for *V* in terms of *U, m* and *M*. (2 marks)

Question 7/ 46

In a car, the driver's head collides horizontally with an airbag at 8.0 m s^{-1}. The driver's head stops in 0.16 s. This can be modelled as a horizontal collision between the head (mass 7.0 kg) and the airbag.

a. Calculate the magnitude of the impulse that the airbag exerts on the driver's head during this collision.

(2 marks)

b. Compare the impulse that the airbag exerts on the driver's head with the impulse that the driver's head exerts on the airbag.

(1 mark)

Question 8/ 46

[Adapted VCAA 2016 SB Q8]

An X-ray photon with a momentum of $6.6 \times 10^{-23} \text{ N s}$ collides with a stationary electron. The electron's momentum gain is $1.1 \times 10^{-22} \text{ N s}$ in the same direction as the incident X-ray photon. Calculate the magnitude of the momentum of the photon after the collision.

(2 marks)

Question 9/ 46

A basketball is bounced on a floor, striking the floor at $8 \mathrm{~m} \mathrm{~s}^{-1}$, and rebounding at $6 \mathrm{~m} \mathrm{~s}^{-1}$. Its mass is 400 g. The collision takes 80 ms.

a. What is the change in velocity of the ball during its bounce?

(2 marks)

b. What is the impulse of the net force on the ball during its bounce?

(2 marks)

c. What is the average net force exerted on the ball during its bounce?

(2 marks)

Question 10/ 46

Airbags in cars are designed to lengthen the time of collisions of people with parts of the car in accidents. Explain why this should lead to fewer injuries to people in cars.

(4 marks)

Question 11/ 46

A mass collides with another mass in deep space (where $g = 0$). Magnets ensure the masses stick together. They move off at the same speed (conservation of momentum). In a similar collision on a table on Earth, both masses come to a stop quickly.

Explain why.

(3 marks)

Question 12/ 46

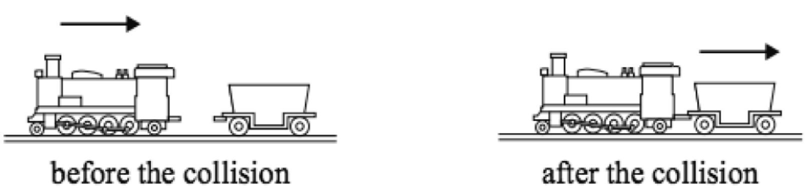
The law of conservation of momentum applies in *isolated* systems. Explain what is meant by an isolated system.

(2 marks)

Question 13/ 46

[Adapted VCAA 2016 SA Q1]

An engine of mass 20 tonnes and moving at $3.0\ \mathrm{m\ s^{-1}}$ collides with a stationary wagon of mass 10 tonnes. They couple together and move off at $2.0\ \mathrm{m\ s^{-1}}$, as shown.



Determine whether the collision is elastic or inelastic. Show your working.

(2 marks)

Question 14/ 46

A physics student, Sam K, is playing soccer.

a. Calculate the impulse she gives to a stationary soccer ball of mass 400 g that is kicked and moves off at a speed of $30\ \mathrm{m\ s^{-1}}$ ($108\ \mathrm{km\ h^{-1}}$).

(2 marks)

b. Determine the average force of her kick if the impact between her foot and the soccer ball lasts 6.0 ms.

(2 marks)

Question 15/ 46

[Adapted VCAA 2016 SA Q1]

An engine of mass 20 t moving at $3.0 \mathrm{~m~s}^{-1}$, collides with a stationary wagon of mass 10 t. They couple and move off together, as shown.

a. Calculate the speed of the engine and the wagon after the collision.

(2 marks)

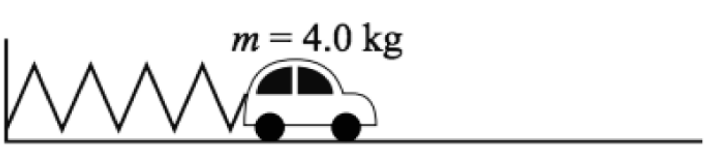
b. In another situation the engine, moving to the right at $2.0 \mathrm{~m~s}^{-1}$, collides with but does not couple with the stationary wagon. After the collision, the wagon moves off to the right at $2.0 \mathrm{~m~s}^{-1}$. Calculate the velocity (speed and direction) of the engine after the collision. Show your working.

(3 marks)

Question 16/ 46

[Adapted VCAA 2016 SA Q4]

A toy car of mass 4.0 kg is held against a compressed spring, and released. Friction is negligible. The car moves off at $2.0 \mathrm{~m~s}^{-1}$.



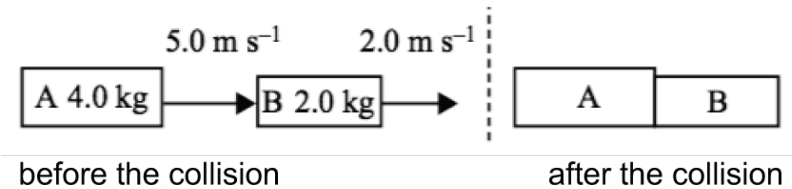
Calculate the impulse given to the car by the spring. Include a unit.

(2 marks)

Question 17/ 46

[VCAA 2017 SB Q12]

Students are using two trolleys, Trolley A of mass 4.0 kg and Trolley B of mass 2.0 kg, to investigate kinetic energy and momentum in collisions. Before the collision, Trolley A is moving to the right at $5.0 \mathrm{~m~s}^{-1}$ and Trolley B is moving to the right at $2.0 \mathrm{~m~s}^{-1}$, as shown in the diagram. The trolleys collide and lock together, as shown on the next page.



Determine, using calculations, whether the collision is elastic or inelastic. Show your working and justify your answer.

(3 marks)

Question 18/ 46

[VCAA 2017 Sample SB Q11]

Students conduct an experiment using two trolleys, A and B, of mass 6.0 kg and 2.0 kg respectively. In the experiment, Trolley A moves at $2.0 \mathrm{~m~s}^{-1}$ and Trolley B is stationary before they collide. There is a spring between the two trolleys, attached to Trolley B. When the trolleys collide, they compress the spring and then move apart. After the collision, Trolley A moves at $1.0 \mathrm{~m~s}^{-1}$. The experimental set-up is shown below. Ignore the mass of the spring.

Calculate the speed of Trolley B immediately after the collision.

(2 marks)

Question 19/ 46

[VCAA 2019 NHT SB Q7]

Students use high-speed photography to analyse a collision between a bat and ball. The experiment is arranged so that the bat and ball are both moving horizontally just before and just after the collision, as shown below. Assume that the bat and ball are point masses. The students record the following.

• $\text{Mass of bat} = 2.0\ \text{kg}$

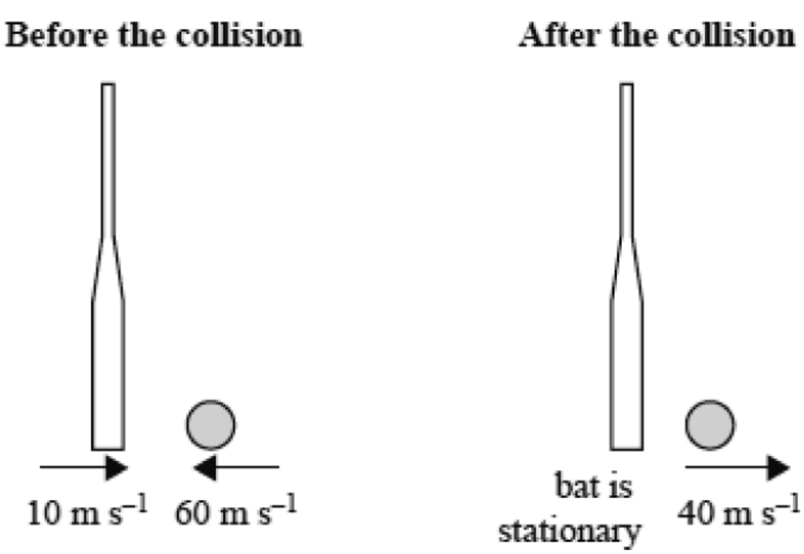
• $\text{Mass of ball} = 0.20\ \text{kg}$

• $\text{Speed of bat immediately before collision} = 10\ \text{m s}^{-1}$ (bat is stationary after collision)

• $\text{Speed of ball immediately before collision} = 60\ \text{m s}^{-1}$ (towards bat)

• $\text{Speed of ball immediately after collision} = 40\ \text{m s}^{-1}$ (away from bat)

• $\text{Time ball is in contact with bat} = 0.010\ \text{s}$



a. Calculate the magnitude of the impulse given by the bat to the ball. Include an appropriate unit. Show your working.

(3 marks)

b. Calculate the average force of the bat on the ball during the collision. Show your working.

(2 marks)

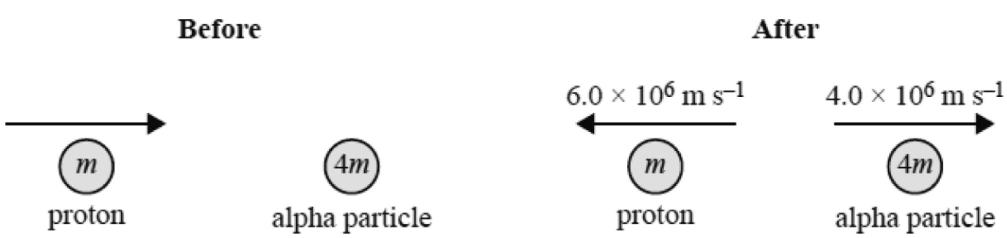
c. Use calculations to determine whether the collision between the bat and the ball is elastic or inelastic. Show your working.

(2 marks)

Question 20/ 46

[VCAA 2019 SB Q9]

A proton in an accelerator collides head-on with a stationary alpha particle, as shown below. After the collision, the alpha particle travels at a speed of $4.0 \times 10^6 \text{ m s}^{-1}$. The proton rebounds at $6.0 \times 10^6 \text{ m s}^{-1}$.



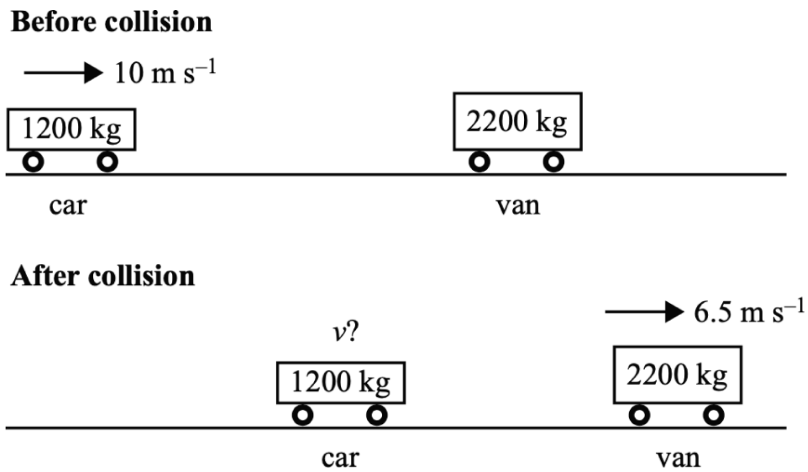
Find the proton speed before the collision. Model the alpha particle mass as 4*m*, and the proton mass as *m*. Show your working. Ignore relativistic effects.

(3 marks)

Question 21/ 46

[VCAA 2020 SB Q10]

Jacinda designs a computer simulation program as part of her practical investigation into the physics of vehicle collisions. She simulates colliding a car of mass 1200 kg, moving at 10 m s^{-1}, into a stationary van of mass 2200 kg. After the collision, the van moves to the right at 6.5 m s^{-1}. The situation is shown below.



a. Calculate the speed of the car after the collision and indicate the direction it would be travelling in. Show your working.

(4 marks)

b. Explain, using appropriate physics, why this collision represents an example of either an elastic or an inelastic collision.

(3 marks)

c. i. The collision between the car and the van takes 40 ms. Calculate the magnitude and indicate the direction of the average force on the van by the car.

(3 marks)

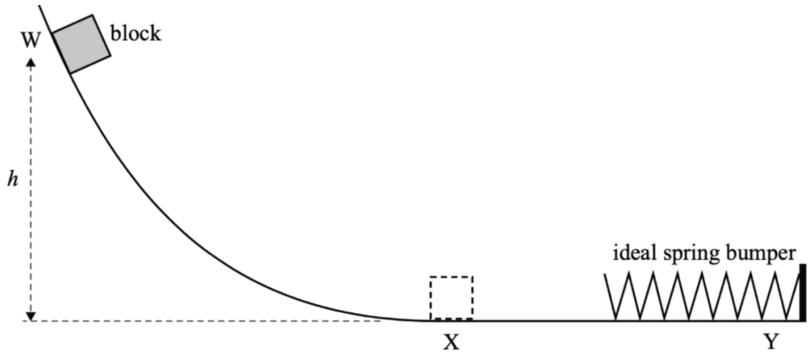
ii. Calculate the magnitude and indicate the direction of the average force on the car by the van.

(2 marks)

Question 22/ 46

[Adapted VCAA 2021 SB Q9]

In a model of a proposed ride at a theme park, a 5.0 kg smooth block slides down a ramp from point W and into an ideal spring bumper without any friction or air resistance, as shown below. The final section of the ramp, between points X and Y, is horizontal. The block comes to an instantaneous stop at point Y. The maximum compression of the spring is 3.0 m and the spring constant is 100 N m^{-1}.



a. Calculate the magnitude of the maximum momentum of the block. Show your working.

(2 marks)

b. When the block comes to rest, its momentum is zero. In terms of the principle of conservation of momentum, state what has happened to the momentum of the block as it comes to rest.

(1 mark)

Question 23/ 46

[Adapted VCAA 2021 NHT SB Q18]

A small rubber ball of mass 50 g falls vertically from a given height and rebounds from a hard floor. Just before the ball hits the floor, it has a certain amount of vertical momentum, p. At one instant when the ball is in contact with the floor, it is stationary before it rebounds.

What has happened to the vertical momentum, p, of the ball when it is stationary?

(1 mark)

Question 24/ 46

[Adapted VCAA 2021 SB Q17]

A 'space sail' on a tiny interstellar cylindrical probe relies on the momentum of photons from a nearby star to exert a propulsive force, as shown.

Missing Image

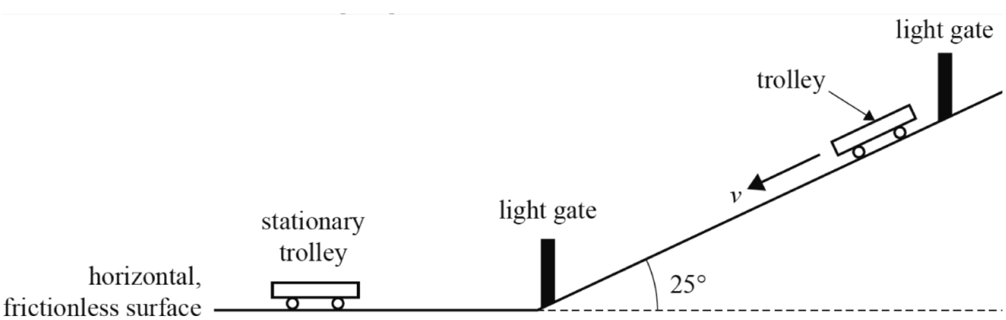
2.0×10^{18} photons strike the sail at 90° to its surface every second and reflect elastically. The photons have a momentum of 1.55×10^{-26} kg m s^{-1}. Calculate the force that the reflecting photons exert on the space sail. Show your working. Give your answer correct to two significant figures.

(3 marks)

Question 25/ 46

[Adapted VCAA 2022 SB Q7]

Kym and Kelly are experimenting with trolleys on a ramp inclined at 25°, as shown below. They release a trolley with a mass of 2.0 kg from the top of the ramp. The trolley moves down the ramp, through two light gates and onto a horizontal, frictionless surface. Kym and Kelly calculate the acceleration of the trolley to be 3.2 m s^{-2} using the information from the light gates.



When it reaches the bottom of the ramp, the trolley travels along the horizontal, frictionless surface at a speed of 4.0 m s^{-1} until it collides with a stationary identical trolley. The two trolleys stick together and continue in the same direction as the first trolley.

a. Calculate the speed of the two trolleys after the collision. Show your working and clearly state the physics principle that you have used.

(3 marks)

b. Determine, with calculations, whether this collision is an elastic or inelastic collision. Show your working.

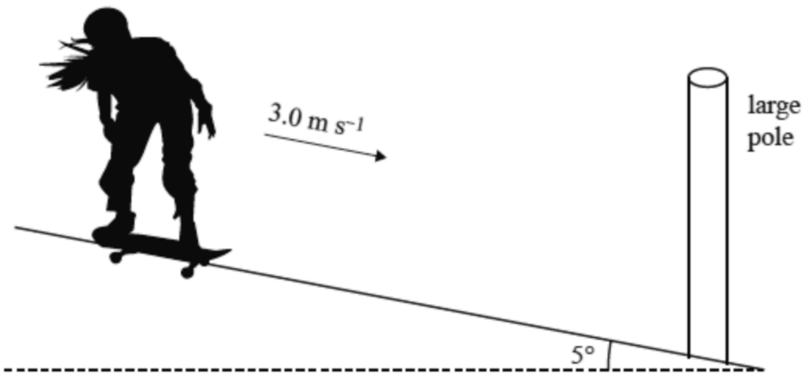
(3 marks)

Question 26/ 46

[Adapted VCAA 2023 SB Q8]

Maia is at a skatepark. She stands on her skateboard as it rolls in a straight line down a gentle slope at a constant speed of $3.0 \mathrm{~m~s}^{-1}$, as shown. The slope is 5° to the horizontal.

The combined mass of Maia and the skateboard is 65 kg.



Near the bottom of the ramp, Maia takes hold of a large pole and comes to a complete rest while still standing on the skateboard. Maia and the skateboard now have no momentum or kinetic energy.

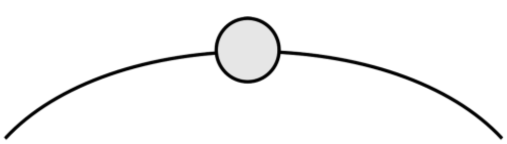
Explain what happened to both the momentum and the kinetic energy of Maia and the skateboard. No calculations are required.

(2 marks)

Chapter 5 Projectile motion

Question 1/ 15

A netball is thrown towards the net. It is shown below at the highest point of its flight. Air resistance is negligible.



Which one or more of the following best describes the ball at its highest point?

A It is travelling at the fastest speed of its flight.

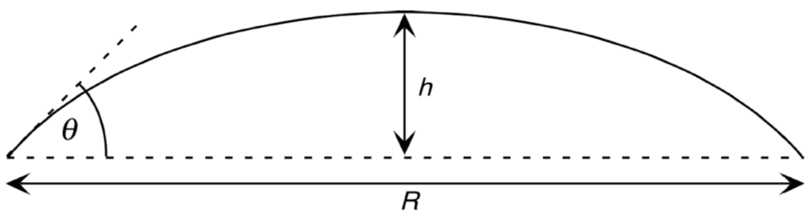
B At this point it stops momentarily.

C The net force on the ball is vertically downward.

D At this point there is no net force on the ball.

Question 2/ 15

A ball flies through the air following the path shown in the diagram. Air resistance has been ignored.



The range *R* for these symmetrical flights is given by $R = \frac{v^2 \sin 2\theta}{g}$.

Students experimenting with different values of θ find that the range, *R*, is the same for two different angles of θ. One of the values is 35°.

Question 3/ 15

The other angle is closest to

A 65°

B 60°

C 55°

D 50°

Question 4/ 15

They also find that, for a given value of *v*, the angle that gives the greatest range is closest to

A 0°

B 30°

C 45°

D 60°

Question 5/ 15

For $v = 20 \text{ m s}^{-1}$ and $\theta = 30°$, which of the following is closest to the time for the complete flight shown above?

A 1.0 s

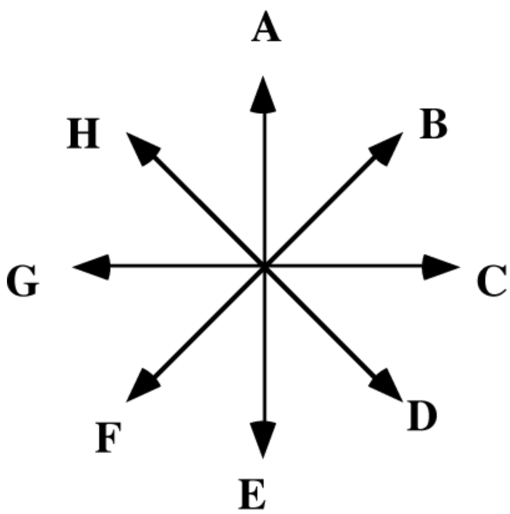
B 1.8 s

C 2.0 s

D 3.5 s

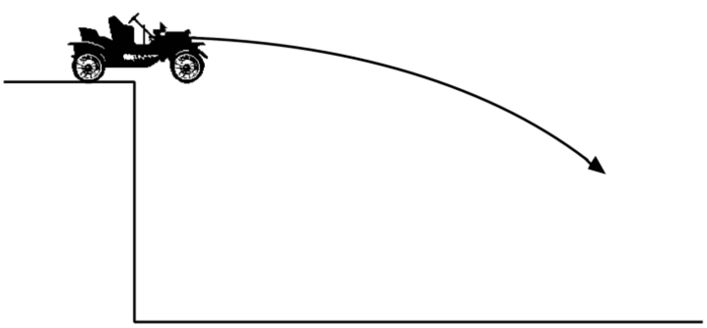
Question 6/ 15

If air resistance was significant and taken into account, the shape of the trajectory would change. Which of the following arrows would best describe the direction of the resultant force acting on the ball at the highest point in its flight?



Question 7/ 15

A car is demonstrating its safety features. Air resistance is very small. It follows a parabolic path before crashing.



Throughout the flight, its horizontal component of velocity remains very close to 10 m s^{-1}. This means that

A the force of gravity is very small.

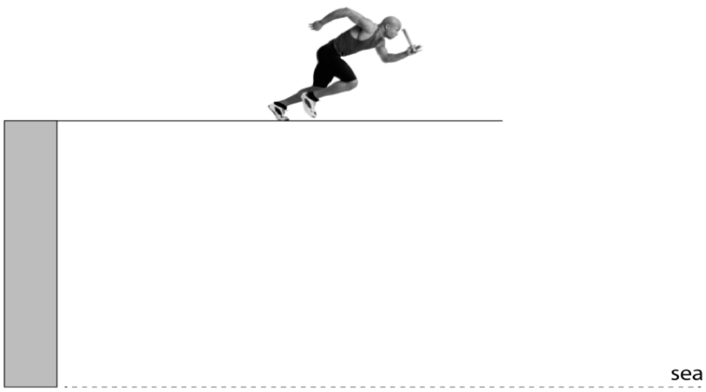
B air resistance is very small.

C there is a strong wind against the car.

D air resistance is balanced by the force of the car's engine.

Question 8/ 15

Students are running along a pier whose end is 7.0 m above the water.



One student leaves the end of the pier at 10 m s^{-1} and drops into the water. (Ignore air resistance.)

Question 9/ 15

Which of the following is closest to the time that it takes him to strike the water?

A 1.1 s

B 1.2 s

C 1.3 s

D 1.4 s

Question 10/ 15

Which of the following is closest to the horizontal distance (from the end of the pier) that he strikes the water?

A 11 m

B 12 m

C 13 m

D 14 m

Question 11/ 15

A second student reaches the end of the pier at $8\ \mathrm{m\ s^{-1}}$. Which of the following is closest to the time it takes her to strike the water?

A 1.1 s

B 1.2 s

C 1.3 s

D 1.4 s

Question 12/ 15

A ball is thrown vertically into the air from a height of 1.0 m. It remains in the air for 6.1 s. (Ignore air resistance for the next two questions.)

Question 13/ 15

Which of the following is closest to the speed it is thrown at?

A $20\ \mathrm{m\ s^{-1}}$

B $30\ \mathrm{m\ s^{-1}}$

C $40\ \mathrm{m\ s^{-1}}$

D $60\ \mathrm{m\ s^{-1}}$

Question 14/ 15

Which of the following is closest to the distance it travels before it returns to a height of 1.0 m?

A 30 m

B 45 m

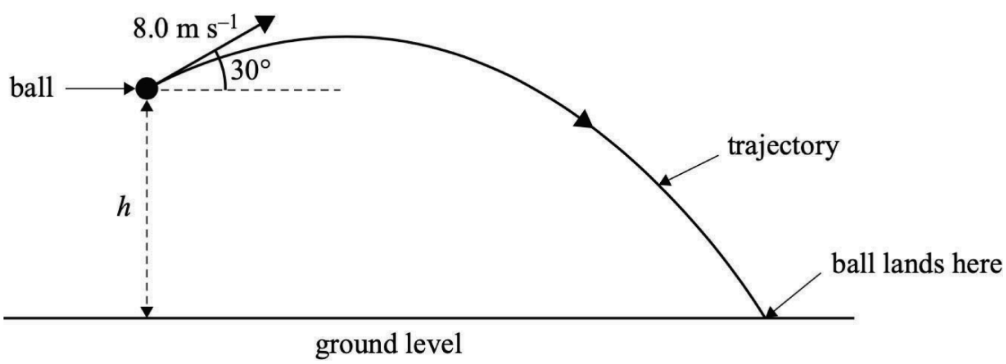
C 60 m

D 90 m

Question 15/ 15

[VCAA 2021 NHT SA Q10]

Melissa launches a ball from height *h* above the ground at a speed of 8.0 m s^{-1} and at an angle of 30° above the horizontal. The time of the ball's flight is 1.0 s. The diagram below shows the trajectory of the ball.



Ignoring air resistance, which one of the following is closest to the horizontal distance that the ball landed from Melissa?

A 4.6 m

B 5.0 m

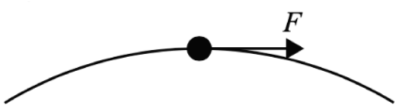
C 6.9 m

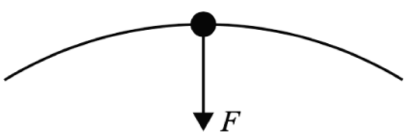
D 8.0 m

Question 16/ 15

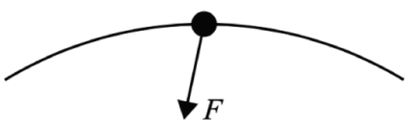
[VCAA 2021 NHT SA Q11]

Which one of the following diagrams best shows the direction of the resultant force, F, on the ball at the position of maximum height in the real situation where air resistance is *not* ignored?

A 

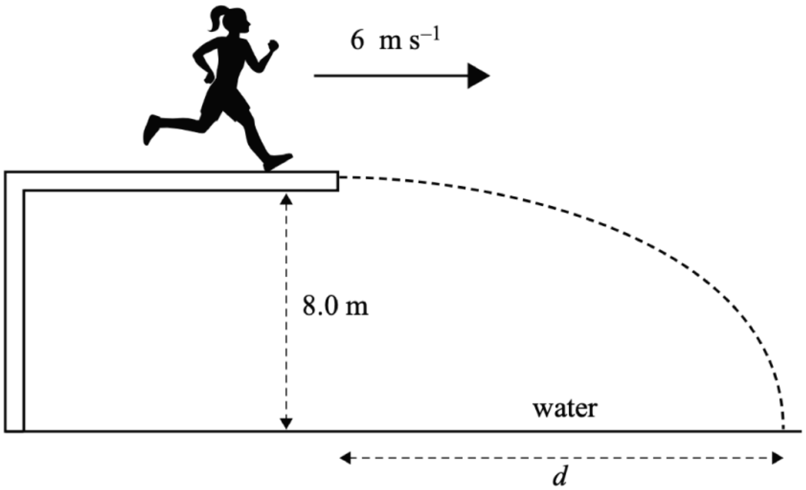
B 

C Missing Image

D 

Question 17/ 15

Lucy is running horizontally at a speed of 6 m s^{-1} along a diving platform that is 8.0 m vertically above the water. Lucy runs off the end of the diving platform and reaches the water below after time t. She lands feet first at a horizontal distance d from the end of the diving platform.



Question 18/ 15

[VCAA 2021 SA Q9]

Which one of the following expressions correctly gives the distance *d*?

A 0.8*t*

B 6*t*

C $5t^2$

D $6t + 5t^2$

Question 19/ 15

[VCAA 2021 SA Q10]

Which one of the following is closest to the time taken, *t*, for Lucy to reach the water below?

A 0.8 s

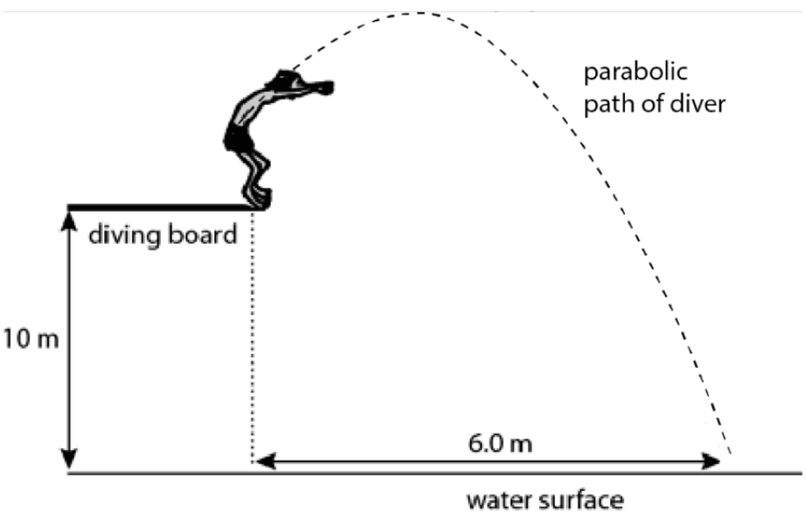
B 1.1 s

C 1.3 s

D 1.6 s

Question 1/ 35

Jim (50 kg) dives off a diving board 10 m above the water surface. He hits the water 2.0 s later, a horizontal distance of 6.0 m from his starting point. The situation is shown in the diagram below. Air resistance forces are negligible.



a. Calculate the horizontal component of Jim's velocity during his flight.

(2 marks)

b. Calculate the magnitude of the vertical component of Jim's velocity at the time he jumps off the board.

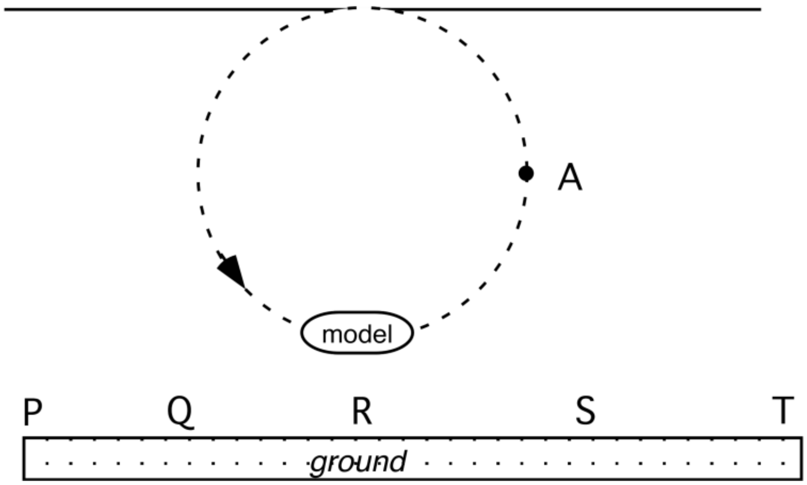
(3 marks)

c. Calculate Jim's total energy $(\mathrm{PE}+\mathrm{KE})$ just before he hits the water.

(3 marks)

Question 2/ 35

A model aeroplane flies an upside-down 'loop the loop'. A metal part comes loose from the model, at point A. Later it strikes the ground.



Which point (P, Q, R, S, T) is closest to where it strikes the ground? Justify your answer.

(2 marks)

Question 3/ 35

A 60 kg high jumper leaves the ground with 1860 J of kinetic energy. At the top of her flight she has a kinetic energy of 660 J. Her centre of mass is now higher than it was on take-off from the ground. Give all your answers to two significant figures.

a. By how much has the height of her centre of mass increased from take-off to the top of her flight?

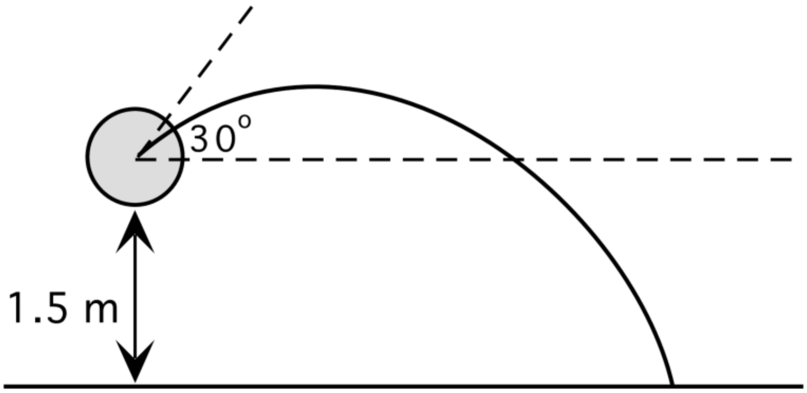
(2 marks)

b. At what speed is she travelling at the top of her flight?

(2 marks)

Question 4/ 35

Kirsty is throwing a shotput from shoulder height, about 1.5 m above the ground. She launches at 6.5 m s^{-1} at an angle of 30°.



a. What is the vertical displacement of the ball between launch and where it strikes the ground? Give size and direction.

(2 marks)

b. Calculate the time of travel for the ball. Show your working.

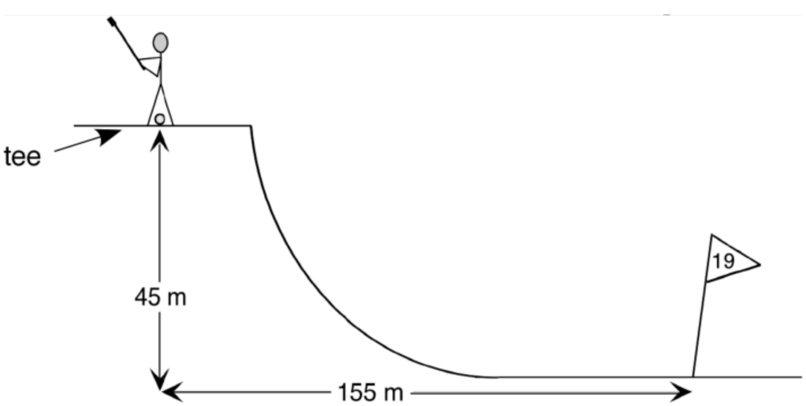
(3 marks)

c. Calculate the range of the ball. Show your working.

(3 marks)

Question 5/ 35

A golfer hits off from an elevated tee, as shown in the diagram.



The ball leaves the tee horizontally and lands in the hole. The horizontal distance between the tee and the hole is 155 m; the vertical distance is 45 m. There is a tailwind that cancels any air resistance.

a. Calculate the speed of the ball leaving the tee.

(2 marks)

As a result of another shot, a ball flies off the same tee at a speed of 50 m s^{-1}, travelling at 30° to the horizontal. Ignore air resistance.

b. How high does it go above the tee?

(2 marks)

c. How long is it in the air?

(2 marks)

d. What is the horizontal distance of the shot?

(2 marks)

Question 6/ 35

The table below gives data from the flight of a soccer ball. Positive readings mean velocity directed upwards (vertical components) or to the right (horizontal components). There is some air resistance present.

Time (s)	**Vertical velocity (ms^{-1})**	**Horizontal velocity (ms^{-1})**
0.00	20.0	20.0
0.10	18.6	19.6
0.20	17.3	19.2
0.30	16.1	18.9
0.40	14.9	18.6
0.50	13.8	18.4

a. At what angle to the horizontal is the ball moving at time $t = 0$ s?

(2 marks)

b. What was the speed of the ball at time $t = 0.50$ s?

(2 marks)

Question 7/ 35

Tam throws a ball a horizontal distance of 100 m. She throws it at an angle of 30°. It lands at the same height. (Ignore air resistance.) Give all your answers to two significant figures.

a. At what speed does the ball leave her hand?

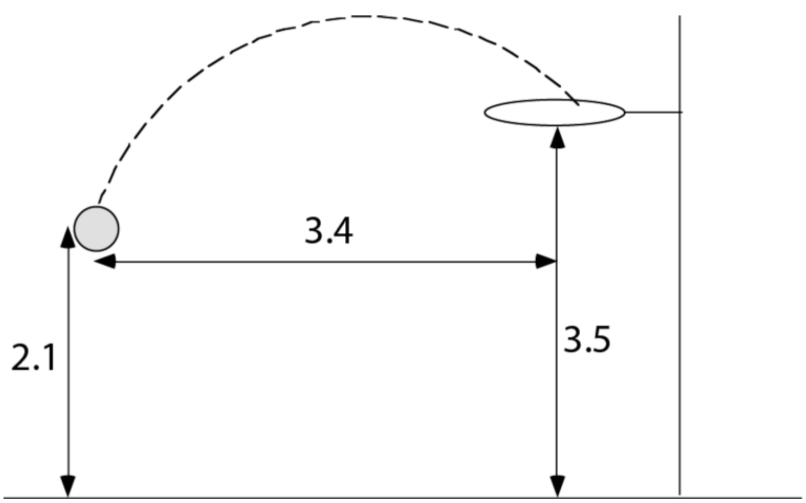
(2 marks)

b. If she throws it at 45° to the horizontal, how fast will she have to throw it to ensure that it still travels 100 m?

(2 marks)

Question 8/ 35

A netball player shoots for goal.



a. What is the vertical displacement involved in the throw?

(2 marks)

b. What is the total displacement involved in the throw?

(2 marks)

c. The ball takes 1.1 s for the journey. What is the horizontal component of its velocity?

(2 marks)

d. What is the vertical component of its launch velocity?

(2 marks)

e. What is its launch speed?

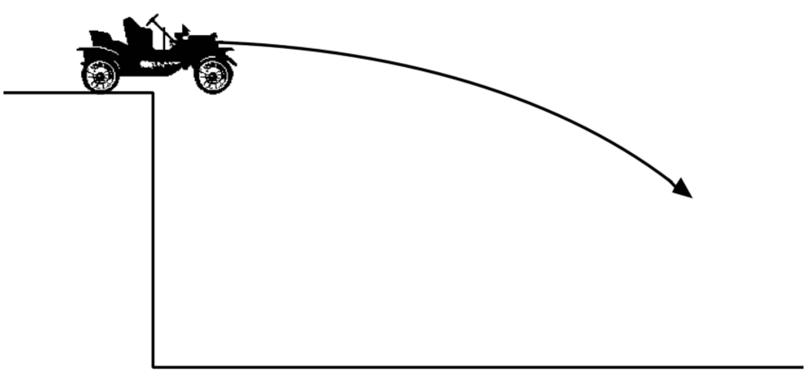
(2 marks)

f. What angle to the horizontal was it launched at?

(2 marks)

Question 9/ 35

A car in a ‘diving’ demonstration is demonstrating its safety features. It takes a parabolic path before crashing to the ground, 1.8 s later. No-one is in the car.



a. What is the initial vertical velocity component of the car?

(2 marks)

b. What is the vertical component of the car’s velocity just before it hits the ground?

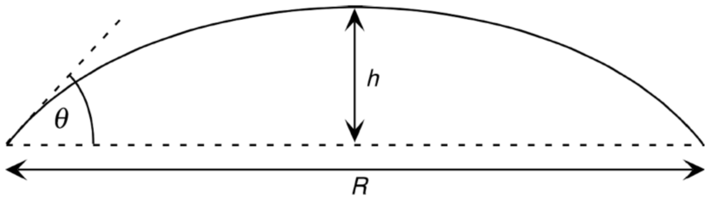
(2 marks)

c. What is the vertical distance that the car falls through?

(2 marks)

Question 10/ 35

A ball flies through the air following the path shown in the diagram.



The ball's mass is 550 g. Its initial kinetic energy is 110 J. The initial angle is θ and maximum height is h.

a. What is the speed of the ball at the start of its flight?

(2 marks)

b. If $h = 8.0$ m, calculate the KE of the ball at maximum height.

(2 marks)

c. Calculate the speed of the ball at maximum height.

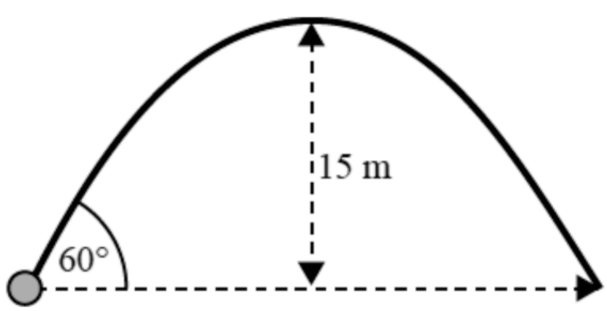
(2 marks)

d. Calculate the angle θ.

(2 marks)

Question 11/ 35

Charlie kicks a football at an angle of 60° to the horizontal on level ground. It rises a vertical distance of 15 m above the point from where he kicks it as shown in the diagram. Ignore air resistance.



a. Calculate the initial speed of the football.

(2 marks)

b. Calculate the time the football is in the air.

(2 marks)

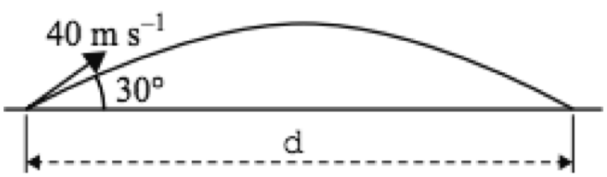
c. Calculate the horizontal distance the ball travels.

(2 marks)

Question 12/ 35

[VCAA 2016 SA Q5]

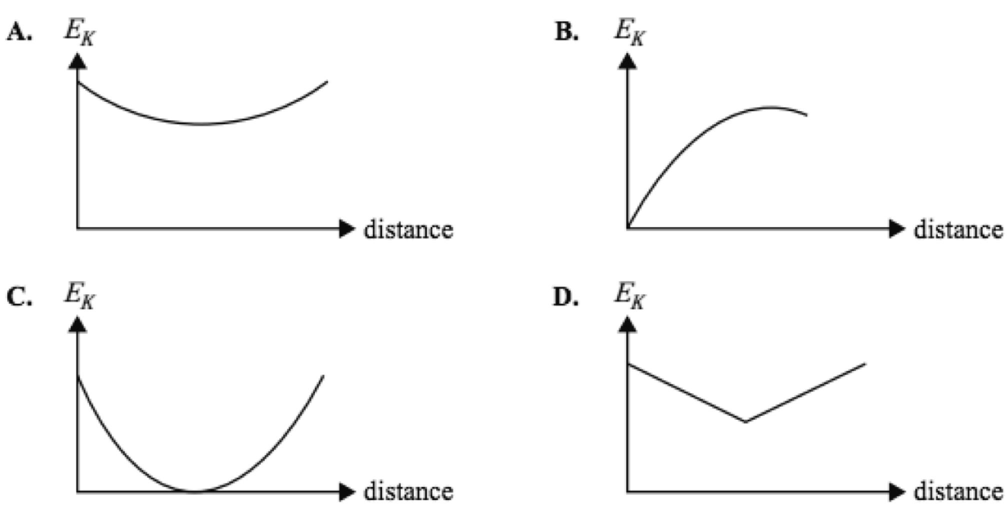
A ball is projected from the ground at an angle of 30° to the horizontal and at a speed of 40 m s^{-1}, as shown. Ignore any air resistance.



a. Calculate the distance, *d*, to the point where the ball hits the ground. Show your working.

(3 marks)

b. Which one of the graphs below best shows the kinetic energy of the ball as a function of horizontal distance, *d*, from the launching point? Explain your answer.

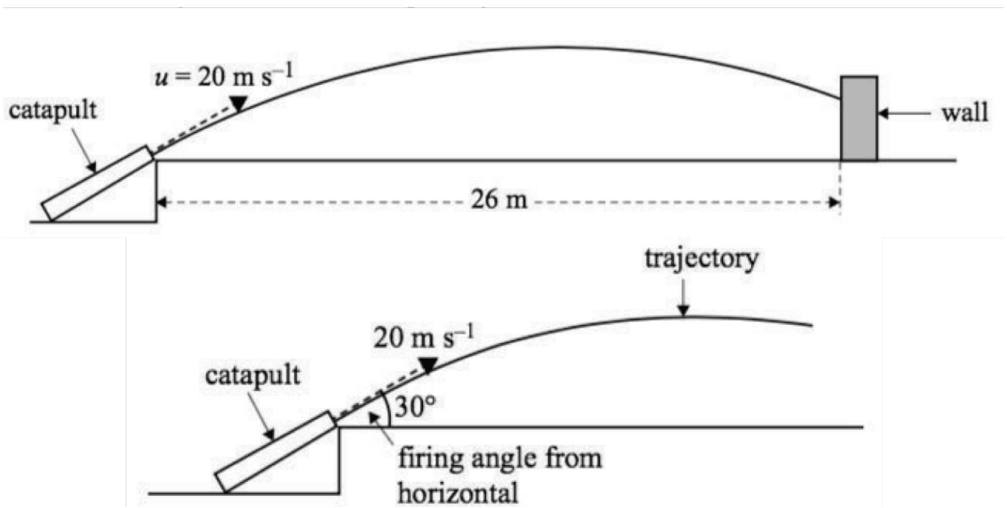


(2 marks)

Question 13/ 35

[Adapted VCAA 2017 SB Q9]

Students use a catapult to investigate projectile motion. A ball of mass 0.10 kg is fired from the catapult at an angle of 30° to the horizontal. The ball leaves the catapult at ground level with a speed of $20 \mathrm{~m} \mathrm{~s}^{-1}$. Instead of reaching the ground, the ball strikes a wall 26 m from the launching point, as shown in the first diagram. The second diagram shows an enlarged view of the catapult. Ignore air resistance.



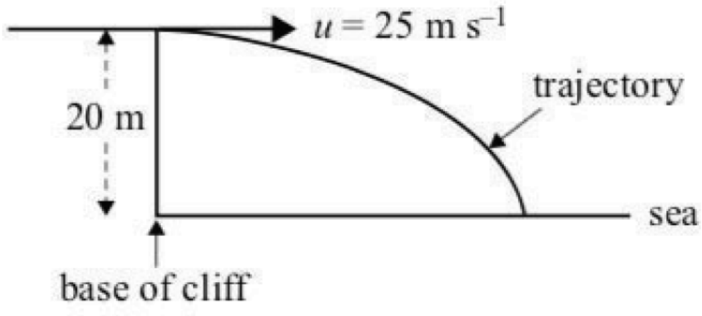
Calculate the height of the ball above the ground when it strikes the wall. Show your working.

(3 marks)

Question 14/ 35

[VCAA 2018 NHT SB Q6]

A rock of mass 2.0 kg is thrown horizontally from the top of a vertical cliff 20 m high with an initial speed of $25 \mathrm{~m} \mathrm{~s}^{-1}$, as shown.



a. Calculate the time taken for the rock to reach the sea. Show your working.

(3 marks)

b. Calculate the horizontal distance from the base of the cliff to the point where the rock reaches the sea. Show your working.

(2 marks)

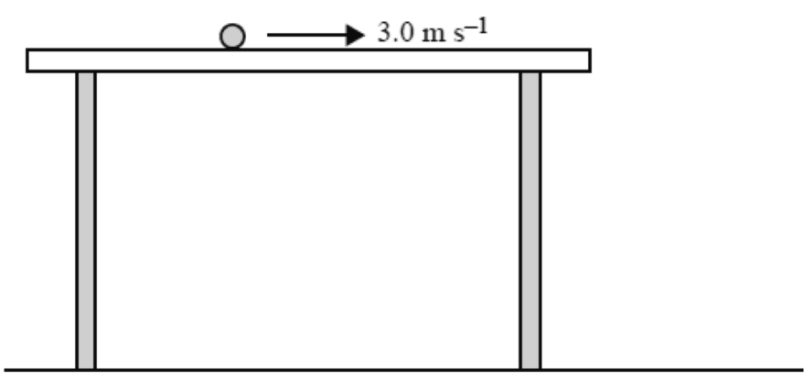
c. Calculate the kinetic energy of the rock as it reaches the surface of the sea. Show your working.

(2 marks)

Question 15/ 35

[VCAA 2018 SB Q7]

A small ball of mass 0.20 kg rolls on a horizontal table at 3.0 m s^{-1}, as shown. The ball hits the floor 0.40 s after rolling off the edge of the table. The radius of the ball may be ignored. In this question, take the value of *g* to be 10 m s^{-2}.



a. Calculate the horizontal distance from the right-hand edge of the table to the point where the ball hits the floor.

(1 mark)

b. Calculate the height of the table. Show your working.

(2 marks)

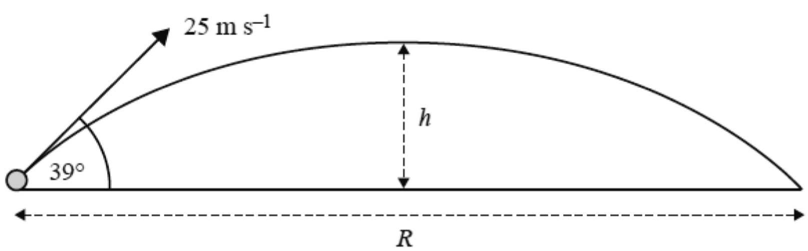
c. Calculate the speed at which the ball hits the floor. Show your working.

(3 marks)

Question 16/ 35

[VCAA 2019 SB Q10]

A projectile is launched from the ground at an angle of 39° and at a speed of 25 m s^{-1}, as shown below. The maximum height that the projectile reaches above the ground is labelled *h*.



a. Ignoring air resistance, show that the projectile's time of flight from the launch to the highest point is equal to 1.6 s. Give your answer to two significant figures. Show your working and indicate your reasoning.

(2 marks)

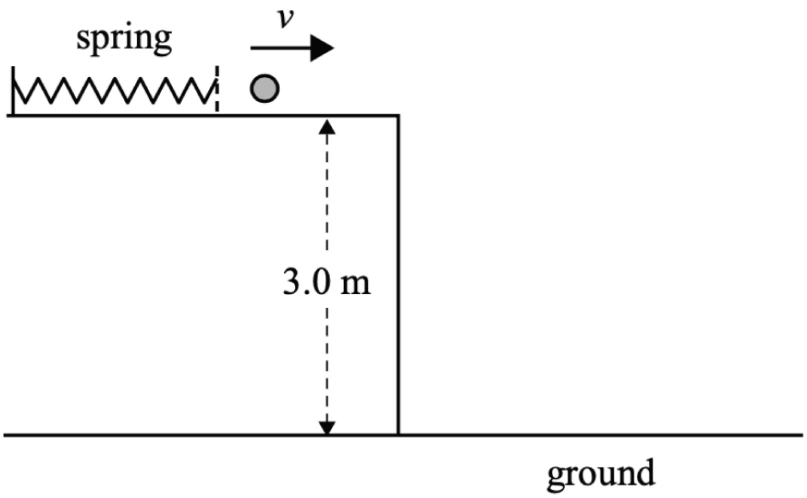
b. Calculate the range, *R*, of the projectile. Show your working.

(2 marks)

Question 17/ 35

[Adapted VCAA 2020 SB Q9]

An ideal spring is compressed by 0.15 m. A ball, mass 0.20 kg, is placed in contact with a compressed spring. The spring is then released, making the ball move horizontally with a speed of 12 m s^{-1} across a smooth surface, as shown.



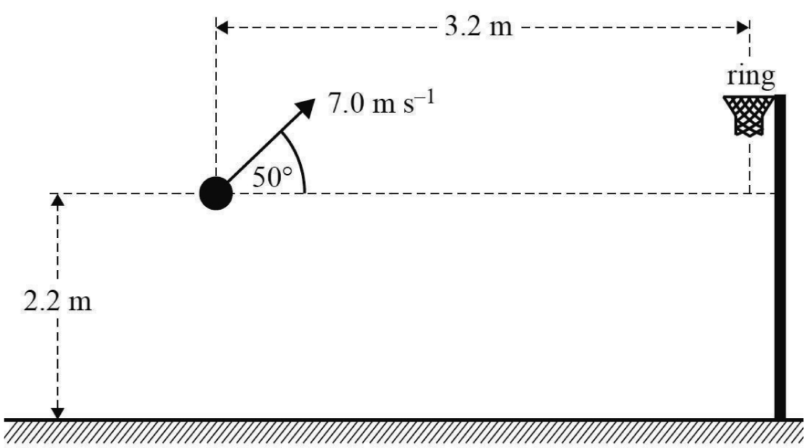
Calculate the speed of the ball after it has fallen a vertical distance of 2.5 m. Show your working.

(3 marks)

Question 18/ 35

[VCAA 2022 NHT SB Q10]

A basketball player throws a ball with an initial velocity of 7.0 m s^{-1} at an angle of 50° to the horizontal, as shown on below. The ball is 2.2 m above the ground when it is released. By the time the ball passes through the ring at the top of the basket, it has travelled a horizontal distance of 3.2 m. Ignore air resistance.



a. Show that the time taken for the ball's flight from launch to passing through the ring is 0.71 s. Show your working.

(2 marks)

b. How far above the ground is the ring at the top of the basket? Show your working.

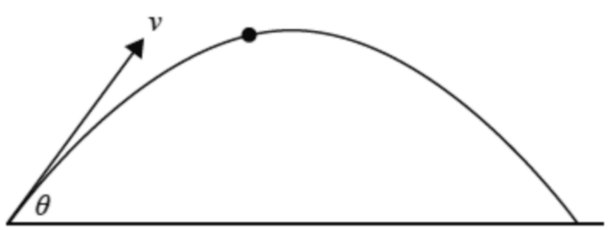
(4 marks)

Question 19/ 35

[VCAA 2023 NHT SB Q12]

Two students investigate the physics of long jumps. They analyse a video of their friend Jemina as she runs along a track and then jumps. She lands in a sand pit that is level with the track.

Jemina's horizontal speed at the moment she jumps is 8.0 m s^{-1}. She is in the air for 0.6 s before landing in the sand pit. The students use $g = 10 \text{ m s}^{-2}$ for their calculations. The motion is modelled as that of a point mass, as shown below.



a. Calculate the horizontal distance that Jemina would be expected to travel if her motion were modelled as a projectile with point mass, as shown above.

(2 marks)

b. Calculate Jemina's vertical speed as she takes off from the track.

(2 marks)

c. Calculate Jemina's velocity as she launches. Include both the magnitude and the angle from the horizontal of her velocity at take-off.

(3 marks)

d. The students use a tape measure to check the horizontal distance that Jemina actually jumps, and find that it is less than the distance they calculated in part **a**. Suggest one possible reason for this.

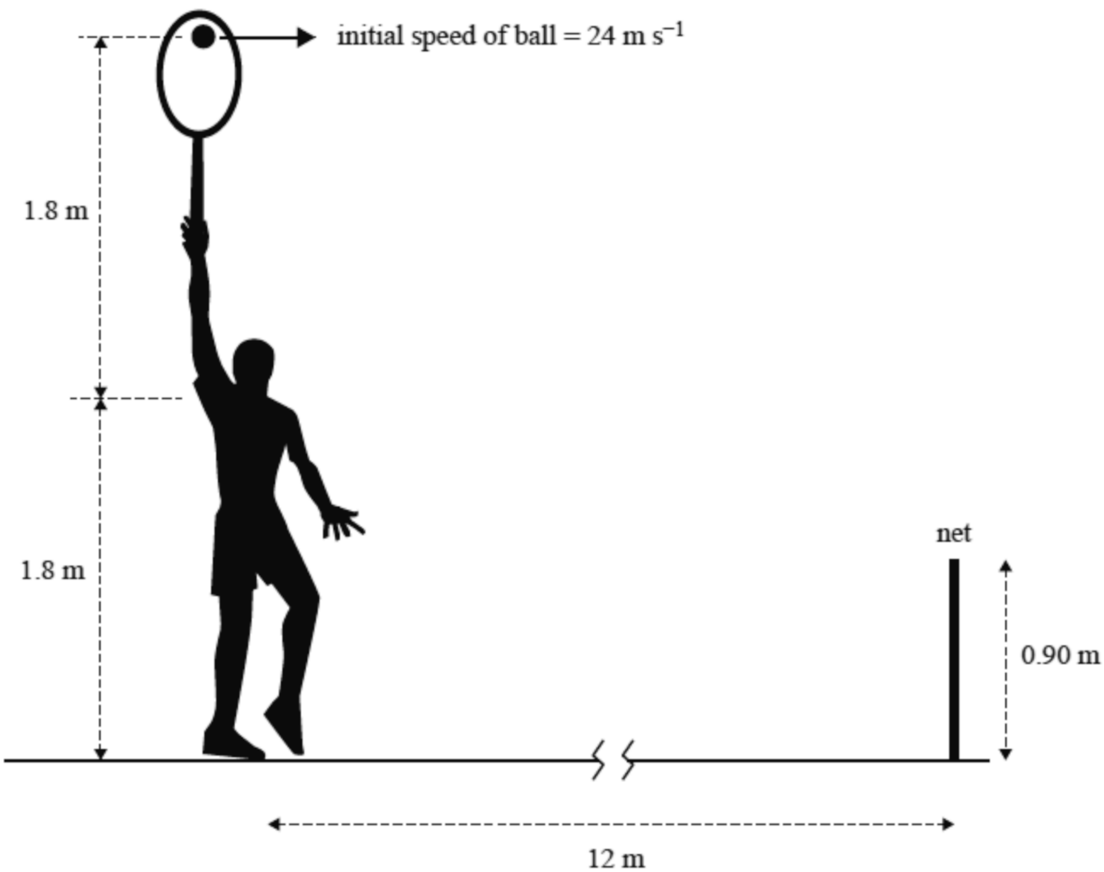
(1 mark)

Question 20/ 35

[Adapted VCAA 2023 SB Q9]

Giorgos is practising his tennis serve using a tennis ball of mass 56 g.

The ball leaves Giorgos's racquet with an initial speed of $24\ \mathrm{m\ s^{-1}}$ in a horizontal direction, as shown below.



How far above the net will the ball be when it passes above the net? Assume that there is no air resistance. Show your working.

(3 marks)

Chapter 6 Circular motion

Question 1/ 13 [VCAA 2023 SA Q9]

In uniform circular motion of an object travelling at constant speed, which of the following statements is true?

A The object is travelling with zero acceleration.

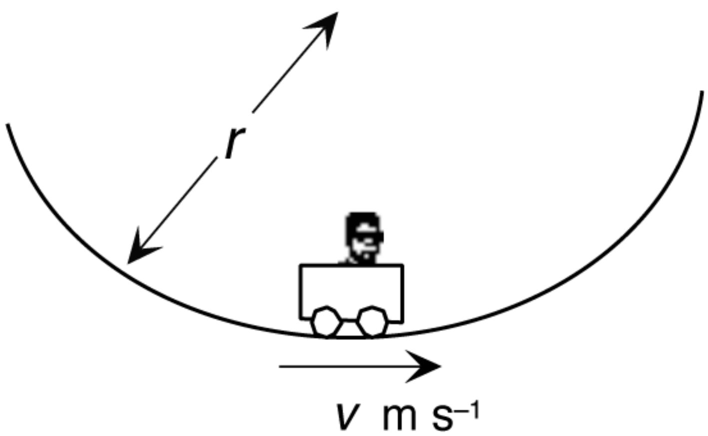
B The object is travelling with constantly changing velocity.

C The object is accelerating away from the centre of the circle.

D The kinetic energy of the object is changing in direction.

Question 2/ 13 [VCAA 2023 SA Q9]

In the sketch, Jim is sitting in a carriage going through a 'valley' on a rollercoaster.



In the 'valley', Jim feels heavier than usual. This is because

A his mass has increased.

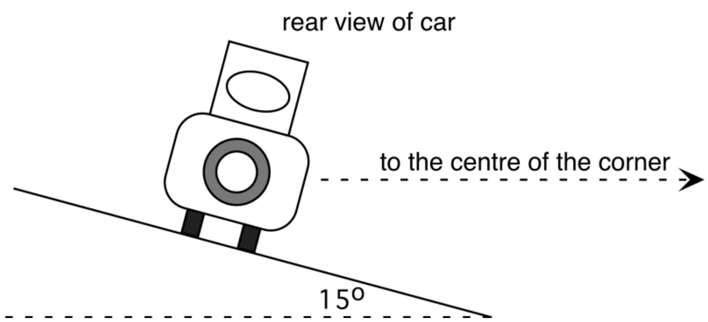
B his weight has increased.

C the normal reaction force from the seat has increased.

D he is accelerating downwards.

Question 3/ 13 [VCAA 2023 SA Q9]

Train tracks and high-speed roads are often banked to assist trains and cars when taking corners. A view *behind* a car on the corner of a high-speed road shows banking of 15° degrees as shown below.



The car is going fast enough so that there is no friction between the tyres and the road acting *down* the slope *sideways*. The weight of the car is *mg*, and the normal reaction from the road is *N*.

Question 4/ 13 [VCAA 2023 SA Q9]

Which of the following gives the magnitude of the net force on the car towards the centre of the corner at this speed?

A *mg* cos15

B *mg* sin15

C *N* cos15

D *N* sin15

Question 5/ 13 [VCAA 2023 SA Q9]

Which of the following gives the best relationship between *N* and *mg*?

A $mg\cos 15 = N$

B $N\cos 15 = mg$

C $N\sin 15 = mg$

D $mg \sin 15 = N$

Question 6/ 13 [VCAA 2023 SA Q9]

A planet of mass 10^5 kg is circling a dwarf star, at a radius of 10^8 m. The planet's period is 10^5 s.

Question 7/ 13 [VCAA 2023 SA Q9]

Which of the following is closest to the speed of the planet in its circular orbit?

A 60 m s^{-1}

B 600 m s^{-1}

C 6000 m s^{-1}

D $60\,000 \text{ m s}^{-1}$

Question 8/ 13 [VCAA 2023 SA Q9]

Which of the following is closest to the gravitational force between the planet and the star?

A 4×10^3 N

B 4×10^4 N

C 4×10^5 N

D 4×10^6 N

Question 9/ 13 [VCAA 2023 SA Q9]

A section of a rollercoaster is sketched below.

Students compare the normal reaction force between the rollercoaster car and the rails at the top of the ‘hills’ to the normal reaction force in the ‘valleys’. Which of the following student opinions is accurate?

A The two normal reaction forces are the same; they are equal to the gravitational force on the car in both cases.

B The normal reaction force on the hills is the same as that in the valleys; they are both equal centripetal forces.

C The normal reaction force on the hills is greater than that in the valleys; the centripetal accelerations are in different directions.

D The normal reaction force in the valleys is greater than that on the hills; the centripetal accelerations are in different directions.

Question 10/ 13 [VCAA 2023 SA Q9]

Which of the following identifies a centripetal force?

A the outward force felt by car passengers whilst rounding a corner

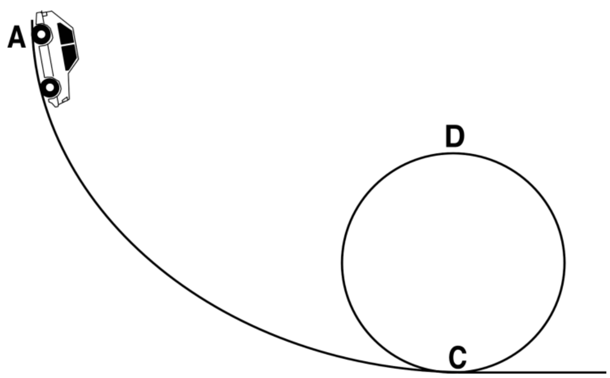
B the force on the Moon that balances gravity

C the force that sends a car skidding off the road on a sharp corner

D the tension in a string whirling a stone in a circle

Question 11/ 13 [VCAA 2023 SA Q9]

A toy car does a loop the loop in the apparatus sketched below.



Which of the following best describes the conditions that ensure that the car does not fall off at the point D?

A The gravitational force on the car must be greater than the centripetal force on the car.

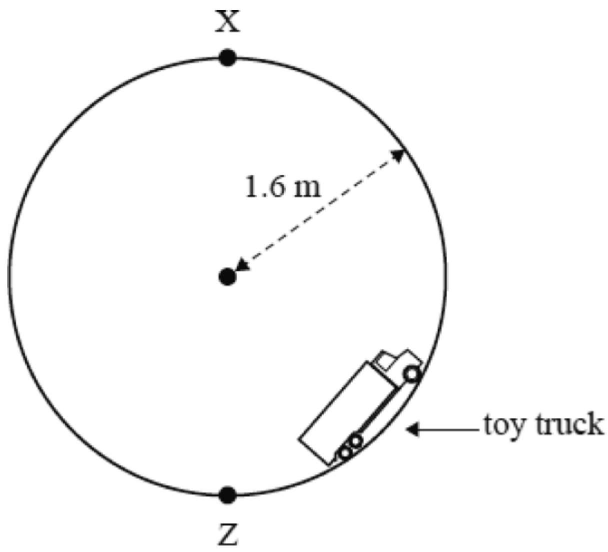
B The reaction force from the rails must be equal to the centripetal force on the car minus the weight of the car.

C The reaction force from the rails must be equal to the centripetal force on the car plus the weight of the car.

D The reaction force on the car must be directed upwards.

Question 12/ 13 [VCAA 2023 SA Q9]

A toy truck travels on a track around a vertical loop of radius 1.6 m, as shown below. Assume that the toy truck is a point mass.



The minimum speed at which the toy truck must be moving at point X for it to stay on the track is closest to

A 1.6 m s^{-1}

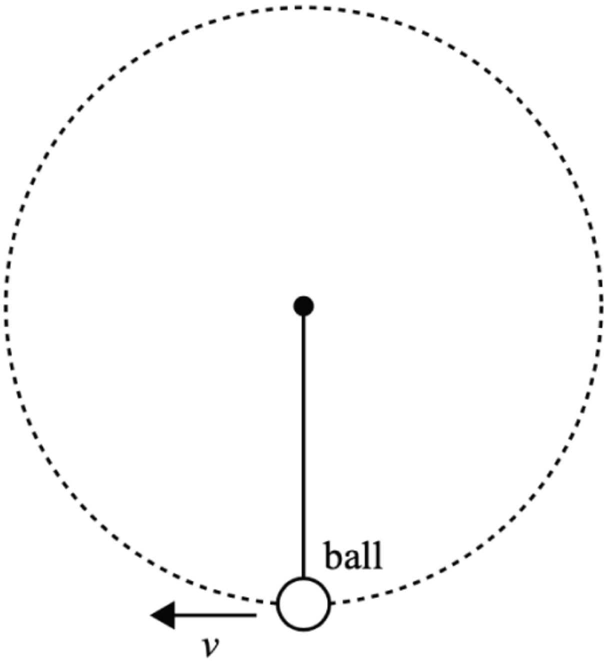
B 3.2 m s^{-1}

C 4.0 m s^{-1}

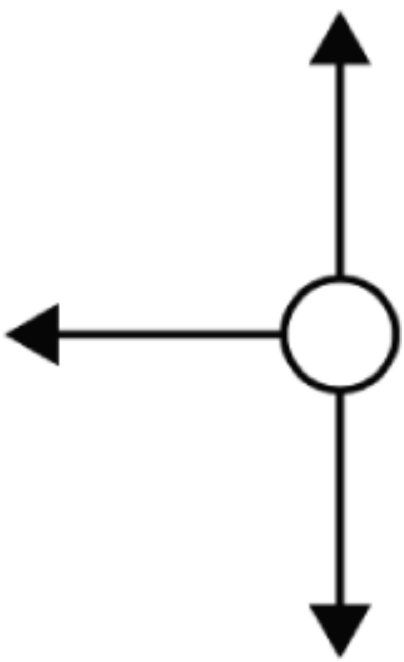
D 16 m s^{-1}

Question 13/ 13 [VCAA 2023 SA Q9]

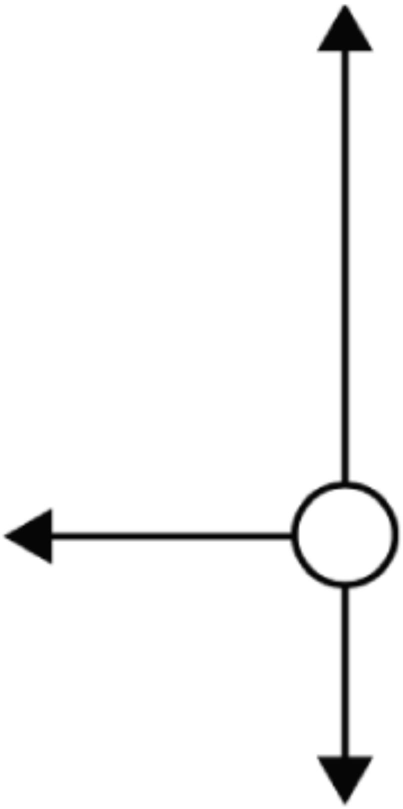
A ball is attached to the end of a string and rotated in a circle at a constant speed in a vertical plane, as shown in the diagram below.



The arrows in options **A.** to **D.** below indicate the direction and the size of the forces acting on the ball. Ignoring air resistance, which one of the following best represents the forces acting on the ball when it is at the bottom of the circular path and moving to the left?



A



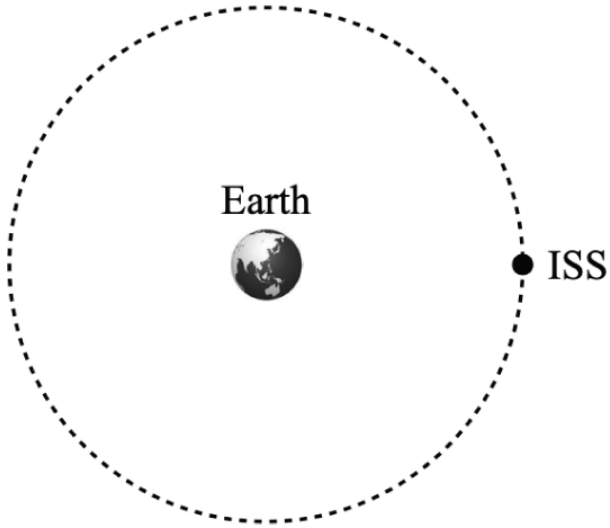
B

C

D

Question 14/ 13 [VCAA 2023 SA Q9]

The International Space Station (ISS) is travelling around Earth in a stable circular orbit, as shown in the diagram below.



Which one of the following statements concerning the momentum and the kinetic energy of the ISS is correct?

A Both the momentum and the kinetic energy vary along the orbital path.

B Both the momentum and the kinetic energy are constant along the orbital path.

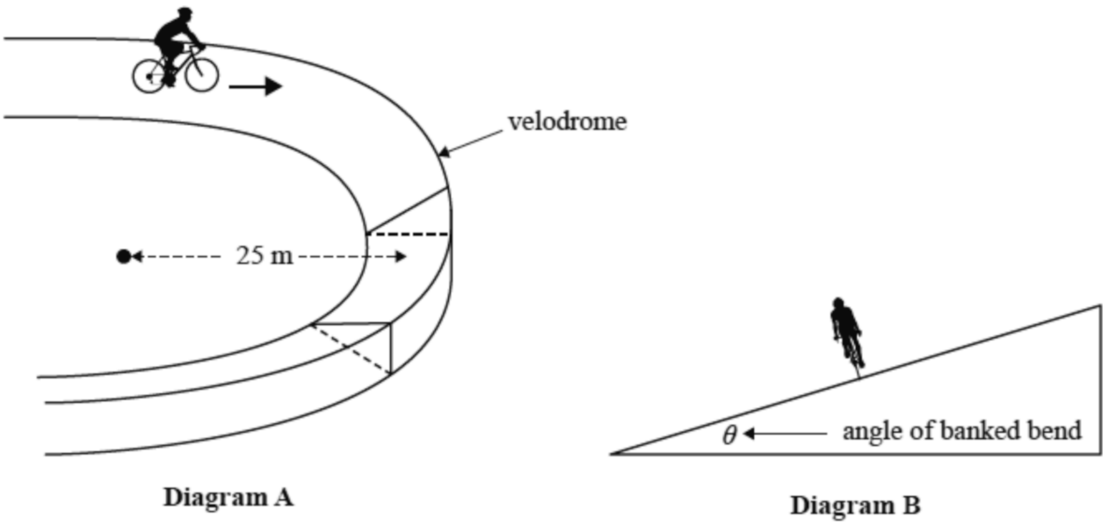
C The momentum is constant, but the kinetic energy changes throughout the orbital path.

D The momentum changes, but the kinetic energy remains constant throughout the orbital path.

Question 15/ 13 [VCAA 2023 SA Q9]

An engineer is designing a banked circular curve of radius 25 m in a new bicycle velodrome.

Diagram A shows the bicycle approaching the banked section, and diagram B shows the front view of a bicycle moving out of the page as it rounds the banked bend.



The bicycle is travelling at 11 m s^{-1} on the banked section. At this speed there are no sideways frictional forces between the wheels and the road surface.

Which one of the following is closest to the angle of the banked bend?

A 2.6°

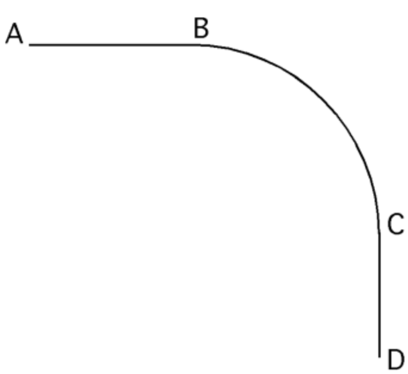
B 10°

C 26°

D 30°

Question 1/ 41 [Adapted VCAA 2023 SB Q9]

A cyclist of mass 60 kg is riding along the path shown in the diagram. From point A to B the path is a straight line, from B to C the path is circular, and from C to D it is a straight line. She rides at a constant speed of 10 m s^{-1} throughout. Between points B and C, the cyclist is accelerating at 5.0 m s^{-2}.



a. Explain how the cyclist can be accelerating between B and C when she is travelling at constant speed.

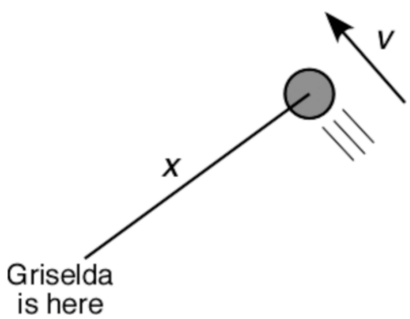
(2 marks)

b. Calculate the radius of the circular section between B and C.

(2 marks)

Question 2/ 41 [Adapted VCAA 2023 SB Q9]

Griselda throws the *hammer* (a mass on the end of a chain) in an athletic contest. Just before she lets go, it is moving in a circle, as shown (from above). The length of the chain between Griselda and the mass is 1.2 m, the tension in the chain is 720 N and the mass is 4.0 kg. Just before she lets go, the mass is moving at $v \text{ m s}^{-1}$.



a. Describe the direction of the net force acting on the round ball of the hammer. Assume that the chain is horizontal.

(2 marks)

b. Find *v*.

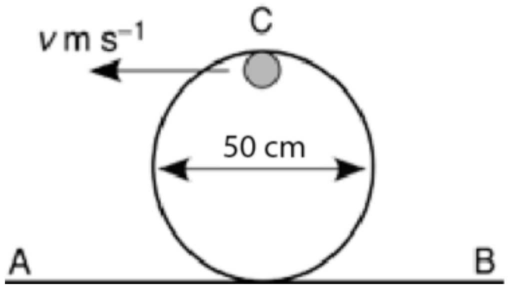
(2 marks)

c. Describe the horizontal motion of the centre of mass of the hammer after release.

(1 mark)

Question 3/ 41 [Adapted VCAA 2023 SB Q9]

In a ‘loop the loop’ novelty ball game, a ball is fired along the track below. The ball has a mass of 50 g.



a. What is the minimum speed it needs to have at point C?

(3 marks)

b. In another trial, the ball is travelling at 2.0 m s^{-1} at point C. What is the reaction force between the track and the ball at point C?

(2 marks)

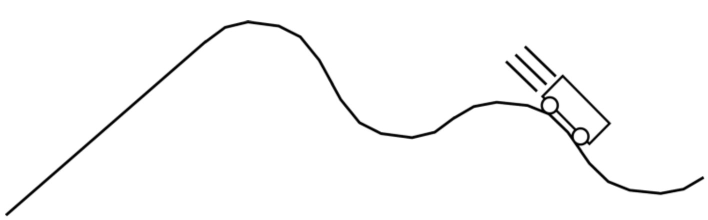
Question 4/ 41 [Adapted VCAA 2023 SB Q9]

Kermit Cookie rides his pony in a very tight circle of radius 5 m. The friction force between the pony’s hooves and the ground cannot exceed 8000 N. The mass of the pony and Kermit is 400 kg. What is the maximum speed they can achieve without slipping during this turn?

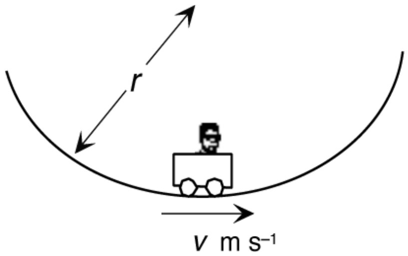
(2 marks)

Question 5/ 41 [Adapted VCAA 2023 SB Q9]

Rollercoaster rides often have a high hill at the start, followed by a series of smaller ones. At the tops of the hills, passengers feel lighter than usual; at the bottom of the valleys, they feel heavier.



In the sketch, Jim is sitting in a car going through one of the valleys. Jim has a mass of 65 kg, and the valley is close to circular, with a radius of 20 m. The carriage he is sitting in is travelling at 10 m s^{-1}. The gravitational field is *g*.



a. Draw arrows on the diagram to represent the forces acting on Jim. Label the arrows clearly so that it is clear what force each arrow represents.

(3 marks)

b. What is the magnitude of Jim's acceleration at the bottom of the valley?

(2 marks)

c. Describe how 'heavy' Jim feels at the bottom of the valley, compared to his normal weight.

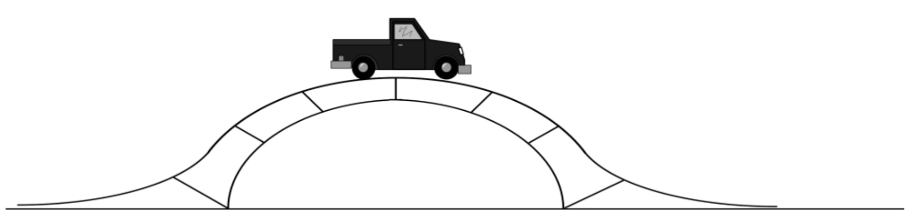
(2 marks)

d. A little later, Jim travels over a hill on the rollercoaster. He feels lighter than usual. Explain why. Include a force diagram in your explanation.

(3 marks)

Question 6/ 41 [Adapted VCAA 2023 SB Q9]

A circular humpback bridge has a sign warning that 'Cars may lose contact with the road surface at the crest if they exceed a speed of 36 km h^{-1}.



The bridge radius (at its crest) is 10 m.

a. What would be the acceleration of the truck if it travelled at 10 m s^{-1} at the crest of the bridge (and did not lose contact with the surface)?

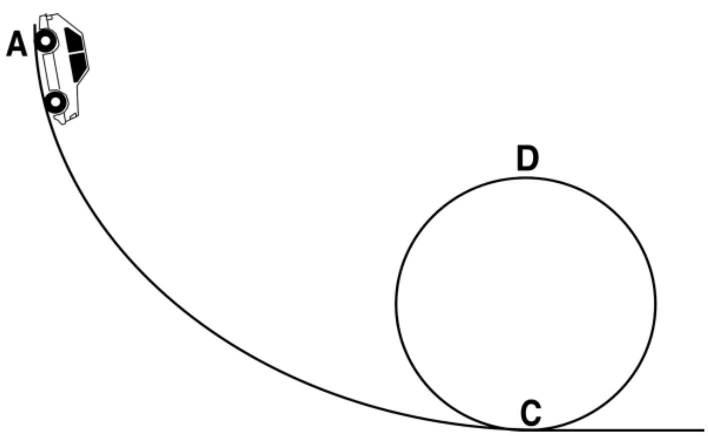
(2 marks)

b. Explain why the truck is likely to lose contact with the road surface at a speed of 10 m s^{-1}.

(4 marks)

Question 7/ 41 [Adapted VCAA 2023 SB Q9]

A ride at an amusement park involves passengers ‘looping the loop’ in a car, as shown. The car starts from rest at A, which is 22 m above C. The car and its passengers have a combined mass of 250 kg. The circular part of the track (with C at the bottom and D at the top) has a radius of 8.0 m.



a. Calculate the speed of the car at C. Ignore friction and air resistance.

(2 marks)

b. What speed will the car be going at D (if the car stays on the track)?

(2 marks)

c. What will be the normal reaction on the car from the track at D?

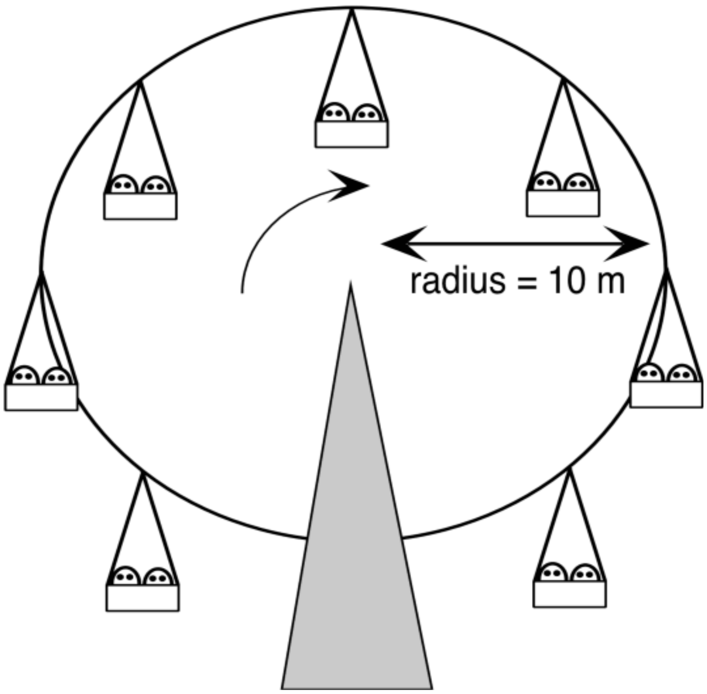
(2 marks)

d. The passengers feel lighter than usual at D. Explain why this is so. Include an estimate of their perceived percentage weight reduction.

(4 marks)

Question 8/ 41 [Adapted VCAA 2023 SB Q9]

Jemima and Fred are riding a Ferris wheel at a park. These are large vertical wheels that rotate slowly. This Ferris wheel is, however, travelling faster than normal. It completes a whole revolution in 20 s, and it has a radius of 10 m.



a. What speed is the perimeter of the wheel travelling at?

(2 marks)

b. What is the net force acting on a 60 kg passenger who is 10 m from the centre of the wheel?

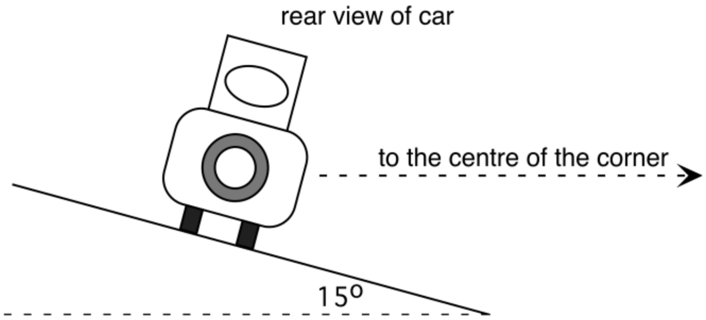
(2 marks)

c. Jemima and Fred notice that they feel lighter at the top of the wheel, compared with the bottom of the wheel. Give physics reasons to explain their observations.

(4 marks)

Question 9/ 41 [Adapted VCAA 2023 SB Q9]

High-speed roads are often banked to assist cars when cornering. A view *behind* a car on the corner of a high-speed road shows banking of 15°.



The car is going fast enough so that there is friction between the tyres and the road acting *down* the slope *sideways*. The bend it is taking is approximately circular and has a radius of 167 m.

a. Draw arrows representing the following forces acting on the car:

• weight, *mg*

• normal reaction, *N*

• friction, *Fr*.

(3 marks)

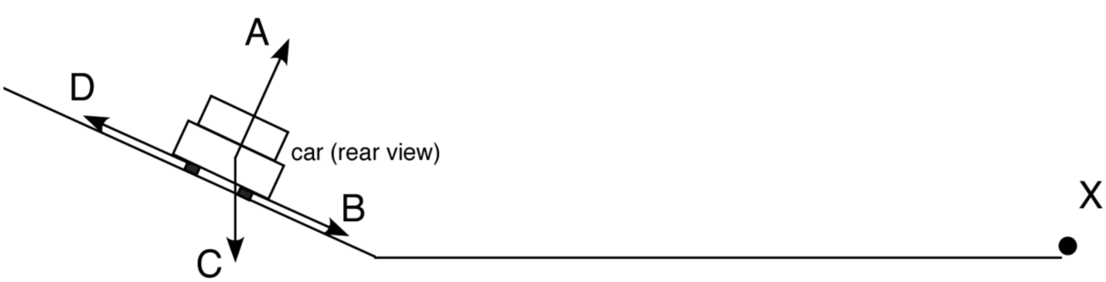
The car now slows, until it travels at the speed where sideways friction is no longer needed to assist the car to turn the corner; at this speed $Fr = 0$.

b. Calculate the speed required to reduce the sideways friction to zero. The radius of the curve is 167 m.

(2 marks)

Question 10/ 41 [Adapted VCAA 2023 SB Q9]

The diagram shows the *rear* view of a car travelling around a corner on a banked road. The car is travelling away from us (into the page). The banking has been designed so that cars that travel at 28 m s^{-1} *do not require* any sideways frictional force between their tyres and the road to travel around the corner safely.



a. When the car is travelling *faster* than the recommended speed, which of the arrows above best corresponds to the direction of these forces?

• Gravity force on the car

• Normal reaction force of the road on the car

• The sideways frictional force on the tyres from road

(3 marks)

b. When the car is travelling *slower* than the recommended speed, which of the arrows above best corresponds to the direction of these forces?

• Gravity force on the car

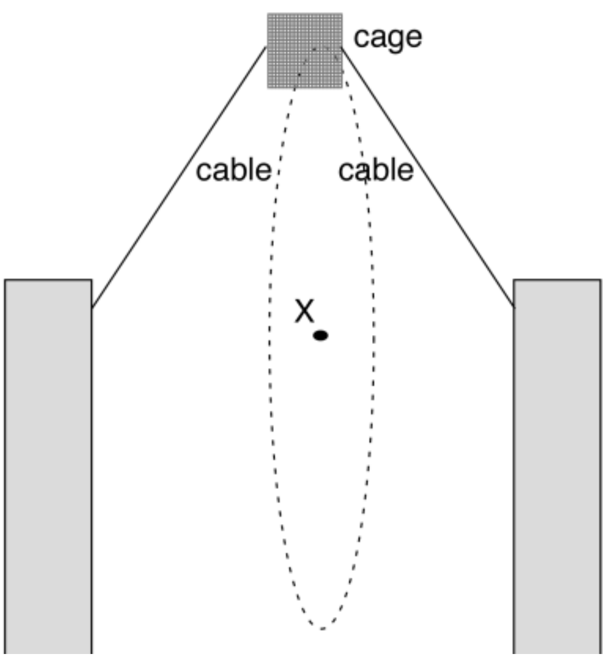
• Normal reaction force of the road on the car

• The sideways frictional force on the tyres from road

(3 marks)

Question 11/ 41 [Adapted VCAA 2023 SB Q9]

In an adventure ride, riders are strapped in a cage moving in a vertical circle on cables. These are at an angle of 30° to the vertical. The radius of the circle is 8.0 m. The cage has a total mass of 250 kg.



At the top of the circular path, the cage is travelling at 10 m s^{-1}.

a. Calculate the net force acting on the cage at this point.

(2 marks)

b. Show that the tension in each of the cables at the top of the circle is close to 390 N.

(2 marks)

c. At the bottom of the circle, the gravitational potential energy (GPE) of the car has decreased. This loss in GPE has been converted to KE. Calculate the speed of the car at the bottom of the circular path.

(2 marks)

d. The owners of the ride are concerned that the cables are safe. They believe that the tension in the cables will be greater at the bottom of the circular path. Are they correct? Justify your answer with reasons drawn from your knowledge of physics principles.

(3 marks)

e. As the ride slows to a stop, it is travelling at $8 \mathrm{~m} \mathrm{~s}^{-1}$ at the lowest point of the circular path. Calculate the tension in the cables at this point.

(2 marks)

Question 12/ 41 [Adapted VCAA 2023 SB Q9]

A small car of mass 600 kg travels in a horizontal circle of radius 20.0 m at a constant speed of $10 \mathrm{~m} \mathrm{~s}^{-1}$.

a. Calculate the magnitude of the centripetal acceleration acting on the car.

(2 marks)

b. Calculate the magnitude of the centripetal force acting on the car.

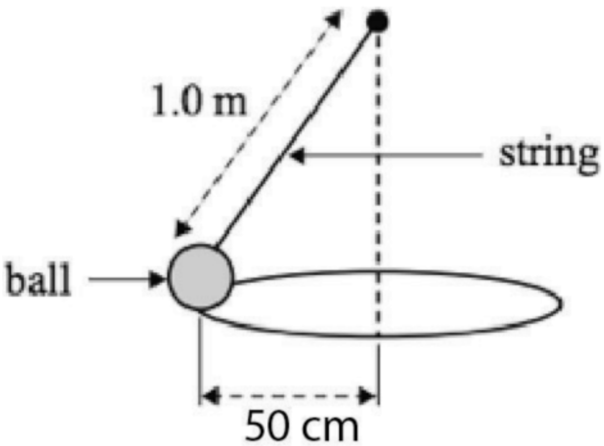
(2 marks)

c. In which direction does the centripetal force on the car act?

(2 marks)

Question 13/ 41 [Adapted VCAA 2023 SB Q9]

A steel ball of mass 2.0 kg is swinging in a circle of radius 0.50 m at a constant speed of 1.7 m s^{-1} at the end of a 1.0 m long string, as shown.



a. Draw all the forces acting on the ball as lines with arrows. Also draw the resultant force as a dotted line (with arrow), labelled F_R.

(2 marks)

b. Calculate the tension in the string. Show your working.

(3 marks)

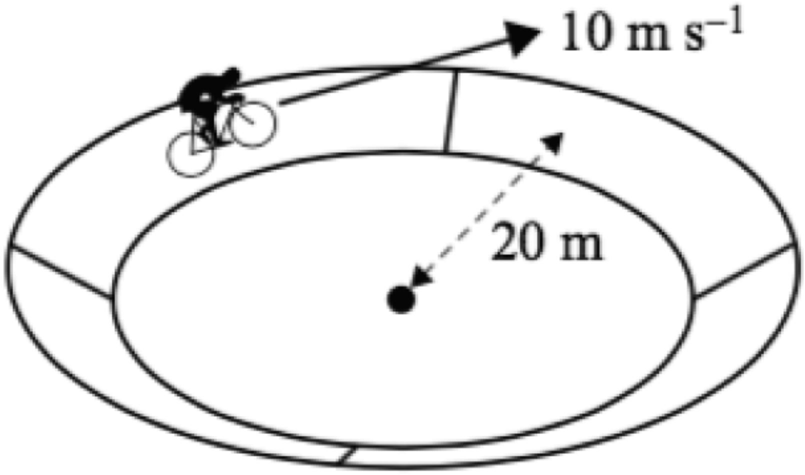
Question 14/ 41 [Adapted VCAA 2023 SB Q9]

According to one model of the atom, the electron in the ground state of a hydrogen atom moves around the stationary proton in a circular orbit with a radius of 53 pm (53×10^{-12} m). The force acting between the proton and the electron at this separation is equal to 8.2×10^{-8} N. Calculate the speed of the electron in this circular path. The mass of the electron is 9.1×10^{-31} kg.

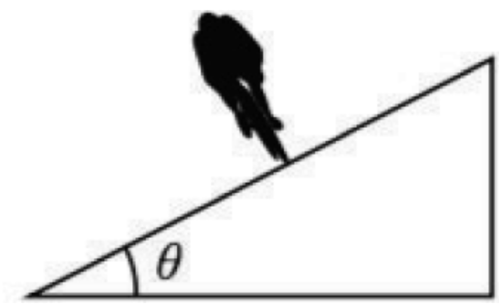
(3 marks)

Question 15/ 41 [Adapted VCAA 2023 SB Q9]

A bicycle and its rider have a total mass of 100 kg and travel around a circular banked track at a radius of 20 m and at a constant speed of $10\ \mathrm{m\ s^{-1}}$, as shown. The track is banked so that there is no sideways friction force applied by the track on the wheels.



a. On the diagram below, draw all the forces on the rider and the bicycle, considered as a single object, as arrows. Draw the net resultant force as a dashed arrow labelled F_{NET}.



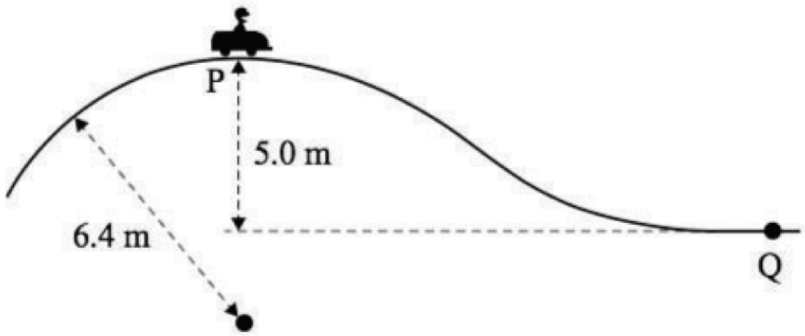
(2 marks)

b. Calculate the correct angle of bank for there to be no sideways friction force applied by the track on the wheels. Show your working.

(2 marks)

Question 16/ 41 [Adapted VCAA 2023 SB Q9]

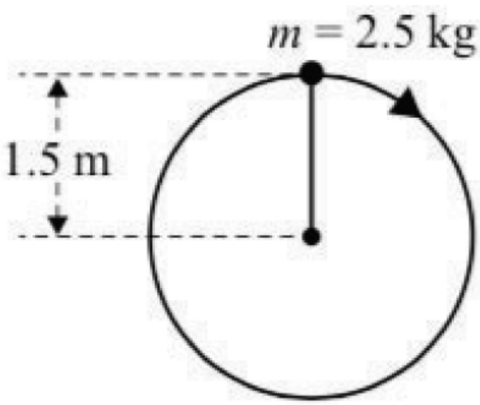
A roller-coaster is arranged so that the normal reaction force on a rider at the top of the circular arc at point P, shown below, is briefly zero. The section of the track at point P has a radius of 6.4 m.



Calculate the speed that the car needs to have to achieve a normal reaction force on the rider at point P. (2 marks)

Question 17/ 41 [Adapted VCAA 2023 SB Q9]

In an experiment, a ball of mass 2.5 kg is moving in a vertical circle at the end of a string, as shown. The string has a length of 1.5 m.



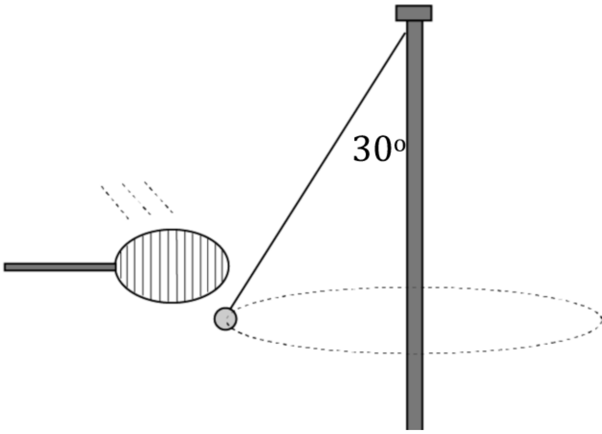
a. Calculate the minimum speed the ball must have at the top of its arc for the string to remain tight (under tension). (2 marks)

b. In another experiment, the ball is moving at 6.0 m s^{-1} at the top of its arc. Calculate the speed of the ball at the lowest point.

(3 marks)

Question 18/ 41 [Adapted VCAA 2023 SB Q9]

A 600 g ball swings in a horizontal circle on the end of a 1.5 m cord attached to a pole, as shown below. The string makes an angle of 30° with the vertical pole.



a. Calculate the magnitude of the tension in the cord.

(2 marks)

b. Calculate the size of the centripetal acceleration of the ball.

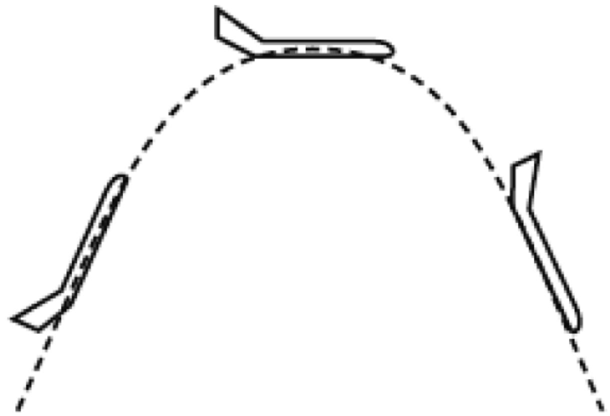
(3 marks)

c. Calculate the speed of the ball.

(3 marks)

Question 19/ 41 [Adapted VCAA 2023 SB Q9]

Members of the public can now pay to take zero gravity flights in specially modified jet aeroplanes that fly at an altitude of 8000 m above Earth's surface. A typical trajectory is shown below. At the top of the flight, the trajectory can be modelled as an arc of a circle.



a. Calculate the radius of the arc that would give passengers zero gravity at the top of the flight if the jet is travelling at 180 m s^{-1}. Show your working.

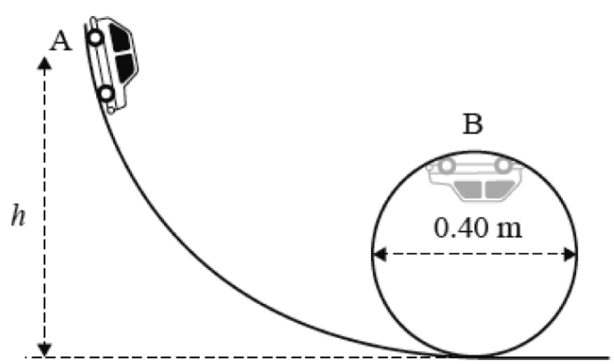
(2 marks)

b. Is the force of gravity on a passenger zero at the top of the flight? Explain what 'zero gravity experience' means.

(2 marks)

Question 20/ 41 [Adapted VCAA 2023 SB Q9]

A 250 g toy car performs a loop in the apparatus shown below.



The car starts from rest at point A and travels along the track without any air resistance or retarding frictional forces. The radius of the car's path in the loop is 0.20 m. When the car reaches point B it is travelling at a speed of 3.0 m s^{-1}.

a. Calculate the value of h. Show your working.

(3 marks)

b. Calculate the magnitude of the normal reaction force on the car by the track when it is at point B. Show your working.

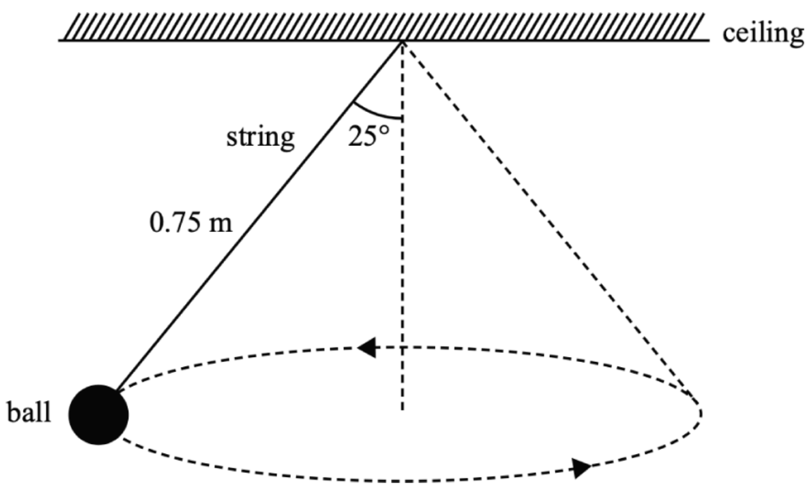
(3 marks)

c. Explain why the car does not fall from the track at point B, when it is upside down.

(3 marks)

Question 21/ 41 [Adapted VCAA 2023 SB Q9]

The diagram below shows a small ball of mass 1.8 kg travelling in a horizontal circular path at a constant speed while suspended from the ceiling by a 0.75 m long string.



a. Use labelled arrows to indicate on the diagram the two physical forces acting on the ball.

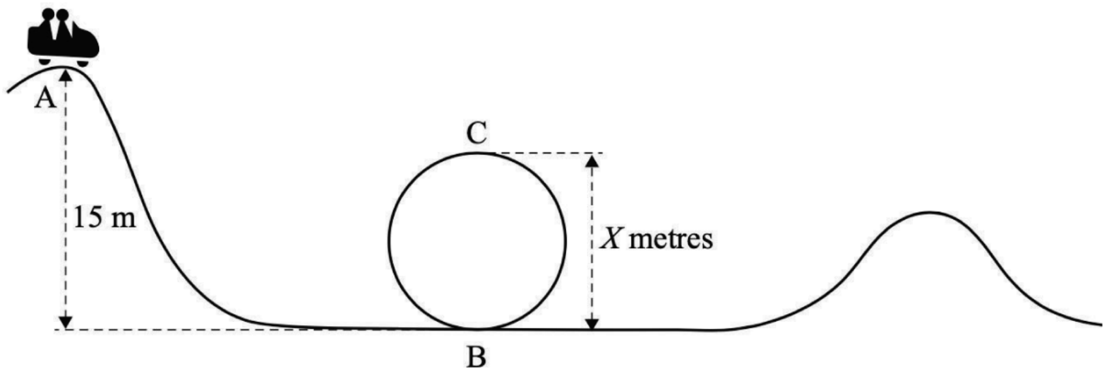
(2 marks)

b. Calculate the speed of the ball. Show your working.

(4 marks)

Question 22/ 41 [Adapted VCAA 2023 SB Q9]

Abbie and Brian are about to go on their first loop-the-loop roller-coaster ride. As competent Physics students, they are working out if they will have enough speed at the top of the loop to remain in contact with the track while they are upside down at point C, shown below. The radius of the loop CB is *r*.



The highest point of the roller-coaster (point A) is 15 m above point B and the car starts at rest from point A. Assume that there is negligible friction between the car and the track.

a. By considering the forces acting on the car, show that the condition for the car to just remain in contact with the track at point C is given by $v^2/r = g$. Show your working.

(2 marks)

b. What is the maximum height of the loop (*X* metres) that will ensure that the car stays in contact with the track at point C? Show your working.

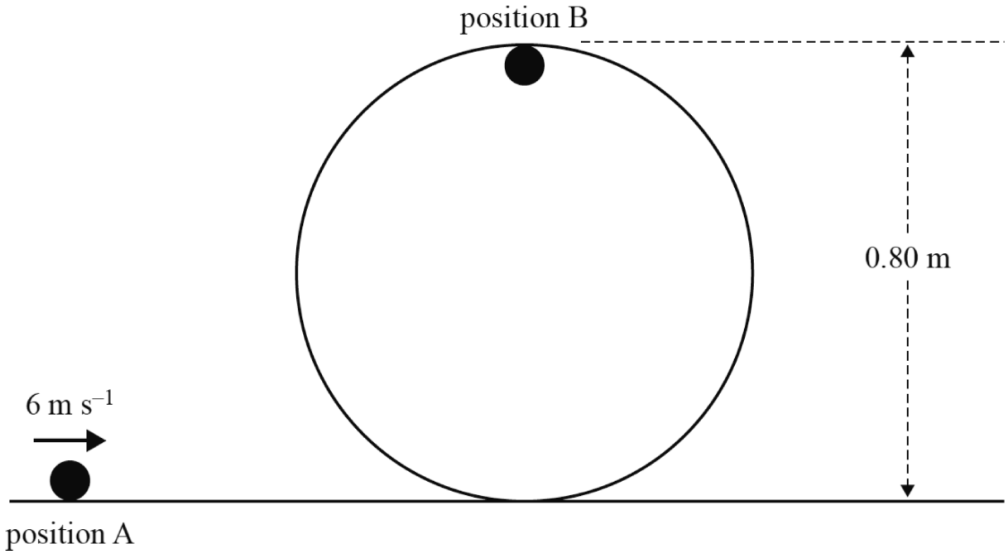
(3 marks)

c. If friction is taken into account, will Abbie and Brian need to increase or decrease their predicted value for the radius of the loop? Explain your answer.

(3 marks)

Question 23/ 41 [Adapted VCAA 2023 SB Q9]

A small ball of mass 0.30 kg travels horizontally with a kinetic energy of 5.4 J. It enters a vertical circular loop of diameter 0.80 m, as shown below. Assume that the radius of the ball and that the frictional forces are negligible.

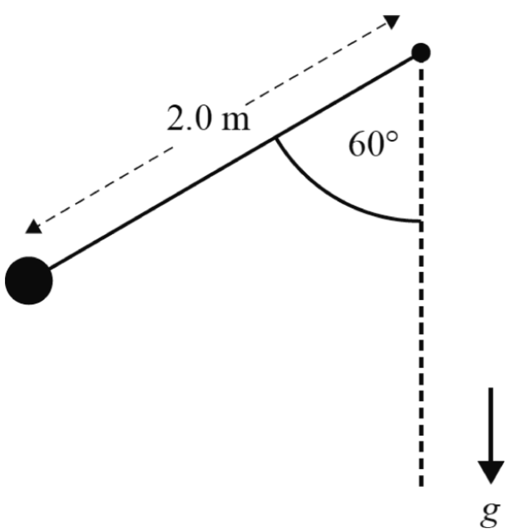


Will the ball remain on the track at the top of the loop at position B? Give your reasoning.

(4 marks)

Question 24/ 41 [Adapted VCAA 2023 SB Q9]

A spherical mass of 2.0 kg is attached to a piece of string of length of 2.0 m. The spherical mass is pulled back until it makes an angle of 60° with the vertical, as shown below.

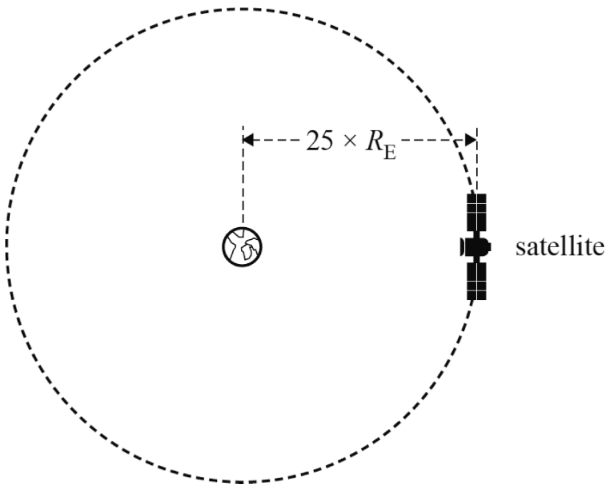


The spherical mass is then released. Ignore the mass of the string. The maximum speed of the spherical mass is 4.4 m s^{-1}. Calculate the maximum tension in the string.

(3 marks)

Question 25/ 41 [Adapted VCAA 2023 SB Q9]

A satellite is moving in a stable circular orbit 25 Earth radii from the centre of Earth, as shown below. The period of the satellite is *T*.

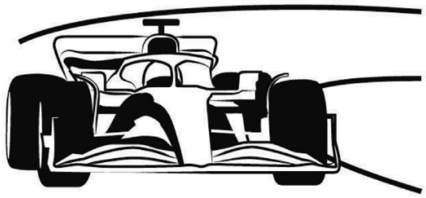


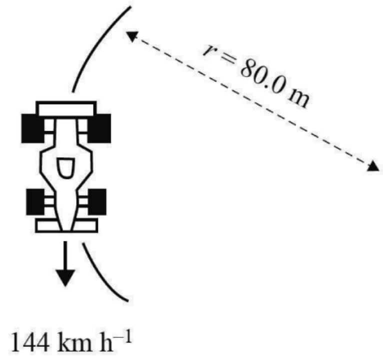
Indicate the direction of the acceleration of the satellite by drawing an arrow on the satellite in the diagram above.

(1 mark)

Question 26/ 41 [Adapted VCAA 2023 SB Q9]

A Formula 1 racing car is travelling at a constant speed of 144 km h^{-1} (40 m s^{-1}) around a horizontal corner of radius 80.0 m. The combined mass of the driver and the car is 800 kg. The left-hand diagram below shows a front view and the right-hand diagram shows a top view.





a. Calculate the magnitude of the net force acting on the racing car and driver as they go around the corner.

(2 marks)

b. On the right-hand diagram, draw the direction of the net force acting on the racing car using an arrow.

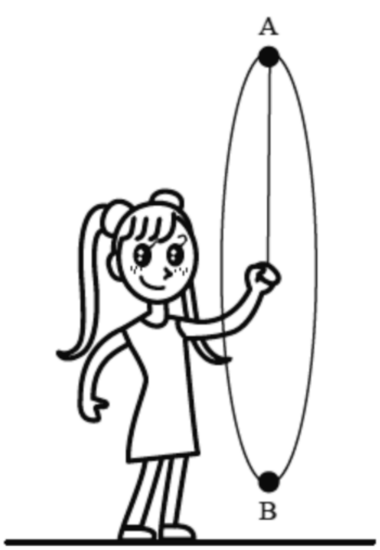
(1 mark)

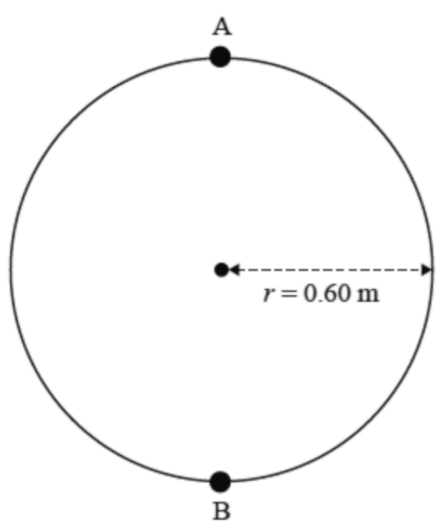
c. Explain why the racing car needs a net horizontal force to travel around the corner and state what exerts this horizontal force.

(2 marks)

Question 27/ 41 [Adapted VCAA 2023 SB Q9]

Lee ties a small ball of mass 100 g to a string and rotates it in a vertical circle, as shown in the left-hand diagram below. Assume that the ball is rotated at a constant speed of 3.0 m s^{-1}. The radius, *r*, of the circle is 0.60 m. The right-hand diagram below shows a side view.





a. On the right-hand diagram, draw arrows to represent each of the forces acting on the small ball at position A, at the top of the circle, and at position B, at the bottom of the circle. Label each arrow clearly and use the lengths of the arrows to show the relative approximate magnitudes of the forces. No calculations are required.

(4 marks)

b. Calculate the tension force in the string when the ball is at position B.

Use $g = 10 \text{ m s}^{-2}$.

(2 marks)

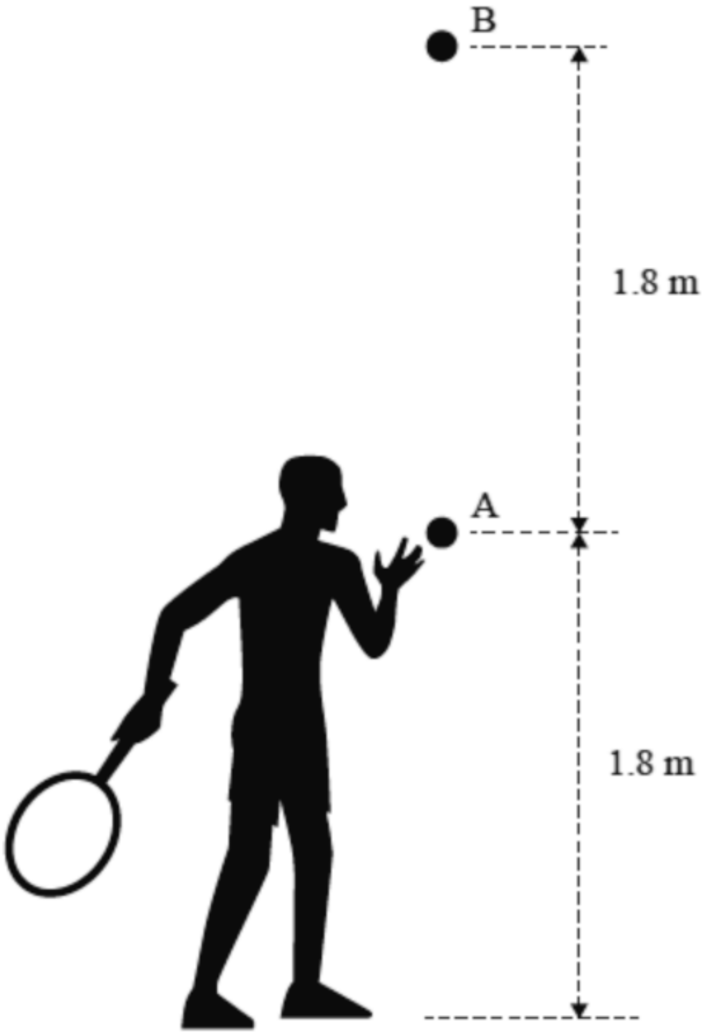
c. Lee now increases the speed of the ball to a new constant speed, which is greater than 3.0 m s^{-1}, and notices that the string breaks when the ball is at position B. Explain why the string is more likely to break at position B than at position A.

(3 marks)

Question 28/ 41 [Adapted VCAA 2023 SB Q9]

Giorgos is practising his tennis serve using a tennis ball of mass 56 g.

a. Giorgos practises throwing the ball vertically upwards from point A to point B, as shown below.

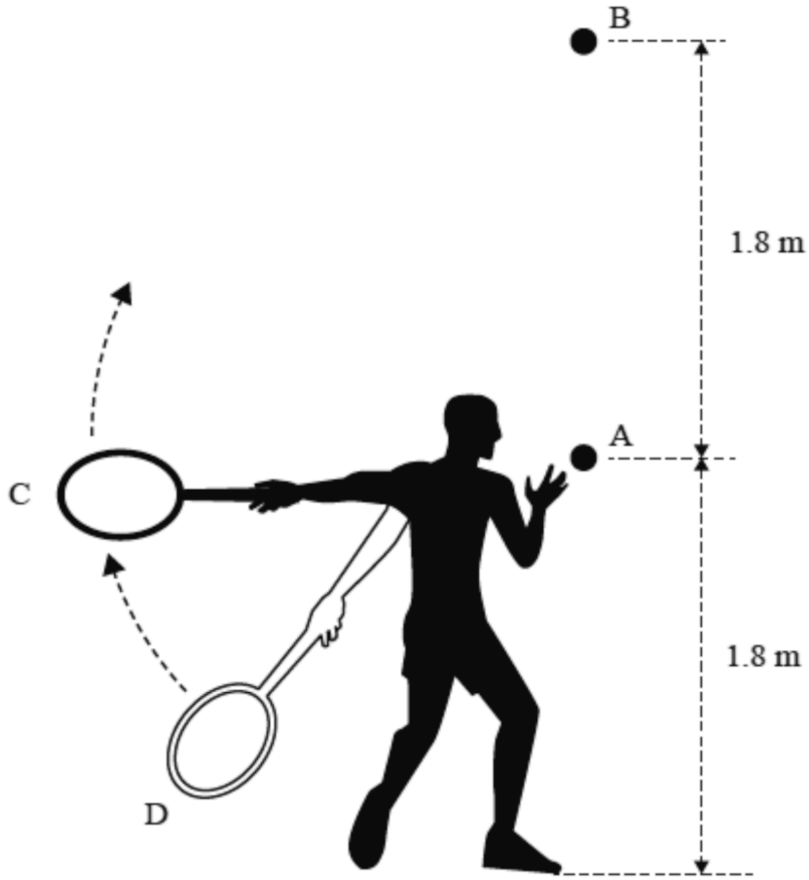


His daughter Eka, a physics student, Models the throw, assuming that the ball is at the level of Giorgos's shoulder, point A, both when it leaves his hand and also when he catches it again. Point A is 1.8 m from the ground. The ball reaches a maximum height, point B, 1.8 m above Giorgos's shoulder.

Show that the ball is in the air for 1.2 s from the time it leaves Giorgos's hand, which is level with his shoulder, until he catches it again at the same height.

(2 marks)

b. Giorgos swings his racquet from point D through point C, which is horizontally behind him at shoulder height, as shown below, to point B. Eka models this swing as circular motion of the racquet head. The centre of the racquet head moves with constant speed in a circular arc of radius 1.8 m from point C to point B.



The racquet passes point C at the same time that the ball is released at point A and then the racquet hits the ball at point B.

Calculate the speed of the racquet at point C.

(2 marks)

Chapter 7 Fields and their patterns

Question 1/ 18

Which of the following best describes the force between two isolated positive point charges?

A There is an attractive force caused by the direct interaction of the two charges.

B There is a repulsive force caused by the direct interaction of the two charges.

C There is an attractive force caused by the interaction of the electric field of one charge with the other charge.

D There is a repulsive force caused by the interaction of the electric field of one charge with the other charge.

Question 2/ 18

A key difference between the electrostatic forces between two positive charges and magnetic forces between two bar magnets is that

A electrostatic forces rely on electric fields, but magnetic forces are direct interactions between magnets.

B the electrostatic forces can be either attractive or repulsive, but the magnetic forces are always attractive.

C the electrostatic force will always be positive, but the magnetic force can be attractive or repulsive.

D both forces can be attractive or repulsive, but magnetic forces only work at short ranges.

Question 3/ 18

At the time of writing this question, magnetic monopoles have not been observed. However, if they were discovered, the pattern of their magnetic field would likely be most similar to the field pattern of

A a moving isolated electric charge.

B a bar magnet.

C an isolated point mass.

D a closely spaced pair of positive and negative electric charges.

Question 4/ 18

The following kinds of monopoles have **not** yet been observed.

A positive electric

B negative electric

C magnetic north

D gravitational

Question 5/ 18

Which of the following statements is correct?

A Electrostatic and magnetic fields are vector fields; gravitational fields are not.

B Electrostatic and gravitational fields are vector fields; magnetic fields are not.

C Magnetic and gravitational fields are vector fields; electrostatic fields are not.

D Electrostatic, magnetic and gravitational fields are all vector fields.

Question 6/ 18

Which of the following is closest to a uniform field?

A the electric field between two large charged parallel plates

B the electric field close to an isolated positive charge

C the magnetic field close to a current in a long straight wire

D none of the above is close to a uniform field

Question 7/ 18

The inverse square law does *not* apply to which of the following?

A the gravitational field of a point mass

B the electric field of an isolated positive charge

C the electric field of an isolated negative charge

D the magnetic field of a bar magnet

Question 8/ 18

Which of the following could be described as a static field?

A the gravitational field of the Moon as it passes overhead

B the electric field of a vibrating positive charge

C the magnetic field around a coil carrying AC current

D the magnetic field around a coil carrying DC current

Question 9/ 18

Which of the following interactions always produces repulsive forces?

A electrostatic charges of opposite sign

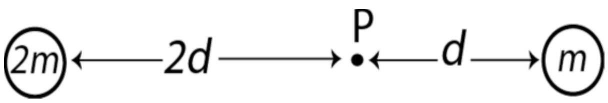
B electrostatic charges of same sign

C two bar magnets

D masses of matter and anti-matter

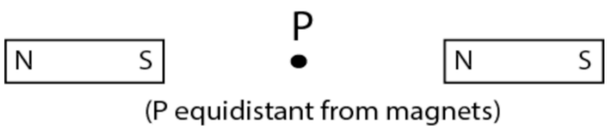
Question 10/ 18

Which of the following diagrams shows the situation in which the vector sum of fields produces a zero field at P? Diagram A shows two masses, diagrams B and C show electric charges, and diagram D shows two bar magnets.

A 

B 

C 

D 

Question 11/ 18

Which of the following statements best summarises current information about monopoles and dipoles?

A Dipoles are only possible in electric fields.

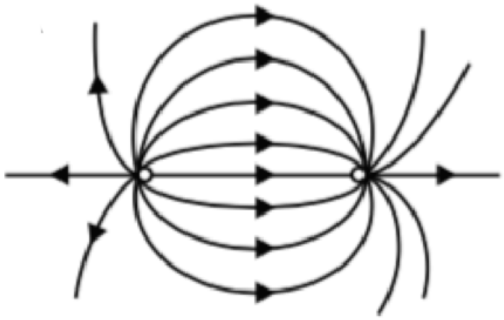
B Monopoles are never observed in gravitational fields.

C Monopoles are not observed in electric fields.

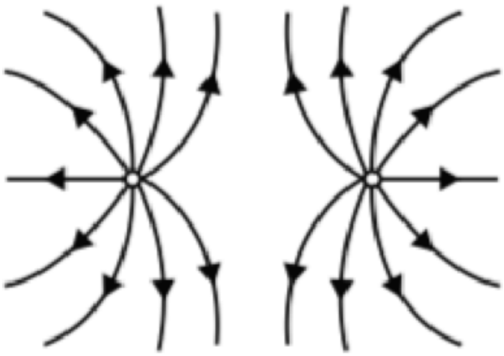
D Dipoles exist in electric and magnetic fields.

Question 12/ 18

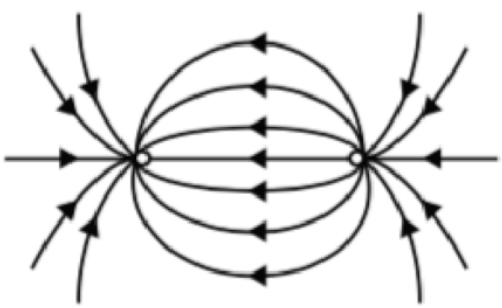
Which one of the following diagrams best shows the electric field pattern surrounding two equal, positive point charges?



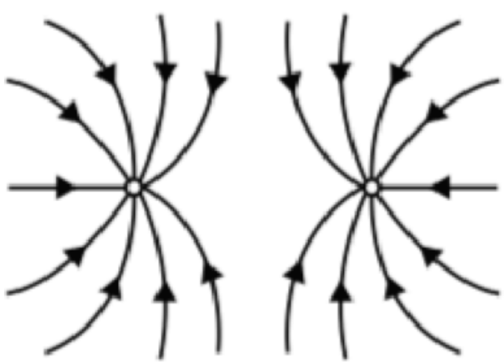
A



B



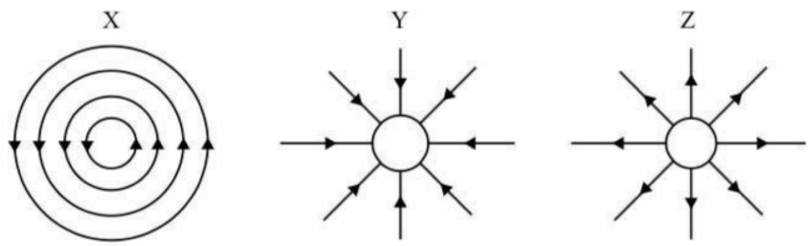
C



D

Question 13/ 18

The three diagrams X, Y and Z below represent different types of fields.



Which one of the following statements about these diagrams is correct?

A X could be an electric field, Y could be a gravitational field and Z could be a magnetic field.

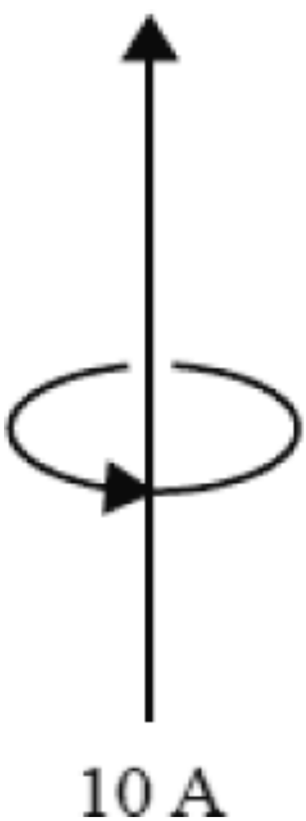
B X could be a gravitational field, Y could be an electric field and Z could be a magnetic field.

C X could be a magnetic field, Y could be a gravitational field and Z could be an electric field.

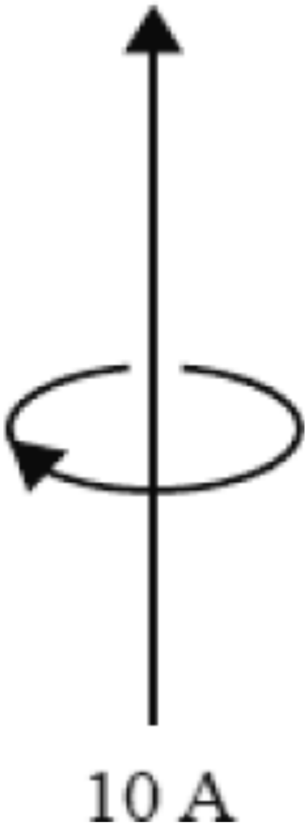
D X could be a gravitational field, Y could be a magnetic field and Z could be an electric field.

Question 14/ 18

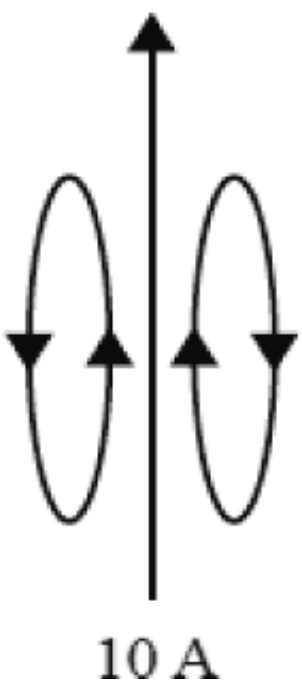
A straight wire carries a current of 10 A. Which one of the following diagrams best shows the magnetic field associated with this current?



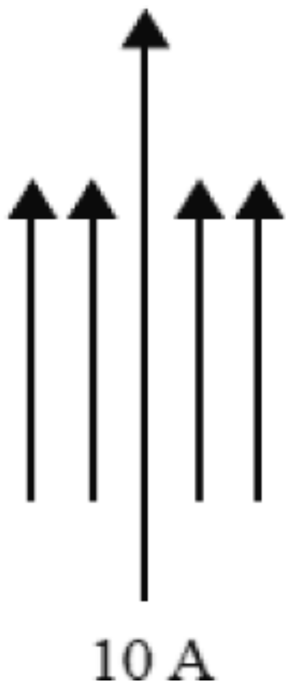
A



B

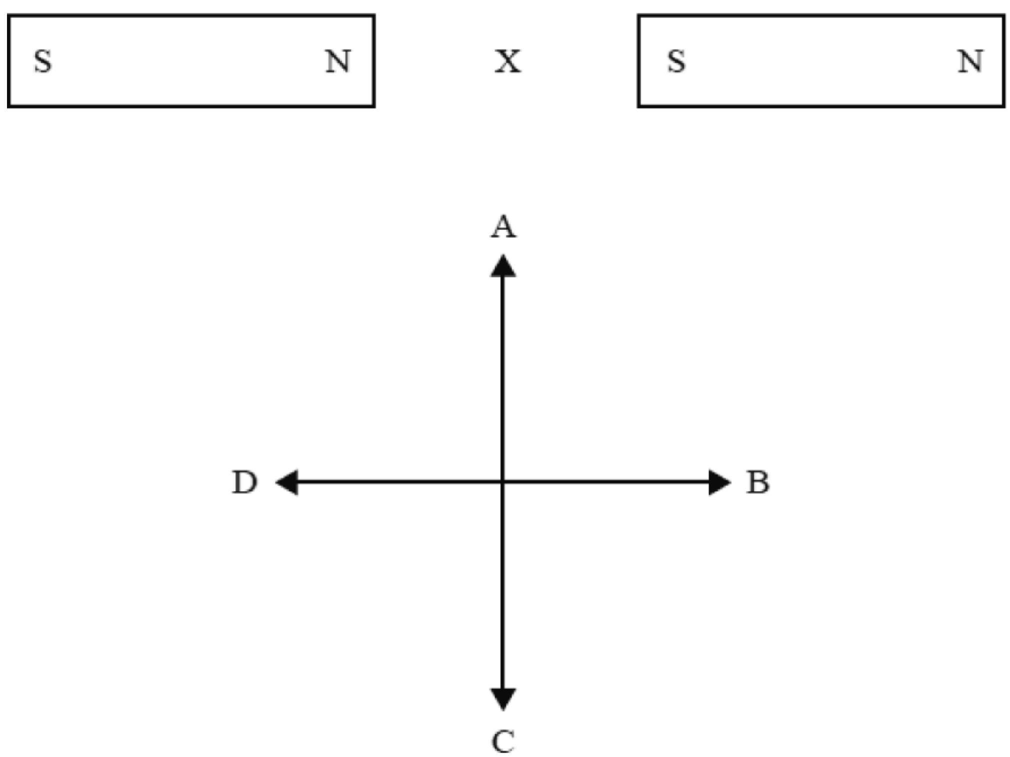


C

D 

Question 15/ 18

Two identical bar magnets are placed end to end, as shown below. Point X is midway between the bar magnets. Which direction best shows the direction of the magnetic field at point X?



A A

B B

C C

D D

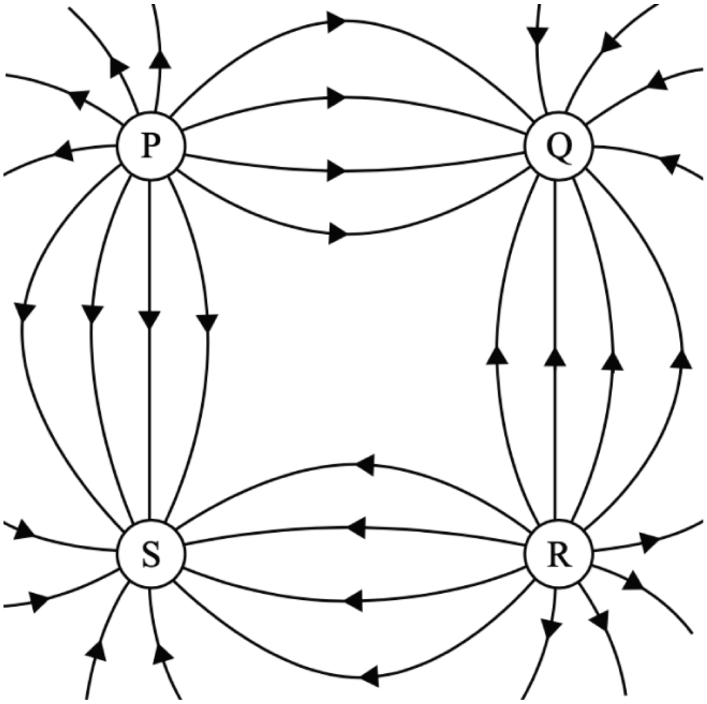
Question 16/ 18

Magnetic and gravitational forces have a variety of properties. Which of the following best describes the attraction/repulsion properties of magnetic and gravitational forces?

Magnetic forces	Gravitational forces
either attract or repel	only attract
only repel	neither attract nor repel
only attract	only attract
either attract or repel	either attract or repel

Question 17/ 18

The diagram below shows the electric field lines between four charged spheres: P, Q, R and S. The magnitude of the charge on each sphere is the same.

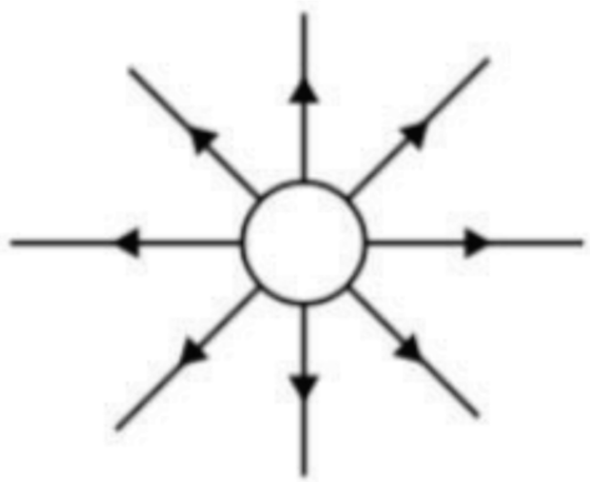


Which of the following correctly identifies the type of charge (+ positive or − negative) that resides on each of the spheres P, Q, R and S?

P	Q	R	S
−	+	−	+
+	−	+	−
−	−	+	+
+	+	−	−

Question 18/ 18

Consider the diagram below, which shows a stationary object with field lines that extend outwards from the object.



The field shown is most likely to be identified as an example of

A an electric field that is uniform.

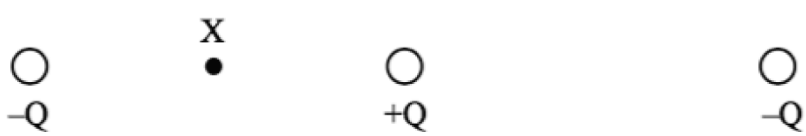
B an electric field that is non-uniform.

C a gravitational field that is uniform.

D a gravitational field that is non-uniform.

Question 1/ 29 [VCAA 2020 SB Q1]

Three charges are arranged in a line, as shown below.



Draw an arrow at point X to show the direction of the resultant electric field at X. If the resultant electric field is zero, write the letter 'N' at X.

(1 mark)

Question 2/ 29 [VCAA 2020 SB Q1]

Two small equal masses are shown in the diagram below. They can be considered to be point masses.

a. Identify any point(s) where the combined gravitational field of the two masses is zero, by marking it on the diagram.

(1 mark)

b. Sketch the pattern of the gravitational field between the masses, using at least four field lines. Mark each field line with an appropriate arrow to show the direction of the field.

(2 marks)

Question 3/ 29 [VCAA 2020 SB Q1]

Two small charges of opposite sign are shown in the diagram below. They can be considered to be point charges.

a. Sketch the pattern of the electric field between the charges, using at least four field lines. Mark each field line with an appropriate arrow to show the direction of the field.

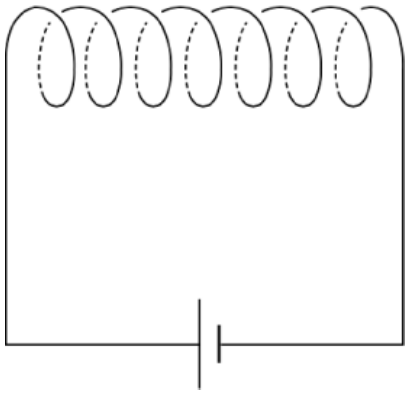
(2 marks)

b. Students are debating whether the point midway between the two charges is a point of zero field strength. Give your judgement on this, including reasons.

(2 marks)

Question 4/ 29 [VCAA 2020 SB Q1]

The diagram below shows a solenoid. Draw five lines with arrows to show the magnetic field of the solenoid.



(2 marks)

Question 5/ 29 [VCAA 2020 SB Q1]

Two long straight wires are parallel, as shown in the left-hand diagram below. Viewed from *below*, they can be shown as in the right-hand diagram. Note that the currents are in the same direction.

a. Sketch the pattern of the magnetic field lines as seen from below the wires. Use six (or more) lines.

(2 marks)

b. The current in *one* wire is reversed. Sketch the field pattern now.

(2 marks)

Question 6/ 29 [VCAA 2020 SB Q1]

a. Give an example of a non-uniform magnetic field. Include a pattern of field lines.

(2 marks)

b. Give an example of a non-uniform electrostatic field. Include a pattern of field lines.

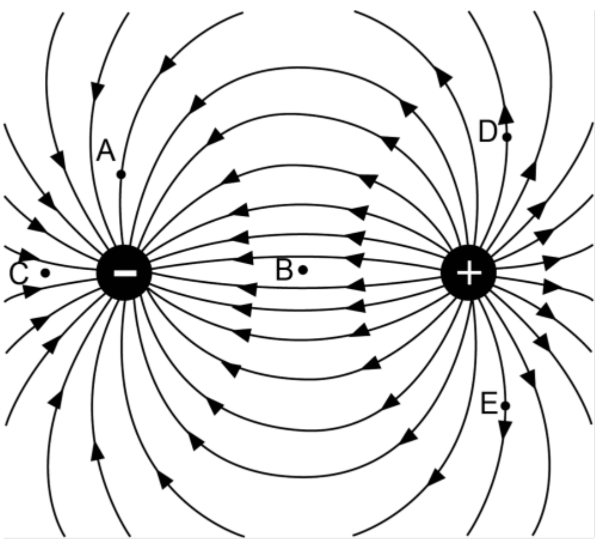
(2 marks)

c. Give an example of a non-uniform gravitational field. Include a pattern of field lines.

(2 marks)

Question 7/ 29 [VCAA 2020 SB Q1]

An electrostatic field line pattern is shown below.



a. Use the field pattern to compare the direction of the field at points A and E. Explain your reasoning.

(2 marks)

b. Use the field pattern to compare the direction of the field at points B and C. Explain your reasoning.

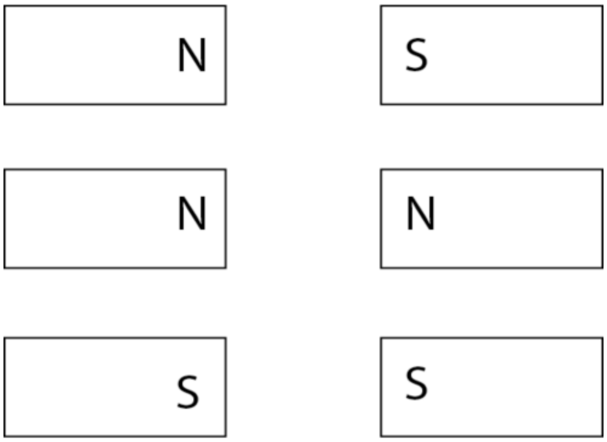
(2 marks)

c. Use the field pattern to compare (qualitatively) the strength of the field at points B and D. Explain your reasoning.

(2 marks)

Question 8/ 29 [VCAA 2020 SB Q1]

Two bar magnets are arranged in three different ways, as shown.



In the space between the magnets in each arrangement, draw *at least four* magnetic field lines. Attach arrowheads to each field line, showing its direction.

(3 marks)

Question 9/ 29 [VCAA 2020 SB Q1]

Compare and contrast the shapes and directions of the fields from a single isolated positive point charge and a single isolated point mass.

(3 marks)

Question 10/ 29 [VCAA 2020 SB Q1]

Gravitation, magnetism and electricity can be explained using a field model. According to our understanding of physics and current experimental evidence, these three field types can be associated with only monopoles, only dipoles or both monopoles and dipoles. In the table below, indicate whether each field type can be associated with only monopoles, only dipoles or both monopoles and dipoles by ticking the appropriate box.

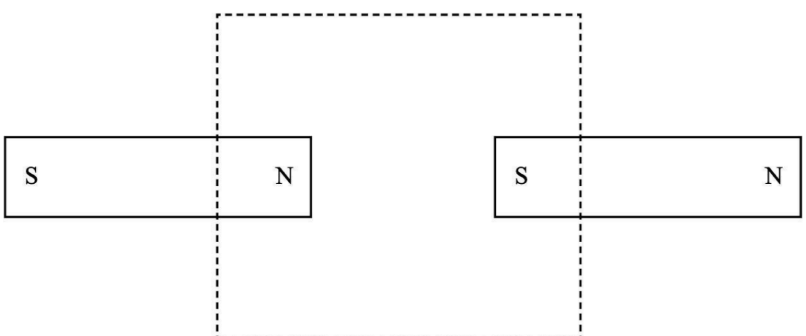
Field type	Only monopoles	Only dipoles	Both monopoles and dipoles
gravitation			
magnetism			
electricity			

(3 marks)

Question 11/ 29 [VCAA 2020 SB Q1]

Two bar magnets are placed close to each other, as shown below.

Sketch the shape and the direction of *at least four* magnetic field lines between the two poles within the dashed border shown.



(2 marks)

Chapter 8 Gravitational fields

Question 1/ 24

Which of the below gives the correct units for G?

A $\mathrm{N\ kg^{-1}}$

B $\mathrm{m^3 s^{-2}\ kg^{-1}}$

C $\mathrm{N\ m\ kg^{-2}}$

D none of the above

Question 2/ 24

Scientists want to put a satellite into an orbit where the gravitational field of Earth is half its value at Earth's surface. The altitude of this orbit above Earth's surface will be

A $3R$

B $\sqrt{2}R - R$

C $4R$

D $\sqrt{2}R$

Question 3/ 24

If the Moon were to be put into a new orbit of twice its current radius, its potential energy would

A increase.

B decrease.

C remain unchanged.

D increase or decrease, depending on its speed in the new orbit.

Question 4/ 24

Two satellites are in orbit at the same height around Earth. Satellite 1 has a mass 10 times that of satellite 2. Determine which option is closest to the ratio:

$\frac{period\ of\ satellite\ 1}{period\ of\ satellite\ 2}$

A 100

B 10

C 1

D 0.10

Question 5/ 24

A Moon transfer vehicle has a weight of 625 000 N on Earth's surface. On the surface of the Moon a *possible* value for its approximate weight could be

A 0 N

B 625 000 N

C 62 500 kg

D 100 000 N

Question 6/ 24

The acceleration due to gravity on the surface of Mars is close to 3.8 m s^{-2}. Which of the following is closest to the weight of an object on Mars that weighs 76 N on Earth?

A 7.6 kg

B 29 N

C 290 N

D 760 N

Question 7/ 24

Which of the following best describes the forces acting on a satellite in stable orbit around Earth?

A The gravity force from Earth

B The gravity force from Earth, balanced by an equal outwards force

C No force is required; conservation of momentum ensures its motion

D A force from the engines of the satellite

Question 8/ 24

A satellite in orbit around Earth is at a height where the value of $g = 4.9\ \mathrm{m\ s^{-2}}$. Which of the following is closest to the centripetal acceleration of the satellite while in this orbit?

A $0\ \mathrm{m\ s^{-2}}$

B $4.9\ \mathrm{m\ s^{-2}}$

C $9.8\ \mathrm{m\ s^{-2}}$

D $19.6\ \mathrm{m\ s^{-2}}$

Question 9/ 24

Which of the following is closest to the period of a geostationary satellite?

A 12 hours

B 86 400 s

C 1 year

D 0 s because it is stationary

Question 10/ 24

Two satellites are in orbit at the same height. Satellite 1 has a mass of 100 kg; satellite 2 has a mass of 1000 kg. Which statement below is correct?

A They have the same potential energy and orbital period.

B They have different potential energies and the same orbital period.

C They have the same potential energy and different orbital periods.

D They have the different potential energies and orbital periods.

Question 11/ 24

[VCAA 2018 NHT SA Q2]

DATA

$$\text{Mass of Mercury} = 3.34 \times 10^{23} \text{ kg}$$

$$\text{Radius of Mercury} = 2.44 \times 10^{6} \text{ m}$$

$$\text{Universal gravitational constant } G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

The gravitational field strength at the surface of Mercury (assumed spherical and uniform) is close to

A $9.00 \times 10^6 \text{ N kg}^{-1}$

B 9.81 N kg^{-1}

C 3.74 N kg^{-1}

D $3.74 \times 10^{-2} \text{ N kg}^{-1}$

Question 12/ 24

Two satellites in circular orbits around Earth have different masses but are travelling at the same speed. This means that

A they will travel at different radii.

B they will circle Earth with different periods.

C they will have the same potential energy.

D the gravitational force on them will be different.

Question 13/ 24

[VCAA 2018 SA Q7]

At one point on Earth's surface at a distance *R* from the centre of Earth, the gravitational field strength is measured as 9.76 N kg^{-1}. Which one of the following is closest to Earth's gravitational field strength at a distance 2*R* above the surface of Earth at that point?

A 1.08 N kg^{-1}

B 2.44 N kg^{-1}

C 3.25 kg^{-1}

D 4.88 N kg^{-1}

Question 14/ 24

[VCAA 2019 NHT SA Q4]

The gravitational field strength at the surface of Mars is $3.7\ \mathrm{N\ kg^{-1}}$. Which one of the following is closest to the change in gravitational potential energy when a 10 kg mass falls from 2.0 m above Mars's surface to Mars's surface?

A 3.7 J

B 7.4 J

C 37 J

D 74 J

Question 15/ 24

[VCAA 2019 SA Q4]

The magnitude of the acceleration due to gravity at Earth's surface is *g*. Planet Y has twice the mass and half the radius of Earth. Both planets are modelled as uniform spheres. Which one of the following best gives the magnitude of the acceleration due to gravity on the surface of Planet Y?

A $\frac{1}{2}g$

B $1g$

C $4g$

D $8g$

Question 16/ 24

[VCAA 2020 SA Q2]

Jupiter's moon Ganymede is its largest satellite. Ganymede has a mass of 1.5×10^{23} kg and a radius of 2.6×10^{6}m. Which one of the following is closest to the magnitude of Ganymede's surface gravity?

A 0.8 m s^{-2}

B 1.5 m s^{-2}

C 3.8 m s^{-2}

D 9.8 m s^{-2}

Question 17/ 24

[VCAA 2021 NHT SA Q4]

A person has a mass of 60.0 kg. Which one of the following is closest to the weight of this person on Earth's surface?

A 60.0 kg

B 60.0 N

C 588 kg

D 588 N

Question 18/ 24

[VCAA 2021 NHT SA Q5]

When a spacecraft orbits Earth, its orbital period is not a function of the

A mass of Earth.

B mass of the spacecraft.

C velocity of the spacecraft.

D height of the spacecraft above Earth.

Question 19/ 24

[VCAA 2021 SA Q4]

The planet Phobetor has a mass four times that of Earth. Acceleration due to gravity on the surface of Phobetor is 18 m s^{-2}. If Earth has a radius *R*, which one of the following is closest to the radius of Phobetor?

A *R*

B 1.5*R*

C 2*R*

D 4*R*

Question 20/ 24

[VCAA 2022 NHT SA Q3]

The gravitational field strength at the surface of a uniform spherical planet of radius *R* is $g \text{ N kg}^{-1}$. At a distance of 3*R* above the planet's surface, the strength of gravity will be closest to

A 0

B $\frac{g}{3}$

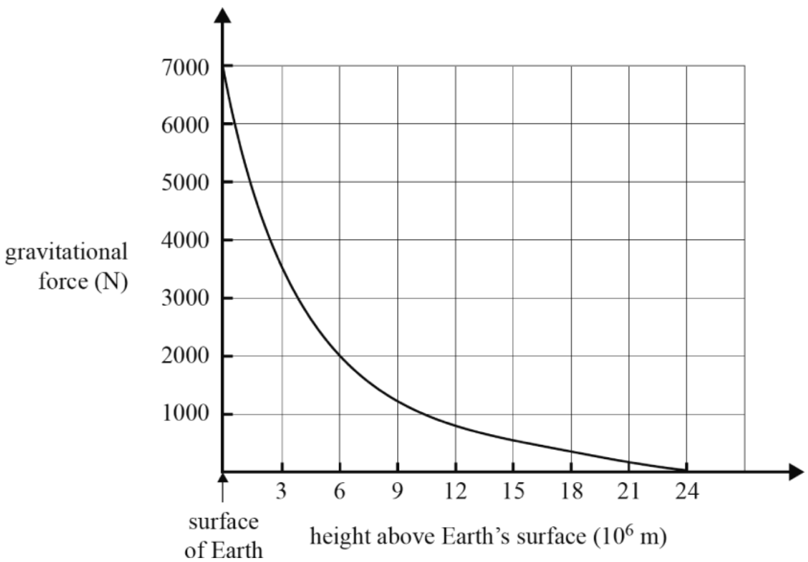
C $\frac{g}{9}$

D $\frac{g}{16}$

Question 21/ 24

[VCAA 2022 NHT SA Q4]

The Mars *Odyssey* spacecraft was launched from Earth to explore Mars. The graph below shows the gravitational force acting on the 700 kg Mars *Odyssey* spacecraft plotted against its height above Earth's surface.



Which one of the following is closest to the minimum launch energy needed for the Mars Odyssey spacecraft to 'escape' Earth's gravitational attraction?

A 4.0×10^4 J

B 1.5×10^5 J

C 4.0×10^{10} J

D 1.5×10^{11} J

Question 22/ 24

[VCAA 2023 NHT SA Q3]

Two identical satellites, S_1 and S_2, each of mass *m*, are placed into two circular orbits around Earth. Satellite S_1 has an orbital radius of 5*R*. Satellite S2 has an orbital radius of *R*.

Which one of the following best gives the value of $\frac{\text{gravitational force exerted on } S_1 \text{ by Earth}}{\text{gravitational force exerted on } S_2 \text{ by Earth}}$?

A $\frac{1}{25}$

B $\frac{1}{10}$

C 10

D 25

Question 23/ 24

[VCAA 2023 NHT SA Q8]

Saturn has 83 moons. One of them, Enceladus, has a mass 1.08×10^{20} kg and a circular orbit of radius 2.38×10^{8} m.

The mass of Saturn is 5.68×10^{26} kg.

Which one of the following is closest to the gravitational force of attraction between Enceladus and Saturn?

A 0 N

B 1300 N

C 4.9×10^{8} N

D 7.2×10^{19} N

Question 24/ 24

[VCAA 2023 SA Q3]

Space scientists want to place a satellite into a circular orbit where the gravitational field strength of Earth is half of its value at Earth's surface.

Which one of the following expressions best represents the altitude of this orbit above Earth's surface, where

R is the radius of Earth?

A $(\sqrt{2}\mathrm{R}/\bar{2})$ - R

B $\sqrt{2}\mathrm{R}$

C $(\sqrt{2}\mathrm{R}) - \mathrm{R}$

D $2\mathrm{R} - \sqrt{2}\mathrm{R}$

Question 1/ 56

Calculate the gravitational force attracting two masses of 1 kg, separated by 0.40 m.

(2 marks)

Question 2/ 56

A space shuttle of mass 200 t is in circular orbit around Earth, at a height of 200 km.

DATA: mass of $\mathrm{Earth} = 6.0 \times 10^{24}\ \mathrm{kg}$; radius of $\mathrm{Earth} = 6.4 \times 10^{6}\ \mathrm{m}$

Calculate the kinetic energy of the space shuttle in this orbit. Show your working.

(4 marks)

Question 3/ 56

From the frame of reference of Earth, the Moon orbits it once every 27.3 days. The orbit circumference (assumed circular) is equal to $2.4 \times 10^{6}\ \mathrm{km}$. Calculate the acceleration of the Moon in this frame of reference. Show your working.

(3 marks)

Question 4/ 56

A geosynchronous satellite is one with a period of 24 h positioned exactly above the equator. It appears motionless viewed from the surface of Earth. Explain why it must be in an orbit above the equator.

(4 marks)

Question 5/ 56

A rocket is disabled at a height of nine Earth radii above the surface of Earth. It is at rest. By how much will its velocity change in the next 200 s?

(Take g at Earths surface $= 10\ \mathrm{m\ s^{-2}}$; assume *g* does not change in 200 s.)

(2 marks)

Question 6/ 56

Between the Sun and Earth, there will be a point where the sum of their gravitational fields will be zero. This point is a distance x from the centre of Earth, and the radius of Earth's orbit about the Sun is R. Write down an equation that would enable you to find x, in terms of R, M_e (the mass of Earth), and M_s (the mass of the Sun). Do not attempt to solve the equation.

(2 marks)

Question 7/ 56

A small satellite orbits Mars. It has a kinetic energy of 3.0×10^{10} J, and it is at a constant distance of 8.0×10^{7} m from the centre of Mars. What is the *weight* of the satellite at this height? Show your working.

(3 marks)

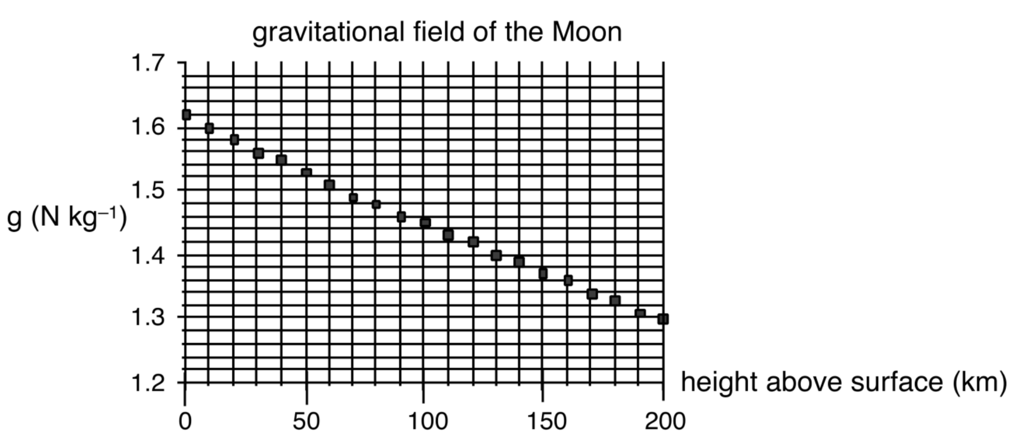
Question 8/ 56

An Earth-calibrated balance, which compares a known mass with an unknown mass by a balancing mechanism, will work satisfactorily on the Moon but not in a satellite in stable orbit. Explain why this is so.

(4 marks)

Question 9/ 56

An experiment fires a mass of 50 kg vertically from the surface of the Moon to a maximum height of 180 km. There is no air resistance.



Use the graph to deduce the velocity of the mass. Explain your method.

(4 marks)

Question 10/ 56

One of Kepler's laws for planetary motion of planets around the Sun can be expressed in the form $T^2 \propto R^3$. Show that this holds for planets in circular orbits around the Sun.

(3 marks)

Question 11/ 56

Read the following extract.

Jupiter, the largest planet in the solar system, has several moons. Galileo discovered four of them in 1610/11 AD. They are Io, Europa, Ganymede and Callisto; more details about them are shown in the table below.

Moon name	Distance from centre of Jupiter	Mass (relative units)	Period of rotation (days)
Io	4.2×10^8 m	1.0	1.77
Europa	6.7×10^8 m	0.7	3.55
Ganymede	1.1×10^9 m	3.7	7.16
Callisto	1.87×10^9 m	2.6	

a. Explain why the period of rotation of the three closest moons increases with the distance from the centre of Jupiter, and it is *not* related to the masses of the moons involved.

(4 marks)

b. Calculate the period of rotation of Callisto. Express your answer to two significant figures. Show your working.

(4 marks)

Question 12/ 56

a. Calculate the gravitational field *g* on the surface of Phobos (a moon of Mars). Assume it is uniform and spherical. Show your working.

DATA: mass of Phobos: 1.07×10^{16} kg; radius of Phobos: 11.3 km

(2 marks)

b. Assuming constant density, state *g* at the centre of Phobos.

(1 mark)

Question 13/ 56

Calculate the mass of Earth from the following data. Show your working.

$\text{Radius of Moons orbit} = 3.8 \times 10^{8}\ \text{m; period of Moon} = 28\ \text{days}$

(3 marks)

Question 14/ 56

Show that two satellites of different mass with the same radius orbit about Earth must have the same speed and period. Assume circular orbits.

(3 marks)

Question 15/ 56

A spacecraft is placed in orbit around Saturn so that it always over the same point on Saturn's surface on its equator.

$$\text{Saturns mass} = 5.68 \times 10^{26} \text{ kg, Saturns period of rotation} = 10.25 \text{ h}$$

a. Calculate the period, in seconds, of the spacecraft's orbit.

(1 mark)

b. Calculate the radius of the orbit of the spacecraft. Show your working.

(3 marks)

Question 16/ 56

Two students discuss the gravitational field *inside* Earth (assumed to be a uniform sphere). Jacinta says that the field will increase towards the centre of Earth, but Josie says that it will decrease to zero. Evaluate these statements.

(4 marks)

Question 17/ 56

[VCAA 2016 SA Q6]

a. Explain the conditions for a satellite to be in a geostationary orbit (that is, stationary over a fixed point on Earth's surface). There is no need to calculate the actual radius of the orbit.

(3 marks)

b. Roger states that there are a number of situations on or near Earth's surface where a person may feel 'weightless'. Emily states that this is impossible. It is only possible to feel 'weightless' in deep space where there is no, or very little, gravitational force on a person. Is Emily correct or incorrect? Explain your answer.

(3 marks)

Question 18/ 56

[VCAA 2017 SB Q4]

Charon, a moon of Pluto, has a circular orbit.

DATA

$$\text{Mass of Pluto} = 1.3 \times 10^{22}\ \text{kg; radius of Pluto} = 1.2 \times 10^{6}\ \text{m}$$

$$\text{Mass of Charon} = 1.6 \times 10^{21}\ \text{kg; radius of Charons orbit} = 1.8 \times 10^{7}\ \text{m}$$

$$\text{Universal gravitational constant } (G) = \ 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$$

Assume that Pluto is a uniform sphere.

a. Calculate the gravitational field strength on the surface of Pluto. Show your working and include an appropriate unit.

(3 marks)

b. Calculate the period of orbit of Charon. Show your working.

(3 marks)

c. Scientists wish to place a spacecraft, of mass 1000 kg, in an orbit of the same radius as Charon. Three students, Rick, Melissa and Nam, are discussing the situation and have different opinions. Rick says as the spacecraft is lighter, it will have to move at a greater speed than Charon to achieve the same orbit. Melissa says the spacecraft would need to move at the same speed as Charon. Nam says the spacecraft would need only to move at a lower speed as it is lighter than Charon. Evaluate these three opinions. Detailed calculations are *not* necessary.

(3 marks)

Question 19/ 56

[Adapted VCAA 2018 SB Q1]

A 1500 kg satellite is in a circular orbit around Earth at an altitude of 850 km.

$\text{Earths radius} = 6400\ \text{km}$; its $\text{mass} = 6.0 \times 10^{24}\ \text{kg}$; $G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$.

a. Calculate the period of the satellite in seconds.

(3 marks)

b. The controllers of the satellite use its motors to move the satellite into a higher, but still stable, orbit.

i. Will this increase, decrease or have no effect on the speed of the satellite? Justify your answer.

(3 marks)

ii. Will this increase, decrease or have no effect on the gravitational potential energy of the satellite? Take the surface of Earth as the zero of gravitational potential energy. Justify your answer.

(3 marks)

Question 20/ 56

In December 2003, a spacecraft was put into orbit around Mars. The orbital period was 7.5 h. Assume that the orbit was circular, and use the data below.

$\text{Mass of Mars} = 6.4 \times 10^{23}\ \text{kg}$; $\text{radius of Mars} = 3.4 \times 10^{6}\ \text{m}$.

a. Calculate the speed of the spacecraft when in orbit around Mars. Show the steps of your working.

(3 marks)

b. Calculate gravitational field due to Mars acting on the spacecraft. Show your working.

(3 marks)

c. Calculate the *height* of the orbiting spacecraft above the surface of Mars. Show your working.

(4 marks)

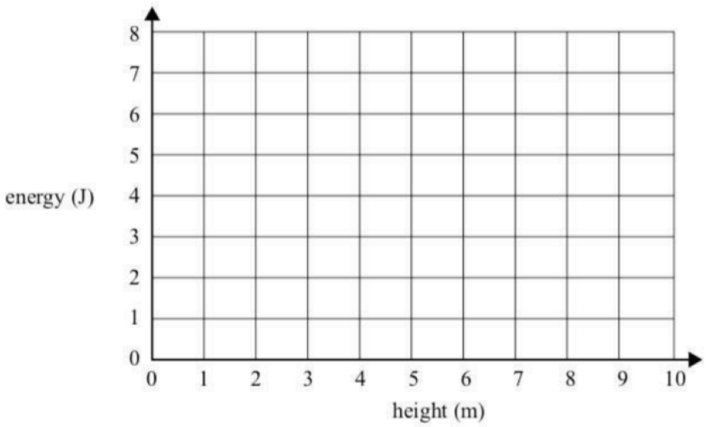
Question 21/ 56

[Adapted VCAA 2017 Sample SB Q1]

A probe of mass 0.20 kg is released from 10 m above Mars's surface. Assume the gravitational field strength is uniform (the same as at the surface). Ignore air resistance. Graph the probe's gravitational potential energy against the height above the Martian surface on the grid below: label it as U_g. Take potential energy at the surface of Mars as zero. Include the initial potential energy value. On the same axes, sketch the kinetic energy of the probe; label this as E_K.

DATA

$$\text{Mass}_{\text{MARS}} = 6.4 \times 10^{23}\ \text{kg}; \text{Radius}_{\text{MARS}} = 3.4 \times 10^{6}\ \text{m}; G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}.$$



(3 marks)

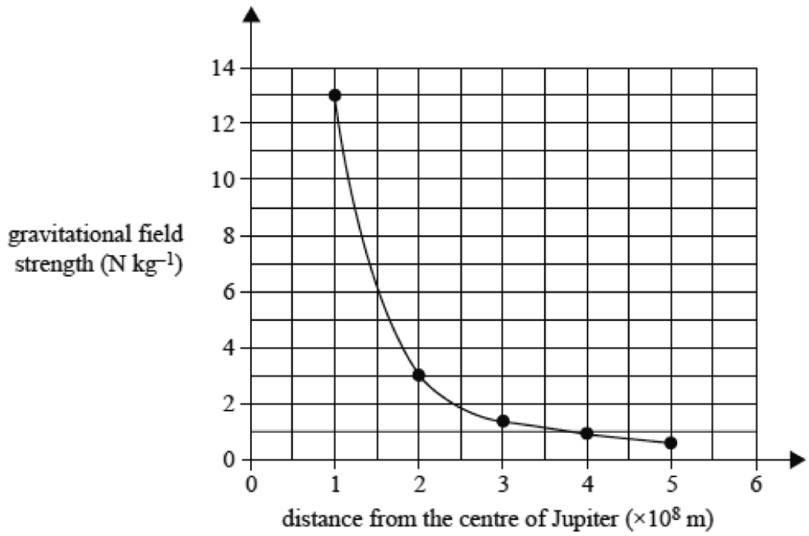
Question 22/ 56

[VCAA 2018 SB Q9]

The spacecraft *Juno* has been put into orbit around Jupiter. The table below contains information about the planet Jupiter and the spacecraft Juno. The graph below shows gravitational field strength (N kg^{-1}) as a function of distance from the centre of Jupiter.

Data

mass of Jupiter	1.90×10^{27} kg
radius of Jupiter	7.00×10^{7} m
mass of spacecraft *Juno*	1500 kg



a. Calculate the gravitational force acting on Juno by Jupiter when Juno is at a distance of 2.0×10^8 m from the centre of Jupiter. Show your working.

(2 marks)

b. Use the graph on the previous page to estimate the magnitude of the change in gravitational potential energy of the spacecraft Juno as it moves from a distance of 2.0×10^8 m to a distance of 1.0×10^8 m from the centre of Jupiter. Show your working.

(3 marks)

c. Europa is a moon of Jupiter. It has a circular orbit of radius 6.70×10^8 m around Jupiter. Calculate the period of Europa's orbit. Show your working.

(3 marks)

Question 23/ 56

[VCAA 2019 NHT SB Q10]

A spacecraft with astronauts on board is in orbit around Mars at an altitude of 1.6×10^6 m above the surface of Mars. The mass of Mars is 6.4×10^{23} kg and its radius is 3.4×10^6 m. Take the universal gravitational constant, *G*, to be 6.7×10^{-11} N m^2 k g^{-2}. The mass of the spacecraft is 2.0×10^4 kg.

a. Calculate the period of orbit of the spacecraft around Mars. Show your working.

(4 marks)

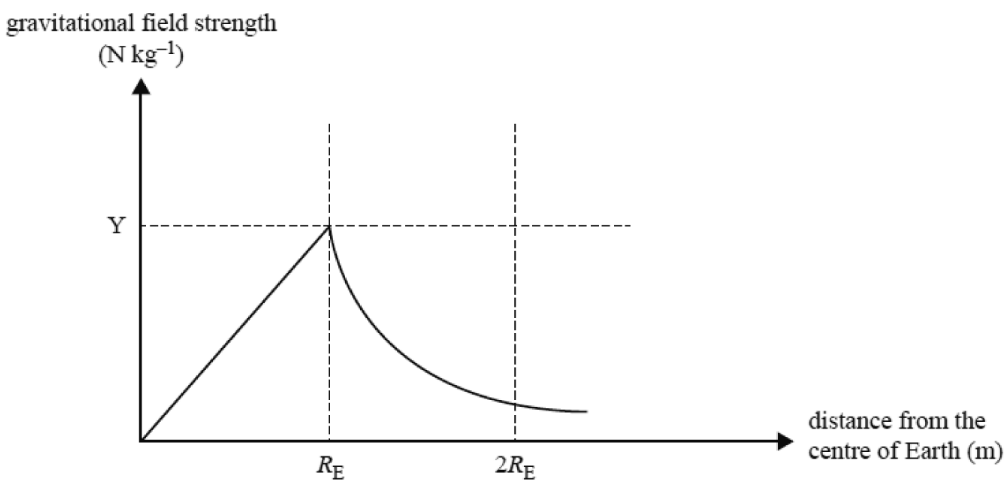
b. The altitude of the spacecraft above the surface of Mars is doubled so that the spacecraft is now in a new stable orbit. Will the speed of the spacecraft be greater, the same or lower in this new orbit? Explain your reasoning.

(2 marks)

Question 24/ 56

[VCAA 2019 SB Q4]

Assume that a journey from approximately 2 Earth radii ($2R_E$) down to the centre of Earth is possible. The radius of Earth (R_E) is 6.37×10^6 m. Assume that Earth is a sphere of constant density. A graph of gravitational field strength versus distance from the centre of Earth is shown below.



a. What is the numerical value of Y?

(1 mark)

b. Explain why the gravitational field strength is 0 N kg^{-1} at the centre of Earth.

(2 marks)

c. Calculate the increase in potential energy for a 75 kg person hypothetically moving from the centre of Earth to the surface of Earth. Show your working.

(2 marks)

Question 25/ 56

[VCAA 2019 SB Q5]

Navigation in vehicles or on mobile phones uses a network of global positioning system (GPS) satellites. The GPS consists of 31 satellites that orbit Earth. In December 2018, one satellite of mass 2270 kg, from the GPS Block IIIA series, was launched into a circular orbit at an altitude of 20 000 km above Earth's surface.

a Identify the type(s) of force(s) acting on the satellite and the direction(s) in which the force(s) must act to keep the satellite orbiting Earth.

(2 marks)

b Calculate the period of the satellite to three significant figures. You may use data from the table below in your calculations. Show your working.

(3 marks)

Data

mass of satellite	2.27×10^3 kg
mass of Earth	5.98×10^{24} kg
radius of Earth	6.37×10^6 m
altitude of satellite above Earth's surface	2.00×10^7 m
gravitational constant	6.67×10^{-11} N m^2 kg^{-2}

Question 26/ 56

[VCAA 2020 SB Q4]

The Ionospheric Connection Explorer (ICON) space weather satellite, constructed to study Earth's ionosphere, was launched in October 2019. ICON will study the link between space weather and Earth's weather at its orbital altitude of 600 km above Earth's surface. Assume that ICON's orbit is a circular orbit. Use $R_E = 6.37 \times 10^6$ m.

a. Calculate the orbital radius of the ICON satellite.

(1 mark)

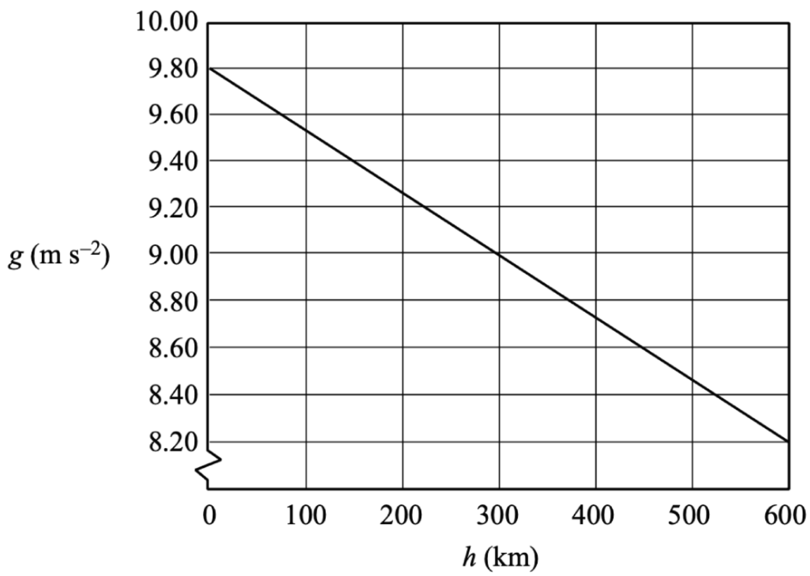
b. Calculate the orbital period of the ICON satellite correct to three significant figures. Show your working.

(4 marks)

c. Explain how the ICON satellite maintains a stable circular orbit without the use of propulsion engines.

(2 marks)

d. The graph on the next page shows the strength of Earth's gravitational field, *g*, as a function of orbital altitude, *h*, above the surface of Earth.



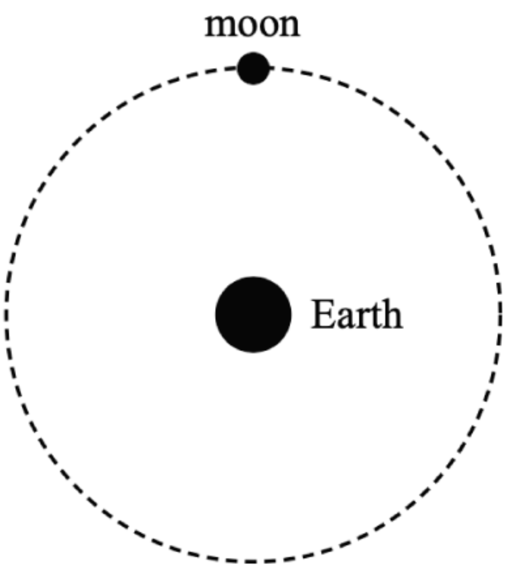
Determine the change in gravitational potential energy of the ICON satellite as it travels from Earth's surface to its orbital altitude of 600 km above Earth's surface. The mass of the ICON satellite is 288 kg.

(3 marks)

Question 27/ 56

[VCAA 2021 NHT SB Q3]

The motion of Earth's moon can be modelled as a circular orbit around Earth, as shown below.



Data:

mass of Earth	5.98×10^{24} kg
mass of the moon	7.35×10^{22} kg
radius of the moon's orbit around Earth	3.84×10^{8} m
universal gravitational constant (G)	6.67×10^{-11} N m^2 kg^{-2}

a. Calculate the magnitude of the gravitational force that Earth exerts on the orbiting moon. Give your answer correct to three significant figures. Show your working.

(3 marks)

b. The average orbital period of Earth's moon is 27.32 days. The moon is moving slightly further away from Earth at an average rate of 4 cm per year. Given this information, will the average orbital period of Earth's moon decrease, stay the same or increase? Explain your answer.

(3 marks)

Question 28/ 56

[VCAA 2021 SB Q3]

To calculate the mass of distant pulsars, physicists use Newton's law of universal gravitation and the equations of circular motion. The planet Phobetor orbits pulsar PSR $\mathrm{B}1257+12$ at an orbital radius of $6.9 \times 10^{10}\ \mathrm{m}$ and with a period of $8.47 \times 10^{6}\ \mathrm{s}$. Assuming that Phobetor follows a circular orbit, calculate the mass of the pulsar.

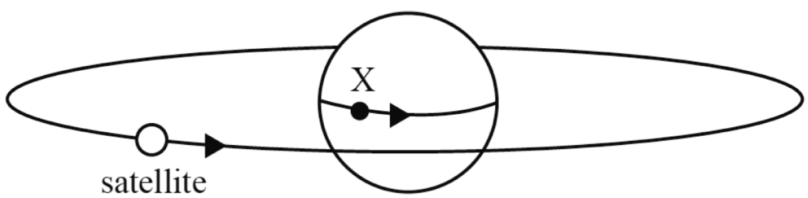
Show all your working.

(3 marks)

Question 29/ 56

[VCAA 2022 SB Q2]

There are over 400 geostationary satellites above Earth in circular orbits. The period of orbit is one day (86 400 s). Each geostationary satellite remains stationary in relation to a fixed point on the equator. The diagram below shows an example of a geostationary satellite that is in orbit relative to a fixed point, X, on the equator.



a. Explain why geostationary satellites must be vertically above the equator to remain stationary relative to Earth's surface.

(2 marks)

b. Using $G = 6.67 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}$, $M_{\mathrm{E}} = 5.98 \times 10^{24}\ \mathrm{kg}$ and $R_{\mathrm{E}} = 6.37 \times 10^{6}\ \mathrm{m}$, show that the altitude of a geostationary satellite must be equal to $3.59 \times 10^{7}\ \mathrm{m}$.

(4 marks)

c. Calculate the speed of an orbiting geostationary satellite.

(3 marks)

Question 30/ 56

[VCAA NHT 2023 SB Q5]

The diagram below shows the sun, the moon and Earth.

The mass of the sun is approximately 3.3×10^5 times the mass of Earth.

The distance from the sun to the moon is approximately 390 times the distance from Earth to the moon.

Missing Image

Calculate $\frac{\text{magnitude of the sun's gravitational force on the moon}}{\text{magnitude of Earth's gravitational force on the moon}}$.

(3 marks)

Question 31/ 56

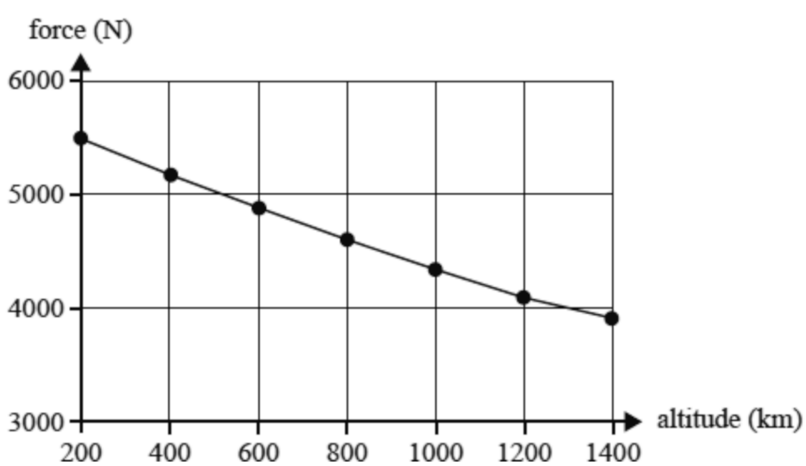
[VCAA NHT 2023 SB Q6]

Measuring very small changes in Earth's surface mass, the 600 kg satellite GRACE-FO1 is in a circular orbit around Earth at an altitude of 500 km. The radius of Earth is 6.37×10^6 m.

a. Calculate the magnitude and direction of the satellite's centripetal acceleration. Give your answer correct to three significant figures.

(3 marks)

b. The diagram below shows a graph of the gravitational force that would act on GRACE-FO1 for a range of altitudes.



Estimate the energy required to lift the satellite from its present orbit at an altitude of 500 km to a new orbit at an altitude of 1400 km.

(2 marks)

Question 32/ 56

[VCAA 2023 SB Q2]

Phobos is a small moon in a circular orbit around Mars at an altitude of 6000 km above the surface of Mars. The gravitational field strength of Mars at its surface is 3.72 N kg^{-1}. The radius of Mars is 3390 km.

a. Show that the gravitational field strength 6000 km above the surface of Mars has a value of 0.48 N kg^{-1} .

(2 marks)

b. Calculate the orbital period of Phobos. Give your answer in seconds.

(3 marks)

c. Phobos is very slowly getting closer to Mars as it orbits.

Will the orbital period of Phobos become shorter, stay the same or become longer as it orbits closer to Mars? Explain your reasoning.

(2 marks)

Chapter 9 Electric fields

Question 1/ 25

Two equal positive isolated electric charges separated by a distance *d* and exert a force *F* on each other. To decrease the force to *F*/3, the distance would have to increase to

A 3*d*

B $\sqrt{3}d$

C $9d$

D $\frac{d}{3}$

Question 2/ 25

Two equal positive isolated electric charges of value q are separated by a distance d and exert a force F on each other. One of the charges is increased to $2q$; the other is increased to $3q$. The force will change to

A $6F$

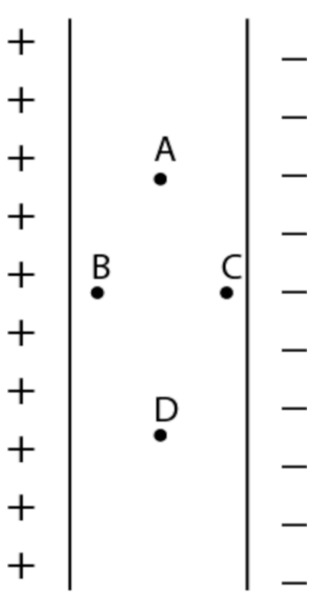
B $3F$

C $2F$

D $3\frac{F}{2}$

Question 3/ 25

A uniform electric field can be produced by two large parallel conducting plates with a small spacing between them, as shown in the diagram below. Points A and D are midway between the plates.



The direction of the field between the plates at points A, B, C and D is best described as

A towards the right at all points.

B towards the left at all points.

C zero at points A and D, but towards the right at B and C.

D zero at points A and D; towards the left at B and towards the right at C.

Question 4/ 25

The potential energy of a negative charge would

A increase as charge moves from B to C.

B decrease as charge moves from B to C.

C decrease as charge moves from A to D.

D increase as charge moves from A to D.

Question 5/ 25

The size of the electrostatic force acting on a small negative charge at each of the points A, B, C and D can be described as

A largest at B, zero at A and D, and smallest at C.

B largest at C, zero at A and D, and smallest at B.

C largest at B, equal at A and D, and smallest at C.

D equal at all four points.

Question 6/ 25

The direction of the electrostatic force acting on a small positive charge at each of the points A, B, C and D can be described as

A to the right at B, zero at A and D, and to the left at C.

B to the right at C, zero at A and D, and to the left at B.

C to the right at all four points.

D to the left at all four points.

Question 7/ 25

Two large parallel conducting plates are separated by 15 cm. A potential difference of 225 V is applied across the plates. Which of the following best describes the electric field in the space between the plates?

A There is a uniform field of 1500 V m^{-1} from the $+$ plate to the $-$ plate.

B There is a uniform field of 1500 V m^{-1} from the $-$ plate to the $+$ plate.

C There is a uniform field of 15 V m^{-1} from the $+$ plate to the $-$ plate.

D There is a uniform field of 15 V m^{-1} from the $-$ plate to the $+$ plate.

Question 8/ 25

An alpha particle ($\text{charge} = +3.2 \times 10^{-19}\text{C}, \text{mass} = 6.6 \times 10^{-27} \text{ kg}$) is placed midway between the plates. Which of the following best describes the force on the particle?

A There is a force of 7.2×10^{-17} N towards the $-$ plate.

B There is a force of 7.2×10^{-17} N towards the $+$ plate.

C There is a force of 4.8×10^{-16} N towards the $-$ plate.

D There is a force of 4.8×10^{-16} N towards the + plate.

Question 9/ 25

The magnitude of the acceleration of the alpha particle described in the previous two questions is closest to

A $1.1 \times 10^{10}\ \mathrm{m\ s^{-2}}$

B $7.3 \times 10^{10}\ \mathrm{m\ s^{-2}}$

C $1.4 \times 10^{-19}\ \mathrm{m\ s^{-2}}$

D $3.0 \times 10^{8}\ \mathrm{m\ s^{-2}}$

Question 10/ 25

If a stationary alpha particle were placed at the positive plate, it would

A remain there, as it is a position of minimum potential energy.

B move at a constant speed of $1500\ \mathrm{m\ s^{-1}}$ towards the negative plate.

C move towards the negative plate and gain $7.2 \times 10^{-17}\mathrm{J}$ of kinetic energy.

D oscillate about the midpoint, with a kinetic energy of $7.2 \times 10^{-17}\mathrm{J}$.

Question 11/ 25

Electrons are accelerated from rest in an electron gun by a potential difference of 50 kV. What is their final speed? (Ignore relativistic effects.)

A $1.0 \times 10^5 \mathrm{~m~s^{-1}}$

B $4.7 \times 10^7 \mathrm{~m~s^{-1}}$

C $1.3 \times 10^8 \mathrm{~m~s^{-1}}$

D $2.9 \times 10^8 \mathrm{~m~s^{-1}}$

Question 12/ 25

[VCAA 2017 SA Q2]

Millikan, a famous scientist, measured the size of the electron charge by balancing an upwards electric force with a gravitational force on a small oil drop. In a repeat of this experiment, an oil drop with a charge of 9.6×10^{-19} C was placed in an electric field of $10^4 \mathrm{~V~m^{-1}}$. Which one of the following is closest to the electrical force on the oil drop?

A 9.6×10^{-14} N

B 9.6×10^{-15} N

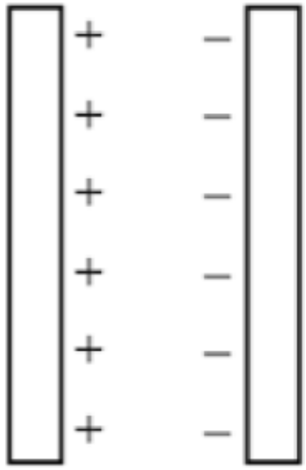
C 9.6×10^{-22} N

D 9.6×10^{-23} N

Question 13/ 25

[VCAA 2017 SA Q3]

Two large charged plates with equal and opposite charges are placed close together, as shown in the diagram below. A distance of 5.0 mm separates the plates. The electric field between the plates is equal to $1000 \mathrm{~N~C^{-1}}$.



Which one of the following is closest to the voltage difference between the plates?

A 5.0 V

B 200 V

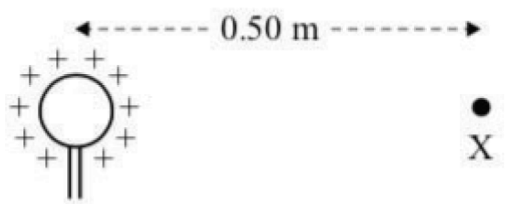
C 5000 V

D 5 000 000 V

Question 14/ 25

[Adapted VCAA 2018 NHT SA Q3]

A Van de Graaff generator, a piece of electric field demonstration equipment, consists of a small electrically charged sphere, as shown in the diagram.



A Van de Graaff generator has a sphere with a charge of 5.0×10^{-7} coulombs on it. Take the Coulomb's law constant as $k = 9.0 \times 10^{9}\ \mathrm{N\ m^2\ C^{-2}}$. Which one of the following best gives the magnitude of the electric field at point X in the diagram above, 0.50 m from the sphere?

A $1.8 \times 10^{-2}\ \mathrm{V\ m^{-1}}$

B $3.6 \times 10^{-2}\ \mathrm{V\ m^{-1}}$

C $1.8 \times 10^4\ \mathrm{V\ m^{-1}}$

D $3.6 \times 10^4\ \mathrm{V\ m^{-1}}$

Question 15/ 25

An electron is accelerated to a speed of $3.0 \times 10^7\ \mathrm{m\ s^{-1}}$ in a vacuum by a voltage *V*.

Which of the following is closest to the value of *V*? (Ignore relativistic effects.)

A 250 V

B 2500 V

C 25 000 V

D 250 000 V

Question 16/ 25

[Adapted VCAA 2017 Sample SA Q5]

A small sphere with a charge of $+1.0 \times 10^{-9}$ C is placed 30 cm from a metal sphere with a charge of $+1.0 \times 10^{-8}$ C on it. Both act as point charges. Which of the following best gives the magnitude of the force between the spheres? Take $k = 9.0 \times 10^9\ \mathrm{N\ m^2 C^{-2}}$.

A $1.1 \times 10^{-14}\ \mathrm{N}$

B $1.0 \times 10^{-6}\ \mathrm{N}$

C $3.0 \times 10^{-6}\ \mathrm{N}$

D $3.0 \times 10^{-5}\ \mathrm{N}$

Question 17/ 25

[VCAA 2018 SA Q4]

A small sphere has a charge of $2.0 \times 10^{-6}\mathrm{C}$. Take $k = 8.99 \times 10^{9}\ \mathrm{N\ m^{2}\ C^{-2}}$. The strength of the electric field due to this charge at a point 3.0 m from the sphere is best given by

A $2.9 \times 10^{-3}\ \mathrm{V\ m^{-1}}$

B $6.0 \times 10^{-3}\ \mathrm{V\ m^{-1}}$

C $9.0 \times 10^{-3}\ \mathrm{V\ m^{-1}}$

D $2.0 \times 10^{3}\ \mathrm{V\ m^{-1}}$

Question 18/ 25

[VCAA 2019 SA Q2]

The electric field between two parallel plates that are $1.0 \times 10^{-2}\mathrm{m}$ apart is $2.0 \times 10^{-4}\ \mathrm{N\ C^{-1}}$. Which one of the following is closest to the voltage between the plates?

A $2.0 \times 10^{-8}\ \mathrm{V}$

B $2.0 \times 10^{-6}\ \mathrm{V}$

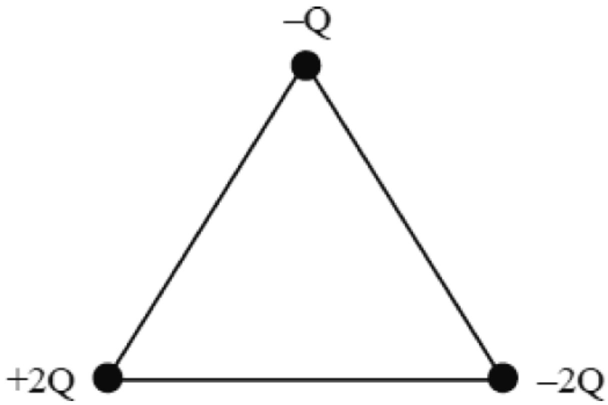
C $2.0 \times 10^{-4}\ \mathrm{V}$

D $1.0 \times 10^{-2}\ \mathrm{V}$

Question 19/ 25

[VCAA 2019 SA Q3]

Three charges $(-Q,\ +2Q,\ -2Q)$ are placed at the vertices of an isosceles triangle, as shown below.



Which one of the following arrows best represents the direction of the net force on the charge $-Q$?

A 

B 

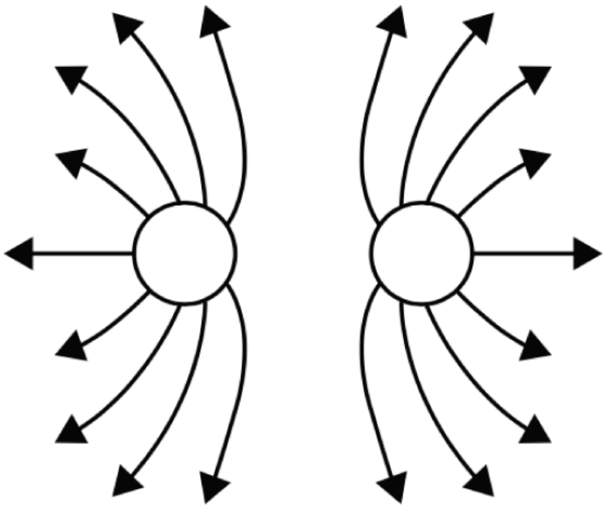

C


D

Question 20/ 25

[VCAA 2020 SA Q1]

The diagram below shows the electric field lines between two charges of equal magnitude.



The best description of the two charges is that the

A charges are both positive.

B charges are both negative.

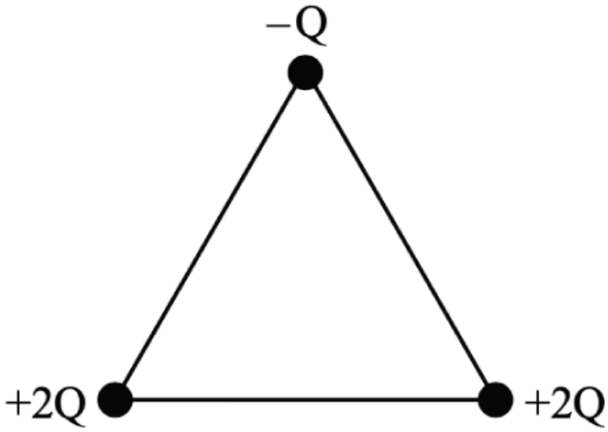
C charges can be either both positive or both negative.

D left-hand charge is positive and the right-hand charge is negative.

Question 21/ 25

[VCAA 2021 SA Q2]

Three charges, $-Q$, $+2Q$ and $+2Q$, are placed at the vertices of an equilateral triangle, as shown below.



Which one of the following arrows best represents the direction of the net force on the charge $-Q$?


A


B

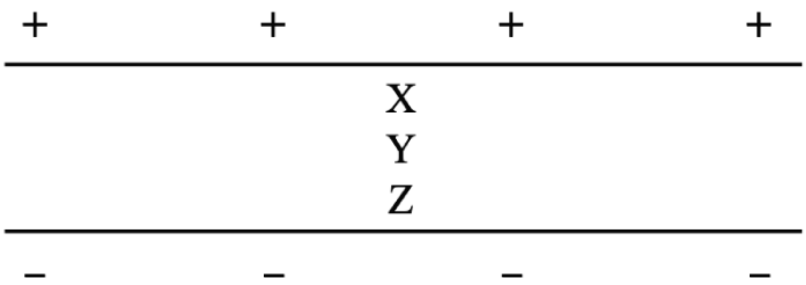

C


D

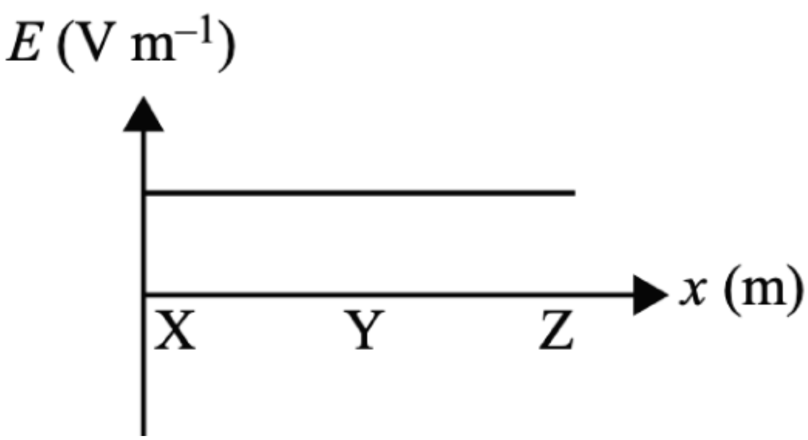
Question 22/ 25

[VCAA 2021 SA Q3]

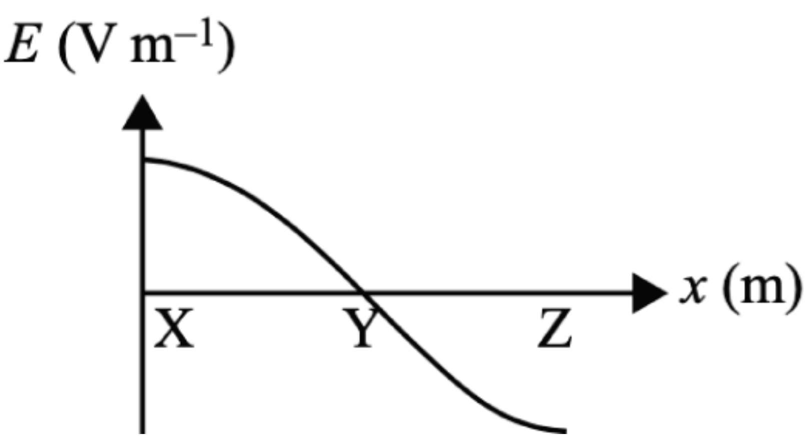
The diagram below shows two parallel metal plates with opposite charges on each plate. X, Y and Z represent different distances from the positive plate.



Which one of the graphs below best shows the electric field strength, *E*, versus the position, x, between the two parallel plates?

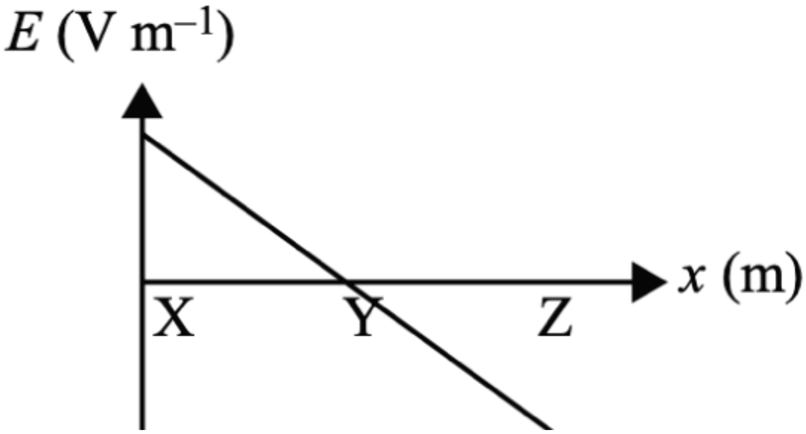


A

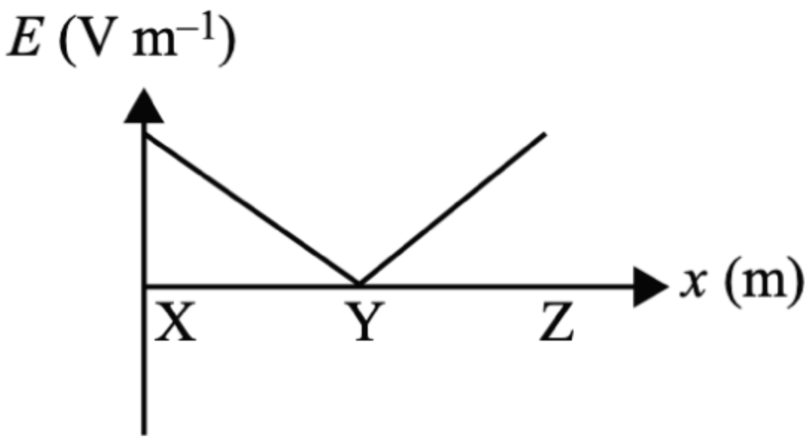


B

C



D



Question 23/ 25

[VCAA 2022 NHT SA Q1]

Two parallel plates that are 10 mm apart have a potential difference of 5.0 kV between them. Which one of the following best gives the strength of the electric field between the plates?

A 5.0×10^{-1} V m^{-1}

B 5.0×10^{1} V m^{-1}

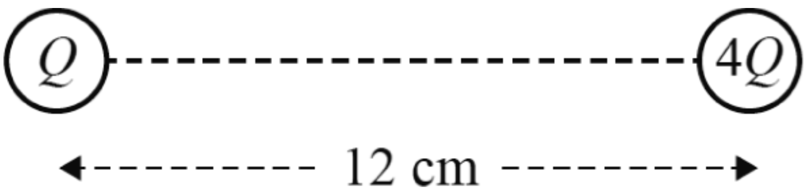
C 5.0×10^{2} V m^{-1}

D 5.0×10^{5} V m^{-1}

Question 24/ 25

[VCAA 2022 SA Q4]

Two point charges, *Q* and 4*Q*, are placed 12 cm apart, as shown in the diagram below.



On the straight line between the charges *Q* and 4*Q*, the electric field is

A non-zero everywhere.

B zero at a point 2.4 cm from *Q*.

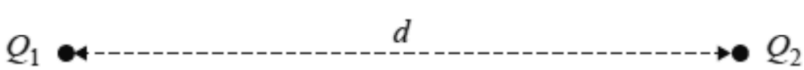
C zero at a point 3 cm from *Q*.

D zero at a point 4 cm from *Q*.

Question 25/ 25

[VCAA 2023 SA Q2]

The diagram below shows two charges, Q_1 and Q_2, separated by a distance, *d*.



There is a force, *F*, acting between the two charges.

Which one of the following is closest to the magnitude of the force acting between the two charges if both d and the charge on Q_1 are halved?

A *F*/4

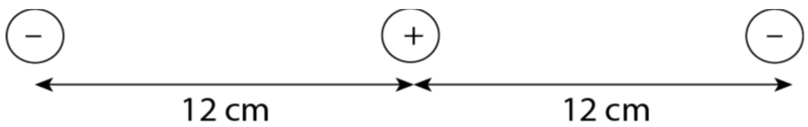
B *F*

C 2*F*

D 4*F*

Question 1/ 46

Three point charges, each of 6 μC, are separated along a line, as shown in the diagram.



a. Sketch the shape of the electric field in the vicinity of these three charges, using field lines. There should be at least four lines starting or finishing on each of the charges.

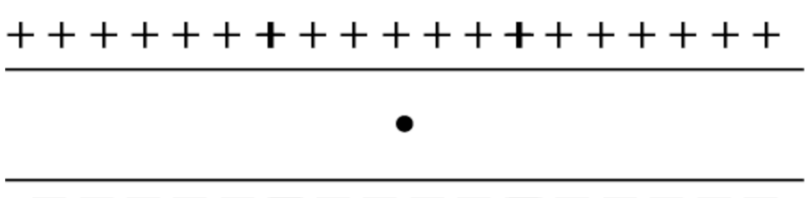
(3 marks)

b. The two left-hand charges are secured in place. Calculate the force acting on the right-hand charge, giving its direction. Show your working.

(3 marks)

Question 2/ 46

A tiny charged oil drop is suspended by the electric field midway between two large parallel plates, as shown in the diagram below.



a. State the sign of the charge on the oil drop.

(1 mark)

b. The electric field has strength 10000 V m^{-1} and the charge on the particle is 3.2×10^{-12} C. Calculate the mass of the charged particle. Show your working.

(3 marks)

c. One student (Amy) discussing the experiment suggests that if the particle were closer to either plate, the particle would accelerate upwards. Her friend (Xu) disagrees and says that the particle would still remain suspended. Evaluate these two responses.

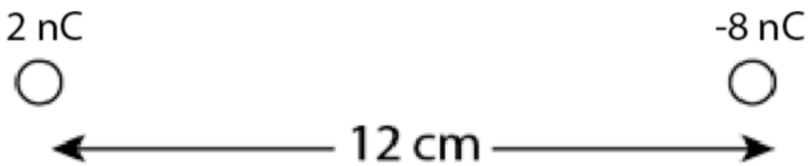
(3 marks)

d. The distance between the plates in 2.0 cm. Calculate the potential difference between the two plates.

(2 marks)

Question 3/ 46

Two point charges, of $+2\ \mathrm{nC}$ and $-8\ \mathrm{nC}$, are placed 12 cm apart as shown in the diagram below.



a. Calculate the strength of the electric field at a point exactly midway between the two charges. Show your working.

(3 marks)

b. Describe the direction of the electric field at this point.

(1 mark)

c. There is a point *x* cm to the *left* of the $+2\ \mathrm{nC}$ charge where the electric field is zero. Show that this point is given by $x = 12\ \mathrm{cm}$.

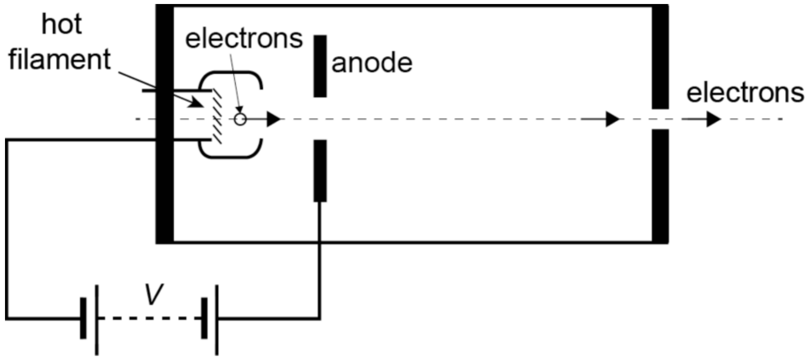
(3 marks)

d. If the charges were moved towards each other, would the total potential energy increase, decrease or remain the same? Explain.

(3 marks)

Question 4/ 46

A schematic diagram of the injector into a synchrotron is shown below.



The electrons are emitted from the hot filament at very low speeds and can be considered to be at rest. The electric field between the anode and the filament can be considered uniform. The space between the anode and the filament is 4.0 cm. (Relativistic effects can be ignored in this question.)

a. If the accelerating voltage between the anode and the filament is 2500 V, calculate the speed of the electrons as the reach the anode.

(2 marks)

b. Calculate the size of the electric field acting on the electrons when they are emitted from the filament.

(1 mark)

c. Calculate the acceleration of the electrons between the filament and the anode.

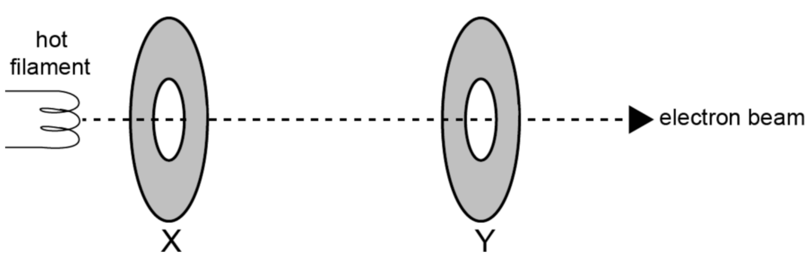
(2 marks)

d. A scientist proposes increasing the distance between the anode and the filament but leaving the accelerating voltage unchanged. Discuss the effect on the electrostatic force on the electrons, their acceleration, and their speed as they reach the anode.

(3 marks)

Question 5/ 46

The diagram below shows part of a linear electron accelerator.



The electrons pass through plate X with a speed of $5.0 \times 10^6 \text{ m s}^{-1}$. They reach plate Y with a speed of $1.0 \times 10^7 \text{ m s}^{-1}$.

a. Calculate the magnitude of the potential difference between plates X and Y.

(2 marks)

b. If the distance between plates X and Y is 1.5 mm, and the electric field is uniform, calculate the magnitude of the field in this region.

(2 marks)

Question 6/ 46

In an electrostatic paint sprayer, droplets of paint are accelerated by an electric field onto the paint target. In one application, the droplets have a mass of 5.0 mg and each are given a kinetic energy of 15 J. The accelerating field is uniform and covers a distance of 1.2 cm. The charge on the droplets is 3.2×10^{-5} C.

a. Calculate the strength of the electric field acting on the paint droplets.

(2 marks)

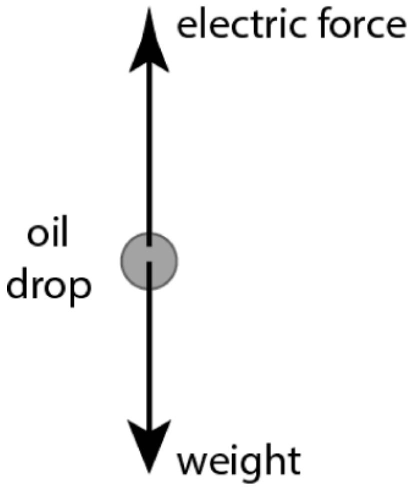
b. Calculate the accelerating voltage involved.

(2 marks)

Question 7/ 46

In a variation of Millikan's famous experiment to determine the quantum of charge (the charge on a single electron), a charged oil drop is held stationary against gravity in an electric field.

A drop of mass 1.6×10^{-6} kg is held stationary by an electric field of $1.0 \times 10^{12} \text{ V m}^{-1}$, directed downwards.



a. State whether the oil drop has excess electrons or a shortage of electrons, giving a reason for your answer.

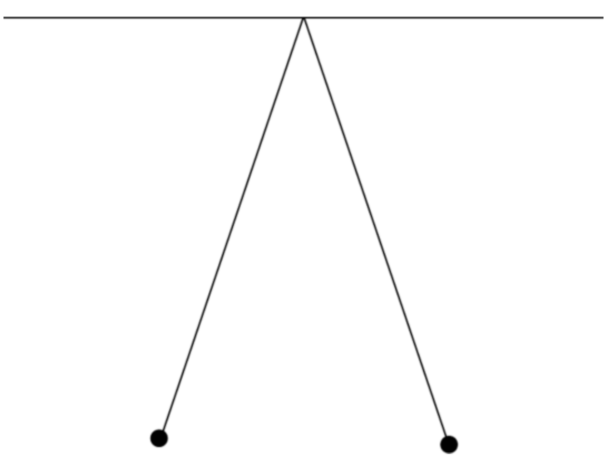
(2 marks)

b. Calculate the number of excess or shortage of electrons on the oil drop.

(3 marks)

Question 8/ 46

Students are conducting an experiment with two equally charged particles suspended on insulating strings, as shown in the diagram below. There is a tension, *T*, acting in each string.



a. Sketch the direction of the two electrostatic forces acting as arrows attached to the particles.

(1 mark)

b. The angle between the two strings is equal to 30°. If the mass of each particle is 0.5 mg, calculate the tension in each string. Show your working.

(3 marks)

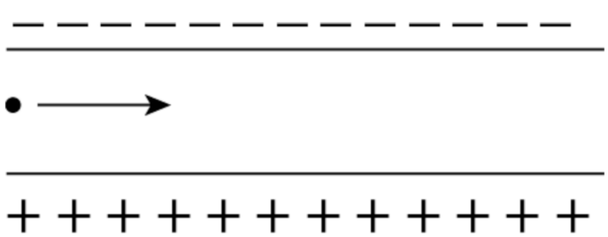
c. Show that the size of the electrostatic force, F_E, on each particle is given by $F_E = T \sin 15$.

Show your reasoning clearly and in detail.

(3 marks)

Question 9/ 46

An electron is fired between two charged parallel plates, as shown in the diagram below. The electron is travelling horizontally to the right with a speed of 5.0×10^6 m s^{-1}.



a. Calculate the kinetic energy of the electron in eV to two significant figures.

(2 marks)

b. The voltage across the two plates is 5000 V; their spacing is 0.25 cm. State the magnitude and direction of the electric field between the plates.

(2 marks)

c. Calculate the magnitude of the acceleration of the electrons when they are between the plates.

(2 marks)

d. Describe (in words) the direction of the acceleration of the electrons while they are between the plates.

(1 mark)

Question 10/ 46

[Adapted VCAA 2016 SB Q2]

In the electron gun of a synchrotron, electrons are accelerated from rest to reach a final speed of $8.0 \times 10^7 \text{ m s}^{-1}$. Ignore relativistic effects.

a. Calculate the electron gun accelerating voltage in kilovolts.

(2 marks)

A magnetic field of $4.0 \times 10^{-4} \text{ T}$ causes these electrons to turn through a part of a circle.

b. Calculate the radius of the circle.

(2 marks)

c. Calculate the magnitude of the force acting on these electrons.

(2 marks)

Question 11/ 46

[Adapted VCAA 2017 SB Q2]

According to one model of the atom, the electron in the ground state of a hydrogen atom moves around the stationary proton in a circular orbit with a radius of 53 pm $(53 \times 10^{-12} \text{ m})$. Show that the magnitude of the force acting between the proton and the electron at this separation equals $8.2 \times 10^{-8} \text{ N}$. Take $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$ and the magnitude of the electron and proton charges as $1.6 \times 10^{-19} \text{ C}$. Show all the steps of your working.

(2 marks)

Question 12/ 46

[VCAA 2018 NHT SB Q2]

The electron gun of a particle accelerator accelerates electrons between two plates that are 10 cm apart and have a potential difference of 5000 V between them.

DATA

mass of electron	9.1×10^{-31} kg
charge on electron	-1.6×10^{-19} C

a. Calculate the magnitude of the electric field between the plates. Include an appropriate unit.

(2 marks)

b. Calculate the magnitude of the force on an electron between the plates.

(2 marks)

c. Calculate the speed of the electrons as they exit the electron gun. Ignore relativistic effects. Assume that the initial speed of the electrons is zero.

(2 marks)

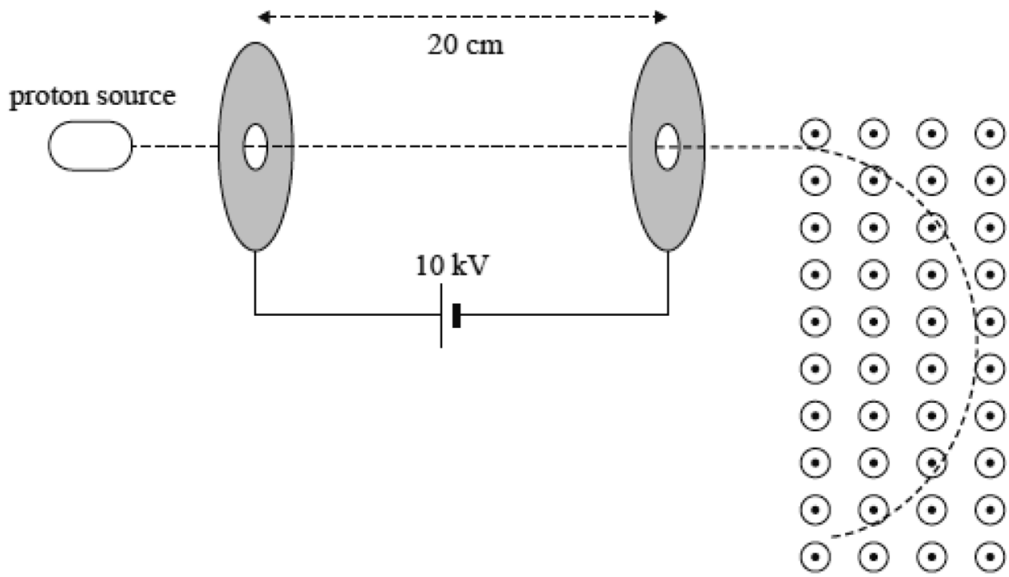
Question 13/ 46

[Adapted VCAA 2018 SB Q1]

An electric field accelerates a proton between two plates. The proton exits into a region of uniform magnetic field at right angles to its path, directed out of the page, as shown on the next page.

Data

mass of proton	1.7×10^{-27} kg
charge on proton	$+1.6 \times 10^{-19}$ C
accelerating voltage	10 kV
distance between plates	20 cm
strength of magnetic field	2.0×10^{-2} T



a. Calculate the strength of the electric field between the plates.

(1 mark)

b. Calculate the speed of the proton as it leaves the electric field. Show your working.

(2 marks)

Question 14/ 46

[VCAA 2019 SB Q2]

The diagram below shows two equal positive stationary charges placed near each other.

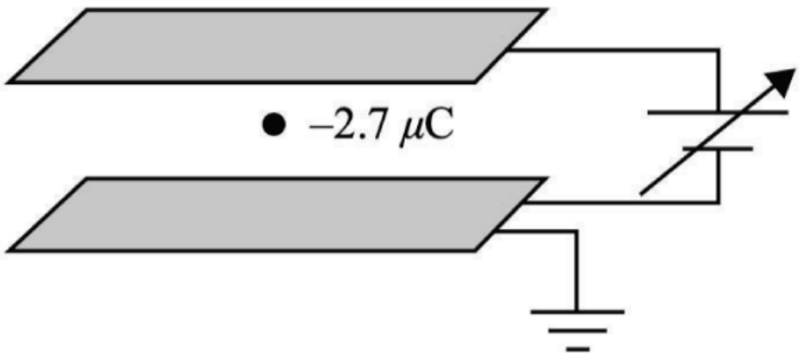
Sketch on the diagram the shape and direction of the electric field lines. Use at least *eight* field lines.

(2 marks)

Question 15/ 46

[VCAA 2021 NHT SB Q1]

A small sphere carrying a charge of $-2.7\mu\mathrm{C}$ is placed between charged parallel plates, as shown below. The potential difference between the plates is set at 15.5 V, which just holds the sphere stationary. The electric field between the plates is uniform.



a. In which direction (up, down, right, left) will the sphere move if the voltage is increased?

(1 mark)

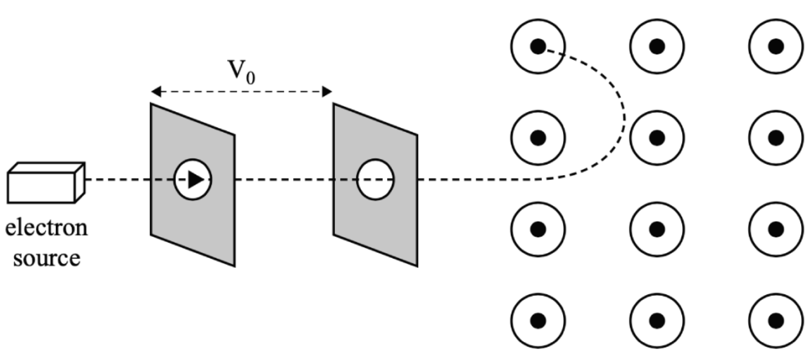
b. Calculate the value of the electric force that is holding the sphere stationary if the plates are 2.0 mm apart. Show your working.

(2 marks)

Question 16/ 46

[Adapted VCAA 2021 NHT SB Q2]

An electron is accelerated from rest by a potential difference of V_0. It emerges at a speed of $2.0 \times 10^7\ \mathrm{m\ s^{-1}}$ into a magnetic field.



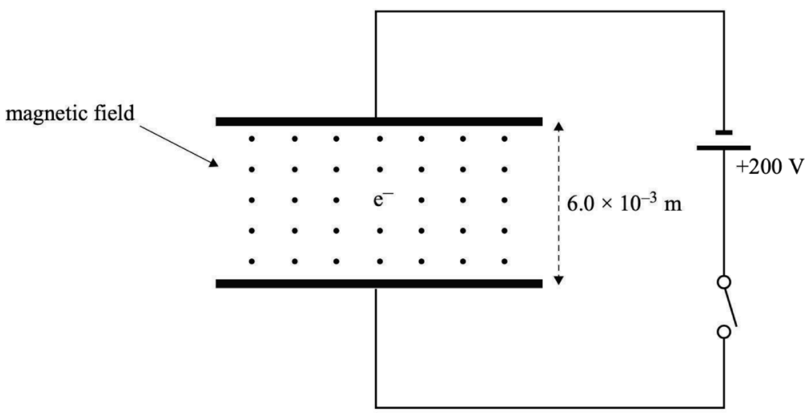
Calculate the value of the accelerating voltage, V_0. Show your working.

(3 marks)

Question 17/ 46

[Adapted VCAA 2021 SB Q5]

The diagram following shows a stationary electron $(\mathrm{e}-)$ in a uniform magnetic field between two parallel plates. The plates are separated by a distance of 6.0×10^{-3} m, and they are connected to a 200 V power supply and a switch. Initially, the plates are uncharged. Assume that gravitational effects on the electron are negligible.



The switch is closed. Determine the magnitude and the direction of any electric force now acting on the electron. Show your working.

(3 marks)

Question 18/ 46

[VCAA 2022 NHT SB Q1]

A particle with mass *m* and charge *q* is accelerated from rest by a potential difference, *V*. The only force acting on the particle is due to the electric field associated with this potential difference.

a. Show that the speed of the particle is given by $v = \sqrt{\frac{2qV}{m}}$ and state the principle of physics used in your answer.

(2 marks)

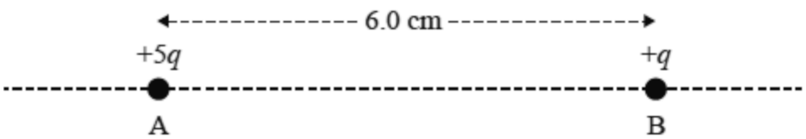
b. Calculate the speed of an electron accelerated from rest by a potential difference of 200 V.

(2 marks)

Question 19/ 46

[VCAA 2023 NHT SB Q1]

Two small charges, A and B, are placed 6.0 cm apart in a straight line, as shown below.



Charge A has a magnitude of $+5q$ coulombs and charge B has a magnitude of $+q$ coulombs.

If the force exerted by charge A on charge B is 5.1×10^{-24} N to the right, determine the value of q.

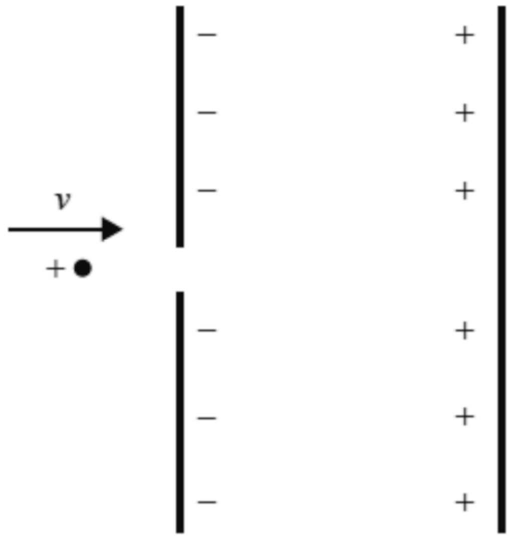
(3 marks)

Question 20/ 46

[VCAA 2023 NHT SB Q2]

A positively charged particle carrying a charge of $+1.5 \times 10^{-8}$ C enters a region between two large, charged plates with opposite charges, as shown below.

The potential difference between the plates is 2.0 kV, and the kinetic energy of the charged particle as it enters the hole is 2.8×10^{-5} J. Ignore gravitational effects and air resistance.



Ariel and Jamie discuss what they think will happen to the particle after it enters the region between the two equally but oppositely charged plates.

Ariel says that the particle has insufficient kinetic energy to reach the positively charged plate and will travel part of the way before returning towards the negatively charged plate.

Jamie says that the particle will collide with the positively charged plate and then head back towards the negatively charged plate.

Evaluate Ariel and Jamie's statements, giving clear reasons for your answer.

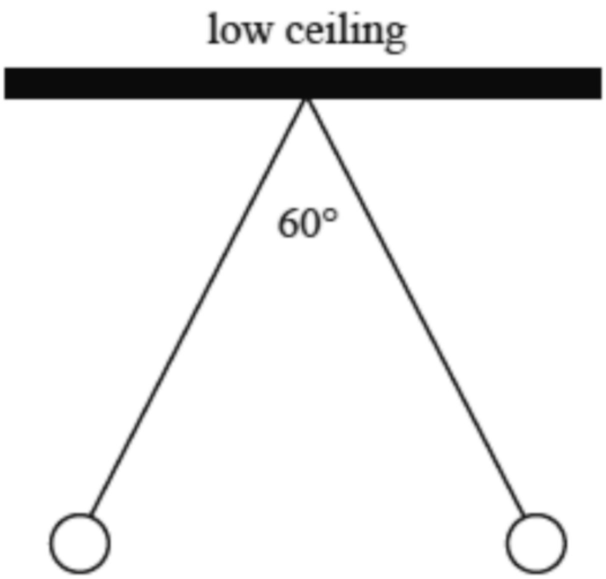
(3 marks)

Question 21/ 46

[VCAA 2023 SB Q1]

Some physics students are conducting an experiment investigating both electrostatic and gravitational forces. They suspend two equally charged balls, each of mass 4.0 g, from light, non-conducting strings suspended from a low ceiling.

The charged balls repel each other with the strings at an angle of 60°, as shown below.



There are three forces acting on each ball:

• a tension force, *T*

• a gravitational force, F_{g}

• an electrostatic force, F_{E}

a. On the diagram shown above, using the labels *T*, F_{g} and F_{E}, draw each of the three forces acting on each of the charged balls.

(2 marks)

b. Show that the tension force, *T*, in each string is 4.5×10^{-2} N. Use $\mathrm{g} = 9.8\ \mathrm{N\ kg^{-1}}$.

(2 marks)

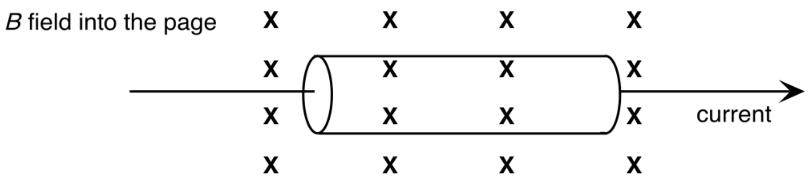
c. Calculate the magnitude of the electrostatic force, F_{E}**.**

(2 marks)

Chapter 10 Magnetic fields

Question 1/ 23

Electrons moving through a resistor experience a force if the resistor is in a magnetic field. A resistor is oriented east–west as shown, with Earth's magnetic field into the page. The current is to the right.



An electron travelling through the resistor will experience a force due to the magnetic field; the direction of the force will be

A up.

B down.

C into page.

D out of page.

Question 2/ 23

A vertical lightning conductor gets a 'bolt from the blue' – a discharge from thunderclouds above. This sends electrons in the conductor rushing downwards. Assume Earth's magnetic field is horizontal. In which direction does Earth's magnetic field push the lightning conductor?

A North

B South

C East

D West

Question 3/ 23

The Earth's magnetic field in Question 2 is horizontal and has a value of 2×10^{-5} T, and the lightning conductor is 2.5 m long; the current in the conductor is close to 200 000 A. The magnetic force is closest to

A 10 N

B 1.6 N

C 1.0×10^{-4} N

D 2.5×10^{-10} N

Question 4/ 23

During a severe storm, the lightning conductor is tipped over towards the north, so that it now makes an angle of 30° to the horizontal and is no longer at right angles to the magnetic field. Which of the following best describes the new magnetic force on the lightning conductor when a current of around 10^4 A flows through it?

A It is the same as before.

B It is greater than before.

C It is less than before, but not zero.

D There is now no magnetic force on the conductor.

Question 5/ 23

When a wire is pushed by a magnetic force perpendicular to the field, which of the following can you be sure about?

A A current is flowing in the wire.

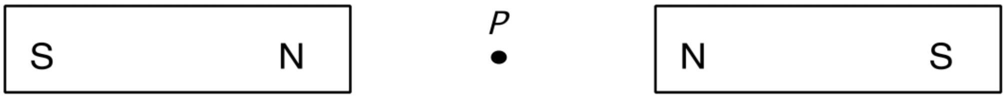
B The force *F* on the wire is given by the formula $F = BI$.

C The force on the wire is equal to the sum of all the magnetic forces on the protons inside the wire.

D The wire is in the same direction as the magnetic field.

Question 6/ 23

Jon is investigating fields produced by magnets as research for a model electric motor. One arrangement of magnets is shown. The magnets are identical; *P* is exactly midway between the two N poles.



Which of the following best describes the magnetic field at *P*?

A It is stronger than the field due to one magnet only.

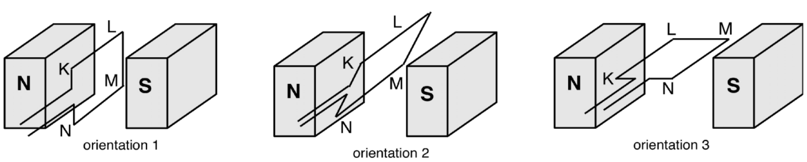
B It is about the same as the field due to one magnet only.

C It is weaker than the field due to one magnet only.

D It is close to zero.

Question 7/ 23

The figures below show a single turn loop of wire in a uniform magnetic field. The loop's position can be altered; three orientations are shown. In each case there is a current flowing in the coil from K to L to M to N.



Question 8/ 23

What is the direction of the force on the side KL in each of the three orientations?

A

Orientation 1 ***Orientation 2*** ***Orientation 3***

Orientation 1	***Orientation 2***	***Orientation 3***
up	up	zero

B

down down down

C

up down zero

D

up up up

Question 9/ 23

Is the force on side LM ever zero?

A In all three orientations

B In orientation number 1

C In orientation number 2

D In orientation number 3

Question 10/ 23

A group of students is considering how to create a magnetic monopole. Which one of the following is correct?

A Break a bar magnet in half.

B Pass a current through a long solenoid.

C Pass a current through a circular loop of wire.

D It is not known how to create a magnetic monopole.

Question 11/ 23

An electron is travelling in a circle of radius 1.0 cm at right angles to a magnetic field of 5 mT. Which of the following is closest to its speed?

A $10^5 \mathrm{~m~s}^{-1}$

B $10^6 \mathrm{~m~s}^{-1}$

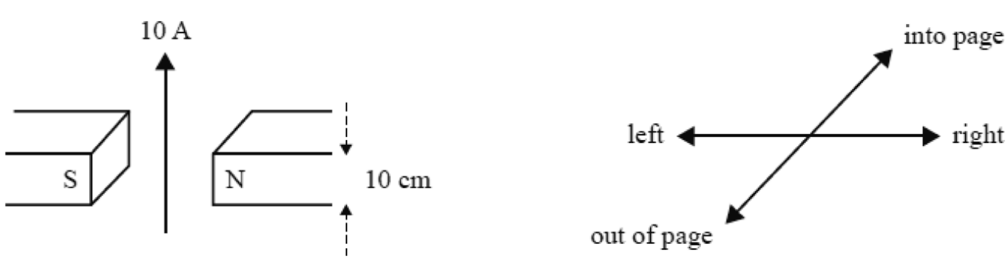
C $10^7 \mathrm{~m~s}^{-1}$

D $10^8 \mathrm{~m~s}^{-1}$

Question 12/ 23

[VCAA 2018 SA Q1]

A wire carrying a current of 10 A is placed in a uniform magnetic field of $B = 4.0 \times 10^{-4} \mathrm{~T}$, as shown below. 10 cm of the wire is in the field.



Which one of the following best gives the magnitude of the force acting on the wire?

A $4.0 \times 10^{-2} \mathrm{~N}$

B $4.0 \times 10^{-4} \mathrm{~N}$

C 1.6×10^{-8} N

D 4.0×10^{-12} N

Question 13/ 23

[VCAA 2018 SA Q2]

Which one of the following best gives the direction of the force acting on the wire?

A out of page

B into page

C right

D left

Question 14/ 23

A powerline carries a current of 1000 A DC in the direction east to west. At the point of measurement, Earth's magnetic field is horizontally north, and its strength is 5.0×10^{-5}T.

Question 15/ 23

[VCAA 2019 NHT SA Q2]

Which one of the following best gives the direction of the electromagnetic force on the powerline?

A horizontally west

B horizontally north

C vertically upwards

D vertically downwards

Question 16/ 23

[VCAA 2019 NHT SA Q3]

The magnitude of the force on each metre of the powerline is best given by

A 5.0×10^{3} N

B 5.0×10^{2} N

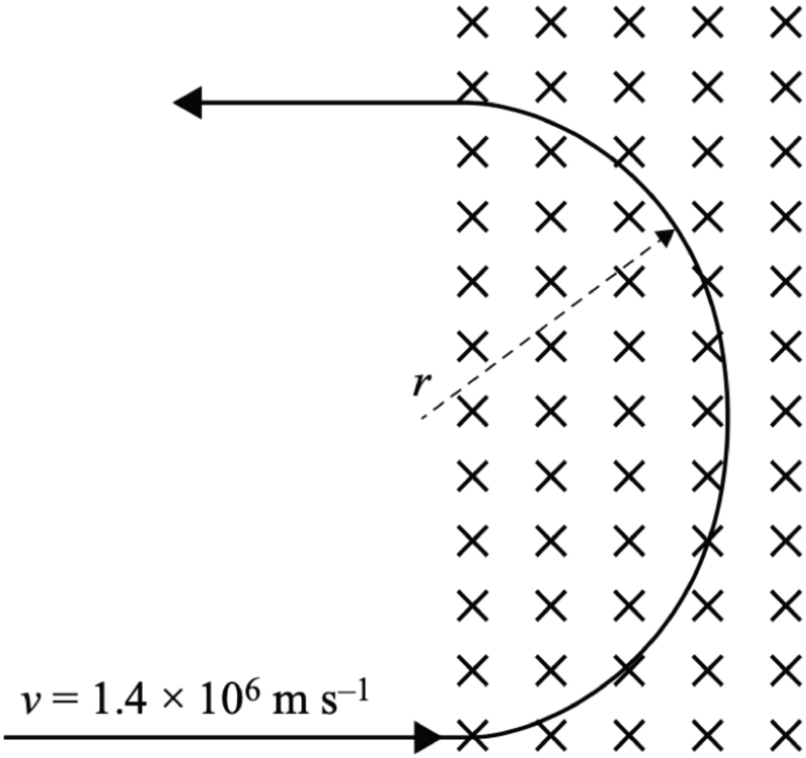
C 5.0×10^{-2} N

D 5.0×10^{-5} N

Question 17/ 23

[VCAA 2020 SA Q3]

A positron with a velocity of $1.4 \times 10^{6}\ \mathrm{m\ s^{-1}}$ is injected into a uniform magnetic field of $4.0 \times 10^{-2}\ \mathrm{T}$, directed into the page, as shown in the diagram below. It moves in a vacuum in a semicircle of radius *r*. The mass of the positron is $9.1 \times 10^{-31}\ \mathrm{kg}$ and the charge on the positron is $1.6 \times 10^{-19}\ \mathrm{C}$. Ignore relativistic effects.



Which one of the following best gives the speed of the positron as it exits the magnetic field?

A $0 \mathrm{~m} \mathrm{~s}^{-1}$

B much less than $1.4 \times 10^6 \mathrm{~m} \mathrm{~s}^{-1}$

C $1.4 \times 10^6 \mathrm{~m} \mathrm{~s}^{-1}$

D greater than $1.4 \times 10^6 \mathrm{~m} \mathrm{~s}^{-1}$

Question 18/ 23

[VCAA 2020 SA Q4]

The speed of the positron is changed to $7.0 \times 10^5 \mathrm{~m} \mathrm{~s}^{-1}$. Which one of the following best gives the value of the radius r for this speed?

A $\frac{r}{4}$

B $\frac{r}{2}$

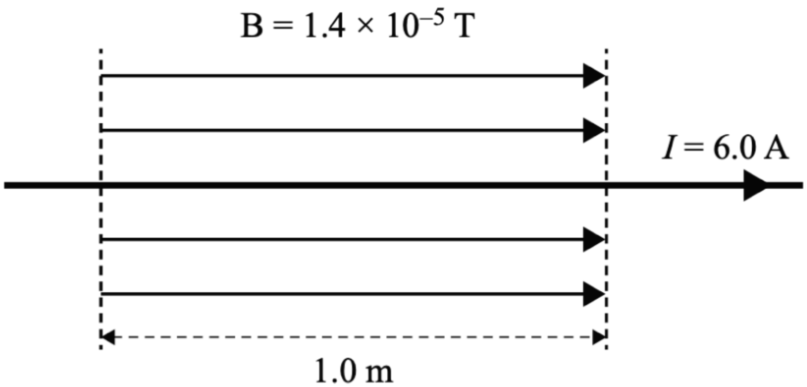
C r

D $2r$

Question 19/ 23

[VCAA 2021 NHT SA Q1]

A wire carrying a current, *I*, of 6.0 A passes through a magnetic field, *B*, of strength 1.4×10^{-5} T, as shown below. The magnetic field is exactly 1.0 m wide.



The magnitude of the force on the wire is closest to

A 0 N

B 2.3×10^{-6} N

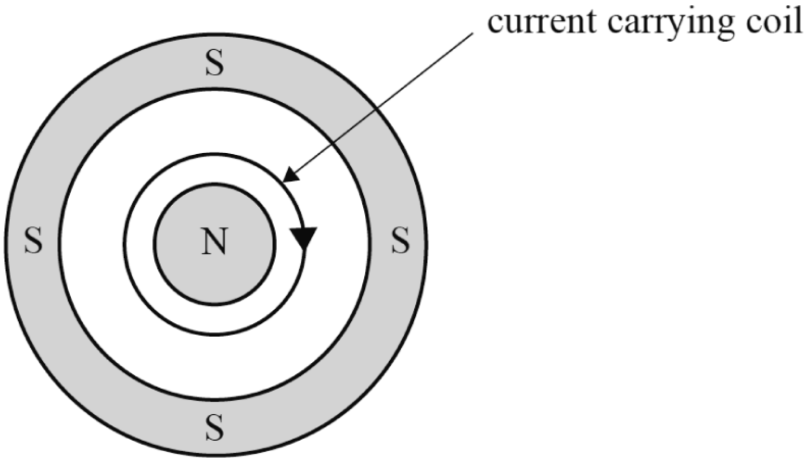
C 8.4×10^{-5} N

D 4.3×10^{5} N

Question 20/ 23

[VCAA 2022 NHT SA Q2]

A loudspeaker consists of a current carrying coil within a radial magnetic field, as shown in the diagram below. The direction of the current in the coil is also shown.



Which one of the following best describes the direction of the force on the coil?

A out of the page

B down the page

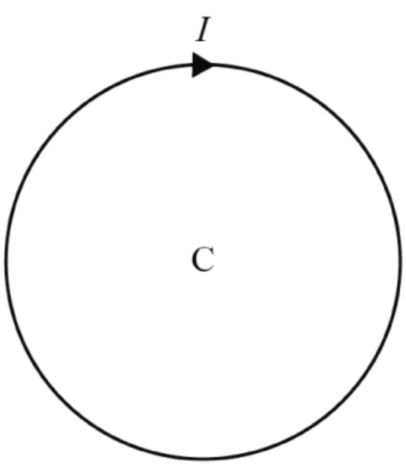
C into the page

D up the page

Question 21/ 23

[VCAA 2022 SA Q1]

A single loop of wire carries a current, *I*, as shown in the diagram below.



Which one of the following best describes the direction of the force on the coil?

A to the left

B to the right

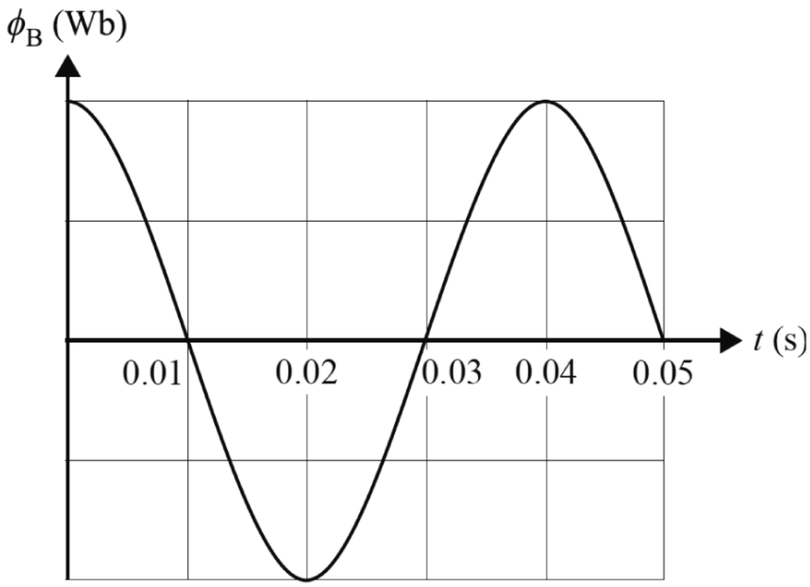
C into the page

D out of the page

Question 22/ 23

[VCAA 2022 SA Q2]

The diagram below shows the magnetic flux variation through the coil of an AC generator.



Which one of the following is closest to the frequency of the magnetic flux variation through the coil of the AC generator?

A 0.04 Hz

B 10 Hz

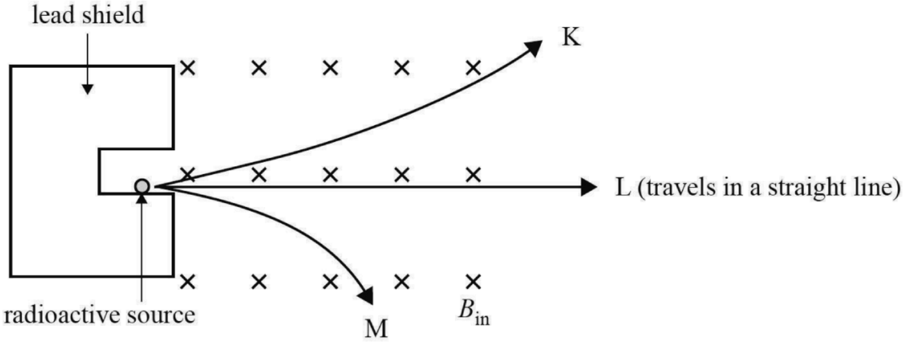
C 20 Hz

D 20 Hz

Question 23/ 23

[VCAA 2022 SA Q3]

Particles emitted from a radioactive source travel through a magnetic field, B_{in}, directed into the page, as shown schematically in the diagram below. Three particles, K, L and M, follow the paths indicated by the arrows.



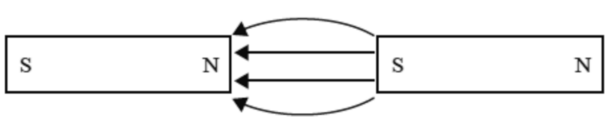
Which of the following correctly identifies the charges on particles K, L and M?

K	L	M
positive	no charge	negative
positive	negative	negative
negative	no charge	positive
no charge	no charge	no charge

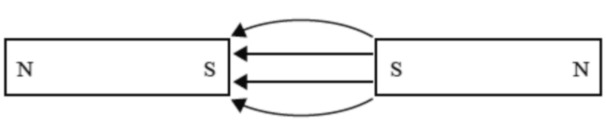
Question 24/ 23

[VCAA NHT 2023 SA Q3]

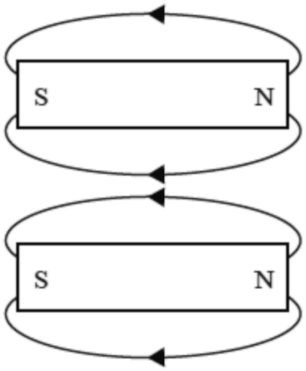
Which one of the following diagrams best represents the magnetic field between two magnets?



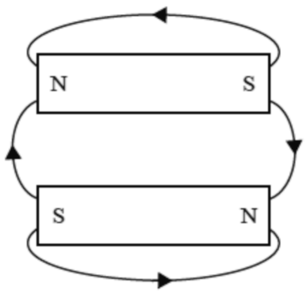
A



B



C

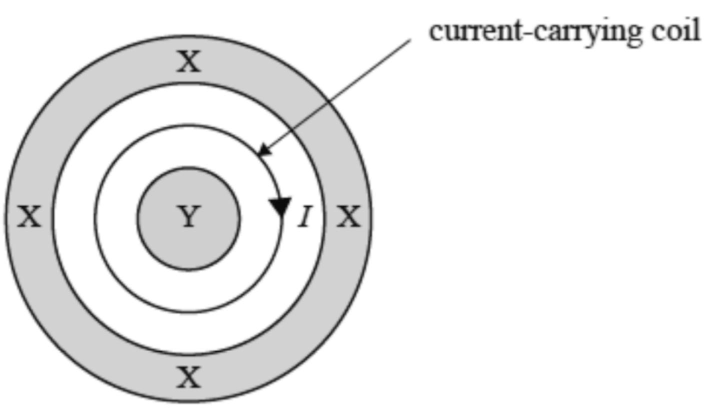


D

Question 25/ 23

[VCAA 2023 SA Q1]

One type of loudspeaker consists of a current-carrying coil within a radial magnetic field, as shown in the diagram below. X and Y are magnetic poles, and the direction of the current, *I*, in the coil is clockwise as shown.



The force, *F*, acting on the current-carrying coil is directed into the page.

Which one of the following statements correctly identifies the magnetic polarities of X and Y?

A X is a north pole and Y is a south pole.

B X is a south pole and Y is a north pole.

C Both X and Y are north poles.

D Both X and Y are south poles.

Question 1/ 48

A bending magnet in an accelerator causes a beam of electrons moving at $1.5 \times 10^7 \text{ m s}^{-1}$ to move in a circular path of radius 0.25 m. Calculate the magnitude of the magnetic field.

(2 marks)

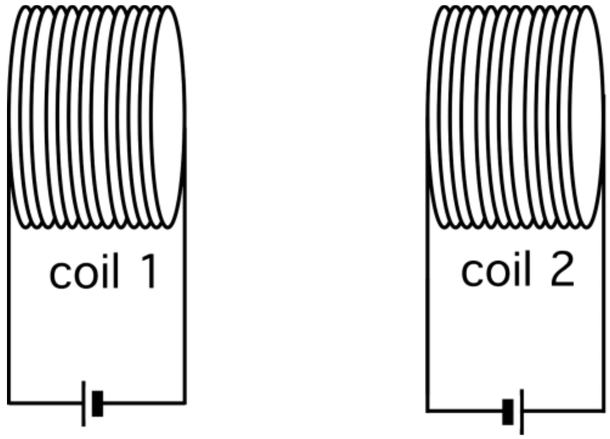
Question 2/ 48

A wire of length 2 m in a magnetic field of 0.15 T experiences a sideways magnetic force of 3 N. What is the current flowing in it?

(2 marks)

Question 3/ 48

Two coils, shown below, provide separate magnetic fields. A current is flowing through both coils. As a result, they exert forces on each other.

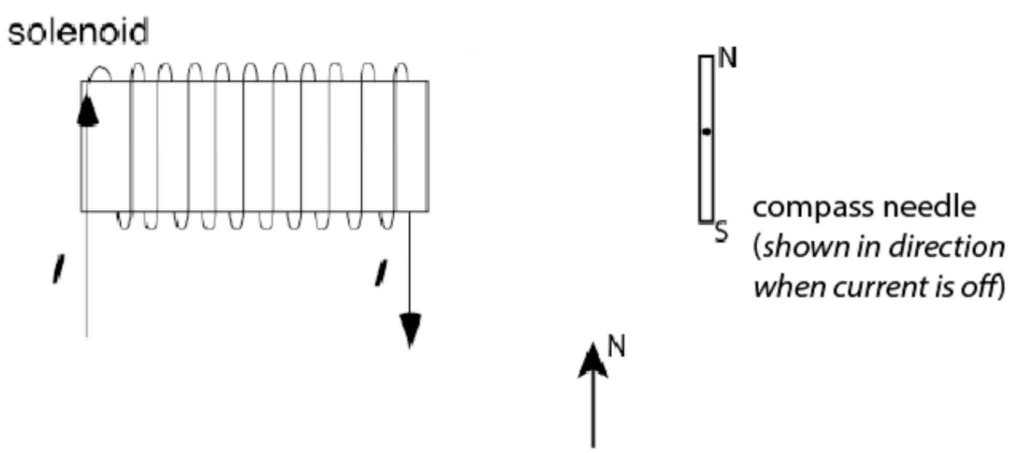


What is the direction of the force on coil 1? Show your reasoning.

(3 marks)

Question 4/ 48

Students measure the field of a current-carrying solenoid by comparing it to Earth's magnetic field. A balanced compass needle is pivoted about its centre and put in the position shown below. With the current *off*, the needle points to north.



a. When the current is switched *on*, the needle turns through 30°. Describe, with reasons, the direction it turns.

(2 marks)

b. Earth's magnetic field at the location is 30 μT. Calculate the strength of the magnetic field of the solenoid at the position of the compass needle. Show your working.

(3 marks)

Question 5/ 48

The Aurora Australis is a display of light above the south pole, caused by the spiralling paths of charged particles emitting photons. A proton travels at $40\ \mathrm{km\ s^{-1}}$, at right angles to a magnetic field of $5.0 \times 10^{-5}\ \mathrm{T}$. The mass of a proton is $1.7 \times 10^{-27}\ \mathrm{kg}$, and its charge is $+1.6 \times 10^{-19}\ \mathrm{C}$.

a. Calculate the magnetic force acting on the proton.

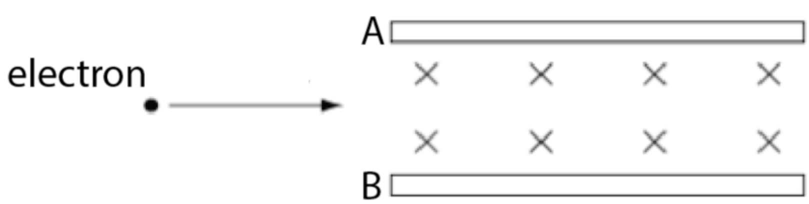
(2 marks)

b. Calculate the radius of the circular path of the proton.

(2 marks)

Question 6/ 48

The speed of charged particles can be measured by passing them through a combination of electric and magnetic fields at right angles to each other. An electron is shown entering the space between two parallel charged plates, where there is such a combination of fields.



a. Determine which plate, A or B, must be at the highest potential if the electron is to pass though the space undeflected. Show your reasoning.

(2 marks)

b. At a speed of $200\ 000\ \mathrm{m\ s^{-1}}$, the electron passes through undeflected. If the magnetic field is of strength 0.2 T, calculate the strength of the electric field between the plates.

(2 marks)

c. The voltage across the plates is equal to 1000 V. Calculate the spacing of the plates.

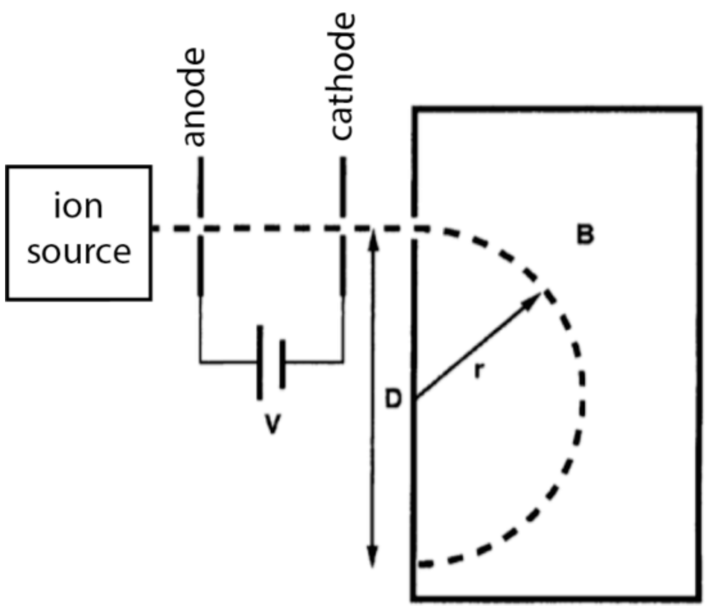
(2 marks)

d. Suppose an alpha particle (charge: $+3.2 \times 10^{-19}$ C; mass: 6.6×10^{-27} kg) replaces the electron and is travelling at the same speed. Discuss the changes required to ensure that it also remains undeflected.

(3 marks)

Question 7/ 48

The outline of a simple mass spectrometer is sketched below. An ion source provides ionised atoms that are then accelerated through a potential difference of V volts, as shown. The ions then enter a region of uniform magnetic field and are bent into a circular path (region B). (The whole apparatus is evacuated.)



a. State the sign of the ions in this arrangement, giving a reason for your answer.

(2 marks)

b. Explain why the ions travel in a circular path in region B.

(3 marks)

c. Identify the direction of the uniform magnetic field in region B. Give a reason for your answer.

(2 marks)

d. In a particular experiment, ions of mass 11.6×10^{-27} kg carrying one electronic charge are accelerated by a voltage of 4000 V. Calculate the speed that they enter region B. (Assume that their speed is zero as they pass through the anode and constant from the point they leave the hole in the cathode.) Show your working.

(3 marks)

e. The ions strike the detecting plate a distance $D = 2r$ from their entry into region B, as shown in the diagram. In one experiment $D = 12.8\ \text{cm}$. Calculate the value of the magnetic field in region B. Include a unit. Show your working.

(4 marks)

f. In another experiment, the speed of the ions entering region B and the strength of the magnetic field in region B both remain the same, but the value for *D* halves. Students discussing this result suggest the following possibilities:

Student A: these ions have the same mass but double the charge.

Student B: these ions have the same charge but half the mass.

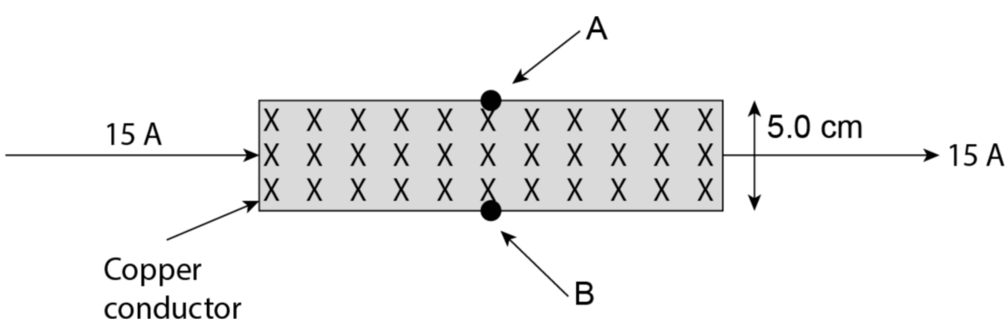
Student C: these ions have both double the charge and half the mass.

Evaluate these responses.

(4 marks)

Question 8/ 48

Scientists investigate magnetic forces acting on electrons flowing through a conductor in a magnetic field. The conductor, a bar of copper of width 5.0 cm, and the magnetic field are at right angles to each other, as shown below. The magnetic field is 0.75 T.



When the scientists connect a sensitive voltmeter between points A and B, they measure a voltage, but only when a magnetic field is present.

a. Explain why the voltage occurs across the conductor only when a magnetic field is present, in terms of the electrons in the conductor.

(3 marks)

b. Identify whether point A or point B is at the higher potential, giving reasons.

(2 marks)

c. The voltage they measure is equal to 0.75 μV. Calculate the electric field across the conductor, between points A and B, assuming a uniform field.

(2 marks)

d. Assume that the force on the electrons from the electric field (qE) balances the magnetic force on the electrons to show that the voltage, V, between A and B is equal to Bvd, where d is the distance between A and B, and v is the speed of the electrons flowing in the conductor. Show your reasoning.

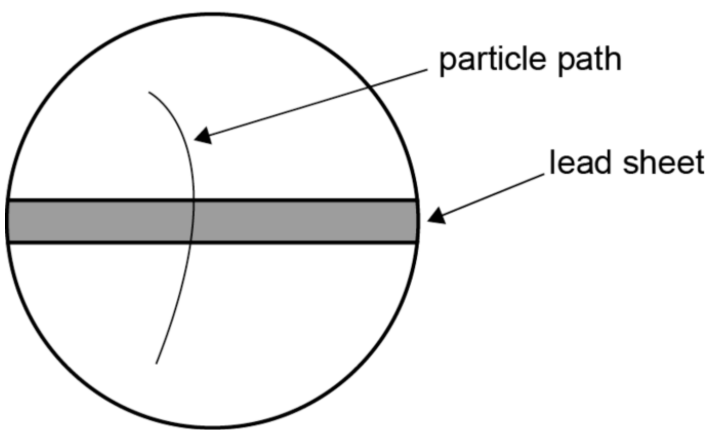
(2 marks)

e. Use the result in part **d.** to calculate the speed of the electrons.

(2 marks)

Question 9/ 48

The path of a charged particle in a particle detector is shown in the diagram below. There is a strong uniform magnetic field at right angles to the page, directed into the page, and the particle travels through a piece of lead, where it loses some kinetic energy.



a. The particle is moving upwards. Explain why this must be the case, using physics principles.

(3 marks)

b. Determine the sign of the charge of the particle, giving a reason for your answer.

(2 marks)

c. The radius of the curvature of the path (r) can be measured, as can the strength of the magnetic field (B)

and the charge of the particle (q). Write an equation for the momentum of the particle in terms of these variables. Show your reasoning.

(3 marks)

Question 10/ 48

[Adapted VCAA 2016 SA Q13]

A 3.0 m long, vertical, copper lightning conductor is located in a region where Earth's magnetic field is horizontal and pointing north. A current of 2000 A flows down the conductor to Earth during an electrical storm. Force detectors measure a force on the lightning conductor of 0.32 N.

a. Calculate the magnitude of Earth's magnetic field acting on the lightning conductor.

(2 marks)

b. Describe the direction of the force on the lightning conductor. Explain your reasoning.

(2 marks)

Question 11/ 48

[VCAA 2018 NHT SB Q3]

A uniform electric field accelerates protons from rest to a speed of $5.00 \times 10^7 \text{ m s}^{-1}$.

DATA

mass of proton	1.67×10^{-27} kg
charge on proton	$+1.60 \times 10^{-19}$ C

a. The protons then pass into a region of uniform magnetic field that is at right angles to their velocity. They are bent into a circular path. Explain why the path is circular in shape.

(3 marks)

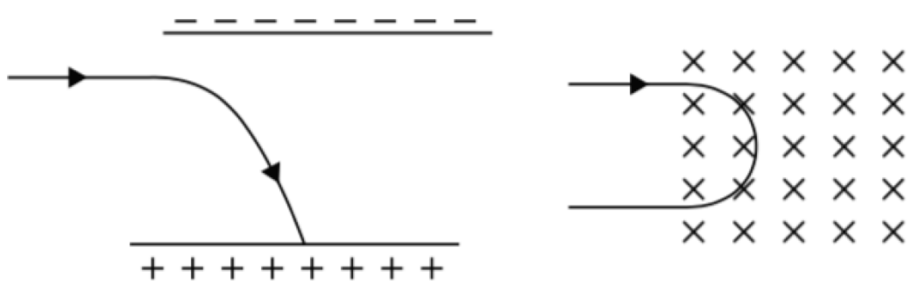
b. The strength of the uniform magnetic field is 500 mT. Calculate the magnitude of the magnetic force on the protons.

(3 marks)

Question 12/ 48

[Adapted VCAA 2017 Sample SB Q2]

A beam of electrons travelling in a particle accelerator are deflected by a uniform electric field (left-hand diagram below). In another situation they are deflected by a uniform magnetic field (right-hand diagram below).



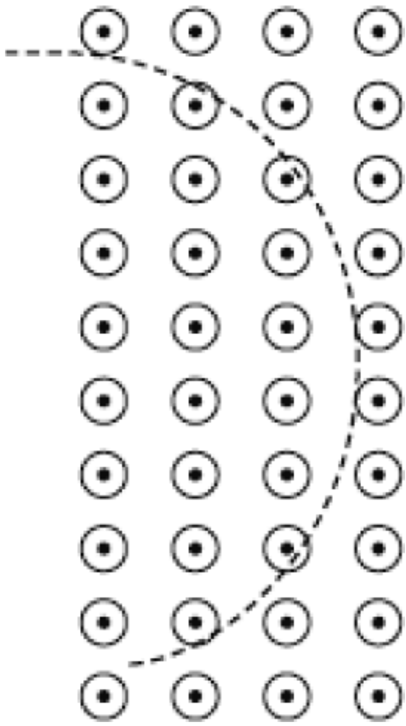
Explain why the paths of the electrons in the two situations have different shapes.

(2 marks)

Question 13/ 48

[Adapted VCAA 2018 SB Q1]

A proton enters a region of uniform magnetic field with a speed of $1.0 \times 10^6 \text{ m s}^{-1}$ and moves in a circular path.



Calculate the radius of the path of this proton in the magnetic field. Show your working. (Use $B = 20\ \text{mT}$, $\text{proton charge} = 1.6 \times 10^{-19}\ \text{C}$, $\text{proton mass} = 1.7 \times 10^{-27}\ \text{kg}$.

(2 marks)

Question 14/ 48

[Adapted VCAA 2019 NHT SB Q1]

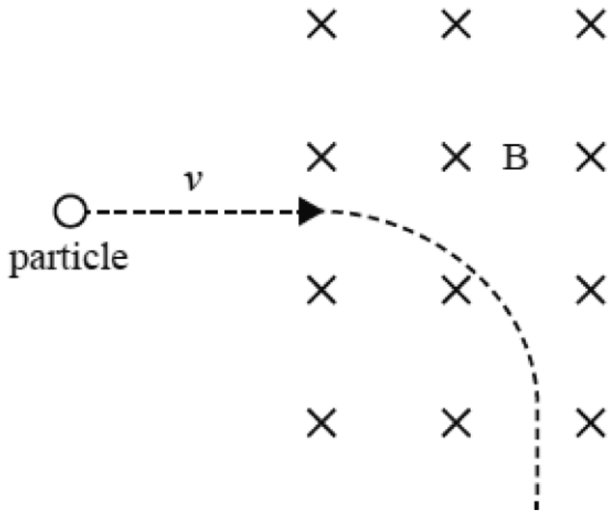
Electrons move into a region of uniform magnetic field. The field is perpendicular to the velocity of the electrons. Will their path be a straight line, part of a parabola or part of a circle? Give a reason for your answer.

(2 marks)

Question 15/ 48

[VCAA 2019 SB Q1]

A particle of mass *m* and charge *q* travelling at velocity *v* enters a uniform magnetic field B, as shown below.



a Is the charge *q* positive or negative? Give a reason for your answer.

(1 mark)

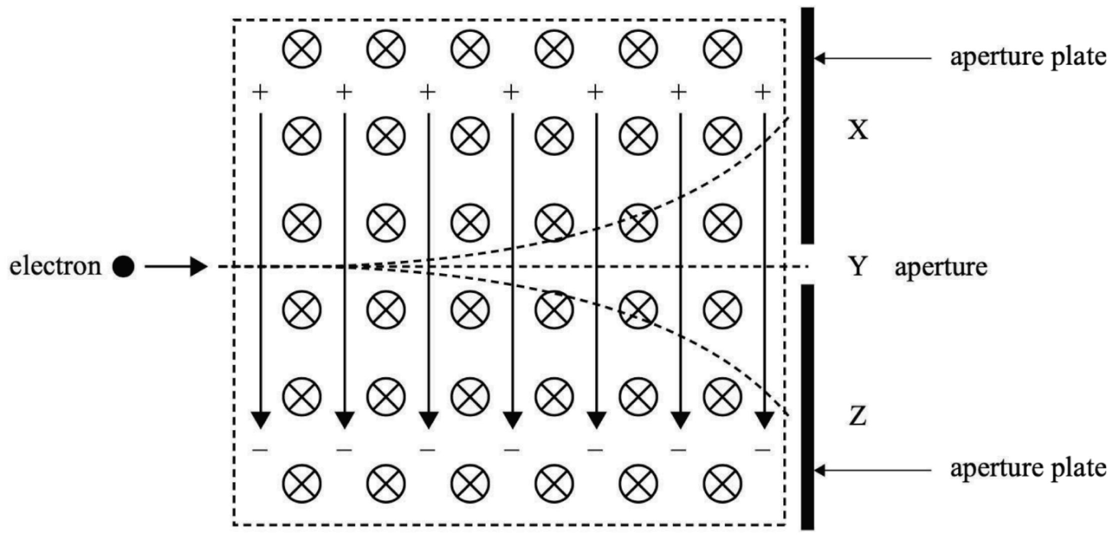
b Explain why the path of the particle is an arc of a circle while the particle is in the magnetic field.

(2 marks)

Question 16/ 48

[VCAA 2020 SB Q3]

Electron microscopes use a high-precision electron velocity selector consisting of an electric field, *E*, perpendicular to a magnetic field, *B*. Electrons travelling at the required velocity, v_0, exit the aperture at point Y, while electrons travelling slower or faster than the required velocity, v_0, hit the aperture plate, as shown below.



a. Show that the velocity of an electron that travels straight through the aperture to point Y is given by $v_0 = \frac{E}{B}$.

(1 mark)

b. Calculate the magnitude of the velocity, v_0, of an electron that travels straight through the aperture to point Y if $E = 500\ \text{kVm}^{-1}$ and $B = 0.25\ \text{T}$. Show your working.

(2 marks)

c. i. At which of the points – X, Y or Z – in the diagram could electrons travelling faster than v_0 arrive?

(1 mark)

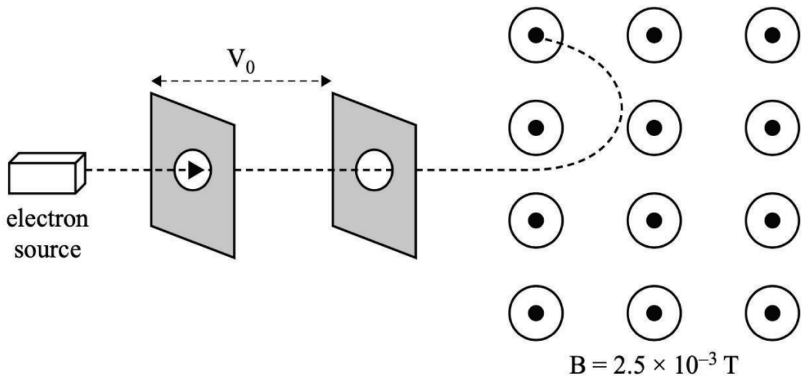
ii. Explain your answer to part **c.i.**

(2 marks)

Question 17/ 48

[Adapted VCAA 2021 NHT SB Q2]

An electron is accelerated from rest by a potential difference of V_0. It emerges at a speed of $2.0 \times 10^7\ \text{m s}^{-1}$ into a magnetic field, B, of strength $2.5 \times 10^{-3}\ \text{T}$ and follows a circular arc, as shown below.



a. Explain why the path of the electron in the magnetic field follows a circular arc.

(2 marks)

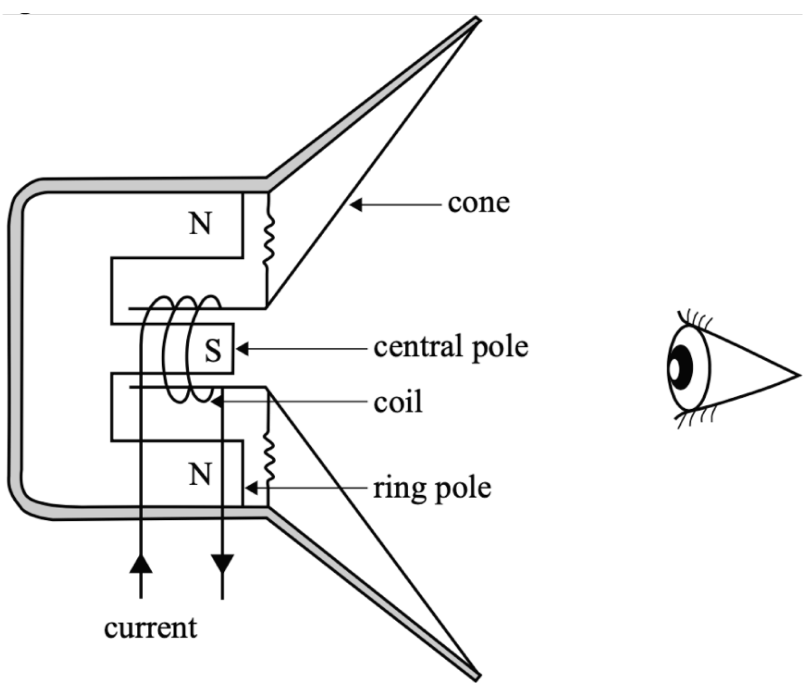
b. Calculate the radius of the path travelled by the electron. Show your working.

(3 marks)

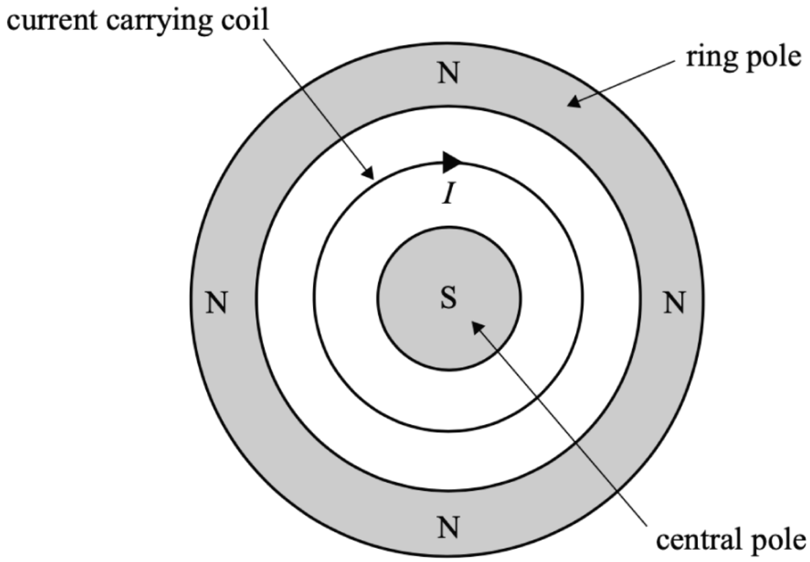
Question 18/ 48

[VCAA 2021 SB Q2]

A schematic side view of one design of an audio loudspeaker is shown in the diagram below. It uses a current carrying coil that interacts with permanent magnets to create sound by moving a cone in and out.



The diagram below shows a schematic view of the loudspeaker from the position of the eye shown in in the previous diagram. The direction of the current is clockwise, as shown.



a. Draw four magnetic field lines on the diagram above, showing the direction of each field line using an arrow.

(1 mark)

b. Which one of the following gives the direction of the force acting on the current carrying coil?

A left

B right

C up the page

D down the page

E into the page

F out of the page

(1 mark)

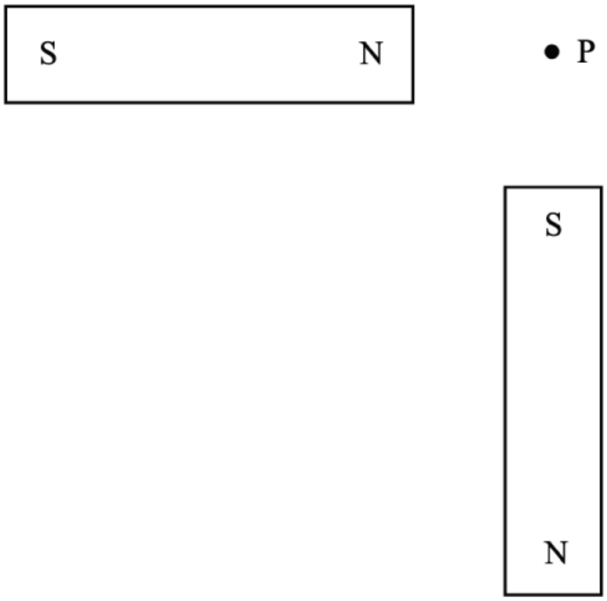
c. The current carrying coil has a radius of 5.0 cm and 20 turns of wire, and it carries a clockwise current (*I*) of 2.0 A. Its magnetic field strength (*B*) is 200 mT. Calculate the magnitude of the force, *F*, acting on the current carrying coil. Show your working.

(2 marks)

Question 19/ 48

[VCAA 2021 SB Q1]

Two identical bar magnets of the same magnetic field strength are arranged at right angles to each other and at the same distance from point P, as shown.



a. At point P on the diagram above, draw an arrow indicating the direction of the combined magnetic field of the two bar magnets.

(1 mark)

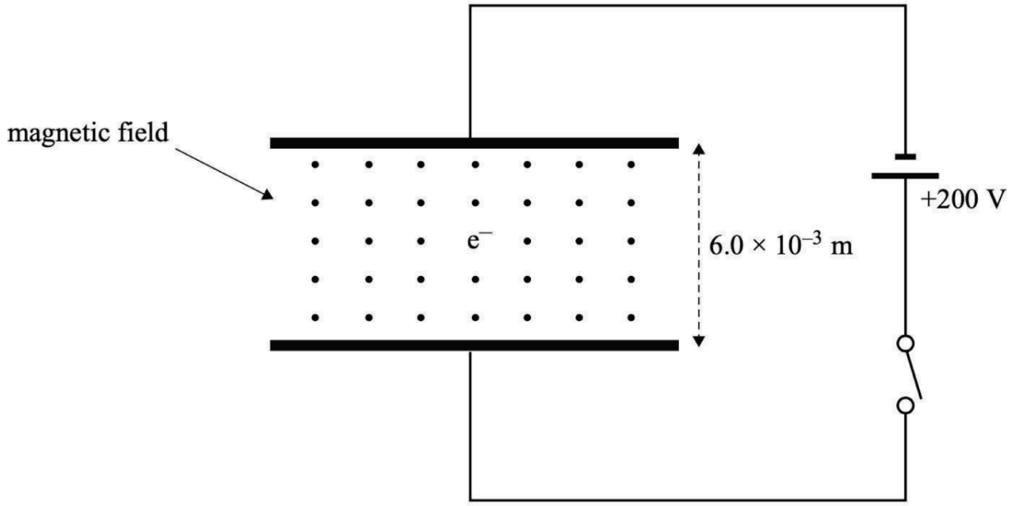
b. Calculate the magnitude of the combined magnetic field strength of the two bar magnets if each bar magnet has a magnetic field strength of 10.0 mT at point P.

(2 marks)

Question 20/ 48

[Adapted VCAA 2021 SB Q5]

The diagram below shows a stationary electron $(\mathrm{e}-)$ in a uniform magnetic field between two parallel plates. The plates are separated by a distance of $6.0 \times 10^{-3}\mathrm{m}$, and they are connected to a 200 V power supply and a switch. Initially, the plates are uncharged. Assume that gravitational effects on the electron are negligible.



a. Explain why the magnetic field does not exert a force on the electron. Justify your answer with an appropriate formula.

(2 marks)

b. Ravi and Mia discuss what they think will happen to the size and direction of the magnetic force on the electron after the switch is closed. Ravi says that there will be a magnetic force of constant magnitude, but it will be continually changing direction. Mia says that there will be a constantly increasing magnetic force, but it will always in the same direction. Evaluate these two statements, giving clear reasons for your answer.

(4 marks)

Question 21/ 48

[VCAA 2022 NHT SB Q3]

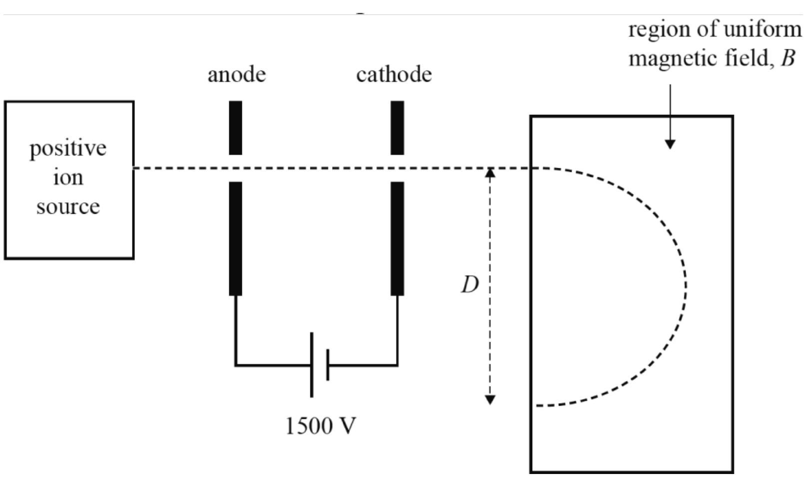
A positron and an electron are fired one at a time into a strong uniform magnetic field in an evacuated chamber. They are fired at the same speed but from opposite sides of the chamber. Their initial velocities are initially perpendicular to the magnetic field and opposite in direction to each other, as shown in the diagram below. A positron has the same mass as an electron $(9.1 \times 10^{-31}\ \mathrm{kg})$ and has the same magnitude of electric charge as an electron $(-1.6 \times 10^{-19}\ \mathrm{C})$ but is positively charged $(+1.6 \times 10^{-19}\ \mathrm{C})$.

On the diagram, sketch and label the respective paths that the positron and the electron will take while in the uniform magnetic field.

Question 22/ 48

[VCAA 2022 SB Q3]

A schematic diagram of a mass spectrometer that is used to deflect charged particles to determine their mass is shown in the diagram below. Positive singly charged ions (with a charge of $+1.6 \times 10^{-19}$C) are produced at the ion source. These are accelerated between an anode and a cathode. The potential difference between the anode and the cathode is 1500 V. The ions pass into a region of uniform magnetic field, *B*, and are directed by the field into a semicircular path of diameter *D*.



a. Calculate the increase in the kinetic energy of each ion as it passes between the anode and the cathode. Give your answer in joules.

(2 marks)

b. Each ion has a mass of 4.80×10^{-27} kg. Show that each ion has a speed of 3.16×10^5 m s^{-1} when it exits the cathode. Assume that the ion leaves the ion source with negligible speed. Show your working.

(2 marks)

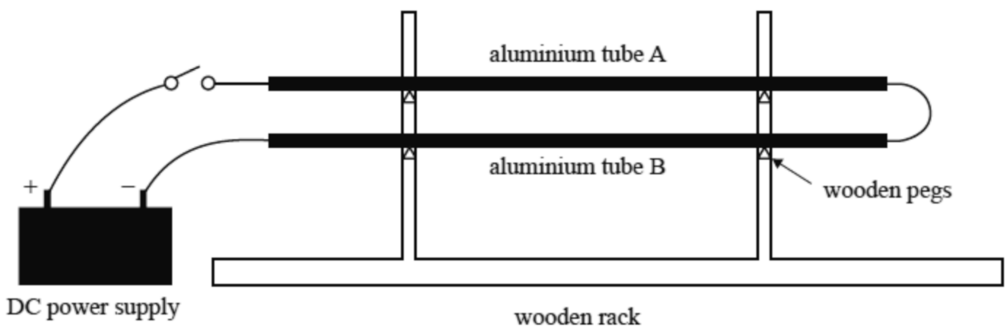
c. The current carrying coil has a radius of 5.0 cm and 20 turns of wire, and it carries a clockwise current (*I*) of 2.0 A. Its magnetic field strength (*B*) is 200 mT. Calculate the magnitude of the force, *F*, acting on the current carrying coil. Show your working.

(3 marks)

Question 23/ 48

[VCAA NHT 2023 SB Q3]

Two thin, light aluminium tubes, A and B, are supported in a vertical wooden rack, as shown below. Both of the aluminium tubes rest horizontally on wooden pegs.



The two thin, light aluminium tubes form a series circuit with a DC power supply. It was observed that one of the tubes jumped upwards when the DC power supply was switched on.

Identify which tube jumped upwards and explain why this occurred.

(3 marks)

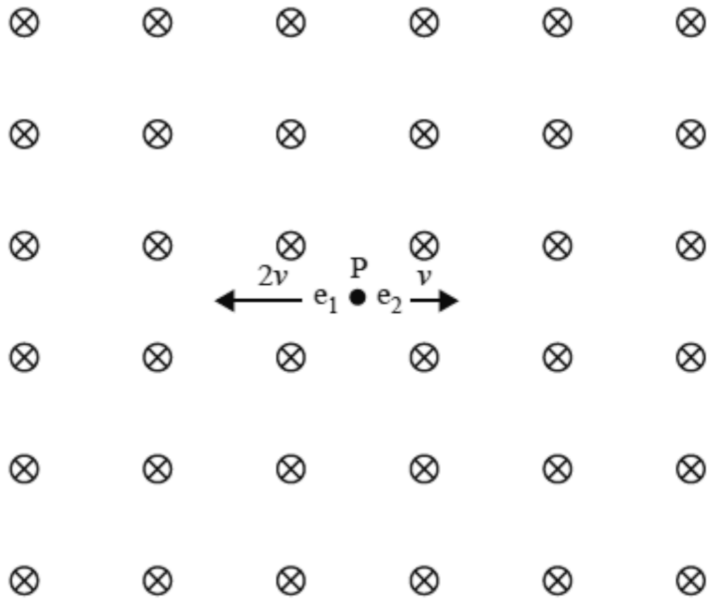
Question 24/ 48

[VCAA NHT 2023 SB Q4]

Two electrons, e_1 and e_2, are emitted, one after the other, from point P in a uniform magnetic field, as shown below.

Both electrons travel perpendicular to the magnetic field, but in opposite directions. Throughout their journey, both electrons remain within the magnetic field.

Electron e_1 travels at twice the speed of e_2. Relativistic effects can be ignored as both electrons are travelling at low speeds. Electrostatic effects at point P can be ignored as the two electrons are emitted at different times.



Which one of the following three outcomes occurs?

- Outcome 1 – Electron e_1 returns to point P in the shortest time.
- Outcome 2 – Electron e_2 returns to point P in the shortest time.
- Outcome 3 – Both electrons take the same time to return to point P.

Explain your answer.

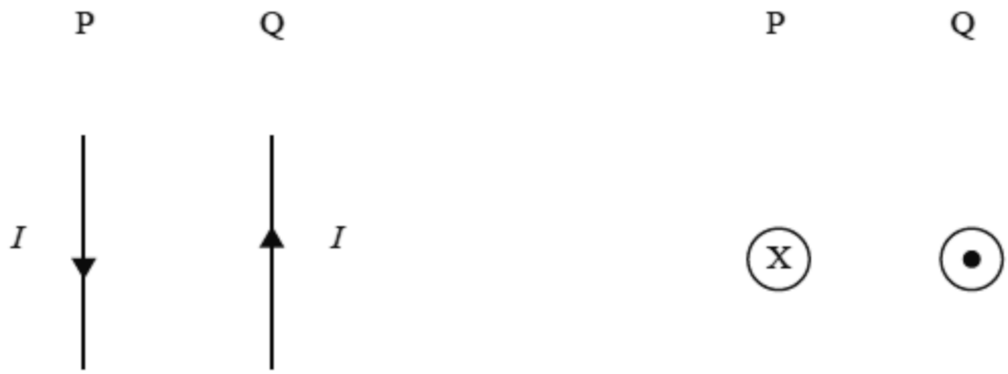
(3 marks)

Question 25/ 48

[VCAA 2023 SB Q3]

Two long, straight current-carrying wires, P and Q, are parallel, as shown below (left diagram). The current in the wires is the same in magnitude and opposite in direction.

The diagram on the right shows the wires as viewed from above.



a. On the right hand diagram, sketch the magnetic field around the wires, showing the direction of the magnetic field. Use at least five field lines.

(3 marks)

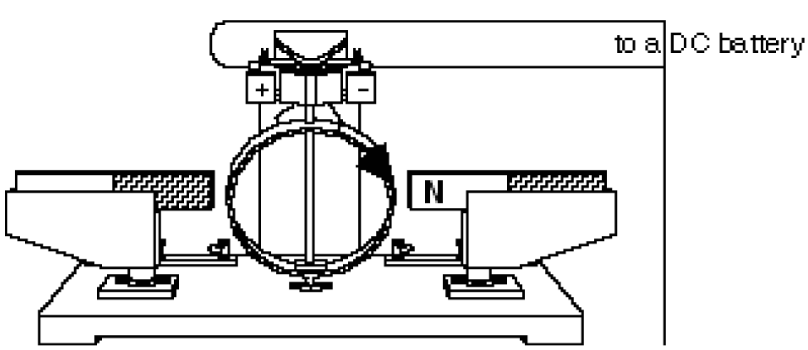
b. Do the two wires, P and Q, attract or repel each other? Explain your reasoning.

(2 marks)

Chapter 11 DC electric motors

Question 1/ 7

A simple DC motor, like the one shown below, has one rotating coil. Its field is supplied by permanent magnets.



The clockwise direction of the current in the coil is shown by the arrow in the diagram. The shaded end of each magnet is a south pole, and the clear part of each magnet is a north pole.

The arrangement at the top of the coil where current from the battery is transferred to the coil is called the *commutator*.

Question 2/ 7

When current flows through the coil, the coil will (viewed from above)

A rotate clockwise.

B rotate anticlockwise.

C rotate either way, depending on the initial direction of motion.

D not rotate, it will simply vibrate about the position shown.

Question 3/ 7

Which of the following would be likely to *increase* the speed of the motor? (Assume that the coil is very light.)

A Decrease the number of turns of the rotating coil.

B Increase the area of the rotating coil.

C Decrease the area of the rotating coil.

D Decrease the current in the rotating coil.

Question 4/ 7

If the permanent magnets were replaced by DC electromagnets with the same poles, which of the changes below would be necessary to keep the motor rotating as above?

A Replace the commutator with sliprings.

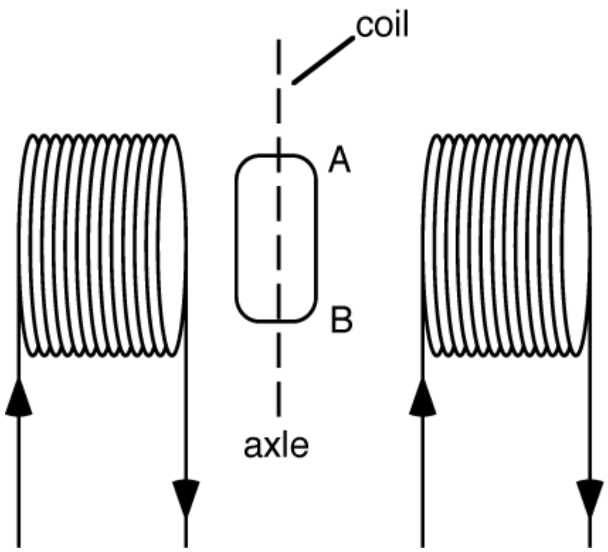
B Rectify the DC current.

C Reverse the direction of the poles.

D No changes are required.

Question 5/ 7

A coil on an axle is placed between the poles of an electromagnet.



A current is flowing in the coil between the electromagnets. The coil is rotating like a motor (a commutator is fitted). Side AB of the coil is rotating towards us. Which of the following best describes the current in the coil?

A It is flowing from A to B along this side.

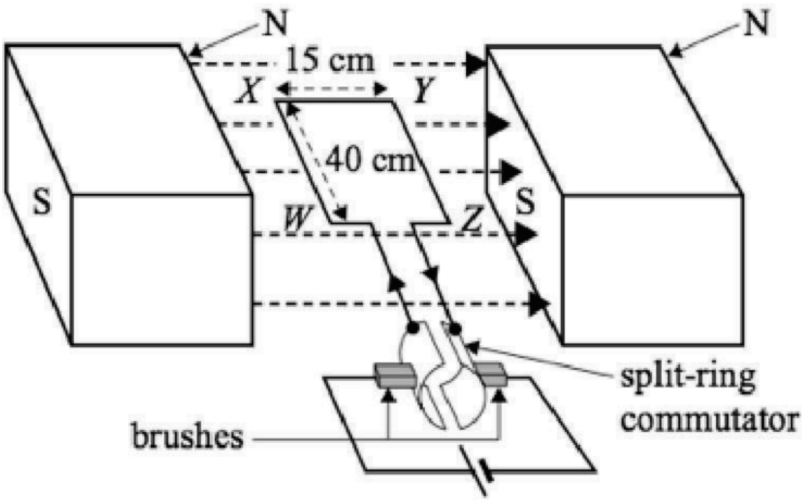
B It must be alternating.

C It is flowing from B to A along this side.

D It could be flowing in either direction, one cannot tell.

Question 6/ 7

A DC motor with permanent magnets is shown. The coil of the motor has 75 turns. The dimensions of the coil (which is free to turn) are shown. The direction of the magnetic field is shown.



Question 7/ 7

With the coil in the position shown, and with the current flowing as shown, the coil is likely to

A remain in the position shown, as the *BIl* forces are balanced.

B rotate in a clockwise direction (viewed from the battery), due to opposite *BIl* forces on sides *XW* and *YZ*.

C rotate in an anticlockwise direction (viewed from the battery), due to opposite *BIl* forces on sides *XW* and *YZ*.

D rotate only if one of the magnets is reversed in direction.

Question 8/ 7

The primary function of the split-ring commutator is to

A prevent the wires from the power supply becoming tangled.

B increase the size of the turning force on the coil.

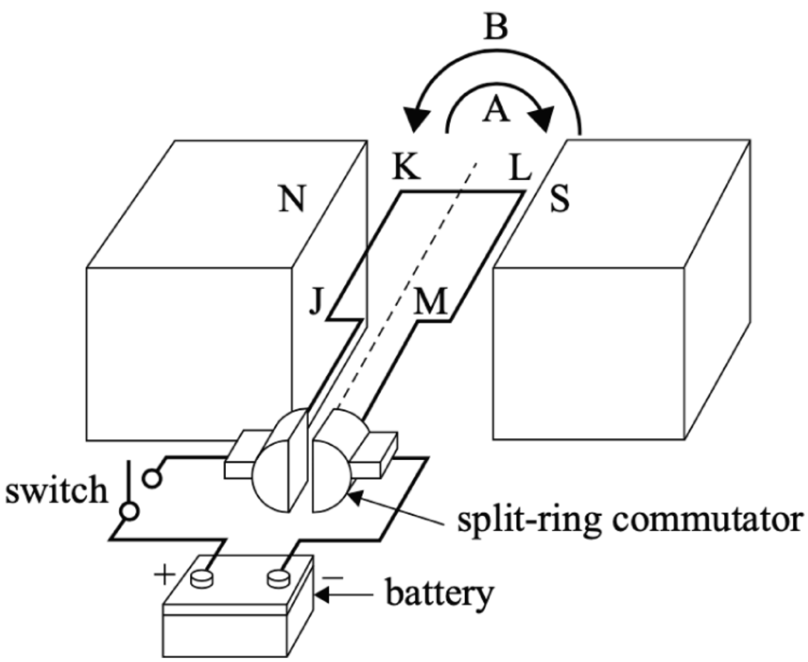
C convert the DC from the battery into an AC voltage.

D ensure that the coil rotates continuously in one direction.

Question 9/ 7

[VCAA 2021 SA Q5]

The diagram below shows a small DC electric motor, powered by a battery that is connected via a split-ring commutator. The rectangular coil has sides KJ and LM. The magnetic field between the poles of the magnet is uniform and constant.



The switch is now closed, and the coil is stationary and in the position shown in the diagram. Which one of the following statements best describes the motion of the coil when the switch is closed?

A The coil will remain stationary.

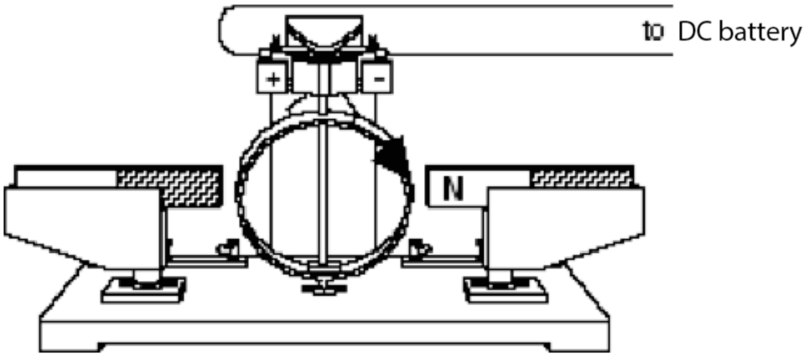
B The coil will rotate in direction A, as shown in the diagram.

C The coil will rotate in direction B, as shown in the diagram.

D The coil will oscillate regularly between directions A and B, as shown in the diagram.

Question 1/ 19

A simple DC motor, like the one shown below, has one rotating coil. Its field is supplied by permanent magnets.

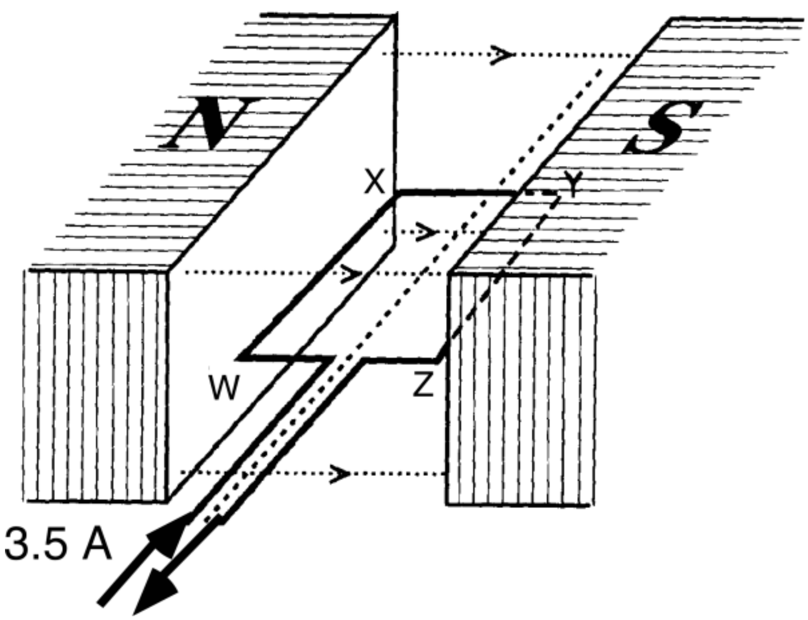


Jimmy thinks that reversing the poles of *one* of the magnets would increase the magnetic field and hence the speed of the motor. Analyse this idea.

(2 marks)

Question 2/ 19

The coil and permanent magnets of a DC motor are sketched below.



The magnets shown above have a field of 45 mT between the poles. The 30-turn coil WXYZ has a current of 3.5 A in each turn. WX and $\mathrm{YZ} = 10\ \mathrm{cm}$, and XY and $\mathrm{ZW} = 5\ \mathrm{cm}$.

a. Describe the directions of the forces acting on the sides WX and YZ.

(2 marks)

b. Calculate the magnitude of the total force on the side WX.

(2 marks)

c. Calculate the magnitude of the total force on the side XY.

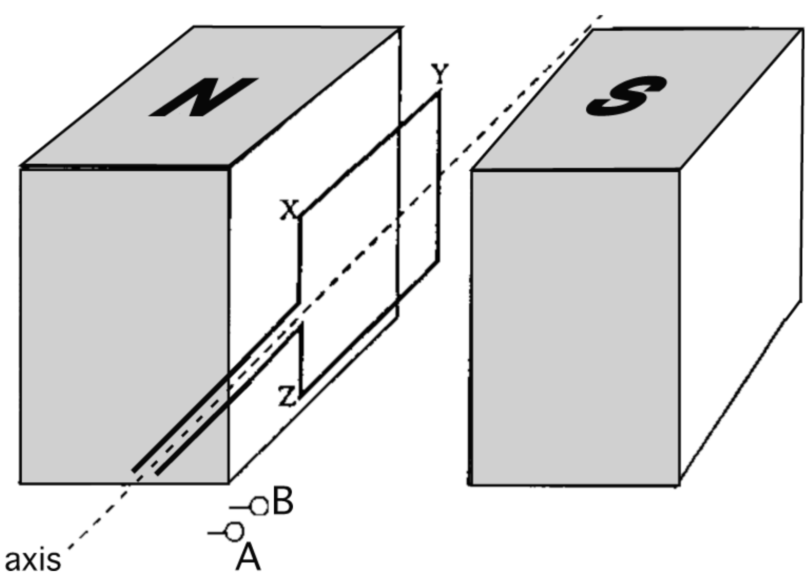
(2 marks)

d. For the coil to continue to rotate, a *commutator* is needed between points WZ and the DC supply. Explain its *function*.

(3 marks)

Question 3/ 19

The diagram below shows a coil free to rotate about a horizontal axis with little friction. The coil is completely immersed in a uniform magnetic field.



If the points A and B are connected to a source of DC current, and suitable connections are made between A and B and the coil (not shown), a DC motor can be constructed. Outline the *function* of these connections.

(3 marks)

Question 4/ 19

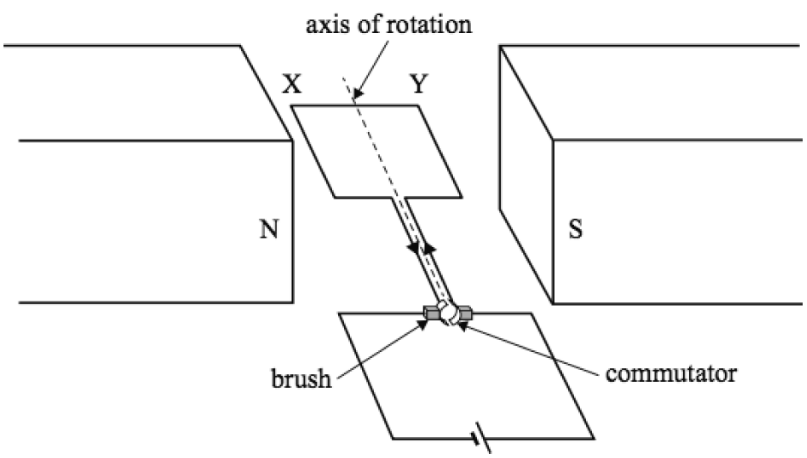
Explain what would happen to the torque, (τ), of a simple DC motor if the current, *I*, external magnetic field, *B*, and the number of loops of wire in the coil, *N*, were all in turn increased.

(3 marks)

Question 5/ 19

[Adapted VCAA 2016 SA Q14]

Students build a simple electric motor, as shown.



a. Describe the position(s) where the magnetic force on side XY is zero.

(2 marks)

b. The students discover that the motor starts moving more readily from some positions that from others. Describe the best orientation(s) for starting the motor to move from rest, and explain why.

(2 marks)

c. To increase the speed of the motor, the students suggest a number of improvements. The following improvements are suggested:

i increase the battery voltage

ii replace the single turn coil with a multiple turn coil

iii increase the resistance of the coil

iv reverse one of the poles of the permanent magnets.

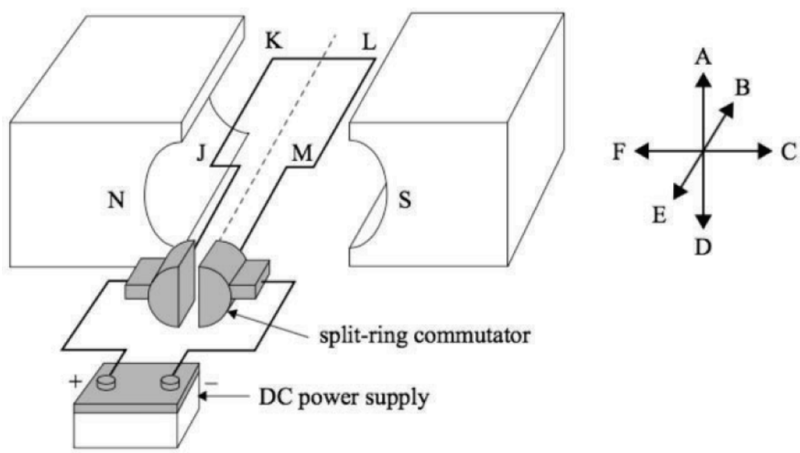
Evaluate these suggestions.

(4 marks)

Question 6/ 19

[VCAA 2017 SB Q3]

A schematic diagram of a simple DC motor is shown below. It consists of two magnets, a single 9.0 V DC power supply, a split-ring commutator and a rectangular 10 loop coil of wire. The resistance of the coil of wire is 6.0 Ω. The length of the side JK is 12 cm and the length of the side KL is 6.0 cm. The strength of the uniform magnetic field is 0.50 T.



a. Determine the size and direction (A–F) of the force acting on side JK.

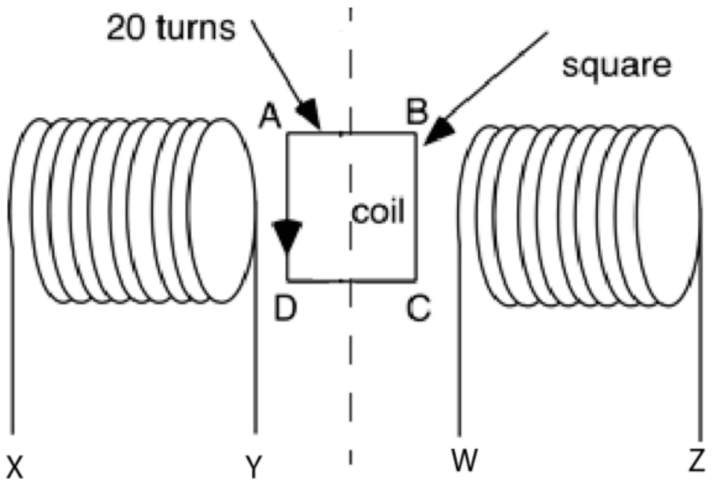
(3 marks)

b. What is the size of the force acting on the side KL in the orientation shown in the diagram above? Explain your answer.

(2 marks)

Question 7/ 19

A diagram of a simple DC motor is shown below. It has a 20-turn square coil free to rotate in a uniform magnetic field. Two electromagnets supply the field. The commutator and brushes are not shown. The arrow shows the current in the rotating coil.



a. At one time, side AD moves *out of the page*, and BC is moves *into the page*. What is the direction of the current in the two electromagnets?

(2 marks)

b. The uniform magnetic field between the electromagnet coils is 200 mT. The square coil has a 5.0 cm side. Calculate the maximum and minimum values of the size of the magnetic flux through the square coil during a full rotation of the coil. Include a unit in your answer.

(3 marks)

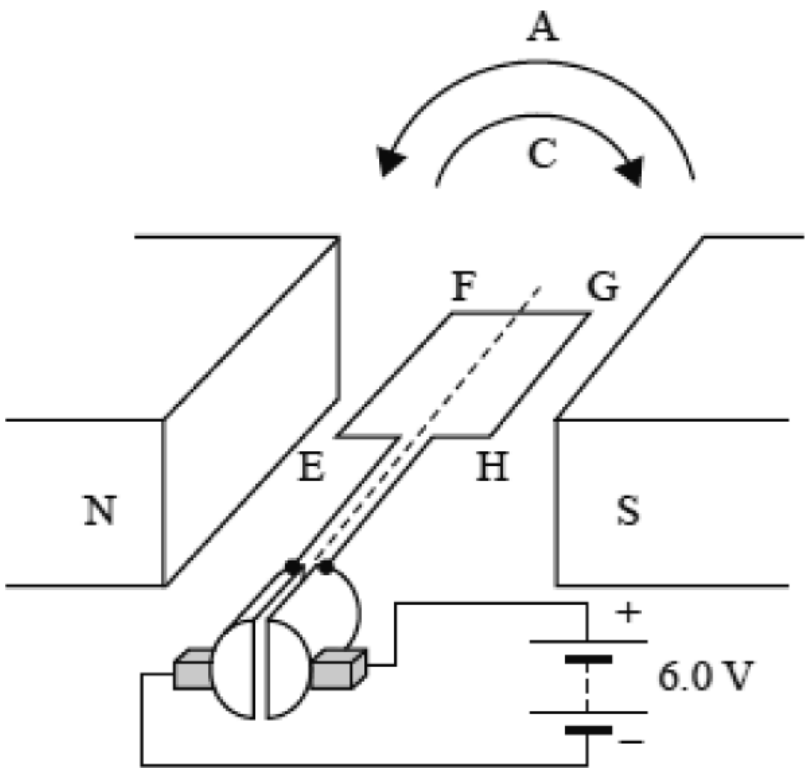
c. When the coil is in the position shown, the current flowing in the coil is 1.2 A. Calculate the size of the force on side AD, the size of the net force on the square coil, and the size of the force on the side AB.

(3 marks)

Question 8/ 19

[VCAA 2018 SB Q3]

Students build a model of a simple DC motor, as shown below.



a. The motor is set with the coil horizontal, as shown, and the power source is applied. Will the motor rotate in a clockwise (C) or anticlockwise (A) direction? Explain your answer.

(3 marks)

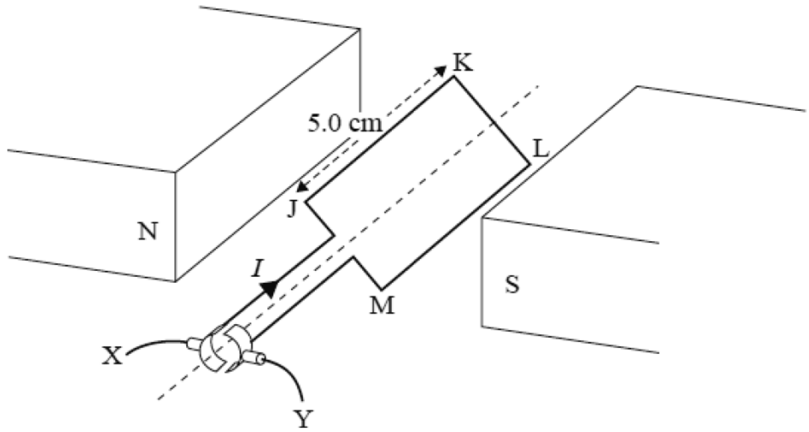
b. One student suggests that slip rings would be easier to make than a commutator and that they should use slip rings instead. Explain the effect that replacing the commutator with slip rings would have on the operation of the motor, if no other change was made.

(2 marks)

Question 9/ 19

[VCAA 2019 SB Q3]

The diagram below shows a schematic of a DC motor. The motor has a coil, JKLM, consisting of 100 turns. The permanent magnets provide a uniform magnetic field of 0.45 T. The commutator connectors, X and Y, provide a constant DC current, *I*, to the coil. The length of the side JK is 5.0 cm. The current *I* flows in the direction shown in the diagram.



a. Which terminal of the commutator is connected to the positive terminal of the current supply?

(1 mark)

b. Draw an arrow on the diagram to indicate the direction of the magnetic force acting on the side JK.

(1 mark)

c. Explain the role of the commutator in the operation of the DC motor.

(2 marks)

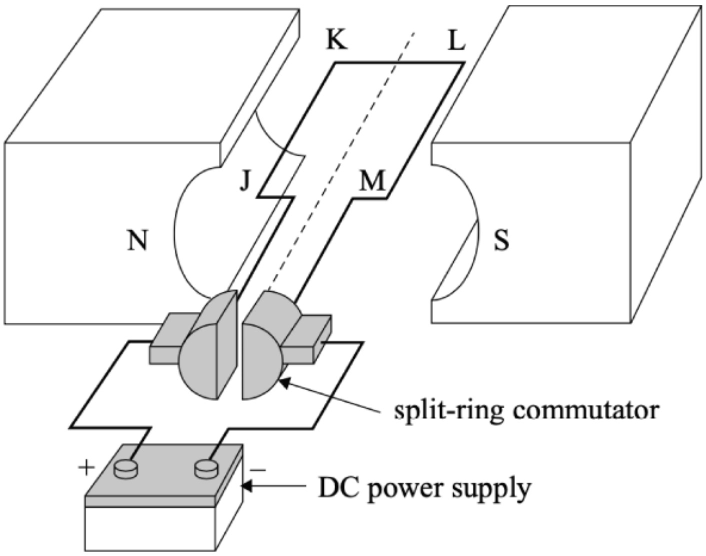
d. A current of 6.0 A flows through the 100 turns of the coil JKLM. The side JK is 5.0 cm in length. Calculate the size of the magnetic force on the side JK in the orientation shown in the diagram. Show your working.

(2 marks)

Question 10/ 19

[VCAA 2021 SB Q4]

The diagram below shows a schematic diagram of a simple one-coil DC motor. A current is flowing through the coil.



a. Draw an arrow on the diagram to indicate the direction of the force acting on the side JK of the coil.

(1 mark)

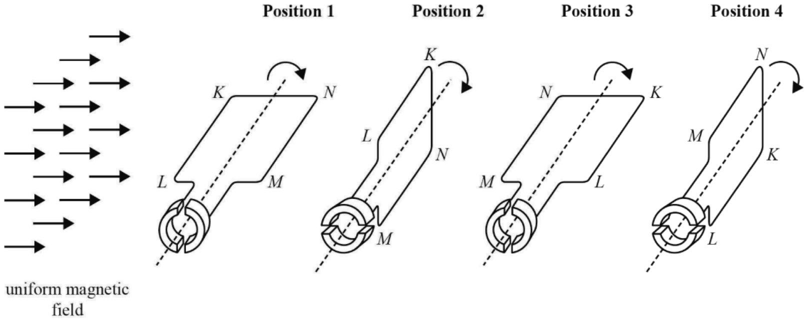
b. Explain the purpose of the split-ring commutator.

(2 marks)

Question 11/ 19

[VCAA 2022 SB Q1]

The diagram below shows four positions (1, 2, 3 and 4) of the coil of a single-turn, simple DC motor. The coil is turning in a uniform magnetic field that is parallel to the plane of the coil when the coil is in Position 1, as shown. When the motor is operating, the coil rotates about the axis through the middle of sides LM and NK in the direction indicated. The coil is attached to a commutator. Current for the motor is passed to the commutator by brushes that are not shown in the diagram.



a. When the coil is in Position 1, in which direction is the current flowing in the side KL – from K to L or from L to K? Justify your answer.

(2 marks)

b. When the coil is in Position 3, in which direction is the current flowing in the side KL – from K to L or from L to K?

(1 mark)

c. The side KL of the coil has a length of 0.10 m and experiences a magnetic force of 0.15 N due to the magnetic field, which has a magnitude of 0.5 T. Calculate the magnitude of the current in the coil.

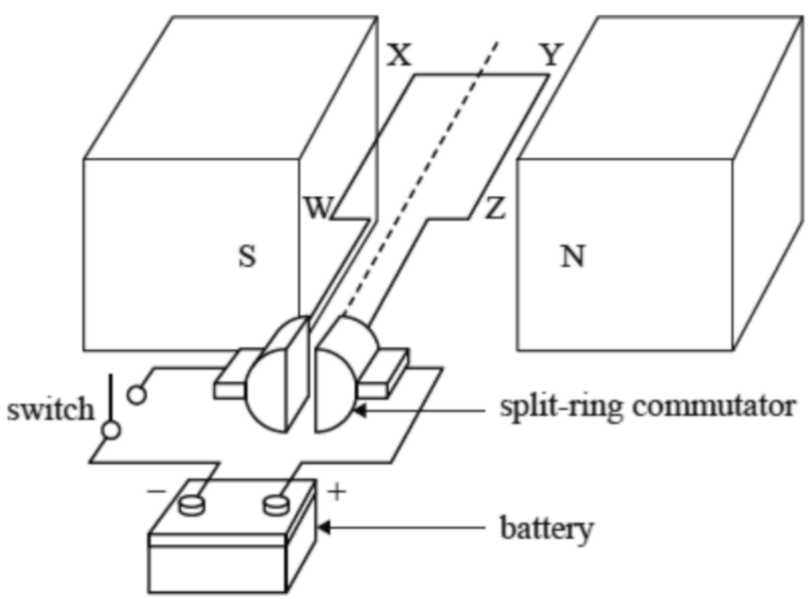
(2 marks)

Question 12/ 19

[VCAA NHT 2023 SB Q7]

A schematic diagram of a simple DC motor, powered by a battery is shown below.

The motor has a rectangular coil, WXYZ, consisting of 45 turns. The side WX has a length of 6.0 cm and the side XY has a length of 4.0 cm. The coil is connected to a split-ring commutator. Two permanent magnets provide a uniform magnetic field of 80 mT. Both the coil and the commutator are free to turn. The switch is now closed.



a. Will the motor spin clockwise, spin anticlockwise or remain stationary when viewed from the battery side?

(1 mark)

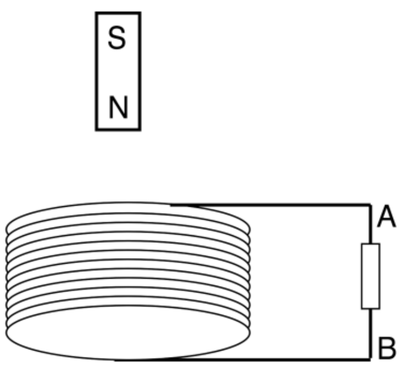
b. Calculate the magnitude of the force on the side YZ if a current of 3.2 A flows through the coil.

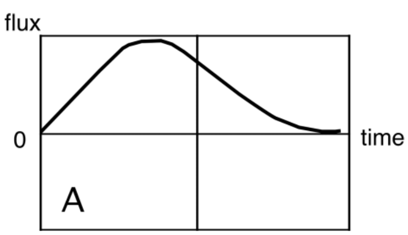
(2 marks)

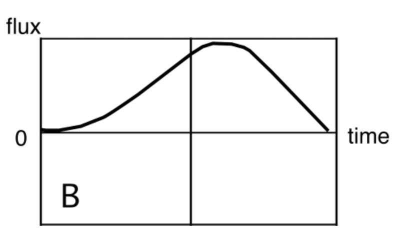
Chapter 12 Generation principles

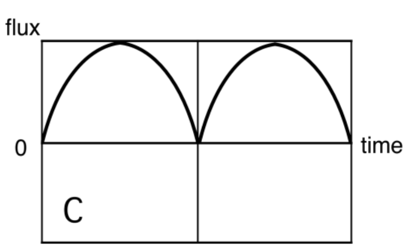
Question 1/ 22

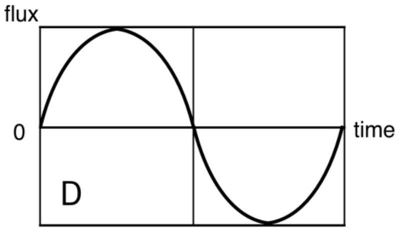
A magnet drops through a coil of area $0.2\ \mathrm{m}^2$. Which of the graphs below best describes how the flux through the coil changes with time?



A 

B 

C 



D

Question 2/ 22

Which of the following best describes how the emf changes with time?

A It rises from zero to a maximum and then drops back to zero.

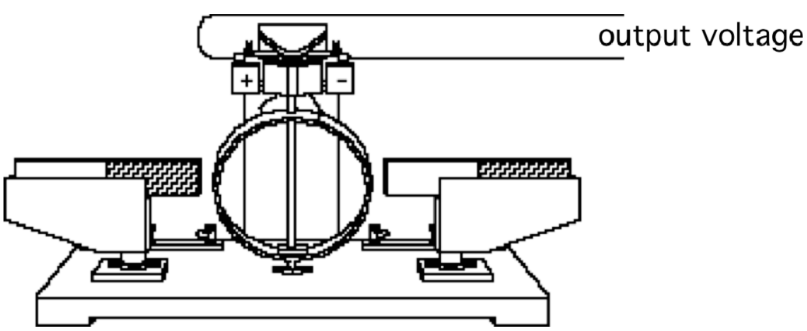
B It rises from zero to a maximum and then drops back to zero. It does this twice.

C It rises from zero to a negative maximum, drops back to zero, increases to a maximum in the opposite direction, and then drops back to zero.

D It rises from zero to a maximum and stabilises on that value.

Question 3/ 22

A simple DC motor has one coil and permanent magnets.



Question 4/ 22

If spun by hand, it produces an output voltage. The best reason for this is that

A the flux through the coil changes.

B the attraction of the two permanent magnets forces electrons to move.

C this action will cause an equal and opposite reaction.

D friction generates heat which accelerates the electrons.

Question 5/ 22

The connection between the coil and the output is a split-ring commutator. This means that the output voltage is best described as a

A sinusoidal voltage.

B steady DC voltage.

C varying AC voltage.

D DC voltage whose size varies with time.

Question 6/ 22

If the commutator were replaced with slip-rings, which of the following would now best describe the output voltage?

A A sinusoidal AC voltage

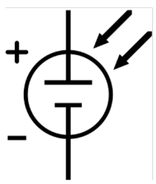
B A steady DC voltage

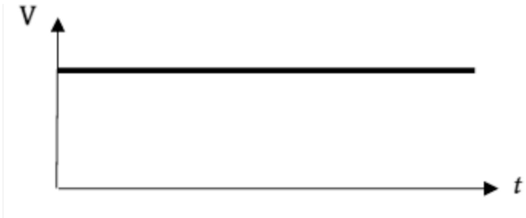
C A varying AC voltage

D A DC voltage whose size varies with time

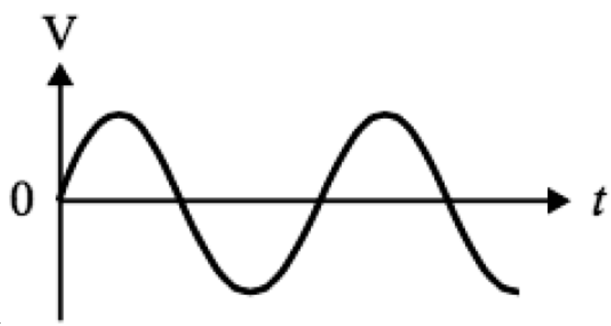
Question 7/ 22

The DC output of a photovoltaic cell (left) is shown below (right).

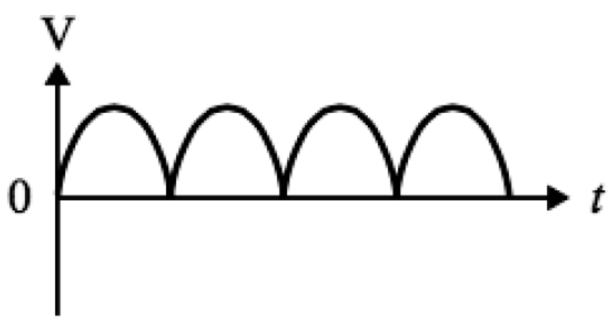




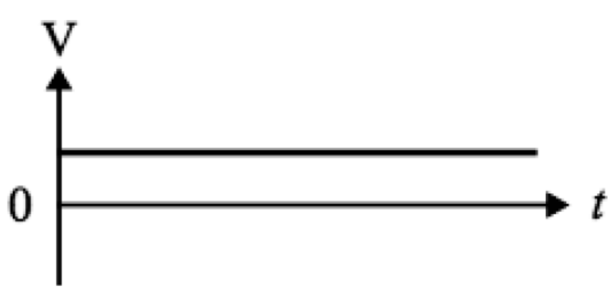
The output of the photovoltaic cell is now connected to an *inverter* in a household rooftop system. Which one of the following graphs best represents the output of the inverter?



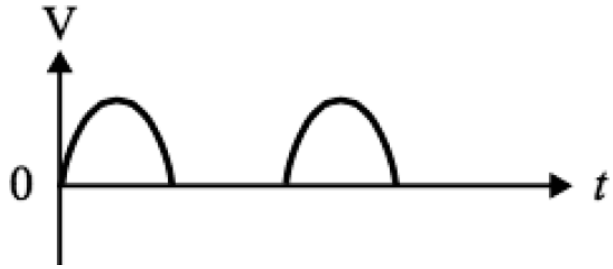
A



B



C

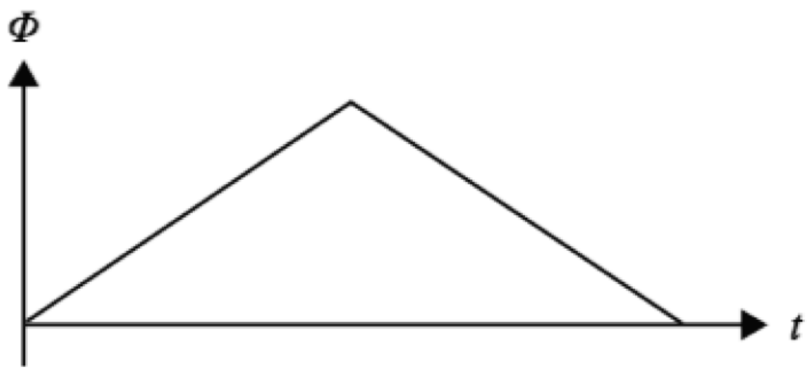


D

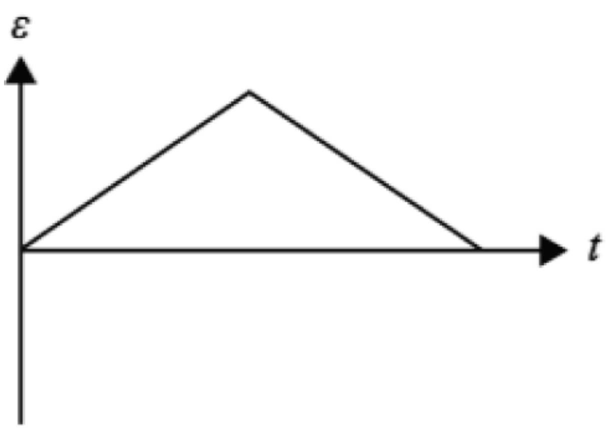
Question 8/ 22

[VCAA 2017 SA Q6]

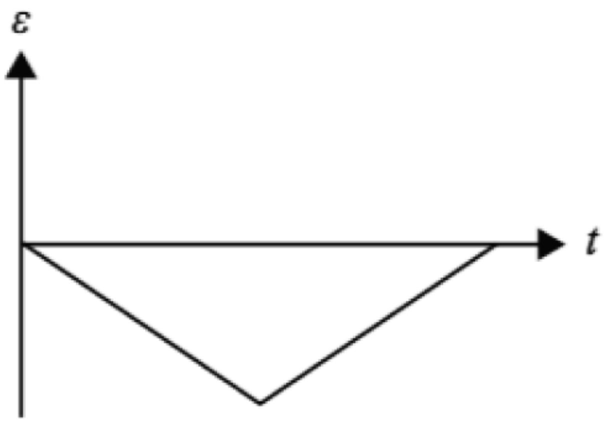
The graph below shows the change in magnetic flux (Φ) through a coil of wire as a function of time (*t*).



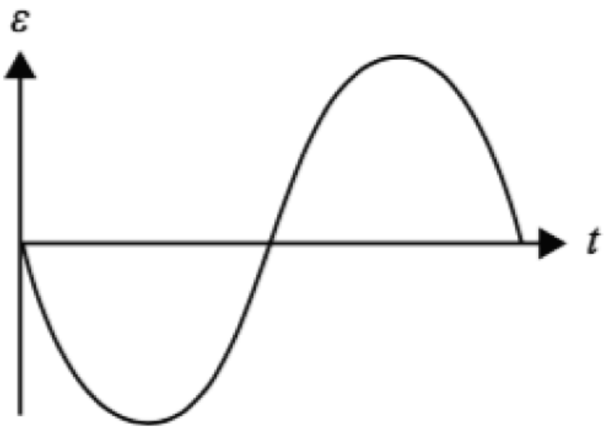
Which one of the following graphs best represents the induced EMF (*ε*) across the coil of wire as a function of time (*t*)?



A



B



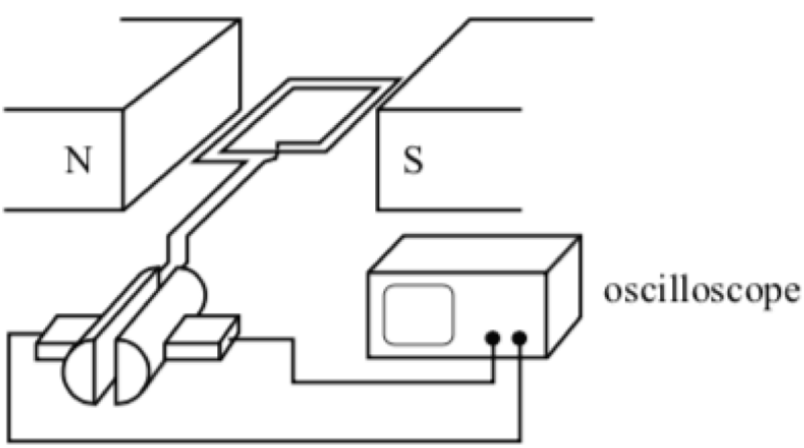
C

D Missing Image

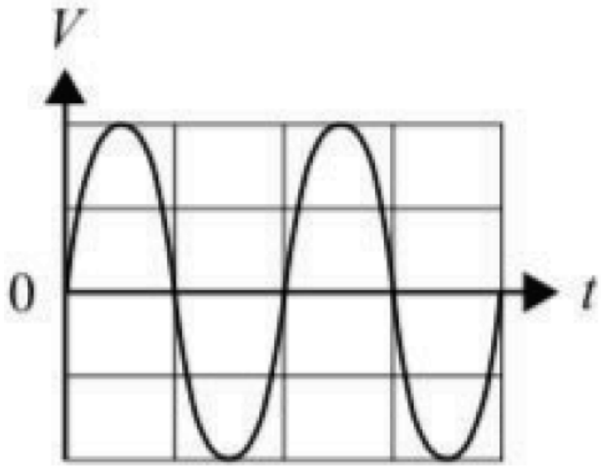
Question 9/ 22

[VCAA 2018 NHT SA Q4]

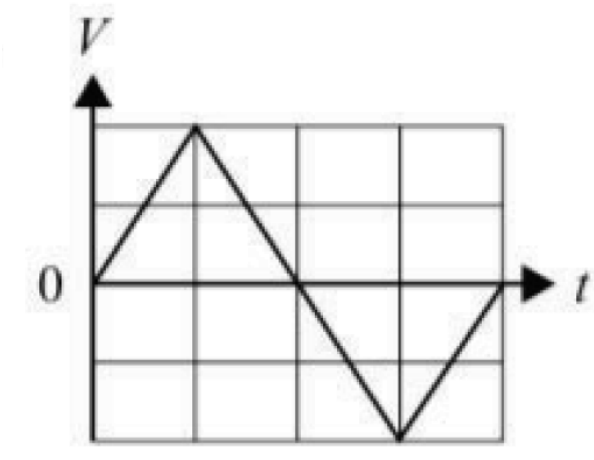
A simple DC generator consists of two magnets that produce a uniform magnetic field, in which a square loop of wire of 100 turns rotates at constant speed, and a commutator, as shown in the diagram below.



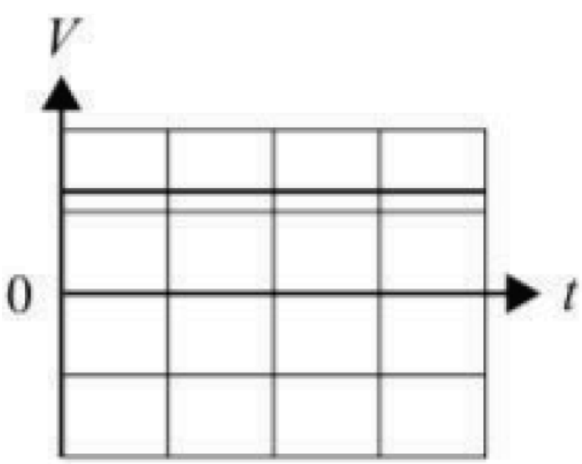
Which one of the following graphs on the next page best shows the display observed on the oscilloscope?



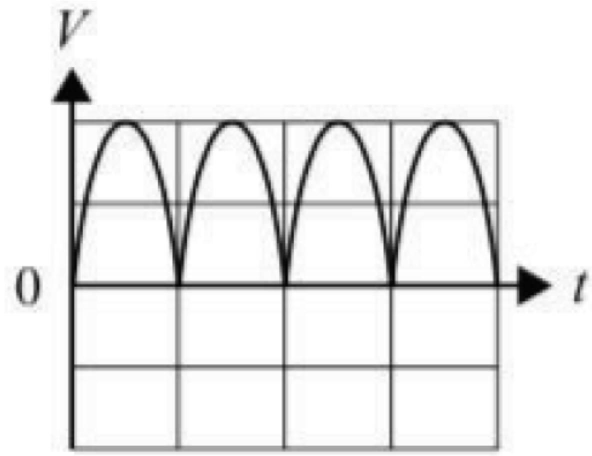
A



B



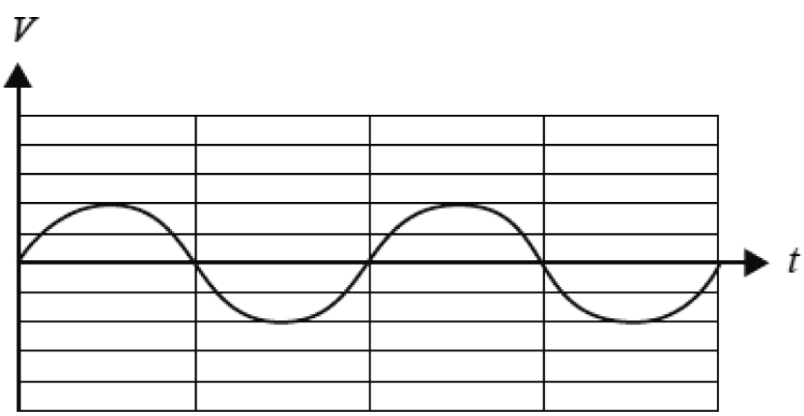
C

D 

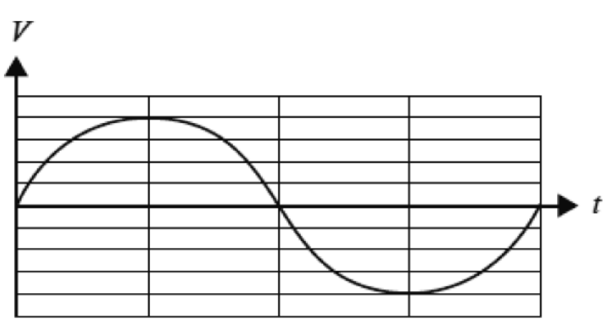
Question 10/ 22

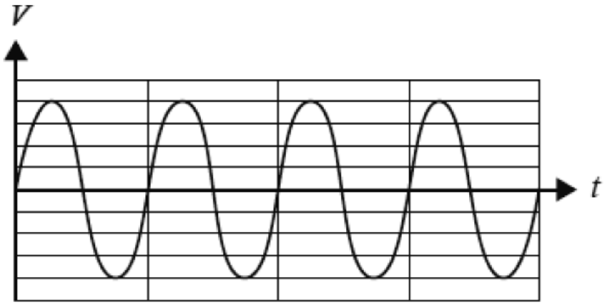
[VCAA 2019 NHT SA Q7]

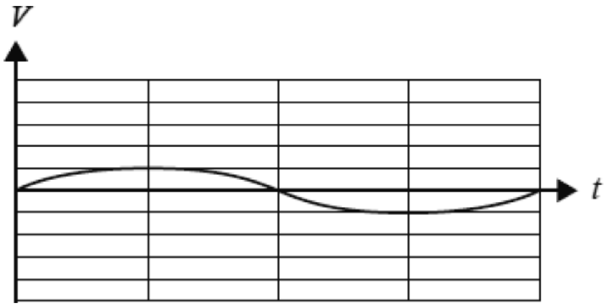
An alternator is rotating at 10 revolutions per second. Its output is measured by an oscilloscope. The signal produced is shown below.

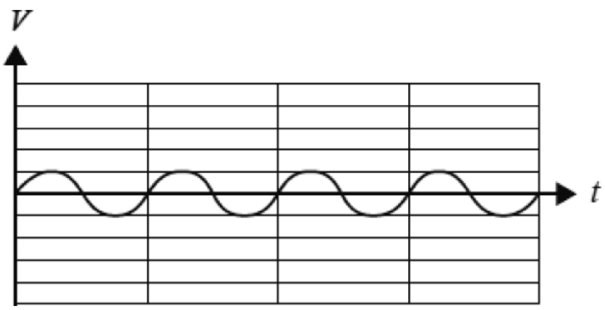


The alternator is then slowed so that it rotates at five revolutions per second. Which one of the following graphs best shows the display observed on the oscilloscope?

A 

B


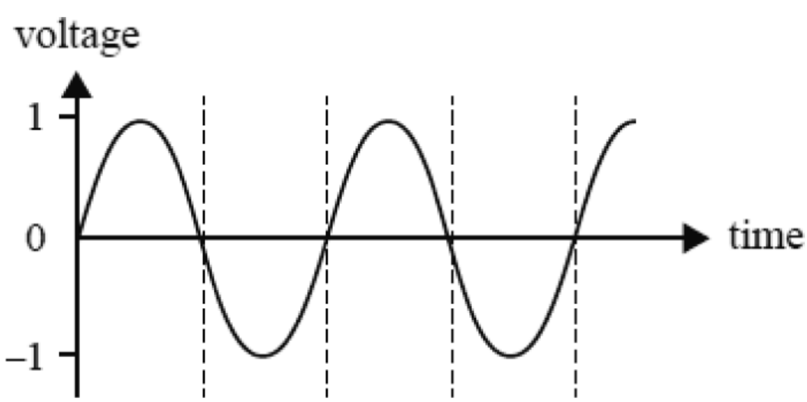
C


D


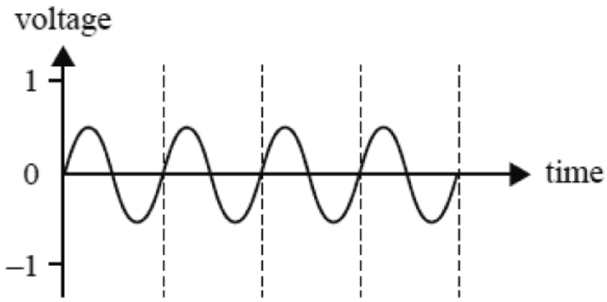
Question 11/ 22

[VCAA 2019 SA Q7]

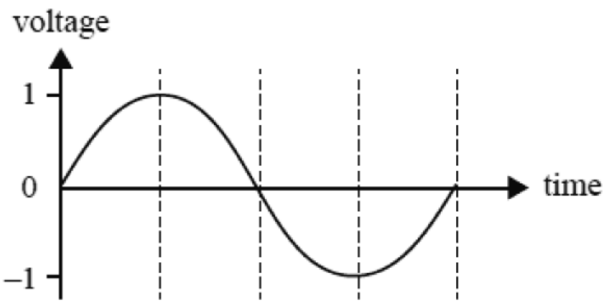
The coil of an AC generator completes 50 revolutions per second. A graph of output voltage versus time for this generator is shown below.



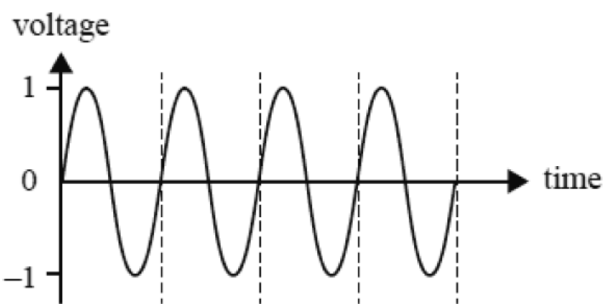
Which one of the following graphs best represents the output voltage if the rate of rotation is changed to 25 revolutions per second?



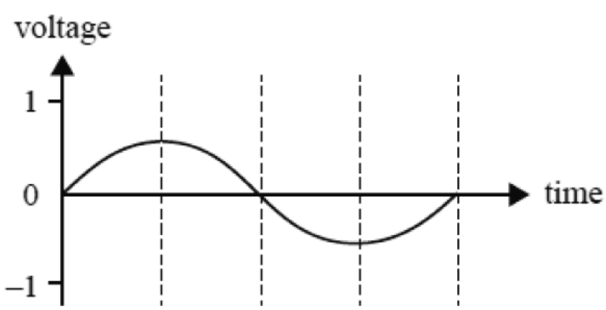
A



B



C

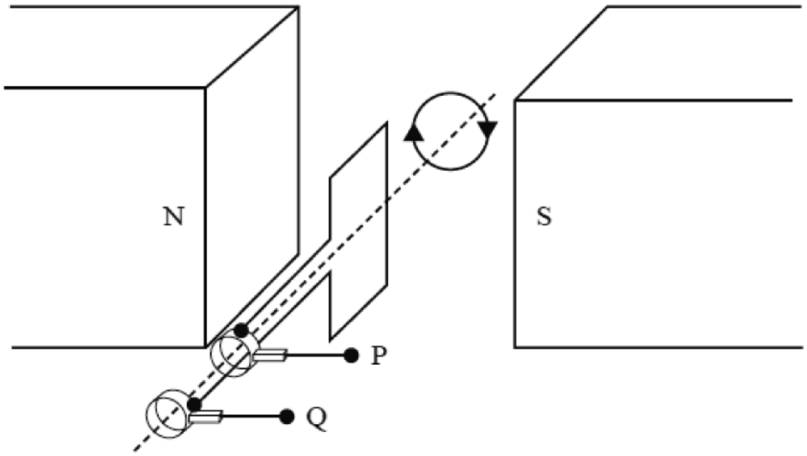


D

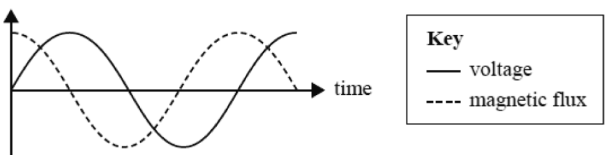
Question 12/ 22

[VCAA 2019 SA Q8]

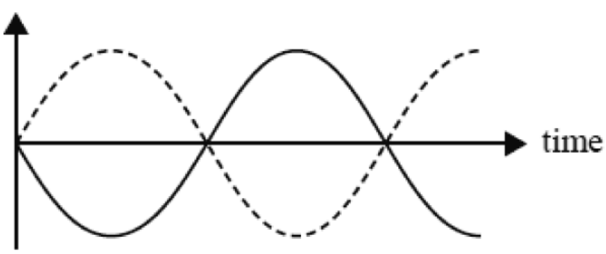
An electrical generator is shown in the diagram below. The generator is turning clockwise.



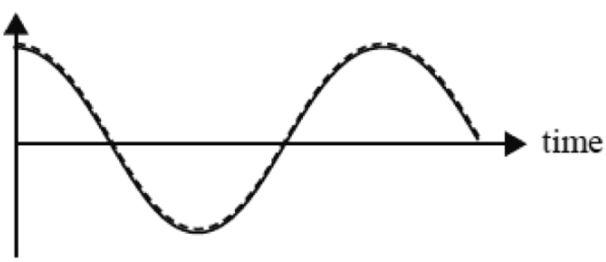
The voltage between P and Q and the magnetic flux through the loop are both graphed as a function of time, with voltage versus time shown as a solid line and magnetic flux versus time shown as a dashed line. Which one of the following graphs on the next page best shows the relationships for this electrical generator?



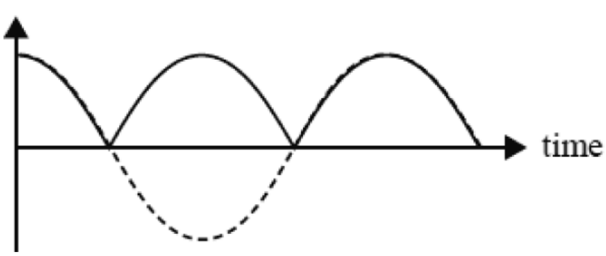
A



B



C

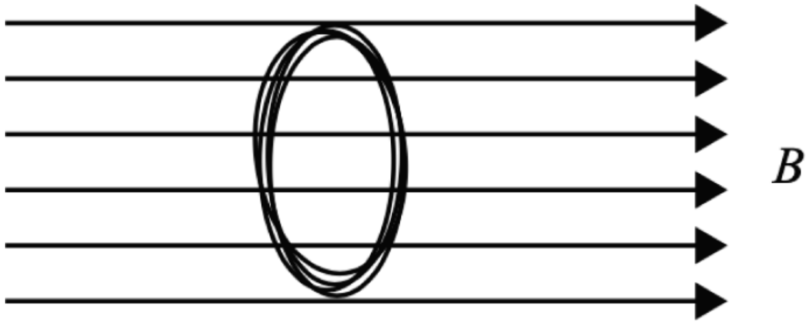


D

Question 13/ 22

[VCAA 2020 SA Q5]

A coil consisting of 20 loops with an area of 10 cm^2 is placed in a uniform magnetic field *B* of strength 0.03 T so that the plane of the coil is perpendicular to the field direction, as shown in the diagram below.



What is the value of the flux through the coil?

A 0 Wb

B 3.0×10^{-5} Wb

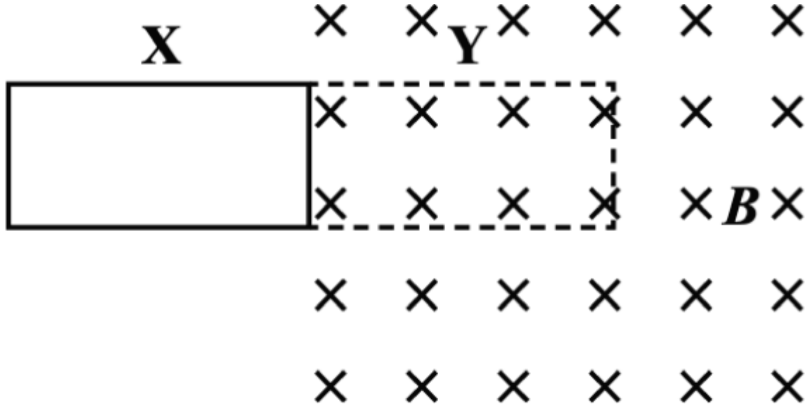
C 6.0×10^{-4} Wb

D 3.0×10^{-1} Wb

Question 14/ 22

[VCAA 2020 SA Q6]

A single loop of wire moves into a uniform magnetic field B of strength 3.5×10^{-4} T over time $t = 0.20$ s from point X to point Y, as shown in the diagram below. The area *A* of the loop is 0.05 m^2.



The magnitude of the average induced EMF in the loop is closest to

A 0 V

B 3.5×10^{-6} V

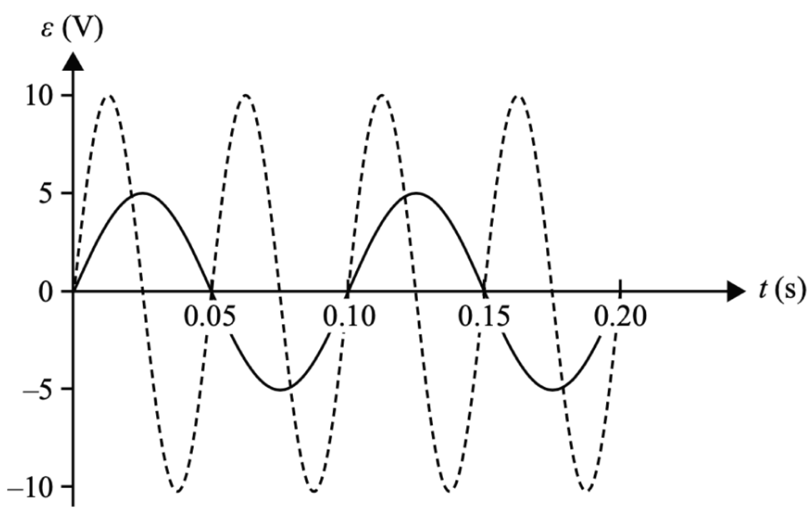
C 8.8×10^{-5} V

D 8.8×10^{3} V

Question 15/ 22

[VCAA 2021 NHT SA Q8]

In the diagram below, the solid line represents the graph of output EMF, ε, versus time produced by an AC generator. A single change is made to the AC generator and its operation, and the new graph of output EMF, ε, versus time is shown as a dashed line.



Which one of the following best describes the change made to the AC generator?

A The area of the coil was doubled.

B The speed of rotation was halved.

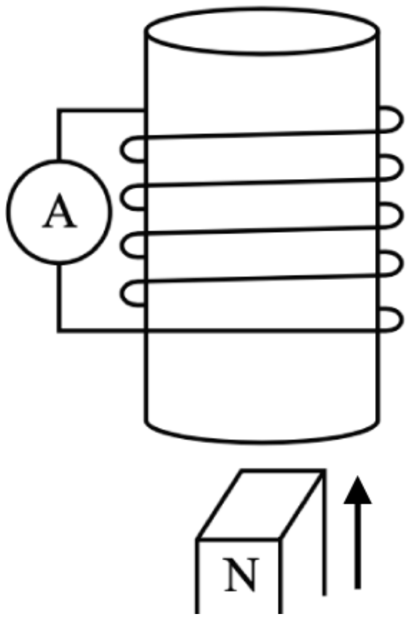
C The speed of rotation was doubled.

D The number of turns of the wire in the coil was doubled.

Question 16/ 22

[VCAA 2021 SA Q9]

The diagram below shows a bar magnet moving upward into a coil. Which of the following correctly identifies the direction of the induced current, as viewed from the top of the coil, and the direction of the magnetic field produced by the induced current inside the coil?

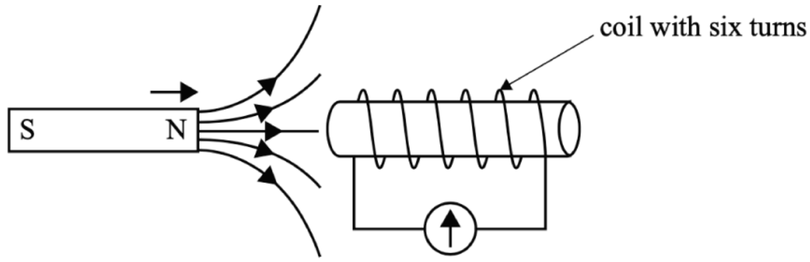


Current direction	Magnetic field direction
clockwise	↓
clockwise	↑
anticlockwise	↑
anticlockwise	↓

Question 17/ 22

[VCAA 2021 SA Q6]

A magnet approaches a coil with six turns, as shown in the diagram below. During time interval Δt, the magnetic flux changes by 0.05 Wb and the average induced EMF is 1.2 V.



Which one of the following is closest to the time interval Δt?

A 0.04 s

B 0.01 s

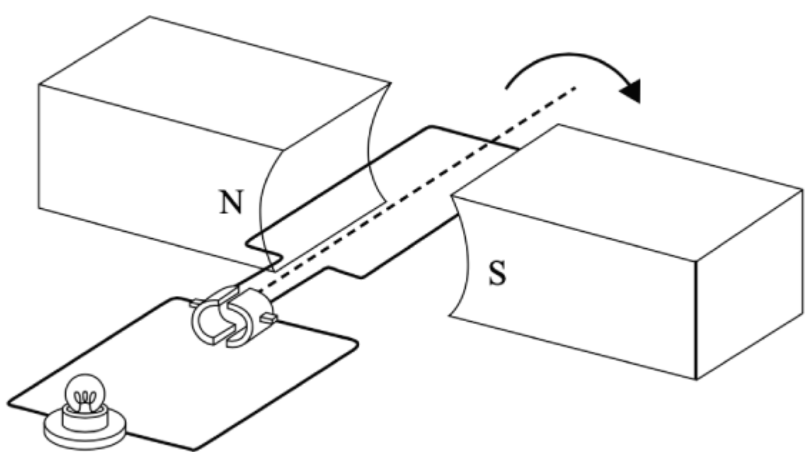
C 0.25 s

D 0.50 s

Question 18/ 22

[VCAA 2021 SA Q8]

The diagram below shows a simple electrical generator consisting of a rotating wire loop in a magnetic field, connected to an external circuit with a light globe, a split-ring commutator and brushes. The direction of rotation is shown by the arrow.



Which one of the following best describes the function of the split-ring commutator in the external circuit?

A It delivers a DC current to the light globe.

B It delivers an AC current to the light globe.

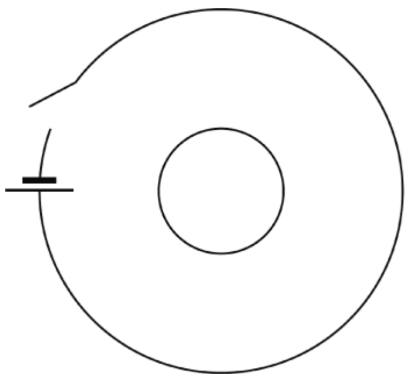
C It ensures the force on the side of the loop nearest the north pole is always up.

D It ensures the force on the side of the loop nearest the north pole is always down.

Question 19/ 22

[VCAA 2022 NHT SA Q6]

Two concentric loops of conducting wire are placed on a flat horizontal surface. The outer loop contains an open switch and a battery cell. The inner loop consists of a single closed loop of wire. The diagram below shows the arrangement of the two loops, as viewed from above. Which one of the following best describes the induced current in the inner loop when the switch is closed in the outer loop, as viewed from above?



A a steady clockwise current

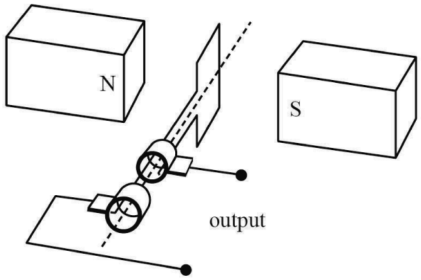
B a steady anticlockwise current

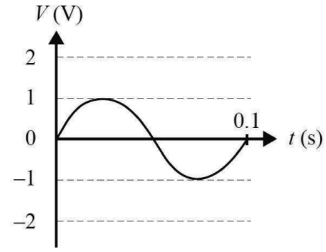
C a momentary clockwise current

D a momentary anticlockwise current

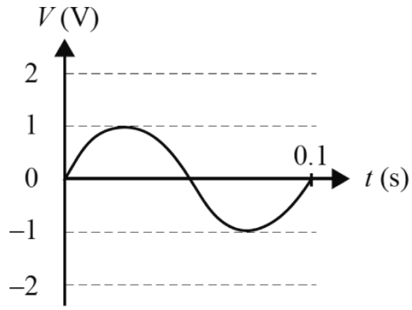
Question 20/ 22

A simple electricity generator is shown in the diagram below. When the coil is rotated, the output voltage across the slip rings is measured. The graph shows how the output voltage varies with time.

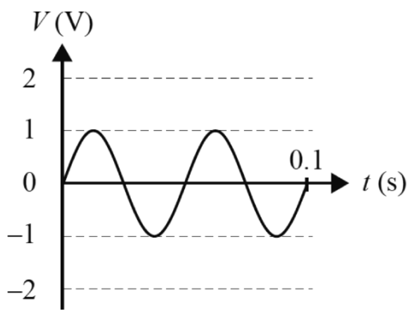




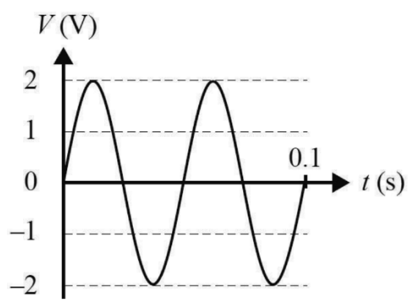
The frequency of rotation of the generator is now doubled. Which one of the following graphs best represents the output voltage measured across the slip rings?



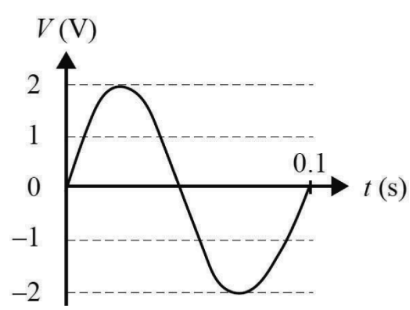
A



B



C



D

Question 21/ 22

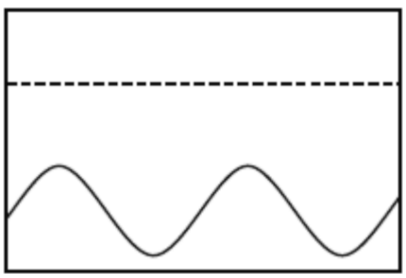
[VCAA 2023 NHT SA Q7]

Electrical generators may use slip rings or split-ring commutators when generating electricity. When operating at equal frequencies, the output voltages of these two types of generators can be displayed together on an oscilloscope screen.

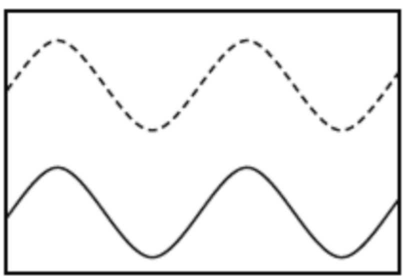
The output of the split-ring commutator is displayed as a dotted line.

The output of the slip rings is displayed as a solid line.

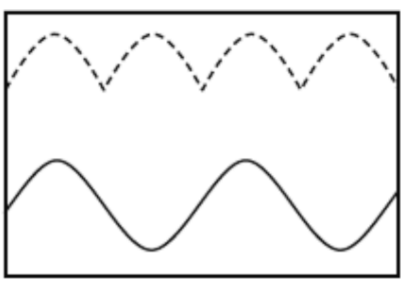
Which one of the following diagrams best represents the two outputs?



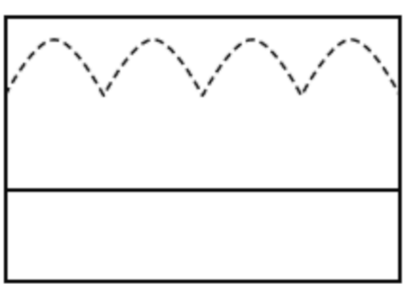
A



B



C

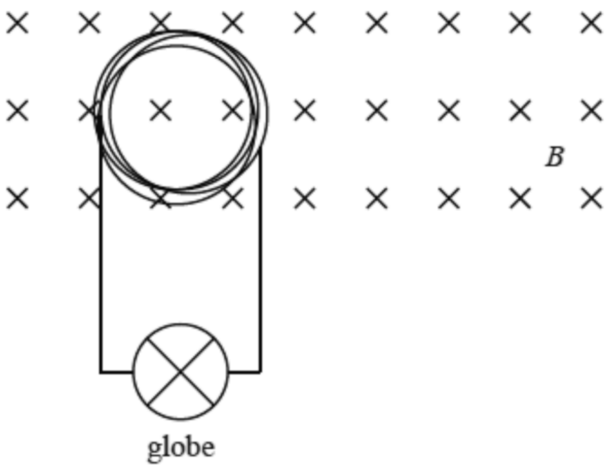


D

Question 22/ 22

[VCAA 2023 SA Q5]

The diagram below shows a stationary circular coil of conducting wire connected to a low-resistance globe in a uniform, constant magnetic field, *B*.



The magnetic field is switched off.

Which one of the following best describes the globe in the circuit before the magnetic field is switched off, during the time the magnetic field is being switched off and after the magnetic field is switched off?

Before	During	After
Off	On	Off
On	On	Off
On	Off	Off
Off	On	On

Question 23/ 22

[VCAA 2023 SA Q6]

The radius of the coil is 5 cm and the magnetic field strength is 0.2 T. The coil has 100 loops. Assume that the magnetic field is perpendicular to the area of the coil.

Which one of the following is closest to the magnitude of the magnetic flux through the coil of wire when the magnetic field is switched on?

A 0.0016 Wb

B 0.16 Wb

C 16 Wb

D 1600 Wb

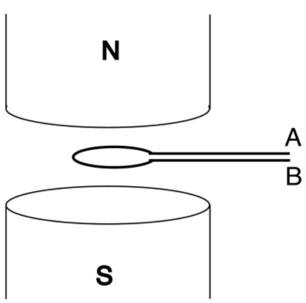
Question 1/ 50

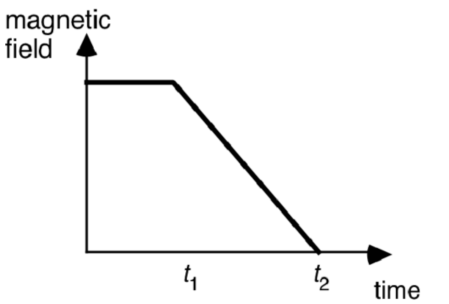
A coil is stationary in a steady 0.15 T magnetic field (at right angles to its area). The strength of the field changes to 0.10 T in a time of 0.15 s. The area of the coil is 0.20 m^2 and it has 100 turns. Calculate the average emf induced during this time. Show your working.

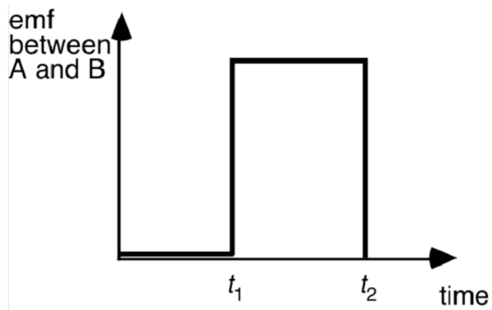
(3 marks)

Question 2/ 50

A single coil of area 0.15 m^2 of wire lies flat between the poles of an electromagnet, as shown. The field of the magnet changes as shown in the left-hand graph below. The emf between A and B is also shown as a function of time.







a. Explain why the induced voltage varies with time as shown.

(3 marks)

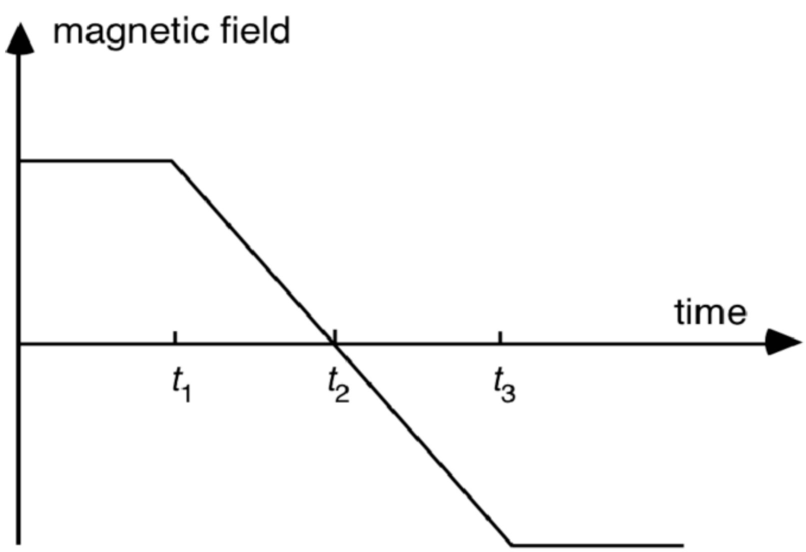
b. In a second experiment, the magnetic field is exactly *halved*, and the time interval between t_1 and t_2 is exactly *doubled*. Sketch the graph of the emf between A and B as a function of time.

(3 marks)

c. If the time interval between t_1 and t_2 is 25 ms and the initial value of the magnetic field is 200 mT, calculate the maximum value of the emf between A and B.

(2 marks)

In a third experiment, the field in the electromagnet is reduced to zero, reversed and increased again, as shown in the graph below.

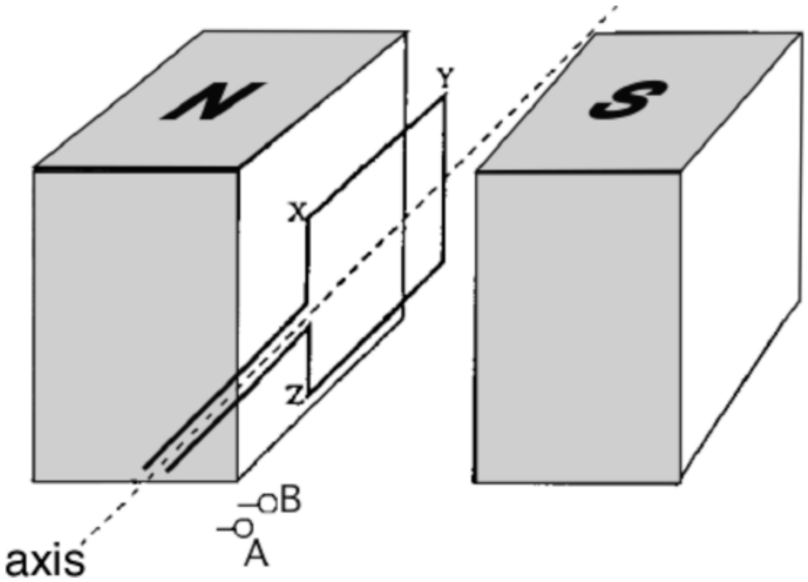


d. Sketch the shape of the emf induced between A and B in this case and explain your answer.

(4 marks)

Question 3/ 50

The diagram below shows a coil free to rotate about an axis with little friction. The coil is completely immersed in a uniform magnetic field.



a. If the coil is made to spin by an external force, the arrangement can produce an AC voltage between A and B. Such an arrangement is described as an *alternator*. Outline the nature of the connections between A and B and the coil for this to occur.

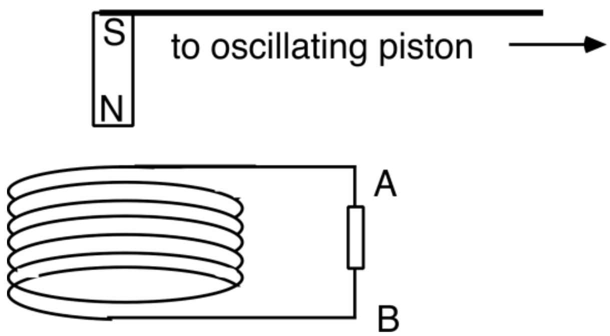
(3 marks)

b. Alternatively, with another kind of connection, a *DC* voltage can be produced between A and B. Outline the nature of the connections between the coil and A and B for this to occur.

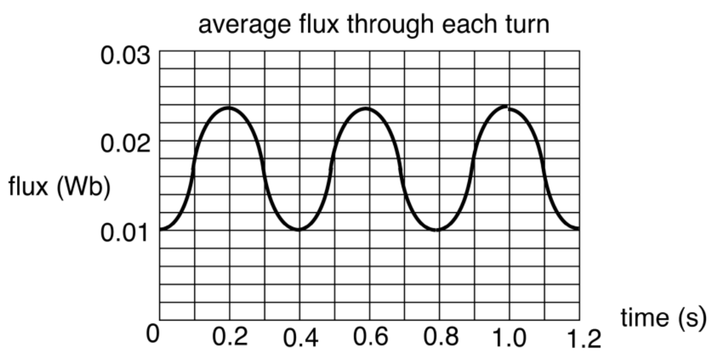
(3 marks)

Question 4/ 50

A magnet on the end of a lever oscillates up and down through a coil, as shown. The coil has an area of $0.20\ \text{m}^2$ and 50 turns.



The graph on the next page shows how the magnetic flux through the coil changes with time as the magnet moves into and out of the coil.



a. Sketch the emf across the coil against time, from $t = 0$ to $t = 0.4$ s.

(3 marks)

b. Calculate the *average* emf between $t = 0.4$ s and $t = 0.6$ s.

(2 marks)

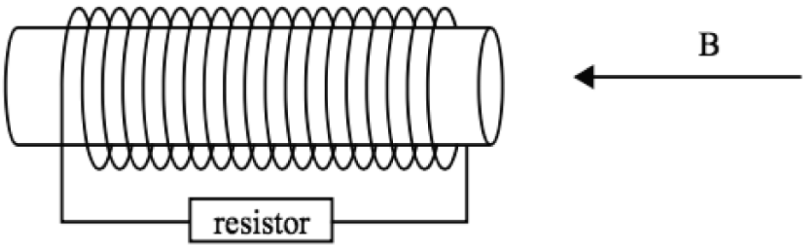
c. If the generator is attached to a load of resistance 4.5 Ω, find the average current. The resistance of the coil is very low.

(2 marks)

Question 5/ 50

[VCAA 2016 SA Q15]

A coil is wound around a cardboard cylinder, as shown in the diagram.



The cross-sectional area of the coil is $0.0060\ \text{m}^2$. There are 1000 turns in the coil. The coil is immersed in a uniform external magnetic field of strength 0.0050 T. Its direction is shown by the arrow labelled B in the diagram.

a. Calculate the magnitude of the flux through the first turn of the coil. Include an appropriate unit.

(2 marks)

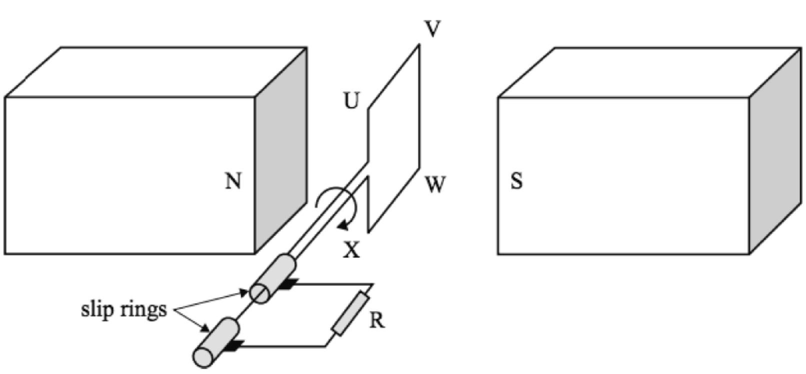
b. The external magnetic field is now reduced to zero. This results in an emf in the coil. Describe the direction of the current in the resistor during this time (use the words 'left' and 'right'). Give reasons for your answer.

(3 marks)

Question 6/ 50

[VCAA 2016 S Q17]

Samira and Mark construct a simple slip-ring alternator, as shown.



When the coil is rotating steadily, it takes 40 ms for each complete rotation and produces a peak emf of 3.5 V.

a. Calculate the frequency of the AC emf.

(2 marks)

b. Calculate the RMS value of the AC emf.

(1 mark)

c. Describe the orientation of the rotating coil when the magnitude of the emf is a maximum. Give reasons for your answer.

(2 marks)

d. To increase the magnitude of the emf produced by the alternator, a student suggests making a number of changes to the alternator. He suggests these changes:

• increase the number of turns in the rotating coil

• increase the frequency of the rotating coil

• increase the strength of the permanent magnets

• reduce the resistance of the resistor R.

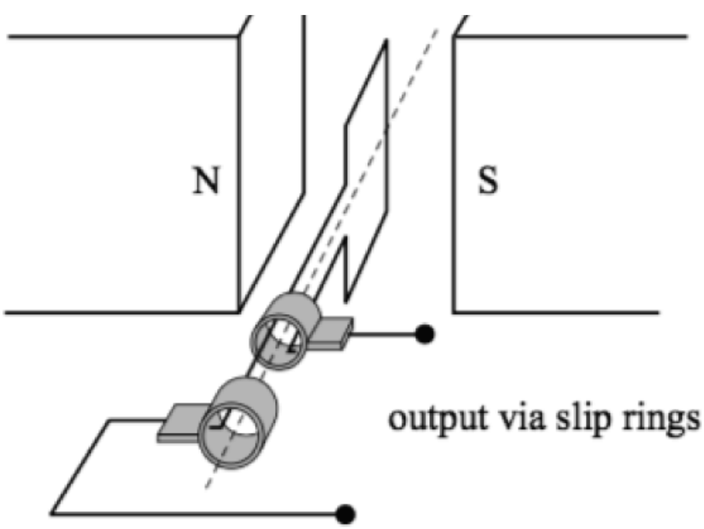
Evaluate these responses.

(4 marks)

Question 7/ 50

[Adapted VCAA 2017 SB Q5]

The alternator in the diagram has a 10 turn rectangular coil with sides of 0.30 m and 0.40 m. The coil rotates four times a second in a uniform magnetic field. The magnetic flux through the coil in the position shown is 0.20 Wb.



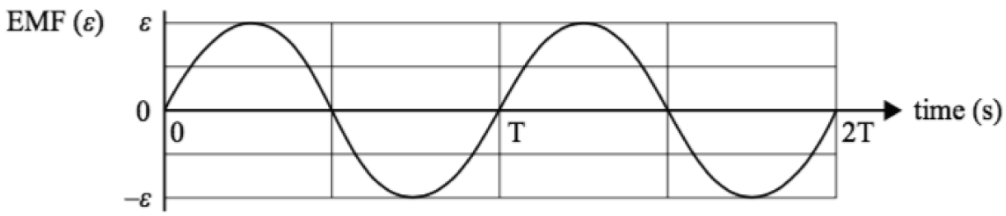
a. Calculate the magnitude of the magnetic field. Include an appropriate unit.

(3 marks)

b. Calculate the magnitude of the average EMF (ε) generated in a quarter of a turn. Show all the steps of your working.

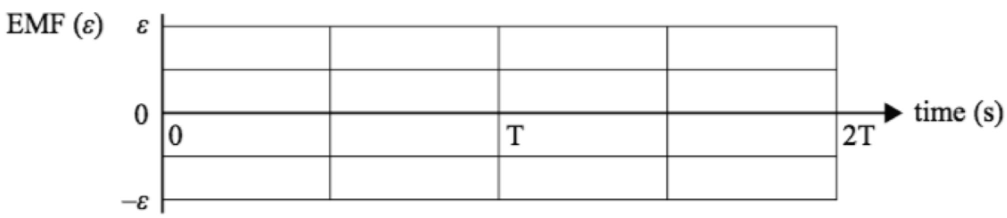
(3 marks)

c. The graph below shows the output EMF (ε) versus time graph of the alternator for two complete cycles.



The two slip rings are now replaced with a split-ring commutator.

On the diagram below, sketch the EMF (ε) versus time graph of this new arrangement for two complete cycles.

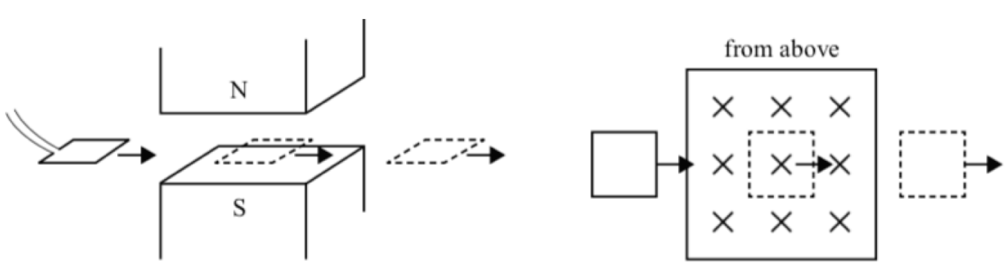


(2 marks)

Question 8/ 50

[VCAA 2018 NHT SB Q4]

Students move a square loop of wire of 100 turns and of cross-sectional area $4.0 \times 10^{-4} \mathrm{m}^2$. The loop moves at constant speed from outside left, into, through and out of a magnetic field, as shown in the left-hand diagram. The area between the poles has a uniform magnetic field of magnitude $2.0 \times 10^{-3} \mathrm{T}$. The right-hand diagram shows the view from above.



a. On the axes provided below, sketch the magnetic flux, Φ_B, through the loop as it moves into, through and out of the magnetic field.

(2 marks)

b. On the axes provided below, sketch the EMF induced through the loop as it moves into, through and out of the magnetic field.

(2 marks)

c. The loop takes 2.0 s to move from completely outside to completely inside the magnetic field. Calculate the magnitude of the induced EMF in the loop as it moves into the magnetic field.

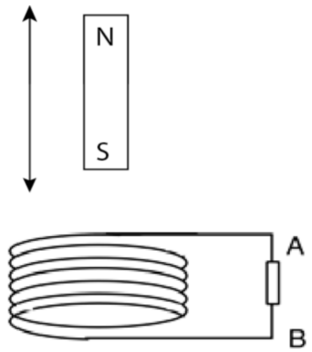
(2 marks)

d. Determine the direction of the induced current in the loop as it moves into the magnetic field as viewed from above (clockwise or anticlockwise). Justify your answer.

(3 marks)

Question 9/ 50

A generator coil of area 0.2 m^2 with 7 turns, has an associated magnet that oscillates up and down through it, as shown in the diagram.



a. Describe the direction of the induced current through the resistor between A and B when the magnet is travelling down towards the coil.

(2 marks)

b. The graph below shows how the average flux through each turn changes with time. Identify when the magnet is momentarily stationary. Give your answers to one significant figure.

(2 marks)

Missing Image

c. Sketch the variation of the current in the resistor between A and B as a function of time (no need to indicate *direction* through the resistor).

(2 marks)

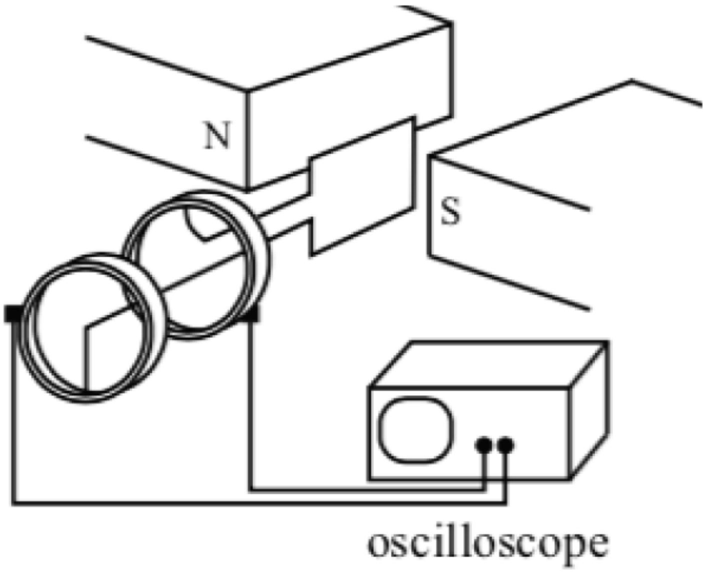
d. Calculate the *average* emf across the coil between time $t = 0.4$ s and $t = 0.6$ s.

(2 marks)

Question 10/ 50

[VCAA 2017 Sample SB Q4]

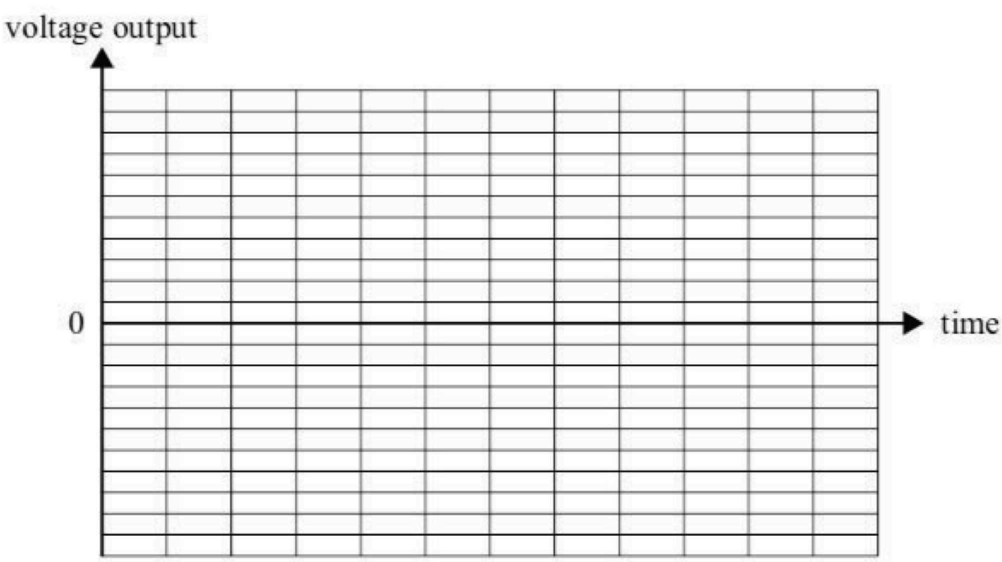
The diagram below shows a simple alternator. The strength of the magnetic field is 0.50 T, the loop has 20 turns, the area of the loop is $0.020\ \mathrm{m}^2$ and the rate of rotation is 10 Hz.



a. Calculate the magnitude of the average EMF induced as the loop turns from the instant shown to a point one-quarter of a period later. Show your working and include an appropriate unit.

(3 marks)

b. The alternator gradually slows to a stop. On the grid provided below, sketch the voltage output expected. Scale values are not required on the axes.

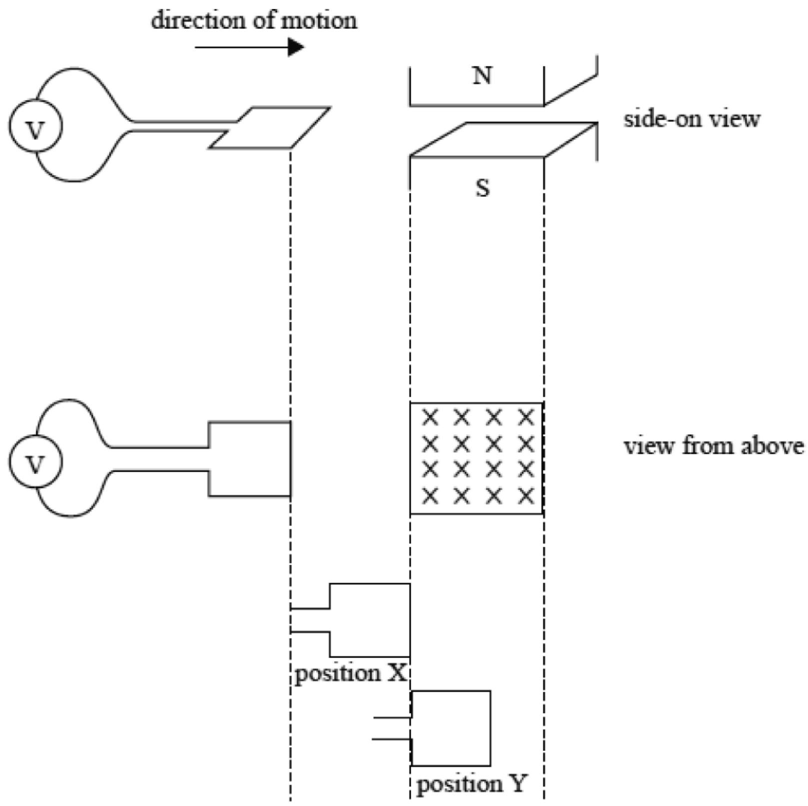


(3 marks)

Question 11/ 50

[VCAA 2018 SB Q2]

A square loop of wire of 10 turns with a cross-sectional area of $1.6 \times 10^{-3}\ \mathrm{m}^2$ passes at a constant speed into, through and out of a magnetic field of magnitude $2.0 \times 10^{-2}\ \mathrm{T}$, as shown below. The loop takes 0.50 s to go from position X to position Y.

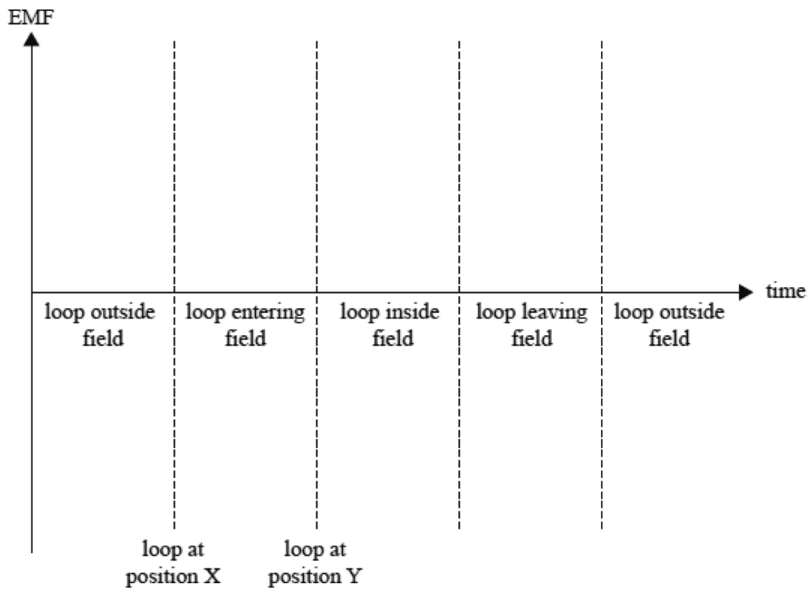


a. Calculate the average EMF induced in the loop as it passes from just outside the magnetic field at position X to just inside the magnetic field at position Y. Show your working.

(3 marks)

b. Sketch the EMF induced in the loop as it passes into, through and out of the magnetic field. You do not need to include values on the axes.

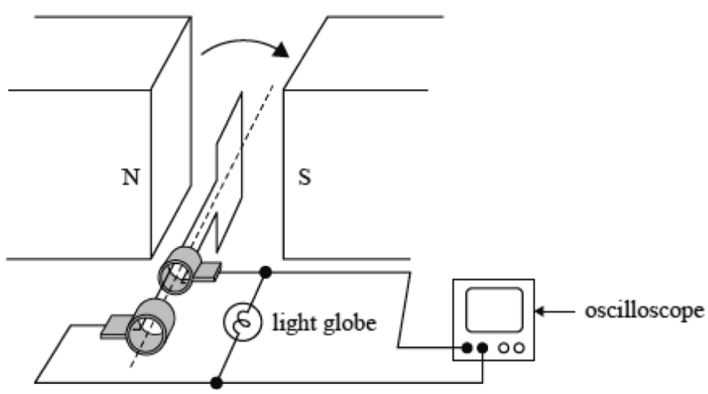
(3 marks)



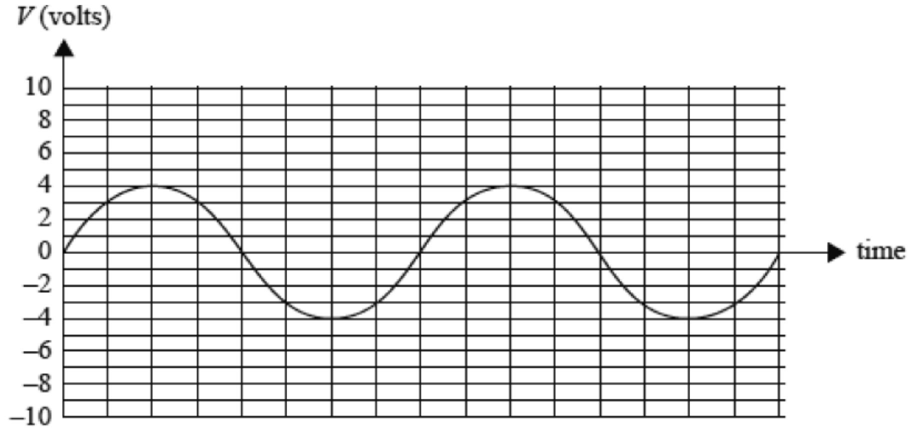
Question 12/ 50

[VCAA 2018 SB Q4]

The diagram shows a simple AC alternator with the output connected to an oscilloscope and a light globe. The oscilloscope can be considered as having a very large resistance. The coil is rotated, as shown.



The output on the oscilloscope is shown in the diagram below.

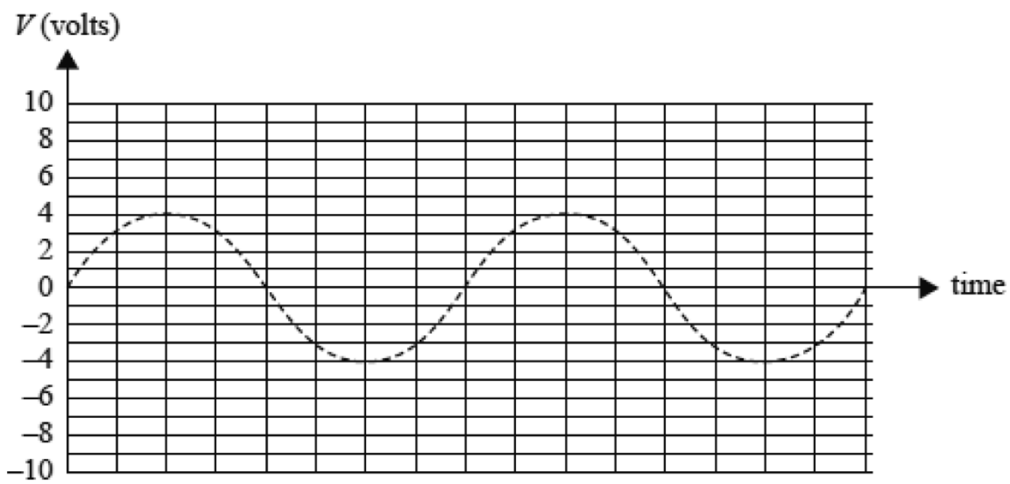


a. The AC alternator is to be replaced with a battery. What voltage should the battery have for the light globe to light up with the same average brightness as it did with the alternator? Show your working.

(2 marks)

b. The rate of rotation of the loop is doubled. On the diagram below, sketch the output that will now be seen on the oscilloscope. The original waveform is shown as a dashed line.

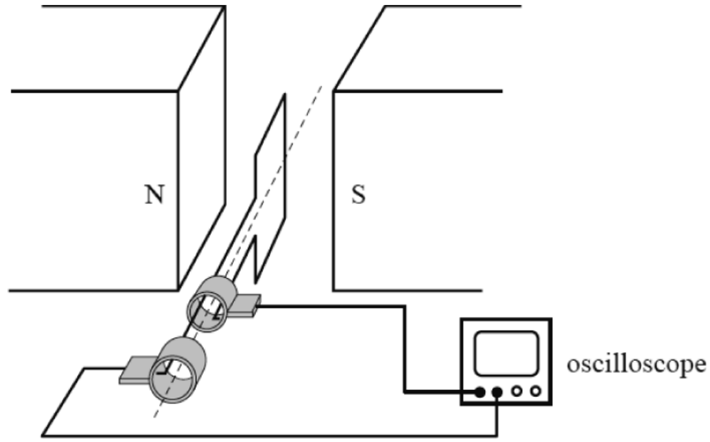
(2 marks)



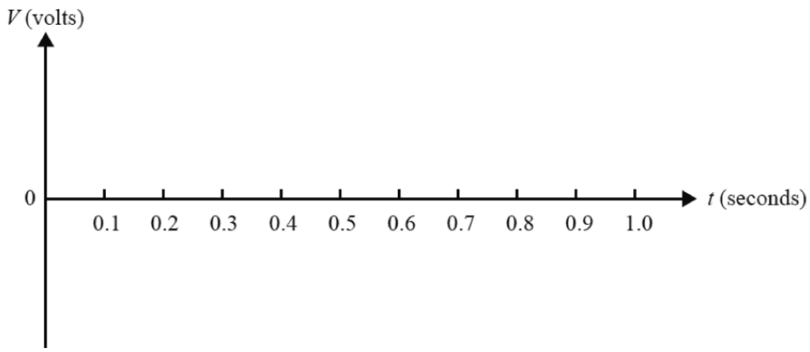
Question 13/ 50

[Adapted VCAA 2019]

A square loop of wire with a cross-sectional area of $0.010\ \mathrm{m}^2$ and 20 turns rotates in a magnetic field of strength $4.0 \times 10^{-2}\ \mathrm{T}$. The wires of the loop are connected to two slip rings and an oscilloscope, as shown below.



The loop takes 0.10 s to make a quarter rotation (from a position at right angles to the field to a position parallel to the field). On the axes provided below, sketch the output signal that would be displayed on the oscilloscope over 1.0 s. A value or scale on the *y* axis is not necessary. Take the position of the loop at $t = 0$ to be that shown in the diagram above.

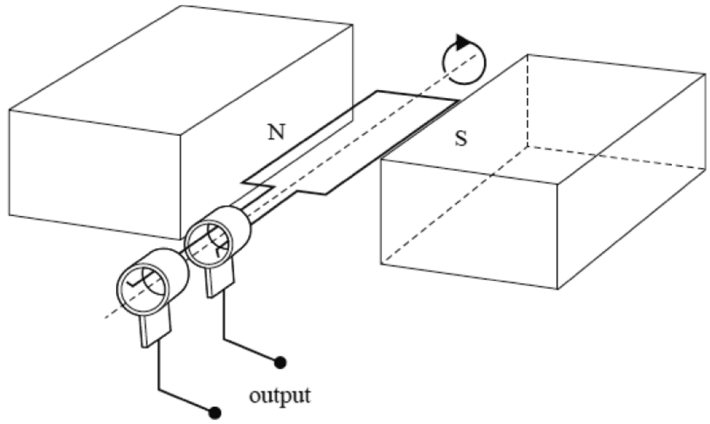


(2 marks)

Question 14/ 50

[VCAA 2019 SB Q7]

Students in a Physics practical class investigate the piece of electrical equipment shown below. It consists of a single rectangular loop of wire that can be rotated within a uniform magnetic field. The loop has dimensions $0.50 \text{ m} \times 0.25 \text{ m}$ and is connected to the output terminals with slip rings. The loop is in a uniform magnetic field of strength 0.40 T.



a. Circle the name that best describes the piece of electrical equipment shown in the diagram.

alternator DC generator DC motor AC motor

(1 mark)

b. i. What is the magnitude of the flux through the loop when it is in the position shown in the diagram?

(1 mark)

ii. Explain your answer to part **bi**.

(1 mark)

The students connect the output terminals of the piece of electrical equipment to an oscilloscope. One student rotates the loop at a constant rate of 20 revolutions per second.

c. Calculate the period of rotation of the loop.

(1 mark)

d. Calculate the maximum flux through the loop. Show your working.

(2 marks)

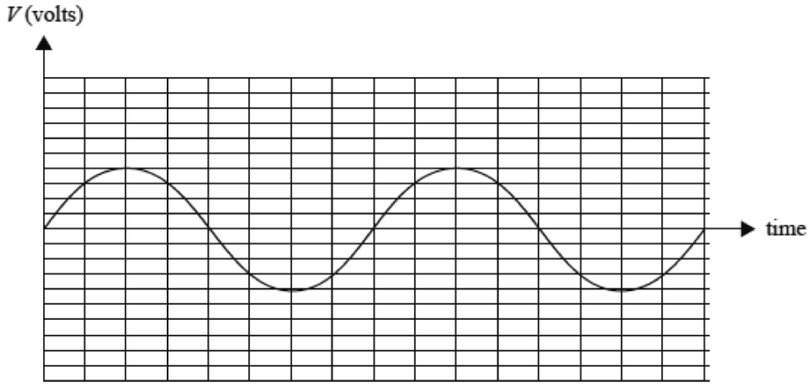
e. The loop starts in the position shown in the diagram. What is the average voltage measured across the output terminals for the first quarter turn? Show your working.

(2 marks)

f. State two ways that the amplitude of the voltage across the output terminals can be increased.

(2 marks)

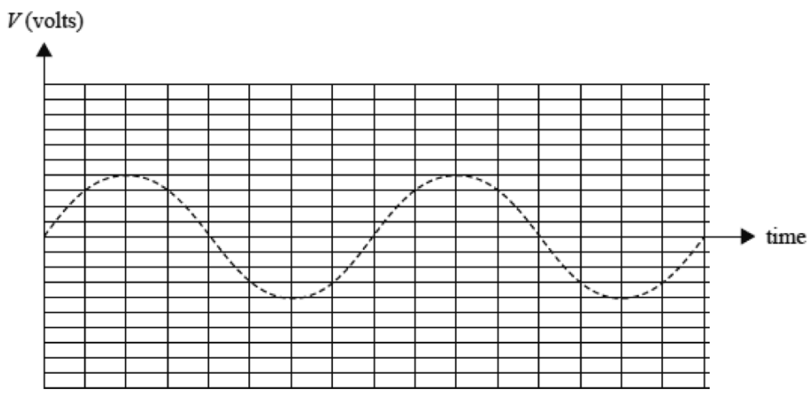
g. The diagram below shows the output voltage graph shown on the oscilloscope for two cycles.



The students now replace the slip rings in the earlier diagram with a split-ring commutator.

On the diagram below, sketch with a *solid* line the output that the students will now observe on the oscilloscope. Show two complete revolutions. The original output is shown with a *dashed* line.

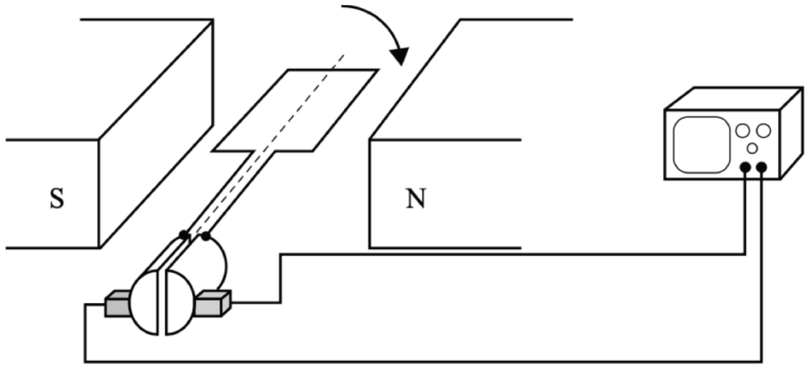
(1 mark)



Question 15/ 50

[VCAA 2020 SB Q5]

A rectangular wire loop with dimensions $0.050 \text{ m} \times 0.035 \text{ m}$ is placed between two magnets that create a uniform magnetic field of strength 0.2 mT. The loop is rotated with a frequency of 50 Hz in the direction shown in the diagram. The ends of the loop are connected to a split-ring commutator to create a DC generator. The loop is initially in the position shown in the diagram.



a. In which direction – clockwise or anticlockwise – will the induced current travel through the loop for the first quarter turn as seen from above?

(1 mark)

b. Calculate the average EMF measured in the loop for the first quarter turn.

(3 marks)

c. On the axes provided below, sketch the output EMF versus time, *t*, for the first two rotations. Include a scale on the horizontal axis.

(3 marks)

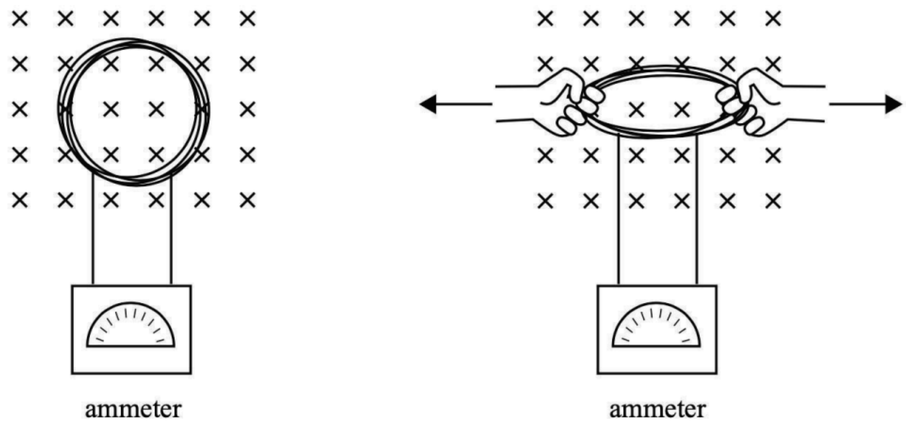
d. Suggest two modifications that could be made to the apparatus shown in the initial diagram that would increase the output EMF of the DC generator.

(2 marks)

Question 16/ 50

[VCAA 2020 SB Q6]

Two Physics students hold a coil of wire in a constant uniform magnetic field, as shown in the left-hand diagram. The ends of the wire are connected to a sensitive ammeter. The students then change the shape of the coil by pulling each side of the coil in the horizontal direction, as shown in the right-hand diagram. They notice a current register on the ammeter.



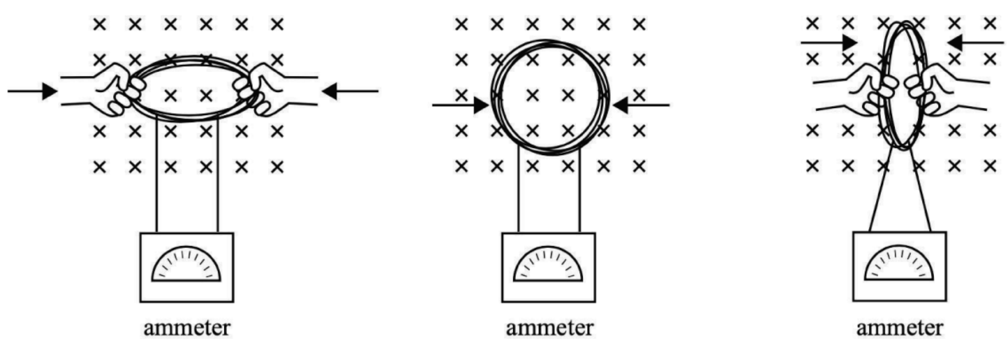
a. Will the magnetic flux through the coil increase, decrease or stay the same as the students change the shape of the coil?

(1 mark)

b. Explain, using physics principles, why the ammeter registered a current in the coil and determine the direction of the induced current.

(3 marks)

c. The students then push each side of the coil together, as shown in the diagram below, so that the coil returns to its original circular shape, as shown, and then changes to the shape shown in right-hand diagram below.



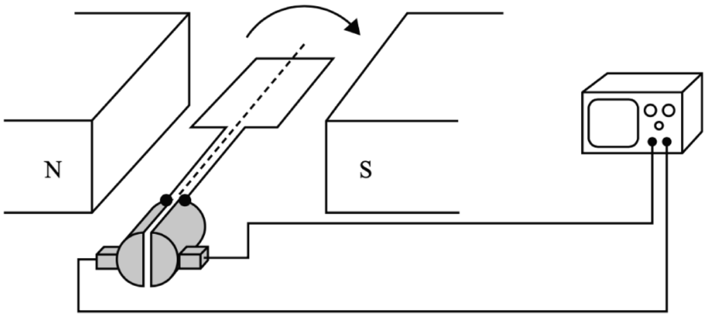
Describe the direction of any induced currents in the coil during these changes. Give your reasoning.

(2 marks)

Question 17/ 50

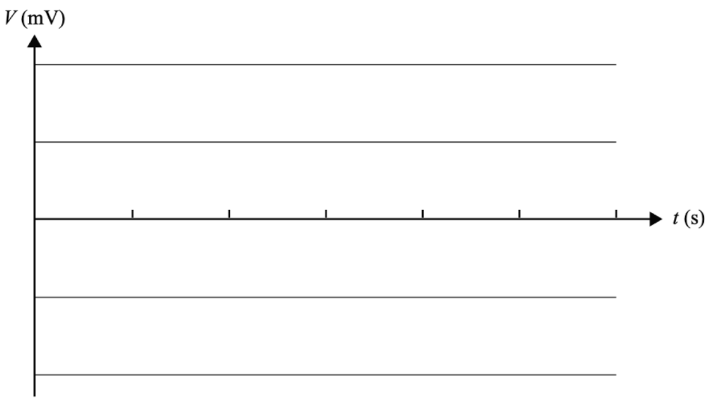
[VCAA 2021 NHT SB Q5]

Physics students who are investigating the generation of electricity spin a coil at a constant 10 rotations per second in a uniform magnetic field. They observe the output on an oscilloscope. The experimental set-up is shown on the next page. The peak voltage produced by the coil is 5 mV.



On the axes below, sketch the voltage versus time graph observed on the screen of the oscilloscope for one complete rotation of the coil from the position shown in the diagram. Include appropriate scales on each axis.

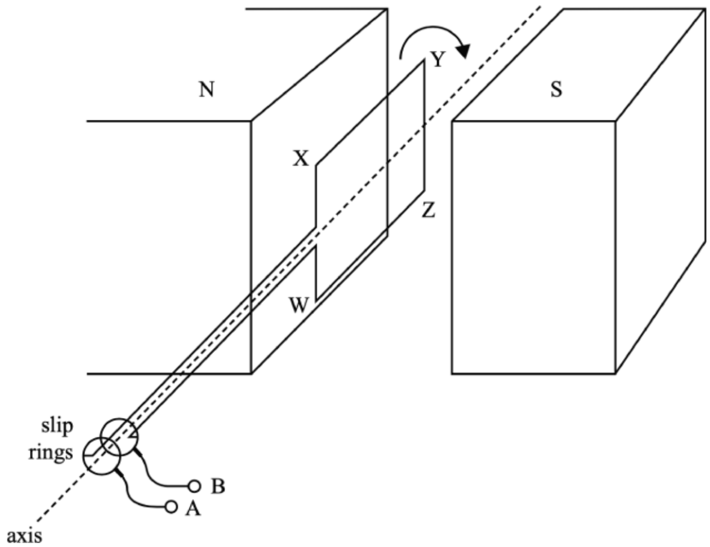
(3 marks)



Question 18/ 50

[VCAA 2021 NHT SB Q6]

Gir and Kau are investigating electromagnetic induction. They have a single wire loop of dimensions $\mathrm{XY} = 0.030\ \mathrm{m}$ long and $\mathrm{YZ} = 0.020\ \mathrm{m}$ wide, which is placed in a uniform magnetic field of strength 0.20 T. The loop is rotated clockwise about an axis, as shown below.



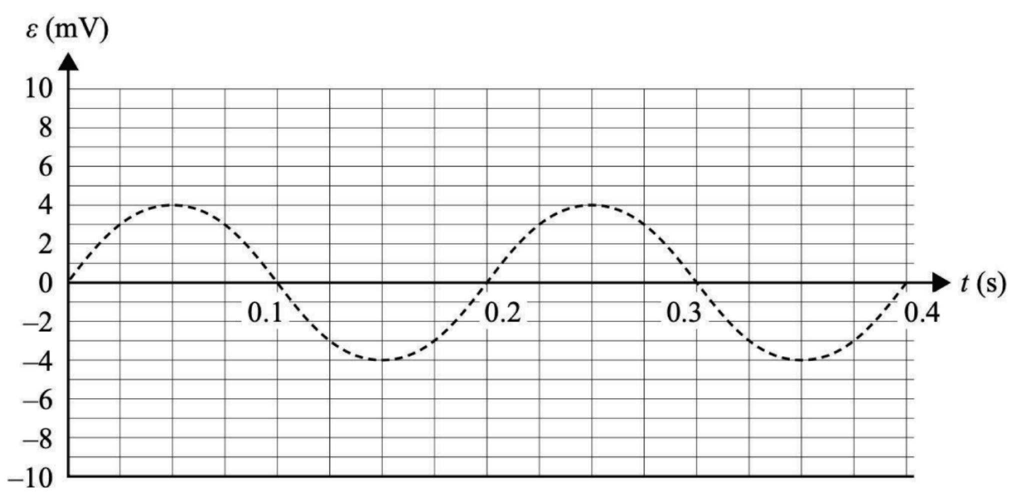
a. Explain the purpose of the slip rings in the apparatus shown in the diagram above.

(2 marks)

b. Calculate the size of the magnetic flux through the loop when it is oriented as shown in the diagram above. Show your working.

(2 marks)

The loop is rotated by Kau at a constant frequency, f, and an EMF, ε, is generated. The diagram below shows the generated EMF versus time trace observed on the screen of an oscilloscope.

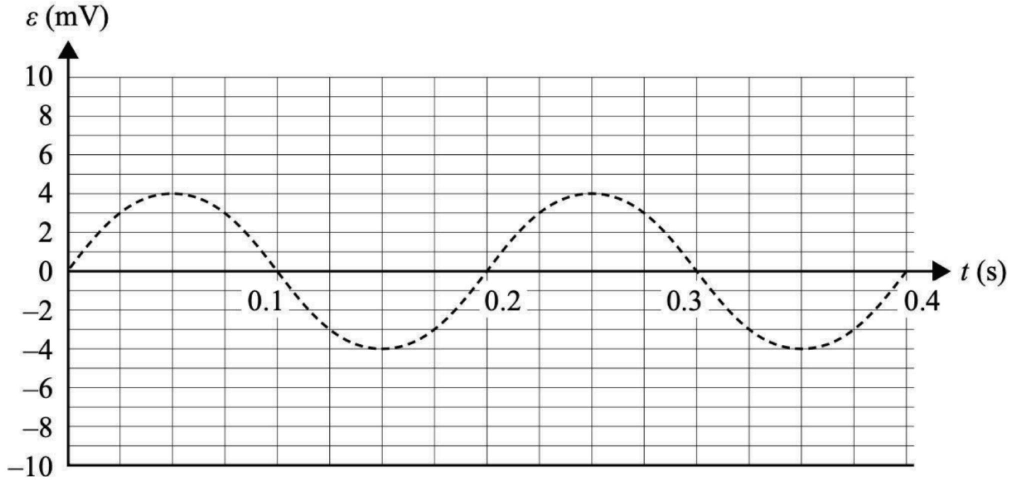


c. Calculate the frequency of the rotation from the oscilloscope trace shown in the diagram above.

(1 mark)

d. Gir now doubles the number of turns in the loop from one turn to two turns, creating two loops. The loops are again rotated at the same constant frequency, *f*. On the diagram on the next page, sketch a graph that shows the resulting variation of the EMF with time between points A and B. The original output is shown as a dashed line.

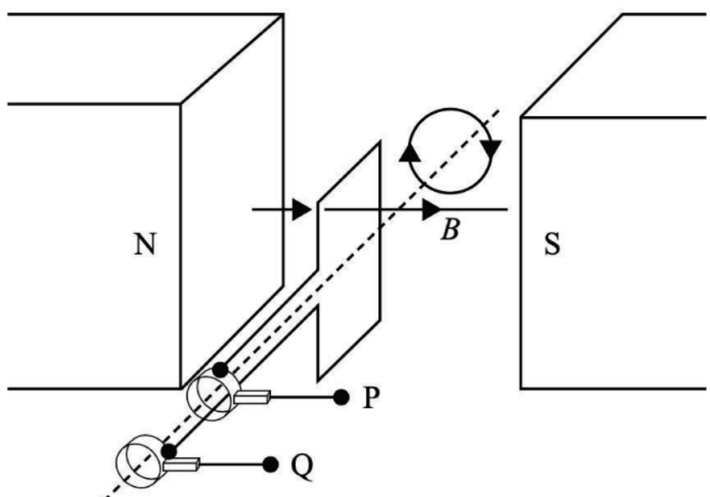
(2 marks)



Question 19/ 50

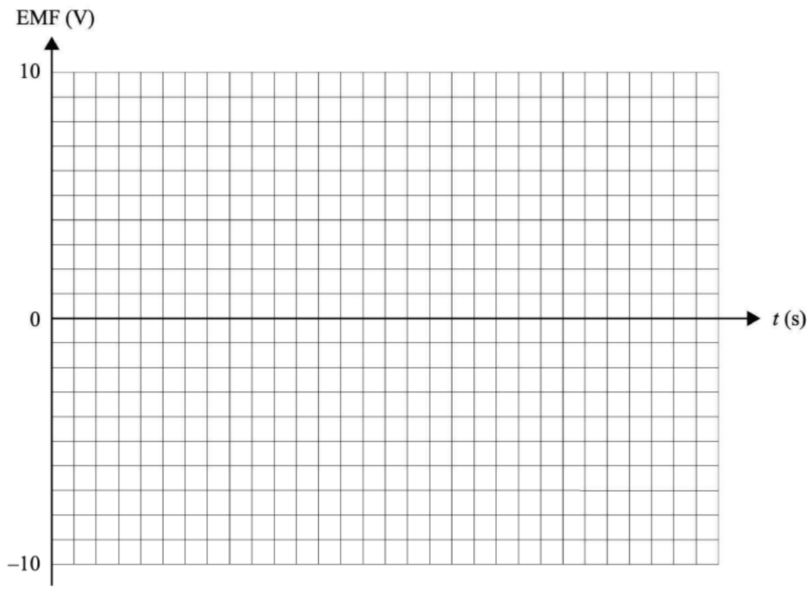
[VCAA 2021 SB Q6]

The diagram below shows a simple AC generator. A mechanical energy source rotates the loop smoothly at 50 revolutions per second and the loop generates an RMS voltage of 4.25 V. The magnetic field, *B*, is constant and uniform. The direction of rotation is as shown in in the diagram below.



a. Sketch the output EMF between P and Q versus time, *t*, on the grid below, starting with the loop in the position shown in in the diagram. Show at least two complete revolutions, and include the maximum voltage on the vertical axis and a time scale on the horizontal axis.

(4 marks)



b. Describe the function of the slip rings shown in the diagram.

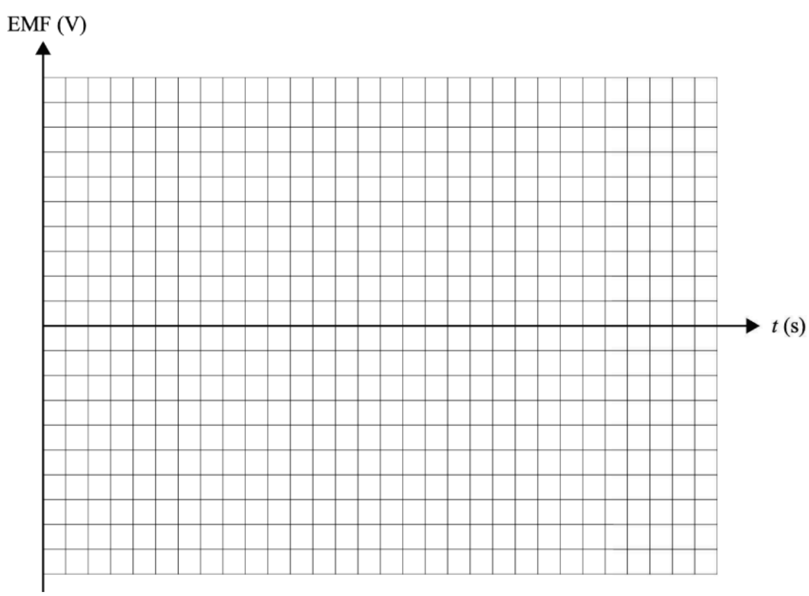
(1 mark)

c. i. How could the AC generator shown be changed to a DC generator?

(1 mark)

ii. Sketch the output EMF versus time, t, for this DC generator *for at least two* complete revolutions on the grid below. Include a time scale on the horizontal axis. No scale is required for the vertical axis.

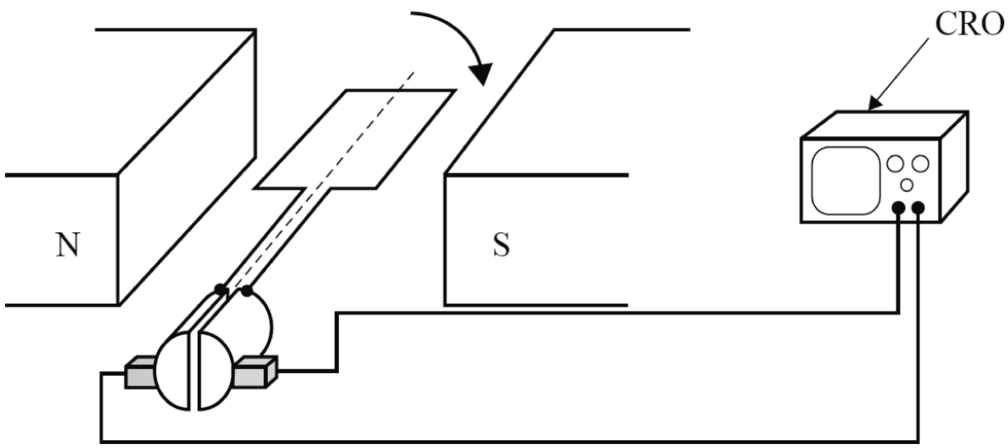
(2 marks)



Question 20/ 50

[VCAA 2022 NHT SB Q4]

The diagram below shows a schematic diagram of a simple DC generator with the output connected to a cathode ray oscilloscope (CRO). The DC generator consists of a rectangular wire coil of 200 turns placed in a uniform magnetic field of strength 5.0 mT. The coil is rotated with a frequency of 60 Hz in the direction shown in the diagram The average EMF generated in the coil for the first quarter turn is 35 mV. The coil is initially in the position shown in the diagram.



a. When viewed from above, will the induced current in the coil be clockwise or anticlockwise during the first quarter turn?

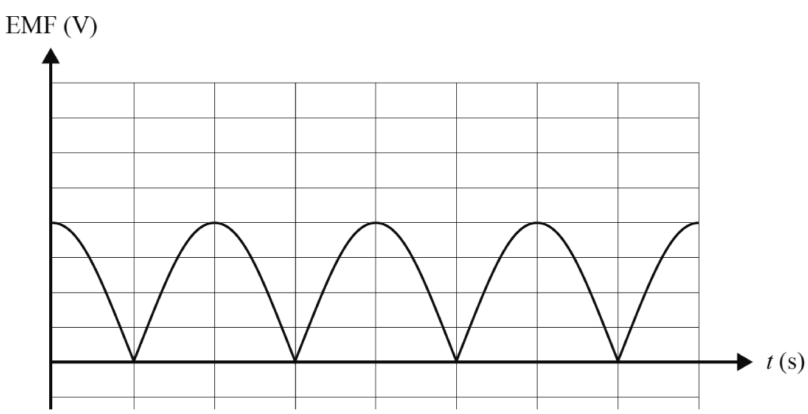
(1 mark)

b. Calculate the area of one loop of the rectangular wire coil. Show your working.

(3 marks)

c. The graph on the next page shows the EMF induced in the coil over two full turns. On the same axes, sketch the output EMF that would result if the number of turns in the coil is changed to 100 turns and the frequency of rotation is changed to 30 Hz.

(2 marks)



Question 21/ 50

[VCAA 2022 NHT SB Q5]

A bar magnet is moved towards a single closed loop of conducting wire with the bar magnet's south pole closest to the loop, as shown in the diagram below. The loop is stationary.

The area and the shape of the loop remain constant and the magnet is not changed. Explain, in terms of magnetic flux, how a current is induced in the loop.

(2 marks)

Question 22/ 50

[VCAA 2022 SB Q4]

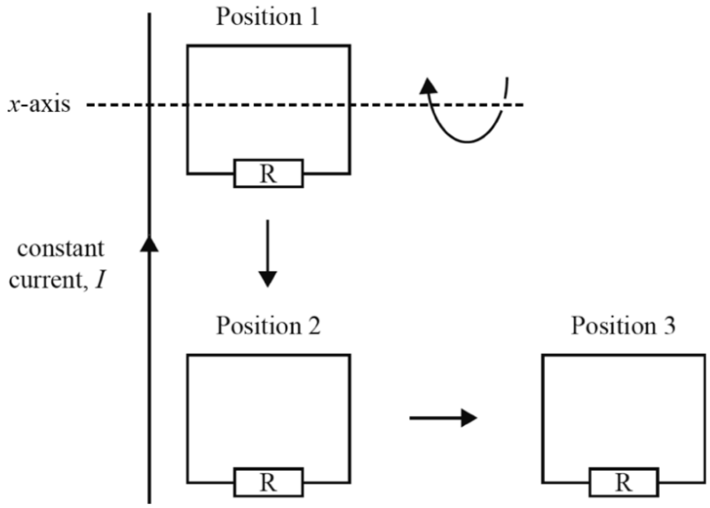
A square loop of wire connected to a resistor, R, is placed close to a long wire carrying a constant current, *I*, in the direction shown in the diagram below.

The square loop is moved three times in the following order:

• Movement A – Starting at Position 1 in the diagram, the square loop rotates one full rotation at a steady speed about the *x*-axis. The rotation causes the resistor, R, to first move out of the page.

• Movement B – The square loop is then moved at a constant speed, parallel to the current carrying wire, from Position 1 to Position 2 in the diagram.

• Movement C – The square loop is moved at a constant speed, perpendicular to the current carrying wire, from Position 2 to Position 3 in the diagram.



Complete the table below to show the effects of each of the three movements by:

• sketching any EMF generated in the square loop during the motion on the axes provided (scales and values are not required)

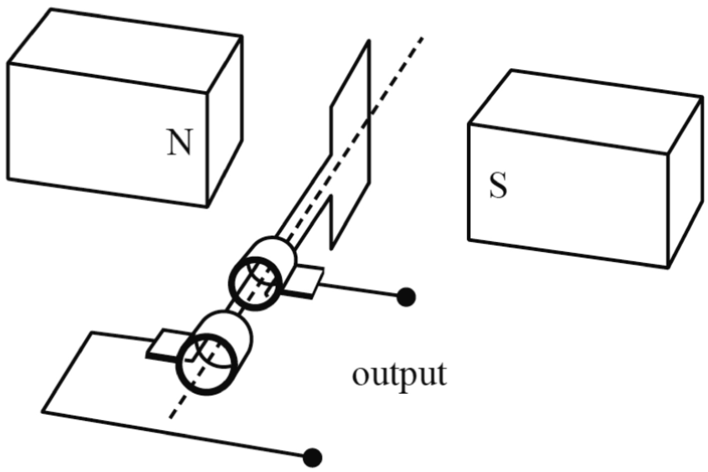
• stating whether any induced current in the square loop is 'alternating', 'clockwise', 'anticlockwise' or has 'no current'.

Movement	**Possible induced EMF**	**Direction of any induced current (alternating/clockwise /anticlockwise/no current)**
A rotation about *x*-axis		
B moving from Position 1 to Position 2		
C moving from Position 2 to Position 3		

Question 23/ 50

[VCAA 2022 SB Q6]

The diagram below shows a simple alternator consisting of a rectangular coil of area $0.060 \mathrm{~m}^2$ and 200 turns, rotating in a uniform magnetic field. The magnetic flux through the coil in the vertical position shown in diagram is $1.2 \times 10^{-3} \mathrm{Wb}$.



a. Calculate the strength of the magnetic field in the diagram. Show your working.

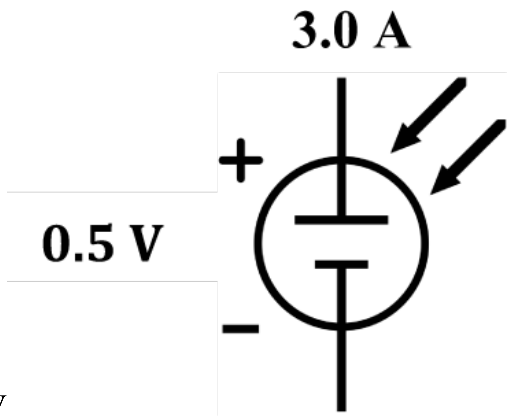
(2 marks)

b. The rectangular coil rotates at a frequency of 2.5 Hz. Calculate the average induced EMF produced in the first quarter of a turn. Begin the quarter with the coil in the vertical position shown in the diagram.

(3 marks)

Question 24/ 50

One particular photovoltaic (PV) cell, shown below, produces 0.5 V and generates a current, in full sunlight, of 3.0 A.



0.5 V

a. Calculate the power output of a single photovoltaic (PV) cell operating at optimum conditions.

(2 marks)

b. Draw a circuit showing two of these PV cells wired in series. Calculate the output voltage, current and power of this series combination.

(2 marks)

c. Draw a circuit showing two of these PV cells wired in parallel. Calculate the output voltage, current and power of this parallel combination.

(2 marks)

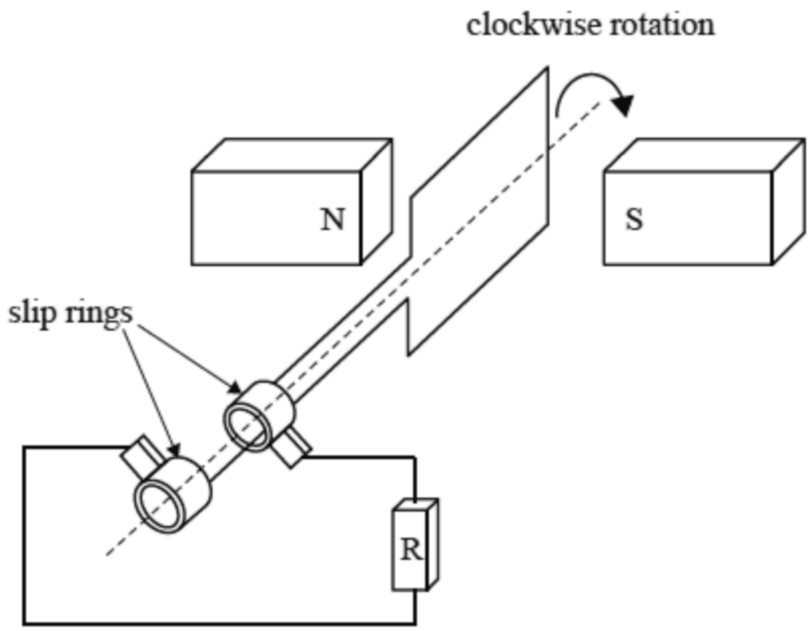
d. How many PV cells, and in what configuration (series or parallel), would you need to generate 36 W at 3.0 A and 12.0 V?

(2 marks)

Question 25/ 50

[VCAA NHT 2023 SB Q8]

Sarah and Raminda construct a simple alternator, as shown below.



When the coil is rotating steadily, it takes 50.0 ms to complete one revolution and the peak EMF generated is 4.30 V.

a. Calculate the frequency of the alternator.

(1 mark)

b. Calculate the EMF, V_{RMS}, generated. Show your working and give your answer correct to three significant figures.

(2 marks)

c. To increase the magnitude of the EMF produced by the alternator, Raminda suggests making a number of changes to the alternator.

Sarah insists that each change be investigated one at a time.

In the spaces provided, indicate whether each suggestion will increase, decrease or have no effect on the EMF produced by the alternator.

Suggested change	**Effect on EMF (increases, decreases or has no effect)**
reduce the resistance of resistor R	
increase the strength of the permanent magnets	
reduce the period of rotation of the coil to 25 ms	
increase the number of turns of the rotating coil	

(4 marks)

Question 26/ 50

[VCAA NHT 2023 SB Q10]

A single rectangular loop of wire containing a cut out section labelled EF moves to the right at a constant speed of 2.4 m s^{-1}, as shown below. At time $t = 0$, the right-hand edge of the loop enters a constant magnetic field into the page.

Missing Image

The induced EMF produced as a function of time is shown in the graph below.

Missing Image

While the loop enters, and is partially within, the field, an EMF is generated between points E and F.

a. Which point, E or F, is positive?

(1 mark)

b. Explain why the induced EMF is constant during the time period 0.00 s to 0.025 s.

(2 marks)

c. Calculate the strength of the magnetic field through which the rectangular loop travels.

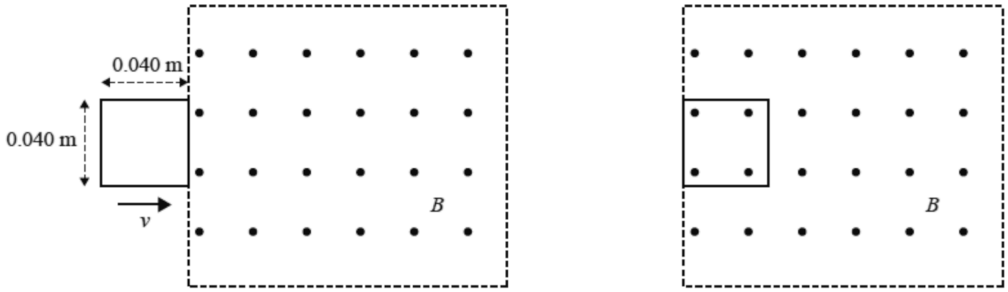
(3 marks)

Question 27/ 50

[Adapted VCAA 2023 SB Q5]

The diagram below (left) shows a single square loop of conducting wire placed just outside a constant uniform magnetic field, *B*. The length of each side of the loop is 0.040 m. The magnetic field has a magnitude of 0.30 T and is directed out of the page.

Over a time period of 0.50 s, the loop is moved at a constant speed, *v*, from completely outside the magnetic field to completely inside the magnetic field as shown below.

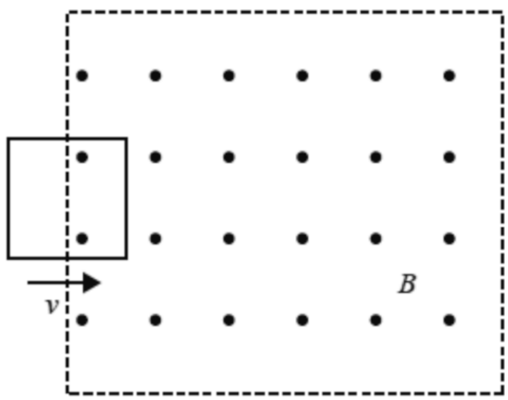


a. Calculate the average EMF produced in the loop as it moves from the position just outside the region of the field to the position completely within the area of the magnetic field. Show your working.

(2 marks)

b. On the small square loop in the diagram below, show the direction of the induced current as the loop moves into the area of the magnetic field.

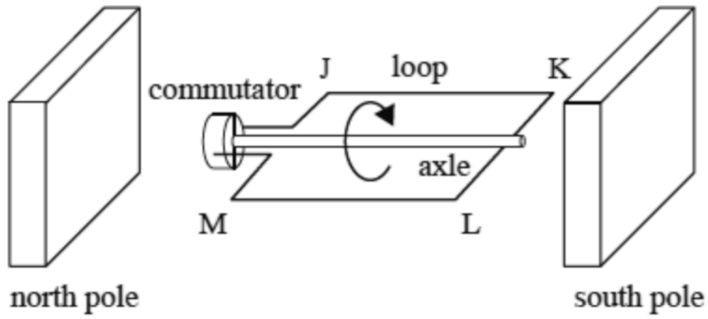
(1 mark)



Question 28/ 50

[VCAA 2023 SB Q6]

Kim and Charlie are attempting to create a DC generator and have arranged the magnets along the axis of rotation of the wire loop, J, K, L and M, as shown below. They are having some trouble getting it to work. They rotate the loop in the direction of the arrow, as shown.



a. Using physics concepts, explain why this orientation of the magnets will not generate an *EMF*.

(2 marks)

b. Kim and Charlie decide to move the magnets so that an *EMF* is generated. On the diagram above draw the positions of the magnets to ensure that an *EMF* is generated.

(1 mark)

Chapter 13 Transformers and transmission

Question 1/ 28

The key principle involved in the operation of an electrical transformer is

A electromagnetic induction.

B Ohm's law.

C conservation of energy.

D conservation of momentum.

Question 2/ 28

An ideal transformer is required to transform 210 V_{RMS} to 7 V_{RMS}.

Question 3/ 28

The ratio of primary turns/secondary turns is closest to

A 0.03

B 0.3

C 3

D 30

Question 4/ 28

When a current of 600 mA flows in the primary coil, the current in the secondary is equal to (without energy losses)

A 18 mA

B 20 mA

C 18 A

D 20 A

Question 5/ 28

210 V_{RMS} is equal to

A 149 V_{PEAK}

B 297 V_{PEAK}

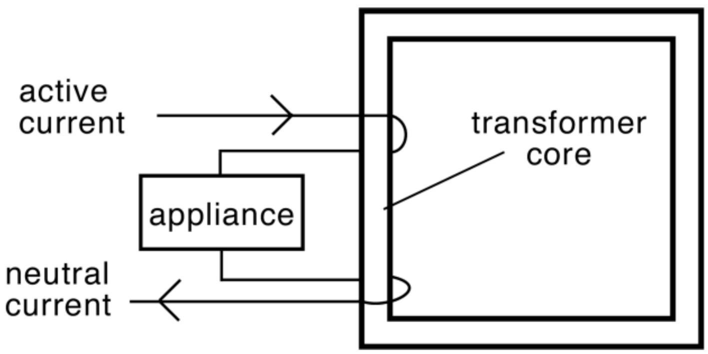
C 297 $V_{PEAK-PEAK}$

D 594 V_{PEAK}

Question 6/ 28

One form of household safety device, sometimes described as RCI, relies on detecting an *inequality* between the active and neutral currents in a circuit.

One method of detecting any inequality is shown in the diagram following. The active and neutral wires are both wound around the transformer core in opposite directions to each other.



When the AC active current is greater than the AC neutral current, which of the following best describes the situation in the transformer core?

A There is no flux through the transformer core.

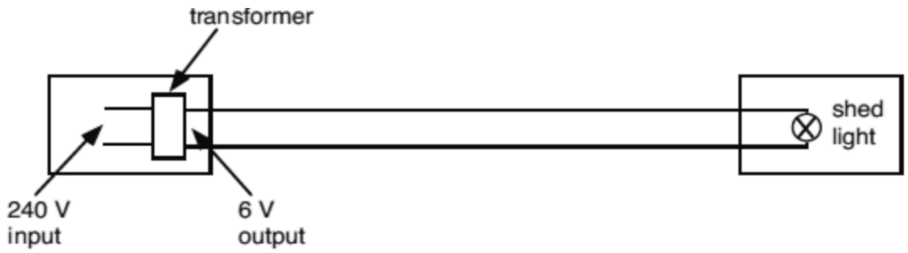
B There is an increasing flux through the transformer core.

C There is a decreasing flux through the transformer core.

D There is a changing flux through the transformer core.

Question 7/ 28

Electricity for a light in a shed is supplied via a long piece of 2-core flex connecting the light to a 6 V transformer output.



When the shed light is turned on, it draws a current of 3.5 A RMS. Which of the following best describes the current in the shed light?

A A steady current of 3.5 A

B A varying current with a peak value of $+3.5$ A

C A varying current $(\text{peak value} \sim 5\ \text{A})$ but an average of 0 A

D A varying current $(\text{peak value} \sim 5\ \text{A})$ but an average of 3.5 A

Question 8/ 28

A DC motor with $R = 0.80\ \Omega$ needs at least 15 kW of electric power. Which of the following voltage values would be suitable?

A 24 V

B 60 V

C 90 V

D 120 V

Question 9/ 28

High AC voltages are used for the long-distance transmission of a fixed amount of electrical energy primarily because

A high voltages deter damaging bird strikes on the equipment.

B high voltages can mean higher currents and lower losses.

C high AC voltages are efficiently obtained using transformers.

D high voltages can mean lower currents and lower losses.

Question 10/ 28

Which one of the following voltage and current combinations would produce a power output closest to 120 W_{RMS}?

A 12 V DC and 10 A DC

B 12 V_{PEAK} AC and 10 A_{PEAK} AC

C 18 V_{PEAK} AC and 15 A_{PEAK} AC

D $34\ V_{P-P}$ AC and $10\ A_{P-P}$ AC

Question 11/ 28

Students doing a VCE Physics practical investigation use a step-down transformer with 240 V_{RMS} AC to 12 V_{RMS} AC.

Question 12/ 28

[VCAA 2017 SA Q4]

Which one of the following best gives the ratio of the number of turns, $N_{primary}$: $N_{secondary}$?

A 1:4

B 1:20

C 4:1

D 20:1

Question 13/ 28

[VCAA 2017 SA Q5]

The transformer delivers 48 W_{RMS} to a resistor. The transformer is ideal. Which one of the following best gives the peak current in the secondary coil?

A 0.2 A

B 4.0 A

C 5.7 A

D 11.3 A

Question 14/ 28

A step-down transformer is used to convert 240 V_{RMS} AC to 16 V_{RMS} AC. Assume that the transformer is ideal.

Question 15/ 28

[VCAA 2018 NHT SA Q5]

Which one of the following best gives the peak voltage of the input to the transformer?

A 171 V

B 240 V

C 339 V

D 480V

Question 16/ 28

[VCAA 2018 NHT SA Q6]

The ratio of turns in the primary (input) to turns in the secondary (output) is best given by

A 15:1

B 1:15

C 24:1

D 1:24

Question 17/ 28

[VCAA 2018 NHT SA Q7]

The power input to the primary of the transformer is 30 W. Which one of the following best gives the RMS current in the secondary (output)?

A 0.50 A

B 1.9 A

C 8.0 A

D 15 A

Question 18/ 28

A proposed transformer will take 220 kV AC power and transform it to 66 kV, with an output power of 100 kW. There are 120 turns in the secondary coil. Which of the following gives the closest values for the number of turns in the primary coil, and the current in the secondary coil? (All values are RMS.)

A 36 turns, 1.5 A

B 400 turns, 1.5 A

C 400 turns, 0.7 A

D 36 turns, 0.7 A

Question 19/ 28

Which of the following combinations will give a value of output power closest to 100 W (RMS)?

A 70 V (peak) and 2 A (RMS)

B 50 V (RMS) and 1.4 A (peak)

C 50 V (peak) and 2 A (peak)

D 100 V (peak to peak) and 2 A (peak)

Question 20/ 28

When a DC supply (instead of AC) is connected to the primary coil of a transformer, there will be no continuous voltage generated in the secondary coil. The best reason for this is that

A the flux in the primary coil does not transfer to the secondary coil.

B the flux transfers to the secondary coil, but it does not vary with time.

C AC is required in the primary to generate any flux at all.

D DC causes a very high resistance in the coils as it is not time varying.

Question 21/ 28

[Adapted VCAA 2019 NHT SA Q6]

A light globe operates correctly at 12 V_{RMS} AC power supply. If the light globe is operated using a battery instead of the mains supply, what voltage should the battery have for the light globe to operate correctly?

A 12 V

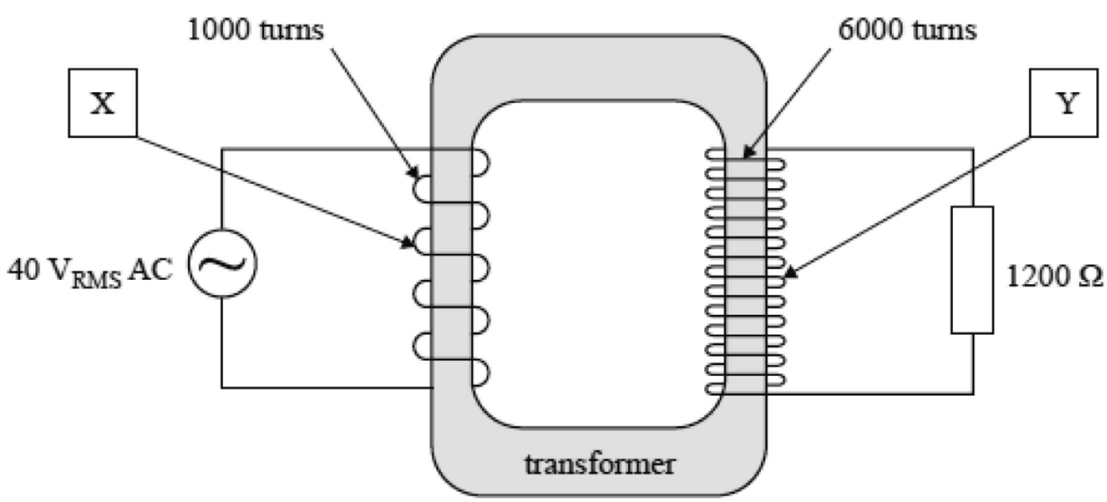
B 17 V

C 8.5 V

D 6.0 V

Question 22/ 28

A 40 V_{RMS} AC generator and an ideal transformer are used to supply power. The diagram below shows the generator and the transformer supplying 240 V_{RMS} to a 1200 Ω resistor.



Question 23/ 28

[VCAA 2019 SA Q5]

Which of the following correctly identifies the parts labelled X and Y, and the function of the transformer?

A

Part X	Part Y	Function of transformer
primary coil	secondary coil	step-down

B

primary coil	secondary coil	step-up

C

secondary coil	primary coil	step-down

D

secondary coil	primary coil	step-up

Question 24/ 28

[VCAA 2019 SA Q6]

Which one of the following is closest to the RMS current in the primary circuit?

A 0.04 A

B 0.20 A

C 1.20 A

D 1.50 A

Question 25/ 28

[VCAA 2020 SA Q7]

An ideal transformer has an input DC voltage of 240 V, 2000 turns in the primary coil and 80 turns in the secondary coil. The output voltage is closest to

A 0 V

B 9.6 V

C $6.0 \times 10^{3}\text{V}$

D $3.8 \times 10^{7}\text{V}$

Question 26/ 28

[VCAA 2021 NHT SA Q6]

The mains voltage in a particular part of Australia is AC with a voltage of 240 V_{RMS}. Which one of the following is closest to the peak-to-peak voltage, $\text{V}_{\text{p}-\text{p}}$, for this mains voltage?

A 170 V

B 340 V

C 480 V

D 680 V

Question 27/ 28

[VCAA 2021 NHT SA Q7]

Electrical power stations are often situated far from the cities that require the power that they generate. Which one of the following best describes the reason for the high-voltage transmission of electrical energy?

A Transformers can be used to increase the voltage in the cities.

B High voltages reduce the energy losses in the transmission lines.

C High voltages provide the large currents needed for efficient transmission.

D High voltages can reduce the overall total resistance in the transmission lines.

Question 28/ 28

[VCAA 2021 SA Q7]

A mobile phone charger uses a step-down transformer to transform 240 V AC mains voltage to 5.0 V. The mobile phone draws a current of 3.0 A while charging. Assume that the transformer is ideal and that all readings are RMS.

Which one of the following is closest to the current drawn from the mains during charging?

A 48 A

B 16 A

C 1.2 A

D 0.06 A

Question 29/ 28

[Adapted VCAA 2022 NHT SA Q5]

The ratio of the number of turns in an ideal step-up transformer is 1:350. An alternating RMS current of 30.0 mA is supplied to the primary coil. The RMS current in the output will be closest to

A 0 mA

B 0.086 mA

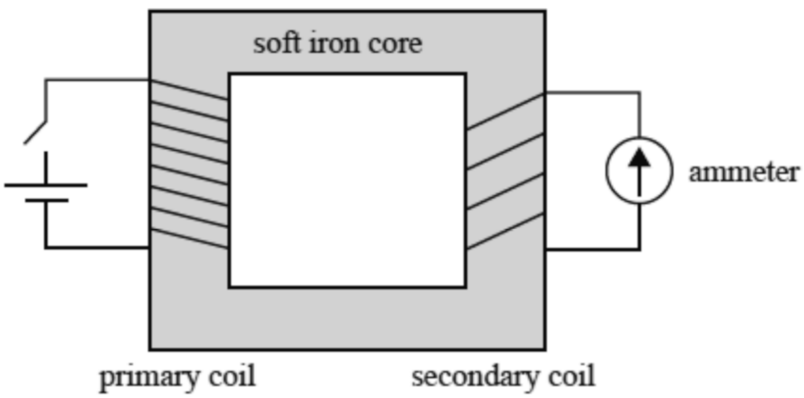
C 30.0 mA

D $1.1 \times 10^4 \text{mA}$

Question 30/ 28

[VCAA 2023 NHT SA Q5]

The diagram below shows an ideal transformer in which the primary coil is connected to a battery and a switch. An ammeter is connected to the secondary coil.



When the switch is closed, the pointer on the ammeter momentarily deflects. How could the deflection on the ammeter be made larger?

A decrease the number of primary coils

B decrease the number of secondary coils

C increase the number of secondary coils

D place a resistor in series with the ammeter

Question 31/ 28

[VCAA 2023 NHT SA Q6]

An RMS current of 15.6 A is equivalent to a peak-to-peak current of

A 11.0 A

B 22.1 A

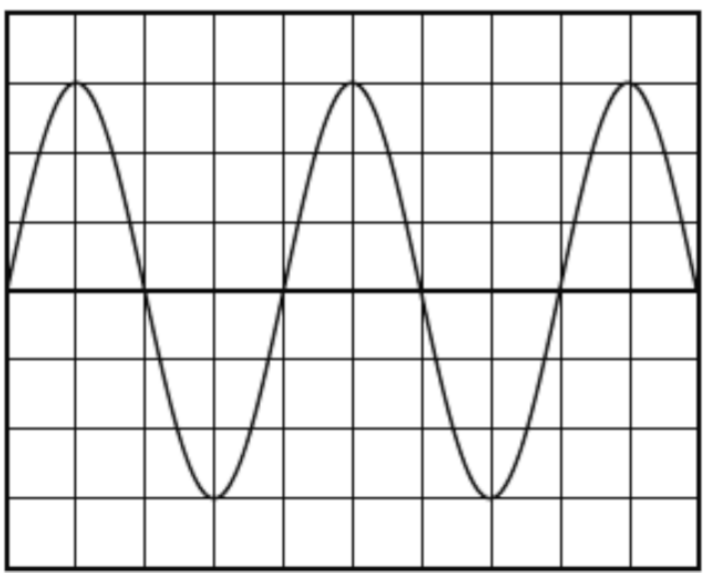
C 44.1 A

D 55.2 A

Question 32/ 28

[VCAA 2023 SA Q7]

An oscilloscope is connected to a sinusoidal AC voltage source. The resulting trace on the oscilloscope screen is shown on the next page. One vertical division on the oscilloscope screen represents a potential difference of 20 V, and one horizontal division represents a time interval of 10 ms.



Which one of the following is closest to both the peak-to-peak voltage and the frequency of the signal shown in the diagram?

A 42 V and 10 Hz

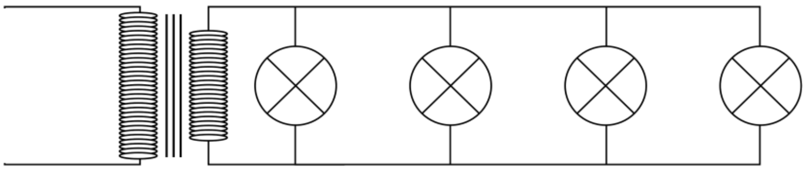
B 60 V and 25 Hz

C 120 V and 10 Hz

D 120 V and 25 Hz

Question 1/ 54

A transformer is used to provide a low voltage supply for decorative lighting on a tree in Syd's backyard. The circuit is represented below.



The input of the transformer is connected to 240 V AC. The globes in the circuit are designed to operate properly from 12 V AC.

a. If the transformer can be considered ideal, calculate the ratio:

$$\frac{\text{primary turns}}{\text{secondary turns}}$$

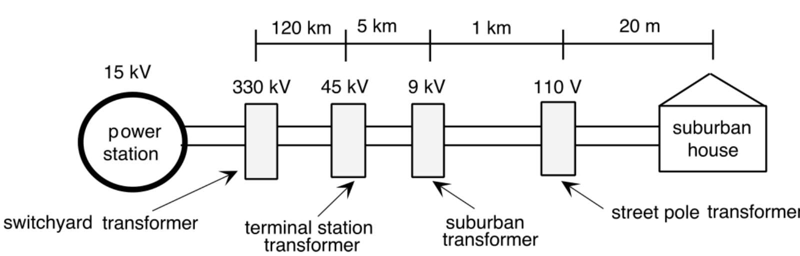
(2 marks)

b. Explain why the input of the transformer *must* be AC rather than smooth DC. Refer to the basic principle of physics involved.

(3 marks)

Question 2/ 54

Electric power is delivered to an overseas city with a range of different transmission voltages. All the voltages and currents are RMS.



The power station generator produces energy at 15 kV. In the adjacent switchyard this is stepped up to 330 kV before transmission to the outer suburban area. The diagram shows the output voltages of the various transformers before delivery to each household at 110 V.

a. Calculate the value of the ratio:

$$\frac{\text{number of turns on secondary of switchyard transformer}}{\text{number of turns on primary of switchyard transformer}}$$

(1 mark)

At the primary of the street pole transformer, the current is 1.5 A, and the voltage is very close to 9 kV. The transformer can be assumed to have no significant power losses within it.

b. What RMS current flows in the secondary of the street pole transformer?

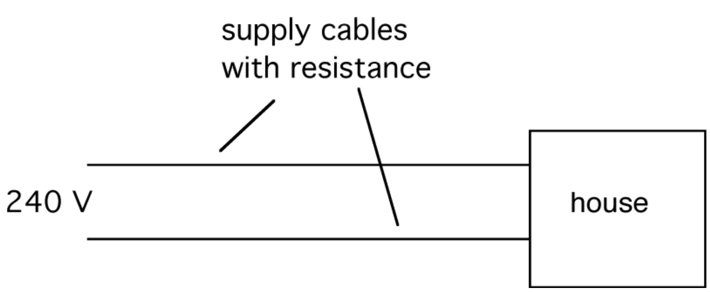
(2 marks)

c. Although the switchyard transformer produces electricity at 330 kV, the input voltage to the next transformer is 325 kV. Explain why this occurs, quoting relevant formulas. Use the symbol *R* for the resistance of the transmission lines.

(2 marks)

Question 3/ 54

A house in the country receives its electricity some kilometres from the main supply cables. The cables involved have resistance, which means that some voltage is 'lost' along them. The diagram below outlines the situation.



a. The voltage received at the country house changes, depending on the current being drawn by the house. Explain why this occurs.

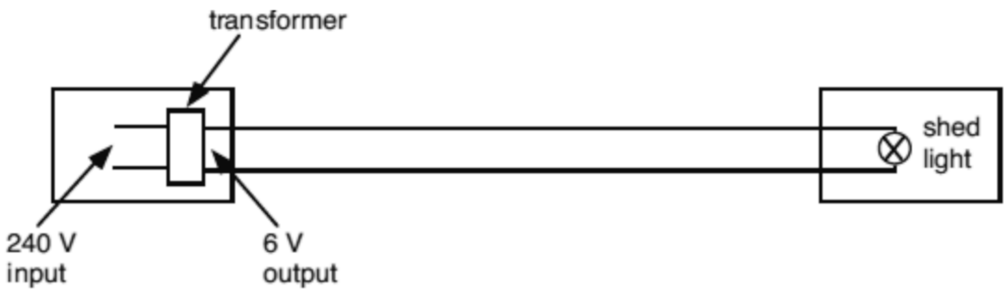
(3 marks)

b. On one occasion, the voltage received at the house is measured as 225 V_{RMS}. The current being drawn at the time is 45 A_{RMS}. Calculate the resistance of the supply cables.

(2 marks)

Question 4/ 54

Electricity for a light in a shed is supplied via a long piece of 2-core flex connecting the light to a 6 V transformer, whose output power is 21 W.



a. If the transformer input coil contains 960 turns, how many turns are there on the output coil?

(1 mark)

b. The wires to the shed have some resistance, with the result that the shed light operates off *less* than 6.0 V. The voltage at the light is 5.0 V. Calculate the total resistance of the wires leading out to the shed.

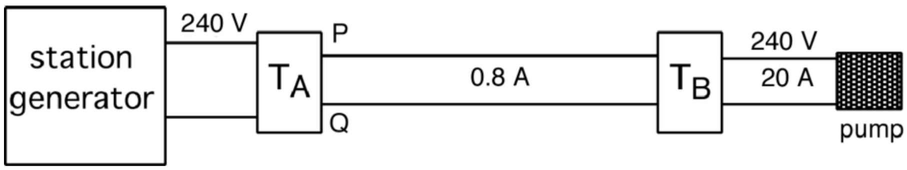
(2 marks)

c. Calculate the power dissipated in the wires leading out to the shed when the shed light is switched on.

(2 marks)

Question 5/ 54

A system for delivering power to an isolated pump from the 240 V generator that supplies a cattle station is shown below.



Transformers T_A and T_B were installed to reduce the power loss in transmission (assume no power is lost in the transformers).

a. Explain why T_A and T_B increase the fraction of generator output power transferred to the pump. Your answer should clearly show the nature (step-up or step-down) of the transformers, and the physics involved.

(3 marks)

b. The RMS current in the transmission wires is 0.8 A. What is the output voltage V_{PQ} from T_A?

(2 marks)

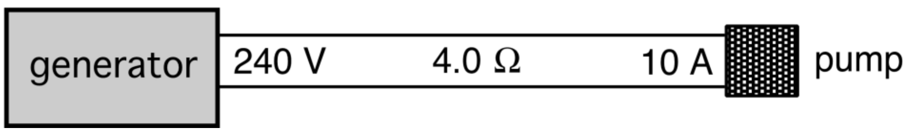
c. The primary coil of T_A consists of 100 turns of wire. How many turns of wire are in the secondary coil of T_A?

(2 marks)

d. If the transmission wires have a combined resistance of 4.0 Ω, what power is dissipated in these?

(2 marks)

Before the transformers were installed, wires connected the generator and pump directly. In this arrangement the pump drew 10 A.



e. Under this arrangement, how much power was lost in the cables?

(2 marks)

Question 6/ 54

A step-down transformer has a turns ratio of 20:1. It is designed to operate from the mains supply (240 V). It is used to produce higher currents than would normally be available from the mains supply.

a. The mains supplies 10 A_{RMS} at 240 V_{RMS}. What is the maximum RMS current the step-down transformer could supply from its secondary coil?

(2 marks)

b. It is undesirable to connect the secondary of such a transformer to high resistance loads if large currents are required. Explain why.

(3 marks)

Question 7/ 54

Explain why high voltages are used for the transmission of AC electricity over long distances.

(2 marks)

Question 8/ 54

Transformers are often treated as being ‘ideal’ transformers.

a. With regard to the ratio of the power in: power out for a transformer, what is meant by saying a transformer is an ‘ideal’ transformer?

(2 marks)

b. A typical transformer for a smart phone feels warm when in use. Explain why this smart phone transformer is not an ‘ideal’ transformer.

(2 marks)

Question 9/ 54

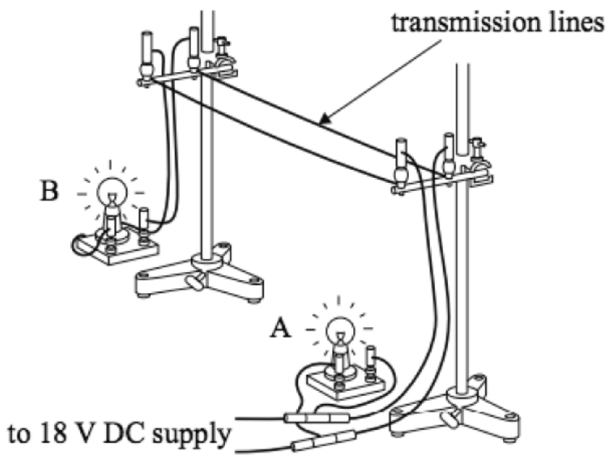
Early domestic electricity was supplied as DC. AC soon became preferred. Outline one key advantage that AC has over DC for domestic power supplies.

(2 marks)

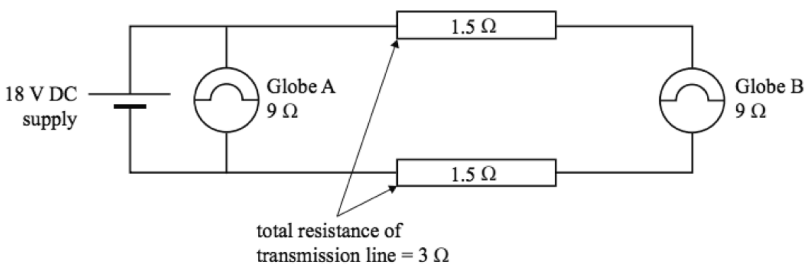
Question 10/ 54

[Adapted VCAA 2016 SA Q16]

Ruby and Max investigate transmission of electric power with a model system.



The circuit of the arrangement is shown below.



Ruby and Max use an 18 V DC power supply, as shown. The transmission lines have a *total* resistance of 3.0 Ω. The resistance of the globes is a constant 9.0 Ω, and that the other connecting wires have zero resistance.

a. Calculate the power delivered to Globe A.

(2 marks)

b. Calculate the total voltage drop over the transmission lines. Show your working.

(2 marks)

c. Calculate the power delivered to Globe B.

(3 marks)

Ruby notices the voltage supply to houses is AC and there are transformers used (on street poles and at the city edge). Ruby and Max next investigate the use of transformers to reduce power losses in transmission. They have two transformers – a 1:10 step-up transformer and a 10:1 step-down transformer.

d. Redraw the circuit above with an 18 V AC supply and with the transformers correctly connected. Label the transformers as step up and step down.

(2 marks)

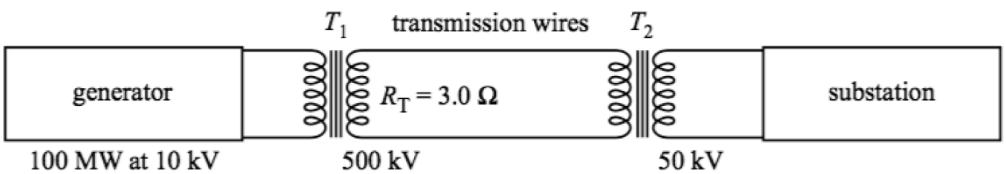
e. Explain why transformers would reduce transmission losses. Your answer should include reference to key physics formulas and principles.

(3 marks)

Question 11/ 54

[VCAA 2017 SB Q6]

The diagram shows a generator at an electrical power station that generates 100 MW_{RMS} of power at a voltage of 10 kV_{RMS} AC. Transformer T_1 steps the voltage up to $500 kV_{RMS}$ AC for transmission through transmission wires that have a total resistance, R_T, of 3.0 Ω. Transformer T_2 steps the voltage down to $50\ kV_{RMS}$ AC at the substation. Assume that both transformers are ideal.



a. The current in the transmission lines is 200 A. Calculate the total electrical power loss in the transmission wires.

(2 marks)

b. Transformer T_1 stepped the voltage up to $250\ kV_{RMS} AC$ instead of $500\ kV_{RMS}\ AC$. By what factor would the power loss in the transmission lines increase?

(2 marks)

Question 12/ 54

A computer transformer rated at 140 W_{RMS} is connected to the mains 240 V_{RMS} electricity. It transforms the voltage to 28 V_{RMS}. Assume the transformer is ideal.

a. Calculate the current supplied to the transformer by the mains electricity.

(2 marks)

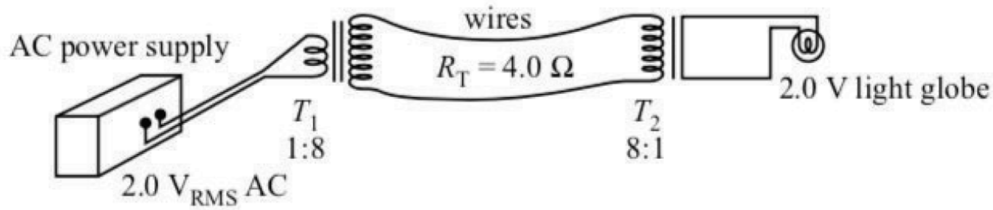
b. Calculate the current supplied to the computer by the transformer.

(2 marks)

Question 13/ 54

[VCAA 2018 NHT SB Q5]

Students construct a model to show the transmission of electricity in transmission lines. The apparatus is shown below.



The students use two transformers, T_1 and T_2, with ratios of 1:8 and 8:1 respectively, and a 2.0 V_{RMS} AC power supply. Assume that the transformers are ideal. The students use a light globe that operates correctly when there is a voltage of 2.0 V across it. The wires of the transmission lines have a total resistance of 4.0 Ω. The students measure the current in the wires to be 0.50 A.

a. Calculate the power loss in the wires.

(2 marks)

b. Calculate the voltage across the light globe.

(4 marks)

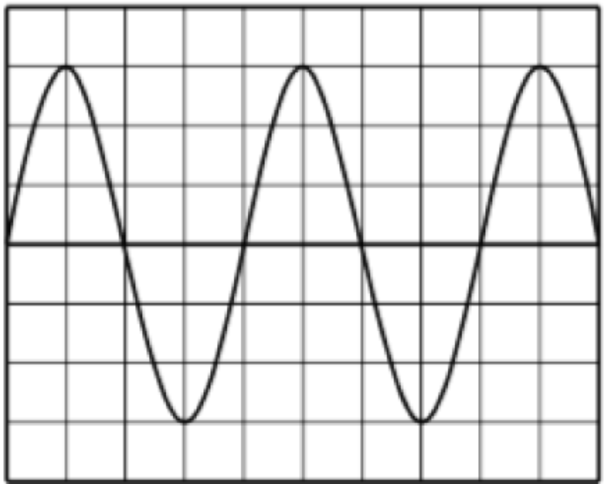
c. The light globe does not operate correctly, as it would with a voltage of 2.0 V. Describe **one** change the students could make to the model to make the light globe operate correctly.

(2 marks)

Question 14/ 54

[Adapted VCAA 2017 Sample SB Q5]

An oscilloscope is connected to a sinusoidal AC source. The trace obtained on the oscilloscope screen, where one horizontal division represents a time of 20 ms and one vertical division represents 10 V, as shown below.



a. Calculate the RMS voltage for the signal shown in the diagram.

(2 marks)

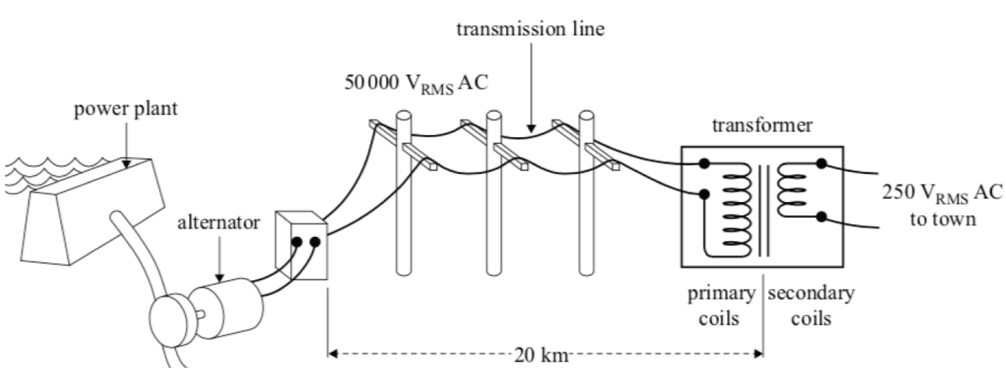
b. Calculate the frequency for the signal shown in the diagram.

(1 mark)

Question 15/ 54

[Adapted VCAA 2017 Sample SB Q10]

A rural town is supplied with electricity from a small hydro-electric power plant 20 km from the town. The alternator generates electricity at 5000 V. This is stepped up in a transformer to 50 000 V. Electricity is transmitted to the town through a two-wire high-voltage transmission line. The input voltage to the transmission line at the alternator end is $50000\ V_{RMS} AC$. The current in the line is 15 A_{RMS}. At the edge of the town, a transformer converts the voltage to 250 V_{RMS} AC for use in the town. The total resistance of the transmission line is 40 Ω. The system is shown on the next page. The transformers are ideal.



a. Calculate the total power loss in the transmission line. Show your working.

(3 marks)

b. Calculate the voltage input from the transmission line to the step-down transformer at the town end of the line.

(3 marks)

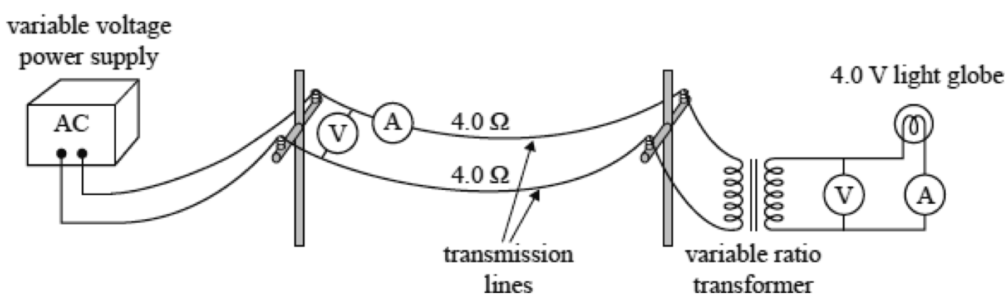
c. Explain why AC rather than DC is generally used for long-distance power transmission. Include the steps involved in the process of long-distance power transmission.

(3 marks)

Question 16/ 54

[VCAA 2018 SB Q5]

A Physics class is investigating power loss in transmission lines. The students construct a model of a transmission system. They first set up the model as shown below. The model consists of a variable voltage AC power supply, two transmission lines, each of $4.0\ \Omega$ $(\text{total resistance} = 8.0\ \Omega)$, a variable ratio transformer, a light globe and meters as needed. The purpose of the model is to operate the 4.0 V light globe. A variable ratio transformer is one in which the ratio of turns in primary windings to turns in secondary windings can be varied. The resistance of the connecting wires can be ignored.



In their first experiment, the transformer is set on a ratio of 4:1 and the current in the transmission lines is measured to be 3.0 A. The light globe is operating correctly, with $4.0\ V_{RMS}$ across it.

a. Calculate the power dissipated in the light globe. Show your working.

(2 marks)

b. Calculate the voltage output of the power supply. Show your working.

(3 marks)

c. Calculate the total power loss in the transmission lines. Show your working.

(2 marks)

In a second experiment, the students set the variable ratio of the transformer at 8:1 and adjust the variable voltage power supply so that the light globe operates correctly, with $4.0\ V_{RMS}$ across it.

d. Calculate the total power loss in the transmission lines in this second experiment. Show your working.

(3 marks)

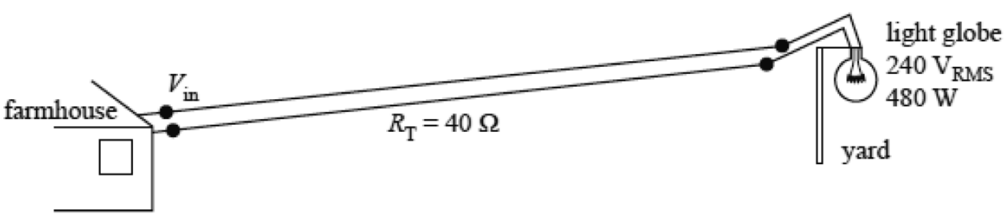
e. Suggest two reasons why high voltages are often used for the transmission of electric power over long distances.

(2 marks)

Question 17/ 54

[VCAA 2019 NHT SB Q4]

An electrician is installing a power supply to a yard located 500 m from a farmhouse in order to operate a 240 V_{RMS}, 480 W light globe, as shown in the diagram. The connecting wires have a total resistance, R_T, of 40 Ω. At the farmhouse, the electrician provides the required input voltage, V_{in}, to the connecting wires for the light globe to operate at 240 V_{RMS} and 480 W.



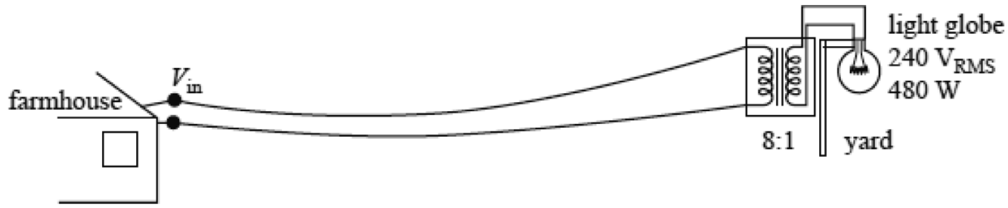
a. When the light globe is operating at 240 V_{RMS} and 480 W, what is the power loss in the connecting wires? Show your working.

(2 marks)

b. Calculate the RMS voltage of V_{in}. Show your working.

(3 marks)

c. To reduce the power loss in the connecting wires, the electrician changes the input voltage, V_{in}, and installs an 8:1 step-down transformer at the yard. After these changes, the light globe still operates at 240 V_{RMS} and 480 W, as shown in the diagram below.



Calculate the RMS power loss in the connecting wires for this new situation. Show your working.

(3 marks)

Question 18/ 54

[VCAA 2019 SB Q6]

A home owner on a large property creates a backyard entertainment area. The entertainment area has a low-voltage lighting system. To operate correctly, the lighting system requires a voltage of $12\ \mathrm{V_{RMS}}$. The lighting system has a resistance of 12 Ω.

a. Calculate the power drawn by the lighting system.

(1 mark)

To operate the lighting system, the home owner installs an ideal transformer at the house to reduce the voltage from $240\ \mathrm{V_{RMS}}$ to $12\ \mathrm{V_{RMS}}$. The home owner then runs a 200 m long heavy-duty outdoor extension lead, which has a total resistance of 3 Ω, from the transformer to the entertainment area.

b. The lights are a little dimmer than expected in the entertainment area. Give one possible reason for this and support your answer with calculations.

(4 marks)

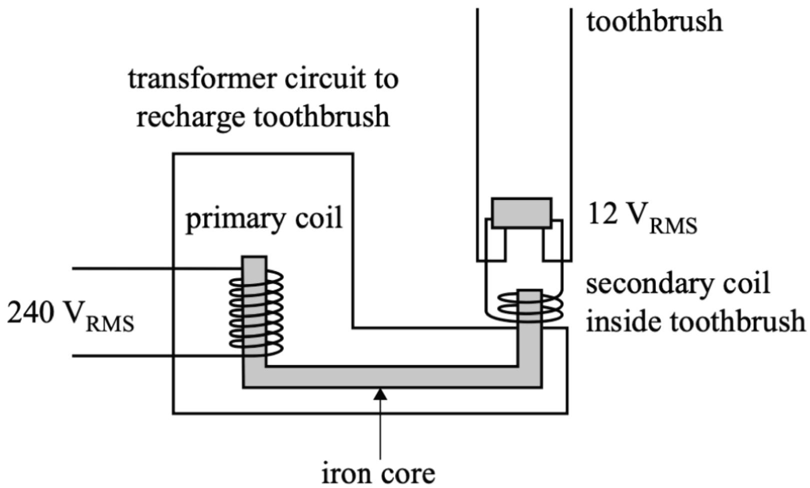
c. Using the same equipment, what changes could the home owner make to improve the brightness of the lights? Explain your answer.

(2 marks)

Question 19/ 54

[VCAA 2020 SB Q7]

A rechargeable electric toothbrush uses a transformer circuit, as shown in the diagram below. A secondary coil inside the toothbrush is connected, via an iron core, to a primary coil that is connected to the mains power supply. The mains power is 240 V_{RMS} and the toothbrush recharges at $12\ V_{RMS}$. The average power delivered by the transformer to the toothbrush is 0.90 W. Assume that the transformer is ideal.



a. Calculate the peak voltage in the secondary coil. Show your working.

(2 marks)

b. Determine the ratio of the number of turns $\frac{N_p}{N_s}$.

(1 mark)

c. Calculate the RMS current in the primary coil while the toothbrush is charging. Show your working.

(2 marks)

Question 20/ 54

[VCAA 2021 NHT SB Q7]

Angela and Janek are installing two low-voltage lights in their outdoor garden. They have a $240\ V_{RMS}$ AC transformer with an output voltage of $12\ V_{RMS}$ AC. Each light has a constant resistance of 6.0 Ω. For the purposes of calculations, assume that the transformer is ideal.

a. Describe what is meant by an ideal transformer in terms of the input power and the output power.

(1 mark)

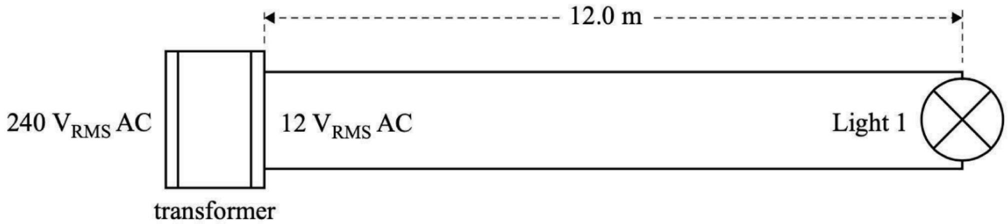
b. Calculate the ratio of the number of turns of the primary coil to the number of turns of the secondary coil.

(1 mark)

c. Each light is designed to operate at $12\ \mathrm{V_{RMS}}$. Calculate the power dissipated in one light when it is operated at $12\ \mathrm{V_{RMS}}$. Show your working.

(2 marks)

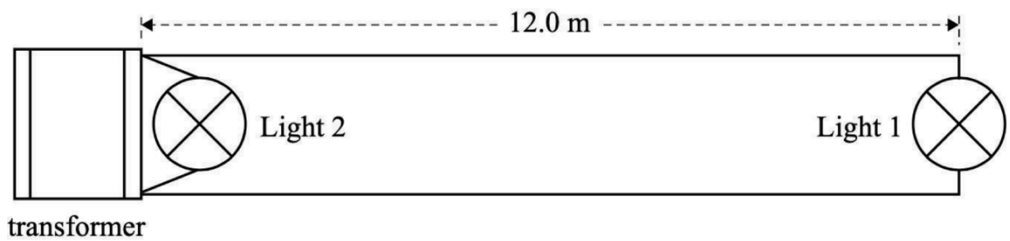
Angela and Janek now connect the first light, Light 1, to the transformer using two wires, each 12.0 m long, as shown below. Each wire has a resistance of 0.05 Ω per metre.



d. Calculate the RMS voltage across Light 1. Show your working.

(3 marks)

e. Angela and Janek now connect the second light, Light 2, directly across the secondary of the transformer, as shown below.



They thought that with the circuit shown above, Light 1 and Light 2 would be equally bright. However, they observed that Light 2 was brighter than Light 1.

Explain why Light 2 was observed to be brighter than Light 1.

(3 marks)

Question 21/ 54

[VCAA 2021 SB Q7]

The generator of an electrical power plant delivers 500 MW to external transmission lines when operating at

25 kV. The generator's voltage is stepped up to 500 kV for transmission and stepped down to 240 V 100 km away (for domestic use). The overhead transmission lines have a total resistance of 30.0 Ω. Assume that all transformers are ideal.

a. Explain why the voltage is stepped up for transmission along the overhead transmission lines.

(2 marks)

b. Calculate the current in the overhead transmission lines. Show your working.

(2 marks)

c. Determine the maximum power available for domestic use at 240 V. Show all your working.

(3 marks)

Question 22/ 54

[Adapted VCAA 2022 NHT SB Q6]

A laptop computer requires a transformer to reduce the voltage to its rechargeable battery while the battery is charging. The power point supplies an RMS voltage of 240 V and delivers an RMS current of 0.35 A. The transformer converts the voltage to an RMS voltage of 8.0 V. Assume that the transformer is ideal.

a. Calculate the ratio of the number of turns $N_{\text{primary}}/N_{\text{secondary}}$. Show your working.

(2 marks)

b. Calculate the RMS current delivered by the power point while the battery is charging.

(2 marks)

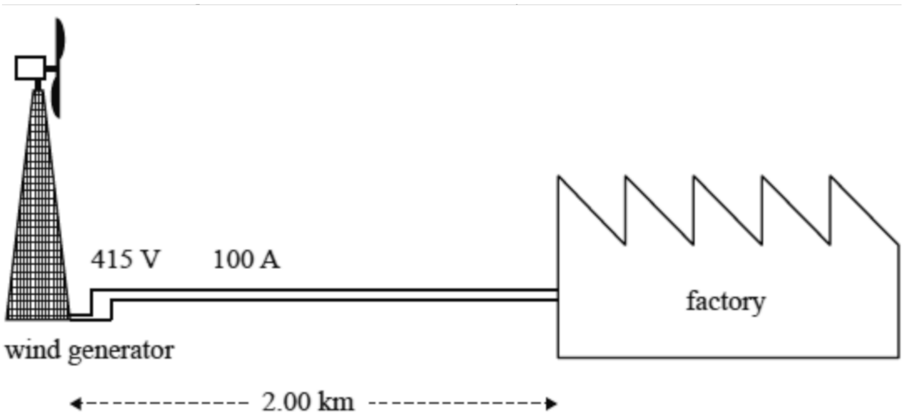
Question 23/ 54

[VCAA 2022 SB Q5]

A wind generator provides power to a factory located 2.00 km away, as shown below.

When there is a moderate wind blowing steadily, the generator produces an RMS voltage of 415 V and an

RMS current of 100 A. The total resistance of the transmission wires between the wind generator and the factory is 2.00 Ω.



a. Calculate the power, in kilowatts, produced by the wind generator when there is a moderate wind blowing steadily.

(1 mark)

b. To operate correctly, the factory's machinery requires a power supply of 40 kW. Determine whether the energy supply system, as shown, will be able to supply power to the factory when the moderate wind is blowing steadily. Justify your answer with calculations.

(3 marks)

c. The factory's owner decides to limit transmission energy loss by installing two transformers: a step-up transformer with a turns ratio of 1:10 at the wind generator and a step-down transformer with a turns ratio of 10:1 at the factory. Each transformer can be considered ideal. With the installation of the transformers, determine the power, in kilowatts, now supplied to the factory.

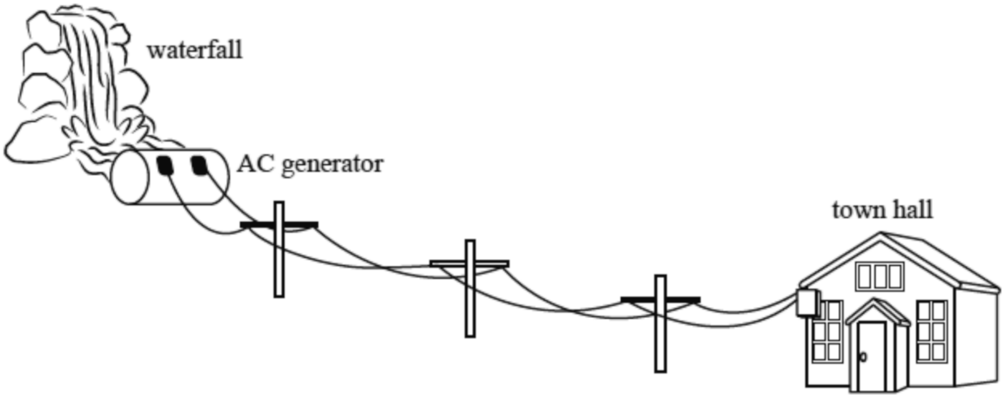
(3 marks)

Question 24/ 54

[VCAA NHT 2023 SB Q9]

A local community wishes to power its town hall using hydro-electricity. A waterfall drives an AC generator, with power delivered to the hall via transmission lines, as shown below.

The generator has an RMS power output of 4.2 kW when operating normally.



The town hall's electrical loads have a total resistance of 20 Ω and require 2.6 kW of RMS power when operating normally.

a. Calculate the RMS voltage at the town hall under these conditions. Show your working.

(2 marks)

b. Calculate the resistance of the transmission lines.

(3 marks)

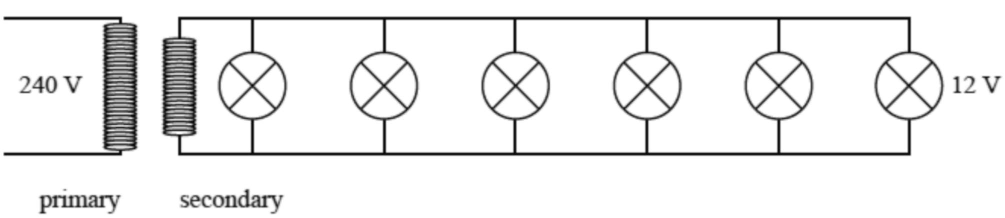
c. Suggest two changes the community could make to the system that would reduce power losses without changing the output of the AC generator or the load at the town hall.

(2 marks)

Question 25/ 54

[VCAA 2023 SB Q4]

A transformer is used to provide a low-voltage supply for six outdoor garden globes. The circuit is shown below. Assume there is no power loss in the connecting wires. All voltage values are RMS values.



The input of the transformer is connected to a power supply that provides an AC voltage of 240 V. The globes in the circuit are designed to operate with an AC voltage of 12 V. Each globe is designed to operate with a power of 20 W.

a. Assuming that the transformer is ideal, calculate the ratio of primary turns to secondary turns of the transformer.

(1 mark)

The globes are turned on.

b. Calculate the current in the primary coil of the transformer.

(2 marks)

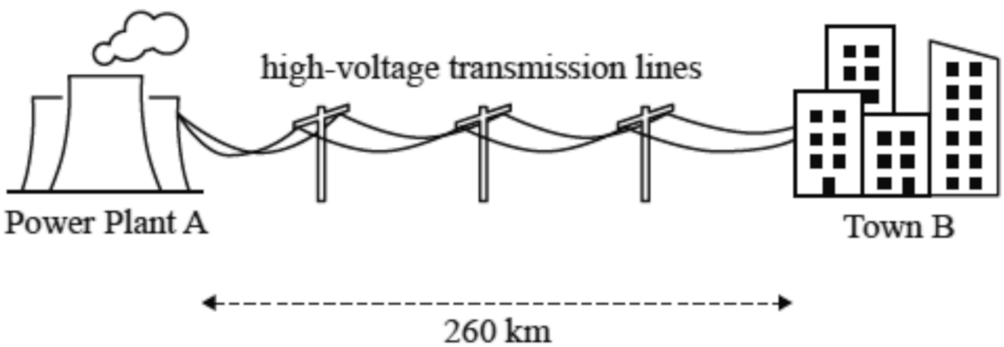
c. Explain why the input current to the primary coil of the transformer must be AC rather than constant DC for the globes to shine.

(2 marks)

Question 26/ 54

[VCAA Adapted 2023 SB Q7]

Two high-voltage transmission lines span a distance of 260 km between Power Plant A and Town B, as shown on the next page. Power Plant A provides 350 MW of power. The potential difference at Power Plant A is 500 kV. The current in the transmission lines has an RMS value of 700 A and the power loss in the transmission lines is 20 MW.



a. Show, using calculations, that the total resistance of the two transmission lines is 41 Ω

(2 marks)

b. Town B needs a minimum of 480 kV.

Determine whether 480 kV will be available to Town B. Show your working.

(3 marks)

c. Explain what would happen if the electricity between Power Plant A and Town B were to be transmitted at 50 kV instead of 500 kV. Assume that the resistance of the transmission lines is still 41 Ω and the power supplied by Power Plant A is 350 MW.

(2 marks)

Chapter 14 Interference, diffraction, standing waves

Question 1/ 30

When two sound waves meet, they

A pass through each other without being changed.

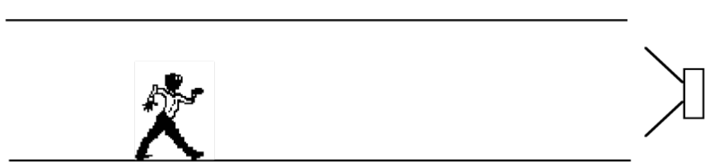
B reflect off each other.

C pass through each other, combining effects when they overlap.

D diffract off each other.

Question 2/ 30

A very large pipe in a science museum is open at both ends, as shown. It is large enough for people to walk inside it. A large loudspeaker faces one end. Jin is walking along the pipe.



During a demonstration, one frequency resonates strongly in the pipe.

Which of the following best explains the cause of this resonance?

A A standing wave is generated in the loudspeaker.

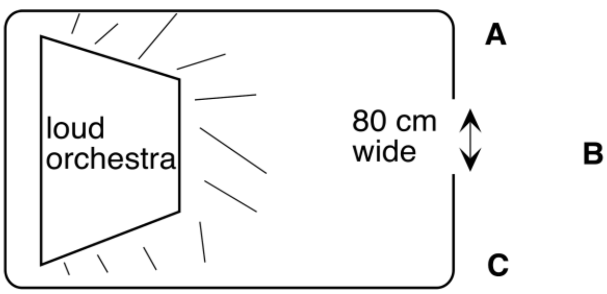
B Waves moving to the left from the loudspeaker reflect from Jin.

C Waves moving to the left from the loudspeaker reflect from the far end.

D Odd harmonics are formed in the pipe.

Question 3/ 30

An orchestra is playing in a hall with an open door; it is 80 cm wide. The speed of sound is 320 m s^{-1}. Which of the following statements is likely to be true?



A Listeners at A and C can hear all notes below 400 Hz clearly.

B Listeners at B can only hear frequencies above 400 Hz.

C Listeners at A and C can hear all frequencies clearly.

D Listeners at A and C can only hear frequencies above 400 Hz.

Question 4/ 30

Telescopes observing distant stars produce sharper images when the diameter of their viewing aperture is increased. This is likely to because

A they gather sharper light.

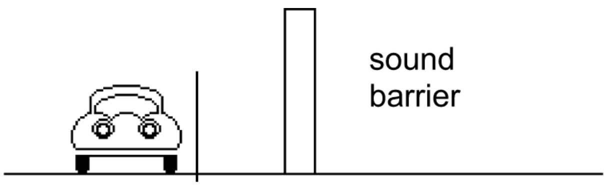
B the larger aperture reduces spread due to diffraction.

C the larger area smooths out minor fluctuations.

D the larger aperture prevents interference effects.

Question 5/ 30

Sound barriers at the side of freeways are more effective at reducing high-frequency sounds (e.g. 2000 Hz sirens) than low-frequency noises (e.g. 200 Hz noises from trucks). Which *one or more* of the following best explains this?



A Sounds of 200 Hz have a relatively long wavelength.

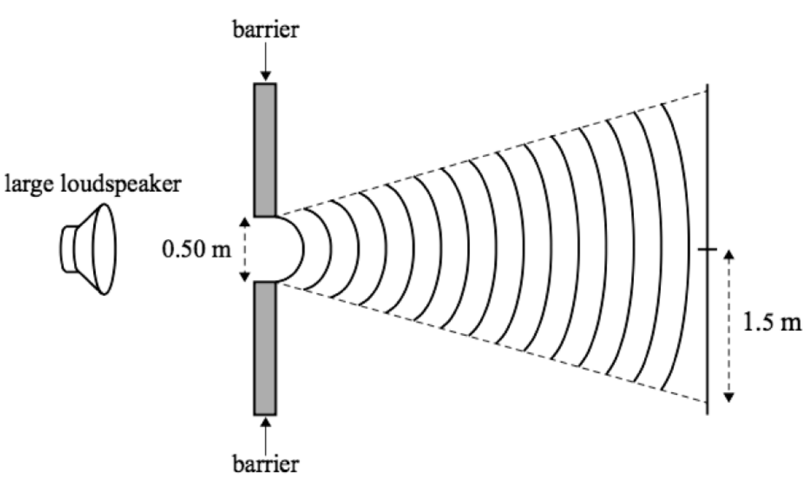
B Sounds of 200 Hz have a relatively short wavelength.

C Short wavelength sounds diffract easily around the barrier.

D Long wavelength sounds diffract easily around the barrier.

Question 6/ 30

A loudspeaker is operating to the left of a barrier with a gap in its centre.



The frequency of the sound is 1200 Hz. The width of the gap is 0.5 m. At some distance from the gap, the students note that the edge of the diffraction pattern is 1.5 m from the centre line, as shown.

Question 7/ 30

[Adapted VCAA 2015 SB Q10]

The students increase the frequency to 3000 Hz. Which one of the following is most likely to be observed?

A The edge of the pattern will still be about 1.5 m from the centre line.

B The edge of the pattern will be closer to the centre line.

C The edge of the pattern will be further out than 1.5 m.

D There will now be no edge of the pattern.

Question 8/ 30

[VCAA 2015 B Q11]

The students now repeat the experiment in their classroom, but do not observe such a clear edge to the pattern. Which one of the following is the most likely reason for this?

A The room is too big for the wavelength.

B The room is too small for the wavelength.

C The doorway allowed a proportion of the sound to escape and so destructive interference did not occur completely.

D Reflection from walls and ceiling of the classroom mean that destructive interference does not occur completely at the edge of the pattern.

Question 9/ 30

The distance from Earth to the Moon is measured using a laser beam focused by a mirror. The beam is aimed at a reflector on the Moon surface; the time for the journey is measured. When the beam leaves Earth, it is a few metres wide, but when it reaches the Moon it is over 6 km wide. The best explanation is that

A the vacuum of space allows the beam to spread over the long distance.

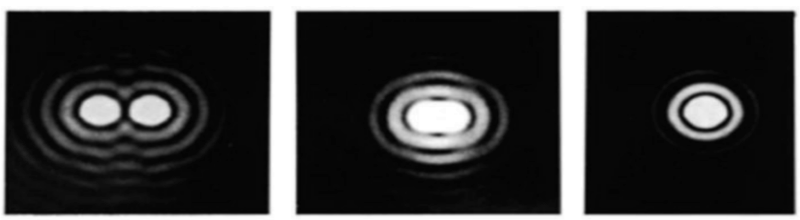
B the aperture of the focusing mirror gives rise to diffraction.

C there is a limit to the ability of the mirror to focus.

D the diameter of the focusing mirror is too great.

Question 10/ 30

When cars with two headlights are a long way away on a straight road, it is hard to tell that there are *two* headlights; our eyes cannot resolve the two objects.



close for away

If the headlights gave out *violet* light, they would be easier to resolve, because

A the wavelength of violet light is less than the average wavelength of white light.

B the wavelength of violet light is longer than the average wavelength of white light.

C the speed of violet light is the faster than the speed of white light.

D the speed of violet light is slower than the speed of white light.

Question 11/ 30

A beam of electromagnetic radiation of frequency $1 \times 10^{15}\mathrm{Hz}$ is directed at a hole of diameter 0.1 mm. A circular diffraction pattern is detected 10 m from the hole, with a diameter of 6 mm. When the hole is changed for one of diameter of 0.2 mm, and the radiation is changed to a frequency $5 \times 10^{14}\mathrm{Hz}$, the pattern is likely to be circular, with a diameter close to

A 3 mm

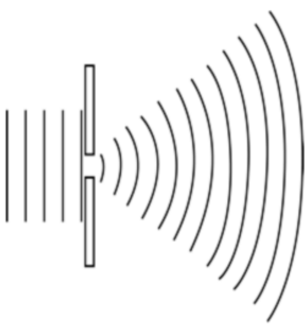
B 6 mm

C 12 mm

D 60 mm

Question 12/ 30

When small water waves are directed at a barrier with a small gap, diffraction results, as shown in the somewhat idealised diagram below.



Students decrease the period of the water waves. Which of the following best describes what they are now likely to see in the waves to the right of the gap?

A The pattern will be unchanged.

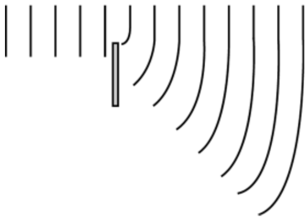
B The pattern will spread further.

C The pattern will become narrower.

D The wavelength will increase, but the spread will remain the same.

Question 13/ 30

Water waves striking a barrier can change direction, as in the diagram below.



This is most likely an example of

A diffraction

B refraction

C reflection

D dispersion

Question 14/ 30

Plucking a guitar string causes a resonance in that string. This is due to a

A standing wave in the string due to superposition of longitudinal waves.

B standing wave in the string due to superposition of transverse waves.

C transverse and a longitudinal wave superimposing.

D string being of a special length.

Question 15/ 30

Marching soldiers crossing bridges are asked to ‘break step’ to avoid large amplitude oscillations. Which of the following best describes the conditions for this?

A Such resonances only occur when the bridge is of a special length.

B A large number of people walking can, on its own, cause resonances.

C A regular marching frequency always causes resonances of this kind.

D The marching frequency corresponding to the natural vibration frequency.

Question 16/ 30

Which of the following best describes what happens to a two-slit interference pattern when the slits are moved apart?

A The dark and light bands become less widely separated.

B The dark and light bands become more widely separated.

C The wavelength of the light is increased.

D The wavelength of the light is reduced.

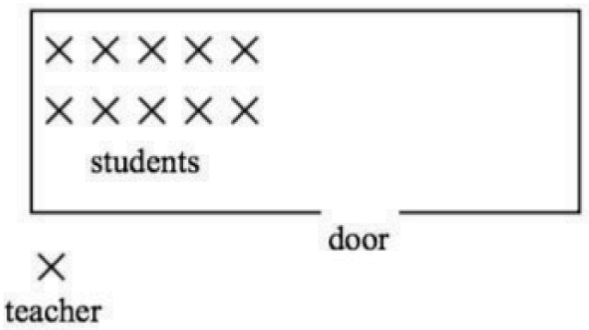
Question 17/ 30

Which *one or more* of the options above describes what happens to a two-slit interference pattern when the medium is changed to one of greater refractive index (for example, air is changed to water)?

Question 18/ 30

[VCAA 2017 SA Q14]

A teacher stands in the corridor a short distance from the open door of her classroom, as shown in the diagram. She can hear the students, but cannot see them.



Which one of the following best explains why the teacher can hear her students?

A The speed of sound is much greater than the speed of light.

B The speed of sound is comparable with the speed of light.

C Sound diffracts because the wavelength of sound is much smaller than the width of the door.

D Sound diffracts because the wavelength of sound is comparable with the width of the door.

Question 19/ 30

Jannie is standing between two loudspeakers at a sporting ground. They are being tested with a note of a single frequency of 340 Hz. The loudspeakers emit sound reasonably well in all directions.

When she stands midway between the speakers the sound is quite loud, but as she moves away from this point towards either speaker the sound gets softer. Which of the following best helps explain why this happens?

A Waves from each speaker arrive at the central point in phase.

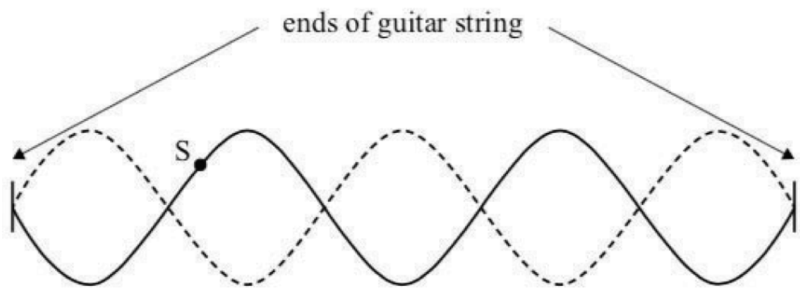
B Waves from each speaker have a path difference of an exact whole number of wavelengths everywhere.

C Waves from each speaker have a path difference of exactly zero everywhere.

D The speakers are specially designed to keep in phase everywhere.

Question 20/ 30

Kim plucks one of his guitar strings, causing it to vibrate as shown below. Two extreme positions of the resulting standing wave in the string are shown. For the purpose of the following questions, the amplitude of the vibrations has been exaggerated.



Question 21/ 30

[VCAA 2017 Sample SA Q15]

Which one of the following statements best indicates how we interpret the motion of the guitar string shown above?

A It is the result of two transverse waves travelling along the string in the same direction.

B It is the result of two transverse waves travelling along the string in opposite directions.

C It is the result of two longitudinal waves travelling along the string in the same direction.

D It is the result of two longitudinal waves travelling along the string in opposite directions.

Question 22/ 30

[VCAA 2017 Sample SA Q16]

S is a point on the guitar string, as on the previous page. For the instant *immediately after* that shown on the previous page, the direction in which point S on the guitar string will move is

A upwards.

B to the left.

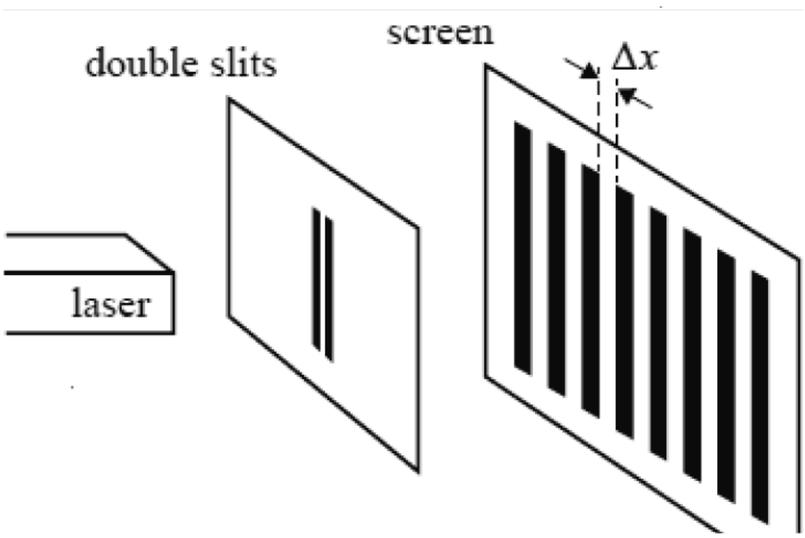
C to the right.

D downwards.

Question 23/ 30

[VCAA 2018 SA Q12]

A teacher sets up an apparatus to demonstrate Young's double-slit experiment. A pattern of bright and dark bands is observed on the screen, as shown below.



Which one of the actions below will increase the distance, Δx, between the adjacent dark bands in this interference pattern?

A Decrease the distance between the slits and the screen.

B Decrease the wavelength of the light.

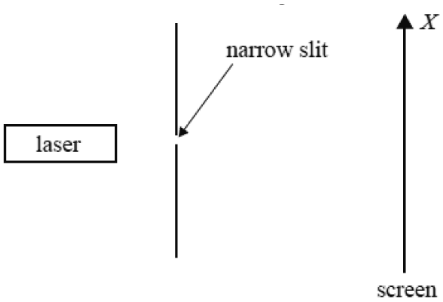
C Decrease the slit separation.

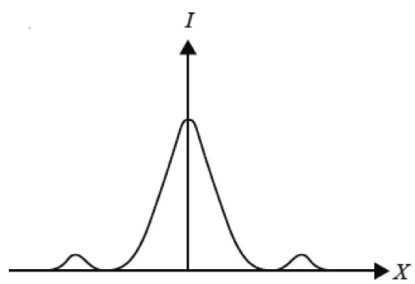
D Decrease the slit width.

Question 24/ 30

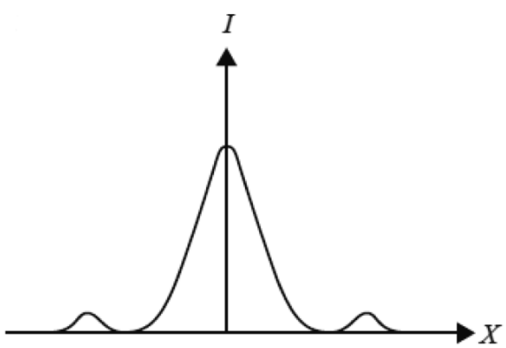
[VCAA 2019 NHT SA Q15]

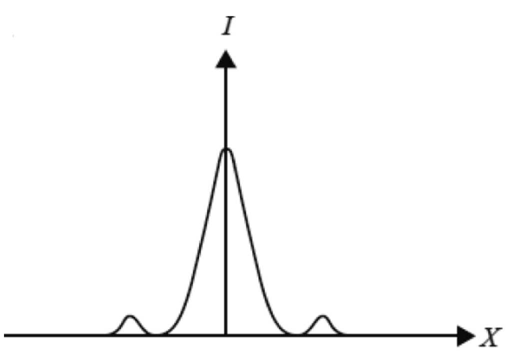
Monochromatic laser light of wavelength 600 nm shines through a narrow slit. The intensity of the transmitted light is recorded on a screen some distance away, as shown below in the diagram on the left. The intensity graph of the pattern seen on the screen is shown below on the right.

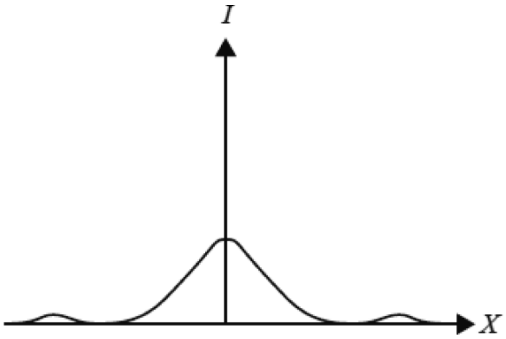


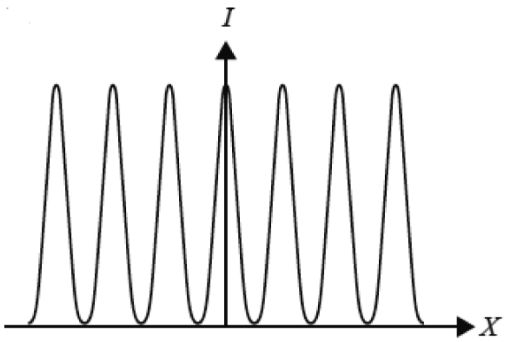


Which one of the following intensity graphs best represents the pattern that would be seen if a slightly wider slit were used?

A


B


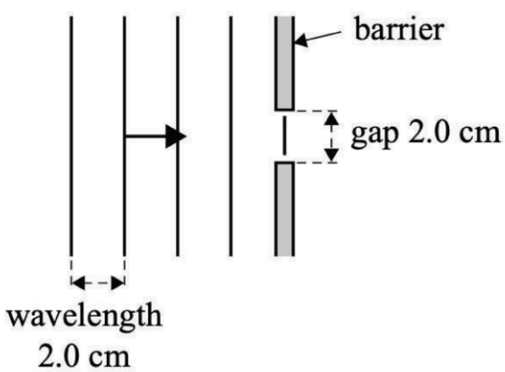
C 

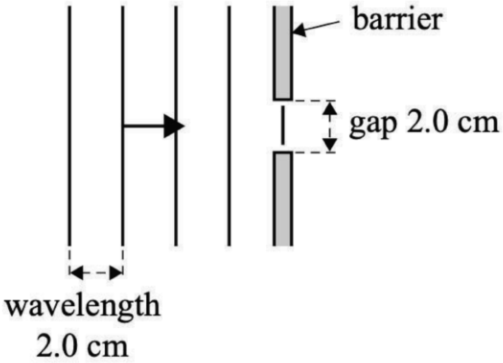
D 

Question 25/ 30

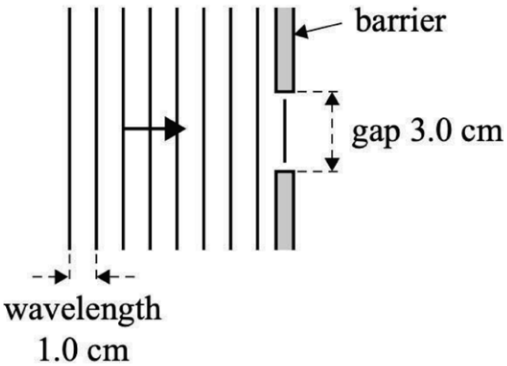
[VCAA 2020 SA Q14]

Students are investigating the diffraction of waves using a ripple tank. Water waves are directed towards barriers with gaps of different sizes, as shown below. In which one of the following would the greatest diffraction effects be observed?

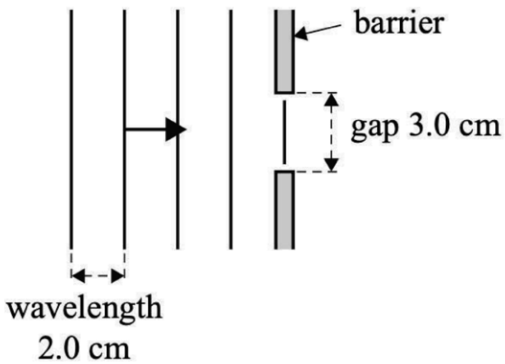
A 



B



C

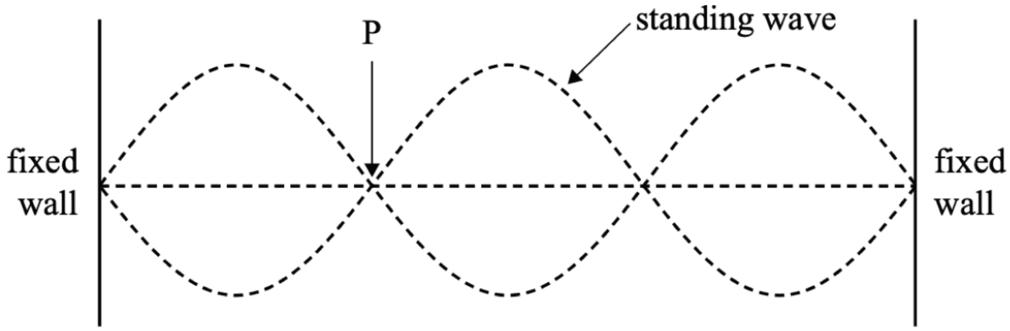


D

Question 26/ 30

[VCAA 2021 NHT SA Q14]

The diagram below represents a standing wave.



The point P on the standing wave is

A a node resulting from destructive interference.

B a node resulting from constructive interference.

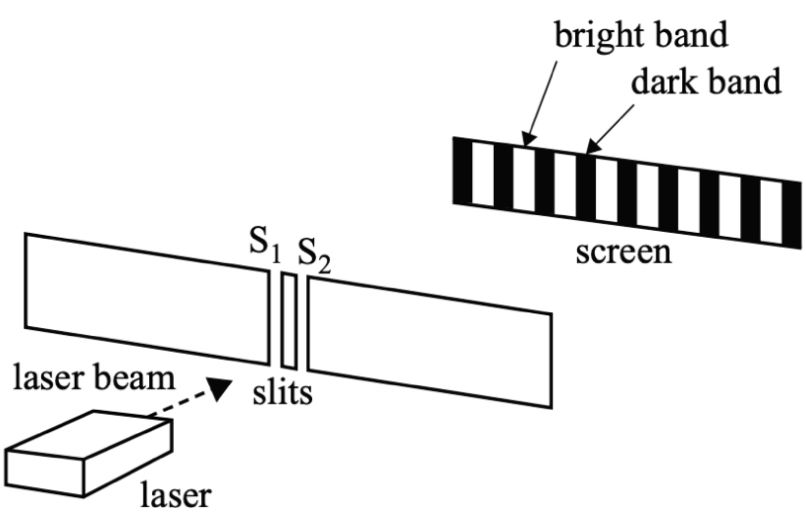
C an antinode resulting from destructive interference.

D an antinode resulting from constructive interference.

Question 27/ 30

[VCAA 2021 NHT SA Q16]

A red laser used in a double-slit experiment creates an interference pattern on a screen, as shown below.



The red laser is replaced with a green laser. Which one of the following best explains what happens to the spacing between adjacent bright bands when the green laser is used?

A The spacing increases.

B The spacing decreases.

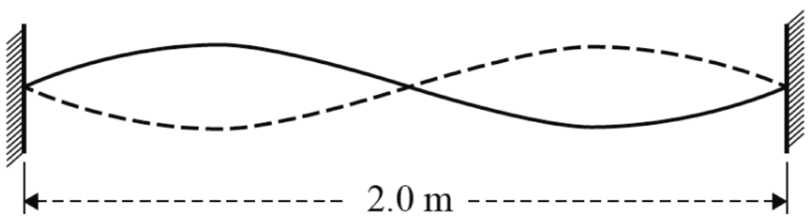
C The spacing stays the same.

D The spacing cannot be determined from the information given.

Question 28/ 30

[VCAA 2022 NHT SA Q12]

The diagram below represents a standing wave on a string fixed at both ends, with a node at the centre. The wave has a frequency of 5.0 Hz and the distance between the two fixed ends is 2.0 m.



A 0.40 m s^{-1}

B 2.5 m s^{-1}

C 5.0 m s^{-1}

D 10 m s^{-1}

Question 29/ 30

[VCAA 2022 NHT SA Q19]

Diffraction is a property of waves. Electrons display wave-like properties when producing diffraction patterns. This is because electrons

A always carry an electric charge.

B can move around nuclei in fixed orbits.

C have a wavelength related to their momentum.

D can jump between energy levels within an atom.

Question 30/ 30

[VCAA 2022 SA Q13]

A travelling wave produced at point A is reflected at point B to produce a standing wave on a rope, as represented in the diagram below.

The distance between points A and B is 2.4 m. The period of vibration of the standing wave is 1.6 s. The speed of the travelling wave along the rope is closest to

A 0.75 m s^{-1}

B 1.0 m s^{-1}

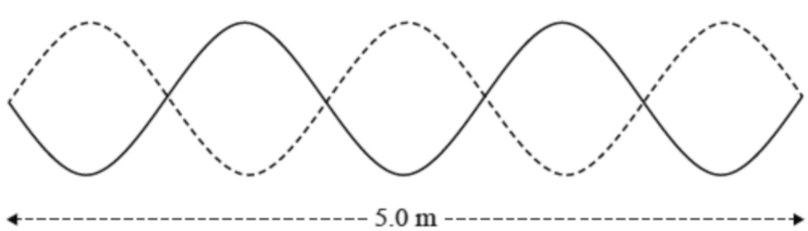
C 1.5 m s^{-1}

D 2.0 m s^{-1}

Question 31/ 30

[VCAA 2022 NHT SA Q19]

A standing wave is produced on a flexible string, as shown in the diagram below. The diagram shows the wave at two different times – the solid line represents what the wave looks like at a particular time and the dotted line represents what the wave looks like exactly half a cycle later.



Which one of the following is closest to the wavelength of the standing wave?

A 0.5 m

B 1.0 m

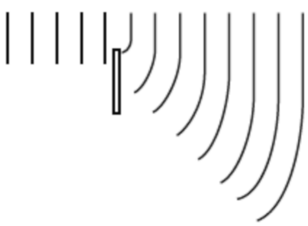
C 1.5 m

D 2.0 m

Question 32/ 30

[VCAA 2023 SA Q16]

Water waves travelling at constant speed and hitting a barrier can change direction, as shown in the diagram below.



Which one of the following best identifies this phenomenon?

A diffraction

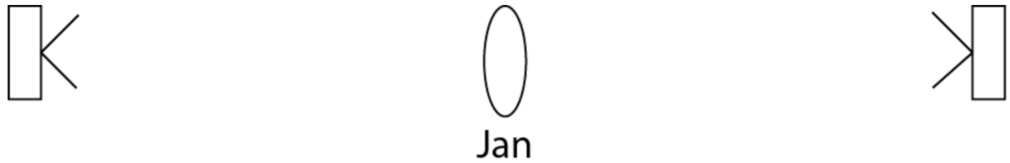
B dispersion

C refraction

D resonance

Question 1/ 67

Jan is standing midway between two speakers. They are emitting sound in phase, at 175 Hz, and she hears a loud sound of that frequency. Assume that Jan does not have any effect on the sound waves.



The speakers are 10 m apart. As she moves to the left, the sound intensity falls. When she is 4.5 m from the left-hand speaker, the intensity reaches a minimum.

a. Explain why the intensity drops to a minimum.

(3 marks)

b. Calculate the wavelength of the 175 Hz sound.

(2 marks)

c. Use this data to calculate the speed of sound.

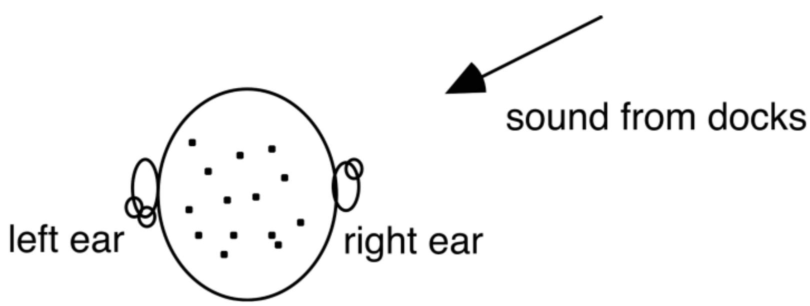
(2 marks)

d. Describe the nature of the sound wave that forms in the space between the two loudspeakers.

(2 marks)

Question 2/ 67

Dan is listening to a ship whistle coming from the docks.

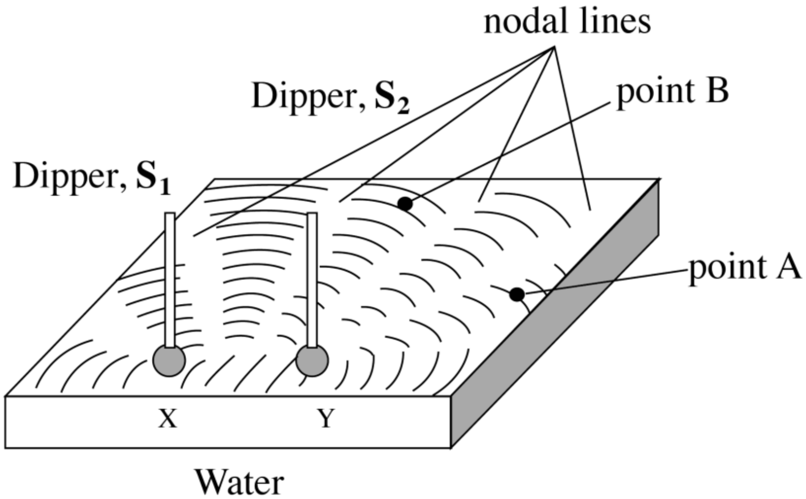


Dan can tell where the sound is coming from by comparing the intensities in each of his ears. Explain why Dan would find it harder to locate low-frequency sound than high-frequency sound.

(2 marks)

Question 3/ 67

Two dippers make circular waves in phase in a shallow tank of water, as shown.



The dark lines in the diagram show areas of water where there is no wave motion in the water. Between these dark lines (nodal lines), water waves are travelling away from the dippers; the bright sections are wave crests. Point B is equidistant from X and Y.

a. Explain why there are travelling waves in some parts of the tank and flat water in other parts.

(3 marks)

X is the point where dipper S_1 touches the water, and Y the point where S_2 touches. The wavelength of the travelling water waves is 1 cm.

b. Find the distance $(\mathrm{AX} - \mathrm{AY})$ in cm.

(1 mark)

c. Describe the movement of the water along the line joining points X and Y, giving your reasoning.

(3 marks)

d. The speed of the water waves is $5\ \mathrm{cm\ s^{-1}}$. Calculate the period of the dippers (in seconds).

(2 marks)

e. Discuss the effect on the pattern of nodal lines if each of these changes was implemented:

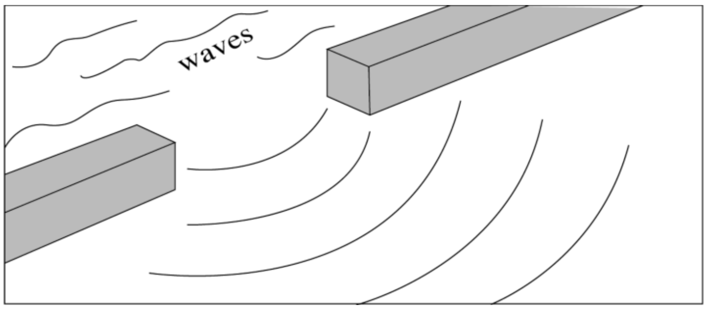
• reducing the distance XY

• increasing the frequency of the dippers.

(4 marks)

Question 4/ 67

Straight water waves are incident on a narrow opening at a harbour, as shown.

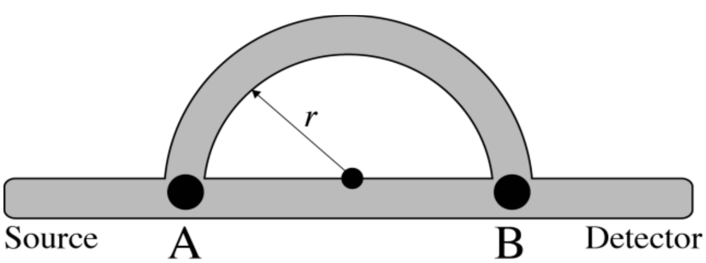


Boat owners in the harbour would like to reduce the amount that the waves spread out as they travel through the opening. Some suggest that a narrower opening would reduce both the spreading and the amount of wave energy entering the harbour. Evaluate this response.

(3 marks)

Question 5/ 67

Sound travels along a tube sketched below. At point A, about half the sound travels along the curved section, the other half is undeflected at this point, and at point B the two paths rejoin. The radius of the curved section, *r*, is 80 cm.



a. Show that the path difference for the two pathways is equal to 1.14*r*.

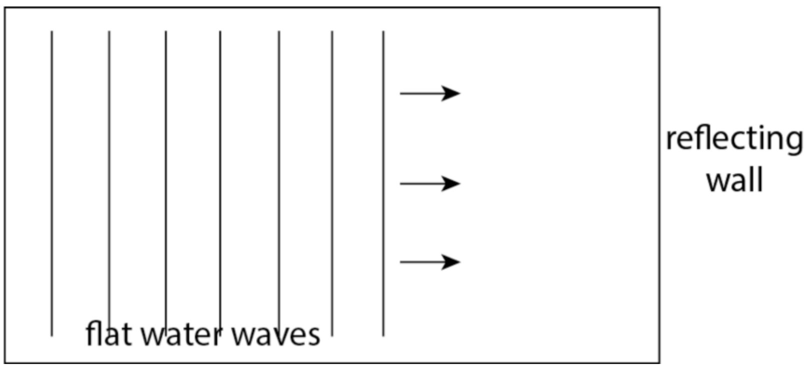
(2 marks)

b. As the sound frequency from the source changes, the detector measures varying degrees of loudness. A sound of frequency 372 Hz is generated. The speed of sound at the time is 340 m s^{-1}. Evaluate whether the sound is likely to be close to a maximum or a minimum. Show your working.

(3 marks)

Question 6/ 67

Plane water waves in a ripple tank are directed towards the flat wall of the tank.



The waves are moving at 6.0 cm s^{-1} towards the right. The frequency of the waves is 3.0 Hz.

a. Calculate the wavelength of the waves.

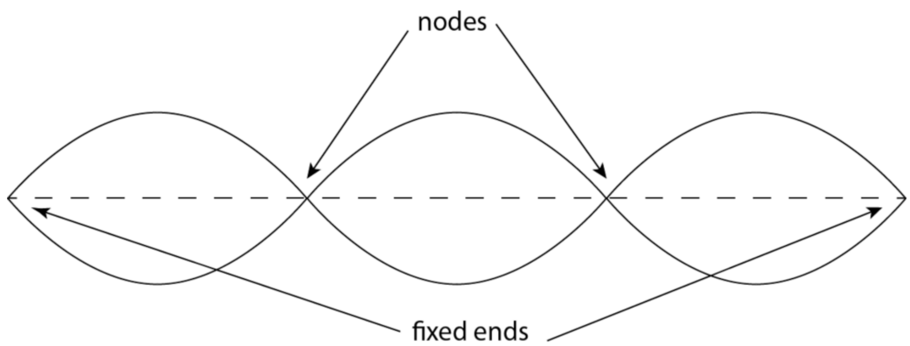
(2 marks)

b. When the waves reach the wall, they reflect (without loss), and travel back to left, interfering with waves travelling right. Describe the resulting waves that form in the tank (including quantitative details).

(4 marks)

Question 7/ 67

A violin string is played forming a 900 Hz sound standing wave. The string is fixed at the ends, and a strobe photo of the vibrating string reveals regions of no vibration (nodes), as shown below. The distance between the fixed ends is 30 cm. The dashed line shows the string’s position when it is not vibrating.



a. Describe the mechanism leading to the formation of the standing wave.

(3 marks)

b. Calculate the period of the standing wave.

(2 marks)

c. Calculate the speed of a transverse wave along the violin string. Show your working.

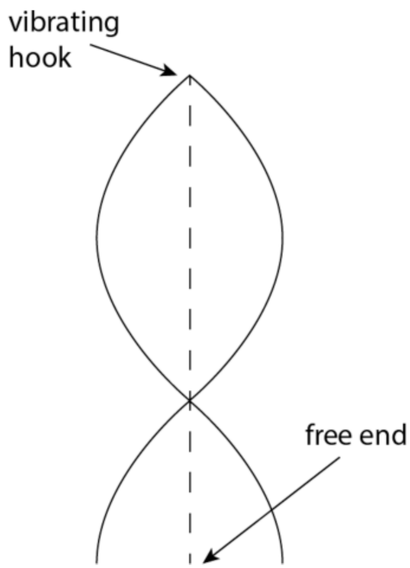
(3 marks)

d. The violin player finds that they can play two other lower frequency notes on the 30 cm length string, with the string otherwise unchanged. Calculate the frequency of these two notes, showing your working.

(3 marks)

Question 8/ 67

A light cord is hanging from a vibrating hook in the ceiling. This sets up standing waves in the cord. The hook can be considered to be stationary, and the hanging end can be considered free. *One* of the possible standing waves is sketched below. The dashed line shows the position of the cord when it is not vibrating. The wave shown has a frequency of 150 Hz. The vertical distance between the hook and the free end is 45 cm.



a. Sketch the shape of two other standing waves, labelling the nodes and antinodes.

(4 marks)

b. Calculate the frequency of the two standing waves that you have sketched. Show your working.

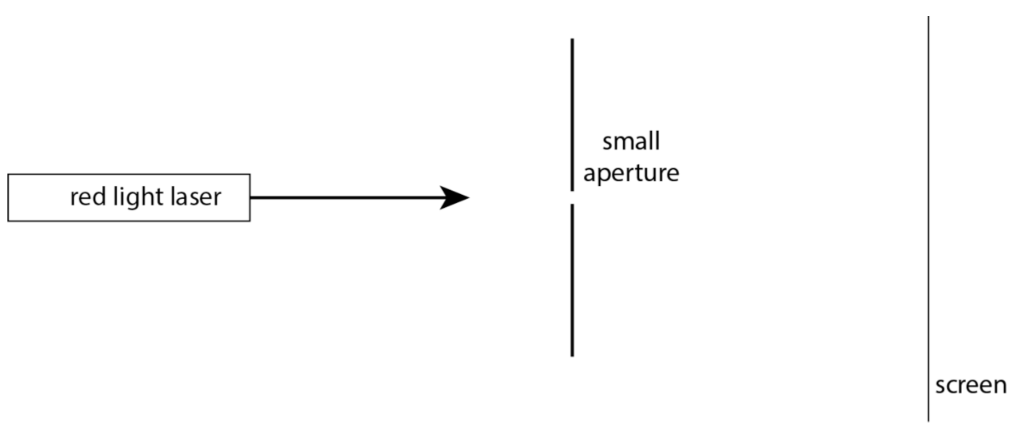
(3 marks)

c. Calculate the speed of a transverse wave along the hanging cord.

(2 marks)

Question 9/ 67

A red laser is directed at a very small width vertical slit in an opaque barrier. This is similar to a Young's two-slit experiment with only one slit. Diffraction effects are clearly seen. The diagram shows the apparatus viewed from above.



a. Describe the pattern seen on the screen.

(2 marks)

b. Describe the change in the pattern if the screen is moved towards the slit.

(1 mark)

c. The red laser is replaced by a green laser. Describe the pattern now. Explain your reasoning.

(2 marks)

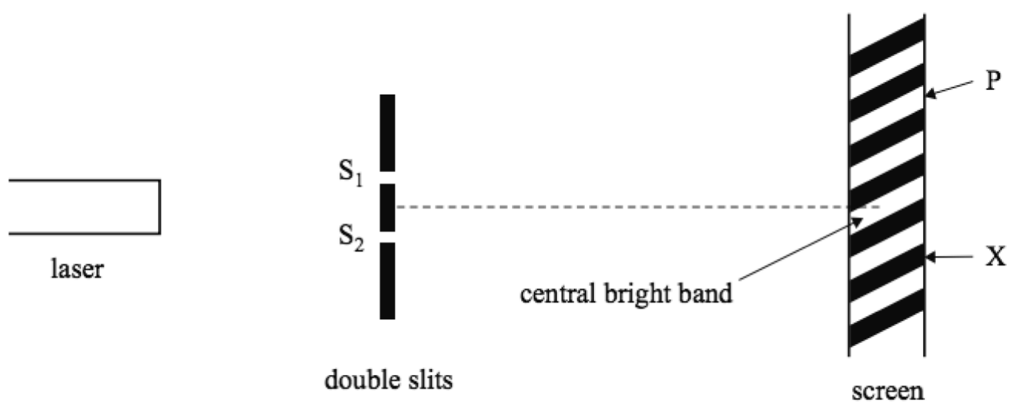
d. The laser is now replaced with a narrow beam of white light from an incandescent light globe. Describe the pattern now. Explain your reasoning.

(3 marks)

Question 10/ 67

[Adapted VCAA 2016 SA Q18]

Amelia and Rajesh conduct an experiment to study interference using a laser and double slits, as shown. X is a dark band as shown.



The path difference $S_1X - S_2X$ is found to be 750 nm.

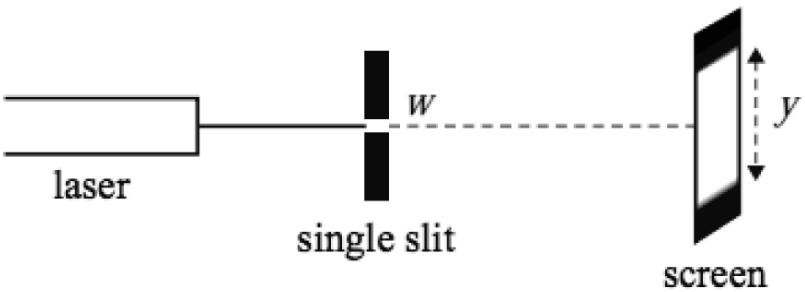
a. Calculate the wavelength of the laser.

(2 marks)

b. P is a bright band. Calculate the path difference $S_2P - S_1P$. Show your working.

(2 marks)

Amelia and Rajesh replace the double slits with a single slit of width *w*, as shown. They find that the width of the central maximum of the diffraction pattern is *y*.



They replace the single slit with another single slit of width 2*w*.

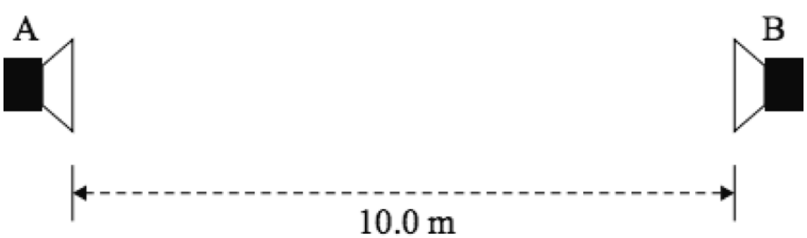
c. Describe the expected change in the width of the central maximum, including your reasoning.

(2 marks)

Question 11/ 67

[Adapted VCAA 2016 SB Q7]

Yasmin and Paul set up the following experiment in a large open area. They connect two speakers that face each other, as shown.



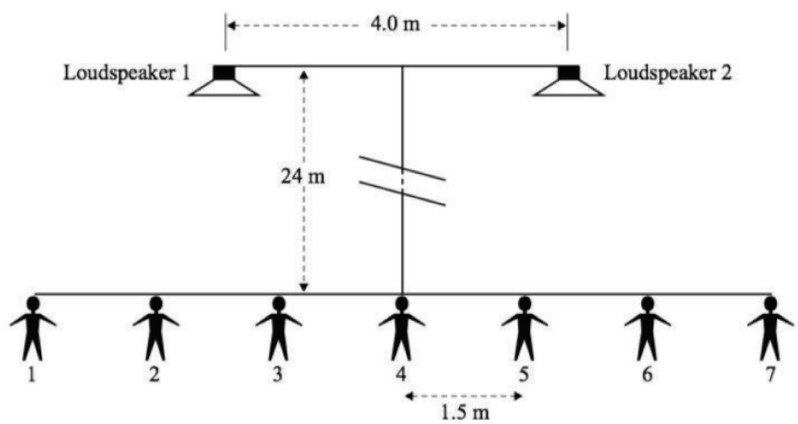
The speakers are 10 m apart and connected to the same signal generator, and produce a sound with a wavelength of 1.0 m. Yasmin stands in the centre, equidistant to speakers A and B. She then moves towards Speaker B and experiences a sequence of loud and quiet regions. She stops at the second region of quietness. How far is she from Speaker B? Show your working.

(3 marks)

Question 12/ 67

[Adapted VCAA 2017 SB Q15]

A Physics teacher is demonstrating wave phenomena to her students. She takes her students to the school oval to listen to 680 Hz sound. The speed of sound in air is 340 m s^{-1}. The teacher sets up two loudspeakers placed 4.0 m apart with the 680 Hz sound in phase. Seven students are placed in a row 24 m from the loudspeakers, as shown in the diagram below. Each student is 1.5 m away from the next student. Student 4 is in the middle and is exactly the same distance from each loudspeaker. When a single loudspeaker is sounding, all the students hear very close to the same intensity.



The teacher now connects both loudspeakers. One student, Elli, predicts that now they will all hear a similar sound of double the intensity. Another student, Sam, disagrees. He says the intensity of the sound will depend on each student's relative distance from each speaker.

a. Evaluate Elli's and Sam's responses.

(3 marks)

b. Will students 2 and 5 in the diagram on the previous page hear similar or different sound intensities? If you predict that one of the students will hear a higher sound intensity, state which student and justify your prediction. Show your working.

(3 marks)

Question 13/ 67

[VCAA 2017 SB Q16]

Standing waves are formed on a string of length 4.0 m that is fixed at both ends. The speed of the waves is 240 m s^{-1}.

a. Calculate the wavelength of the lowest frequency resonance.

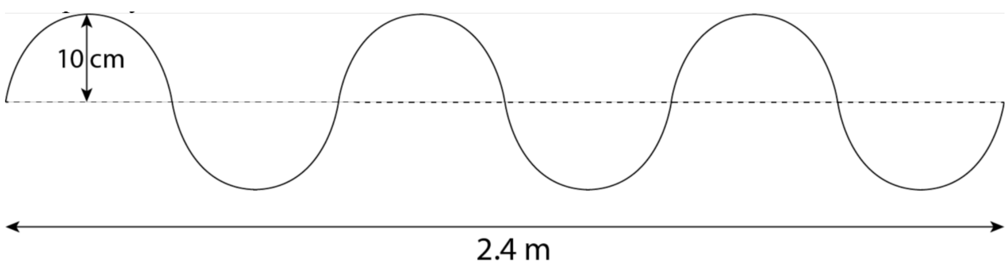
(2 marks)

b. Calculate the frequency of the second-lowest frequency resonance.

(2 marks)

Question 14/ 67

Students create a standing wave in an elastic cord 2.4 m long. They take video shots of the vibrating cord. The diagram below shows the cord at one extreme of its vibration (maximum amplitude). The dashed line shows the ‘at rest’ position of the elastic cord. The frequency of the wave is 100 Hz.



a. State the wavelength of the standing wave.

(1 mark)

b. Sketch the position of the cord at a time 7.5 ms after that shown.

(2 marks)

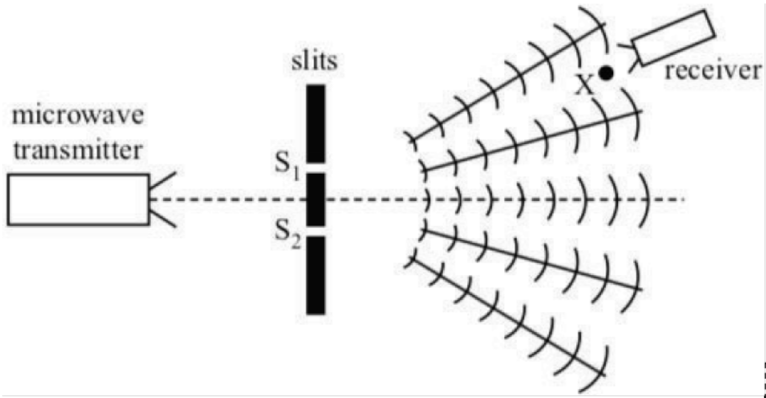
c. Calculate the speed of a transverse wave along the cord.

(2 marks)

Question 15/ 67

[Adapted VCAA 2018 NHT SB Q11]

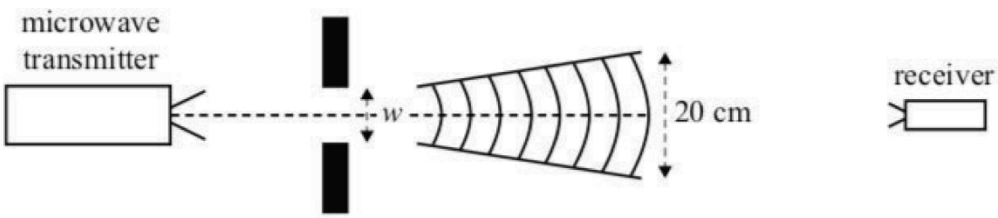
Students use a microwave set to study wave interference. The set consists of a transmitter set to transmit waves of $\lambda = 3.0$ or 6.0 cm, a receiver measuring the intensity and wavelength of the received signal, plates to make single or double slits and a ruler. The speed of the waves is $3.0 \times 10^8 \text{ m s}^{-1}$. The students set up the equipment using 3.0 cm microwaves, placing the receiver at X on the second nodal line (minimum) out from the centre, as shown.



a. Calculate the path difference $S_2X - S_1X$. Show your working.

(2 marks)

The students now replace the two slits with a single slit of width *w*, as shown.

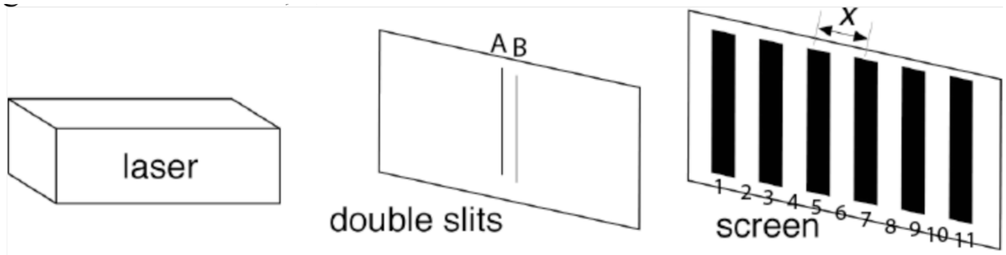


b. With the transmitter set to a wavelength of 3.0 cm, the width of the diffraction pattern is 20 cm at a fixed distance from the slit. They then change the wavelength to 6.0 cm. What effect will this have on the width of the pattern? Explain your answer.

(2 marks)

Question 16/ 67

Students perform a Young's double-slit experiment. The diagram below shows the arrangement. Two narrow slits (A and B) let light from a laser pass through them. The result is a pattern of light and dark bands on a screen. The bands are numbered. The spacing between the bands, *x*, as also shown.



a. One of the bands is *equidistant* from slit A and slit B. Explain why it is not possible for bands 1, 3, 5, 7, 9 or 11 to be that band.

(2 marks)

b. The students measure that the distance from slit A to band 11 is longer than the distance from slit B to band 11 by 1.5 µm. Use this information to calculate the wavelength of the light from the laser. (*Assume that band 6 is the central band*.)

(2 marks)

c. Identify *two* changes to the apparatus that would increase the spacing, *x*. Explain your changes in terms of a wave model of light.

(2 marks)

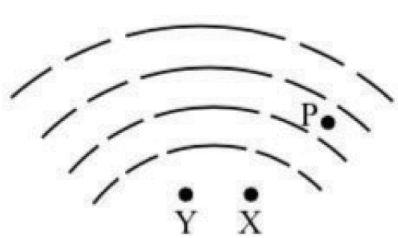
d. Explain why *narrow* slits (A and B) are necessary if the light from the slits is to spread out and overlap after passing through them.

(2 marks)

Question 17/ 67

[Adapted VCAA 2017 Sample SB Q6]

Juan conducts an experiment using a shallow tray of water of waves. He uses two point sources of wavelength 10 cm and frequency 5 Hz to investigate a two point source interference pattern, as shown below.



He observes lines of maxima and minima in the resultant pattern, as shown above. The lines on the diagram represent wave crests. Point P is on a nodal line of minima. Juan measures the distance from source X to point P as 16.0 cm. Determine the distance from source Y to point P.

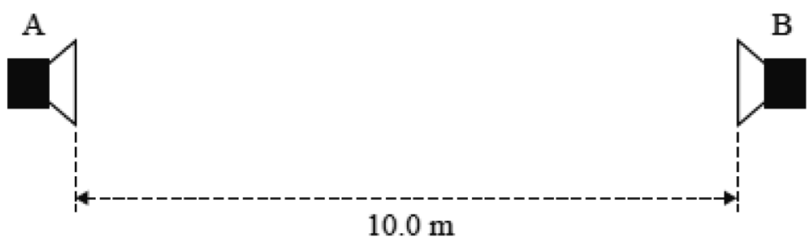
(2 marks)

Question 18/ 67

[Adapted VCAA 2018 SB Q11]

The diagram following shows two speakers, A and B, facing each other. The speakers are connected to the same signal generator/amplifier and the speakers are simultaneously producing the same 340 Hz sound.

Take the speed of sound to be 340 m s^{-1}.



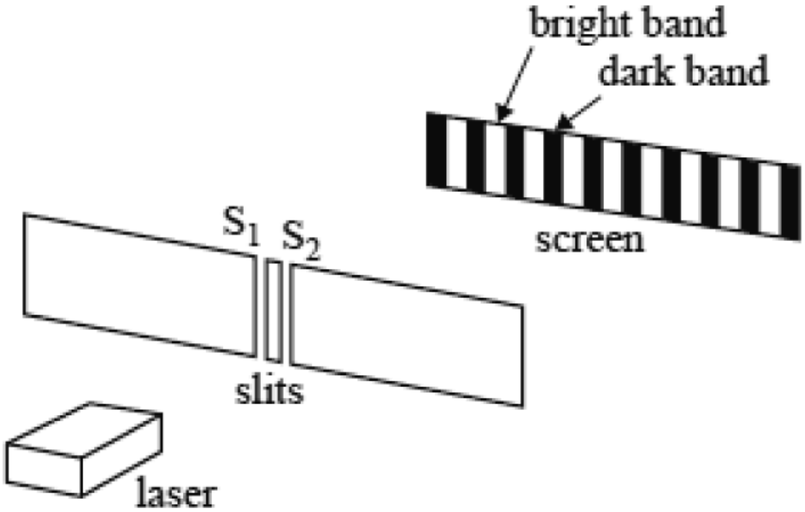
A student stands in the centre, equidistant from speakers A and B. He then moves towards speaker B and experiences a sequence of loud and quiet regions. He stops at the second region of quietness. How far has the student moved from the centre? Explain your reasoning.

(3 marks)

Question 19/ 67

[Adapted VCAA 2018 SB Q13]

Physics students studying interference set up a double-slit experiment using a 610 nm laser, as shown in the diagram below.



A section of the interference pattern observed by the students is shown in the diagram below. There is a bright band at point C, the centre point of the pattern.

a. Explain why point C is in a bright band rather than in a dark band.

(2 marks)

b. Another point on the pattern to the right of point C is further from S_1 than S_2 by a distance of 2.14×10^{-6}m. Mark this point on the diagram by writing an X above the point. You must use a calculation to justify your answer.

(2 marks)

Question 20/ 67

[VCAA 2019 NHT SB Q11]

Kym and Roger conduct an experiment to observe an electron diffraction pattern. 5000 eV electrons are projected through a diffracting grid and the resulting pattern is observed on a screen. Kym and Roger want to calculate the wavelength of X-rays that would produce a similarly spaced diffraction pattern. Kym says that they will need X rays of 5000 eV. Roger says that X-rays of a different energy will be needed.

a. Explain why Roger is correct.

(2 marks)

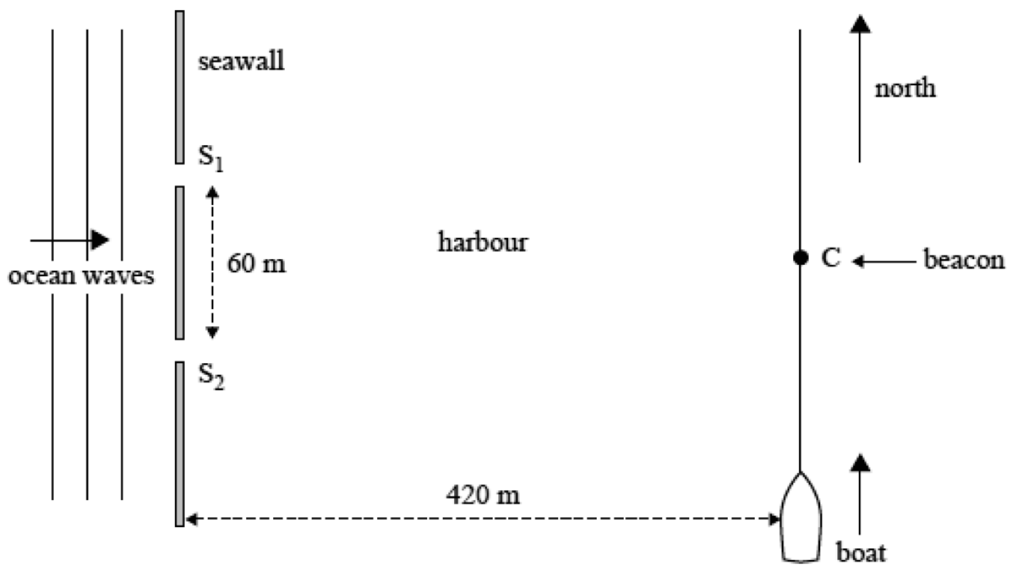
b. Showing each working step involved, calculate the X-ray energy that would be required to produce the similarly spaced diffraction pattern.

(4 marks)

Question 21/ 67

[VCAA 2019 NHT SB Q13]

A seawall that is aligned north–south protects a harbour of constant depth from large ocean waves, as shown in the diagram on the next page. The seawall has two small gaps, S_1 and S_2, which are 60 m apart. Inside the harbour, a small boat sails north parallel to the seawall at a distance of 420 m from the seawall. At point C sits a beacon, equidistant from the two gaps in the seawall. The boat's captain notices that, at about every 42 m, there is calm water, while there are large waves between those calm points.



a. Will the beacon at point C be in calm water or large waves? Give a reason for your answer.

(2 marks)

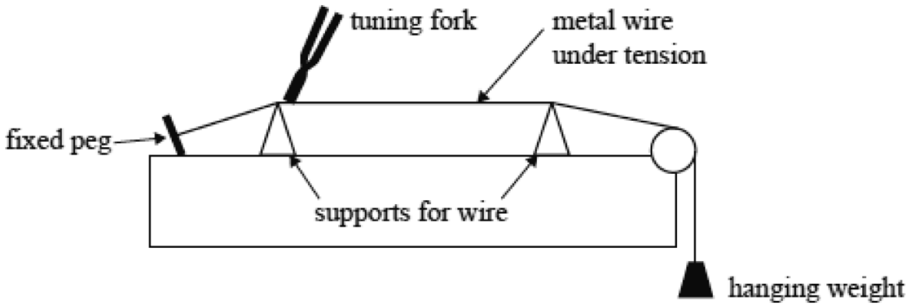
b. Calculate the wavelength of the ocean waves. Show your working.

(2 marks)

Question 22/ 67

[VCAA 2019 NHT SB Q14]

The diagram below shows a simple apparatus that can be used to determine the frequency of a tuning fork.



The apparatus consists of two supports and a metal wire that is stretched between a fixed peg and a hanging weight. The wire is under tension. The tuning fork is set vibrating and is then touched onto the wire close to the left-hand support, which makes the wire vibrate at the same frequency as the tuning fork.

a. Draw a diagram of the simplest standing wave pattern that can exist on the vibrating section of the wire (the fundamental) between the two supports.

(2 marks)

b. When the distance between the supports is 0.92 m, the fundamental frequency resonates in the wire. Calculate the wavelength of the fundamental. Show your working.

(2 marks)

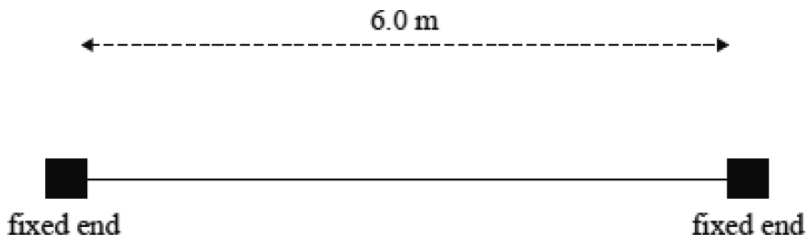
c. Calculate the frequency of the tuning fork if the speed of the waves in the wire is $224 \mathrm{~m} \mathrm{~s}^{-1}$. Show your working.

(2 marks)

Question 23/ 67

[Adapted VCAA 2019 SB Q13]

In an experimental set-up used to investigate standing waves, a 6.0 m length of string is fixed at both ends, as shown in the diagram. The string is under constant tension, ensuring that the speed of the wave pulses created is a constant $40 \mathrm{~m} \mathrm{~s}^{-1}$.



In an initial experiment, a continuous transverse wave of frequency 7.5 Hz is generated along the string. Will a standing wave form? Give a reason for your answer.

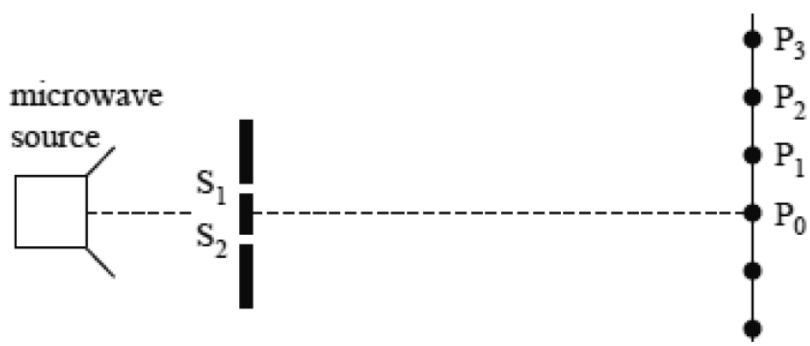
(2 marks)

Question 24/ 67

[VCAA 2019 SB Q14]

Students have set up a double-slit experiment using microwaves. The beam of microwaves passes through a metal barrier with two slits, shown as S_1 and S_2 in the diagram. The students measure the intensity of the resulting beam at points along the line shown in the diagram below.

They determine the positions of maximum intensity to be at the points labelled P_0, P_1, P_2 and P_3. Take the speed of electromagnetic radiation to be 3.00×10^8 m s^{-1}.



The distance S_1 to P_3 is 72.3 cm and the distance S_2 to P_3 is 80.6 cm.

a. What is the frequency of the microwaves transmitted through the slits? Show your working.

(2 marks)

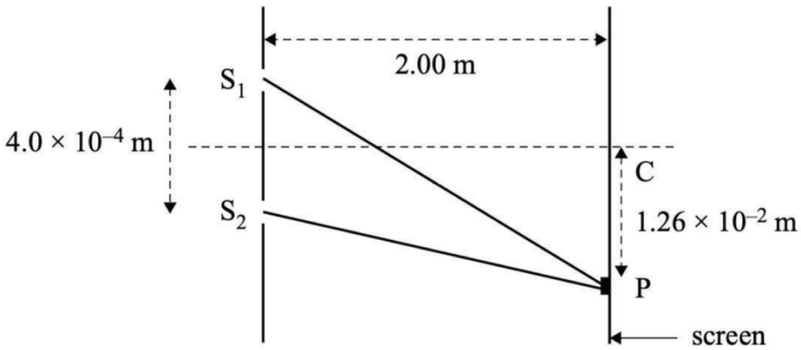
b. The signal strength is at a minimum approximately midway between points P_0 and P_1. Explain the reason why the signal strength would be a minimum at this location.

(2 marks)

Question 25/ 67

[VCAA 2020 SB Q12]

In a Young's double-slit interference experiment, laser light is incident on two slits, S_1 and S_2, that are 4.0×10^{-4} m apart, as shown in the diagram below.



Rays from the slits meet on a screen 2.00 m from the slits to produce an interference pattern. Point C is at the centre of the pattern. The diagram below shows the pattern obtained on the screen.

a. There is a bright fringe at point P on the screen. Explain how this bright fringe is formed.

(2 marks)

b. The distance from the central bright fringe at point C to the bright fringe at point P is $1.26 \times 10^{-2}\mathrm{m}$. Calculate the wavelength of the laser light. Show your working.

(3 marks)

Question 26/ 67

[Adapted VCAA 2021 NHT SB Q16]

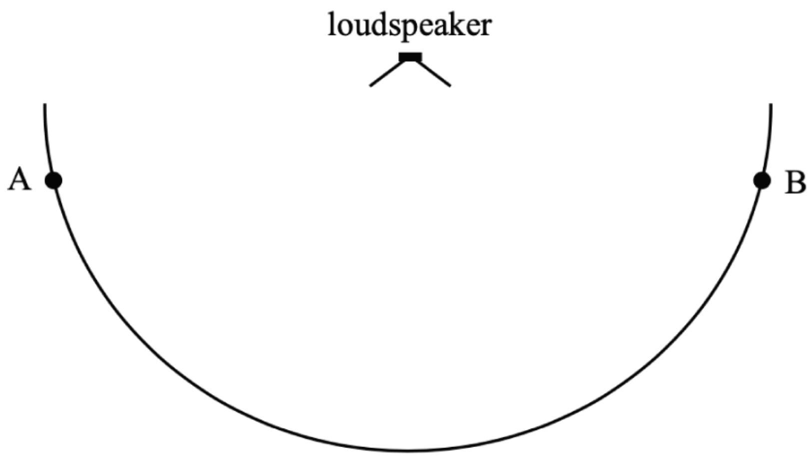
2.0 nm X-rays are incident on a single narrow slit of width $5 \times 10^{-8}\mathrm{m}$. Would a diffraction pattern be observed? Justify your answer.

(3 marks)

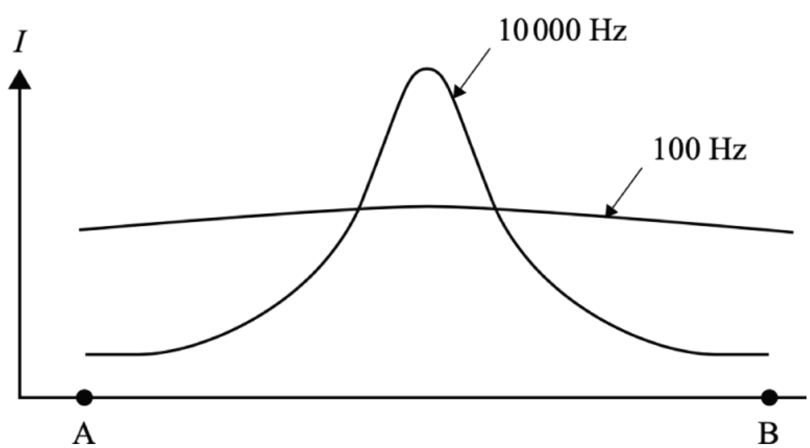
Question 27/ 67

[VCAA 2021 NHT SB Q14]

To explain different aspects of mechanical waves, a Physics teacher sets up a demonstration in a Physics laboratory using a 0.80 m wide loudspeaker and a microphone. The microphone measures the sound intensity at different positions on a circle around the speaker from position A to position B, as shown in the diagram below.



The speed of sound in the Physics laboratory is 334 m s^{-1}. Measurements are made at frequencies of 100 Hz and 10 000 Hz. The loudspeaker emits the 100 Hz and 10 000 Hz frequencies with equal intensity. The graph below shows the intensity, *I*, measured for each frequency at positions on the semicircular line shown in the diagram above between positions A and B.



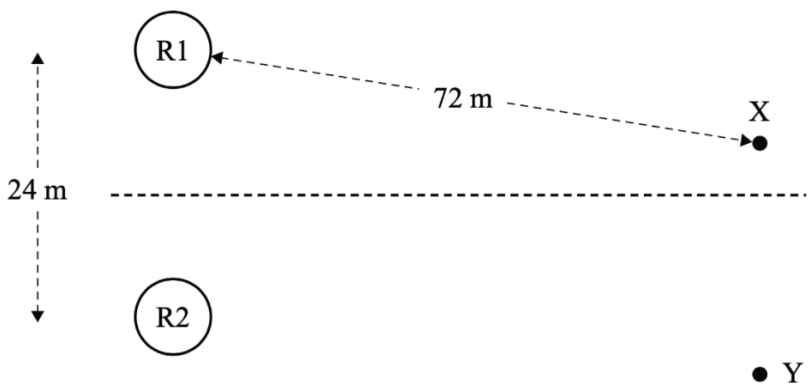
Explain why the response at 10 000 Hz has a greater intensity directly in front of the loudspeaker, while the response at 100 Hz is nearly the same at all positions.

(2 marks)

Question 28/ 67

[VCAA 2021 NHT SB Q12]

Students are testing two identical radio transmitters, R1 and R2, on a football field. The transmitters are positioned 24 m apart, as shown in the diagram below. The transmitters are in phase, both emitting crests simultaneously, and emit waves of wavelength 18 m in all directions. The students are standing at point X, which is located 72 m away from the nearest transmitter, R1.



a. During testing, the radio signal received at point X is detected to be a minimum. Calculate the shortest distance that point X could be from R2. Show your working.

(2 marks)

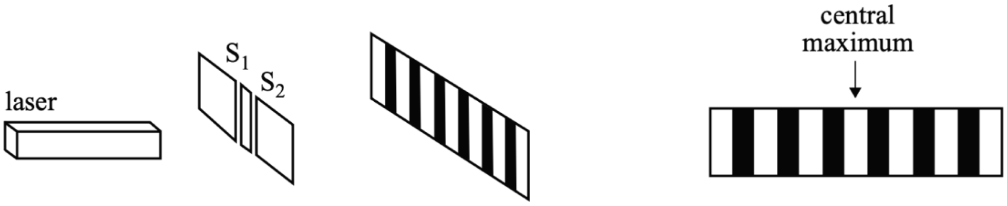
b. At another location on the football field, point Y, the students detect a maximum. Explain why the two observations at points X and Y would support the wave model of light.

(3 marks)

Question 29/ 67

[Adapted VCAA 2021 SB Q13]

In a Young's double-slit experiment, the distance between two slits, S_1 and S_2, is 2.0 mm. The slits are 1.0 m from a screen on which an interference pattern is observed, as shown in the left-hand diagram. The right-hand diagram shows the position of the central maximum of the observed interference pattern.



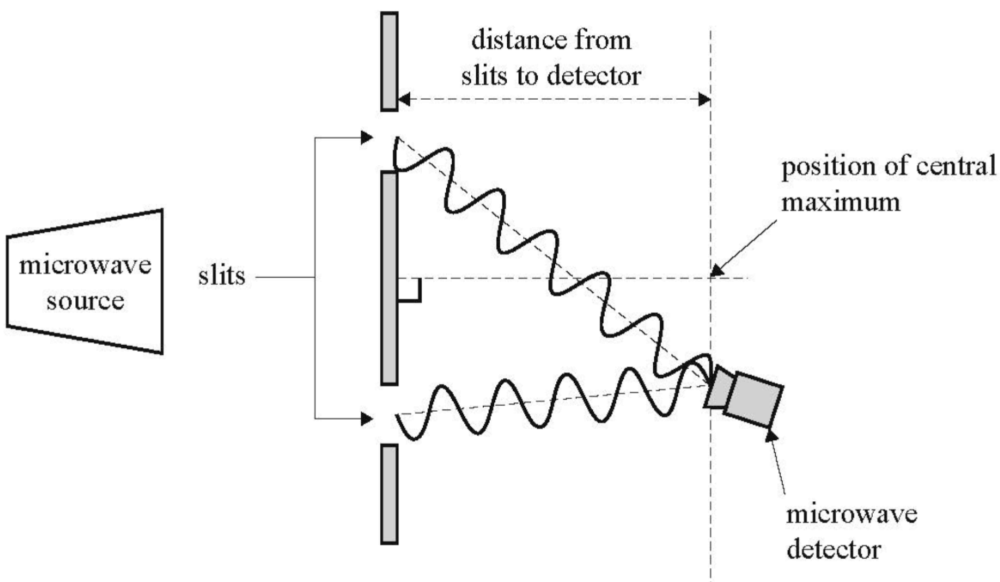
If a laser with a wavelength of 620 nm is used to illuminate the two slits, what would be the distance between two successive dark bands? Show your working.

(2 marks)

Question 30/ 67

[VCAA 2022 NHT SB Q13]

Students are investigating the interference of waves using a source of coherent microwaves, two narrow slits and a microwave detector. The diagram below shows the microwaves travelling from the slits to the detector.



a. The frequency of the microwaves is 12.0 GHz. Calculate the wavelength of the microwaves. Show your working.

(2 marks)

b. Using the information in the diagram and your answer to part **a.**, calculate the path difference between the two waves arriving at the detector. Give your reasoning.

(2 marks)

c. Will the intensity of the microwaves at the detector's position, as shown in the diagram, be a maximum or a minimum? Justify your answer.

(2 marks)

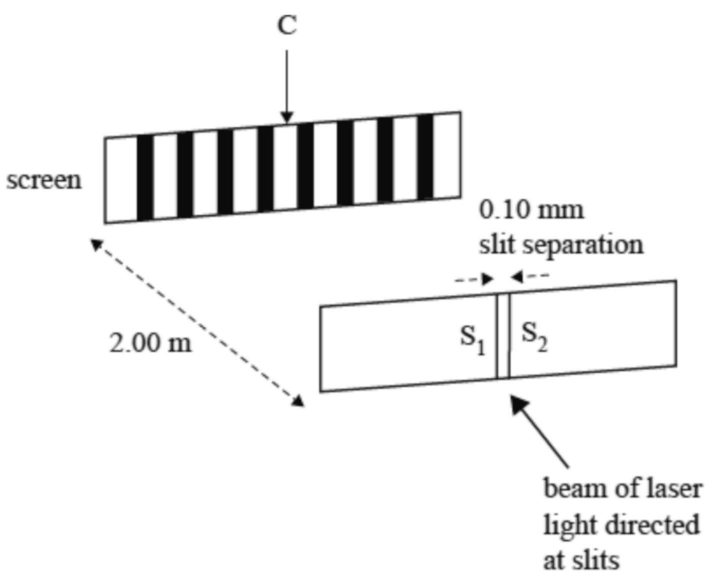
d. The frequency of the microwaves is now halved and the position of the detector is not changed. Describe any changes in the intensity of the microwaves at the detector. Explain your answer.

(3 marks)

Question 31/ 67

[VCAA 2022 SB Q12]

Students conduct an experiment in a Physics laboratory using a laser light source, two narrow slits and a screen, as shown.



Point C is at the centre of the pattern of light and dark bands on the screen. The slit separation is 0.10 mm and the distance between the two slits and the screen is 2.00 m.

a. The band at point C is a bright band. Explain why the band at point C is bright and why there is a dark band to the left of the centre.

(2 marks)

b. The experiment performed by the students is often described as Young's double-slit experiment. Explain how this experiment gave support to those who argued that light has a wave-like nature.

(2 marks)

c. The frequency of the laser light is 6.00×10^{14} Hz. Calculate the spacing of the dark bands on the screen. Show your working.

(2 marks)

d. The students decide to safely immerse the entire apparatus in a liquid. The refractive index of the liquid is unknown but it is greater than the refractive index of air. Using the same laser light, they notice that the spacing of the bands changes. Describe the change observed in the spacing of the bands and explain why this change occurred.

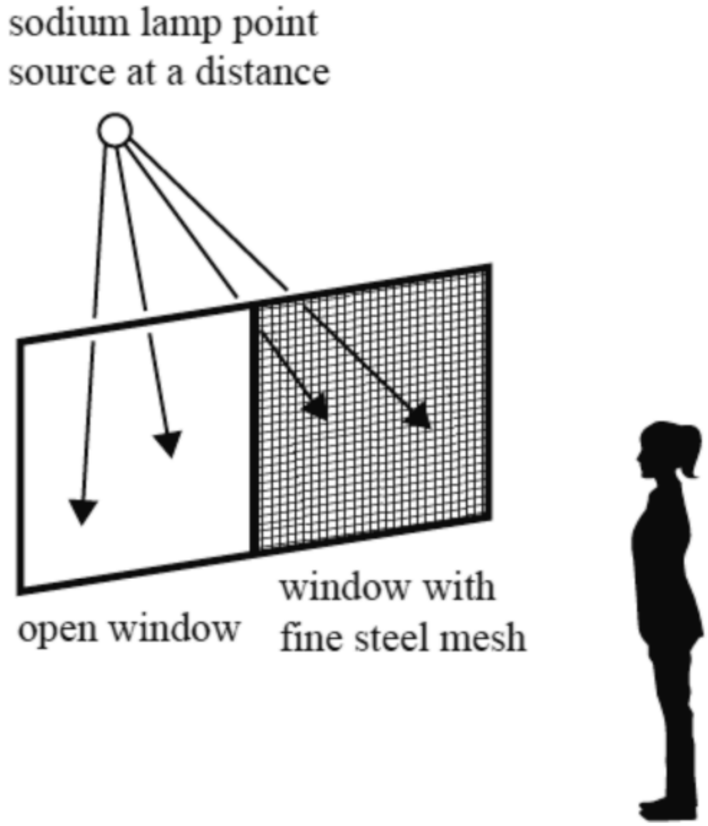
(2 marks)

Question 32/ 67

[VCAA 2022 SB Q16]

A small sodium lamp, emitting light of wavelength 589 nm, is viewed at night through two windows from across a street. The glass of one window has a fine steel mesh covering it and the other window is open, as shown. Assume that the sodium lamp is a point source at a distance.

A Physics student is surprised to see a pattern formed by the light passing through the steel mesh but no pattern for the light passing through the open window. She takes a photograph of the observed pattern to show her teacher, who assures her that it is a diffraction pattern.



a. State the condition that the fine steel mesh must satisfy for a diffraction pattern to form.

(1 mark)

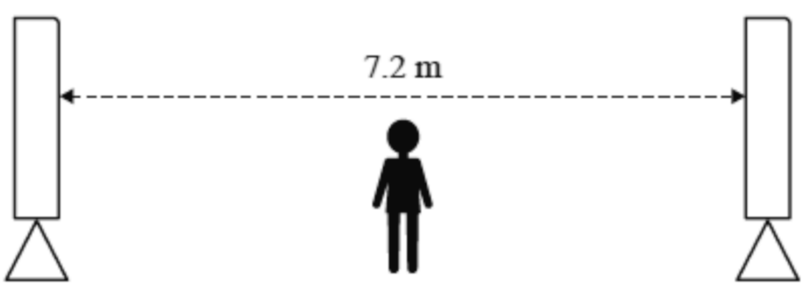
b. Explain why the condition stated in **part a**. does not apply to the open window.

(2 marks)

Question 33/ 67

[VCAA NHT 2023 SB Q15]

Nialle is standing between two loudspeakers on the school oval, as shown below. Sound of a single frequency of 200 Hz is being emitted equally from both speakers. The distance between the speakers is 7.2 m.



When Nialle stands exactly halfway between the speakers, the sound is quite loud. Nialle begins to walk towards one speaker and notices that the sound gets quieter and then louder.

a. Calculate the wavelength of the 200 Hz sound, taking the speed of sound to be 360 m s^{-1}.

(1 mark)

b. Nialle decides that this observation must be due to interference.

Explain how interference accounts for the loud and quiet points.

(3 marks)

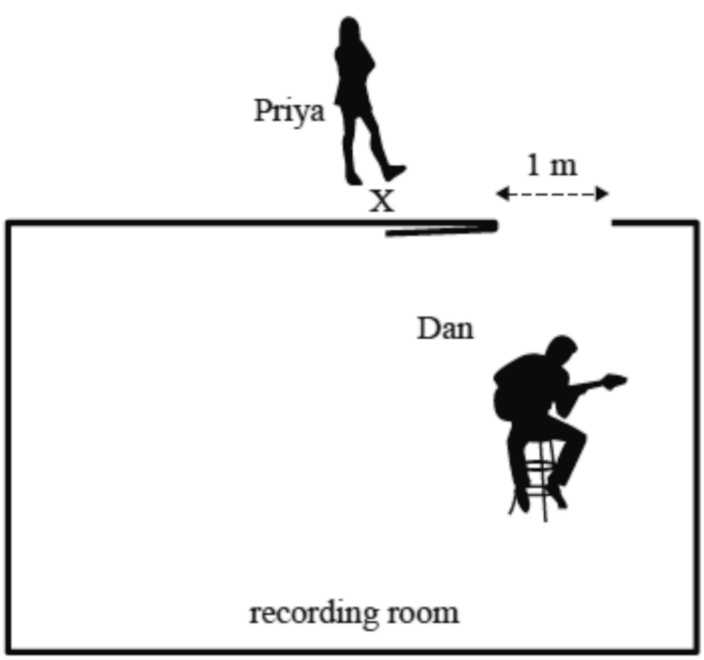
c. Calculate the spacing between two adjacent quiet points.

(2 marks)

Question 34/ 67

[Adapted VCAA NHT 2023 SB Q16]

Priya and Dan are playing music in a soundproof recording room. Priya leaves the room while Dan is still playing. She notices that when she is standing at point X with the door open, as shown below, she can still hear the music. The music is not only softer, but some of the frequencies also seem to be relatively much softer. The door to the recording room is 1 m wide.



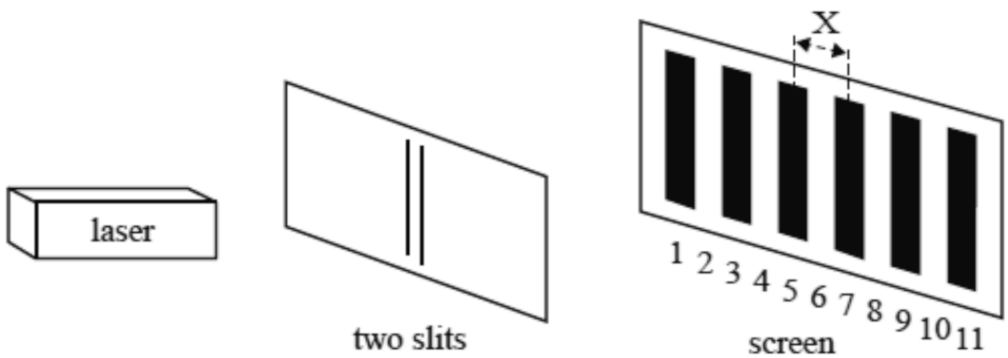
Outline in what way the music sounds different to Priya and explain why.

(3 marks)

Question 35/ 67

[VCAA NHT 2023 SB Q18]

Students carry out a Young's double-slit experiment using the experimental set-up shown below. Laser light passes through two closely spaced narrow slits and forms a pattern of light and dark bands on a screen. The bands are numbered – the even numbers are bright bands and the odd numbers are dark bands. The band spacing is X. Band 6 is equidistant from each of the two slits.



a. Using a wave model of light, explain why Band 3 is dark.

(2 marks)

b. The two slits are 1.00 m from the screen. The spacing between the two slits is 0.100 mm. The wavelength of the laser is 600 nm.

Calculate the band spacing, X, in millimetres.

(2 marks)

c. The whole apparatus is now immersed in an insulating liquid of refractive index 1.2. The spacing of the bands changes.

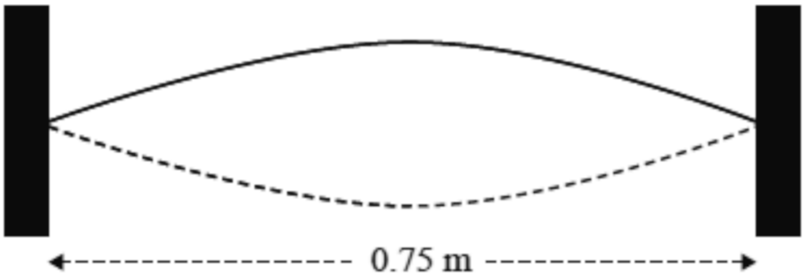
Explain why the spacing of the bands changes and include a calculation of the new band spacing.

(2 marks)

Question 36/ 67

[VCAA 2023 SB Q11]

A guitar string of length 0.75 m and fixed at both ends is plucked and a standing wave is produced. The envelope of the standing wave is shown below.



The speed of the wave along the string is 393 m s^{-1}.

a. What is the frequency of the wave?

(1 mark)

b. Describe how the standing wave is produced on the string fixed at both ends.

(2 marks)

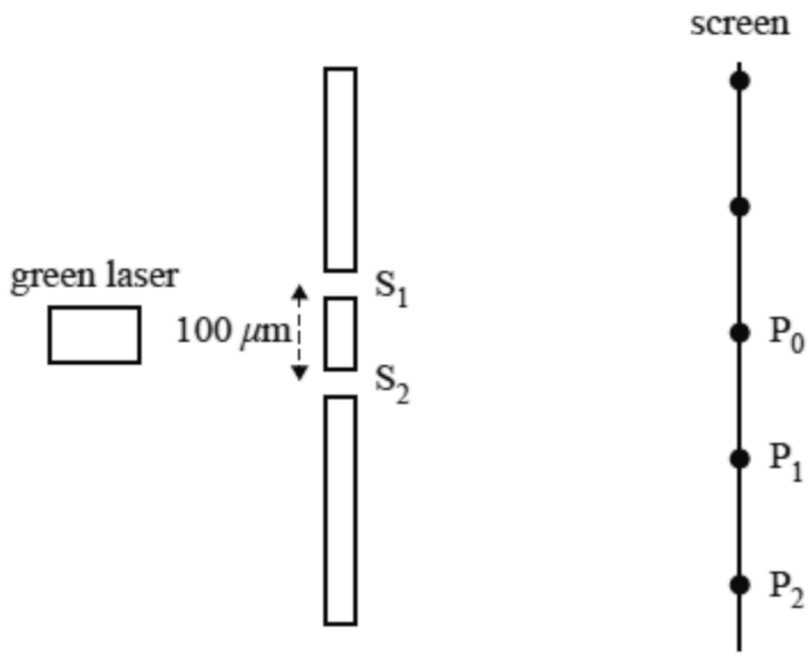
Question 37/ 67

[VCAA 2023 SB Q13]

A group of physics students undertake a Young's double-slit experiment using the apparatus shown below. They use a green laser that produces light with a wavelength of 510 nm.

The light is incident on two narrow slits, S_1 and S_2.

The distance between the two slits is 100 µm.



An interference pattern is observed on a screen with points P_0, P_1 and P_2 being the locations of adjacent bright bands as shown above. Point P_0 is the central bright band.

a. Calculate the path difference between S_1P_2 and S_2P_2. Give your answer in metres.

(2 marks)

b. The green laser is replaced by a red laser.

Describe the effect of this change on the spacing between adjacent bright bands.

(1 mark)

c. Explain how Young's double-slit experiment provides evidence for the wave-like nature of light and not the particle-like nature of light.

(3 marks)

Chapter 15 Particle properties of light, models of light

Question 1/ 21

A searchlight beams out green light, of wavelength 520 nm. The momentum of a single 520 nm photon is closest to

A 3.9×10^{-19}N s

B 1.3×10^{-27}N s

C 6.6×10^{-37}N s

D 3.4×10^{-60}N s

Question 2/ 21

The searchlight power is 5.0 kW. These photons are focused onto a perfectly reflecting mirror. The average force on the mirror is closest to

A 1.7×10^{-5} N

B 3.3×10^{-5} N

C 5.0×10^{3} N

D 1.0×10^{4} N

Question 3/ 21

If the mirror in the previous question was replaced by a perfectly *absorbing* surface, then the force would

A increase by a factor of 2

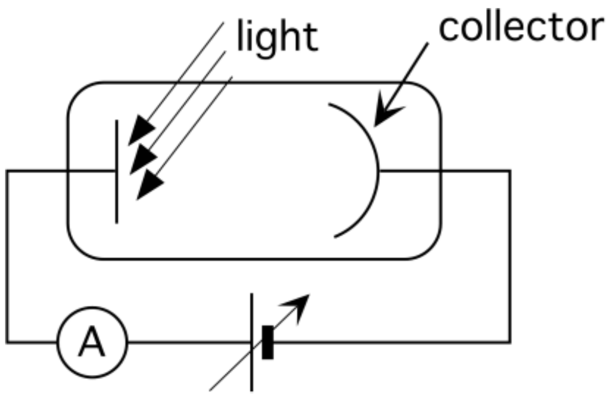
B decrease by a factor of 2.

C remain the same.

D change, but not by a factor of 2.

Question 4/ 21

A photocell is sketched below. This apparatus can be used to determine the maximum energy of emitted photoelectrons. Which of the following values best describes the key measurement for this?



A the maximum current through the ammeter

B the maximum voltage at maximum current

C the smallest voltage to just achieve maximum current

D the smallest voltage to just achieve minimum current

Question 5/ 21

Einstein's explanation of the photoelectric effect contributed a particular insight, namely that

A more intense light carries more energy.

B the energy carried by light can be transferred to electrons.

C different frequency light has different wavelengths.

D the energy that light carries is in discrete quantities.

Question 6/ 21

A dark region in a two-slit interference pattern for light happens because

A the photons annihilate each other at that point.

B the photons involved are not able to be detected.

C the energy of the photons is greatly reduced due to interference.

D the photons cannot be detected at that point.

Question 7/ 21

Which of the following best describes what happens when the intensity of the source of light for the interference pattern is reduced greatly?

A The number of photons is reduced greatly.

B The energy of the photons is reduced greatly.

C The frequency of the photons is reduced greatly.

D The speed of the photons is reduced greatly.

Question 8/ 21

Photoelectrons are emitted almost immediately from the metal surface after light of a suitable wavelength strikes it. The best explanation for this is that

A only one photon is required to liberate one electron.

B very few photons are required to liberate electrons.

C the electrons resonate strongly to the frequency of the incident photons.

D even weak light sources contain lots of energy to liberate electrons.

Question 9/ 21

[VCAA 2018 NHT SA Q16]

When light of a specific frequency strikes a particular metal surface, photoelectrons are emitted. If the light intensity is increased but the frequency of the light remains the same, which of the following is correct?

Number of photoelectrons emitted	Maximum kinetic energy of the photoelectrons
remains the same	remains the same
remains the same	increases
increases	remains the same
increases	increases

Question 10/ 21

A metal surface has a work function of 2.0 eV. The minimum energy of an incoming photon required to eject a photoelectron is

A 3.2×10^{-19} J

B 1.6×10^{-19} J

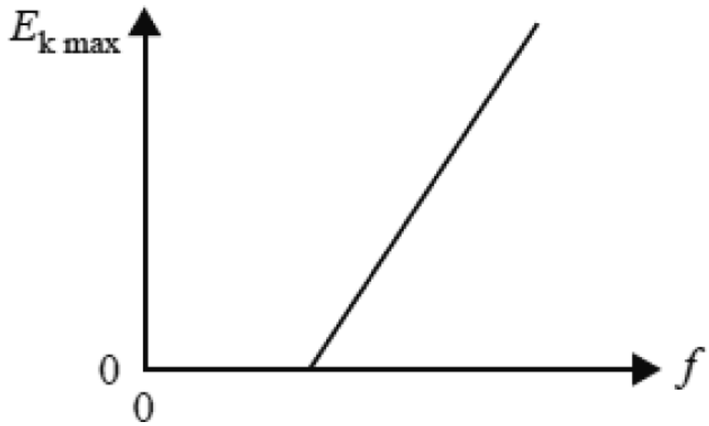
C 8.0×10^{-20} J

D 4.0×10^{-20} J

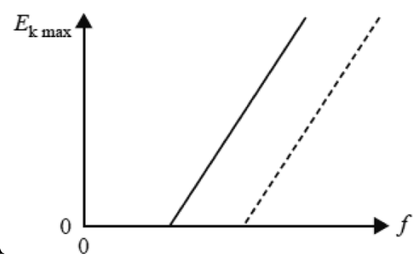
Question 11/ 21

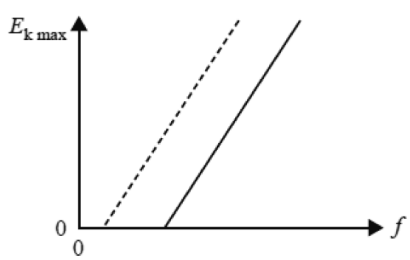
[VCAA 2018 SA Q17]

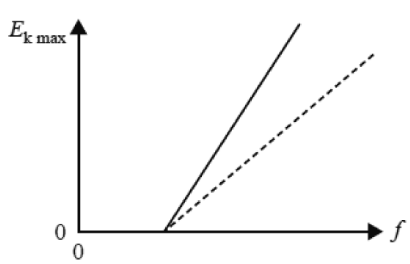
The results of a photoelectric experiment are displayed in the graph below. The graph shows the maximum kinetic energy (E_k max) of photoelectrons versus the frequency (f) of light falling on the metal surface.

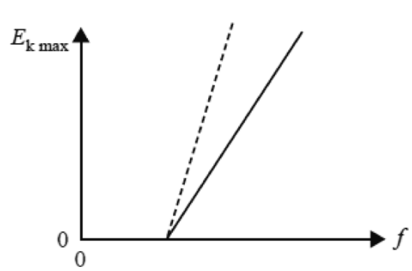


A second experiment is conducted with the original metal surface being replaced by one with a larger work function. The original data is shown with a solid line and the results of the second experiment are shown with a dashed line. Which one of the graphs below shows the results from the second experiment?

A


B


C


D


Question 12/ 21

[VCAA 2019 SA Q16]

Students are conducting a photoelectric effect experiment. They shine light of known frequency onto a metal and measure the maximum kinetic energy of the emitted photoelectrons. The students increase the intensity of the incident light. The effect of this increase would most likely be

A lower maximum kinetic energy of the emitted photoelectrons.

B higher maximum kinetic energy of the emitted photoelectrons.

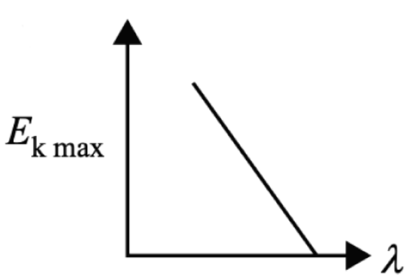
C fewer emitted photoelectrons but of higher maximum kinetic energy.

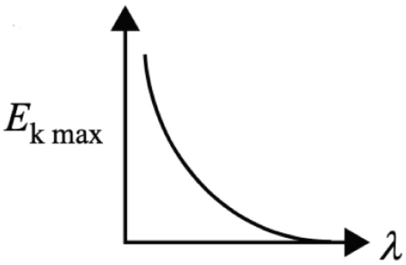
D more emitted photoelectrons but of the same maximum kinetic energy.

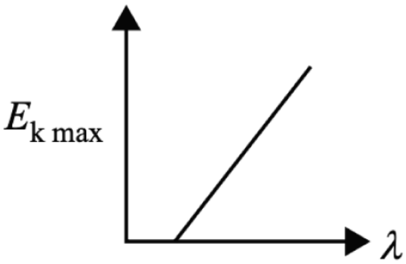
Question 13/ 21

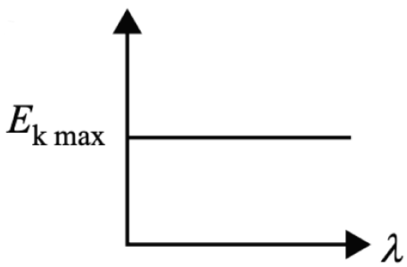
[VCAA 2020 SA Q20]

When photons with energy E strike a metal surface, electrons may be emitted. The maximum kinetic energy, $E_{\text{k max}}$, of the emitted electrons is given by $E_{\text{k max}} = E - W$, where W is the work function of the metal. Which one of the following graphs best shows the relationship between the maximum kinetic energy of these electrons, $E_{\text{k max}}$, and the wavelength of the photons, λ?

A 

B 

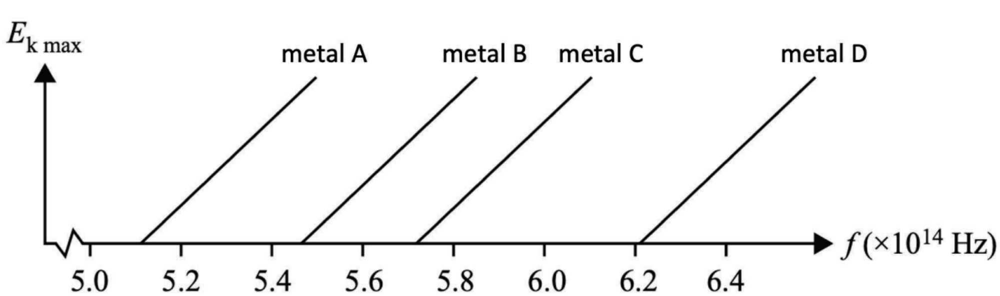
C 

D 

Question 14/ 21

[Adapted VCAA 2020 SA Q16]

The diagram below shows a plot of maximum kinetic energy, $E_{k\,max}$, versus frequency, f, for various metals capable of emitting photoelectrons.



Which one of the following correctly ranks these metals in terms of their work function, from highest to lowest in numerical value?

A Metal A

B Metal B

C Metal C

D Metal D

Question 15/ 21

[VCAA 2021 NHT SA Q18]

Experiments on the photoelectric effect involve shining light onto a metal surface. Measurements are made of the number of emitted electrons and their maximum kinetic energy from the metal surface. This is done for different frequencies and intensities of light. Which one of the following statements would not be one of the experimental findings?

A The ability to eject electrons from this metal depended only on the frequency of light.

B The stopping potential for the photoelectrons was independent of the light intensity.

C The maximum kinetic energy of the photoelectrons depended only on the light intensity.

D At frequencies below the threshold frequency, no electrons were ejected from this metal no matter how high the light intensity was.

Question 16/ 21

[VCAA 2021 NHT SA Q15]

The polarisation of light supports

A the wave model of light.

B the particle model of light.

C both the wave model and the particle model of light.

D neither the wave model nor the particle model of light.

Question 17/ 21

[VCAA 2021 SA Q16]

The diagram below shows a circuit that is used to study the photoelectric effect.

Missing Image

Which one of the following is essential to the measurement of the maximum kinetic energy of the emitted photoelectrons?

A the level of brightness of the light source

B the wavelengths that pass through the filter

C the reading on the voltmeter when the current is at a minimum value

D the reading on the ammeter when the voltage is at a maximum value

Question 18/ 21

[VCAA 2022 NHT SA Q16]

When light of a specific frequency strikes a metal surface, photoelectrons are emitted. If the light intensity is increased but the frequency of the light remains the same, which of the following would be correct?

Number of photoelectrons emitted	Maximum kinetic energy of photoelectrons
increases	remains the same
remains the same	increases
increases	decreases
remains the same	remains the same

Question 19/ 21

[VCAA 2022 SA Q15]

Which one of the following best provides evidence of light behaving as a particle?

A photoelectric effect

B white light passing through a prism

C diffraction of light through a single slit

D interference of light passing through a double slit

Question 20/ 21

[VCAA 2023 NHT SA Q15]

Violet light shines on a metal surface and electrons are emitted. The maximum kinetic energy of electrons emitted is measured to be 0.120 eV.

This energy, when expressed in joules, is closest to

A 1.33×10^{-20} J

B 1.92×10^{-20} J

C 1.33×10^{-18} J

D 1.92×10^{-18} J

Question 21/ 21

[VCAA 2023 NHT SA Q18]

Light of wavelength 300 nm is just able to cause the photoelectric emission of electrons from a lead surface. If light of twice this wavelength were incident on a lead surface

A no photoelectric emission would occur.

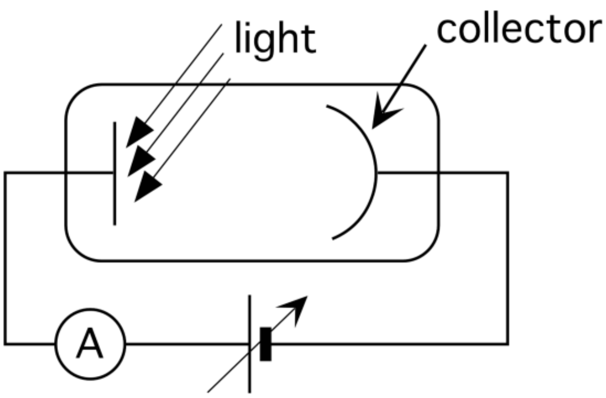
B half as many electrons would be ejected per second.

C the same number of electrons would be ejected per second, with twice the energy.

D the same number of electrons would be ejected per second, with more energy but not necessarily twice as much energy.

Question 1/ 49

A photocell is sketched in the diagram below. This apparatus can be used to determine the maximum energy of emitted electrons. The maximum KE of the photoelectrons depends on the frequency of the light falling on the metal surface, but not on its intensity.



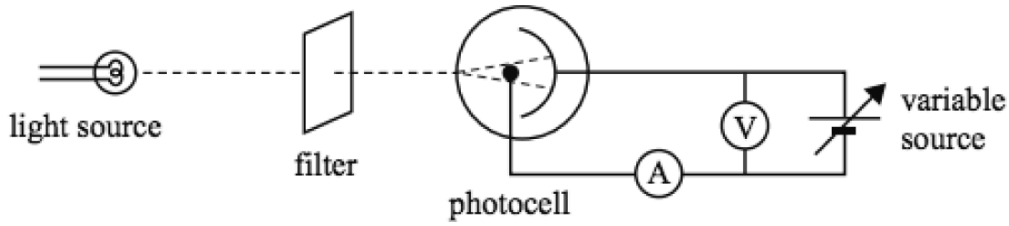
Explain why this observation caused difficulties for the proponents of a wave model of light.

(2 marks)

Question 2/ 49

[VCAA 2016 SA Q19]

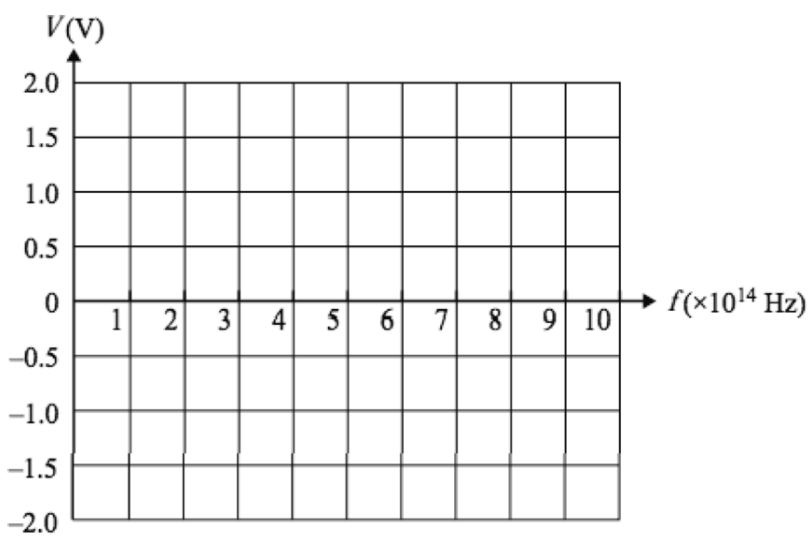
Emily is conducting an experiment to investigate the photoelectric effect. The apparatus is shown below. It consists of a light source, a filter and a photocell (a metal plate with a collecting electrode in a vacuum tube).



Emily uses various filters to shine a particular wavelength on the photocell. She increases the voltage (V) until the current just goes to zero and records this voltage. Emily repeats this process for different frequencies. Her results are shown in the table on the next page.

Frequency (Hz)	Voltage (V)
6.0×10^{14}	0.16
7.0×10^{14}	0.52
8.0×10^{14}	0.88
9.0×10^{14}	1.20

a. On the axes below, plot Emily's data and draw the graph of voltage against frequency.



(2 marks)

b. From the graph, determine the value that Emily would have found for each of the following:

i. Planck's constant

ii. threshold frequency

iii. work function of the metal.

(3 marks)

c. Explain how the recorded voltage measurements give information about the emitted photoelectron.

(2 marks)

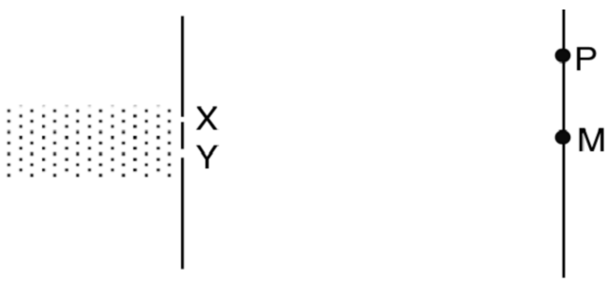
d. For each frequency, Emily doubles the intensity of the incident light.

Describe the graph Emily will now obtain in comparison with the original graph. Do these two graphs support the wave model or particle model of light? Justify your answer.

(3 marks)

Question 3/ 49

A two-slit experiment is successfully performed with light.



Light and dark bands are seen on the screen on the right. M is the midpoint of the pattern. It is opposite the midpoint of XY. The point P in the diagram is the third dark band upwards from M. Explain this in terms of a wave model.

(3 marks)

Question 4/ 49

Calculate the momentum change involved when a single photon of wavelength 1.0×10^{-8} m is reflected from a mirror.

(2 marks)

Question 5/ 49

When very weak light sources are used, photoelectrons are produced almost immediately when the light strikes the metal. This fact tends to support a particle model of light rather than a wave model. Explain.

(3 marks)

Question 6/ 49

The speed of light in water is slower than the speed of light in air. A wave theory of light used this to explain refraction. Use a diagram to show this.

(3 marks)

Question 7/ 49

In a photoelectric experiment, a metal with a work function of 1.8 eV is illuminated with light of $\lambda = 5 \times 10^{-7}\ \mathrm{m}$. Is electron emission possible? Give quantitative reasons.

(2 marks)

Question 8/ 49

Physicists use the expression ‘wave-particle duality’ as light sometimes behaves like particles and sometimes like waves. What evidence is there that light behaves like particles? Explain how this evidence supports a particle model.

(4 marks)

Question 9/ 49

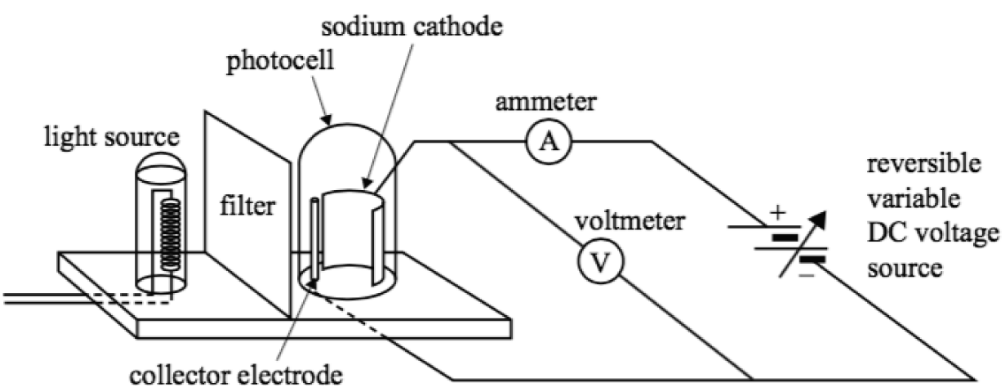
Compare the ratio of the number of photons produced per second by a 5.0 W monochromatic light source of wavelength 400 nm and a 5.0 W monochromatic light source of wavelength 600 nm.

(2 marks)

Question 10/ 49

[VCAA 2017 SB Q17]

In an experiment, blue light of frequency 6.25×10^{14} Hz is shone onto the sodium cathode of a photocell. The apparatus is shown below.



The graph of photoelectric current versus potential difference across the photocell is shown in the graph on the next page.

The threshold frequency for sodium is 5.50×10^{14} Hz.

a. What is the cut-off potential, V_o, when light of frequency 6.25×10^{14} Hz (blue light) is shone onto the sodium cathode of the photocell in the diagram on the previous page?

(2 marks)

b. On the graph of photoelectric current versus potential difference shown above, sketch the curve expected if the light is changed to *ultraviolet* with a significantly *higher* intensity than the original blue light.

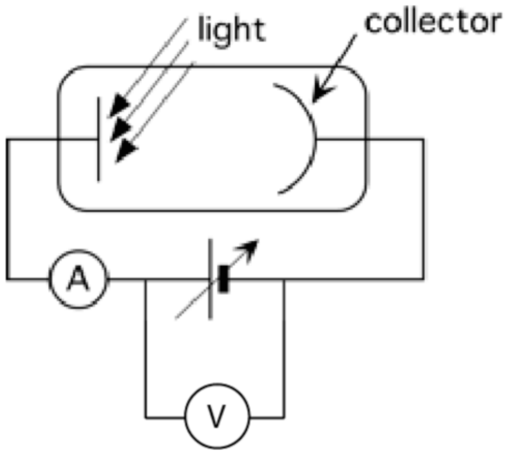
(2 marks)

c. The results of photoelectric effect experiments in general provide strong evidence for the particle-like nature of light. Outline *two* aspects of these results that provide the strong evidence that is not explained by the wave model of light, and explain why.

(5 marks)

Question 11/ 49

The photoelectric effect was first observed in the 19th century. An evacuated photoelectric cell is shown in the diagram below, connected into a circuit.



Electrons are emitted from the left-hand metal plate when light of a sufficiently short wavelength strikes the metal plate. They can then travel around the circuit, provided that the voltage of the battery is not too large.

a. Explain how adjusting the battery voltage, reading the voltmeter, and observing the ammeter can be used to measure the energy of the most energetic photoelectrons.

(3 marks)

b. Einstein's equation for the photoelectric effect can be written as follows:

$E_{K\,max} = hf - W$. Explain the physical meaning of the term *W*.

(2 marks)

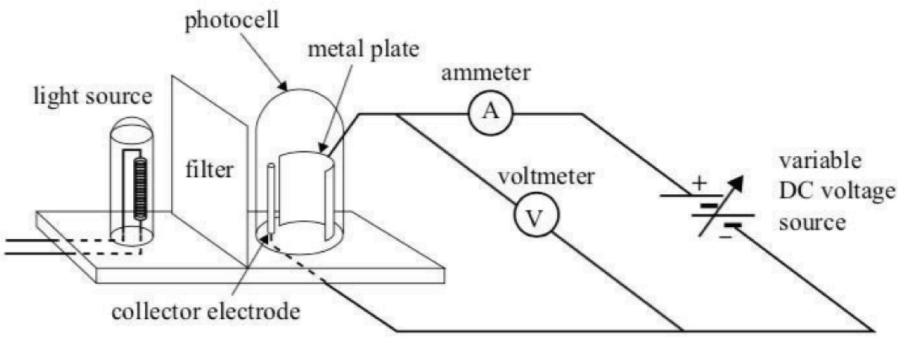
c. Determine a value for *W* if the most energetic electrons have an energy of 1.9 eV, and the incident light has a wavelength of $4.14 \times 10^{-7}\mathrm{m}$.

(2 marks)

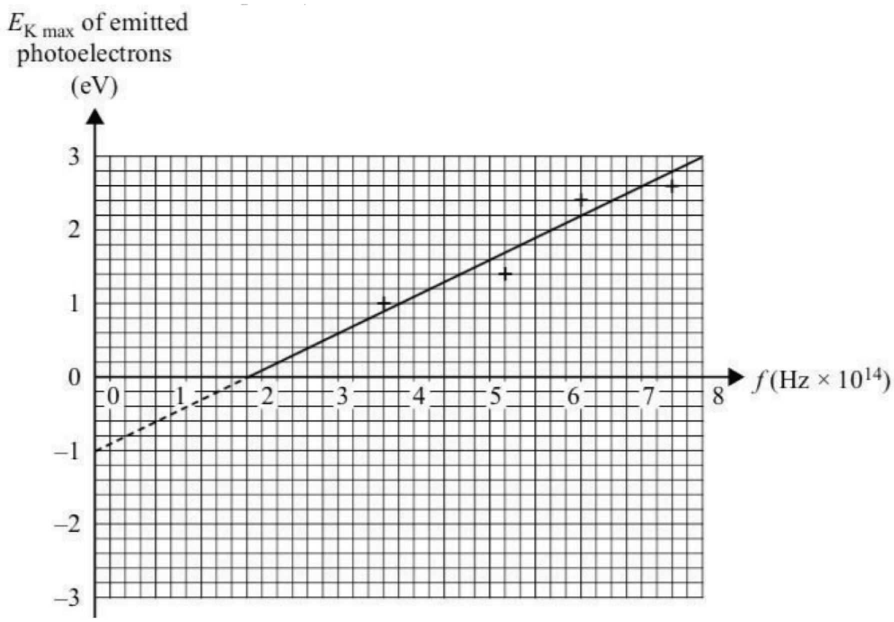
Question 12/ 49

[VCAA 2018 NHT SB Q16]

Students are investigating the photoelectric effect. The apparatus used by the students is shown below. A light source shines light through a filter that only allows one frequency of light to pass through. This monochromatic light shines onto a metal plate and photoelectrons are emitted. Different filters allow different frequencies to strike the metal plate. For each frequency, the maximum kinetic energy of the emitted photoelectrons is measured by using a stopping voltage.



The graph of the data the students collected for the maximum kinetic energy of emitted photoelectrons versus frequency is shown below. A line of best fit has been drawn.



a. Determine the value of Planck's constant, h, that the students would have obtained from this graph.

(2 marks)

b. Determine the value of the minimum frequency, or cut-off frequency, f_0, that the students would have obtained from this graph.

(1 mark)

c. Determine the value of the work function of the metal in the plate that the students would have obtained from this graph.

(1 mark)

d. The students replace the photocell with one that has a different metal plate with a work function of 2.5 eV. On the grid above, draw in the graph they would now expect.

(2 marks)

Question 13/ 49

[VCAA 2018 NHT SB Q17]

The results of photoelectric effect experiments provide evidence for the particle-like nature of light. Outline *one* aspect of the results that would provide this evidence. Your response should explain:

• why a wave model of light cannot satisfactorily explain this aspect of the results

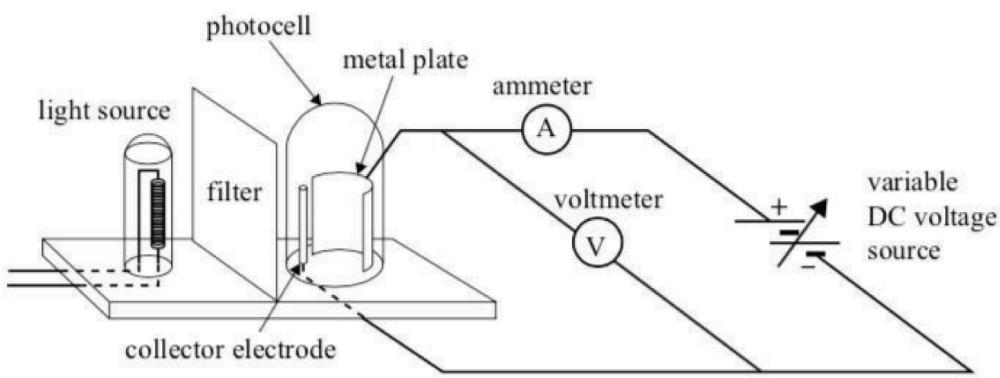
• how the photon theory does explain this aspect of the results.

(6 marks)

Question 14/ 49

[Adapted VCAA 2017 Sample SB Q17]

Students set up the apparatus shown below to study the photoelectric effect; in particular, the relationship between the frequency and intensity of incoming light and the maximum kinetic energy of emitted photoelectrons. Assume that all the filters give light of the same intensity.



The apparatus consists of

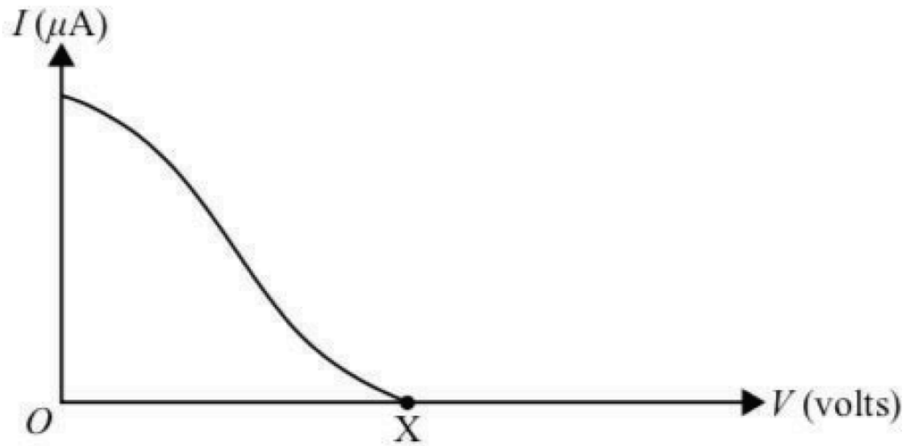
• a source of white light

• a set of filters, each of which allows only light of a one wavelength to pass

• a photocell with a metal plate and a collector electrode in an evacuated glass case

• a voltmeter, an ammeter and a variable DC voltage source in a circuit, as shown.

With one filter in place and the same light source, the students slowly increase the voltage (measured by the voltmeter V) from zero. They plot the current measured by the ammeter A as a function of the voltage. This is shown below.



a. Explain why the current drops to zero at point X.

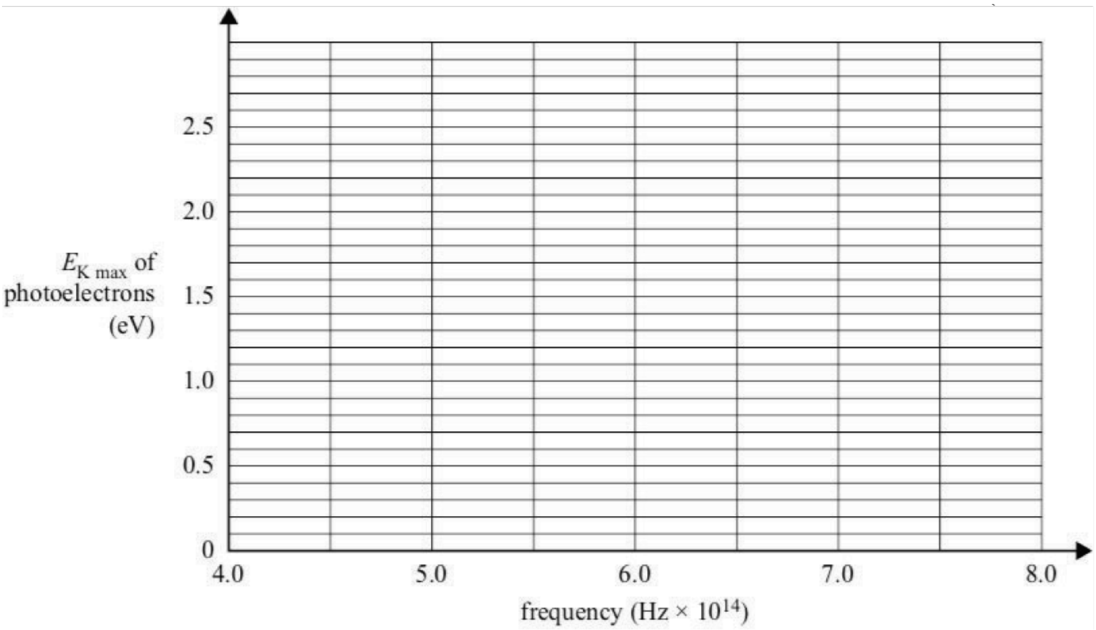
(2 marks)

The students next use five filters to give five frequencies of light falling on the metal plate and measure the stopping voltage on the voltmeter for each frequency. The data collected is shown in the table below.

Frequency $(\mathbf{Hz}) \times \mathbf{10^{14}}$	**Stopping voltage (eV)**
4.5	1.3
5.0	1.5
6.1	2.0
6.9	2.5
7.6	2.8

b. Plot the data given in the table above on the axes provided below, then draw a line of best fit to show maximum kinetic energy of the emitted photoelectrons versus frequency of light falling on the metal plate.

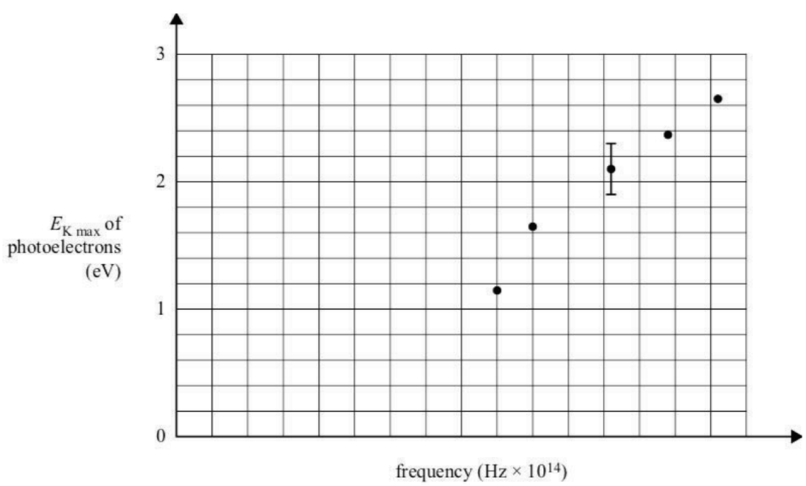
(3 marks)



c. From the graph plotted above, determine the value of Planck's constant, *h*, that the students would have obtained. Give your answer to two significant figures.

(2 marks)

Students perform a photoelectric experiment on another metal determine the uncertainty in their measurements for the maximum kinetic energy of the photoelectrons. This is represented by a vertical bar drawn on one data point in the graph on the next page. (Uncertainties in frequency values can be neglected.)



d. On the graph above, show the steps needed to determine whether the data points may be fitted by a straight line. Explain your reasoning.

(3 marks)

Question 15/ 49

[Adapted VCAA 2017 Sample SB Q18]

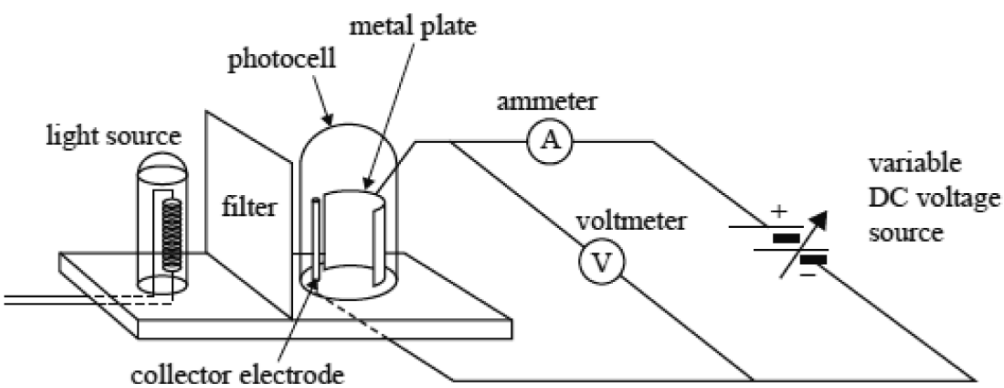
Outline the conclusions about the nature of light that Albert Einstein made from the observations of photoelectric experiments. Include how these conclusions arose from the experimental observations and why these conclusions contradicted the simple wave model.

(5 marks)

Question 16/ 49

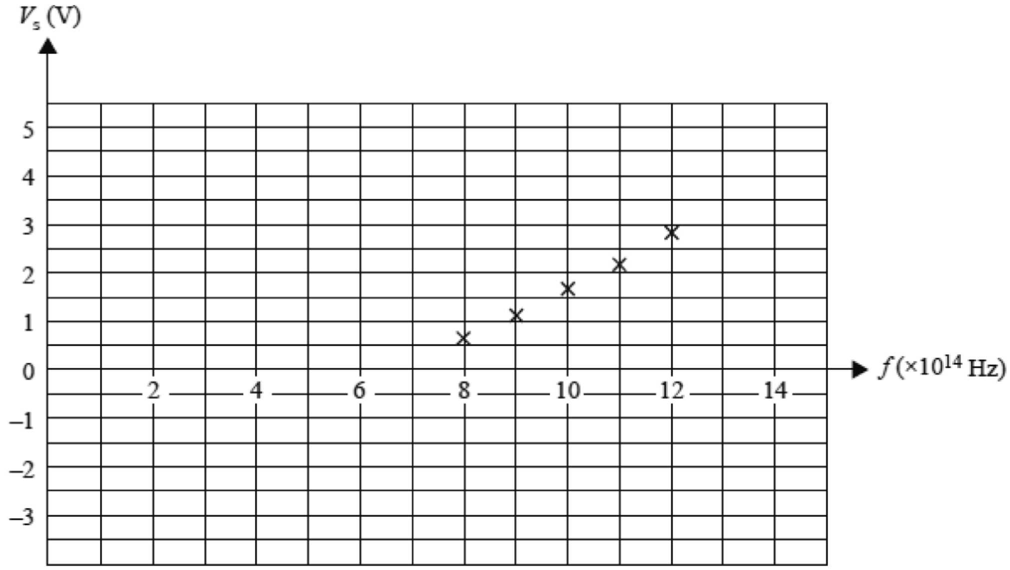
[VCAA 2018 SB Q17]

To investigate the photoelectric effect, Sai and Kym set up an experiment. The apparatus is shown below.



With the light source on and a filter in place, Sai and Kym measure the maximum kinetic energy of emitted photoelectrons by gradually changing the collector voltage until the current measured by the ammeter just falls to zero.

They record this voltage (the stopping voltage) for each frequency of the incident light and plot their results in a graph of stopping voltage, V_s, versus frequency, $f(\times\ 10^{14}\text{Hz})$, of the incident light, as shown on the next page.



With $6.0 \times 10^{14}\text{Hz}$ light, the ammeter always shows zero. Sai wants to repeat the experiment for this frequency with a much brighter light source and wants to expose the metal to the light for much longer. Kym says photoelectrons will never be ejected with this frequency of light.

a i. Who is correct – Sai or Kym?

(1 mark)

ii. What explanation might Sai give to support her opinion that by waiting longer and using a brighter light source, photoelectrons could be ejected from the metal with light of a frequency of 6.0×10^{14} Hz?

(2 marks)

b. Use the graph to calculate Planck's constant. Show your working.

(2 marks)

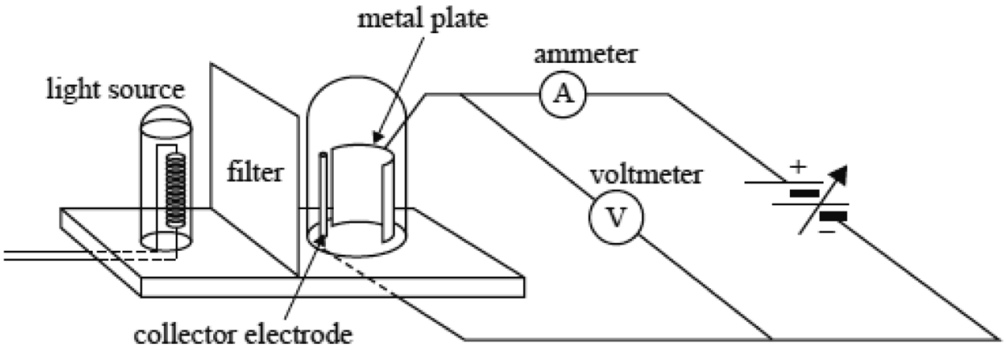
c. Determine the work function of the metal from the graph. Give your reasoning.

(2 marks)

Question 17/ 49

[VCAA 2019 NHT SB Q16]

April sets up the apparatus shown below to investigate the photoelectric effect. She can change the frequency of the light incident on the metal plate by changing the filter and she can change the type of metal of which the plate is made.



a. For her first experiment, April chooses a filter that gives light of frequency 7.13×10^{14} Hz and a metal plate made of caesium with a work function of 1.95 eV. April adjusts the voltage of the collector electrode so that the current becomes smaller and smaller. When the ammeter, A, reaches zero, April records the voltage shown on the voltmeter, V. Use calculations to determine this voltage.

(3 marks)

b. For her second experiment, April uses a metal plate made of zinc. Zinc has a threshold frequency for emission of photoelectrons of 1.04×10^{15} Hz. Photoelectrons are emitted. Calculate the maximum wavelength, in nanometres, of the light for photoelectrons to be emitted from the zinc plate. Show your working.

(2 marks)

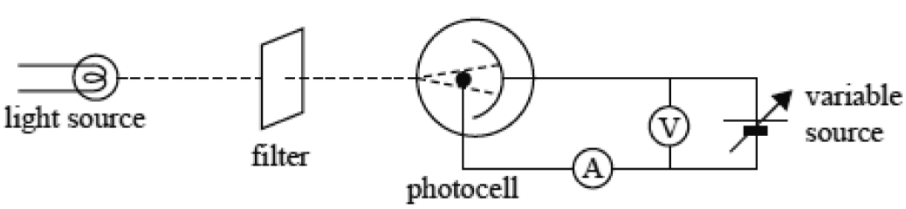
c. For her third experiment, April changes the metal plate from the zinc plate used in the second experiment to a plate made of platinum. Platinum has a threshold frequency of 1.53×10^{15} Hz. April uses light of frequency 7.13×10^{14} Hz but does not make any other changes. Photoelectrons are not emitted. April observes for a longer time and then increases the intensity of the light beam but still finds that photoelectrons are not emitted. Explain how April's observations support the particle model of light but do not support the wave model of light in explaining the photoelectric effect.

(3 marks)

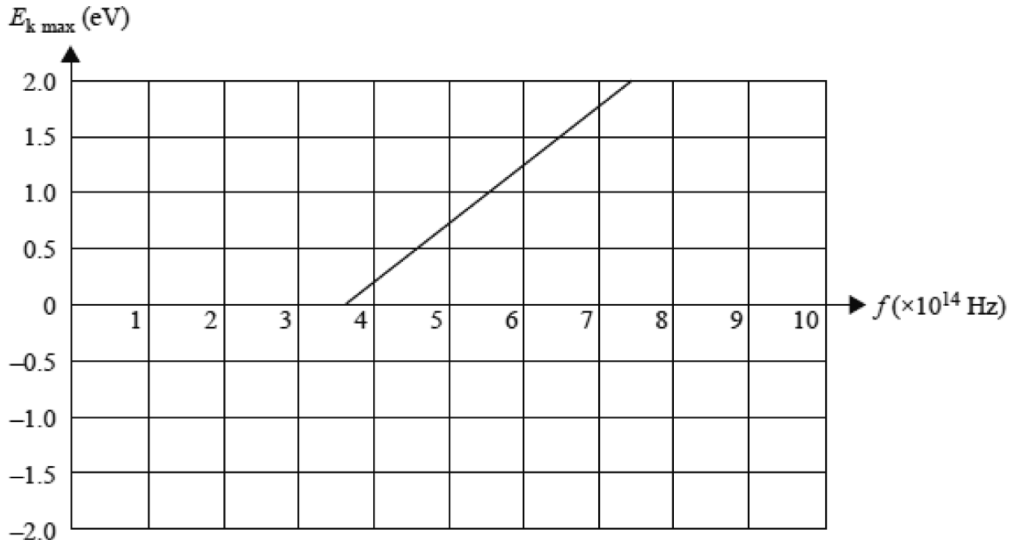
Question 18/ 49

[VCAA 2019 SB Q16]

Students are studying the photoelectric effect using the apparatus shown.



The graph below shows the results the students obtained for the maximum kinetic energy ($E_{k\ max}$) of the emitted photoelectrons versus the frequency of the incoming light.



a. Using only data from the graph, determine the values the students would have obtained for

i. Planck's constant, h. Include a unit in your answer

(2 marks)

ii. the maximum wavelength of light that would cause the emission of photoelectrons

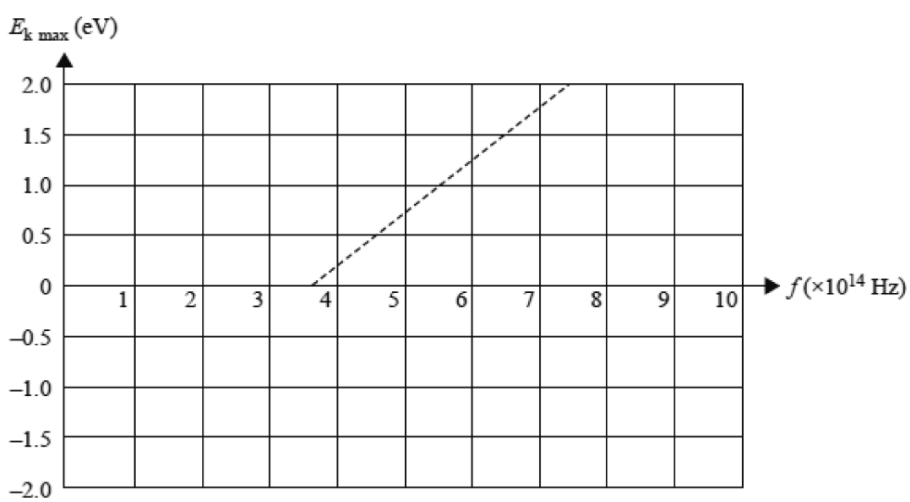
(1 mark)

iii. the work function of the metal of the photocell.

(1 mark)

b. The work function for the original metal used in the photocell is ϕ. On the graph below, draw the line that would be obtained if a different metal, with a work function of $\frac{1}{2}\phi$, were used in the photocell. The original graph is shown as a dashed line.

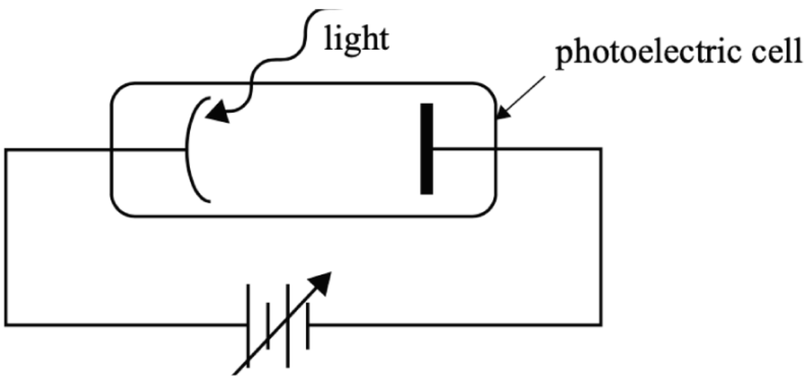
(2 marks)



Question 19/ 49

[VCAA 2020 SB Q15]

The metal surface in a photoelectric cell is exposed to light of a single frequency and intensity in the apparatus shown in the diagram below. The voltage of the battery can be varied in value and reversed in direction.



A graph of photocurrent versus voltage for one particular experiment is shown below.

Missing Image

a. On the diagram above, draw the trace that would result for another experiment using light of the same frequency but with triple the intensity.

(2 marks)

b. What is a name given to the point labelled A on the diagram above?

(1 mark)

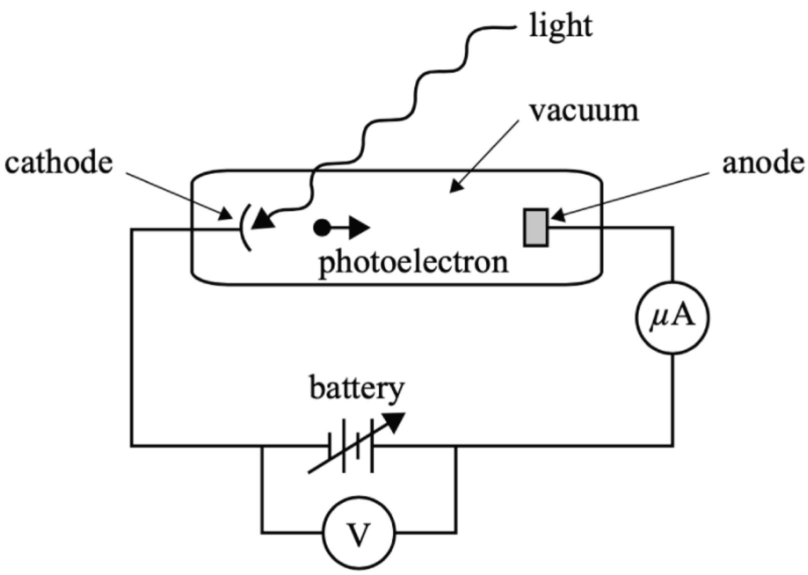
c. Why does the photocurrent fall to zero at the point labelled A the diagram above?

(1 mark)

Question 20/ 49

[VCAA 2021 NHT SB Q15]

The apparatus shown below is used to investigate the photoelectric effect. Light of various wavelengths is shone onto a silver plate (the cathode). The work function of silver is 4.9 eV.



a. Explain what happens when light of wavelength 400 nm hits the silver plate. Use calculations to support your answer.

(2 marks)

b. Explain what happens when light with a photon energy of 5.4 eV hits the silver plate.

(2 marks)

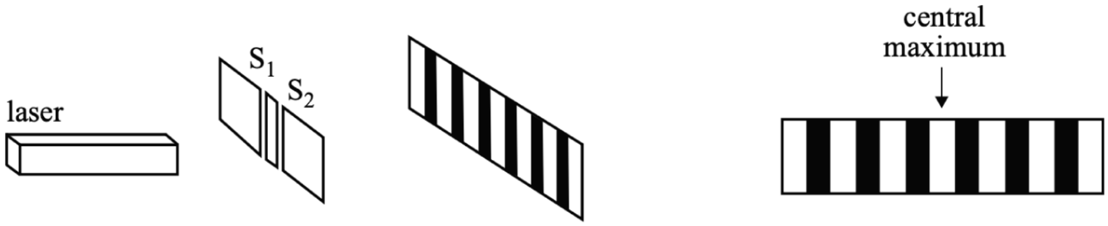
c. Which model of light does this photoelectric investigation support? Specify the model and give two reasons to justify your answer.

(3 marks)

Question 21/ 49

[Adapted VCAA 2021 SB Q13]

In Young's double-slit experiment, the distance between two slits, S_1 and S_2, is 2.0 mm. The slits are 1.0 m from a screen on which an interference pattern is observed, as shown in the left-hand diagram. The right-hand diagram shows the position of the central maximum of the observed interference pattern.



Explain how this experiment supports the wave model of light.

(2 marks)

Question 22/ 49

[VCAA 2021 SB Q15]

A photoelectric experiment is carried out by students. They measure the threshold frequency of light required for photoemission to be 6.5×10^{14} Hz and the work function to be 3.2×10^{-19} J. Using the students' measurements, what value would they calculate for Planck's constant? Outline your reasoning and show all your working. Give your answer in joule-seconds.

(3 marks)

Question 23/ 49

[VCAA 2021 SB Q16]

Light can be described by a wave model and also by a particle (or photon) model. The rapid emission of photoelectrons at very low light intensities supports one of these models but not the other. Identify the model that is supported, giving a reason for your answer.

(2 marks)

Question 24/ 49

[Adapted VCAA 2021 SB Q17]

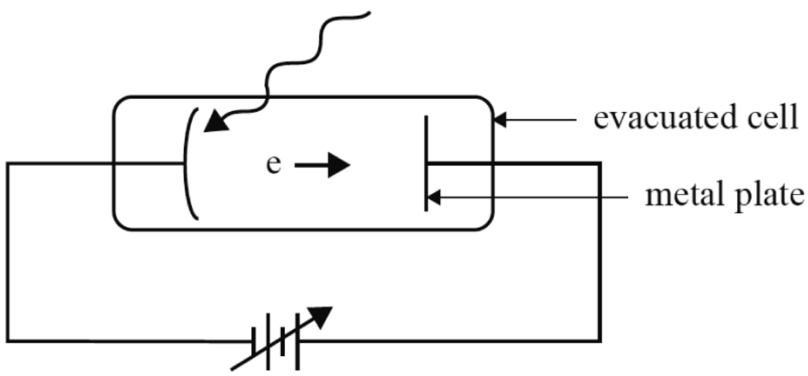
Show that the momentum of a 7.0×10^{15} Hz photon is equal to 1.55×10^{-26} kg m s^{-1}.

(1 mark)

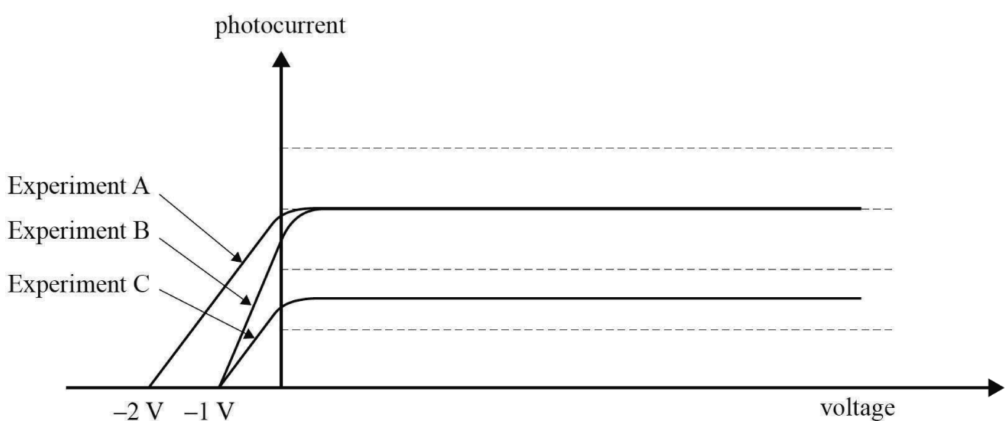
Question 25/ 49

[VCAA 2022 NHT SB Q15]

The diagram below shows an apparatus used to study the photoelectric effect. Light of various frequencies and intensities can be shone onto the metal plate inside an evacuated cell. This sometimes results in the release of photoelectrons. The voltage of the power supply can be varied and the direction can be reversed.



The graph in the diagram below shows the variation of photocurrent with voltage for three experiments, A, B and C, using light of different frequencies and intensities.



a. Using the terms ‘halved’, ‘no change’ or ‘doubled’, how would the intensity and frequency of the light used in Experiment B need to be changed so that Experiment B gives the same results as Experiment A in the diagram above?

(2 marks)

Intensity

Frequency

b. Using the terms ‘halved’, ‘no change’ or ‘doubled’, how would the intensity and frequency of the light used in Experiment B need to be changed so that Experiment B gives the same results as Experiment C in the diagram above?

(2 marks)

Intensity

Frequency

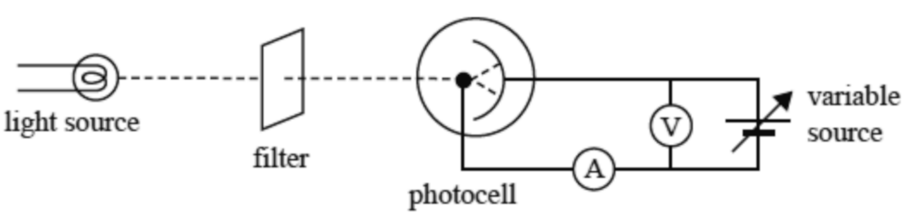
c. The metal plate is made of a metal that has a work function of 2.93 eV. Determine whether photoelectrons will be ejected from the metal plate when it is illuminated by light with a wavelength of 700 nm. Show your working.

(2 marks)

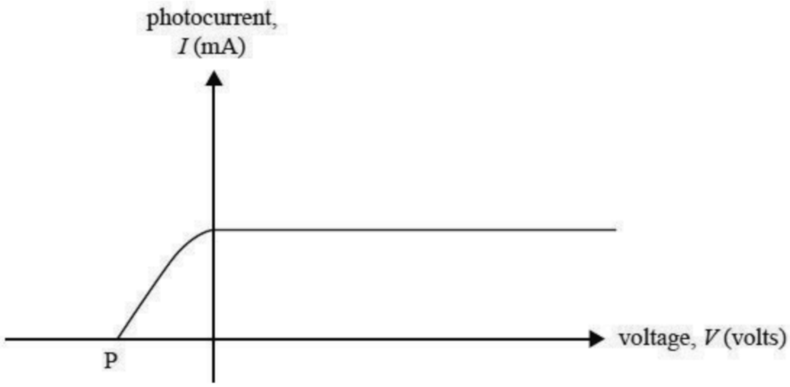
Question 26/ 49

[VCAA 2022 SB Q14]

Sam undertakes a photoelectric effect experiment using the apparatus shown. She uses a green filter.



Sam produces a graph of photocurrent, I, in milliamperes, versus voltage, V, in volts, as shown.



a. Identify what point P represents on the graph.

(1 mark)

b. Sam then significantly increases the intensity of the light. Sketch the resulting graph.

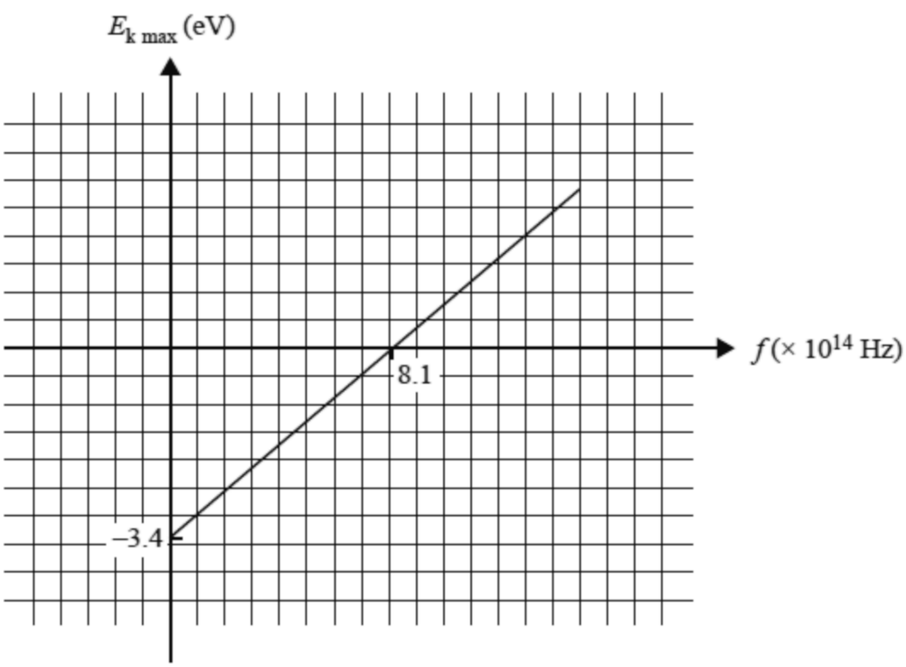
(2 marks)

c. Sam replaces the green filter with a violet filter, keeping the light source at the increased intensity. Sketch the resulting graph.

(2 marks)

d. Further experiments produce a graph of maximum kinetic energy, E_k max, of emitted photoelectrons versus frequency, f, of light. Determine the work function, in electron volts, of the metal surface used in the experiment that produced the data shown on the following page.

(1 mark)



e. From the graph shown above, calculate, in joule-seconds, the value of Planck's constant. Show your working.

(2 marks)

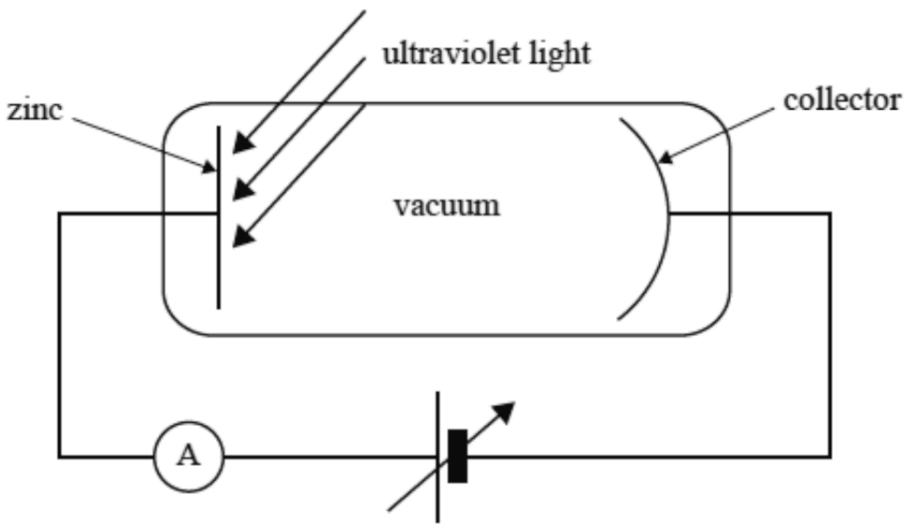
f. State one limitation of the wave model in explaining the results of the photoelectric effect.

(1 mark)

Question 27/ 49

[VCAA NHT 2023 SB Q19]

In an experiment on the photoelectric effect, Sam shines ultraviolet light onto a zinc plate and ejects photoelectrons, as shown below.



a. The work function of zinc is 4.30 eV.

Calculate the minimum frequency of the ultraviolet light that could eject a photoelectron.

(2 marks)

b. Sam wants to produce a greater photocurrent – that is, to emit more photoelectrons. He considers using a much brighter red light instead of the original ultraviolet light source used in part **a**.

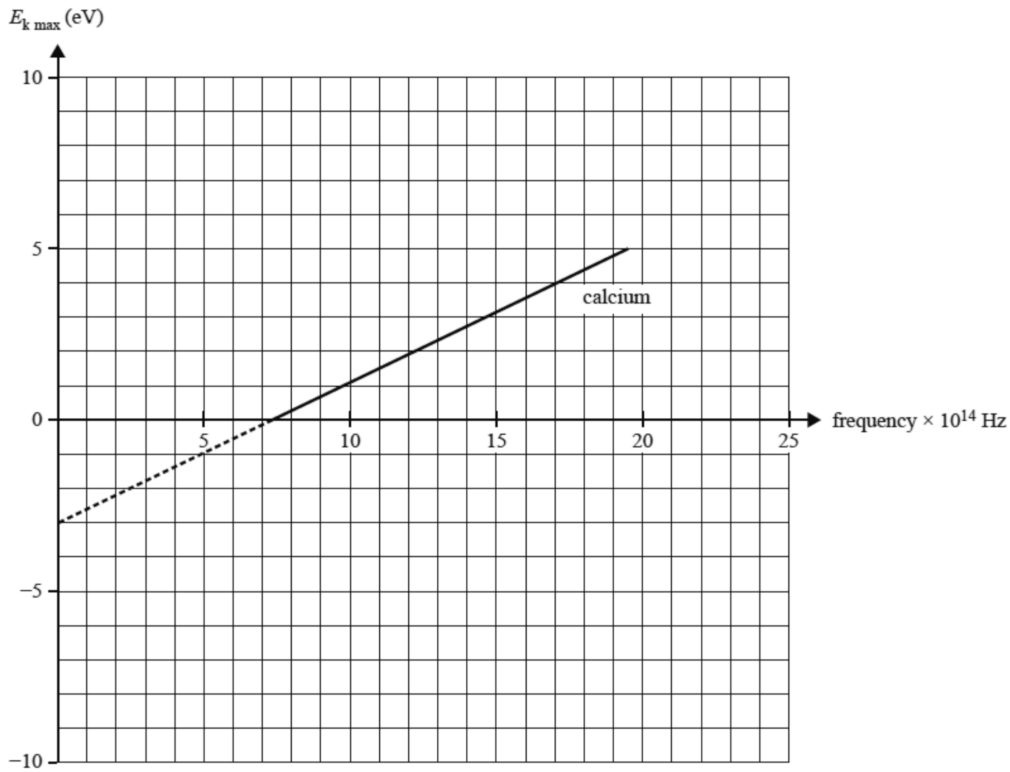
Is Sam's idea likely to produce a greater photocurrent? Explain your answer.

(2 marks)

Question 28/ 49

[VCAA 2023 SB Q13]

In a photoelectric effect experiment, a team of physics students investigated the relationship between the maximum kinetic energy of ejected electrons and the frequency of the light incident on calcium metal. Their results are shown in the diagram below.



a. Using data from the graph estimate the work function for calcium.

(1 mark)

b. Using data from the graph determine the maximum wavelength of the light

that can emit photoelectrons from the calcium surface.

(2 marks)

The calcium metal was replaced with copper metal with a work function of 4.70 eV.

c. On the grid in the diagram, draw the graph that would result when the calcium

metal was replaced with copper metal.

(2 marks)

d. The copper metal is illuminated by photons of wavelength 380 nm.

Will photoelectrons be ejected? Justify your answer using a calculation and any relevant data from the graph shown.

(3 marks)

Chapter 16 Wave properties of matter

Question 1/ 14

The spacing between atoms in a certain metal crystal is $3 \times 10^{-9}\ \mathrm{m}$. Which of the following would be most likely to show wave behaviour when fired at a thin layer of the crystal? Justify your choice.

A 60 eV electrons

B X-rays with a frequency of $10^{19}\ \mathrm{Hz}$

C $10^{-6}\ \mathrm{kg}$ dust particles moving at $0.01\ \mathrm{m\ s^{-1}}$

D Gamma rays of energy 2.5 MeV

Question 2/ 14

In an experiment, electrons are sent at a pair of very closely spaced slits (just like the Young's experiment). The stream of electrons is very slow, and there is only one electron at a time in the apparatus, so at no stage can two electrons interfere destructively with each other. This means that

A no interference pattern will be able to be formed.

B a normal interference pattern will form, with the same spacing as would occur at higher electron numbers.

C an interference pattern will form, but only if the experiment runs for a very long time.

D interference with electrons only happens if the electrons are travelling near the speed of light.

Question 3/ 14

Amy is interested in diffraction patterns of electrons and X-rays through small apertures. She knows that these patterns have their spacing controlled

A only by the size of the diffracting aperture.

B by the size of the aperture and the energy of the X-rays or electrons.

C only by the momentum of the X-rays or electrons.

D by the size of the aperture and the momentum of the X-rays or electrons.

Question 4/ 14

Amy reasoned that neutrons could also show diffraction patterns, if

A the diffracting aperture was comparable with the speed of the neutrons.

B the diffracting aperture was comparable with the ratio $\frac{h}{p}$ of the neutrons.

C the ratio $\frac{h}{p}$ of the neutrons was much smaller than the size of the diffracting aperture.

D the neutrons were moving near the speed of light.

Question 5/ 14

Which of the following expressions is correct for the (non-relativistic) energy of a proton, where E is the energy, m the mass, λ the de Bröglie wavelength, h Planck's constant, and c the speed of light?

A $E = \frac{h^2}{2m\lambda^2}$

B $E = \frac{h}{\lambda}$

C $E = pc$

D $E = hf$

Question 6/ 14

Identify the one statement below about de Bröglie wavelengths that is true.

A Neutrons cannot have a de Bröglie wavelength because it is charged.

B Protons cannot have a de Bröglie wavelength because they never diffract.

C The de Bröglie wavelength of electrons increases with increasing speed.

D As neutrons approach the speed of light their de Bröglie wavelength reduces greatly.

Question 7/ 14

Which of the following formulas applies both to photons and electrons?

A $E\lambda = hc$

B $h = \lambda p$

C $E = pc$

D $E = hf$

Question 8/ 14

[VCAA 2019 SA Q14]

Electrons of mass 9.1×10^{-31} kg are accelerated in an electron gun to a speed of 1.0×10^{7} m s^{-1}. The best estimate of the de Broglie wavelength of these electrons is

A 4.5×10^{-6} m

B 7.3×10^{-8} m

C 7.3×10^{-11} m

D 4.5×10^{-12} m

Question 9/ 14

[VCAA 2019 SA Q15]

Electrons pass through a fine metal grid, forming a diffraction pattern. If the speed of the electrons was doubled using the same metal grid, what would be the effect on the fringe spacing?

A The fringe spacing would increase.

B The fringe spacing would decrease.

C The fringe spacing would not change.

D The fringe spacing cannot be determined from the information given.

Question 10/ 14

[VCAA 2020 SA Q18]

Quantised energy levels within atoms can best be explained by

A electrons behaving as individual particles with different energies.

B electrons behaving as waves, with each energy level representing a diffraction pattern.

C protons behaving as waves, with only standing waves at particular wavelengths allowed.

D electrons behaving as waves, with only standing waves at particular wavelengths allowed.

Question 11/ 14

[VCAA 2021 NHT SA Q17]

Protons of mass $1.67 \times 10^{-27}\ \mathrm{kg}$ are accelerated to a speed of $2.0 \times 10^{3}\ \mathrm{m\ s^{-1}}$. The best estimate of the de Broglie wavelength of these protons is

A $1.2 \times 10^{-10}\ \mathrm{m}$

B $2.0 \times 10^{-10}\ \mathrm{m}$

C $1.2 \times 10^{-7}\ \mathrm{m}$

D $2.0 \times 10^{-7}\ \mathrm{m}$

Question 12/ 14

[VCAA 2021 SA Q17]

Which one of the following is closest to the de Broglie wavelength of a 663 kg motor car moving at $10\ \mathrm{m\ s^{-1}}$?

A $10^{-37}\ \mathrm{m}$

B $10^{-36}\ \mathrm{m}$

C $10^{-35}\ \mathrm{m}$

D $10^{-34}\ \mathrm{m}$

Question 13/ 14

[VCAA NHT 2023 SA Q16]

A proton of mass 1.67×10^{-27} kg is accelerated until its de Broglie wavelength is 5.00×10^{-9} m. The speed of the proton is then closest to

A 1.33×10^{-18} m s^{-1}

B 1.26×10^{-2} m s^{-1}

C 79.4 m s^{-1}

D 5.04×10^{4} m s^{-1}

Question 14/ 14

[VCAA 2023 SA Q17]

Which one of the following statements best explains why it is possible to compare X-ray and electron diffraction patterns?

A X-rays can exhibit particle-like properties.

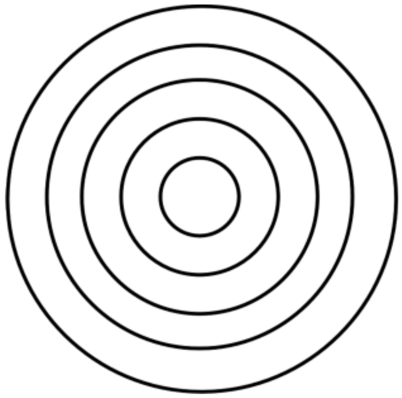
B Electrons can exhibit wave-like properties.

C Electrons are a form of high-energy X-rays.

D Both electrons and X-rays can ionise matter.

Question 1/ 35

X-rays are fired at metal foils. Those passing are *diffracted* to form rings centred on the axis. The pattern is sketched below.



When electrons are fired at the same foils, the same sorts of patterns, with identical dimensions, are formed. The X-ray photons had a wavelength of 8.35×10^{-10} m, and a momentum of 7.94×10^{-25} N s.

a. Calculate a value for Planck's constant from the data, in J s. Give your answer to three significant figures.

(2 marks)

b. The electron and X-ray diffraction patterns have the same spacing between rings. What did the electrons and X-ray photons used in these experiments have in common? Explain.

(3 marks)

Question 2/ 35

An electron is accelerated in a vacuum with a voltage of 900 V. It reaches a speed of 1.8×10^{7} m s^{-1}.

a. Calculate its de Bröglie wavelength.

(2 marks)

b. The electron is aimed at a crystal, whose atomic spacing is close to 120 pm. Are interference effects likely to be observed with electrons of this speed? Support your answer with quantitative information.

(3 marks)

Question 3/ 35

Electrons in a diffraction experiment produce very similar patterns to X-rays with a wavelength of 56 pm. Estimate the momentum of the electrons.

(2 marks)

Question 4/ 35

Which of the following experiments is most likely to show diffraction effects? Support your choice with appropriate calculations.

A. 500 nm photons passing through a 0.05 mm slit.

B. $5 \times 10^6\ \mathrm{m\ s^{-1}}$ electrons passing through a 0.00015 mm slit.

(4 marks)

Question 5/ 35

Calculate the de Bröglie wavelength of 1.9 eV electrons. Ignore relativistic effects. Take $m_\mathrm{e} = 9.1 \times 10^{-31}\ \mathrm{kg}$ and $h = 6.63 \times 10^{-34}\ \mathrm{J\ s}$.

(2 marks)

Question 6/ 35

Physicists use the expression ‘wave-particle duality’ because light sometimes behaves like particles and electrons sometimes behave like waves. What evidence do we have that electrons can behave like waves? Explain how this evidence supports a wave model of electrons.

(2 marks)

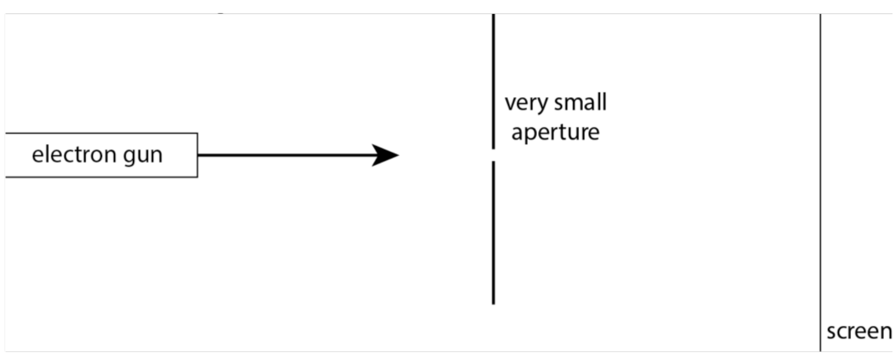
Question 7/ 35

At very small scales, the ‘classical’ laws of physics used to describe motion do not work. Give an example of this.

(3 marks)

Question 8/ 35

Single-slit experiments can be performed with electron beams. In the experimental design below, a beam of 600 eV electrons is aimed at a very narrow slit in gold foil. The slit is vertical and viewed from above. Diffraction effects are clearly seen on the detecting screen on the right.



(not to scale)

For diffraction to be clearly seen with this apparatus, the electron wavelength must be no less than 1/500 of the slit width. What is the maximum slit width for the experiment to succeed? Show your working.

(4 marks)

Question 9/ 35

When a beam of electrons is directed at a very narrow opening, diffraction effects are observed. Discuss how this phenomenon is *not* consistent with a classical mechanics view of the electron as a particle.

(4 marks)

Question 10/ 35

[VCAA 2016 SA Q20]

A beam of electrons is produced in an electron gun. The de Bröglie wavelength of each electron is 0.36 nm.

a. Calculate the speed of the electrons.

(2 marks)

An experiment is undertaken to compare the diffraction of these electrons and X-rays. With a similar gap spacing, the diffraction patterns are found to be nearly identical.

b. Calculate the energy of the X-rays. Show the steps of your working.

(3 marks)

c. Explain why similar patterns are observed.

(2 marks)

Question 11/ 35

[VCAA 2018 NHT SB Q13]

Electrons are accelerated through a potential difference of 4000 V and then pass through a metallic crystal. The resulting diffraction pattern is observed.

a. Calculate the de Bröglie wavelength of these electrons in nm.

(3 marks)

b. A student, Jane, says that X-rays of a suitable wavelength could produce the same diffraction pattern. Calculate the energy of the X-ray beam required to give a similarly spaced diffraction pattern to the electrons. Show your working and give your answer in eV.

(2 marks)

c. Explain how electrons and X-rays can exhibit similar diffraction patterns.

(2 marks)

Question 12/ 35

[VCAA 2017 SB Q19]

Roger and Mary are discussing diffraction. Mary says electrons produce a diffraction pattern. Roger says this is impossible as diffraction is a wave phenomenon and electrons are particles; diffraction can only be observed with waves, as with electromagnetic waves, such as light and X-rays.

Evaluate Mary's and Roger's statements in light of the current understanding of light and matter. Describe *two* experiments that show the difference between Mary's and Roger's views.

(4 marks)

Question 13/ 35

[VCAA 2022 NHT SB Q18]

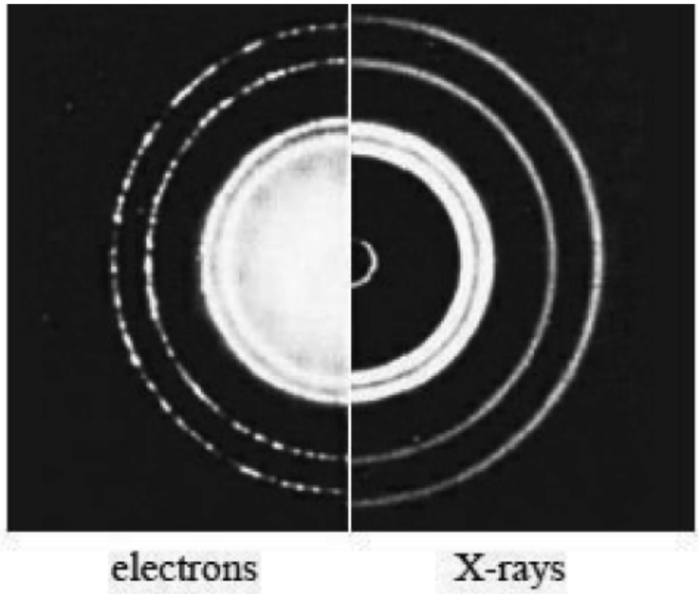
Provide an example of an instance in which classical laws of physics cannot describe motion at very small scales and explain why they cannot.

(3 marks)

Question 14/ 35

[VCAA 2018 SB Q18]

The diffraction patterns for X-rays and electrons through a thin polycrystalline aluminium foil have been combined in the diagram below, which shows an electron diffraction pattern on the left and an X-ray diffraction pattern on the right. The images are to the same scale. The X-rays have energy of 8000 eV.



a. Calculate the electron wavelength in nanometres. Show your working.

(2 marks)

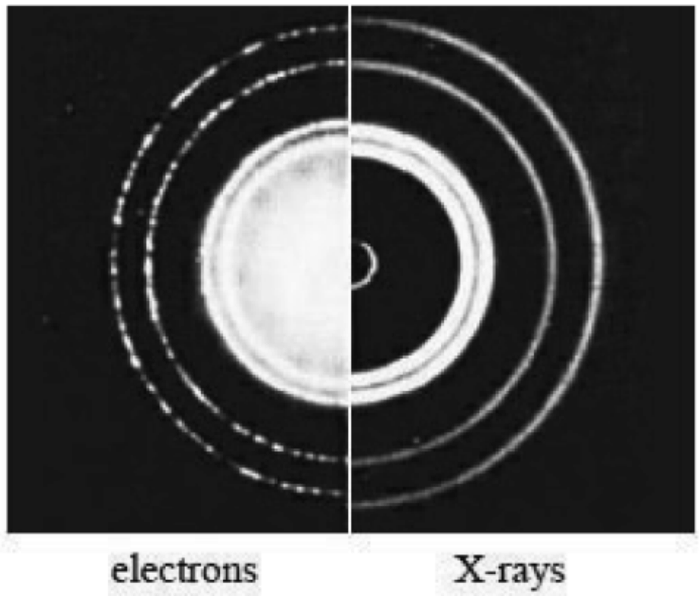
b. Calculate the electron kinetic energy in joules. Show your working.

(3 marks)

Question 15/ 35

[VCAA 2019 SB Q17]

Students are comparing the diffraction patterns produced by electrons and X rays, in which the same spacing of bands is observed in the patterns, as shown below. Note that both patterns shown are to the same scale.



The electron diffraction pattern is produced by 3.0×10^3 eV electrons.

a. Explain why electrons can produce the same spacing of bands in a diffraction pattern as X-rays.

(3 marks)

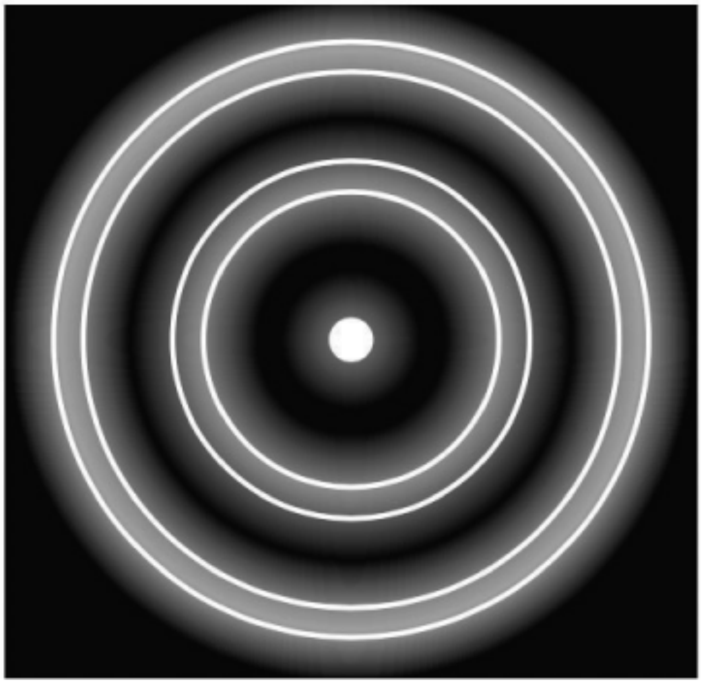
b. Calculate the frequency of X-rays that would produce the same band spacing in a diffraction pattern as for the electrons. Show your working.

(4 marks)

Question 16/ 35

[VCAA 2020 SB Q16]

A beam of electrons travelling at $1.72 \times 10^5 \mathrm{~m~s^{-1}}$ illuminates a crystal, producing a diffraction pattern as shown in the diagram below. Take the mass of an electron to be 9.1×10^{-31} kg. Ignore relativistic effects.



a. Calculate the kinetic energy of one of the electrons. Show your working.

(2 marks)

b. The electron beam is now replaced by an X-ray beam. The resulting diffraction pattern has the same spacing as that produced by the electron beam. Calculate the energy of one X-ray photon. Show your working.

(3 marks)

Question 17/ 35

[VCAA 2021 SB Q18]

Scientists are conducting experiments to compare the circular diffraction patterns formed by X-ray photons and electrons when they pass through small circular apertures. The X-ray photons have an energy of 100 eV and pass through an aperture of diameter 1.24 μm. The electrons are moving at $5.0 \times 10^5 \text{ m s}^{-1}$.

a. Show that the de Broglie wavelength of the electrons is equal to 1.46×10^{-9} m.

(1 mark)

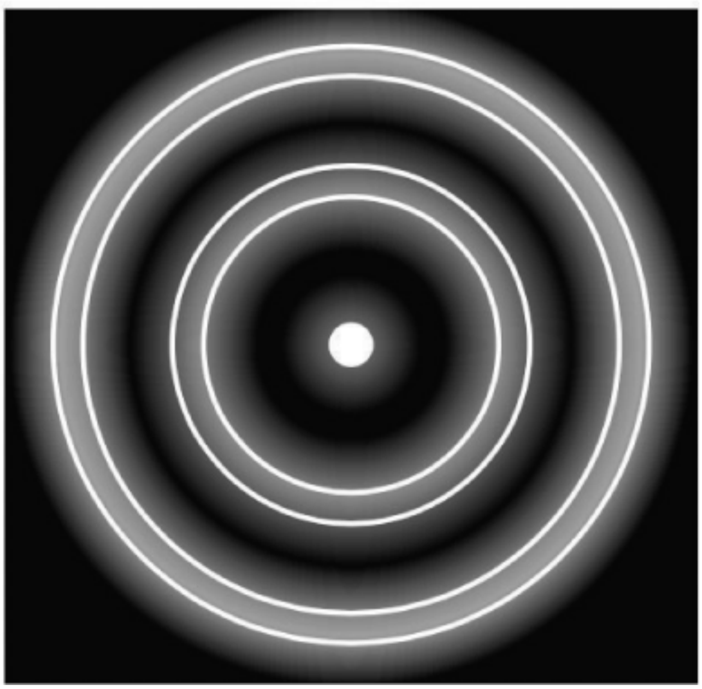
b. The scientists want an aperture for the electrons that forms diffraction patterns with the same spacing as the diffraction patterns formed by the X-ray photons. Calculate the diameter of the aperture that the scientists should choose. Show your working.

(4 marks)

Question 18/ 35

[VCAA 2022 NHT SB Q16]

The diffraction pattern produced by an X-ray beam consisting of photons of energy 400 eV is shown below.



a. Show that the wavelength of an X-ray photon is approximately 3 nm.

(2 marks)

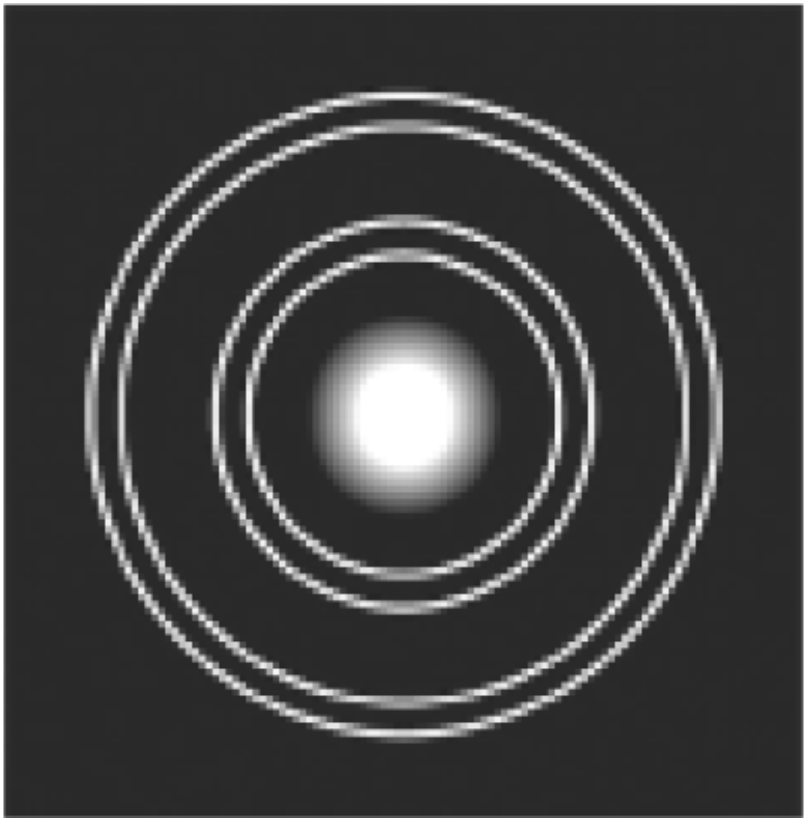
b. A stream of electrons produces a diffraction pattern with the same spacing as the X-ray diffraction pattern shown above. Calculate the speed of an electron in the stream. Take the mass of the electron to be 9.1×10^{-31} kg.

(3 marks)

Question 19/ 35

[VCAA 2022 SB Q17]

A materials scientist is studying the diffraction of electrons through a thin metal foil. She uses electrons with an energy of 10.0 keV. The resulting diffraction pattern is shown below.



a. Calculate the de Bröglie wavelength of the electrons in nanometres.

(4 marks)

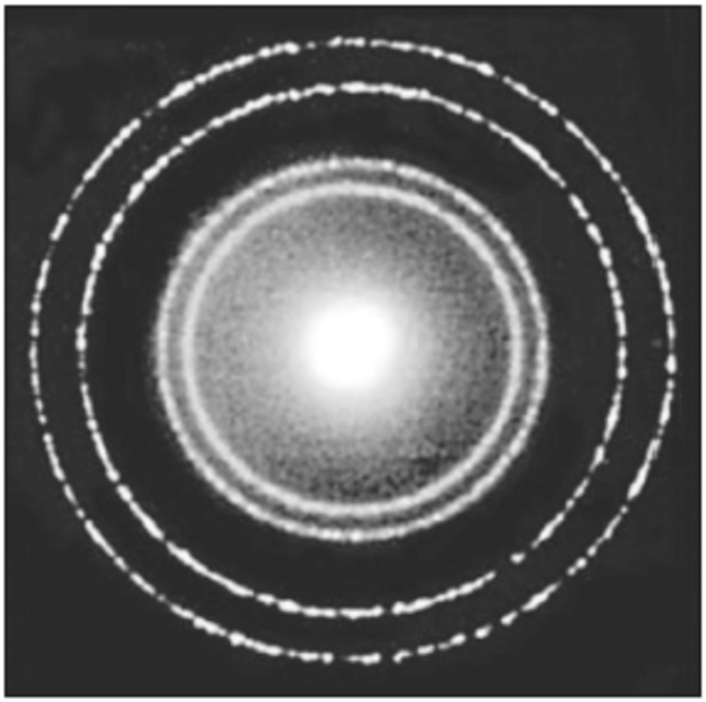
b. The materials scientist then increases the energy of the electrons by a small amount and hence their speed by a small amount. Explain what effect this would have on the de Bröglie wavelength of the electrons. Justify your answer.

(3 marks)

Question 20/ 35

[VCAA NHT 2023 SB Q20]

A beam of electrons, each with a momentum 4.60×10^{-24} kg m s^{-1}, is passed through a salt crystal to produce a diffraction pattern, as shown below.



a. Calculate the de Bröglie wavelength of the electrons.

(2 marks)

b. Explain why electron diffraction patterns from salt crystals provide evidence for the wavelike nature of matter.

(3 marks)

Question 21/ 35

[VCAA 2023 SB Q14]

Neutrons are subatomic particles and, like electrons, they can exhibit both particle-like and wave-like behaviour. Ignore any relativistic effects.

A beam of neutrons that can be used for scientific experiments is produced by a nuclear research reactor.

The mass of a neutron is 1.67×10^{-27} kg.

The de Broglie wavelength of the neutrons produced by the nuclear reactor is 3.02×10^{-10} m.

a. Calculate the speed of the neutrons.

(2 marks)

b. The neutron beam is then sent through a crystal that has an interatomic spacing of 3.62×10^{-10} m.

Would you expect to observe a diffraction pattern? Justify your answer.

(2 marks)

c. Consider an electron beam with the same de Broglie wavelength as the neutron beam, 3.02×10^{-10} m.

Which will have the greater speed: an electron in the electron beam or a neutron in the neutron beam? Justify your answer.

(2 marks)

Chapter 17 Energy levels of atoms

Question 1/ 12

Molybdenum atoms have energy levels at 0, 0.2, 0.4, 2.6 and 20 keV.

Question 2/ 12

A molybdenum atom is excited to the 2.6 keV state. All of the following energy photons could be emitted from the atom, except one. Which one?

A 0.2 keV

B 0.4 keV

C 2.4 keV

D 2.8 keV

Question 3/ 12

An atom of molybdenum in the 0.4 keV state absorbs a photon. Which one of the options below represents a possible energy for this absorbed photon?

A 20 keV

B 19.6 keV

C 0.4 keV

D 2.6 keV

Question 4/ 12

An atom has only four possible energy levels available in an experiment. They are energies E_0, E_1, E_2, and E_3, in increasing energy. An atom is excited to E_3. Which of the following is a possible energy for an emitted photon?

A E_3

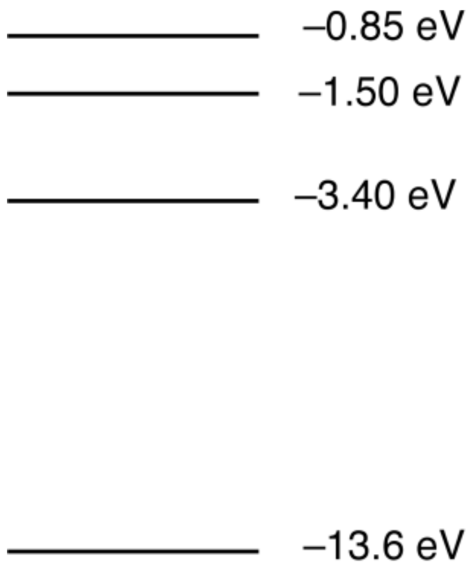
B $E_3 - E_0$

C $E_2 + E_1$

D E_0

Question 5/ 12

The energy levels of hydrogen atoms are shown in the diagram below. The *lowest* level, the ground state, is at $-13.6\ \mathrm{eV}$. For a large number of hydrogen atoms excited to the $-1.50\ \mathrm{eV}$ level, how many different energy photons could be emitted?



energy levels of hydrogen

A 4

B 3

C 2

D 1

Question 6/ 12

An individual atom is excited to the $-0.85\ \mathrm{eV}$ level. Which of the following statements is *false?*

A A 2.55 eV photon would be followed by a 10.2 eV photon.

B A 0.65 eV photon could be followed by a 1.9 eV photon.

C A 0.65 eV photon could be followed by a 12.1 eV photon.

D A 12.75 eV photon could be followed by a 0.65 eV photon.

Question 7/ 12

Which of the following energy photons could an atom of hydrogen in the ground state absorb?

A 10.2 eV

B 1.9 eV

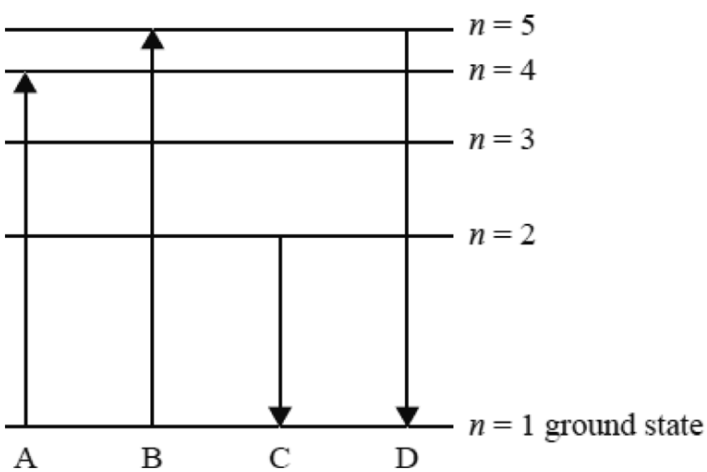
C 2.55 eV

D 0.65 eV

Question 8/ 12

[VCAA 2019 NHT SA Q19]

Part of the energy-level diagram for an unknown atom is shown below.



Which one of the arrows shows a change of energy level corresponding to the absorption of a photon of highest frequency?

A A

B B

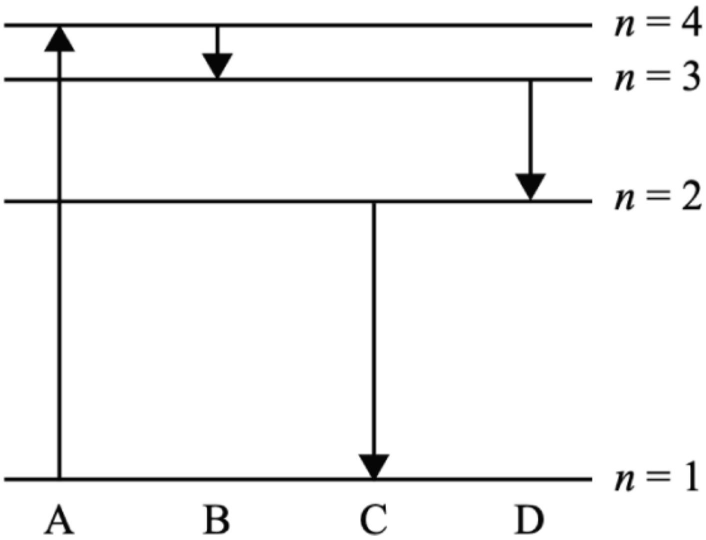
C C

D D

Question 9/ 12

[VCAA 2020 SA Q17]

The diagram below shows some of the energy levels for the electrons within an atom. The arrows labelled A, B, C and D indicate transitions between the energy levels and their lengths indicate the relative size of the energy change.



Which transition results in the emission of a photon with the most energy?

A A

B B

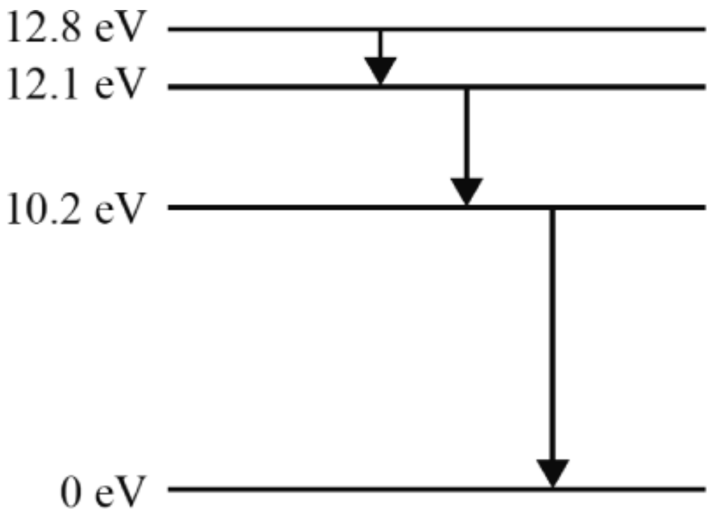
C C

D D

Question 10/ 12

[VCAA 2022 NHT SA Q17]

Some of the energy levels of the hydrogen atom are shown in the diagram below. A hydrogen atom has been excited to the 12.8 eV energy level. It returns to the ground state via the three transitions shown.



Which of the following indicates the energies of the emitted photons?

A 0.7 eV, 2.6 eV, 10.2 eV

B 0.7 eV, 1.9 eV, 10.2 eV

C 1.9 eV, 2.6 eV, 10.2 eV

D 10.2 eV, 12.1 eV, 12.8 eV

Question 11/ 12

[VCAA 2022 SA Q17]

Gamma radiation is often used to treat cancerous tumours. The energy of a gamma photon emitted by radioactive cobalt-60 is 1.33 MeV.

Which one of the following is closest to the frequency of the gamma radiation?

A 1.33×10^{6} Hz

B 3.21×10^{20} Hz

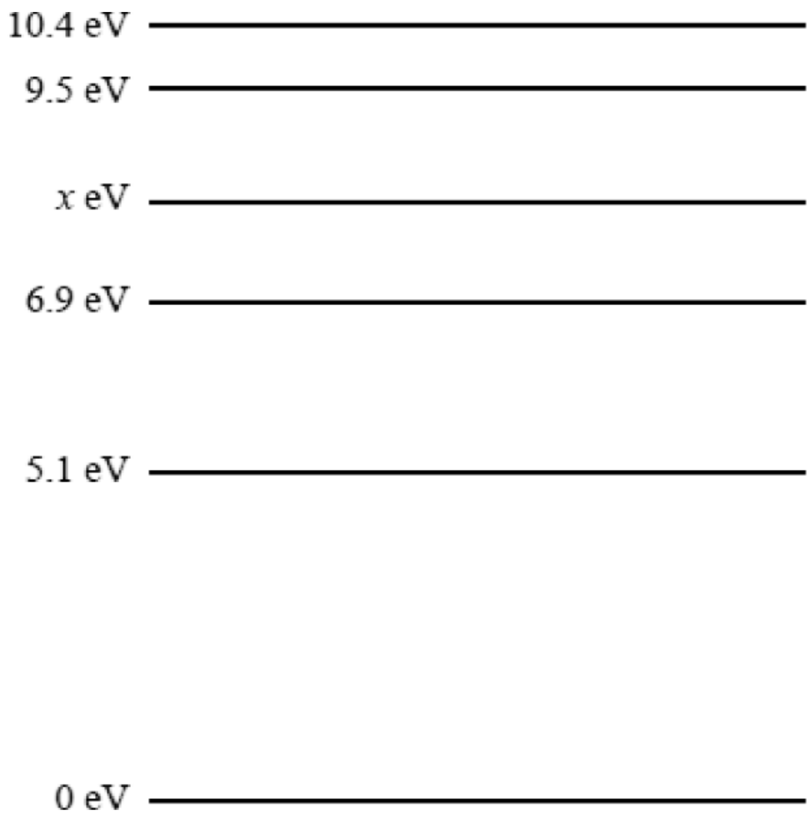
C 3.21×10^{21} Hz

D 2.01×10^{39} Hz

Question 12/ 12

[VCAA NHT 2023 SA Q19]

Some of the energy levels for an unknown atom are shown in the diagram below, with one of the lines labelled *x* eV. These energy levels are not drawn to scale.



A part of the emission spectrum of the atom shows lines at 1.0 eV, 1.6 eV and 1.9 eV.

The value of *x* is closest to

A 7.7

B 7.9

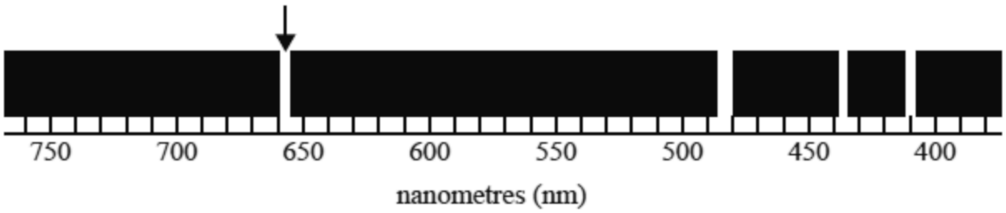
C 8.0

D 8.5

Question 13/ 12

[VCAA 2023 SA Q19]

The diagram below shows the spectrum of light emitted by a hydrogen vapour lamp. The spectral line indicated by the arrow on the diagram is in the visible region of the spectrum.



Which one of the following is closest to the frequency of the light corresponding to the spectral line indicated by the arrow?

A 6.5×10^{2} Hz

B 4.6×10^{14} Hz

C 6.5×10^{14} Hz

D 4.6×10^{16} Hz

Question 1/ 29

An electron makes a 5.9 eV transition between two energy levels. What wavelength photon is likely to be observed as a result?

(2 marks)

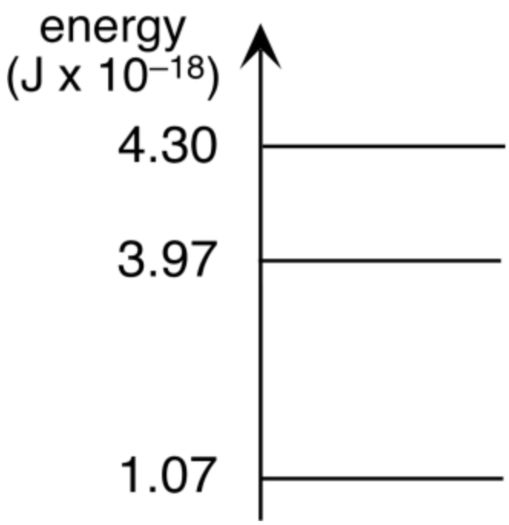
Question 2/ 29

An atom has only four possible energy levels. They have energies E_0, E_1, E_2, and E_3, in increasing energy order. An atom is excited to level E_1. Write down the possible photon energies it could absorb.

(3 marks)

Question 3/ 29

The diagram below shows some energy levels in the neon atom.



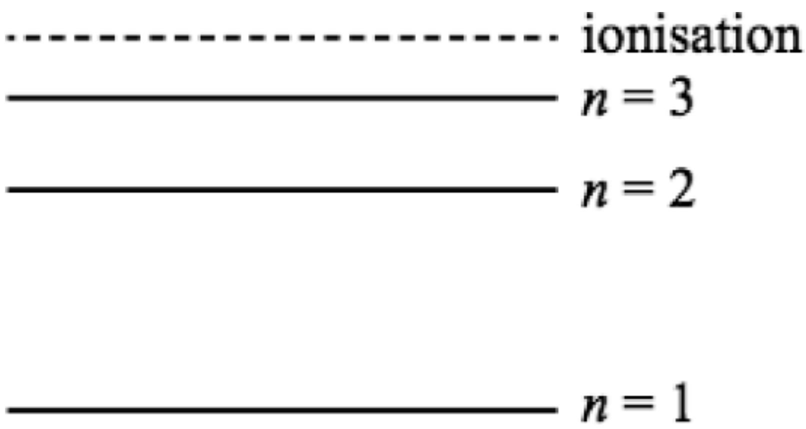
Use the data in the diagram to calculate two photon frequencies that could be absorbed by neon atoms in the lowest state shown in the diagram.

(3 marks)

Question 4/ 29

[Adapted VCAA 2015 SA Q19]

An atom has a single electron in the second $(n = 3)$ excited state. When it returns to the ground $(n = 1)$ state, the emission spectrum has lines of 2.63×10^{16} Hz, 2.22×10^{16} Hz and 0.41×10^{16} Hz. The energy level diagram is shown below.



Use this information to calculate the energy of the $n = 2$ and $n = 3$ states.

(4 marks)

Question 5/ 29

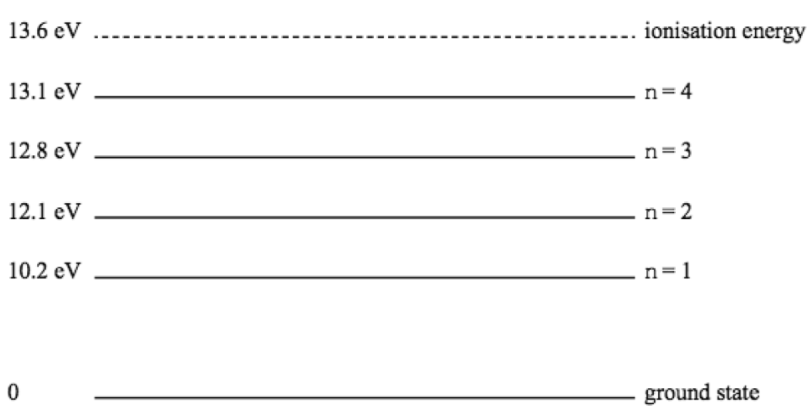
[VCAA 2016 SA 21]

The visible spectrum of the hydrogen atom is observed to emit photons of energy 2.6 eV.

a. Calculate the wavelength of this emission spectral line.

(2 marks)

The energy levels for the hydrogen atom are shown below.



b. Draw an arrow on the diagram above to indicate the transition that could cause the spectral line calculated in part **a.**

(2 marks)

c. A hydrogen atom is excited to the 12.8 eV energy level.

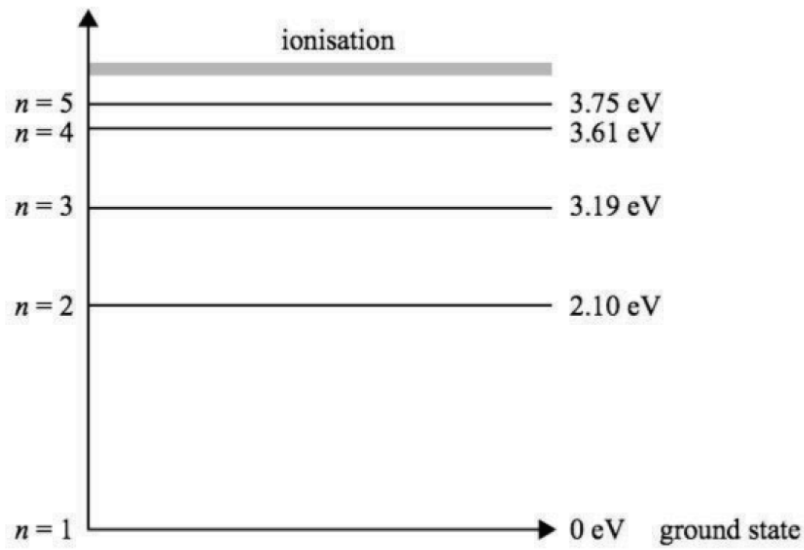
List the possible photon energies that could be emitted as it returns to the ground state.

(3 marks)

Question 6/ 29

[VCAA 2017 SB Q18]

The energy-level diagram for sodium is shown below. Part of the emission spectrum of sodium vapour includes a photon of energy 1.65 eV.



a. Draw an arrow on the energy-level diagram above to demonstrate the atomic energy level transition resulting in the emission of a 1.65 eV photon.

(1 mark)

b. What is the shortest possible wavelength of a photon that can be emitted when the atom decays from the $n = 5$ level to the ground state?

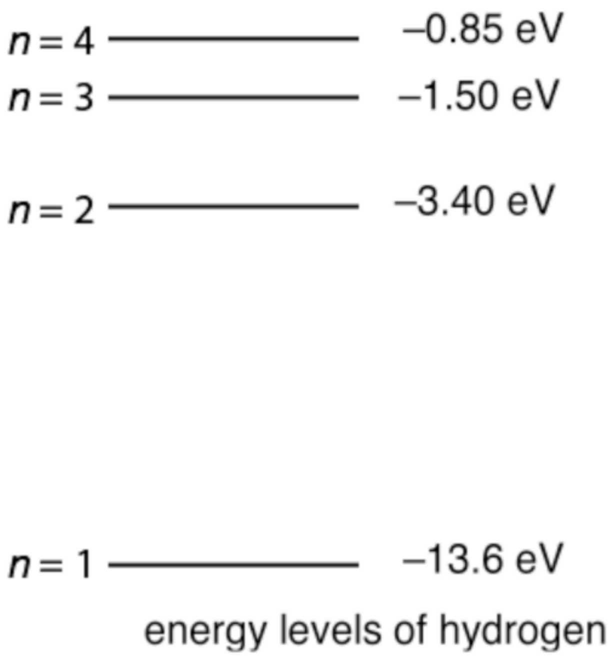
(2 marks)

c. A student measures a spectral line with energy 2.5 eV. In terms of the quantised states of the atom, explain why this is not possible.

(2 marks)

Question 7/ 29

Some of the energy levels of the hydrogen atom are shown below.



a. A photon of wavelength $4.87 \times 10^{-7}\mathrm{m}$ is *emitted* by an excited hydrogen atom within the Sun. Identify the transition occurring within hydrogen by naming the initial and final states.

(2 marks)

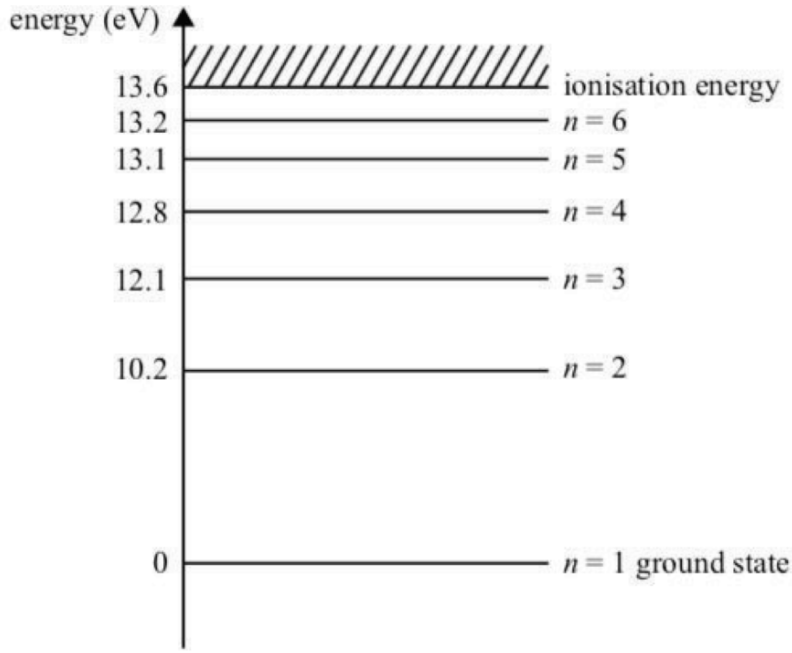
b. A photon of wavelength $1.03 \times 10^{-7}\mathrm{m}$ is *absorbed* by a hydrogen atom within the Sun. Identify the transition occurring within hydrogen by naming the initial and final states.

(2 marks)

Question 8/ 29

[Adapted VCAA 2018 Sample SB Q9]

The diagram shows the energy level diagram for the hydrogen atom.



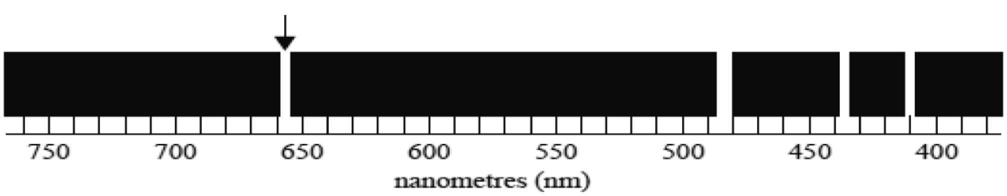
List the possible photon energies following emissions from the $n = 4$ state.

(3 marks)

Question 9/ 29

[VCAA 2018 SB Q19]

The diagram shows the spectrum of light emitted from a hydrogen vapour lamp. The spectral line, indicated by the arrow on the diagram, is in the visible region of the spectrum.



a. The following list gives the four visible colours that are emitted by the hydrogen atom. Circle the colour that corresponds to the spectral line.

violet blue-violet blue-green red

(1 mark)

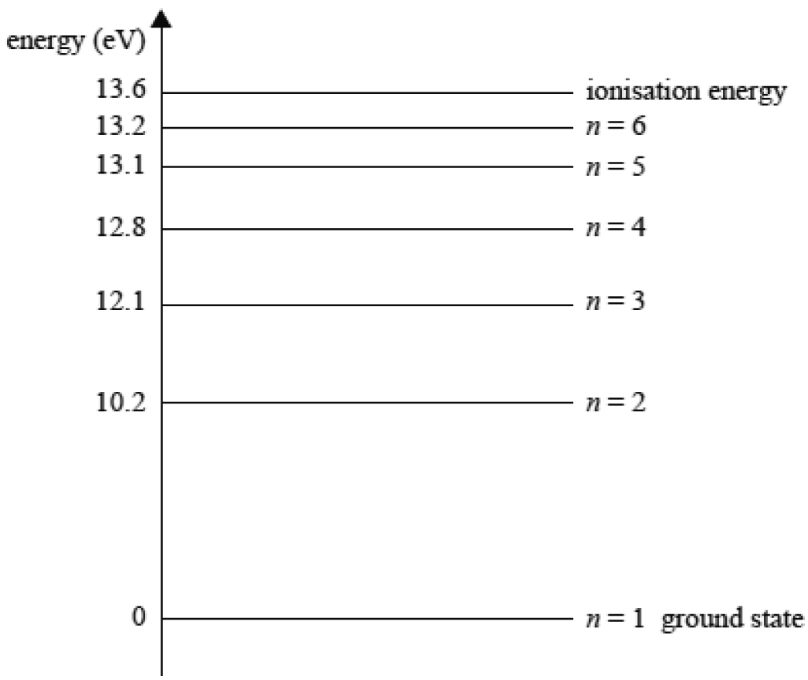
b. Explain why the visible spectrum of light emitted from a hydrogen vapour lamp gives discrete spectral lines, as shown in the diagram above.

(3 marks)

Question 10/ 29

[VCAA 2019 SB Q18]

The energy level diagram for a hydrogen atom is shown below.



a. A hydrogen atom in the ground state is excited to the $n = 4$ state. Explain how the hydrogen atom could be excited to the $n = 4$ state in one step.

(2 marks)

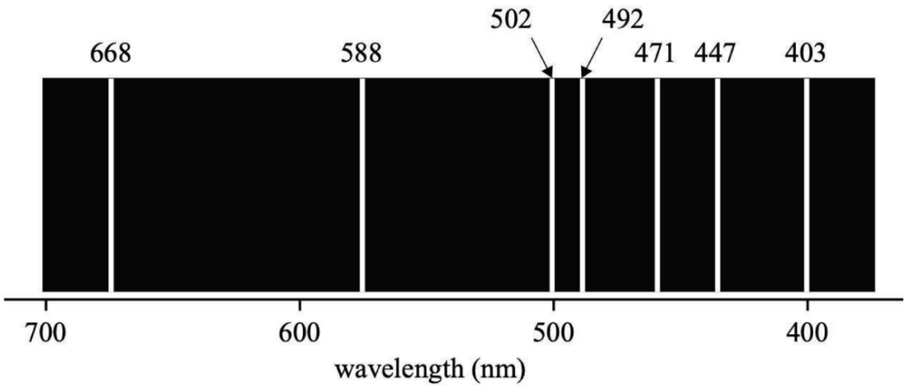
b. List the possible photon energies that could be emitted as the atom goes from the $n = 4$ state to the $n = 2$ state.

(3 marks)

Question 11/ 29

[VCAA 2020 SB Q17]

The diagram below shows the emission spectrum for helium gas.



a. Which spectral line indicates the photon with the lowest energy?

(1 mark)

b. Calculate the frequency of the photon emitted at the 588 nm line. Show your working.

(2 marks)

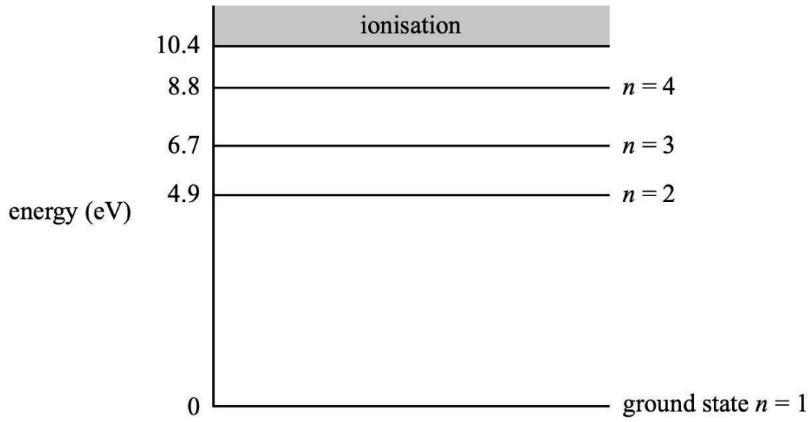
c. Explain why only certain wavelengths and, therefore, certain energies are present in the helium spectrum.

(2 marks)

Question 12/ 29

[VCAA 2021 NHT SB Q17]

Light from a mercury vapour lamp shows a line spectrum related to discrete energy levels. Some of the energy levels for the mercury atom are shown below.



a. Draw an arrow on the diagram above to indicate the transition between the listed energy states that would produce the lowest frequency of an emitted photon.

(1 mark)

b. Calculate the energy of the light emitted when the mercury atom makes a transition from the third energy level $(n=3)$ to its ground state $(n=1)$. Show your working.

(2 marks)

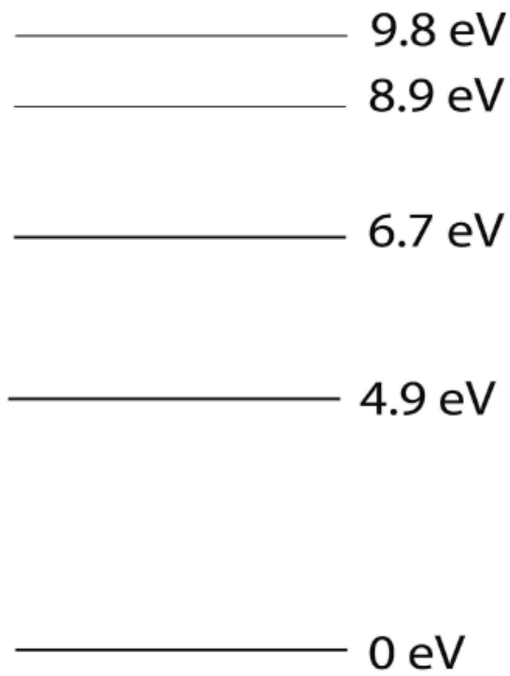
c. Explain what happens to a mercury atom in its ground state if a photon of energy 2.1 eV is incident on it.

(2 marks)

Question 13/ 29

[VCAA 2021 SB Q19]

A simplified diagram of some of the energy levels of an atom is shown below.



a. Identify the transition on the energy level diagram that would result in the emission of a 565 nm photon. Show your working.

(2 marks)

b. A sample of the atoms is excited into the 9.8 eV state and a line spectrum is observed as the states decay. Assume that all possible transitions occur. What is the total number of lines in the spectrum? Explain your answer. You may use the diagram above to support your answer.

(2 marks)

Question 14/ 29

[VCAA 2022 NHT SB Q17]

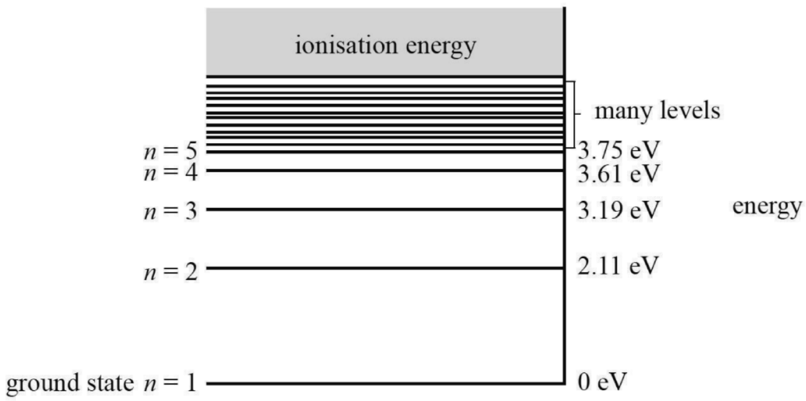
Describe how absorption line spectra are produced and describe their relationship to electron transitions within atoms.

(3 marks)

Question 15/ 29

[VCAA 2022 NHT SB Q19]

The diagram below shows the energy levels of a sodium atom.



A sodium atom is initially in the $n = 4$ excited state.

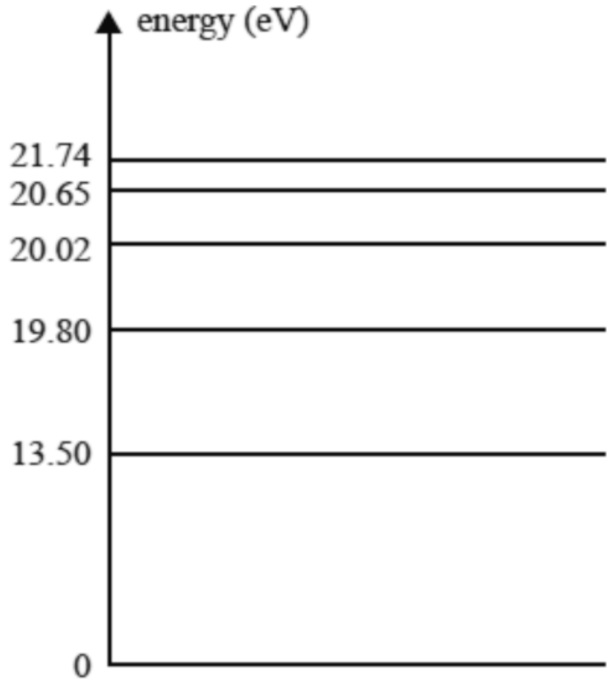
Calculate the highest frequency of light that the sodium atom in this excited state could emit.

(2 marks)

Question 16/ 29

[VCAA 2022 SB Q15]

The diagram below shows some of the energy levels of excited neon atoms. These energy levels are not drawn to scale.



a. Show that the energy transition required for an emitted photon of wavelength 640 nm is 1.94 eV.

(1 mark)

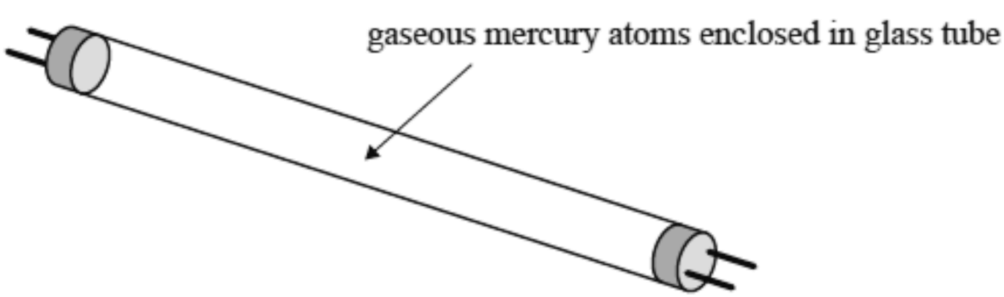
b. Draw an arrow to show the transition that would emit this photon.

(1 mark)

Question 17/ 29

[VCAA 2023 SB Q16]

Fluorescent lights, when operating, contain gaseous mercury atoms, as shown below.



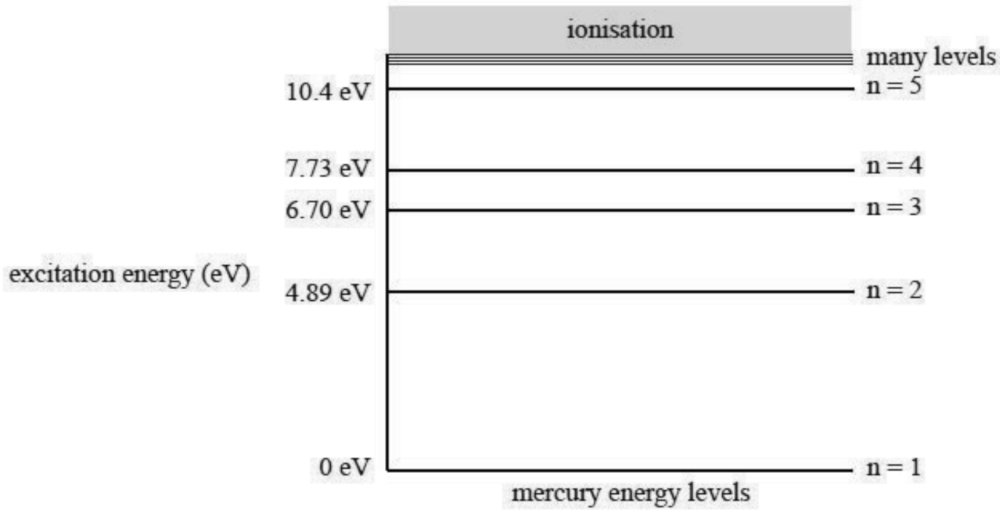
Analysis of the light produced by fluorescent lights shows a number of emission spectral lines, including a prominent line representing a wavelength of 436.6 nm.

a. Calculate the energy of the photons represented by the emission spectral line representing a wavelength of

436.6 nm.

(2 marks)

The diagram on the next page shows the lowest five energy levels for mercury.



b. On the energy level diagram shown above draw an arrow showing the energy level transition that corresponds to the production of the spectral line representing a wavelength of 436.6 nm.

(1 mark)

c. A 6.7 eV photon is absorbed by a mercury atom in the ground state and then the atom transitions back to the ground state.

Identify the energies, in eV, of all the possible photons that could be produced.

(3 marks)

Chapter 18 Relativity

Question 1/ 36

Unstable subatomic particles have different lifetimes, depending on whether they are moving relative to the observer measuring the lifetime. One particle has a lifetime, measured at rest, of 5.1 ps. However, when these particles are moving very fast, they have a lifetime of 510 ps. Which of the following is closest to the speed that these particles are travelling at?

A 99.994% of c

B 99.995% of c

C 99.996% of c

D 99.998% of c

Question 2/ 36

A spaceship is observed moving by an observer; its length is measured to be exactly one-quarter of its proper length. Which of the following is closest to the speed of the spaceship relative to the observer making this measurement?

A $2.3 \times 10^8\ \mathrm{m\ s^{-1}}$

B $2.6 \times 10^8\ \mathrm{m\ s^{-1}}$

C $2.9 \times 10^8\ \mathrm{m\ s^{-1}}$

D $3.2 \times 10^8\ \mathrm{m\ s^{-1}}$

Question 3/ 36

Which of the following is closest to the work that must be done on an electron to increase its speed from zero to $0.3c$?

A $4.0 \times 10^{-23}\ \mathrm{J}$

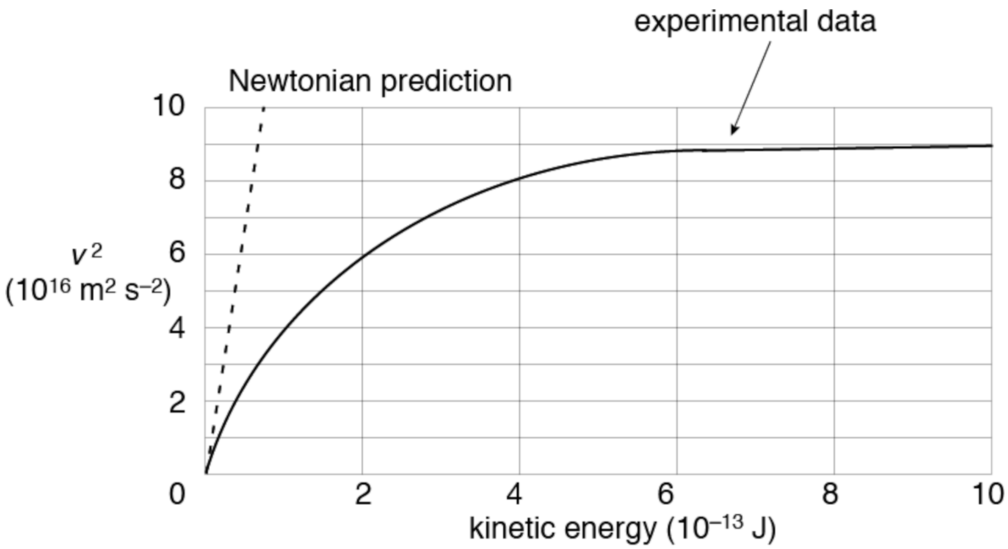
B $8.1 \times 10^{-23}\ \mathrm{J}$

C $1.6 \times 10^{-22}\ \mathrm{J}$

D $3.9 \times 10^{-15}\ \mathrm{J}$

Question 4/ 36

The variation of kinetic energy of electrons with speed is shown in the graph below. The data originates from MIT. The square of the speed is plotted against the kinetic energy of the electrons.



Which of the following equations best explains the shape of the graph above?

A $E_K = m_0c^2$

B $E_K = \gamma\, m_0c^2$

C $E_K = (\gamma + 1)\, m_0c^2$

D $E_K = (\gamma - 1)\, m_0c^2$

Question 5/ 36

Which of the following is *not* a version of the postulates of Einstein's theory of special relativity?

A The laws of physics are the same in all inertial reference frames.

B The speed of light is the same in all media.

C The speed of light is independent of the motion of the source.

D The speed of light is independent of the motion of the observer.

Question 6/ 36

Two anti-particles, a *tau* particle and an *anti-tau* particle, both at rest, annihilate each other producing two photons, each of energy 1.773 GeV. Which of the following is closest to the rest mass of a single tau particle?

A 3.2×10^{-27} kg

B 3.2×10^{-33} kg

C 3.4×10^{-10} kg

D 3.2×10^{-30} kg

Question 7/ 36

Samantha is on a train moving past a station at $v = 0.85c$; Jim is standing still on the station. Which one of the following measurements is not a *proper* measurement (i.e. it is not a proper time or a proper length)?

A The measurement Samantha makes of the time taken for her to pass the station

B Jim’s measurement of the length of the station platform

C Samantha’s measurement of the length of the train

D Jim’s measurement of the length of the train

Question 8/ 36

Which of the following is closest to the speed of a particle produced in an accelerator with a Lorentz factor

(γ) equal to 11.5?

A 2.989×10^8 m s^{-1}

B 2.867×10^8 m s^{-1}

C 2.997×10^8 m s^{-1}

D 2.739×10^8 m s^{-1}

Question 9/ 36

As the speed of a mass tends towards the speed of light, the kinetic energy

A increases proportionally to the square of the speed.

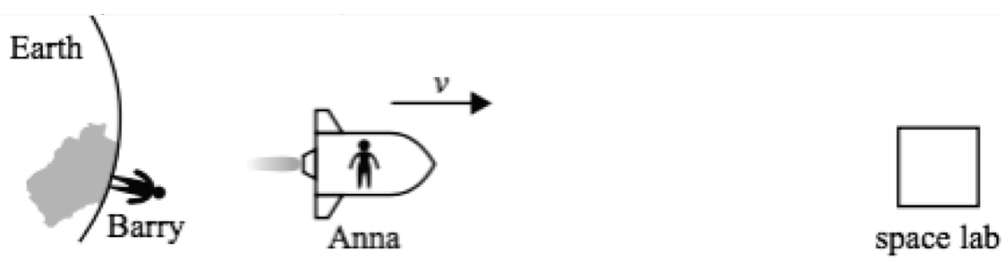
B increases more than proportionally to the square of the speed.

C increases less than proportionally to the square of the speed.

D tends towards an upper limit.

Question 10/ 36

Anna and Barry have identical quartz clocks that use the precise period of vibration of crystals to determine time. Barry and his clock are on Earth. Anna accompanies her clock on a rocket travelling at constant high velocity, *v*, past Earth and towards a space lab (stationary relative to Earth), as shown.



Question 11/ 36

[Adapted VCAA 2016 SB Q1]

Which one of the following statements correctly describes the behaviour of these two clocks?

A The period of vibration in Anna’s clock (observed by Anna) will be shorter than the period of vibration in Barry’s clock (observed by Barry).

B The period of vibration in Anna’s clock (observed by Anna) will be longer than the period of vibration in Barry’s clock (observed by Barry).

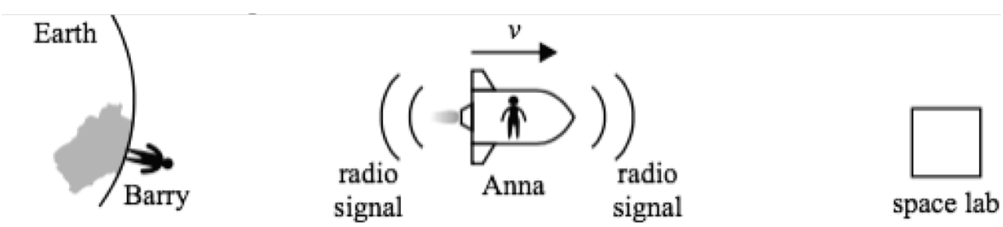
C The period of vibration in Anna’s clock (observed by Anna) will be the same as the period of vibration in Barry’s clock (observed by Barry).

D Only the time on Barry’s clock is reliable because it is at rest.

Question 12/ 36

[VCAA 2016 SB Q2]

When Anna is halfway between Earth and the space lab, she sends a radio pulse towards Earth and towards the space lab, as shown.



As observed by Anna, which one of the following statements correctly gives the order in which this signal is received by Barry and by the space lab?

A Barry receives the signal first.

B The space lab receives the signal first.

C The signal is received by Barry and the space lab at the same time.

D It is not possible to predict since special relativity applies to light but not to radio signals.

Question 13/ 36

[VCAA 2016 SB Q3]

The diagram shows Carla moving towards a loudspeaker at a speed of v_C and Han running towards a light source at speed v_H.

Which of the following correctly shows the speed of sound relative to Carla and the speed of light relative to Han? (The speed of sound in air is v_S.)

Speed of sound relative to Carla	Speed of light relative to Han
v_S	c
$v_S + v_C$	$c + v_H$
$v_S + v_C$	c
$v_S - v_C$	$c - v_H$

Question 14/ 36

[VCAA 2016 SB Q5]

Pions are particles that are present in cosmic rays striking Earth. Pions have a half-life of 26 ns (the time for half of a large number of pions to decay). In which frame of reference will the undilated value of the half-life be observed?

A in the frame of the high-energy source of each pion

B in each pion’s own frame

C in any inertial frame

D in Earth's frame

Question 15/ 36

[Adapted VCAA 2016 SB Q8]

A linear accelerator increases the speed of a charged particle from rest. The particle is accelerated in a time of 40 ns and reaches a speed where $\gamma = 1.6$.

What is the time taken for this acceleration in the particle's own frame of reference?

A 40 ns

B 40 ns divided by the average γ during the trip between the electrodes

C 64 ns

D cannot be determined using special relativity

Question 16/ 36

[VCAA 2017 SA Q10]

A student sits inside a windowless box placed on a smooth-riding train carriage. He conducts a series of motion experiments to investigate frames of reference. Which one of the following observations is correct?

A The results when the train accelerates are identical to the results when the train is at rest.

B The results when the train accelerates differ from the results when the train is in uniform motion in a straight line.

C The results when the train is at rest differ from the results when the train is in uniform motion in a straight line.

D The results when the train accelerates are identical to the results when the train is in uniform motion in a straight line.

Question 17/ 36

[VCAA 2017 SA Q11]

On average, the sun emits $3.8 \times 10^{26}\mathrm{J}$ of energy each second in the form of electromagnetic radiation, which originates from the nuclear fusion reactions taking place in the sun's core. The corresponding loss in the sun's mass each second would be closest to

A 2.1×10^{9} kg

B 4.2×10^{9} kg

C 8.4×10^{9} kg

D 2.1×10^{12} kg

Question 18/ 36

[VCAA 2018 NHT SA Q10]

A linear accelerator (linac) accelerates electrons to an energy of 100 MeV over a distance of about 10 m. After the first metre of acceleration in the linac, the electrons are travelling at approximately 99.9% of the speed of light. The Lorentz factor, γ, for an electron travelling at this speed would be closest to

A 22.4

B 44.8

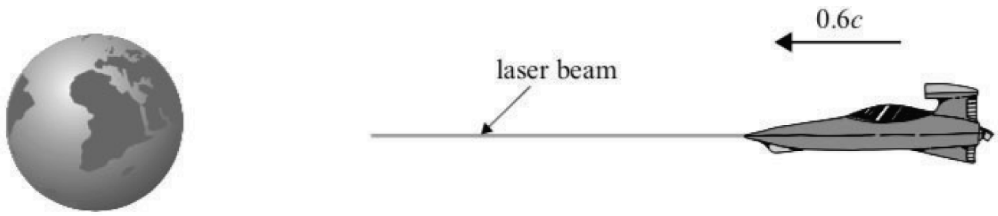
C 500

D 1000

Question 19/ 36

[VCAA 2018 NHT SA Q11]

An alien spaceship has entered our solar system and is heading directly towards Earth at a speed of 0.6*c*, as shown in the diagram below. When it reaches a distance of $3.0 \times 10^{11}\mathrm{m}$ from Earth (in Earth's frame of reference), the aliens transmit a 'be there soon' signal via a laser beam.



How long will the signal take to reach Earth according to an Earth observer?

A 1.0 s

B 1.7 s

C 625 s

D 1000 s

Question 20/ 36

Which of the following is *not* a version of the postulates of Einstein's theory of special relativity?

A The laws of physics are the same in all inertial reference frames.

B The speed of light is the same in all media.

C The speed of light is independent of the motion of the source.

D The speed of light is independent of the motion of the observer.

Question 21/ 36

When a relativistic particle increases its speed from $v = 0.95c$ to $0.975c$, its value for γ increases by

A 1.4

B 3.2

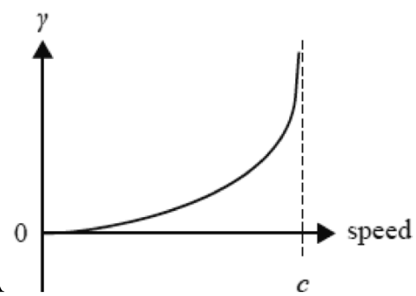
C 4.3

D 10

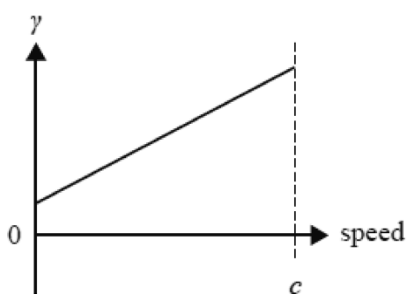
Question 22/ 36

[VCAA 2018 SA Q13]

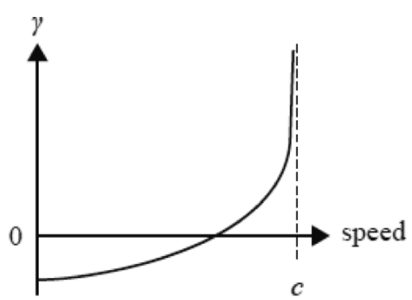
Which one of the following diagrams best represents the graph of γ (the Lorentz factor) versus speed for an electron that is accelerated from rest to near the speed of light, c?



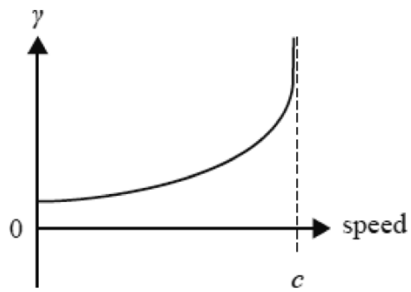
A



B



C



D

Question 23/ 36

[VCAA 2018 SA Q14]

Which one of the following statements about the kinetic energy, E_k, of a proton travelling at relativistic speed is the most accurate?

A The difference between the proton's relativistic E_k and its classical E_k cannot be determined.

B The proton's relativistic E_k is greater than its classical E_k.

C The proton's relativistic E_k is the same as its classical E_k.

D The proton's relativistic E_k is less than its classical E_k.

Question 24/ 36

[VCAA 2019 NHT SA Q16]

In a particle accelerator, magnesium ions are accelerated to 20.0% of the speed of light. Which one of the following is closest to the Lorentz factor, γ, for the magnesium ions at this speed?

A 1.02

B 1.12

C 1.20

D 2.24

Question 25/ 36

[VCAA 2019 NHT SA Q17]

The lifetime of stationary muons is measured in a laboratory to be 2.2 μs. The lifetime of relativistic muons produced in Earth's upper atmosphere, as measured by ground-based scientists, is 16 μs. The resulting time dilation observed by the scientists gives a Lorentz factor, γ, of

A 0.14

B 1.4

C 3.5

D 7.3

Question 26/ 36

[VCAA 2019 NHT SA Q18]

If a particle's kinetic energy is 10 times its rest energy, E_{rest}, then the Lorentz factor, γ, would be closest to

A 9

B 10

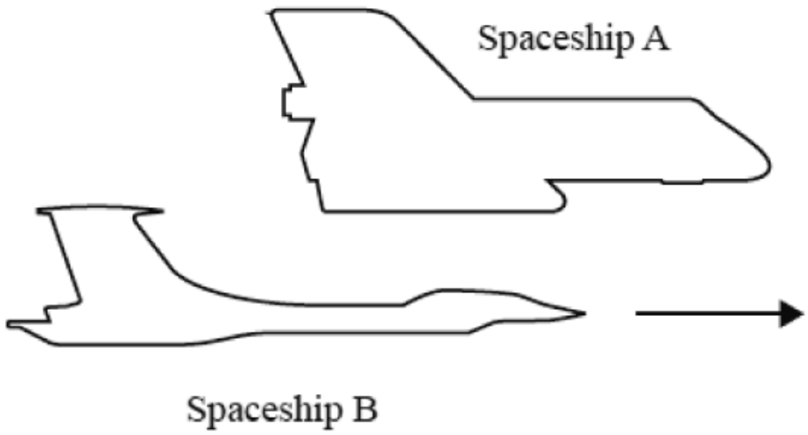
C 11

D 12

Question 27/ 36

[VCAA 2019 SQ Q13]

Joanna is an observer in Spaceship A, watching Spaceship B fly past at a relative speed of $0.943c\,(\gamma = 3.00)$. She measures the length of Spaceship B from her frame of reference to be 150 m. Which one of the following is closest to the proper length of Spaceship B?



A 50 m

B 150 m

C 450 m

D 900 m

Question 28/ 36

[VCAA 2020 SA Q12]

A high-energy proton is travelling through space at a constant velocity of $2.50 \times 10^{8}\ \mathrm{m\ s^{-1}}$. The Lorentz factor, γ, for this proton would be closest to

A 1.81

B 2.44

C 3.27

D 3.39

Question 29/ 36

[VCAA 2020 SA Q13]

Matter is converted to energy by nuclear fusion in stars. If the star Alpha Centauri converts mass to energy at the rate of 6.6×10^9 kg s^{-1}, then the power generated is closest to

A 2.0×10^{18} W

B 2.0×10^{18} J

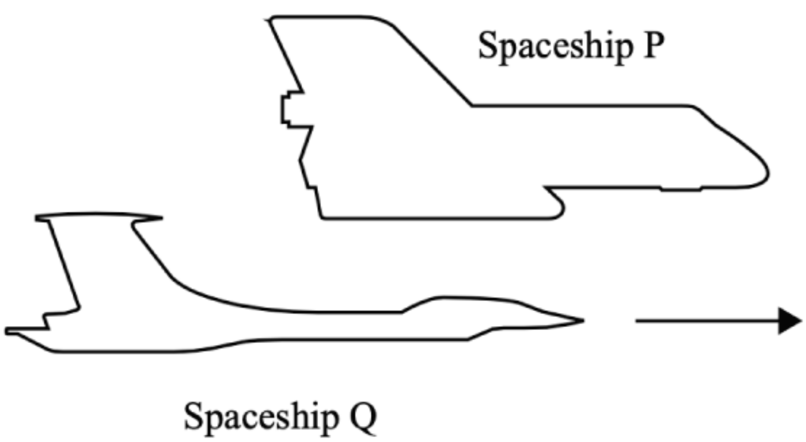
C 6.0×10^{26} W

D 6.0×10^{26} J

Question 30/ 36

[VCAA 2021 NHT SA Q13]

Joanna is an observer in Spaceship P and is watching Spaceship Q fly past at a relative speed of $0.943c$ $(\gamma = 3.00)$. She observes a stationary clock measuring a time interval of 75.0 s between two events in Spaceship Q. This is a proper time interval.



Which one of the following is closest to the time interval observed between the two events in Spaceship P's frame of reference?

A 15.0 s

B 25.0 s

C 125 s

D 225 s

Question 31/ 36

[VCAA 2021 NHT SA Q20]

A nucleus in an excited energy state emits a gamma ray of energy $3.6 \times 10^{-13}\mathrm{J}$ as it decays to its ground state. The initial mass of the excited nucleus is M_i.

The final mass of the nucleus after decay is closest to

A $\mathrm{M_i} - 4 \times 10^{-30}$ kg

B $\mathrm{M_i} - 8 \times 10^{-30}$ kg

C M_i kg

D $\mathrm{Mi} + 4 \times 10^{-30}$ kg

Question 32/ 36

[VCAA 2021 SA Q20]

One of Einstein's postulates for special relativity is that the laws of physics are the same in all inertial frames of reference. Which one of the following best describes a property of an inertial frame of reference?

A It is travelling at a constant speed.

B It is travelling at a speed much slower than *c*.

C Its movement is consistent with the expansion of the universe.

D No observer in the frame can detect any acceleration of the frame.

Question 33/ 36

[VCAA 2022 NHT SA Q10]

Ning travels at 0.67*c* from Earth to the star Proxima Centauri, which is a distance of 4.25 light-years away, as measured by an observer on Earth.

Which one of the following statements is correct?

A In Ning's frame of reference, the distance to Proxima Centauri is less than 4.25 light-years.

B In Ning's frame of reference, the distance to Proxima Centauri is more than 4.25 light-years.

C According to Ning's clock, the trip takes longer than the time measured by Earth-based clocks.

D In Ning's frame of reference, the distance to Proxima Centauri is exactly equal to 4.25 light-years.

Question 34/ 36

[VCAA 2022 NHT SA Q11]

The star Betelgeuse is classified as a red supergiant. At the core of this star, three stationary helium nuclei fuse to form one carbon nucleus and two gamma-ray photons, as represented by the equation below.

$$^4\text{He} + ^4\text{He} + ^4\text{He} \rightarrow ^{12}C + \gamma + \gamma$$

The mass of one helium nucleus is 6.645×10^{-27} kg.

The mass of one carbon nucleus is 1.993×10^{-26} kg.

The energy released from the fusion of three helium nuclei is closest to

A 5.0×10^{-30} J

B 1.5×10^{-21} J

C 4.5×10^{-13} J

D 1.2×10^{-9}

Question 35/ 36

[VCAA 2022 SA Q18]

Which one of the following is an example of an inertial frame of reference?

A a bus travelling at constant velocity

B an express train that is accelerating

C a car turning a corner at a constant speed

D a roller-coaster speeding up while heading down a slope

Question 36/ 36

[VCAA 2022 SA Q19]

A particle produced in a linear particle accelerator is travelling at a speed of $2.99 \times 10^8 \mathrm{~m~s}^{-1}$. Take the speed of light to be $3.00 \times 10^8 \mathrm{~m~s}^{-1}$. Which one of the following is closest to the Lorentz factor (γ) of the particle?

A 5.51

B 7.86

C 12.3

D 15.1

Question 37/ 36

[VCAA NHT 2023 SA Q20]

A pion and its antiparticle, each at rest, annihilate and produce only two photons with a total energy of $4.5 \times 10^{-11}\mathrm{J}$. The masses of the pion and its antiparticle are the same.

The rest mass of the pion is closest to

A 1.3×10^{-28} kg

B 2.5×10^{-28} kg

C 5.0×10^{-28} kg

D 7.5×10^{-20} kg

Question 1/ 69

A spaceship moving past an observer has its length measured as exactly one-quarter of its proper length. Calculate the speed of the spaceship relative to the observer making this measurement.

(2 marks)

Question 2/ 69

Calculate the work that must be done on an electron to increase its speed from rest to 0.3*c*.

(2 marks)

Question 3/ 69

Unstable subatomic particles have different lifetimes, depending on whether they are moving relative to the observer measuring the lifetime. One particle has a lifetime, measured at rest, of 5.1 ps. However, when they are moving close to the speed of light, they have a lifetime of 510 ps. Calculate the speed that these particles are travelling at, as a percentage of c.

(2 marks)

Question 4/ 69

[Adapted VCAA 2016 SB Q6]

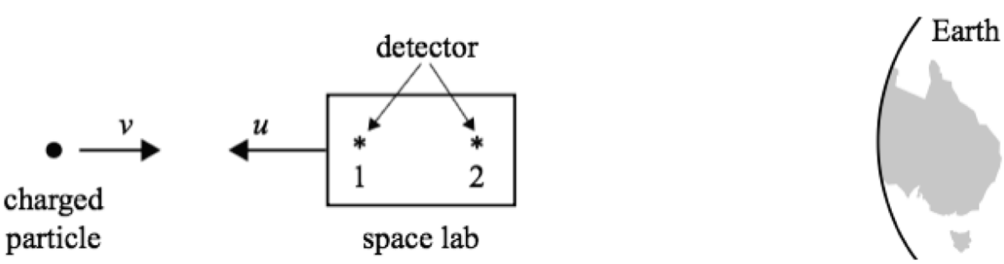
Consider one pion approaching Earth at a speed of $0.98c$. In its own frame of reference it decays after 26 ns after it is formed. How long did the pion exist as observed in Earth's frame of reference?

(2 marks)

Question 5/ 69

[Adapted VCAA 2016 SB Q7]

A space lab travelling at $u = 0.8c\,(\gamma = 1.67)$ away from Earth can record high-energy charged particles passing through its detectors.



One particle is travelling towards Earth at $v = 0.91c\ (= 2.4)$ relative to the space lab. Two detectors, numbered 1 and 2 in the diagram above, are 2.0 m apart in the space lab's frame. How far apart are the two detectors in the particle's frame?

(2 marks)

Question 6/ 69

One of the postulates of special relativity can be written as:

'The speed of light has a constant value for all observers regardless of their motion or the motion of the source.'

Give a specific example of an application of this postulate.

(2 marks)

Question 7/ 69

Sally is in a spaceship moving at a fast but constant velocity. Sam is stationary on the ground. Both have identical atomic clocks. Sam observes Sally's clock 'ticking' at half the rate that his clock ticks at.

a. At what speed is Sally's spaceship moving relative to Sam?

(2 marks)

b. At what rate does Sally observe Sam's clock to be ticking (compared to hers)? Give reasons for your answer.

(2 marks)

c. Sam measures Sally's ship to be 500 m long. Calculate the proper length of Sally's spaceship.

(2 marks)

Question 8/ 69

A very fast train $(v = 0.85c)$ of proper length 700 m enters a tunnel of length 600 m. A trainspotter is watching from a nearby hill and can see both ends of the tunnel. Outline what the trainspotter will observe from the time just before she sees the front of the train entering the tunnel to the time just after the back of the train leaves the tunnel. Explain your reasoning.

(3 marks)

Question 9/ 69

Calculate the value of γ for a spaceship travelling at $0.7711c$. Give your answer to four significant figures.

(2 marks)

Question 10/ 69

A proton $(\text{mass} = 1.67 \times 10^{-27}\ \text{kg})$ in an accelerator beamline $(\text{proper length} = 4.2\ \text{km})$ has a γ value of 2.35.

a. Calculate the speed of the proton relative to the beamline in units of c. Give your answer to three significant figures.

(2 marks)

b. Calculate the length of the beamline in the reference frame of the proton.

(2 marks)

c. Calculate the time of flight of the protons down the full length of the beamline in the reference frame of the scientists standing beside the beamline.

(2 marks)

d. Calculate the kinetic energy of the proton, in units of MeV. Show your working.

(3 marks)

Question 11/ 69

Scientists accelerate a proton from rest to a final speed where $\gamma = 4.5$. The mass of a proton is $1.67 \times$

10^{-27} kg. How much work was done on the proton?

(2 marks)

Question 12/ 69

The Sun's power output is currently about 385 yottawatt $(3.85 \times 10^{26}\ \mathrm{W})$.

a. Calculate the rate at which the Sun's mass is reducing (in $\mathrm{kg\ s^{-1}}$). Show your working.

(3 marks)

b. The Sun's current mass is about 2×10^{30} kg. Estimate the reduction in its mass in one billion years (10^9 y) time. Assume its power output remains the same during that time. Give your answer as a percentage of its current mass, to one significant figure. Show your working.

(3 marks)

Question 13/ 69

[Adapted VCAA 2016 SB Q9]

A proton is accelerated from rest, gaining a kinetic energy of 1.20×10^{-10} J. What value of γ is reached? (The mass of a proton is 1.67×10^{-27} kg.)

(2 marks)

Question 14/ 69

[Adapted VCAA 2016 SB Q10]

A high-energy proton with $\gamma = 3$ collides with a stationary nucleus and rebounds in the opposite direction to its original motion. The kinetic energy of the proton after the collision is mc^2, where *m* is the proton mass. The nucleus gains kinetic energy and the collision is elastic. Determine, in terms of *m* and *c*, the kinetic energy of the nucleus after the collision.

(2 marks)

Question 15/ 69

[VCAA 2017 SB Q10]

The length of a spaceship is measured to be exactly one-third of its proper length as it passes by an observing station. What is the speed of this spaceship, as determined by the observing station, as a multiple of *c*?

(2 marks)

Question 16/ 69

[VCAA 2017 SB Q11]

Tests of relativistic time dilation have been made by observing the decay of short-lived particles. A muon, travelling from the edge of the atmosphere to the surface of Earth, is an example of such a particle.

To model this in the laboratory, another elementary particle with a shorter half-life is produced in a particle accelerator. It is travelling at $0.99875c\,(\gamma = 20)$. Scientists observe that this particle travels 9.14×10^{-5} m in a straight line from the point where it is made to the point where it decays into other particles. It is not accelerating.

a. Calculate the lifetime of the particle in the scientists' frame of reference.

(2 marks)

b. Calculate the distance that the particle travels in the laboratory, as measured in the particle's frame of reference.

(2 marks)

c. Explain why the scientists would observe more particles at the end of the laboratory measuring range than classical physics would expect.

(3 marks)

Question 17/ 69

[VCAA 2018 NHT SB Q15]

An unstable subatomic particle, known as a π_0 meson, decays completely into electromagnetic radiation. The mass of this π_0 meson is $2.5 \times 10^{-28}\ \mathrm{kg}$. How much energy would be released by this π_0 meson if it decays at rest?

(2 marks)

Question 18/ 69

[VCAA 2018 NHT SB Q14]

An Earth-like planet has been discovered orbiting a distant star. A mission to this planet is suggested. The planet is $1.0 \times 10^{18}\ \mathrm{m}$ from Earth. The spaceship suggested for the mission can travel at an average speed of $0.99c\,(\gamma = 7.1)$.

Scientists are concerned about the length of time the passengers would have to spend on the spaceship to travel to this planet. Use special relativity to estimate this time, in years, as measured on the spaceship.

(3 marks)

Question 19/ 69

[VCAA 2018 SB Q14]

Jani is stationary in a spaceship travelling at constant speed. Does this mean that the spaceship must be in an inertial frame of reference? Justify your answer.

(2 marks)

Question 20/ 69

[VCAA 2018 SB Q15]

A stationary scientist in an inertial frame of reference observes a spaceship moving past her at a constant velocity. She notes that the clocks on the spaceship, which are operating normally, run eight times slower than her clocks, which are also operating normally. The spaceship has a mass of 10 000 kg. Calculate the kinetic energy of the spaceship in the scientist's frame of reference. Show your working.

(3 marks)

Question 21/ 69

[VCAA 2018 SB Q16]

Quasars are among the most distant and brightest objects in the universe. One quasar (3C446) has a brightness that changes rapidly with time. Scientists observe the quasar's brightness over a 20-hour time interval in Earth's frame of reference. The quasar is moving away from Earth at a speed of $0.704c$ $(\gamma = 1.41)$. Calculate the time interval that would be observed in the quasar's frame of reference. Show your working.

(2 marks)

Question 22/ 69

[VCAA 2019 SB Q17]

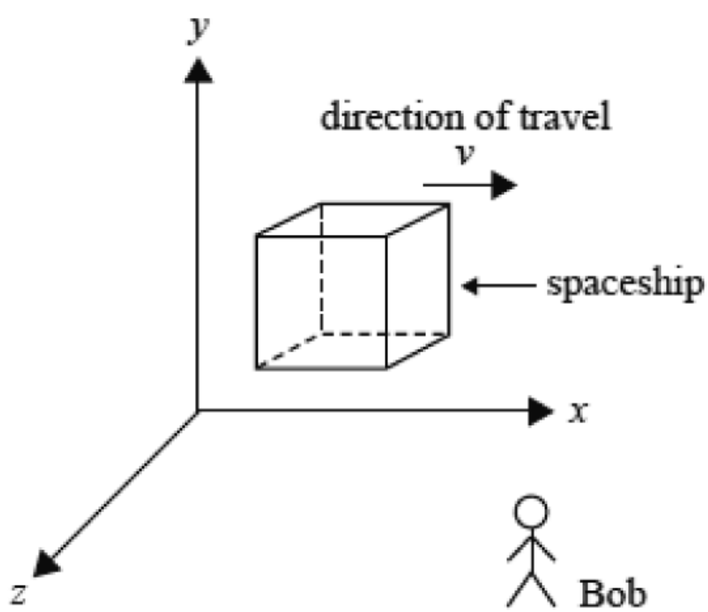
A spaceship is travelling from Earth to the star system Epsilon Eridani, which is located 10.5 light-years from Earth as measured by Earth-based instruments. If the spaceship travels at $0.85c$ $(\gamma = 1.90)$, determine the duration of the flight as measured by the astronauts on the spaceship travelling to Epsilon Eridani. Take one light-year to be 9.46×10^{15} m. Show your working.

(3 marks)

Question 23/ 69

[VCAA 2019 NHT SB Q18]

Alien astronauts are travelling between star systems aboard a cube-shaped spaceship, as shown below. The sides of the cube along the *x*-axis, *y*-axis and *z*-axis are 3200 m in the spaceship's reference frame. The spaceship passes Bob, who is on a space station at speed $v = 0.990c\,(\gamma = 7.09)$.



Determine the dimensions of the cube-shaped spaceship as measured from Bob's frame of reference and explain your reasoning. Give the length of the side along the *x*-axis, the length of the side along the *y*-axis and the length of the side along the *z*-axis.

(3 marks)

Question 24/ 69

[VCAA 2019 NHT SB Q19]

In a nuclear fusion reaction in the Sun's core, two deuterium nuclei, each with a mass of $3.3436 \times 10^{-27}\ \mathrm{kg}$, fuse to produce one helium-4 nucleus with a mass of $6.6465 \times 10^{-27}\ \mathrm{kg}$. Ignore the kinetic energy of the nuclei before the reaction. Calculate the energy released. Show your working.

(2 marks)

Question 25/ 69

[VCAA 2019 SB Q11]

What is the second postulate of Einstein's theory of special relativity regarding the speed of light? Explain how the second postulate differs from the concept of the speed of light in classical physics.

(3 marks)

Question 26/ 69

[VCAA 2020 SB Q11]

An astronaut has left Earth and is travelling on a spaceship at $0.800c\ (\gamma = 1.67)$ directly towards the star known as Sirius, which is located 8.61 light-years away from Earth, as measured by observers on Earth.

a. How long will the trip take according to a clock that the astronaut is carrying on his spaceship? Show your working.

(2 marks)

b. Is the trip time measured by the astronaut in part a. a proper time? Explain your reasoning.

(2 marks)

Question 27/ 69

[VCAA 2021 NHT SB Q10]

Jacinta is standing still while observing a spaceship passing Earth at a speed of 0.984c.

a. Calculate γ for this speed, correct to three significant figures. Show your working.

(2 marks)

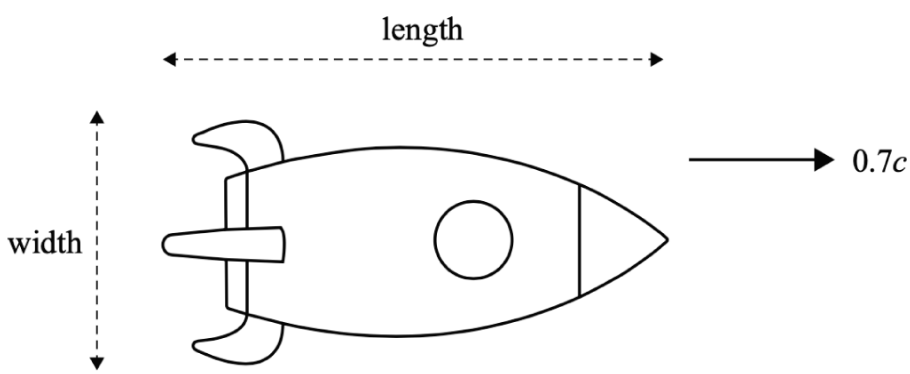
b. The spaceship is travelling to the Alpha Centauri star system in a straight line at this speed. In Jacinta's frame of reference, this distance is measured to be 4.37 light-years (that is, it would take light 4.37 years to travel this distance). Calculate the time that would be measured by Jacinta for the spaceship's journey, correct to three significant figures. Show your working.

(2 marks)

Question 28/ 69

[VCAA 2021 SB Q10]

A new spaceship that can travel at 0.7c has been constructed on Earth. A technician is observing the spaceship travelling past in space at 0.7c, as shown. The technician notices that the length of the spaceship does not match the measurement taken when the spaceship was stationary in a laboratory, but its width matches the measurement taken in the laboratory.



a. Explain, in terms of special relativity, why the technician notices there is a different measurement for the length of the spaceship, but not for the width of the spaceship.

(2 marks)

b. If the technician measures the spaceship to be 135 m long while travelling at a constant 0.7c, what was the length of the spaceship when it was stationary on Earth? Show your working.

(2 marks)

Question 29/ 69

[VCAA 2022 NHT SB Q11]

An experiment is set up at a linear accelerator research facility to study muons. The muons created at the research facility are measured to have a speed of $0.950c$ $(\gamma = 3.20)$.

a. One muon has a lifetime of 2.3 μs, as measured in the muon's frame of reference. Calculate this muon's lifetime, as measured by the researchers. Show your working.

(2 marks)

b. In one observation, a 0.950*c* muon travels 1.5 km, as measured by the researchers. If measured in the muon's frame of reference, would this length be the same, shorter or longer? Use a calculation to justify your answer.

(2 marks)

Question 30/ 69

[VCAA 2022 SB Q9]

A star is transforming energy at a rate of 2.90×10^{25} W. Explain the type of transformation involved and what effect, if any, the transformation would have on the mass of the star. No calculations are required.

(2 marks)

Question 31/ 69

[VCAA 2022 SB Q11]

Explain why muons formed in the outer atmosphere can reach the surface of Earth even though their half-lives indicate that they should decay well before reaching Earth's surface.

(2 marks)

Question 32/ 69

[VCAA NHT 2023 SB Q14]

A spaceship of length 71 m, measured when stationary on Earth, is travelling horizontally past an observer on Earth at a speed of $0.80c$.

a. The spaceship emits a beam of light towards the observer.

State the speed of the light as measured by the observer on Earth.

Justify your answer.

(2 marks)

b. Calculate the length of the spaceship as measured by the observer on Earth.

(2 marks)

Question 33/ 69

[VCAA 2023 SB Q10]

A proton in an accelerator beamline of proper length 4.80 km has a Lorentz factor, γ, of 2.00.

a. Calculate the speed of the proton relative to the beamline in terms of c, the speed of light in a vacuum. Give your answer to three significant figures.

(3 marks)

b. Calculate the length of the beamline in the reference frame of the proton.

(1 mark)

c. Calculate the kinetic energy of the proton in joules. Show your working.

$\text{Mass of proton} = 1.67 \times 10^{-27}$ kg.

(2 marks)

Chapter 19 Principles of practical physics

Question 1/ 25

In experimental investigations, *independent* variables are best described as

A ones that the investigator selects values for.

B the key variables to be measured.

C independent of the investigator's control.

D fixed throughout the experiment.

Question 2/ 25

In experimental investigations, *dependent* variables are those that

A the investigator selects values for.

B are the least important variables to be measured.

C are dependent on the selected values of other variable(s).

D are fixed throughout the experiment.

Question 3/ 25

In experimental investigations, *controlled* variables are those that, generally

A the investigator varies the values for.

B are the least important variables to be measured.

C are dependent on the selected values of other variables.

D are fixed throughout the experiment.

Question 4/ 25

An *accurate* value for a measurement is one that

A is the result of many careful investigations.

B is made by a highly skilled scientific investigator.

C when repeated many times changes very little.

D is close to the true value of the quantity being measured.

Question 5/ 25

Data is said to be *precise* when

A it is the result of a careful investigation.

B repeated many times, the results change very little.

C the same experimental method is used by different investigators.

D it is close to the true value of the quantity being measured.

Question 6/ 25

Data cannot be said to be *valid* when

A systematic errors are very large.

B repeated measurements give a wide range of values.

C the experimental method used is too straightforward.

D the measurement is repeated too many times.

Question 7/ 25

The *error* in a measurement is best understood as

A the difference between the measured value and the true value.

B a mistake in the recording of a measurement.

C a mistake in the experimental method.

D the expected variation in subsequent measurement values.

Question 8/ 25

The experimental *uncertainty* of a measurement is best understood as

A an estimate of the validity of the data.

B the confidence of an experimenter in their experimental technique.

C the repeatability of the measurement.

D an estimate of how far the measurement is from the true value.

Question 9/ 25

A *hypothesis* is best understood as

A a program of investigative research.

B a testable scientific explanation of a phenomenon.

C a well-established scientific belief system.

D a scientific explanation of a phenomenon from a qualified scientist.

Question 10/ 25

A scientific *theory* is best understood as

A a program of investigative research.

B a testable scientific explanation of a phenomenon.

C a well-tested and verified scientific explanation of a phenomenon.

D a scientific explanation of a phenomenon from a qualified scientist.

Question 11/ 25

[Adapted VCAA 2017 SA Q18]

Two students, Rob and Jan, measure the current in a circuit under the same conditions and with the same equipment on separate occasions.

Rob obtains the following readings: 9.50 mA, 9.21 mA, 9.10 mA and 9.60 mA (average 9.35 mA).

Jan obtains the following readings: 9.27 mA, 9.26 mA, 9.30 mA and 9.32 mA (average 9.29 mA).

The value of the current using a very accurate meter is found to be 9.34 mA.

Which one of the following best describes these two sets of measurements?

A Rob's results are more accurate than Jan's results.

B Both sets of results are equally accurate.

C Rob's results are more precise than Jan's results.

D Both sets of results are equally precise.

Question 12/ 25

[VCAA 2017 SA Q19]

Which one of the following best describes a *hypothesis*?

A A possible explanation that needs to be tested against experimental evidence

B An explanation that has been supported by rigorous experimental evidence

C A statement that is widely accepted by scientists

D An explanation that is mathematically correct

Question 13/ 25

[VCAA 2017 SA Q20]

Which one of the following statements about systematic and random error is correct?

A Random error can be reduced by repeated readings.

B Both random and systematic errors can be reduced by repeated readings.

C Systematic errors can be reduced by repeated readings.

D Neither systematic nor random errors can be reduced by repeated readings.

Question 14/ 25

[VCAA 2017 Sample SA Q9]

Some students are measuring the acceleration due to gravity in a region of Earth's surface where the value is well established as $9.81 \pm 0.01 \text{ m s}^{-2}$.

They take five measurements, as follows:

$9.83 \text{ m s}^{-2}; 9.81 \text{ m s}^{-2}; 9.79 \text{ m s}^{-2}; 9.78 \text{ m s}^{-2}; 9.84 \text{ m s}^{-2}$.

Systematic errors are negligible.

The students could reasonably describe the measurement uncertainty of their results as about

A 0.03 m s^{-2}

B 0.10 m s^{-2}

C 0.005 m s^{-2}

D 9.81 m s^{-2}

Question 15/ 25

[VCAA 2018 SA Q18]

The experimental uncertainty in a measurement of any particular quantity is *best* described as

A a quantitative estimate of the doubt associated with the measurement.

B the degree of confidence a scientist has in their experimental technique.

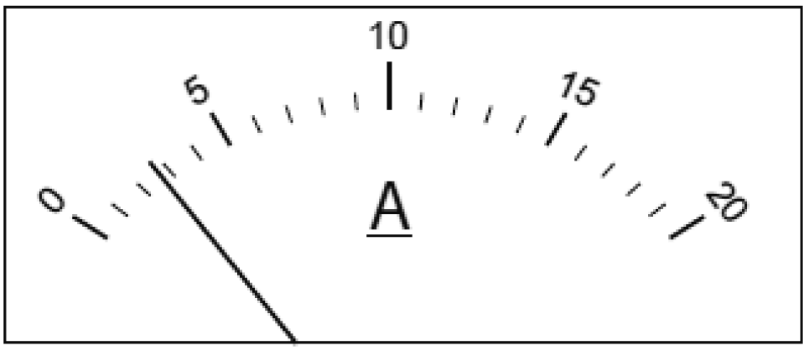
C the difference between the measurement and the true value of the quantity.

D the result of one measurement; repeated measurements can eliminate uncertainty.

Question 16/ 25

[VCAA 2018 SA Q19]

The diagram below shows a properly calibrated ammeter with its pointer registering a current of close to 3 A.



Which one of the following is an appropriate measure of the uncertainty of this single reading of the pointer?

A 0.05 A

B 0.5 A

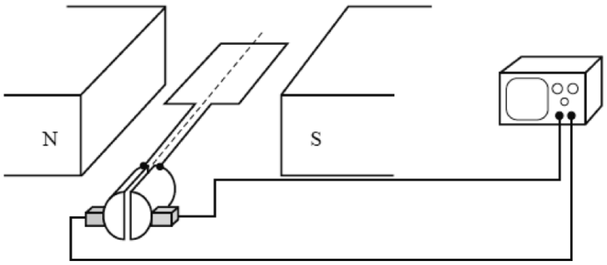
C 0.8 A

D 1 A

Question 17/ 25

[VCAA 2018 SA Q20]

A group of Physics students conducts a controlled experiment to investigate the phenomenon of electromagnetic induction. The students place a coil within a uniform magnetic field, as shown in the diagram below.



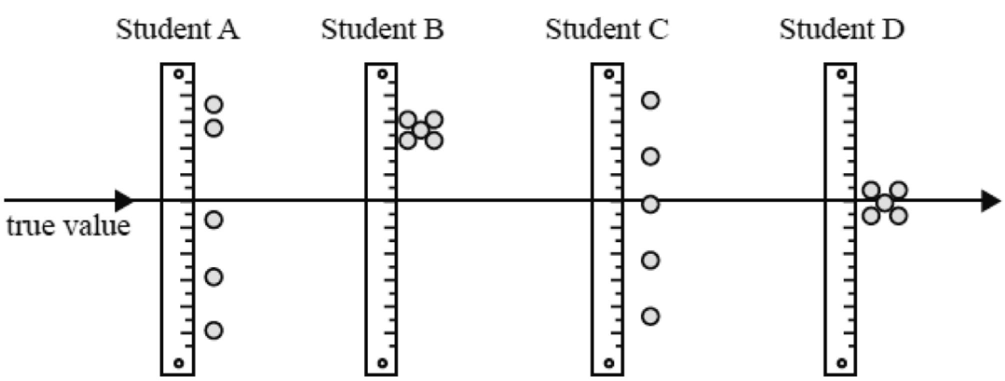
The coil is spun at 50 revolutions per minute, 100 revolutions per minute and then 150 revolutions per minute, and the peak EMF is measured each time on an oscilloscope. Which of the following *best* identifies the independent and dependent variables, and a possible controlled variable in this experiment?

Independent variable	Dependent variable	Controlled variable
speed of rotation	strength of magnetic field	peak EMF
speed of rotation	peak EMF	strength of magnetic field
peak EMF	speed of rotation	strength of magnetic field
peak EMF	strength of magnetic field	speed of rotation

Question 18/ 25

[VCAA 2019 NHT SA Q20]

Four students measure the length of a piece of string. Each student takes five measurements and displays the results as five dots, as shown in the diagram below. A ‘calibrated value’ using a very accurate method is also shown.



Which student produced a set of precise but inaccurate results?

A Student A

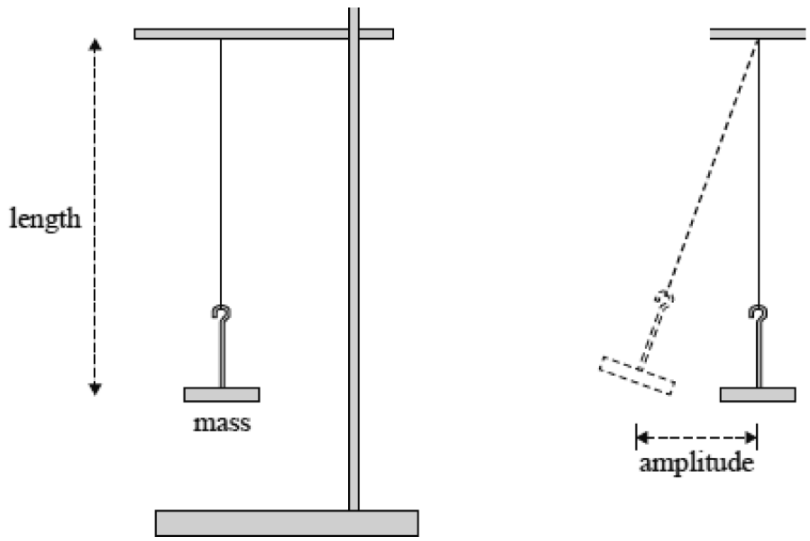
B Student B

C Student C

D Student D

Question 19/ 25

As part of an experimental investigation, Physics students use a pendulum, as shown, to indirectly measure the magnitude of Earth's gravitational field at their location.



The students use a constant mass and a constant amplitude of swing, changing only the length of the pendulum and then measuring the time for five oscillations. They obtain four different time readings for four different lengths of the pendulum. By using the relationship

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where T is the period and l is the length of the pendulum, the students obtain four values for the magnitude of Earth's gravitational field.

Question 20/ 25

[VCAA 2019 SA Q18]

Which of the following best identifies the independent, dependent and controlled variables in the students' experimental investigation?

Independent	Dependent	Controlled
length	time	mass, amplitude
time	length	mass, amplitude
mass	time	length, amplitude
amplitude	length	time, mass

Question 21/ 25

[VCAA 2019 SA Q19]

Which one of the following best explains why the students measured the time for five oscillations rather than the time for one oscillation?

A One oscillation is too quick to see.

B Five oscillations reduce the effect of air friction.

C Five oscillations reduce the uncertainty of the measured period.

D Five oscillations reduce the uncertainty of the measured length.

Question 22/ 25

[VCAA 2020 SA Q19]

Which one of the following best describes a hypothesis?

A a testable scientific explanation

B a well-tested scientific explanation

C a scientific explanation by a famous scientist

D a widely believed and highly plausible explanation

Question 23/ 25

[VCAA 2021 NHT SA Q19]

In an experimental investigation, an independent variable is one that is

A independent of the investigator’s control.

B a value selected by the investigator.

C fixed throughout the experiment.

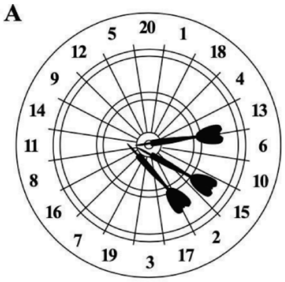
D the key variable to be measured.

Question 24/ 25

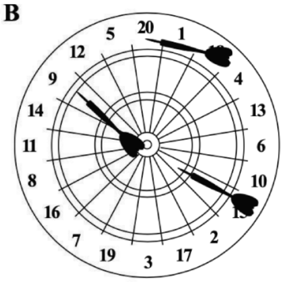
[VCAA 2021 SA Q1]

The aim of darts is to hit the bullseye at the centre of a dartboard. Four darts players (A, B, C and D) each threw three darts. The results of their throws are shown below.

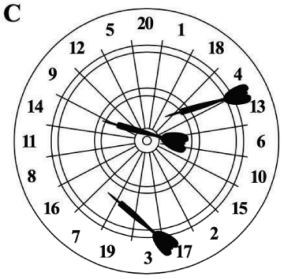
Player A



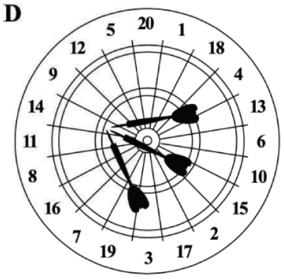
Player B



Player C



Player D



Which one of the players produced a set of attempts that could be described as being precise but inaccurate?

A Player A

B Player B

C Player C

D Player D

Question 25/ 25

[VCAA 2022 SA Q20]

The experimental uncertainty of a measurement is best understood as

A an estimate of the validity of the data.

B a mistake in the experimental method used.

C a mistake in the recording of a measurement.

D an estimate of the maximum likely difference between the measurement and the true value.

Question 26/ 25

[VCAA NHT 2023 SA Q11]

Which one of the following best describes a hypothesis?

A an explanation that is correct

B a statement that is widely accepted by physicists

C an explanation that has been supported by experimental evidence

D a possible explanation that needs to be tested by experimental evidence

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Question 1/ 45

Express the following quantities to three significant figures.

a. 0.0003455 N

b. 34 500 A

c. 8.7964×10^3 C

(3 marks)

Question 2/ 45

Identify the units in the following list that are not SI *base units*:

• kilogram

• milliamp

• grams

• ampere

• seconds

• millikelvin

(2 marks)

Question 3/ 45

Write out the name of the following abbreviations in full:

kA, mV, MPa, mJ, μT, mW

(2 marks)

Question 4/ 45

Students are investigating how the resistance of an incandescent globe changes with the power supplied to the globe. They have access to the globe, a suitable ammeter and voltmeter, connecting wires and a variable voltage power supply.

a. Draw a circuit that they could use to measure the globe resistance at different power inputs. Label the components of the circuit clearly.

(3 marks)

b. Identify dependent, independent and controlled variables in this investigation.

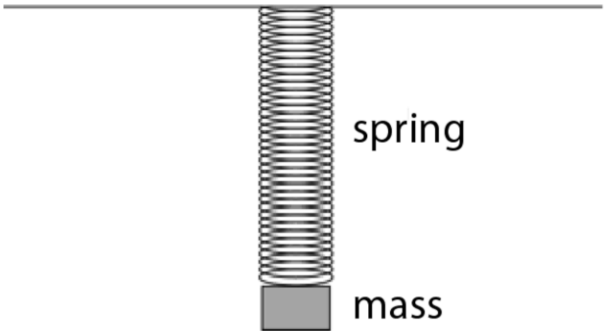
(3 marks)

c. Outline a procedure that they could follow to gather data for their investigation.

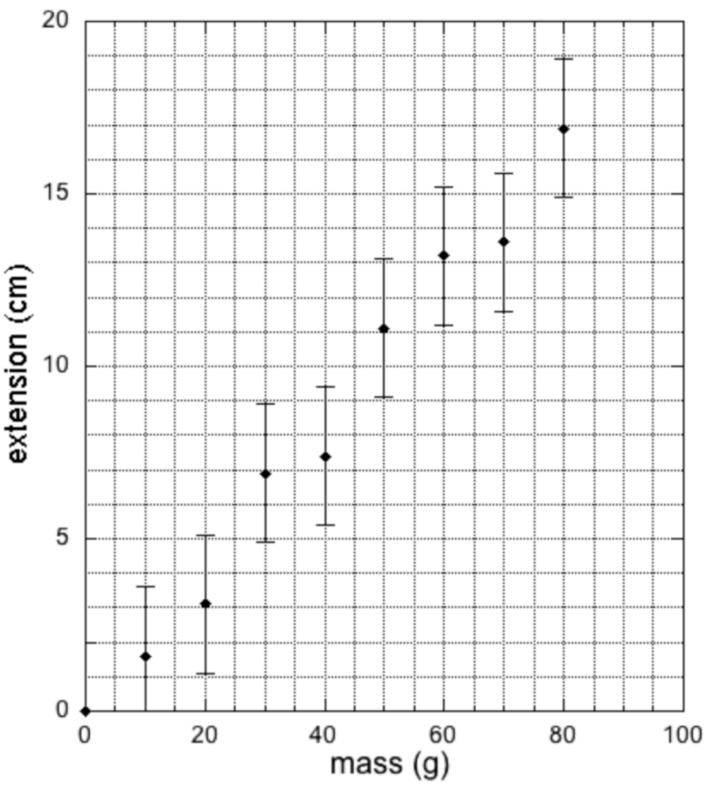
(4 marks)

Question 5/ 45

Students gather data to measure the force constant of a spring attached to the ceiling. Masses are added gently to the lower end of the spring.



They measure the spring extension against the mass size, and draw the graph shown on the next page. The vertical uncertainty bars show the confidence that the students have in the accuracy of their measurements. There are no horizontal bars, as the masses are known very accurately.



a. Draw a trend line through the points. Explain how you decided on the shape and position of the line you draw.

(3 marks)

b. Use your trend line to determine the force constant of the spring, in $\mathrm{Nm^{-1}}$. Show all your working.

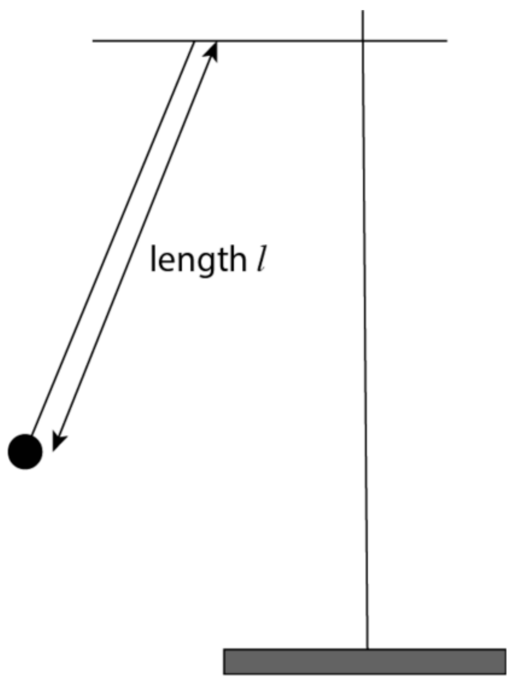
(4 marks)

c. Estimate the uncertainty in your value for the force constant. (You may find it helpful to draw more lines on the graph.) Show your reasoning.

(4 marks)

Question 6/ 45

Students are using a simple pendulum to measure the local gravitational field (*g*). A fishing line supports a small mass from a sturdy stand.



The length of the fishing line supporting the mass $95 \text{ cm} \pm 2 \text{ cm}$. The 2 cm figure represents the measurement uncertainty of the length of the fishing line. The students measure the *period* of the pendulum as it swings through a small angle. They measure the time for 20 complete swings, and they repeat the measurement five times.

a. Explain why they repeat the measurement.

(2 marks)

They then repeat the experiment for five different small masses, and the results with measurement uncertainties are shown in the table below.

Mass (g)	Angle of swing (°)	Period (average of 5 swings)
50	4 ± 1	1.99 ± 0.06
75	4 ± 1	2.02 ± 0.06

Mass (g)	Angle of swing (°)	Period (average of 5 swings)
100	4 ± 1	1.96 ± 0.06
125	4 ± 1	2.03 ± 0.06
150	4 ± 1	1.97 ± 0.06

b. Identify the controlled, independent and dependent variable in this experiment.

(3 marks)

c. One of the students had made the hypothesis that larger masses would result in a longer period. Evaluate the results of the experiment with this hypothesis.

(2 marks)

Their research (using reliable internet sites) shows that, provided the swing amplitude is small, the connection between the period (*T*), length (*l*) and gravitational field (*g*) should be:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

d. They use the formula above to determine a value for the local gravitational field. What value will they obtain? Show your working.

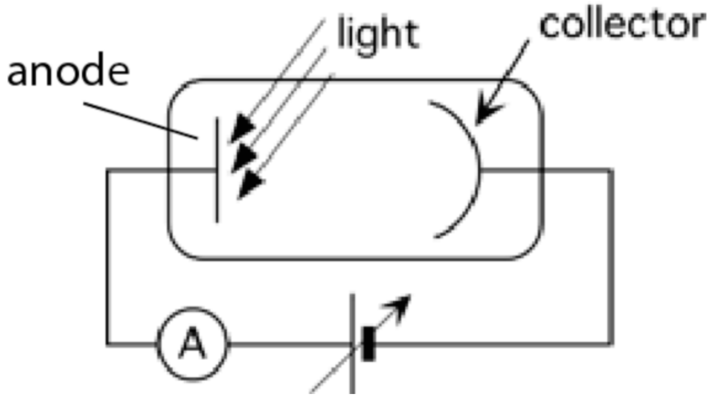
(4 marks)

e. Their teacher tells them that their result should have an experimental uncertainty of close to 8%. Evaluate their result, given that the local value of *g* has been very accurately measured to be $9.81\ \mathrm{N\ kg^{-1}}$.

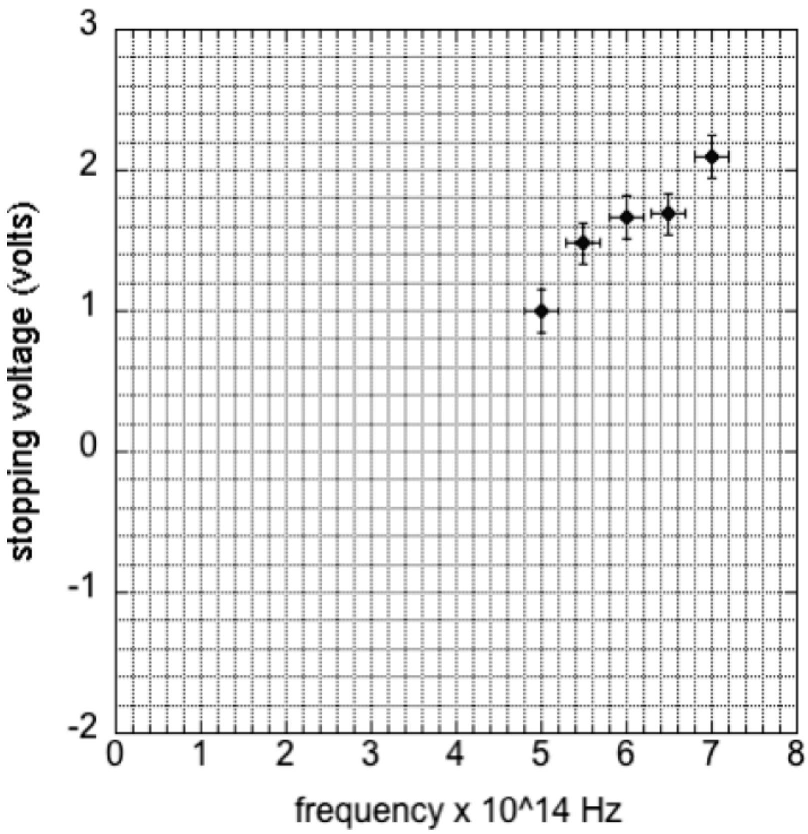
(2 marks)

Question 7/ 45

Students are experimenting with a photocell. When light of a high enough frequency strikes the anode (a metal plate), photoelectrons are emitted.



Students record the power supply voltage that just reduces the current in the ammeter to zero against the frequency of the light (they use a range of filters). The results that they obtain are graphed on the next page. The horizontal and vertical bars attached the graph points show their measurement uncertainties.



a. Draw a line of best fit to the data in the graph.

(2 marks)

b. From your line, calculate the work function of the photocell, in eV.

(2 marks)

c. From your line, calculate the value of Planck's constant, in eV s.

(2 marks)

Question 8/ 45

Students use a resonance tube to measure the wavelength of sound at various frequencies. They change the frequency and measure the resulting wavelength. They aim measure accurately the speed of sound. Results are shown below. They keep the temperature steady at 20°C throughout.

Frequency f (Hz)	**Wavelength λ (cm)**	$\mathbf{1/\lambda\left(m^{-1}\right)}$
100	345	
150	202	
200	179	
250	126	
300	122	

a. Identify the dependent, independent and controlled variables.

(2 marks)

b. Complete the table values in the last column. Use the units indicated.

(3 marks)

c. Plot a graph of frequency (*x*-axis) against ($1/\lambda$) (*y*-axis). Take the uncertainties as $\pm 15\ \mathrm{Hz}$ (for *f*) and $\pm 9\%$ (for $1/\lambda$).

(4 marks)

d. Draw a trendline (line of best fit).

(2 marks)

e. Evaluate whether the linear fit is justified by the uncertainties involved.

(2 marks)

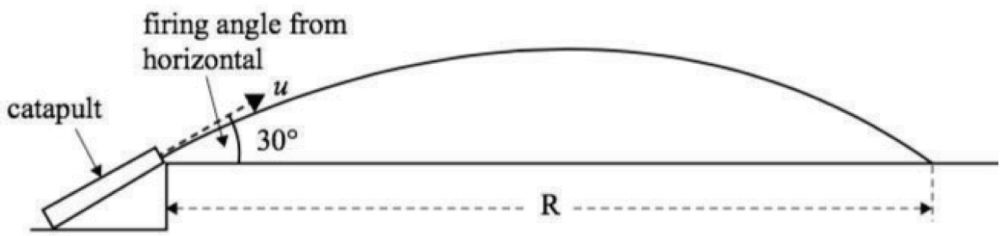
f. Use the trendline gradient to calculate the speed of sound. Show your working.

(3 marks)

Question 9/ 45

[Adapted VCAA 2017 SB Q9]

Students investigate the relationship between various initial variables of projectiles and their range, *R* (on level ground) as in the diagram below. In their investigation they use a 0.10 kg ball and keep the launching catapult at a fixed angle of 30°. The ball lands at the same height that it was launched from.



a. The variables in the experiment can be classified as controlled, dependent or independent. Complete the table below by providing one variable from the experiment described for each classification.

Classification	*Variable*
Controlled	
Dependent	
Independent	

(3 marks)

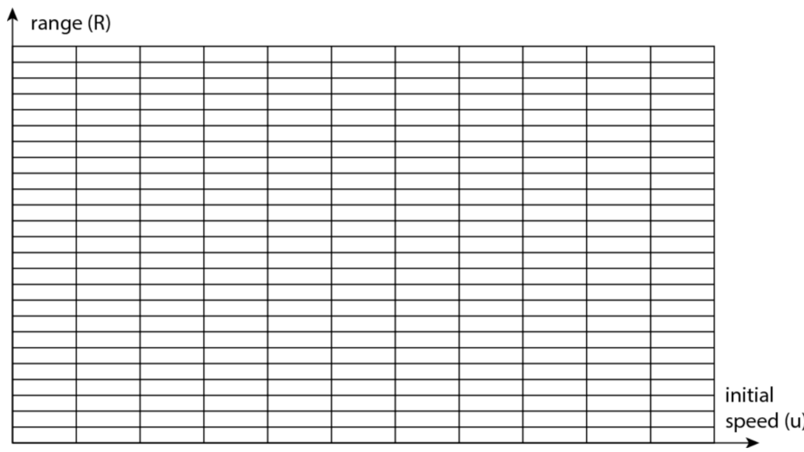
b. The students gather the following data from a series of experiments similar to the experiment described in part **a**.

$u = initial\ speed\ \left(m\ s^{-1}\right)$	$R = range\ (m)$
1.0	0.10
2.0	0.35
3.0	0.78
4.0	1.40
5.0	2.15

The students use a tape measure that is marked with intervals of 10 cm to measure the range that the ball travels at different initial speeds.

On the grid provided below:

- graph the data gathered by the students (from the table above)
- include scales and units on each axis
- insert appropriate uncertainty bars for the range (distance) on the graph
- draw a smooth curve of best fit.



(8 marks)

Question 10/ 45

Two students attempt to measure the local acceleration of gravity by timing the drop of a golf ball. They measure the fall distance with a tape measure (marked in 1 cm intervals) and the time of fall with a stopwatch. They do not have access to more sophisticated equipment. They can choose to drop the ball over distances between 1 and 5 m. The stopwatch measurement uncertainty of time intervals is ± 0.1 s. They aim to use the measured drop time and distance to calculate g.

a. Identify the dependent and independent variables.

(1 mark)

b. Suggest a procedure for conducting the experiment (use dot points) that will maximise the accuracy of the drop time measurements.

(3 marks)

c. Outline the calculation steps that they should take with the drop time measurements to determine a value for *g*.

(2 marks)

d. Which of the measurements that they take has an experimental uncertainty with the greatest effect on the accuracy of their results? Explain your reasoning.

(3 marks)

Question 11/ 45

[VCAA 2018 SB Q20]

Some students have collected data on the orbital period, *T*, and orbital radius, *R*, of five of Saturn's moons. The results are shown in the table below. Assume that the moons are in circular orbits.

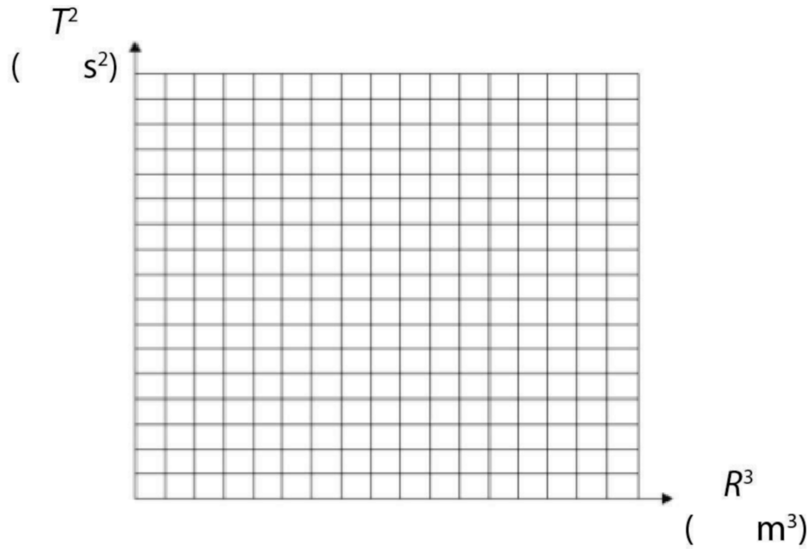
Moon	**Orbital period (s)**	**Orbital radius (m)**	$T^2\ (10^{10}\ \mathrm{s}^2)$	$R^3\ (10^{24}\ \mathrm{m}^3)$
Mimas	8.14×10^4	1.86×10^8	0.66	6.40
Enceladus	1.18×10^5	2.38×10^8	1.39	13.5
Tethys	1.63×10^5	2.95×10^8	2.66	25.7
Dione	2.36×10^5	3.77×10^8	5.57	53.6
Rhea	3.90×10^5	5.27×10^8	15.2	146

a. On the axes provided below:

• plot a graph of the observational data T^2 versus R^3

• include a scale on each axis

• draw a line of best fit.



b. Calculate the gradient of the line of best fit drawn in part **a**. Show your working.

(2 marks)

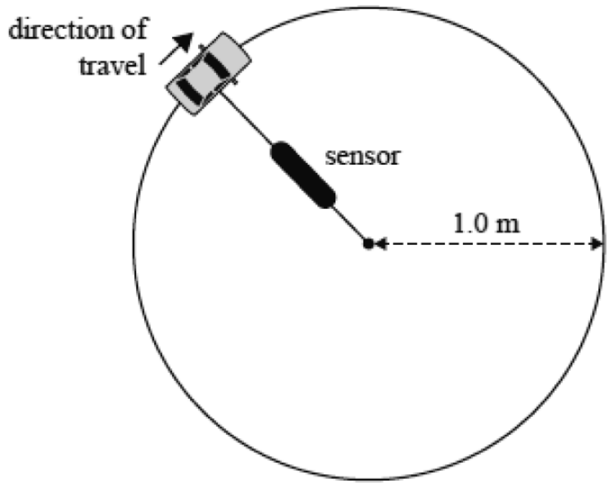
c. Use the value of the gradient calculated in part **b.** to determine the mass of Saturn. Show your working.

(3 marks)

Question 12/ 45

[VCAA 2019 NHT SB Q8]

Students are investigating the forces involved in horizontal circular motion. Their apparatus consists of a model car that travels in a circle at constant speed. The speed of the model car can be set at different values. The car is connected by a string of length 1.0 m to the centre of the circle. Incorporated in the string is a sensor that measures the tension (force) of the string. There is no radial friction force between the car's tyres and the surface that the car moves on. The diagram below shows the experimental arrangement viewed from above.



The students obtain a number of measurements by varying the setting for the period of rotation *T* and recording the force, F_{T}, in the string. They know *T* with great accuracy but the sensor has an experimental uncertainty of $\pm\ 0.4\ \mathrm{N}$.

a. What is experimental uncertainty and how can it be reduced?

[2 marks}

b. Identify the independent variable, the dependent variable and two controlled variables involved in this experiment.

(3 marks)

c. i. The students have recorded the data for the period of rotation, *T*, and the force, F_{T}, in the table below. The radius of the circle is 1.0 m. Calculate the values of $\frac{1}{T^2}$ and write them in the table below.

(1 mark)

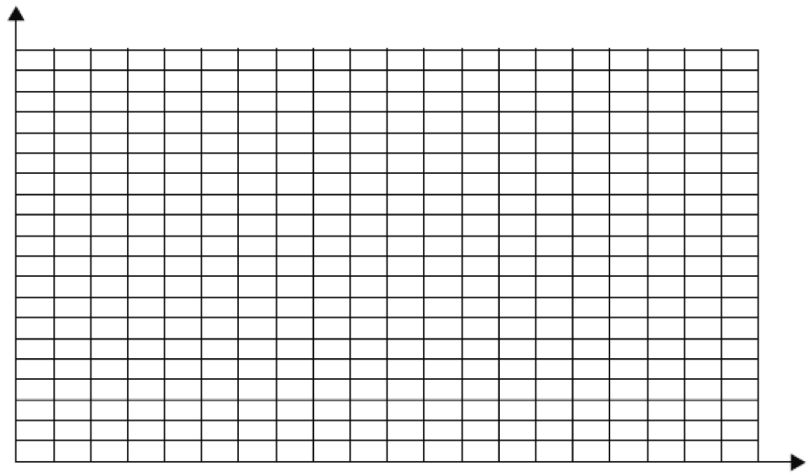
Period (s)	$\frac{1}{T^2}\left(\mathrm{s}^{-2}\right)$	Force $\mathrm{F_T}\ (\mathrm{N})$
5.00		8
10.0		2
15.0		0.9
20.0		0.5

The relationship between F_{T} and *T* is given by the formula

$$F_T = \frac{4\pi^2 mr}{T^2}$$

ii. On the axes provided on the next page, plot a graph of F_{T} versus $\frac{1}{T^2}$ using the data in the table above. Include the correct uncertainty bars for the F_{T} values. Label each of the axes correctly and draw a line of best fit.

(6 marks)



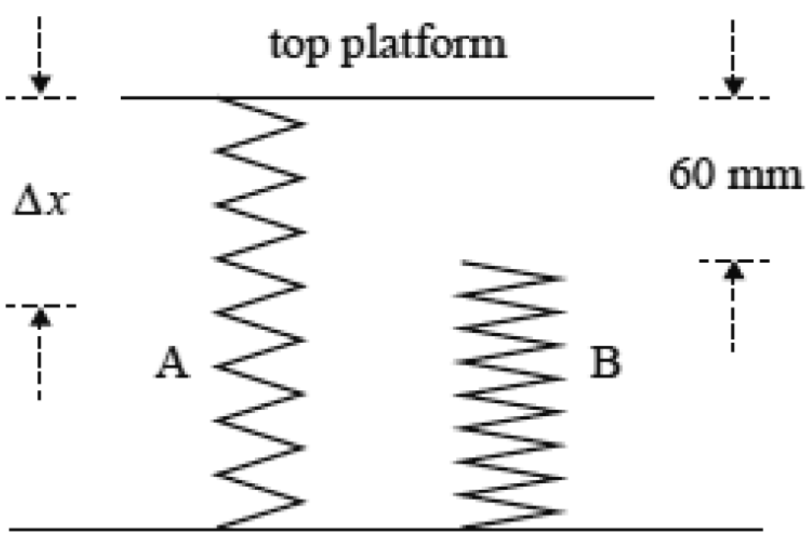
d. Using the line of best fit and the formula given in part **c ii.**, determine the value of *m*, the mass of the car. Show your working.

(3 marks)

Question 13/ 45

[VCAA 2019 SB Q19]

As part of their practical investigation, some students investigate a spring system consisting of two springs, A and B, and a top platform, as shown below. The students place various masses on the top platform. Assume that the top platform has negligible mass.



With no masses on the top platform of the spring system, the distance between the uncompressed Spring A and the top of Spring B is 60 mm. The students place various masses on the top platform of the spring system and note the vertical compression, Δx, of the spring system. They use a ruler with millimetre gradations to take readings of the compression of the spring(s), Δx, with an uncertainty of $\pm 2 \text{ mm}$.

The results of their investigation are shown in the table below.

Mass (g)	**Compression, Δx (mm)**
0	0
300	21
600	40
900	60
1300	68
1700	75
1900	80

The students plot a force (F) versus compression (Δx) graph for the spring system and use $g = 10 \text{ N kg}^{-1}$ for the value of the magnitude of the gravitational field strength.

a. On the axes provided below:

• plot a graph of force (F) versus compression (Δx) for the spring system

• include scales and units on each axis

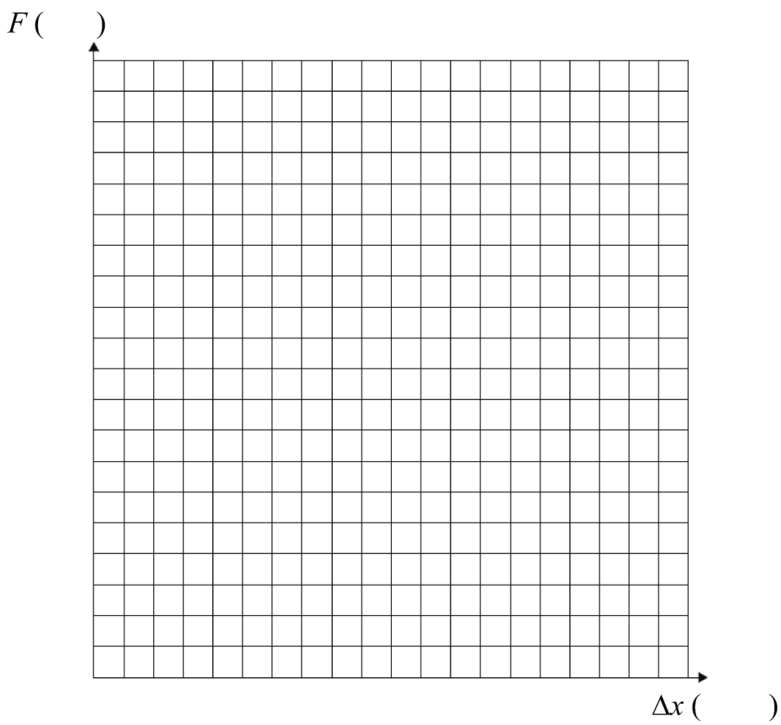
• insert appropriate uncertainty bars for the compression values on the graph

• draw lines that best fit the data for:

– the effect of Spring A alone

– the effect of Spring A and Spring B.

(6 marks)



b. i. Determine the spring constant for Spring A, k_{A}. Show your working.

(2 marks)

ii. Determine the spring constant for Spring B, k_{B}. Show your working.

(2 marks)

c. Using the area under the force (F) versus compression (Δx) graph, or otherwise, determine

i. the potential energy (PE_{A}) stored in Spring A when the spring system is compressed by 80 mm. Show your working.

(2 marks)

ii. the potential energy $(PE_{\mathrm{A+B}})$ stored in the spring system when the spring system is compressed by 80 mm. Show your working.

(2 marks)

iii. the work done to compress Spring B when the spring system is compressed by 80 mm. Show your working.

(2 marks)

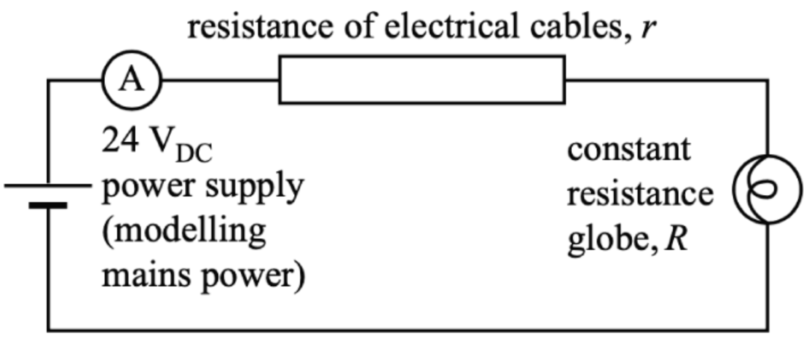
d. Explain how this type of spring system could be used in car spring suspension systems to enable the car to negotiate small bumps and more severe bumps in the road.

(2 marks)

Question 14/ 45

[VCAA 2020 SB Q18]

Students are modelling the effect of the resistance of electrical cables, *r*, on the transmission of electrical power. They model the cables using the circuit shown below.



a. The $24\ \mathrm{V_{DC}}$ power supply models the mains power. Describe the effect of increasing the resistance of the electrical cables, *r*, on the brightness of the constant resistance globe, *R*.

(2 marks)

The students investigate the effect of changing *r* by measuring the current in the electrical cables for a range of values. Their results are shown in the table below.

Resistance of cables, $r\ (\Omega)$	**Current in cables** ***I*** **(A)**	$1/i\ (\mathrm{A}^{-1})$
2.4	2.4	
3.6	2.0	
6.4	1.7	
7.6	1.5	
10.4	1.3	

b. Identify the dependent and the independent variables in this experiment. Give your reasoning.

(2 marks)

c. To analyse the data, the students use the following equation to calculate the resistance of the cables for the circuit.

$r = \frac{24}{i} - R$

Show that this equation is true for the circuit shown above. Show your working.

(2 marks)

d. Calculate the values of $\frac{1}{i}$ and write them in the spaces provided in 1the last column of the table above.

(2 marks)

e. Plot a graph of *r* on the *y*-axis against $\frac{1}{i}$ on the *x*-axis on the grid provided on the next page. On your graph:

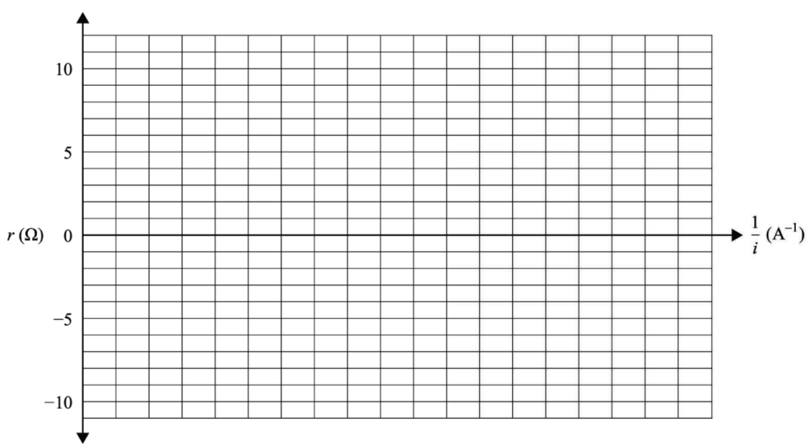
• choose an appropriate scale and numbers for the *x*-axis

• draw a straight line of best fit through the plotted points

• include uncertainty bars ($\pm x$ -direction only) of $\pm 0.02\ \mathrm{A}^{-1}$.

(Uncertainty bars in the *y*-direction are not required.)

(6 marks)



f. Use the straight line of best fit to find the value of the constant resistance globe, *R*. Give your reasoning.

(2 marks)

Question 15/ 45

[Adapted VCAA 2021 NHT SB Q18]

During their practical investigation, some Physics students investigate the bounce of a small rubber ball. The ball falls from a height of 1.00 m and rebounds to a height of 0.78 m. The students record the ball's vertical position versus time by using a smartphone's video feature and a metre ruler.

The uncertainty in the ball's vertical position is $\pm 0.03 \text{ m}$. The results from the students' recorded data are plotted on the graph below.

Missing Image

a. On the graph:

• label each axis and include units on each axis

• insert appropriate uncertainty bars for the height values on the graph, for the readings for the first four data points after the ball is released

• draw smooth curves of best fit.

(5 marks)

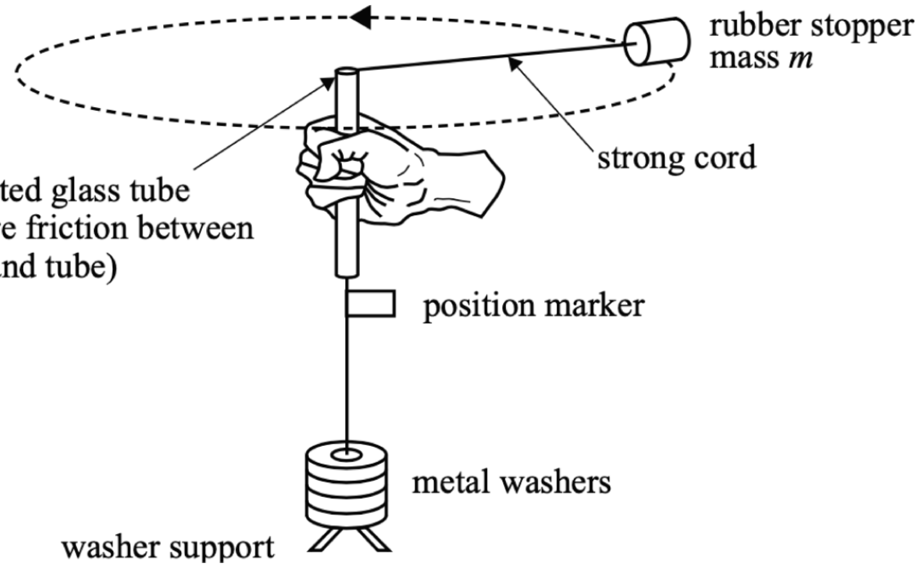
b. Estimate the speed of the ball at the instant of impact using an appropriate gradient of the graph. Use calculations to support your answer.

(3 marks)

Question 16/ 45

[VCAA 2021 SB Q20]

Two Physics students, Jerome and Priya, set out to investigate centripetal force. The diagram below shows the experimental set-up and the apparatus that the students use. In reality, the students find that the cord is not quite horizontal but dips downward slightly due to the gravitational force acting on the rubber stopper. Their teacher explains that they can safely ignore this effect when collecting their experimental results.



Jerome and Priya note the following data in their logbook.

radius of circle	0.75 m
mass of each metal washer	30 g
initial number of washers	10

Priya holds the glass tube and sets the rubber stopper rotating in a horizontal circle. She maintains a constant radius of the circle by keeping the position marker at a fixed position just below the bottom of the glass tube. Jerome uses a stopwatch to measure the time for 20 rotations of the rubber stopper, repeating this measurement three times. He notes all the data collected in their logbook. The experiment is then repeated four more times with two extra metal washers added before each new trial is undertaken.

a. Why did the students take repeated time measurements during the experiment?

(1 mark)

b. The tension in the cord supplies the centripetal force that the rubber stopper needs to rotate in a circle. What is the cause of this tension?

(1 mark)

c. The gravitational force acting on the metal washers is given by Mg, where M is the total mass of the washers and g is the gravitational field.

Symbol	**Symbol represents**
π	a constant
m	mass of rubber stopper
R	radius of rotation

Symbol	Symbol represents
T	period of rotation

Develop an equation between Mg and the quantities listed in the table above.

(3 marks)

Jerome and Priya record some of their results in the table below. The students are told by their teacher that they can use $g = 10\ \text{N kg}^{-1}$ for their calculations.

d. Fill in the blank columns in the table below.

(4 marks)

Line number	Total mass of washers, *M*(kg)	Gravitational force acting on washers, *Mg*(N)	Average time for 20 rotations (s)	Period, *T*(s)	$\frac{1}{T^2}\left(\text{s}^{-2}\right)$
1	0.30		14.0		
2	0.36		12.8		
3	0.42		11.8		
4	0.48		11.0		
5	0.54		10.4		

(4 marks)

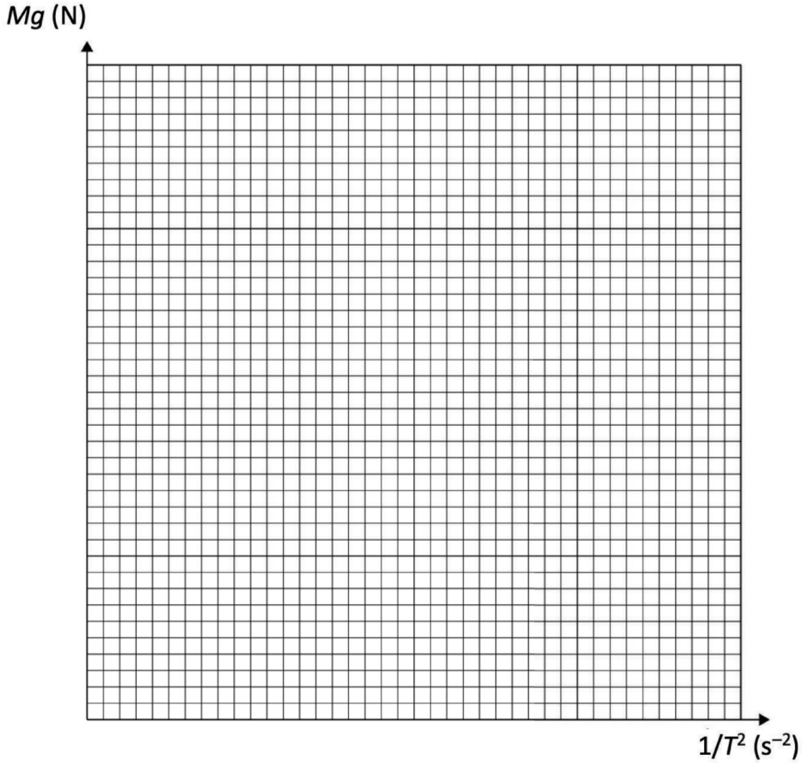
e. Using your values in the table above, plot a graph of *Mg* on the *y*-axis against on the *x*-axis on the grid provided on the next page.

On your graph:

• draw a straight line of best fit through the plotted points

• include uncertainty bars ($\pm x$ -direction only) of $\pm\ 0.1\ \text{s}^{-2}$.

(Uncertainty bars in the *y*-direction are not required.)



f. Calculate the gradient of the graph plotted in part **e**.

(2 marks)

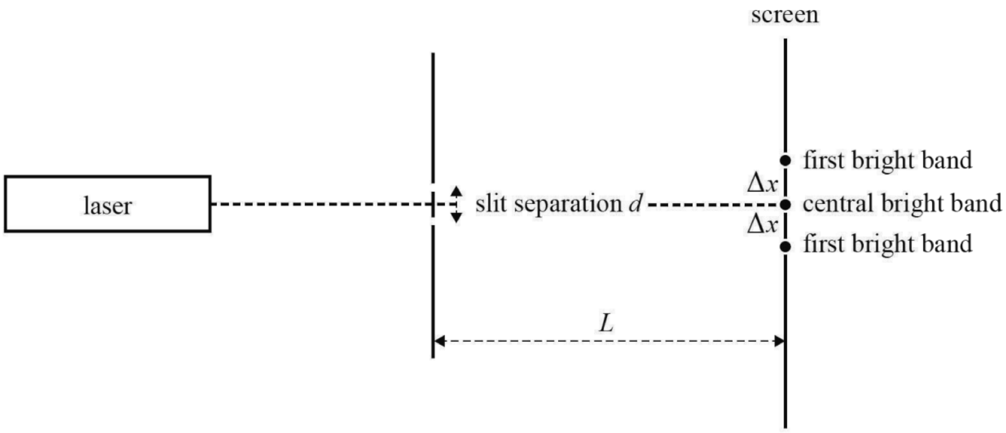
g. Using the gradient calculated in part **f**, show that *m*, the mass of the rubber stopper, is approximately 50 g.

(2 marks)

Question 17/ 45

[VCAA 2022 NHT SB Q20]

A group of Physics students used a double-slit interference experiment to measure the wavelength of the light from a laser. The laser was directed, at right angles, towards a double slit in a darkened room and an interference pattern was observed on a screen. The arrangement is shown schematically in the diagram below.



The students had access to two double-slit slides, one with a slit spacing of 0.16 mm and the other with a slit spacing of 0.26 mm. They placed the screen at distances of $L = 1.5\ \text{m}$, 2.5 m and 3.5 m and measured the average distance, Δx, from the central bright band to the first bright band on either side.

a. Identify the dependent variable, the independent variables and one controlled variable in this experiment.

(3 marks)

The experimental measurements taken are shown in the table.

***L* (mm)**	***d* (mm)**	$\frac{L}{d}$ (no unit) $(\times 1000)$	**Δx (mm)**
1500	0.26		3.3
2500	0.26		5.5
3500	0.26		7.7
1500	0.16		4.9
2500	0.16		8.2
3500	0.16		12.3

The students used the approximate equation $l = \frac{\Delta x d}{L}$ and a graph of Δx plotted against $\frac{L}{d}$ to find a value for the wavelength λ.

b. Calculate the values of $\frac{L}{d}$ to two significant figures and write them in the table above.

(2 marks)

c. Plot the values from the table on the grid provided below.

• Include an appropriate scale, numbers and a unit on the y-axis.

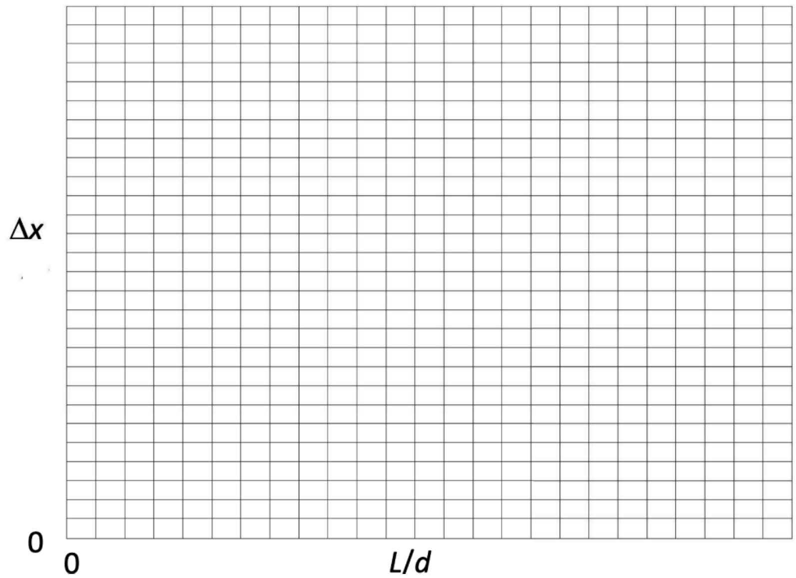
• Include an appropriate scale and numbers on the x-axis.

• Include uncertainty bars in the y-direction of $\pm\ 0.5\ \mathrm{mm}$.

(No uncertainty bars are required in the x-direction.)

• Draw a linear trend line through the plotted points.

(6 marks)



d. Calculate the gradient of the trend line. Show all the steps of your working.

(2 marks)

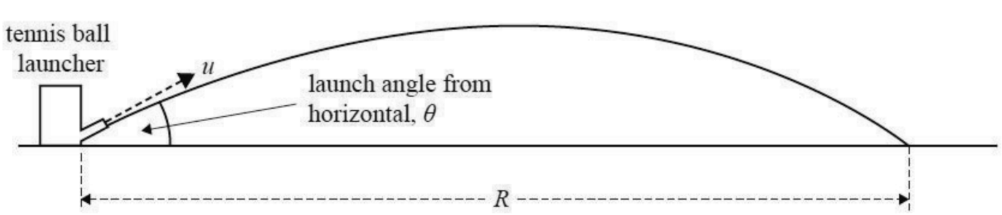
e. Use the gradient from part **d** to determine the wavelength of the laser light. Give all the steps of your reasoning.

(2 marks)

Question 18/ 45

[VCAA 2022 SB Q10]

Physics students use a tennis ball launcher on a level, outdoor oval on a windless day to investigate projectile motion as shown below. Assume that the tennis balls are launched from ground level.



The tennis ball launcher can be set to project tennis balls at various speeds, u, between values of $8 \mathrm{~m~s}^{-1}$ and $30 \mathrm{~m~s}^{-1}$ and at angles, θ, between 10° and 80°. Standard tennis balls of mass 56 g are used.

The students measure the range, *R*, of the projected tennis ball at a fixed speed for various angles.

a. Classify the controlled, dependent or independent variables in this experiment.

(3 marks)

b. The students set the tennis ball launcher to project tennis balls at a speed of $25 \mathrm{~m~s}^{-1}$. They vary the angle between 10° and 80° and measure the range, *R*.

The students repeat each experiment at each angle three times and determine the average range. The results are shown in the table below.

Angle (°)	10	20	30	40	50	60	70	80
Average range (m)	17	30	37	40	40	36	29	15

The students determine that the uncertainty in the measurement of the range is $\pm 1 \mathrm{~m}$.

On the grid provided on the next page:

• plot the data

• add a scale to each axis

• insert appropriate uncertainty bars for the range for at least three data points

• draw a smooth curve of best fit.

(6 marks)

Missing Image

c. From the graph in part **b**, estimate the maximum range and the angle that gives the maximum range.

(2 marks)

d. The students think that air resistance on the tennis ball may affect the maximum range. They decide to compare their data to the theoretical range achieved when air resistance is ignored.

i. Using the range formula, calculate the theoretical range of a projectile launched at an initial speed of $25 \mathrm{~m~s}^{-1}$ and at an angle of 30°. Use $g = 9.8 \mathrm{~m~s}^{-2}$.

(2 marks)

ii. Evaluate whether the effect of air resistance can be ignored by the students when analysing their data. Justify your answer.

(3 marks)

Question 19/ 45

[VCAA NHT 2023 SB Q13]

As part of their practical investigations, two Physics students, Chris and Arya, investigate changes in gravitational potential energy and elastic potential energy for a 2.0 kg mass initially hanging on a spring, as shown on the next page.

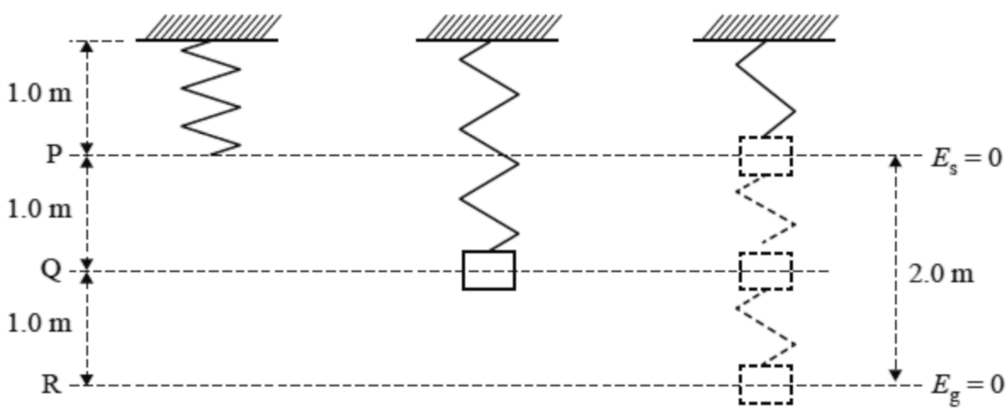
The spring has an unstretched length of 1.0 m, as shown at position P below.

The 2.0 kg mass is placed by Arya on the unstretched spring and it hangs stationary at position Q below.

Their Physics teacher tells them that they can use $g = 10 \text{ m s}^{-2}$ for their calculations.

a. Show that the spring constant of the spring, *k*, is 20 N m^{-1}.

(1 mark)



Chris then pulls the mass down a further 1.0 m below position Q, to position R, and releases it so that it oscillates between positions R and P, as shown below.

The students decide that the gravitational potential energy, E_g, is zero at position R, and that they can use the formula for gravitational potential energy, $E_g = mg\Delta h$, where Δh is the height above position R.

The students also decide that the elastic potential energy is zero at the top position P, and that they can use the elastic potential energy formula $E_s = \frac{1}{2}k(\Delta x)^2$, where Δx is the extension of the spring beyond its unstretched length.

Arya enters the following information into a table.

Position	h(m)	E_g(J)	Δx (m)	E_s (J)
P	2.0	40.0	0	0
	1.5	30.0	0.5	2.5
Q	1.0		1.0	10.0
	0.5	10.0	1.5	
R	0	0	2.0	40.0

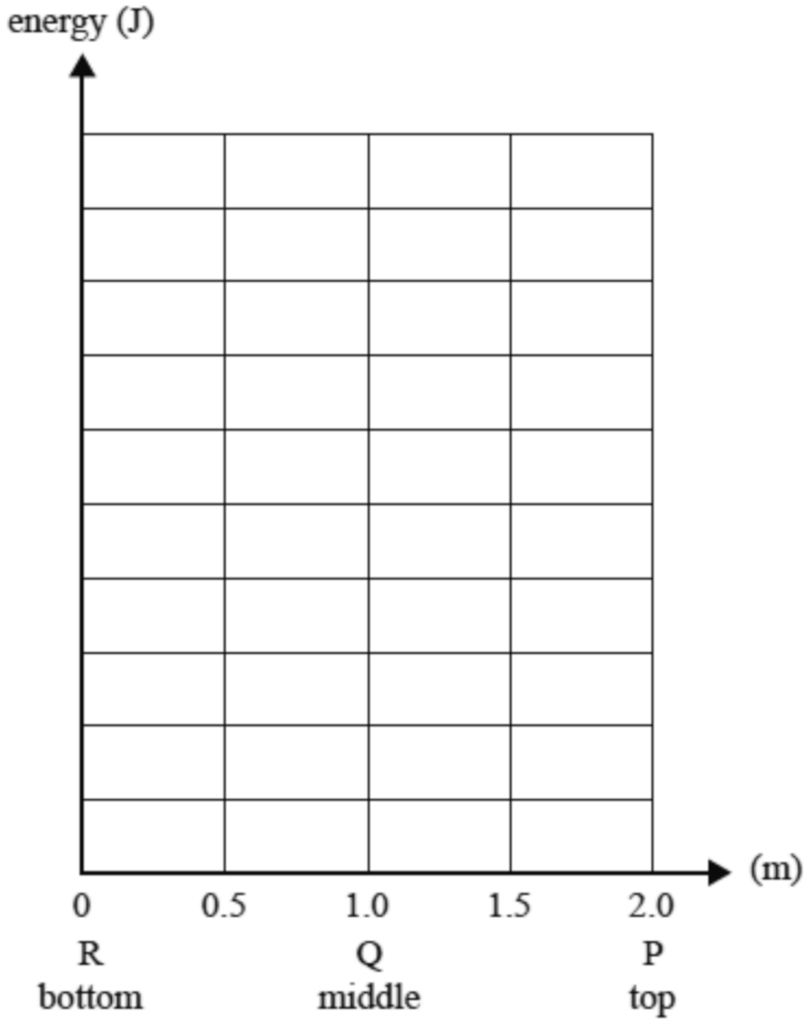
b. Using the formulas for E_g and E_s, verify that Arya's $E_s = 10$ J at position Q is correct and fill in the missing data points in the table. Show your working for each calculation.

(3 marks)

c. On the axes below, plot the E_g and E_s versus position data for the oscillating mass. On your graph:

- choose an appropriate scale and numbers for the *y*-axis
- use small circles for the E_g data and small triangles for the E_s data
- draw a line/curve of best fit through the plotted points for the E_g data
- draw a line/curve of best fit through the plotted points for the E_s data.

(4 marks)



d. Determine the speed of the mass as it goes through position Q.

(3 marks)

e. Arya and Chris discuss the graphs that they have drawn. Chris says that their calculation must be wrong because the graphs should add up to a constant amount – the total energy of the system. However, Arya says that the graphs are correct.

Explain why Chris is incorrect.

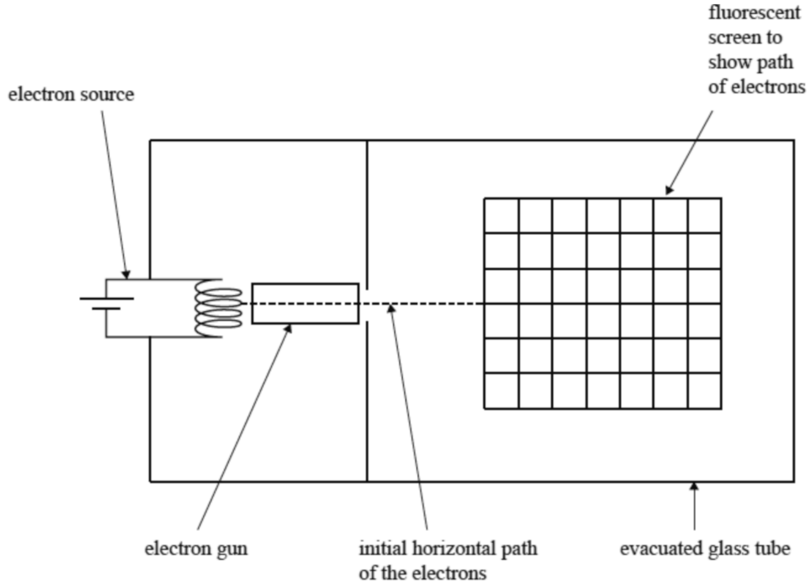
(3 marks)

Question 20/ 45

[VCAA 2023 SB Q17]

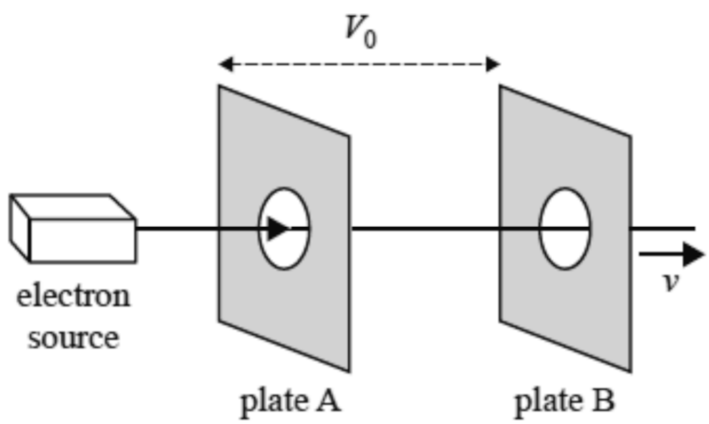
JJ Thomson discovered electrons in 1897. He used evacuated cathode ray tubes to determine the ratio of electric charge to mass of these rays, which we now know were electrons.

Modern-day physics students plan an experiment to measure the ratio of the charge, *e*, to the mass, *m*, of electrons. This can be written as *e/m*. The apparatus they use is shown schematically below.



An electron gun ejects a beam of electrons horizontally from the left side of the apparatus through the evacuated glass tube. A fluorescent screen displays the path the electrons take.

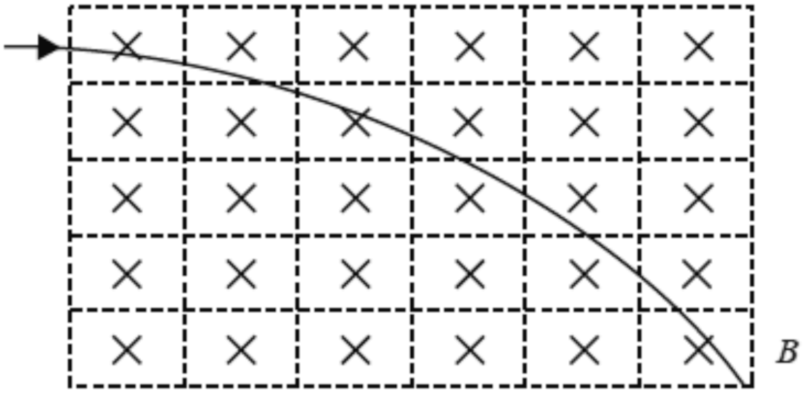
The electron gun can be modelled as shown below. Electrons are produced at the electron source and accelerated between plate A and plate B.



Electrons reach plate A with negligible speed and are accelerated by the potential difference between the plates, V_0, emerging from plate B with speed, *v*.

a. Write an equation that gives the speed, *v*, in terms of potential difference, V_0, the electron mass, *m*, and the electron charge, *e*. Assume that *v* is much less than the speed of light, *c*. (1 mark)

b. A uniform magnetic field, *B*, directed into the page, is applied to the region of the fluorescent screen and the electrons follow a circular arc of radius, *r*, as shown below.



Explain why the path followed by the electrons is a circular arc. (2 marks)

c. Write an equation that represents the relationship between the electron mass, *m*, the electron charge, *e*, the electron speed, *v*, the magnetic field, *B*, and the radius, *r*, of the circular arc. (1 mark)

The equations in **part a**. and **part c**. can be combined to show that

$$V_0 = \frac{eB^2}{2m} r^2$$

(Do not attempt to derive this equation.)

The physics students planning the experiment keep the uniform magnetic field, *B*, constant at 2.0 mT. They vary the voltage, V_0, and measure the resulting radius, *r*, of the circular path of the electrons.

d. Identify the independent variable, the dependent variable and one controlled variable.

(2 marks)

e. The table on the next page shows the values of V_0 and *r* measured by the students. Complete the missing values. (2 marks)

V_0 **(volts)**	*r***(m)**	$r^2(\mathrm{m}^2)$
500	0.036	0.0013
1000	0.052	
1500	0.059	
2000	0.072	

f. On the grid below:

• Plot the values of V_0 on the y-axis and the corresponding value of r^2 on the x-axis. Include a point for $V_0 = 0$.

• Label the axes correctly.

• Add an uncertainty of $+/-\ 0.0002$ to the r^2 values.

• Draw a straight line of best fit through the plotted points.

(7 marks)

g. Using the graph produced in **part f.**, calculate the gradient of the line of best fit. Show your working.

(2 marks)

h. Use the value of the gradient found in **part g.** to find a value for *e/m*. Show your working.

(3 marks)

Solutions

Chapter 1 Motion basics

Question 1/ 11

Which one of the following is closest to the final speed and distance travelled of a ball dropped from a height on the surface of Mars and falls for 3.5 s?

(g on $\text{Mars} = 3.7\ \text{m s}^{-2}$)

A $\text{Final speed} = 35\ \text{m s}^{-1};\ \text{distance} = 61\ \text{m}$

B $\text{Final speed} = 35\ \text{m s}^{-1};\ \text{distance} = 123\ \text{m}$

C $\text{Final speed} = 13\ \text{m s}^{-1};\ \text{distance} = 46\ \text{m}$

D $\text{Final speed} = 13\ \text{m s}^{-1};\ \text{distance} = 23\ \text{m}$

Solution

D Use $v = u + at$ and $x = ut + \frac{1}{2}at^2$.

Question 2/ 11

$25\ \text{km h}^{-1}$ is closest to which one of the following?

A $6.9\ \text{m s}^{-1}$

B $69\ \text{m s}^{-1}$

C $90\ \text{m s}^{-1}$

D $250\ \text{m s}^{-1}$

Solution

A Divide by 3.6.

Question 3/ 11

A car accelerates at 2.0 m s^{-2} for 5.0 s, and at the end of this time is moving at 30 m s^{-1}. Which one of the following is closest to the distance covered in this time?

A 20 m

B 125 m

C 150 m

D 175 m

Solution

B Use $x = vt - \frac{1}{2}at^2$.

Question 4/ 11

Which one of the following is the closest to the speed of the car at the start of the 5.0 s period?

A 5 m s^{-1}

B 10 m s^{-1}

C 15 m s^{-1}

D 20 m s^{-1}

Solution

D Use $v = u + at$.

Question 6/ 11

Which of the following best describes the minimum speed of the ball during its flight and the time it occurs?

A $\text{Minimum speed} = 0\ \text{m s}^{-1}$ at $t = 2.6$ s

B $\text{Minimum speed} = 0\ \text{m s}^{-1}$ at $t = 4.9$ s

C $\text{Minimum speed} = 10\ \text{m s}^{-1}$ at $t = 2.6$ s

D $\text{Minimum speed} = 10\ \text{m s}^{-1}$ at $t = 4.9$ s

Solution

A It stops after 2.5 s ($g = -10$).

Question 7/ 11

Which of the following best describes the distance and displacement of the ball during its flight?

A $\text{Distance} = 0\ \text{m}$ and $\text{displacement} = 0\ \text{m}$

B $\text{Distance} = 31\ \text{m}$ and $\text{displacement} = 32\ \text{m}$

C $\text{Distance} = 64\ \text{m}$ and $\text{displacement} = 32\ \text{m}$

D $\text{Distance} = 64\ \text{m}$ and $\text{displacement} = 0\ \text{m}$

Solution

D From displacement definition and twice the height it rises (use $v^2 = u^2 + 2as$).

Question 8/ 11

Which one of the following best describes the acceleration of the ball during its flight?

A The acceleration direction reverses halfway through the flight.

B The acceleration direction is constant throughout the flight.

C The acceleration magnitude decreases during the flight.

D The acceleration magnitude increases during the flight.

Solution

B Gravity always points downwards.

Question 10/ 11

Which one of the following best describes the motion of the object at $t = 5$ s?

A $\text{Speed} = 15 \text{ m s}^{-1}$; acceleration increasing; $\text{distance travelled} = 150 \text{ m}$

B $\text{Speed} = 15 \text{ m s}^{-1}$; acceleration constant; $\text{distance travelled} = 38 \text{ m}$

C $\text{Speed} = 10\ \text{m s}^{-1}$; acceleration constant; $\text{distance travelled} = 38\ \text{m}$

D $\text{Speed} = 15\ \text{m s}^{-1}$; acceleration constant; $\text{distance travelled} = 75\ \text{m}$

Solution

B Speed from graph; acceleration from gradient.

Question 12/ 11

Which one of the following best describes this motion?

A Constant speed followed by no motion

B Increasing speed followed by constant speed

C Increasing acceleration followed by constant acceleration

D Increasing distance followed by constant speed

Solution

A Gradient of distance–time graph gives speed.

Question 13/ 11

Two trains travel along the same track at $40\ \text{m s}^{-1}$ towards each other. At a separation of 1 km, they start to brake, each with a constant deceleration of $1.7\ \text{m s}^{-2}$. Which one of the following describes what happens?

A The two trains collide.

B The two trains stop with less than 1 m between them.

C The two trains stop with about 30 m between them.

D The two trains stop with about 60 m between them.

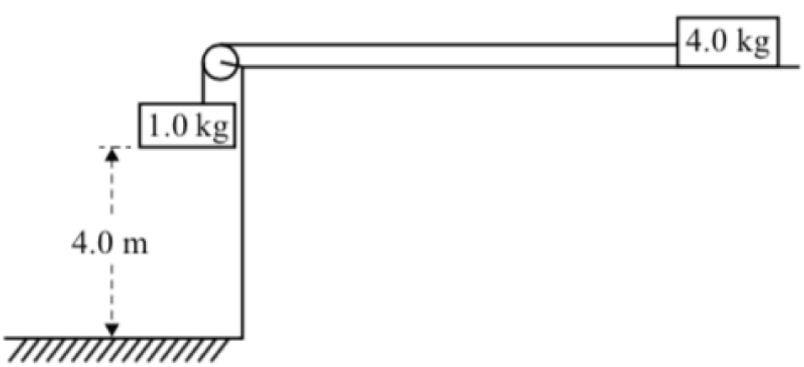
Solution

D Use $v^2 = u^2 + 2ax$; set $v = 0$ to find the stopping distance of each train; subtract the sum from 1000 m.

Question 14/ 11

[Adapted VCAA 2018 NHT SA Q8]

A 1.0 kg mass attached to a string hangs 4.0 m from the ground. The string is massless. The string is connected to a 4.0 kg mass on a horizontal frictionless table. The masses are released from rest and accelerate at 1.96 m s^{-2}.



Which one of the following best gives the speed of the 4.0 kg mass when the 1.0 kg mass strikes the ground after falling 4.0 m?

A 2.0 m s^{-1}

B 4.0 m s^{-1}

C 8.0 m s^{-1}

D 16 m s^{-1}

Solution

B Use $v^2 = u^2 + 2ax$ with $u = 0$.

Question 1/ 22

A speeding motorbike travels past a stationary police car at a speed of 35 m s^{-1}. The police car starts accelerating immediately at 4.0 m s^{-2}, and it keeps accelerating at this rate until it has passed the bike.

a. At what time does the police car overtake the motorbike?

(2 marks)

b. How far does the police car travel before it overtakes the motorbike?

(2 marks)

Solution

a 18 (17.5) s Use $s_{\text{bike}} = 35t = 0.5at^2$ and solve for *t*.

b 613 m Use $s = 35t$.

Question 2/ 22

A golf ball rolls across a smooth grass ‘green’ towards a hole. It is heading straight for the hole. The hole is 24 m distant from the ball, as shown below.

The aim is to make the ball fall in the hole. If it is travelling faster than $2\ \mathrm{m\ s^{-1}}$ when it reaches the hole, it will not fall in. If the ball is slowing down at $0.7\ \mathrm{m\ s^{-2}}$, will it fall in the hole?

(3 marks)

Solution

Falls in Final speed is $1.55\ \mathrm{m\ s^{-1}}$; from $v^2 = u^2 + 2ax$.

Question 3/ 22

A baseball player slides across the ground towards third base. There is considerable friction; he slows down quickly. He slides a distance of 4 m and then stops. Before the slide, he was moving at $9\ \mathrm{m\ s^{-1}}$.

a. What was his average deceleration during the slide?

(2 marks)

b. How long (in time) did the slide last?

(2 marks)

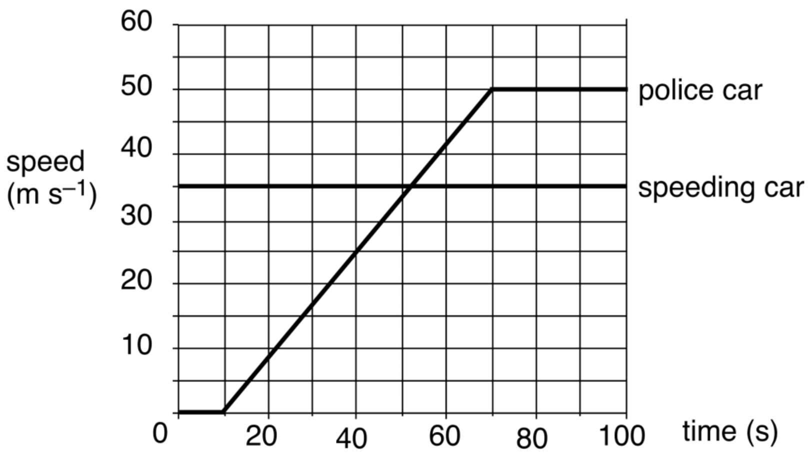
Solution

a $(-)\,10\ \mathrm{m\ s^{-2}}$ Use $v^2 = u^2 + 2as$.

b 0.89 s Use $s = \frac{1}{2}(u+v)\,t$.

Question 4/ 22

The graph shows the speed of two cars. The local speed limit is 90 km h^{-1}.



a. By how much is the speeding car exceeding the speed limit?

(2 marks)

b. The police car gives chase to the speeding car 10 s after it passes. What is the acceleration of the police car at time $t = 45 \text{ s}$ s on the graph?

(2 marks)

c. Using the graph, calculate whether the police car has passed the speeding car by the time of 100 s.

(4 marks)

Solution

a 36 km h^{-1} Convert 35 m s^{-1} to km h^{-1} and subtract 90.

b 0.83 m s^{-2} Gradient of graph.

c No $\text{Area under car graph} = 3000 \text{ m}$; $\text{police car area} = 3500 \text{ m}$.

Question 5/ 22

A cyclist accelerates constantly from rest for 10 s at 2.5 m s^{-2}. In the next 20 s she rides at constant speed, and then slows to rest in the next 5 s, at a uniform rate.

a. Sketch a graph of her speed against time.

(3 marks)

b. What is the magnitude of her braking deceleration?

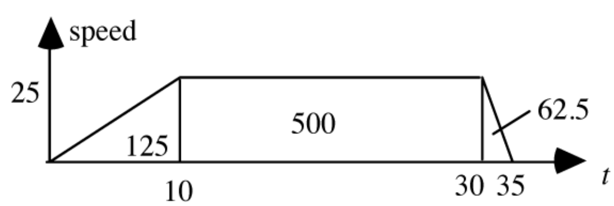
(2 marks)

c. What distance does she cover in the total time interval of 35 s?

(2 marks)

Solution

a

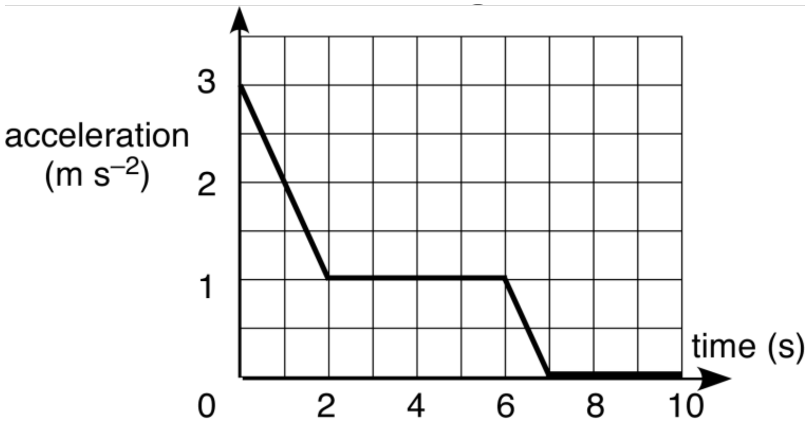


b 5 m s^{-2}. She loses 25 m s^{-1} in 5 s. (-5 m s^{-2} is also OK.)

c 690 m Area under graph.

Question 6/ 22

The graph models the motion of a runner during a race. She starts from rest.



a. Calculate the speed of the runner at time $t = 2$ s.

(2 marks)

b. During which time interval is the runner travelling at constant speed?

(2 marks)

c. Calculate the speed of the runner at time $t = 10$ s.

(2 marks)

Solution

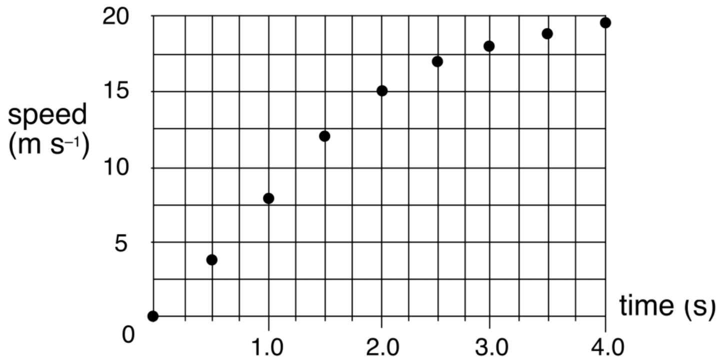
a 4.0 m s^{-1} Area under acceleration graph from $t = 0$ to 2 s.

b 7 s onwards Acceleration is zero at constant speed.

c 8.5 m s^{-1} Total area under graph.

Question 7/ 22

Cyril's new car accelerates away from rest. Its speed-time graph is shown.



a. Estimate when he first breaks the suburban speed limit of $60 \mathrm{~km} \mathrm{~h}^{-1}$.

(2 marks)

b. Estimate the distance travelled in the first 4.0 s.

(2 marks)

c. What was the car's *initial* acceleration?

(2 marks)

Solution

a 2.4 ± 0.2 s Read from graph.

b $51 \pm 2 \mathrm{~m}$ Count squares and convert.

c $8 \pm 0.5 \mathrm{~m} \mathrm{~s}^{-2}$ Initial gradient.

Question 8/ 22

At a dragster race, the winner finishes at $40 \mathrm{~m} \mathrm{~s}^{-1}$. She was accelerating at $10 \mathrm{~m} \mathrm{~s}^{-2}$ for the last second. How much distance did the dragster cover in this last second?

(2 marks)

Solution

35 m Use $s = vt - \frac{1}{2}at^2$ (with $v = 40; t = 1, a = 10$).

Question 9/ 22

During a golf shot, the ball rolls across a flat green, gradually slowing down on account of rolling friction. Ashley strikes the ball 32 m from the hole. The ball just reaches the hole. The rolling friction decelerates the ball at 1 m s^{-2}. What speed did Ashley give the ball at the start of the shot?

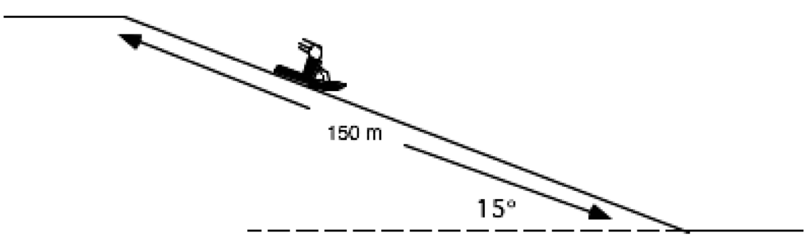
(2 marks)

Solution

8.0 m s^{-1} Use $v^2 = u^2 + 2as$.

Question 10/ 22

Oscarina slides down a snow slope on a toboggan. The total mass of Oscarina and the toboggan is 40 kg. The slope makes an angle of 15° to the horizontal.



The toboggan starts from rest and takes 17 s to reach the bottom of the slope. Calculate the acceleration of the toboggan from these numbers.

(2 marks)

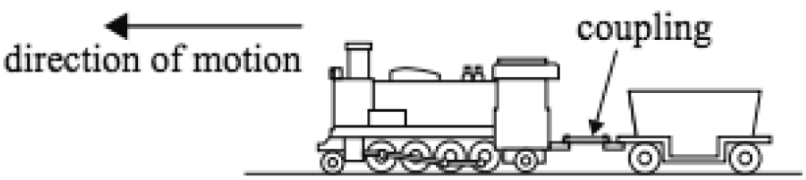
Solution

$1.0(4)\ \mathrm{m\ s^{-2}}$ Use $s = ut + \frac{1}{2}at^2$, with $u = 0$, $s = 150$ and $t = 17$.

Question 11/ 22

[Adapted VCAA 2016 SA Q1]

A train consists of an engine of mass 20 tonnes (20 000 kg) towing one wagon of mass 10 tonnes (10 000 kg), as shown in the diagram.



The train accelerates from rest with a constant acceleration of $0.10\ \mathrm{m\ s^{-2}}$. Calculate the speed of the train after it has moved 20 m.

(2 marks)

Solution

$2.0\ \mathrm{m\ s^{-1}}$ Use $v^2 = u^2 + 2as$.

Chapter 2 Forces

Question 2/ 22

Which diagram best describes a cricket ball moving with very little air resistance?

Solution

B (no air resistance).

Question 3/ 22

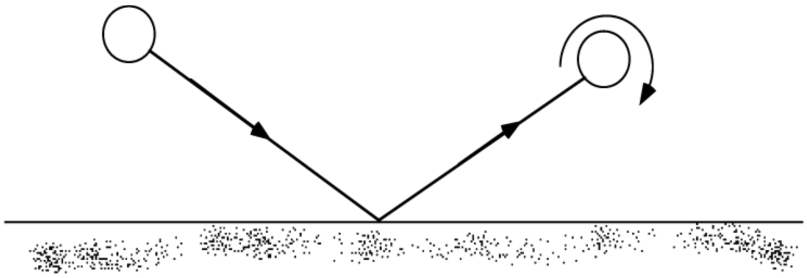
Which diagram best describes a cricket ball moving with substantial air resistance?

Solution

C (air resistance).

Question 4/ 22

The tennis ball shown is striking the ground. Before it strikes the ground, it is not spinning, but afterwards it is.



Which is the best reason why the ball is spinning after hitting the ground?

A The friction exerts a force on the ball towards the right.

B The normal reaction exerts a force on the ball towards the right.

C The friction exerts a force on the ball towards the left.

D The normal reaction exerts a force on the ball towards the left.

Solution

C On impact; friction causes point of contact to slow; ball still moving right; results in a torque on the ball causing spin.

Question 5/ 22

The wheel of a car is shown in the diagrams. The wheel is connected to the car's engine through an axle. The arrows indicate the main forces acting on the wheel from the road. 'N' stands for normal reaction, 'Fr' stands for friction. (The rolling friction is negligible.) The car is moving to the right.

Which of the following is correct? Give a reason for your answer.

A **A** shows the car accelerating. **B** shows the car braking.

B **A** shows the car braking. **B** shows the car accelerating.

C **A** shows the car accelerating hard. **B** shows the car accelerating.

D **A** shows the car braking hard. **B** shows the car braking gently.

Solution

A Friction provides both accelerating and decelerating forces, hence friction forwards when car accelerates, and backwards when car brakes.

Question 6/ 22

John and Betty are riding in a ‘dodgem’ car at a fair. A car behind them bumps into them. (They are not injured.) Which *one or more* of the following best describes what they feel at the start of the collision? Give your reasons.

A John and Betty felt the seatbelts pushing them more strongly.

B John and Betty felt the seatbelts pushing them less strongly.

C John and Betty felt the seats pushing them more strongly.

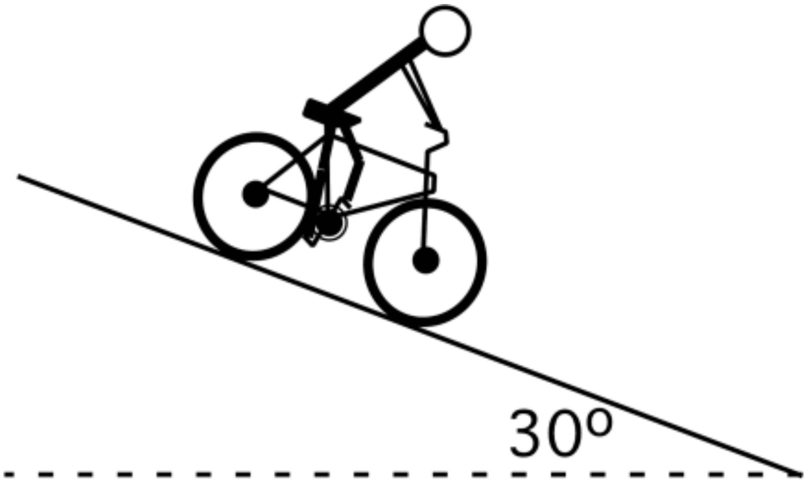
D John and Betty felt the seats pushing them less strongly.

Solution

C Car behind will transfer momentum to them, hence increasing their speed; they will accelerate forwards. Hence, *seat* must exert greater forward force on them to cause this acceleration.

Question 7/ 22

Theo is riding down a hill on his bike. It is a steep hill, and he has the brakes of the bike on so that he does not accelerate.



Theo suddenly removes the brakes and accelerates downhill. Which of the following gives the best estimate of his initial acceleration?

A 100% of *g*

B 75% of *g*

C 50% of *g*

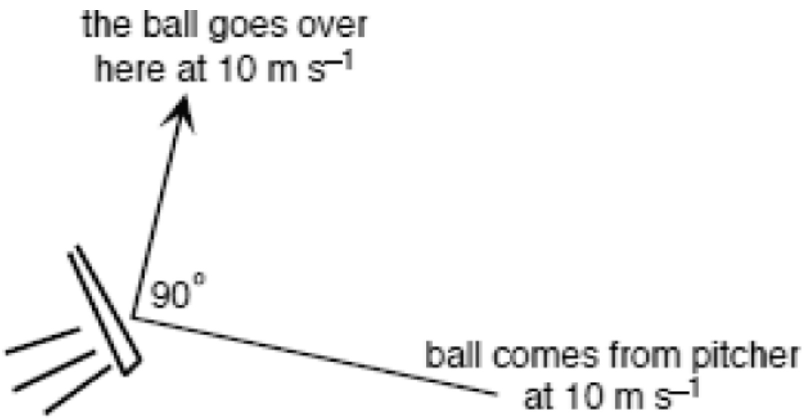
D 25% of *g*

Solution

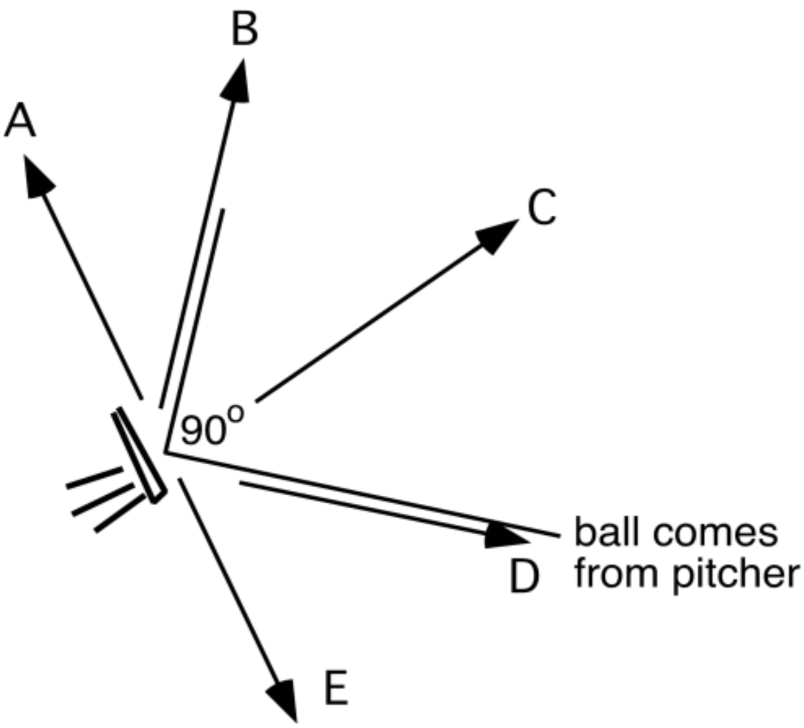
C   Net force is $mg\sin 30°$; acceleration is hence $g\sin 30°$.

Question 8/ 22

A player swings hard at a baseball and sends it a long way. This is a picture of what happened, as seen by a passing bird high overhead.



Which one of the arrows in the diagram best describes the direction of the change in the velocity of the ball?



Solution

C Use a vector diagram to construct $v_{\text{FINAL}} - v_{\text{INITIAL}}$.

A ball falls vertically from few metres and bounces up. The ‘bounce time’ is small. Select the best statement about forces on the ball during the bounce.

A During the bounce, the weight of the ball is equal to the normal reaction from the ground.

B During the bounce, the weight of the ball is larger than the normal reaction from the ground.

C During the bounce, the weight of the ball is less than the normal reaction from the ground.

D During the bounce, the normal reaction from the ground increases with the length of the bounce time, but is always less than the ball’s weight.

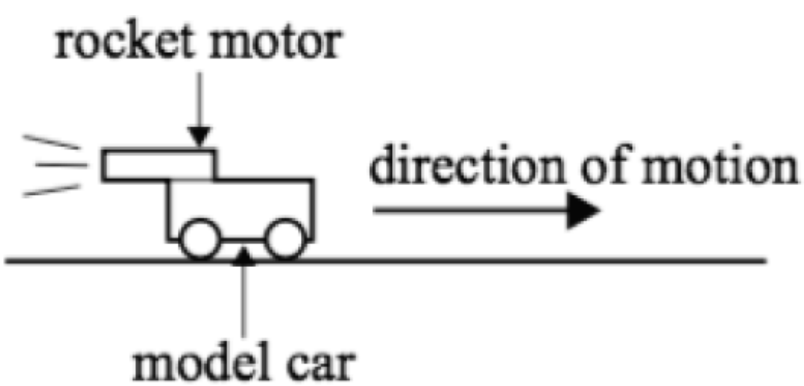
Solution

C Ball is accelerating upwards during bounce; normal reaction force must be greater than weight.

Question 10/ 22

[VCAA 2017 SA Q7]

A model car of mass 2.0 kg is propelled from rest by a rocket motor that applies a constant horizontal force of 4.0 N, as shown below. Assume that friction is negligible. Which one of the following best gives the magnitude of the acceleration of the model car?



A 0.50 m s^{-2}

B 1.0 m s^{-2}

C 2.0 m s^{-2}

D 4.0 m s^{-2}

Solution

C Use $F = ma$.

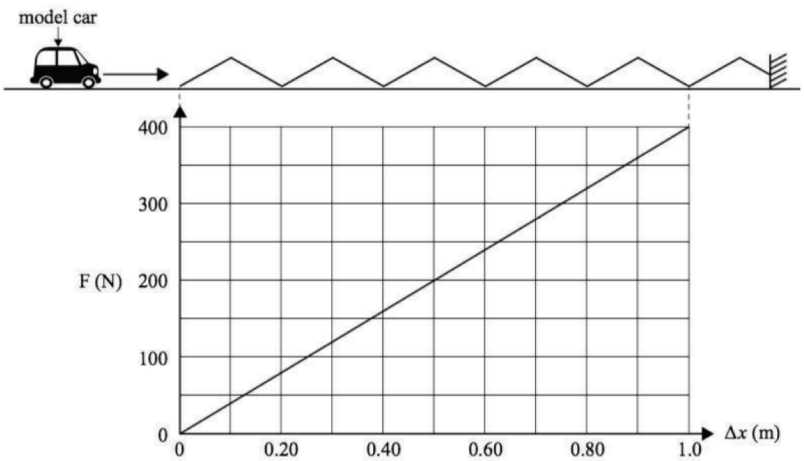
Question 11/ 22

[VCAA 2017 SA Q12]

A model car is on a track and moving to the right. It collides with and compresses a spring that is considered ideal, as shown in the diagram below.

The car compresses the spring to 0.50 m when the car comes to rest. The force-distance graph for the spring is also shown below.

Assume that friction is negligible.



Based on the graph above, what is the best estimate of the spring constant, *k*?

A 100 N m^{-1}

B 200 N m^{-1}

C 400 N m^{-1}

D $800\ \mathrm{N\ m^{-1}}$

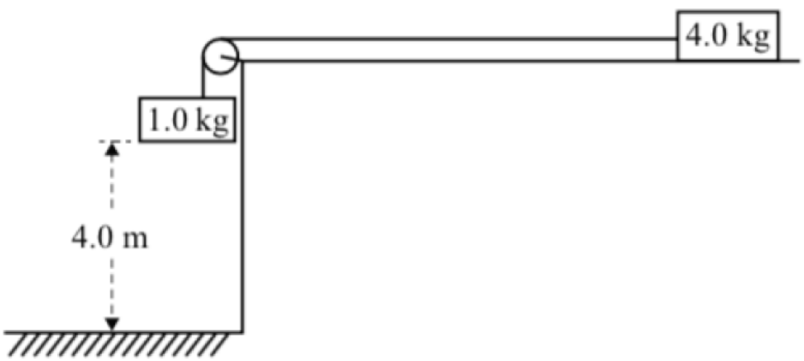
Solution

C $k =$ gradient of graph.

Question 12/ 22

[Adapted VCAA 2018 NHT SA Q8]

A 1.0 kg mass attached to a string hangs 4.0 m from the ground. The string is massless. The string is connected to a 4.0 kg mass on a horizontal frictionless table. The masses are released from rest and accelerate at $1.96\ \mathrm{m\ s^{-2}}$.



The tension in the string is closest to

A 19.6 N

B 15.6 N

C 9.8 N

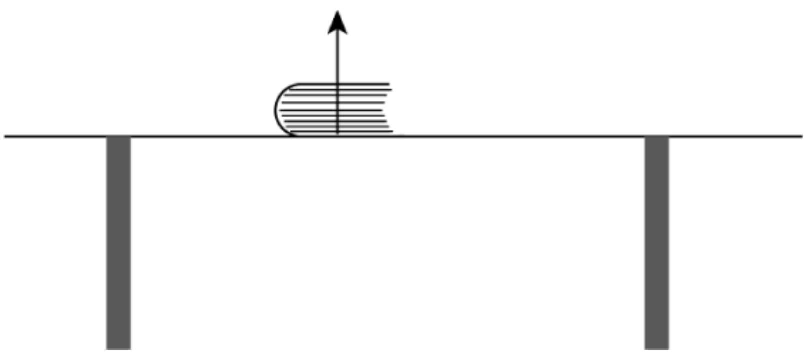
D 7.8 N

Solution

D Apply $F = ma$ to the 4.0 kg mass; $F(\text{tension}) = ma$.

Question 13/ 22

A book rests on a table. A normal reaction force from the table pushes vertically upward on the book.



The action-reaction force pair to this force (according to Newton's third law) is

A the force of gravity acting downwards on the book.

B a normal reaction force on the table from the book.

C a $F = mg$ force acting on the book.

D a compression force on the book pushing the pages together.

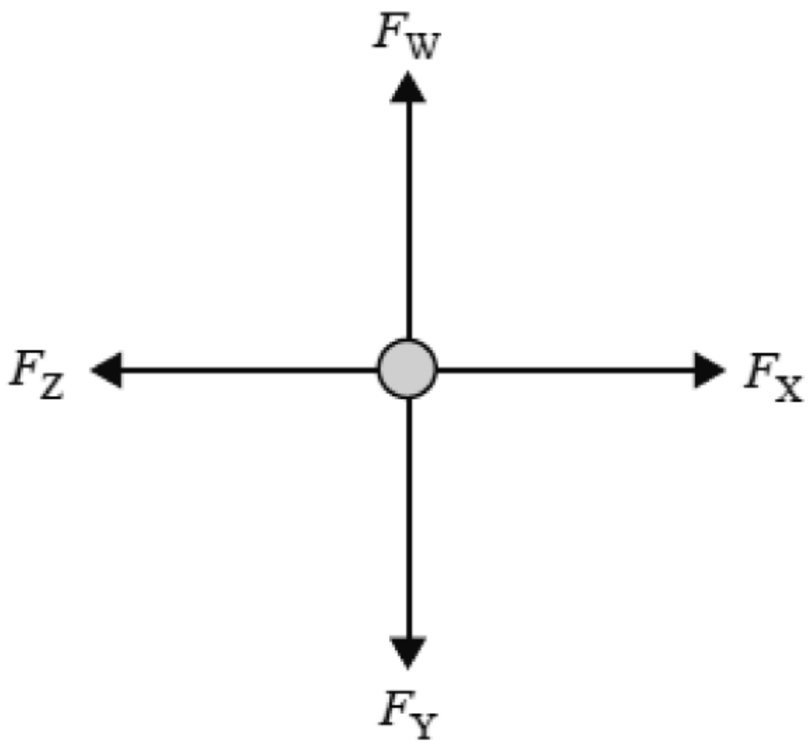
Solution

B From definition of action–reaction pairs.

Question 14/ 22

[VCAA 2018 SA Q5]

Four students are pulling on ropes in a four-person tug of war. The relative sizes of the forces acting on the various ropes are $F_\mathrm{W} = 200\ \mathrm{N}$, $F_\mathrm{X} = 240\ \mathrm{N}$, $F_\mathrm{Y} = 180\ \mathrm{N}$ and $F_\mathrm{Z} = 210\ \mathrm{N}$. The situation is shown in the diagram below.



Which one of the following **best** gives the magnitude of the resultant force acting at the centre of the tug-of-war ropes?

A 28.3 N

B 30.0 N

C 36.1 N

D 50.0 N

Solution

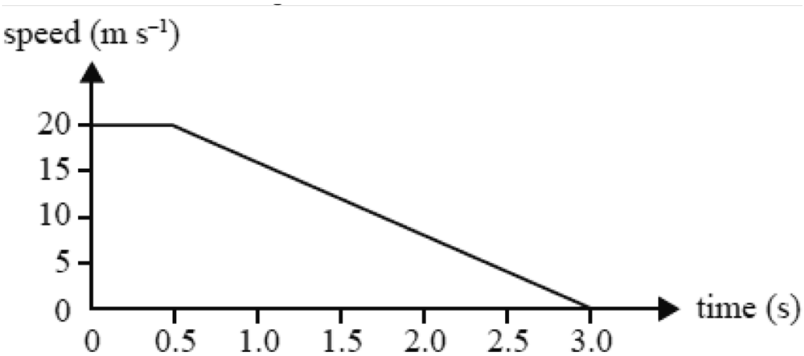
C Net *x*-component is 30 N; net *y*-component is 20 N; add as vectors.

Question 15/ 22

[VCAA 2018 SA Q6]

Lisa is driving a car of mass 1000 kg at $20 \mathrm{~m~s^{-1}}$ when she sees a dog in the middle of the road ahead of her. She takes 0.50 s to react and then brakes to a stop with a constant braking force. Her speed is shown in the graph below.

Lisa stops before she hits the dog.



Which one of the following is closest to the magnitude of the braking force acting on Lisa's car during her braking time?

A 6.7 N

B 6.7 kN

C 8.0 kN

D 20.0 kN

Solution

C Find acceleration from gradient $\left(= 8.0 \mathrm{~m~s^{-2}}\right)$; then use $F = ma$.

Question 16/ 22

[VCAA 2019 SA Q11]

An ultralight aeroplane of mass 500 kg flies in a horizontal straight line at a constant speed of 100 m s^{-1}. The horizontal resistance force acting on the aeroplane is 1500 N. Which one of the following best describes the magnitude of the forward horizontal thrust on the aeroplane?

A 1500 N

B slightly less than 1500 N

C slightly more than 1500 N

D 5000 N

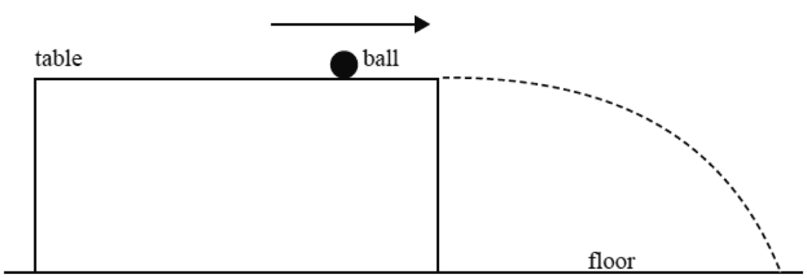
Solution

A Acceleration = 0 therefore net force also = 0.

Question 17/ 22

[VCAA 2019 SA Q12]

A small ball is rolling at constant speed along a horizontal table. It rolls off the edge of the table and follows the parabolic path shown in the diagram below. Ignore air resistance.



Which one of the following statements about the motion of the ball as it falls is correct?

A The ball's speed increases at a constant rate.

B The momentum of the ball is conserved.

C The acceleration of the ball is constant.

D The ball travels at constant speed.

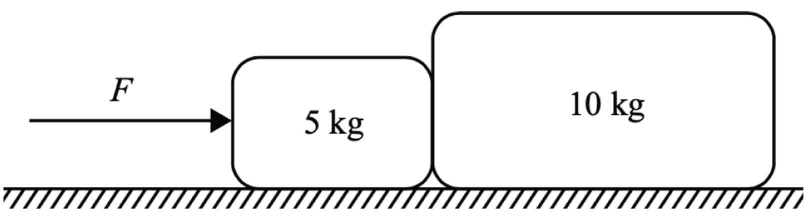
Solution

C The net force (mg) is constant hence so is the acceleration.

Question 18/ 22

[VCAA 2020 SA Q9]

Two blocks of mass 5 kg and 10 kg are placed in contact on a frictionless horizontal surface, as shown in the diagram below. A constant horizontal force, F, is applied to the 5 kg block.



Which one of the following statements is correct?

A The net force on each block is the same.

B The acceleration experienced by the 5 kg block is twice the acceleration experienced by the 10 kg block.

C The magnitude of the net force on the 5 kg block is half the magnitude of the net force on the 10 kg block.

D The magnitude of the net force on the 5 kg block is twice the magnitude of the net force on the 10 kg block.

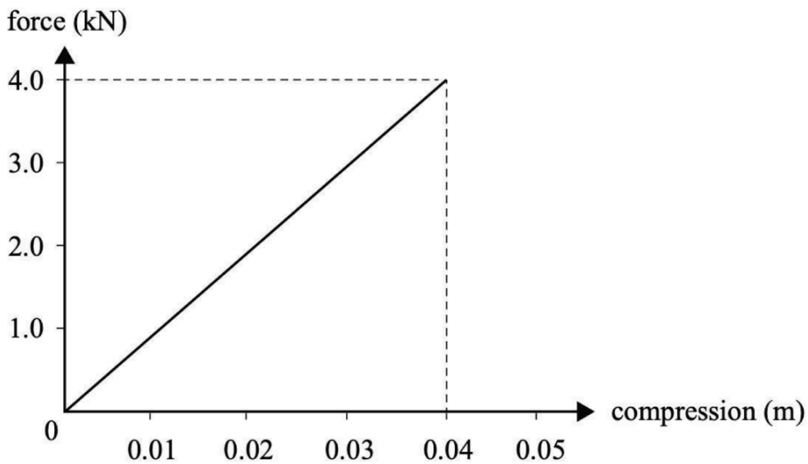
Solution

C Acceleration of both blocks is the same; apply $F_{\text{NET}} = ma$.

Question 19/ 22

[VCAA 2021 SA Q11]

A force versus compression graph for a suspension spring is shown below.



Which one of the following is closest to the spring constant of the spring?

A 0.16 N m^{-1}

B $1.0 \times 10^2 \text{ N m}^{-1}$

C $1.6 \times 10^2 \text{ N m}^{-1}$

D $1.0 \times 10^5 \text{ N m}^{-1}$

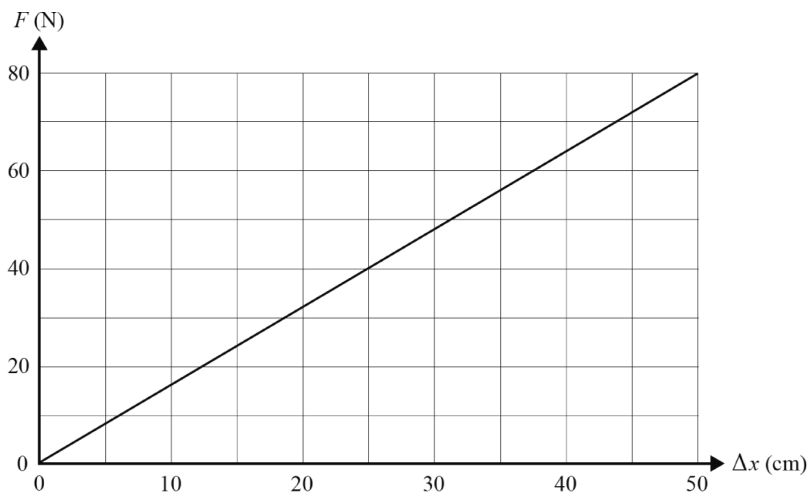
Solution

D The spring constant is equal to the gradient of the graph.

Question 20/ 22

[VCAA 2022 NHT SA Q8]

Maya is given a light spring with an unstretched length of 20 cm. The force versus extension graph for the spring is shown below. Maya hangs the spring vertically and attaches a mass to it so that the new length of the spring is 30 cm.



The spring constant, *k*, of Maya's spring is closest to

A $1.6\ \mathrm{N\ m^{-1}}$

B $40\ \mathrm{N\ m^{-1}}$

C $160\ \mathrm{N\ m^{-1}}$

D $4000\ \mathrm{N\ m^{-1}}$

Solution

C The gradient of the graph (convert cm to m)

Question 21/ 22

[VCAA 2022 NHT SA Q9]

Assuming that the spring has no mass, the value of the mass Maya attached to it is closest to

A 1.6 kg

B 4.9 kg

C 6.6 kg

D 8.2 kg

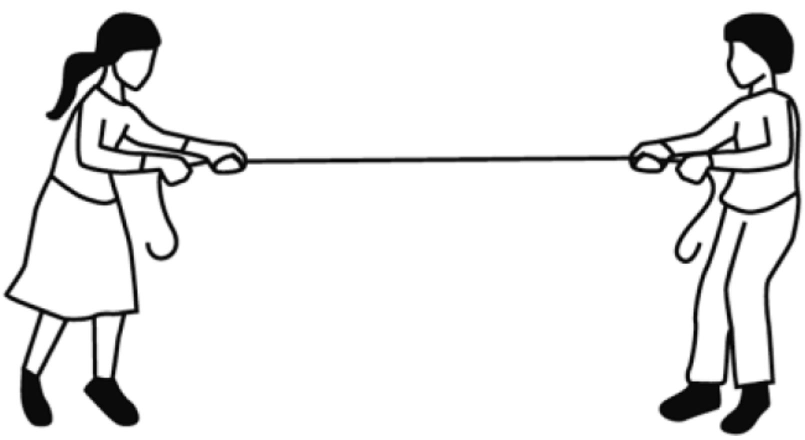
Solution

A In equilibrium, $\text{net force} = 0$. Hence $mg = kx$; make *m* the subject, so $m = kx/g = 160 \times 0.1/9.8 = 1.63$ kg.

Question 22/ 22

[VCAA 2022 SA Q9]

Two students pull on opposite ends of a rope, as shown in the diagram below. Each student pulls with a force of 400 N. Which one of the following is closest to the magnitude of the force of the rope on each student?



A 0 N

B 400 N

C 600 N

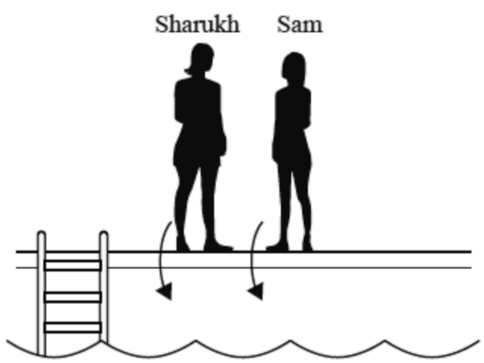
D 800 N

Solution

B Apply Newton's third law.

Question 23/ 22

At a swimming pool, Sharukh and Sam, shown below, step off the low diving board at the same time. Over the small distance they fall, air resistance may be ignored. Sharukh and Sam have masses of 80 kg and 60 kg respectively.



Which one of the following best explains what happens to Sharukh and Sam as they drop straight down into the water?

A Sharukh reaches the surface first because she has a larger mass.

B The net force on Sharukh is larger than that on Sam, so Sharukh reaches the surface first.

C They both reach the surface together because they both experience the same downward force.

D They both reach the surface together because they both experience the same downward acceleration.

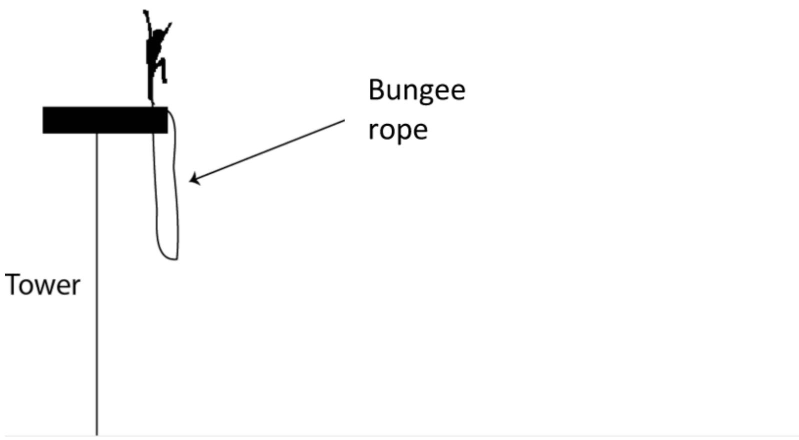
Solution

D The time taken to reach the water can be calculated using $\mathrm{s} = ut + \frac{1}{2}gt^2$.

Since s, u and g are the same for both Sharukh and Sam, they will both reach the surface together as they both experience the same downward acceleration, g.

Question 1/ 49

Jemima is planning a 'bungee jump'. She will jump off a high tower, attached to her starting position by a strong elastic cord, with $k = 147 \text{ N m}^{-1}$. Before she hits the ground, the cord will stop her downwards motion.



Where the bungee cord stops her downwards motion, there are two forces acting on her, one up, and one down. Identify these two forces and calculate their magnitudes. Include units in your answer.

(3 marks)

Solution

Upwards force is tension in the bungee cord $(kx = 2940 \text{ N})$; downward force is her weight $(mg = 490 \text{ N})$.

Question 2/ 49

Read the following.

Crash barriers on freeways are designed to 'absorb the force' of cars crashing into them. To do this, they should not be too strong, and must be designed to crumple slowly under impact. This reduces the average force exerted on the car during a crash.

Use Newton's second law to explain why a crash barrier that 'crumples slowly' will reduce the average force exerted on a car during a crash.

(4 marks)

Solution

- Crash barriers increase the time of the collision.
- Barriers will increase the distance over which the collision takes place.
- $a = \frac{\Delta V}{\Delta t}$ is decreased, since Δt is increased.
- $F = ma$, so F is decreased (or continue with energy argument, with $E = Fx$).

Question 3/ 49

The makers of a 1200 kg car claim it has an acceleration of 9.0 m s^{-2}.

a. Calculate the size of the friction between the car tyres and the road if the car accelerates at this rate. (Assume air resistance and rolling resistance are both very small.)

(2 marks)

b. Calculate the ratio:

$$\frac{\text{frictional force whilst accelerating at 9.0 m s}^{-2}}{\text{ormal reaction force}}$$

(2 marks)

(Total 4 marks)

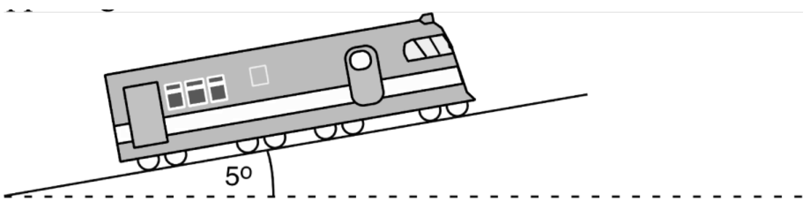
Solution

a 1.1×10^4 N Use $F = ma$.

b 0.92 Answer to previous question divided by *mg*.

Question 4/ 49

A train of mass 600 kg travels up a hill at a constant speed of 10 m s^{-1}. There is very little friction opposing the motion.



Identify the driving force that the wheels of the train are exerting on the track to keep the train travelling up the hill.

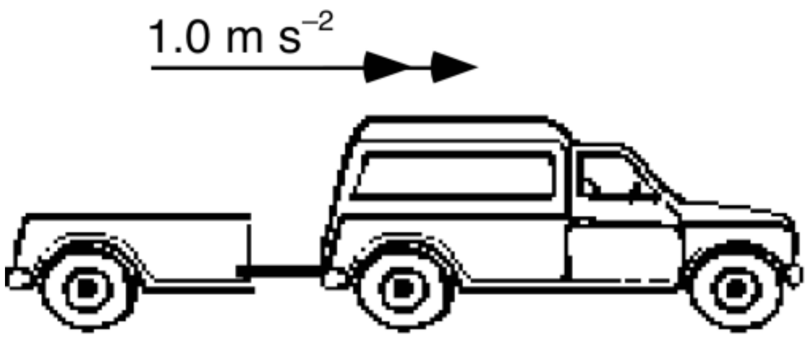
(1 mark)

Solution

512 N $\text{Driving force} = \text{gravitational force down slope} = mg\sin\theta$.

Question 5/ 49

A car towing a trailer along a road is accelerating at 1.0 m s^{-2}. Take opposing friction as zero. The tension in the coupling is 1000 N.



a. What is the mass of the trailer?

(2 marks)

b. If the mass of the car is 1500 kg, what is the driving force that the wheels are exerting on the road?

(2 marks)

c. What is the frictional force that the road is exerting on the driving wheels of the car?

(2 marks)

(Total 6 marks)

Solution

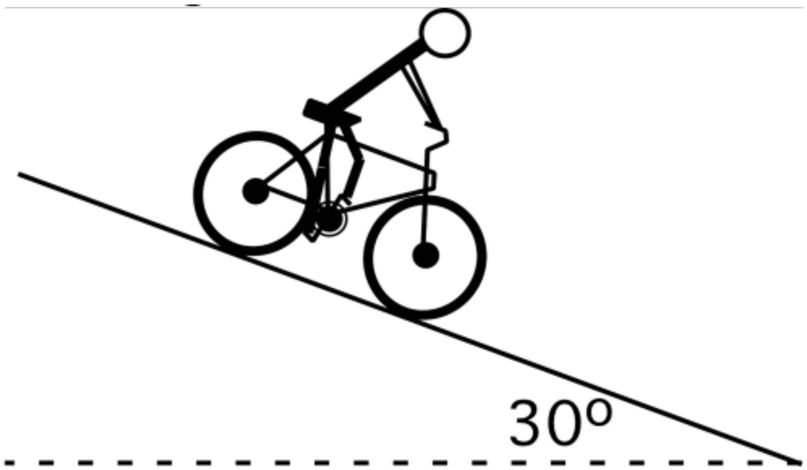
a 1000 kg The 1000 N tension accelerates the trailer.

b 2500 N $F = ma$ (driving wheels cause friction, accelerates system).

c 2500 N Friction is the force that accelerates the car–trailer system.

Question 6/ 49

Theo is riding down a hill on his bike. It is a steep hill, and he has the brakes of the bike on so that he does not accelerate. Ignore air resistance and rolling resistance.



a. Draw arrows representing these three forces on Theo and his bike: weight (*mg*); normal reaction (*N*); braking friction between the tyres and the road (*Fr*).

(3 marks)

b. What is the vector sum of these three forces?

(1 mark)

c. Theo will feel ‘lighter’ than normal while he is accelerating with his brakes off. Explain.

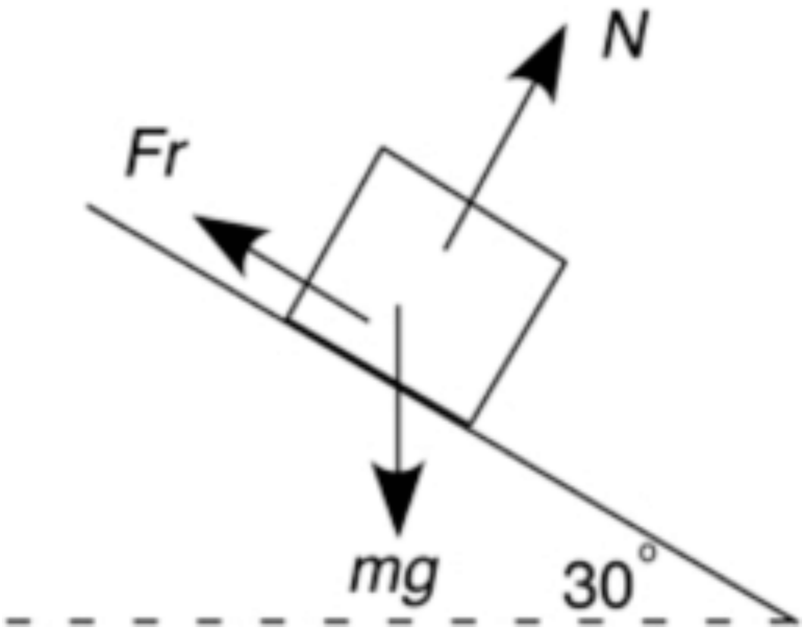
(4 marks)

d. If the hill was a *long* one, his acceleration would decrease as he travelled further down the hill with his brakes off. Explain.

(3 marks)

(Total 11 marks)

Solution



a

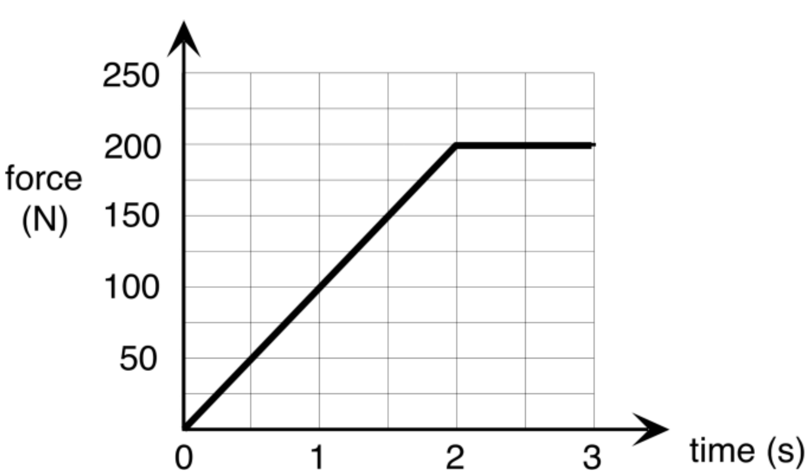
b Zero There is no acceleration and hence no net force.

c From force diagram above, take components of *mg*. This gives $mg\cos 30^\circ = N$. Hence $N < mg\ (N = \text{force he feels as gravity})$. (Note: when Theo accelerates freely down the hill there should be no friction acting on him.)

d As bicycle's speed increases, road and air resistance forces increase, thus reducing the net force down the slope, hence reducing *a*.

Question 7/ 49

Julia accelerates on her bike. The mass of Julia and her bike is 80 kg. The net force acting on her and her bike for the first 3 seconds is shown in the graph.



What is her acceleration at $t = 2.5$ s?

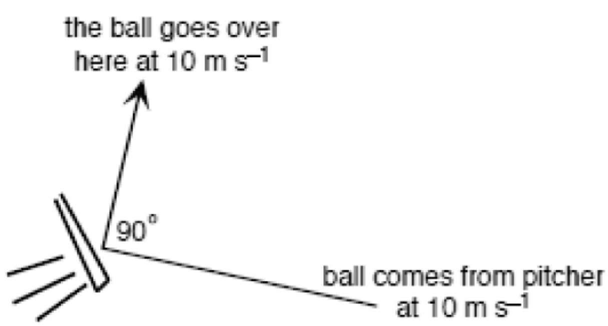
(2 marks)

Solution

2.5 m s^{-2} Use $F = ma$ (read F from the graph).

Question 8/ 49

A player swings hard at a baseball and sends it a long way. This is a picture of what happened, as seen by a passing bird high overhead.



a. What is the size of the magnitude of the change in velocity?

(2 marks)

b. The ball mass is 250 g. Calculate the size of the impulse on the ball.

(2 marks)

c. Calculate the size of the impulse on the bat. Describe the direction of this impulse.

(2 marks)

Solution

a 14 m s^{-1} To find change, subtract initial velocity from final velocity. Do by *adding* the negative of initial velocity to final velocity.

b 3.5 N s $\text{Impulse} = \Delta p. \ (\Delta v = 14 \text{ m s}^{-1})$.

c 3.5 N s Equal and opposite to the impulse on the ball.

Question 9/ 49

Jacinta is rollerblading along a straight flat road at a steady speed of 15 m s^{-1}. The average force of rolling friction from the wheels is around 5.0 N, and the total air resistance force is around 55 N.

a. What is the net force acting on her?

(2 marks)

b. What is the average force the ground is exerting on her rollerblades, in the same direction that she is travelling?

(2 marks)

Solution

a 0 N No acceleration; hence no net force.

b 60 N Must balance the total friction force.

Question 10/ 49

A bike accelerates from rest, covering 16 m in 4 s. The total mass of the bike and its rider is 90 kg.

a. What is its average acceleration?

(2 marks)

b. What is the average net force acting on the bicycle and its rider?

(2 marks)

The bike and rider have three external friction forces on them *while accelerating*: rolling friction, air resistance, and static friction between the tyres and the road.

c. Rolling friction and air resistance are very small. Estimate the size of the static friction between the tyres and the road.

(3 marks)

Solution

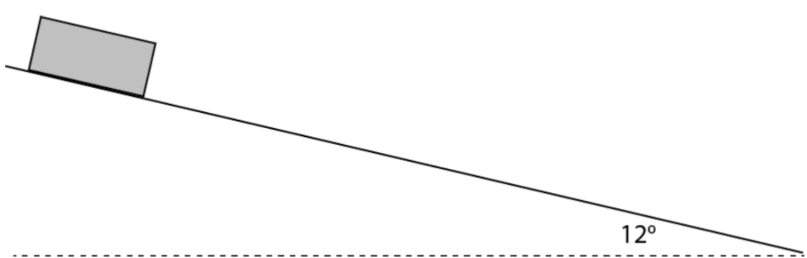
a 2 m s^{-2} Use $m\Delta v = F\Delta t$.

b 180 N Use $F = ma$.

c 180 N External force accelerating bicycle is the static friction.

Question 11/ 49

A 500 g block slides down a plane surface inclined at 12° to the horizontal, as shown. It accelerates at a constant rate of 1.5 m s^{-2}.



Calculate the size of the friction acting on the block as it slides.

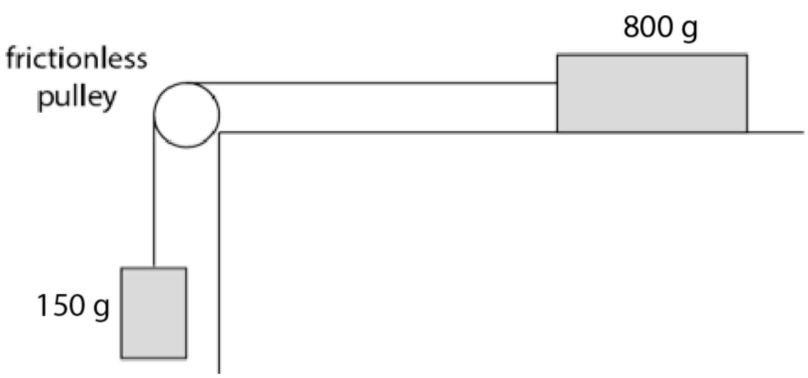
(3 marks)

Solution

0.27 N The net force on the block is $mg\sin\theta - Fr$; this must be equal to *ma*. Substitute and solve.

Question 12/ 49

Two masses are connected by a light non-extensible string as shown in the diagram below. There is no friction in the pulley or the surface of the table under the 800 g mass. The local gravitational field is found to be 9.81 N kg^{-1}.



a. Calculate the gravitational force acting on the 150 g mass, to three significant figures.

(1 mark)

b. Calculate the acceleration of the two masses, to three significant figures.

(3 marks)

c. Calculate the net force acting on the 150 g mass as it falls.

(3 marks)

Solution

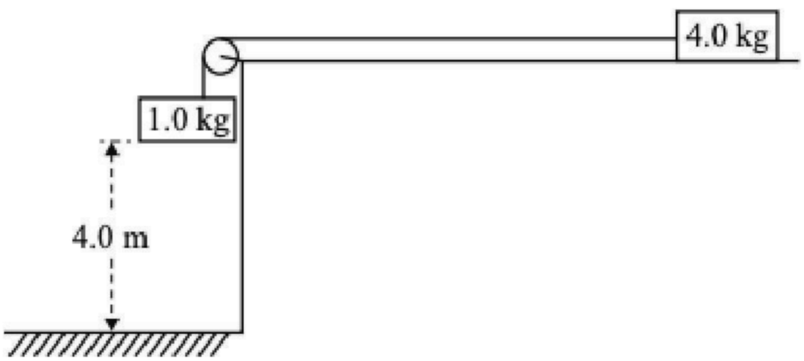
a 1.47 N Use $W = mg$.

b 1.55 m s^{-2} Net force accelerating the $\text{two masses} = 1.47 \text{ N}$; now use $F = ma$. (Alternatively, apply $F = ma$ to each body; this gives $1.47 - T = 0.150 \times a$ and $T = 0.800 \times a$; solve for a.

c 0.232 Net force is given by $ma = 0.150 \times 1.55 = 0.233$ N

Question 13/ 49

Two masses are connected by a light strong string in a frictionless situation shown in the diagram below. The 1.0 kg mass is released from rest.



Calculate the time it takes for the 1.0 kg mass to fall 4.0 m. Show all the steps of your working.

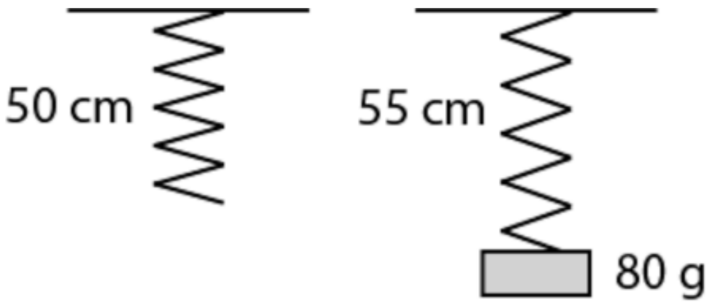
(3 marks)

Solution

2.0(2) s Find the acceleration from net force on the $two\ masses = 9.8 = ma = 5a$; hence $a = 1.96$; now use $s = 0.5at^2$. (Alternative approach using energy conservation also possible and possibly quicker.)

Question 14/ 49

An ideal spring has an unstretched length of 50 cm. A mass of 80 g stretches it to a length of 55 cm.



Calculate the mass required to stretch the spring to a length of 70 cm.

(2 marks)

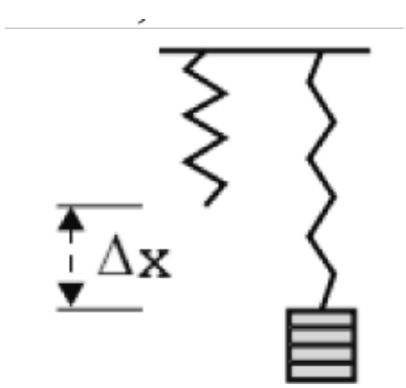
Solution

320 g Easiest method is to observe stretch is proportional to mass weight; stretch is quadruple, hence so is mass. Alternatively, find *k* from $kx = mg$ and then use $m = \frac{kx}{g}$

Question 15/ 49

[Adapted VCAA 2016 SA Q3]

To determine the spring constant, *k*, of a spring, students attach 50 g masses to it consecutively and measure the extension, Δ*x*. This is shown below.



The students' results are shown in the table below.

Number of masses	**Extension from unstretched length, Δx**

Number of masses	Extension from unstretched length, Δx
0	0 cm
1	25 cm
2	50 cm
3	75 cm

Calculate the value of the spring constant, *k*, to two significant figures.

(2 marks)

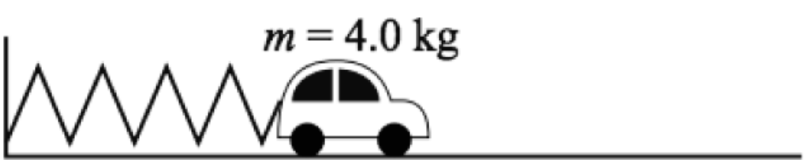
Solution

2.0 N m^{-1} Use $F = mg = k\Delta x$.

Question 16/ 49

[Adapted VCAA 2016 SA Q4]

A small model car of mass 4.0 kg is propelled by a compressed spring.



It leaves the spring with a speed of 2.0 m s^{-1} and travels along a flat surface that has a frictional resistance of 2.0 N. Calculate how far the car travels before it stops. Show your working.

(3 marks)

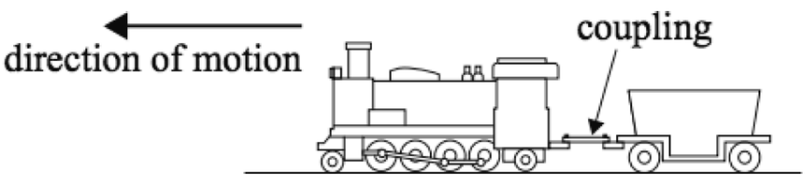
Solution

4.0 m $a = \frac{F}{m}$; then $v^2 = u^2 + 2as$ with $v = 0$. This could also be solved by work done by $\text{friction} = \text{loss}$ in KE.

Question 17/ 49

[Adapted VCAA 2016 SA Q1]

An engine of mass 20 t, moving at $3.0\ \text{m s}^{-1}$, is towing a wagon of mass 10 t, as shown. It is accelerating with a constant acceleration of $0.10\ \text{m s}^{-2}$.



Calculate the tension in the coupling between the engine and the wagon.

(2 marks)

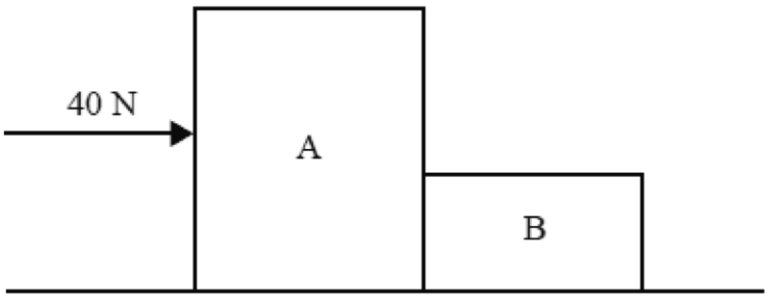
Solution

1000 N Use $F = ma$ applied to wagon; assume friction is negligible.

Question 18/ 49

[VCAA 2018 SB Q8]

Two blocks, A of mass 4.0 kg and B of mass 1.0 kg, are being pushed to the right on a smooth, frictionless surface by a 40 N force, as shown below.



a. Calculate the magnitude of the force on block B by block A ($F_{\text{on B by A}}$). Show your working.

(2 marks)

b. State the magnitude and the direction of the force on block A by block B ($F_{\text{on B by A}}$).

(2 marks)

Solution

a 8.0 N Calculate combined acceleration of the blocks ($F = ma$); this gives $a = 8.0 \text{ m s}^{-2}$; now apply $F = ma$ to block B.

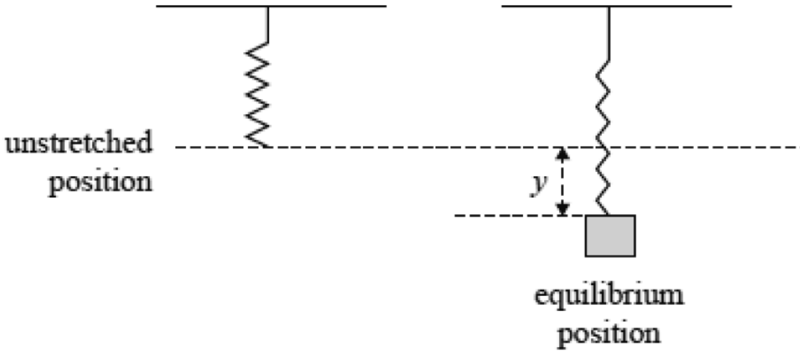
b 8.0 N; left Apply Newton's third law.

Question 19/ 49

[Adapted VCAA 2019 NHT SB Q5]

Students conduct an experiment in which a mass of 2.0 kg is suspended from a spring with a spring constant $k = 100 \text{ N m}^{-1}$. Ignore the mass of the spring.

Take the gravitational field, *g*, to be 10 N kg^{-1}. Take the zero of gravitational potential energy when the mass is at its lowest point. The experimental arrangement is shown in the diagram below.



The mass is attached to the spring and slowly lowered to its equilibrium position. Calculate the extension, *y*, of the spring from its unstretched position to its equilibrium position. Show your working.

(2 marks)

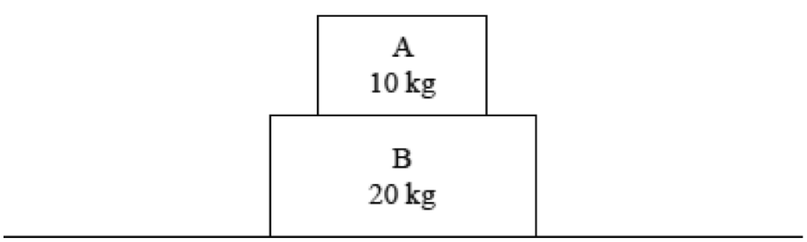
Solution

0.20 m At the equilibrium position $mg = ky$, hence $y = 0.20 \text{ m}$.

Question 20/ 49

[VCAA 2019 NHT SB Q9]

The diagram below shows two masses. Mass A has a mass of 10 kg. It rests on top of Mass B, which has a mass of 20 kg.



Calculate the magnitude and direction of the force on Mass A by Mass B. Take $g = 9.8 \text{ N kg}^{-1}$.

(2 marks)

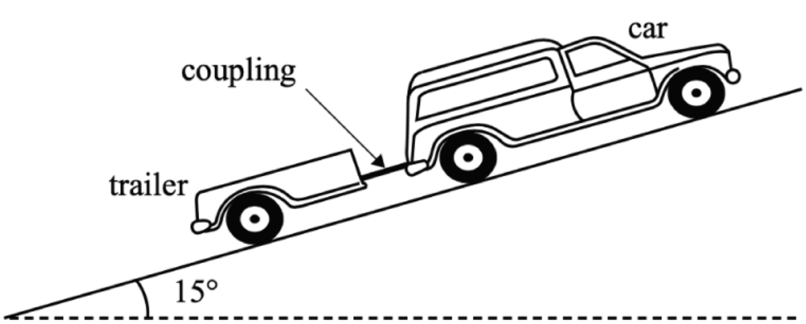
Solution

98 N The reaction force upwards from Mass B must equal the weight of Mass A (*mg*) to maintain equilibrium.

Question 21/ 49

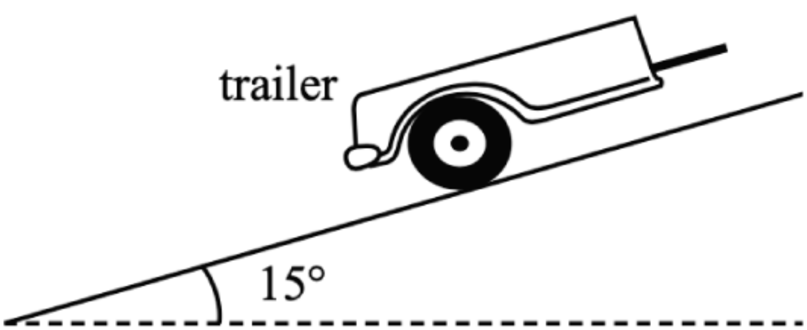
[VCAA 2021 NHT SB Q8]

A car is driving up a uniform slope with a trailer attached, as shown below. The slope is angled at 15° to the horizontal. The trailer has a mass of 200 kg and the car has a mass of 750 kg. Ignore all retarding friction forces down the slope.



a. On the diagram below, draw labelled arrows to indicate the direction of the forces acting on the trailer. The labels should also indicate the kind of force that each arrow represents.

(3 marks)



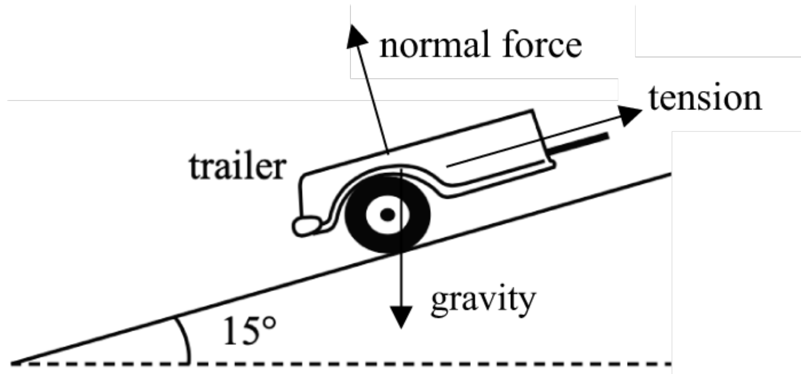
b. The car and trailer are travelling at a constant speed of 8 m s^{-1} up the slope. Calculate the magnitude of the force that the car exerts on the trailer. Show your working.

(2 marks)

(Total 5 marks)

Solution

a



b 507 N Since velocity is constant, $\text{net force} = 0$. Tension force up the slope is equal to the component of *mg* down the slope. Hence $T = mg \sin 15 = 200 \times 9.8 \times 0.259 = 507 \text{ N}$

Question 22/ 49

[Adapted VCAA 2021 NHT SB Q18]

A small rubber ball of mass 50 g falls vertically from a given height and rebounds from a hard floor. The ball's speed immediately before impact is 3.6 m s^{-1}. The ball rebounds upward at a speed of 3.3 m s^{-1} immediately after it leaves the floor. The ball is in contact with the floor for 40 ms.

Calculate the magnitude and direction of the net average force acting on the 50 g ball while it is in contact with the floor. Show your working.

(4 marks)

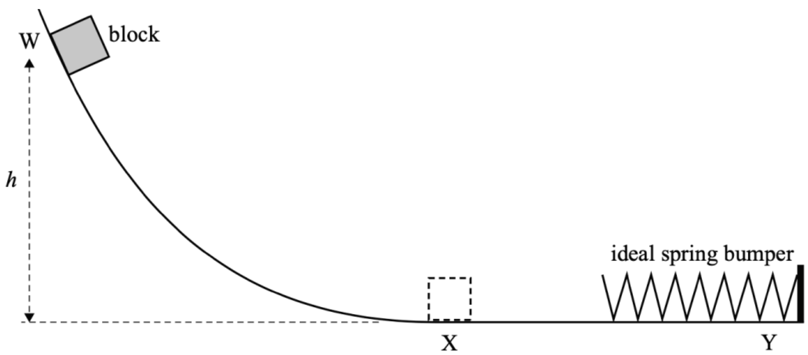
Solution

8.8 N, upwards During collision with the floor, $F = ma$; hence $F = \frac{m\Delta v}{\Delta t} = \frac{0.05 \times 6.9}{0.04} = 8.6 \text{ N}$. Could also be tackled by $F\Delta t = \Delta p$.

Question 23/ 49

[Adapted VCAA 2021 NHT SB Q9]

In a model of a proposed ride at a theme park, a 5.0 kg smooth block slides down a ramp from point W and into an ideal spring bumper without any friction or air resistance, as shown below. The final section of the ramp, between points X and Y, is horizontal. The block comes to an instantaneous stop at point Y.



Describe the acceleration of the block at points W, X and Y.

(4 marks)

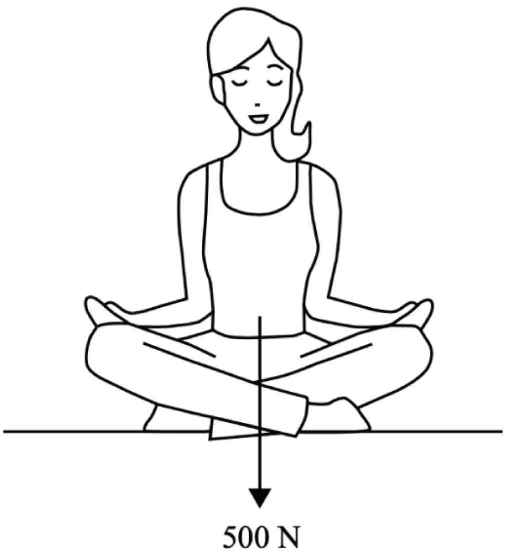
Solution

The net force acting on the block at point W is the tangential component of the gravitational force *mg*. This is *mg*sinθ, where θ is the slope angle of the ramp at point W. Hence the acceleration is non-zero and parallel to the slope at W. At point X, the net force on the block is zero as the normal force exactly balances the *mg* force, and there is no friction, so the acceleration is also zero. At point Y, the net force is from the compressed spring. It is horizontal and to the left, as is the acceleration.

Question 24/ 49

[VCAA 2021 SB Q4]

Liesel, a student of yoga, sits on the floor in the lotus pose, as shown below. The action force, F_g, on Liesel due to gravity is 500 N down.



Identify and explain what the reaction force is to the action force, F_g, shown above.

(2 marks)

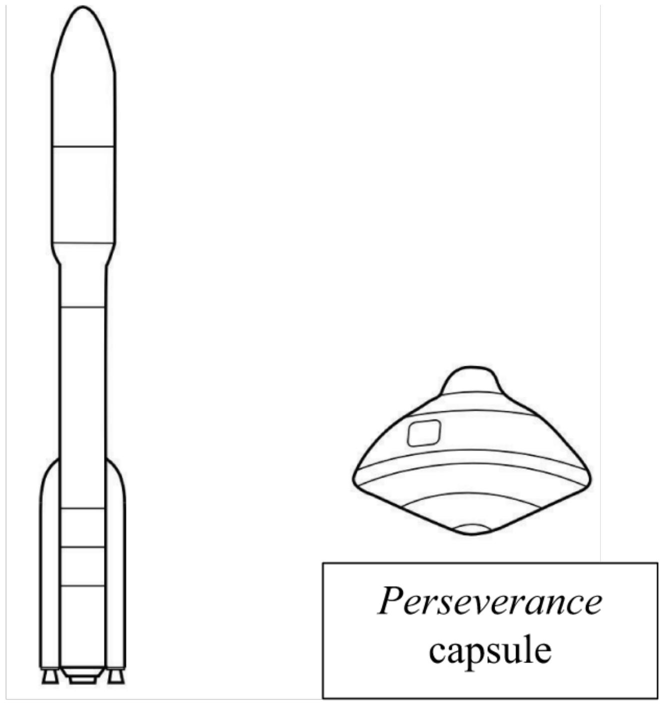
Solution

If the action force is the attractive force from Earth downwards on Leisl, then the reaction force is the attractive force from Leisl upwards on Earth.

Question 25/ 49

[Adapted VCAA 2021 SB Q8]

On 30 July 2020, the National Aeronautics and Space Administration (NASA) launched an Atlas rocket containing the *Perseverance* rover space capsule on a scientific mission to explore the geology and climate of Mars, and search for signs of ancient microbial life.



Atlas rocket

At lift-off from launch, the acceleration of the rocket was 7.20 m s^{-2}. The total mass of the rocket and capsule at launch was 531 tonnes.

Calculate the magnitude and the direction of the thrust force on the rocket at launch. Take the gravitational field strength at the launch site to be $g = 9.80 \text{ N kg}^{-1}$. Give your answer in meganewtons. Show your working.

(3 marks)

Solution

9.03 MN $\text{Net force on rocket} = \text{thrust} - \text{weight}; F_{\text{net}} = T - mg.$

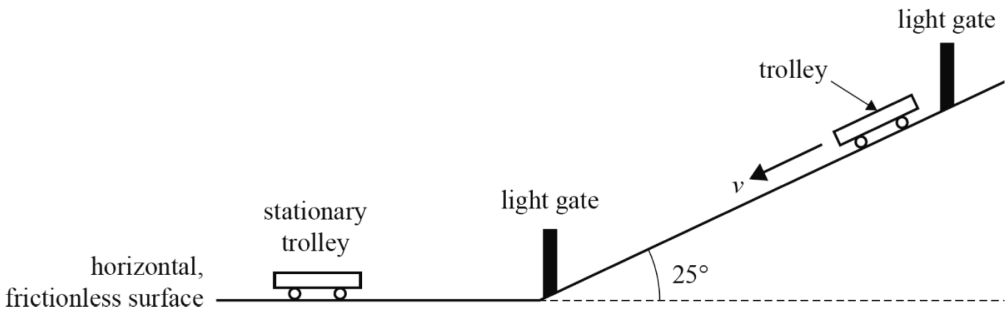
$F\text{net} = ma$; hence $T = ma + mg = m\,(a + g) = 9.03 \times 10^6 \text{ N}.$

Question 26/ 49

[Adapted VCAA 2022 SB Q7]

Kym and Kelly are experimenting with trolleys on a ramp inclined at 25°, as shown below. They release a trolley with a mass of 2.0 kg from the top of the ramp.

The trolley moves down the ramp, through two light gates and onto a horizontal, frictionless surface. Kym and Kelly calculate the acceleration of the trolley to be 3.2 m s^{-2} using the information from the light gates.



a. Show that the component of the gravitational force of the trolley down the slope is 8.3 N. Use $g = 9.8 \text{ m s}^{-2}$.

(2 marks)

b. Assume that on the ramp there is a constant frictional force acting on the trolley and opposing its motion. Calculate the magnitude of the constant frictional force acting on the trolley.

(2 marks)

Solution

a Component of gravity down the slope is $g \sin 25 = 8.28 \text{ N} = 8.3 \text{ N}$.

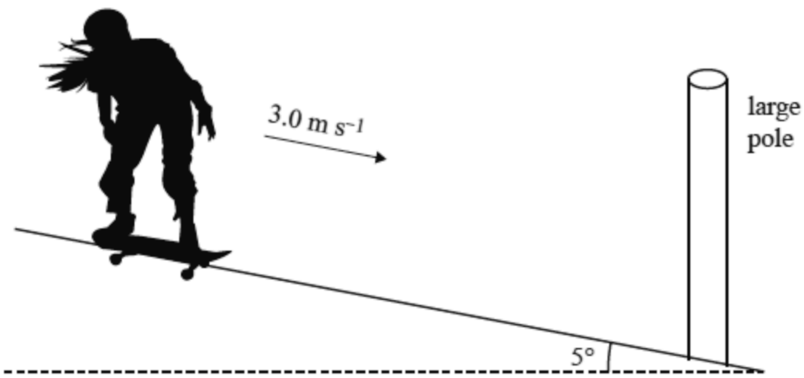
b 1.9 N $\text{Net force} = ma = 8.28 - \text{friction}$; solve for friction.

Question 27/ 49

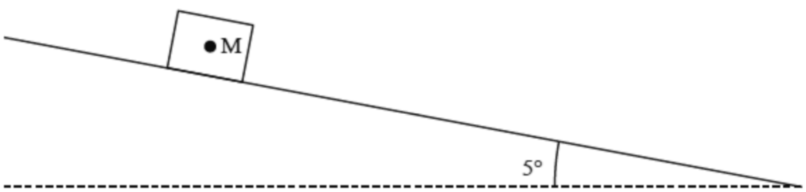
[Adapted VCAA 2023 SB Q8]

Maia is at a skatepark. She stands on her skateboard as it rolls in a straight line down a gentle slope at a constant speed of 3.0 m s^{-1}, as shown. The slope is 5° to the horizontal.

The combined mass of Maia and the skateboard is 65 kg.



a. The combined system of Maia and the skateboard is modelled as a small box with point M at the centre of mass as shown below.



Draw and label arrows to represent each of the forces acting on the system – that is, Maia and skateboard, as they roll down the slope.

(3 marks)

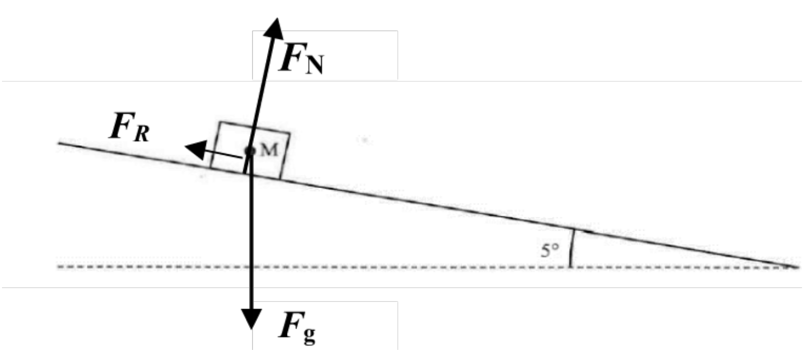
b. Calculate the magnitude of the total frictional forces acting on Maia and the skateboard.

(2 marks)

Solution

a Three forces act as shown, gravity (F_g), normal (F_N) and friction (F_R).

Ideally all the vectors should sum to zero as Maia is moving down the slope at a constant speed.



b 56 N $\text{Friction} = mg\sin\theta = (65)(9.8)\ \sin\ 5^0$

Chapter 3 Energy

Question 1/ 19

A climber ascends a mountain of height 4300 m, starting at a height of 1300 m. She has a mass (including her pack) of 66 kg. Which one of the following is closest to the gravitational potential energy she gains during this climb?

A 130 kJ

B 280 kJ

C 1.95 MJ

D 2.80 MJ

Solution

C Use $\Delta \text{PE} = mg\Delta h$.

Question 3/ 19

The gravitational potential energy she loses as she moves from the top of the slide to the bottom is closest to

A 1.3 kJ

B 13 kJ

C 5.2 kJ

D 52 kJ

Solution

B Use $\Delta \mathrm{PE} = mg\Delta h$; $\Delta h = 150 \times \sin 15°$.

Question 4/ 19

She reaches the bottom of the slide with a speed of $20\ \mathrm{m\ s^{-1}}$. The thermal energy generated during her slide is closest to

A 1.3 kJ

B 6.3 kJ

C 7.0 kJ

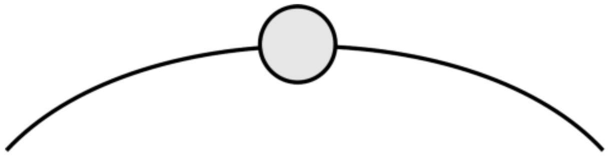
D 13 kJ

Solution

B KE at bottom is 7000 J; subtract from previous answer.

Question 5/ 19

A netball is thrown towards the net. It is shown below at the highest point of its flight. Air resistance is negligible.



Which *one or more* of the following best describes the ball at its highest point?

A At this point its kinetic energy is a minimum.

B At this point its kinetic energy is a maximum.

C At this point its potential energy is zero.

D At this point its potential energy increasing.

Solution

A   Total energy constant; PE is maximum; KE is not zero.

Question 6/ 19

Frankie drops from a height of several metres onto a trampoline. When he makes contact with the trampoline, he is travelling at $10\ \mathrm{m\ s^{-1}}$. The trampoline then stops his motion momentarily. Which of the following best describes his energy changes throughout this process?

A His initial potential energy has been changed into kinetic energy.

B His initial potential energy has been changed directly into elastic potential energy.

C He has gained extra energy from the trampoline.

D His initial potential energy has been changed into kinetic energy and then into elastic energy.

Solution

D Follow the energy changes during his fall.

Question 8/ 19

Which of the following best describes the energy changes?

A The sum of the initial potential energy and the kinetic energy is constant.

B The sum of the initial potential energy, the elastic energy and the kinetic energy varies during the oscillation.

C The kinetic energy is a maximum in the centre of the motion.

D The sum of the initial potential energy and the elastic energy is constant.

Solution

C At centre, net force $(\text{and acceleration}) = 0$; speed maximum.

Question 9/ 19

The spring constant is $20\ \mathrm{N\ m^{-1}}$. The mass is 1.2 kg. The amplitude of the oscillation is closest to

A 0.12 m

B 0.6 m

C 1.2 m

D 1.4 m

Solution

B   Equilibrium point is centre of motion; find from $mg = kx$.

Question 10/ 19

In real life, the mass would come to rest eventually. At this point, the extension of the spring would be closest to

A 0.12 m

B 0.6 m

C 0.7 m

D 1.2 m

Solution

B   Reasoning as for question 7.

Question 11/ 19

At this final rest point, the total energy dissipated to the environment would be closest to

A 3.5 J

B 6.9 J

C 11 J

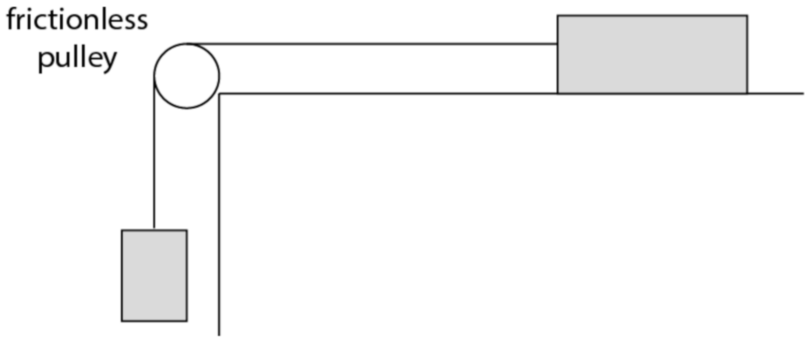
D 14 J

Solution

A Initial $\mathrm{PE} = 7.2$; $\text{final energy} = \mathrm{EPE} = 3.6\ \mathrm{J}$; loss is 3.6 J.

Question 12/ 19

Students conduct an experiment in which two blocks of equal mass are attached and placed as shown in the diagram. The surface has some friction, but the string does not stretch. The blocks are then released.



After a short time, both blocks have gained kinetic energy. Which of the following statements best describes the situation?

A The kinetic energy of the falling mass is equal to the kinetic energy of the sliding mass.

B The kinetic energy of the falling mass is less than the kinetic energy of the sliding mass.

C The kinetic energy of the falling mass is greater than the kinetic energy of the sliding mass.

D The kinetic energy of the falling mass increases more quickly than the kinetic energy of the falling mass.

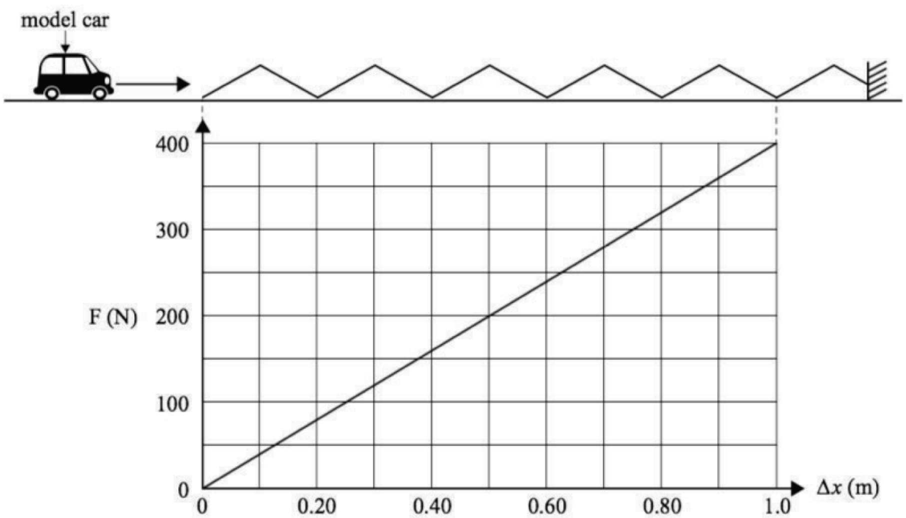
Solution

A Blocks have same mass and speed, hence same KE.

Question 13/ 19

[VCAA 2017 SA Q13]

A model car is on a track and moving to the right. It collides with and compresses a spring that is considered ideal, as shown in the diagram. The car compresses the spring to 0.50 m when the car comes to rest. The force-distance graph for the spring is also shown. Assume that friction is negligible.



What is the initial kinetic energy of the car?

A 25 J

B 50 J

C 100 J

D 200 J

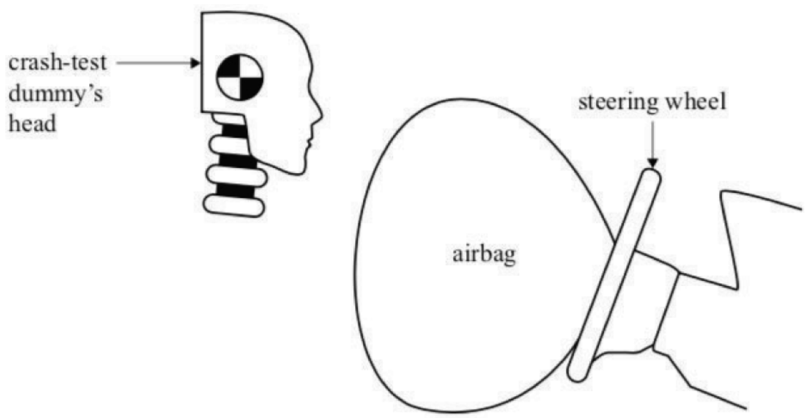
Solution

B Equate area under the graph to the KE or use $E = \frac{1}{2}kx^2$.

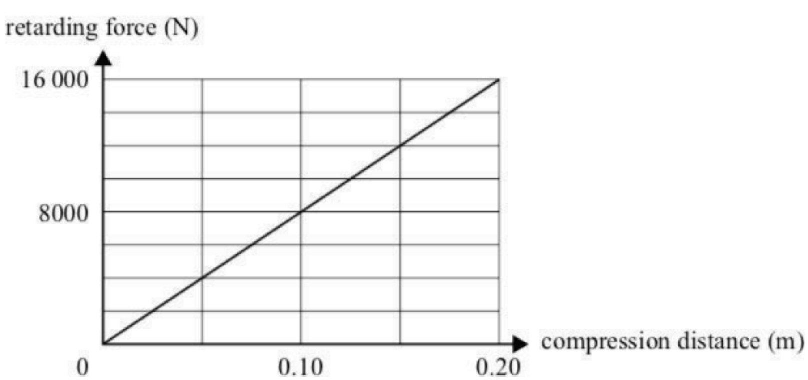
Question 14/ 19

[VCAA 2017 Sample SA Q11]

A test car is equipped with a crash-test dummy and an airbag. The car comes to a sudden stop when it collides with a solid wall, causing the airbag to inflate. The airbag then compresses by 0.10 m when the crash-test dummy hits the airbag. The diagram below shows the relative position of the crash-test dummy's head to the airbag and steering wheel.



The graph of retarding force on the crash-test dummy's head versus compression distance is shown below.



Which one of the following best gives the work done on the airbag in this collision?

A 80 J

B 400 J

C 800 J

D 8000 J

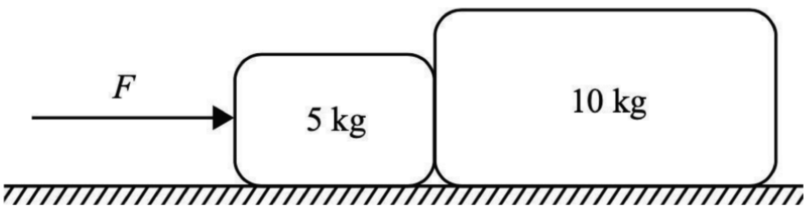
Solution

B   Use area under graph.

Question 15/ 19

[VCAA 2020 SA Q10]

Two blocks of mass 5 kg and 10 kg are placed in contact on a frictionless horizontal surface, as shown in the diagram below. A constant horizontal force, *F*, is applied to the 5 kg block.



If the force *F* has a magnitude of 250 N, what is the work done by the force in moving the blocks in a straight line for a distance of 20 m?

A 5 kJ

B 25 kJ

C 50 kJ

D 500 kJ

Solution

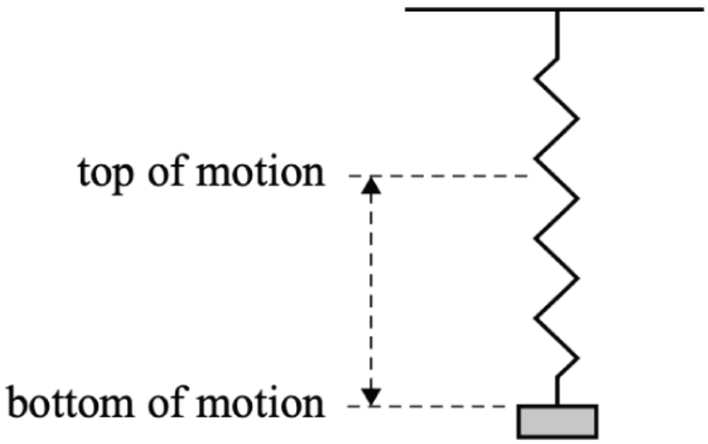
C   Use $W = F \times \Delta x = 250 \times 20 = 5000$ J.

Question 16/ 19

[VCAA 2021 NHT SA Q11]

A mass at the end of an ideal spring is oscillating freely up and down.

Which one of the following best describes the motion of this oscillating mass?



A Its speed is a minimum only at the top of the motion.

B Its speed is a maximum when its acceleration is a maximum.

C Its acceleration has a minimum value at both the top and the bottom of the motion.

D Its acceleration has a maximum value upward when the mass is stationary at the bottom.

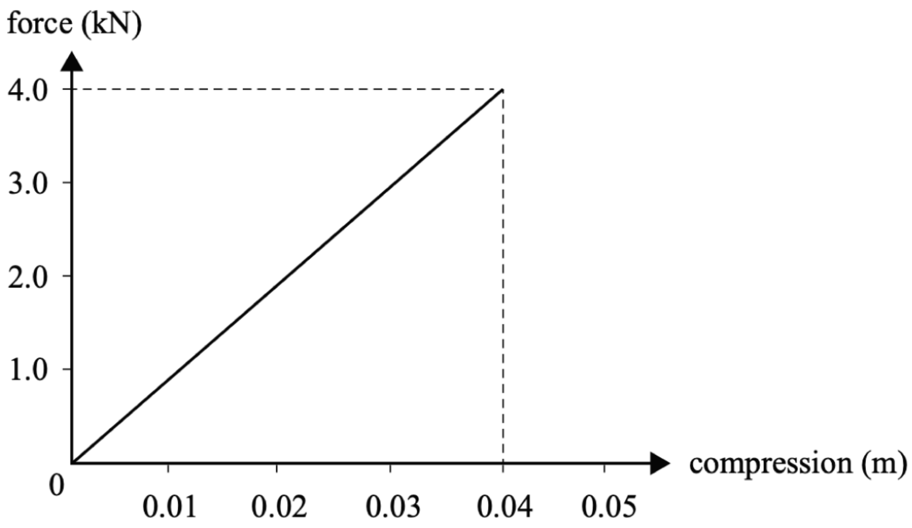
Solution

D At this point the mass is stationary but it is accelerating upwards. Can also tackle this by eliminating other options.

Question 17/ 19

[VCAA 2021 SA Q12]

A force versus compression graph for a suspension spring is shown below.



The spring is compressed to 0.02 m. Which one of the following is closest to the potential energy stored in the spring?

A 0.04 J

B 0.20 J

C 20 J

D 40 J

Solution

C Calculate area under graph or find *k* and use $\mathrm{EPE} = \frac{1}{2}kx^2$.

Question 18/ 19

[VCAA 2022 NHT SA Q7]

A car travelling at 60 km h^{-1} brakes to a complete stop of a distance of 18 m under a constant braking force. Which one of the following is closest to the braking distance required for the same car to come to a complete stop when travelling at 40 km h^{-1} and braking with the same constant braking force?

A 8 m

B 9 m

C 12 m

D 15 m

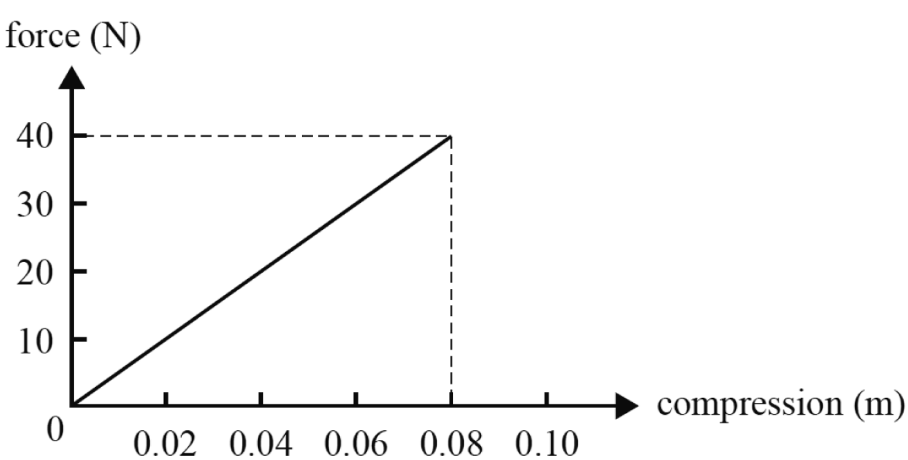
Solution

A Use work done by the braking $\text{force} = \Delta\text{KE}$. $F_{\text{brake}} \times s = \frac{1}{2}mv^2$.

Use as follows: $Fs_1/Fs_2 = mv_1{}^2/mv_2{}^2$ simplifies to $s_1/s_2 = v_1{}^2/v_2{}^2$

Question 19/ 19

The graph below shows force versus compression for a spring used in a Physics investigation.



Which one of the following is closest to the compression required to store 0.9 J of potential energy in the spring?

A 0.05 m

B 0.06 m

C 0.07 m

D 0.08 m

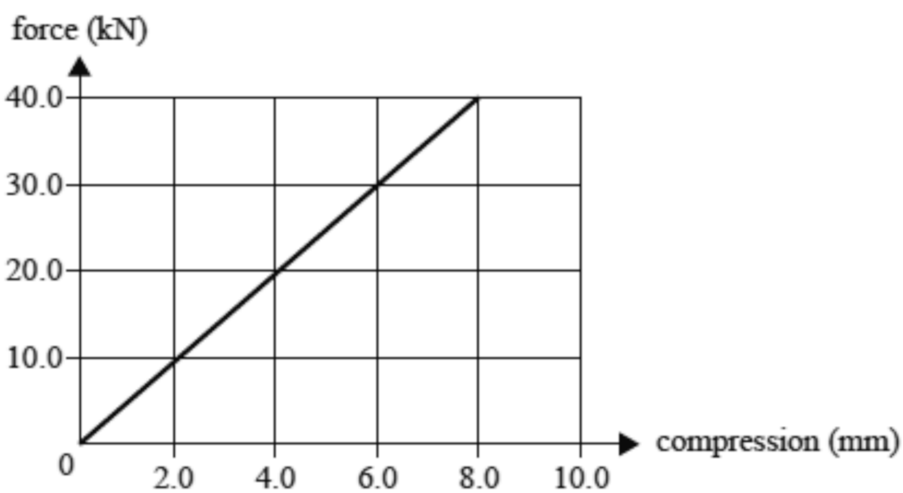
Solution

B Calculate the spring constant *k* from the gradient of the force compression $\text{graph} = 500 \text{ N m}^{-1}$.
Now put $0.9 = \frac{1}{2}kx^2$ and solve for *x*.

Question 20/ 19

[VCAA 2023 SA Q10]

A force versus compression graph for a car spring is shown below.



Which one of the following is closest to the spring constant of the car spring?

A 5.0 N m^{-1}.

B $5.0 \times 10^3 \text{ N m}^{-1}$.

C $5.0 \times 10^5 \text{ N m}^{-1}$.

D $5.0 \times 10^6 \text{ N m}^{-1}$

Solution

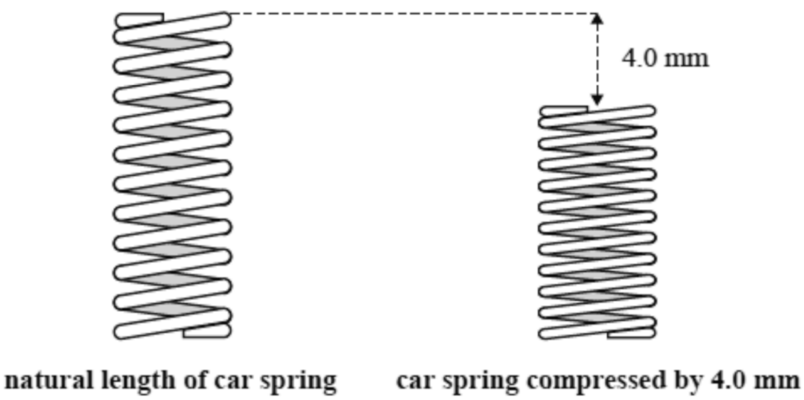
D The spring constant is the given by the gradient of the force vs compression graph.

$k = 5.0 \times 10^6 \text{ N m}^{-1}$

Question 21/ 19

[VCAA 2023 SA Q11]

When the car is sitting on a level surface, the car spring is compressed by 4.0 mm from its natural length, as shown below.



As the car goes over a bump in the road, the car spring compresses an additional 4.0 mm from the initial compression of 4.0 mm, to a total compression of 8.0 mm.

Which one of the following is closest to the additional potential energy stored in the car spring when the car goes over the bump?

A $4.0 \times 10^1 \text{J}$

B $1.2 \times 10^2 \text{J}$

C $1.6 \times 10^2 \text{J}$

D $3.2 \times 10^2 \text{J}$

Solution

B The additional energy stored when the spring is compressed the extra 4.0 mm is given by the area under the graph between 4.0 mm and 8.0 mm. (120 J).

Question 1/ 52

A car (mass 900 kg) brakes steadily from $20 \mathrm{~m~s}^{-1}$ to rest in 4.0 s. It is on a level road, and its brakes are the cause of its decrease in speed.

a. What is the braking distance?

(2 marks)

b. At what rate is thermal energy being dissipated in the brakes?

(2 marks)

Solution

a 40 m $\text{Distance} = \text{average speed} \times \text{time}.$

b $45 \mathrm{~kW~s}^{-1}$ $P = \frac{\Delta E_K}{t}$

Question 2/ 52

A 500 kg car moving at $5.0 \mathrm{~m~s}^{-1}$ runs into the back of a stationary truck of mass 3.0 t. The truck moves forward at $1.0 \mathrm{~m~s}^{-1}$; the car rebounds backwards at $1.0 \mathrm{~m~s}^{-1}$. Show that the combined KE of the car and truck after the collision is less than the combined KE of the car and truck beforehand.

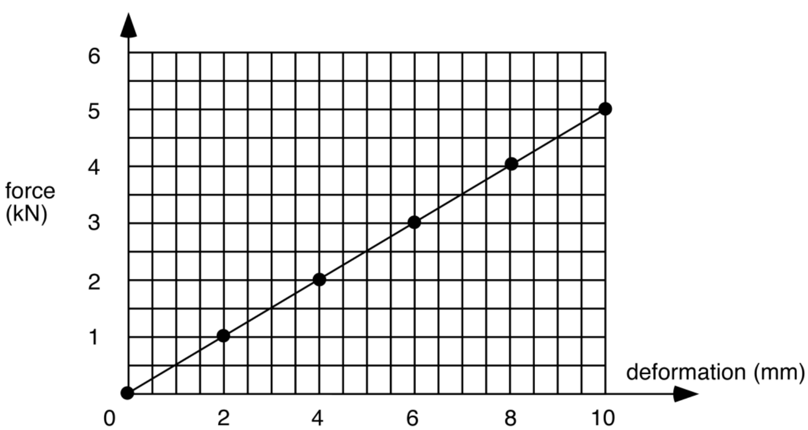
(2 marks)

Solution

$E_{\mathrm{K}} = \frac{1}{2}mv^2$. Difference is $6250 - 1750 = 4500$ J.

Question 3/ 52

During a golf drive, the ball changes speed very rapidly. The forces involved deform the ball considerably. The graph below shows the force on a 50 g golf ball as a function of its deformation.



In a particular drive, Georgia strikes the ball so that it deforms by 8.0 mm during the collision with the club head. Assume that this deformation is elastic.

a. What is the force constant of the golf ball?

(2 marks)

b. How much work has been done in deforming the ball?

(2 marks)

c. How much elastic potential energy is stored in the deformed ball?

(2 marks)

d. Estimate the speed of the ball as it leaves the club head.

(3 marks)

Solution

a $5 \times 10^5\ \mathrm{N\ m^{-1}}$ Gradient of graph.

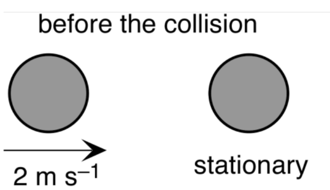
b 16 J Area under graph.

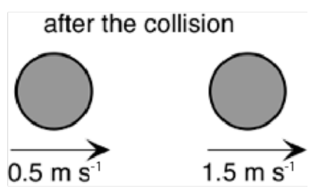
c 16 J Equal to work done.

d $25\ \mathrm{m\ s^{-1}}$ Equate the KE to the stored elastic energy.

Question 4/ 52

The collision between two snooker balls can be modelled by two isolated masses colliding.





a. Show that this collision is not elastic.

(2 marks)

b. Calculate the ratio:

$$\frac{kinetic\ energy\ before\ the\ collision}{kinetic\ energy\ after\ the\ collision}$$

(3 marks)

Solution

a $E_{\mathrm{K(before)}} = 2 \times \mathrm{mass},\ E_{\mathrm{K}}\ (\mathrm{after}) = 125 \times \mathrm{mass}$; hence some KE lost.

b 1.6 Use $E_{\mathrm{K}} = \frac{1}{2}mv^2$ before and after.

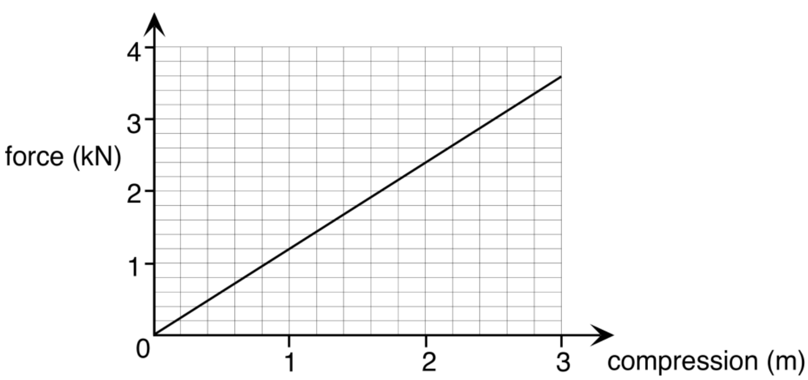
Question 5/ 52

A pole-vaulter achieves much of her height by converting stored elastic energy in the pole into gravitational potential energy. Her mass is 60 kg. She needs to raise her centre of mass by 7.0 m to vault a bar. 90% of her potential energy needs to be supplied from the elastic potential energy in the pole.

a. How much elastic potential energy needs to be stored in the pole?

(2 marks)

After a successful vault, she falls onto a pile of mats to cushion her fall. The compression-force graph for the pile of mats is shown below.



b. Estimate the maximum compression she causes in the mats.

(3 marks)

Solution

a $3.7 \times 10^3 \mathrm{J}$ 90% of $mgh = 3780$ J.

b 2.6 m Equate area under graph, $\frac{1}{2}kx^2$ to $mgh = 4116$ J.

Question 6/ 52

A basketball player bounces a 450 g ball on the court floor. Just before the ball hits the ground, it is travelling at $8\ \mathrm{m\ s^{-1}}$. After it bounces, it leaves the floor at $6\ \mathrm{m\ s^{-1}}$.

a. How much kinetic energy has been converted into other forms of energy during the bounce?

(2 marks)

b. 'Energy cannot be created or destroyed.' Account for the 'missing' kinetic energy in terms of this statement.

(3 marks)

Solution

a 6.3 J Calculate $\frac{1}{2}mv^2$ before and afterwards.

b 'Missing' KE has been converted into thermal energy and sound energy.

Question 7/ 52

Explain what is meant by the statement that 'a collision is *elastic*'.

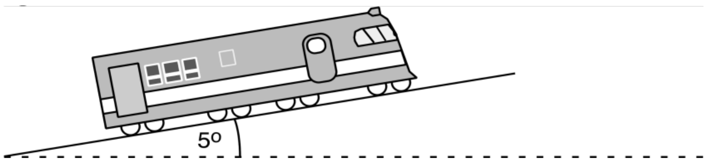
(2 marks)

Solution

In an *elastic* collision, the total KE before the collision is equal to the total KE after the collision.

Question 8/ 52

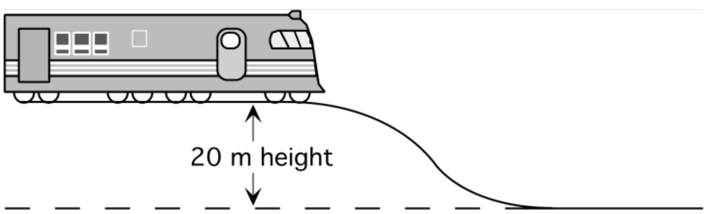
A train of mass 600 kg travels up a hill at a constant speed of $10 \mathrm{~m~s^{-1}}$. The only friction is between the track and the driving wheels. Give all your answers to this question to two significant figures.



a. The train reaches the top of the hill at $10 \mathrm{~m~s^{-1}}$. What is its kinetic energy?

(2 marks)

The train coasts down the hill on the other side into a valley.



b. If there was no opposing friction, what would its speed have been at the bottom of the hill?

(2 marks)

c. In fact, its speed was only $18 \mathrm{~m~s^{-1}}$. How much energy has been transformed into thermal energy?

(2 marks)

d. Later, the train travels up a slope slowly. It gains 4.0 MJ of gravitational PE. The efficiency of its engines is 20%. How much chemical energy (in MJ) did it transform from its fuel in climbing the hill?

(3 marks)

Solution

a 3.0×10^4 J Use $\frac{1}{2}mv^2$.

b $22 \mathrm{~m~s^{-1}}$ At top of hill, the train has $\mathrm{KE} + \mathrm{PE}$; at the bottom, all PE is converted to KE (hence $0.5mu^2 + mgh = \frac{1}{2}mv^2$).

c 5.0×10^4 J Subtract actual KE from predicted KE.

d 20 MJ 4 MJ is 20% of the total transformed chemical energy.

Question 9/ 52

Going up a hill, Sally's car generates a power of 35 kW ($35\ \mathrm{kJ\ s^{-1}}$).

a. How much mechanical energy does it generate every minute?

(2 marks)

b. The car uses 3 litres of petrol every 10 minutes. Each litre of petrol contains 30 MJ of energy. Estimate the car's efficiency.

(3 marks)

Solution

a 2.1 MJ Use $\text{Energy} = P \times t$.

b 23% (20%) Car uses 150 kJ of chemical energy each second.

Question 10/ 52

Two cars travel at $5\ \mathrm{m\ s^{-1}}$, collide head on and lock together. Straight after the collision they travel at $1.5\ \mathrm{m\ s^{-1}}$. What percentage of the KE before the collision transforms into other forms during the collision? Show your working.

(3 marks)

Solution

91% $\mathrm{KE_{AFTER}} = \frac{1}{2}(M+m) \times 1.5^2; \mathrm{KE_{BEFORE}} = \frac{1}{2}(M+m) \times 5^2.$

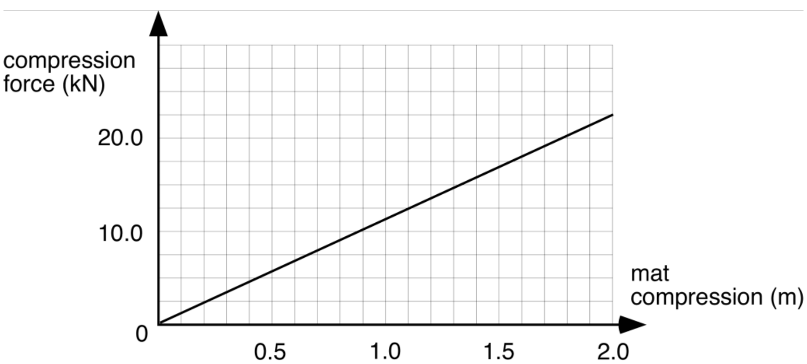
Question 11/ 52

Pole-vaulters use mats to absorb their kinetic energy (KE) when they fall.

a. How much KE would need to be absorbed by a mat under an 80 kg pole-vaulter whose centre of mass has fallen a distance of 7.0 m?

(2 marks)

The compression graph of a proposed pole-vault mat is shown below.



b. What is the force constant of this mat?

(2 marks)

c. Estimate the compression of this mat when it absorbs 6000 J of KE.

(2 marks)

Solution

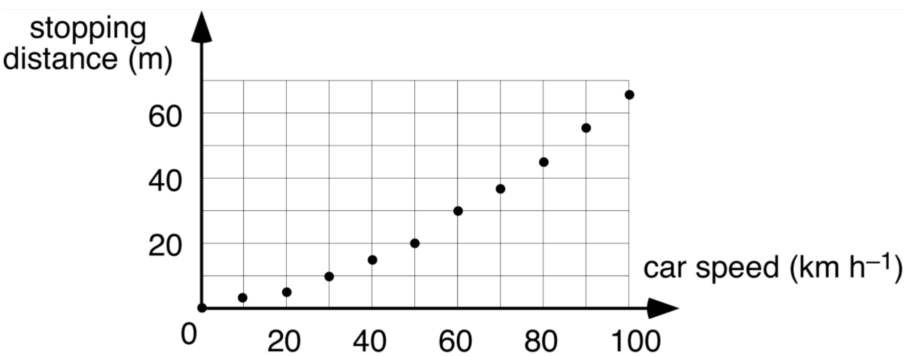
a 5.5 kJ Use *mgh*.

b $1.13 \times 10^4 \text{ N m}^{-1}$ Gradient of the graph.

c 1.03 m $\text{Area} = \text{energy absorbed; area} = \frac{1}{2}kx^2$.

Question 12/ 52

The graph below shows how the stopping distance of a car varies with its speed in good conditions. The car brakes are in good condition.



When the speed doubles (e.g. from 40 to 80 km h^{-1}), the stopping distance increases by much more than a factor of two. Outline how physics principles apply to this situation.

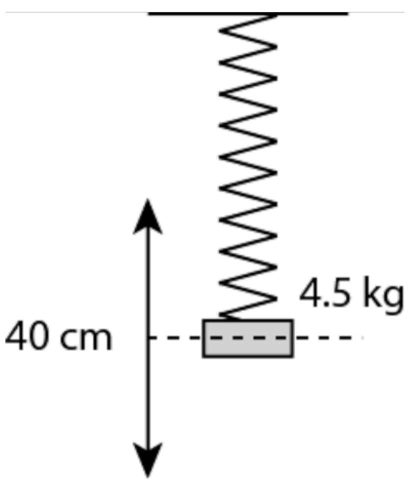
(3 marks)

Solution

The work done by the brakes $(F \times x)$ must equal $0.5mv^2$, hence as the speed goes up, the stopping distance (*x*) must go up as v^2, not as *v*.

Question 13/ 52

A mass of 4.5 kg is oscillating on the end of an ideal spring, as shown in the diagram. The amplitude of the oscillation is 40 cm. The spring constant is equal to $90\ \mathrm{N\ m^{-1}}$.



a. Show that the stretch of the spring at the centre of the oscillation is equal to 49 cm.

(2 marks)

b. Take the lowest point of the oscillation as the zero of gravitational potential energy (GPE). Calculate the GPE at the top of the oscillation.

(1 mark)

c. Calculate the elastic potential energy stored in the system at the centre of the oscillation.

(2 marks)

d. Calculate the maximum elastic potential energy of the system.

(3 marks)

Solution

a At the centre of the oscillation $kx = mg$; make *x* the subject; so $x = 0.49\ \mathrm{m}$.

b 18 J Use $\mathrm{GPE} = mg\Delta h = 17.64$, round to 18 J.

c 11 J $\mathrm{EPE} = \frac{1}{2}kx^2$; $x = 0.49\ \mathrm{m}$, so $\mathrm{EPE} = 10.80$, round to 11 J.

d 21 J Max. EPE of system is at the bottom of the oscillation where the stretch of the spring is 69 cm. Now use $\frac{1}{2}kx^2$ and round result to 2 significant figures.

Question 14/ 52

A horizontal spring launcher is used to fire ball bearings along a frictionless tube, as shown in the diagram, with the spring compressed and ready to fire. The spring is ideal.

The speed and acceleration of the ball bearing change as the spring expands.

a. Describe when the acceleration of the ball bearing is a maximum.

(1 mark)

b. Describe when the speed of the ball bearing is a maximum.

(1 mark)

c. A launcher of this design propels a 10 g ball bearing to a maximum speed of 1.5 m s^{-1} when the maximum compression of the spring is 9.0 cm. Calculate the spring constant. Include a unit in your answer.
(3 marks)

Solution

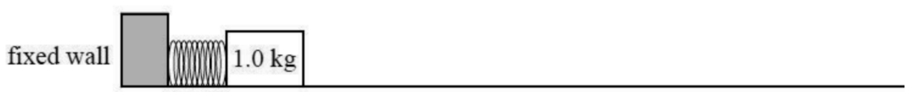
a At the start when the spring compression and spring force is maximum.

b At the time and position when the spring is fully uncompressed.

c 2.8 N m^{-1} Use $\frac{1}{2}kx^2 \text{ (EPE)} = \frac{1}{2}mv^2 \text{ (KE)}$; make *k* the subject and round to 2 significant figures.

Question 15/ 52

A spring is resting against a fixed wall. The spring is compressed by a distance of 10.0 cm from its uncompressed length. A block of mass 1.0 kg is placed against the compressed spring as shown in the diagram and then released. The block leaves the spring with a kinetic energy of 6.0 J and slides along a frictionless surface at a constant speed.



a. Calculate the speed of the block as it slides along the frictionless surface.

(2 marks)

b. Calculate the spring constant, *k*, of the spring. Assume that the spring obeys Hooke's law.

(2 marks)

Solution

Inelastic After collision, A is moving at 2 m s^{-1} (given), use conservation of momentum to calculate speed of B after (5 m s^{-1}), calculate KE_{BEFORE} (128 J) and KE_{AFTER} (108 J).

Question 16/ 52

A car has a braking distance of 18 m when travelling at 60 km h^{-1}.

Determine the braking distance for the same car under the same braking conditions and the same road conditions if the car is travelling at 40 km h^{-1}.

(2 marks)

Solution

8 m $\text{KE} = \frac{1}{2}mv^2 = F.d$ stopping distance at 40 km h^{-1}

$= \frac{40^2}{60^2}(18\text{m}) = 8\text{m}.$

Question 17/ 52

[Adapted VCAA 2016 SB Q3]

Students investigate masses oscillating on the end of a spring. They add masses and the spring extends, as shown in Diagram 1. Then they lift the masses up and release them from the spring's unstretched length, as shown in Diagram 2.

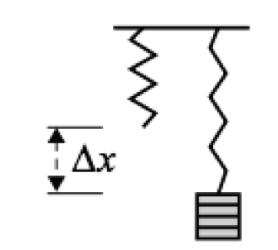


Diagram 1

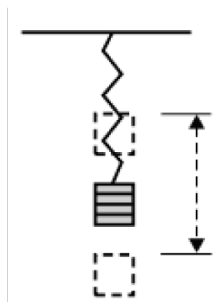
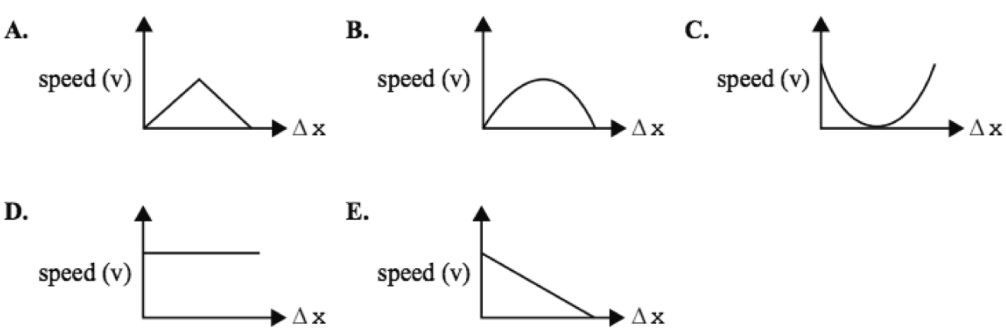


Diagram 2

Which of the graphs on the next page best shows the speed as a function of extension Δx as the masses move from top to bottom? Explain your answer.



(2 marks)

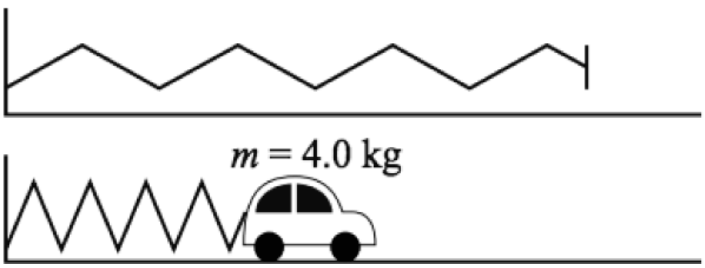
Solution

B v_{MAX} in centre of motion; graph cannot be linear.

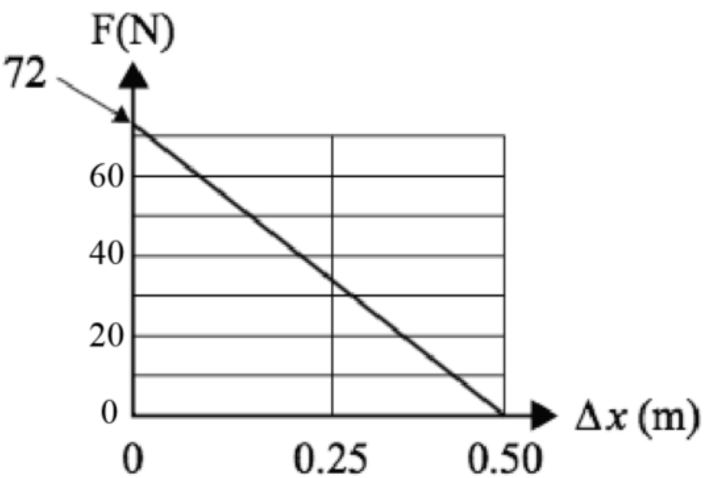
Question 18/ 52

[Adapted VCAA 2016 SB Q4]

In a test, an unpowered toy car of mass 4.0 kg is held against a spring, compressing the spring by 0.50 m, and then released, as shown below. There is negligible friction while the car is in contact with the spring.



The diagram below shows the force–extension graph for the spring.



a. Determine the energy stored in the spring before release.

(2 marks)

b. Calculate the speed of the car as it leaves the spring. Ignore any frictional forces.

(2 marks)

Solution

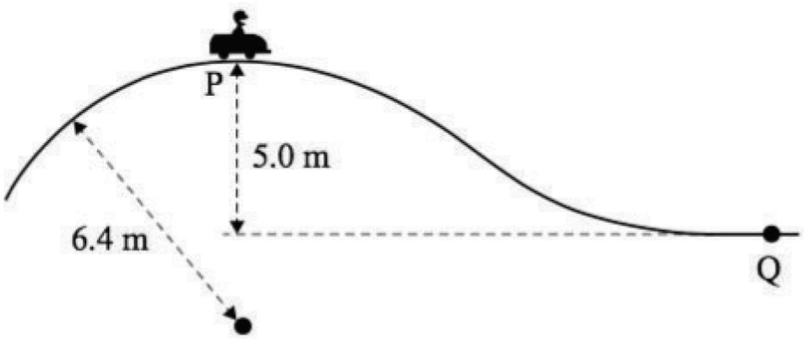
a 18 J Area under graph.

b 3.0 m s^{-1} Set spring energy $= \frac{1}{2}mv^2$.

Question 19/ 52

[Adapted VCAA 2017 SB Q8]

A roller-coaster is arranged so that the car at point P, shown below, is travelling at 4.0 m s^{-1}.



Calculate how fast the car would be moving when it reaches the bottom at point Q, 5.0 m below point P. Assume that there is no friction and no driving force on the car.

(2 marks)

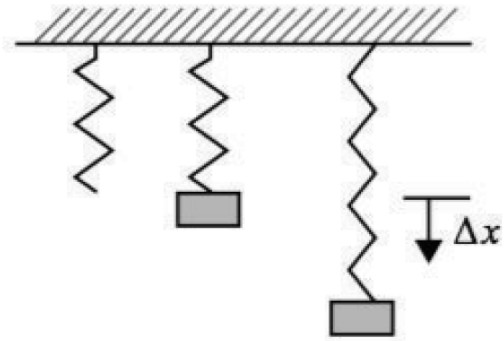
Solution

10.7 m s^{-1} $\text{KE} + \text{GPE}$ at point $\text{P} = \text{KE}$ at Q. (11 m s^{-1} acceptable)

Question 20/ 52

[VCAA 2017 SB Q13]

Pat and Robin hang a mass of 2.00 kg on the end of a spring with spring constant $k = 20.0\ \mathrm{N\ m^{-1}}$. They hold the mass at the unstretched length of the spring and release it, allowing it to fall, as shown in the diagram.



a. Determine how far the spring stretches before the mass comes momentarily to rest at the bottom. Show your working.

(3 marks)

b. Explain how the three energies involved and the total energy of the system vary as the mass falls from the top to the bottom. Calculations are *not* required.

(4 marks)

Solution

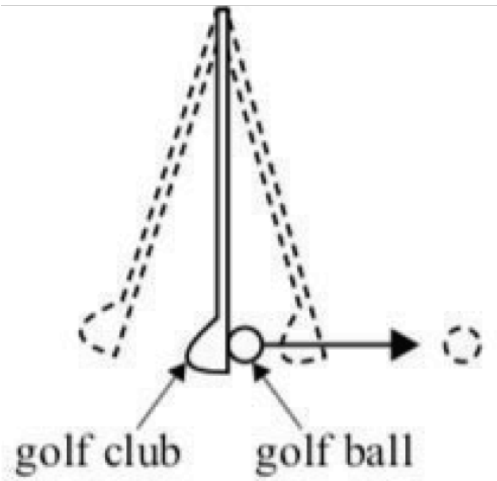
a 1.96 m At the top and bottom no KE is present, so the loss in GPE is converted into EPE. Hence $mgx = \frac{1}{2}kx^2$. Solve for *x*.

b $\text{Total energy} = \text{GPE} + \text{KE} + \text{EPE}$. At the top, $\text{KE} + \text{EPE} = 0$; GPE is max (*mgx*). As it moves towards the midpoint of the motion, GPE decreases but EPE and KE increase. At the midpoint, KE is at its maximum value; GPE is equal to half its initial value. As it approaches the bottom point, GPE and KE approach zero, but EPE approaches its maximum value.

Question 21/ 52

[VCAA 2018 SB Q7]

Students study the behaviour of a golf club hitting a golf ball. They treat it as a collision between the head of the golf club and the golf ball only, as shown.



The students take the following measurements.

mass of head of golf club	0.50 kg
mass of golf ball	0.040 kg
initial speed of golf club	45 m s^{-1}
final speed of golf club after hitting golf ball	40 m s^{-1}

The golf ball is stationary before being hit. The ball's speed immediately after being hit is 63 m s^{-1}. Use calculations to determine whether the collision is elastic or inelastic. Show your working.

(3 marks)

Solution

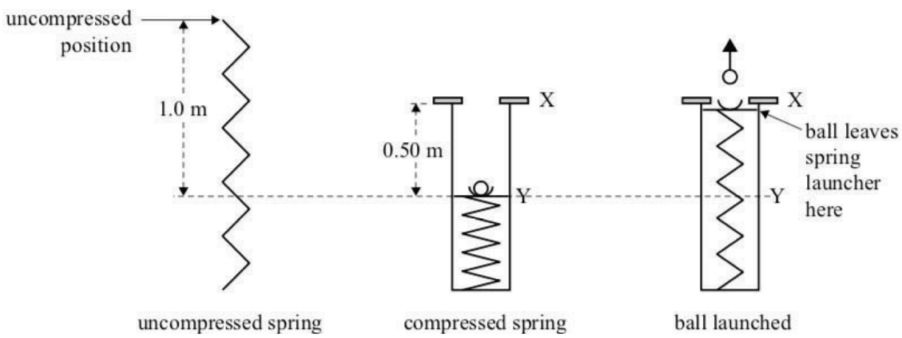
Inelastic Compare KE before and afterwards. Using $\frac{1}{2}mv^2$ this gives $\mathrm{KE}_{\mathrm{BEFORE}} = 506 \text{ J}$;

$\mathrm{KE}_{\mathrm{AFTERWARDS}} = 400 + 79.4 = 479 \text{ J}$.

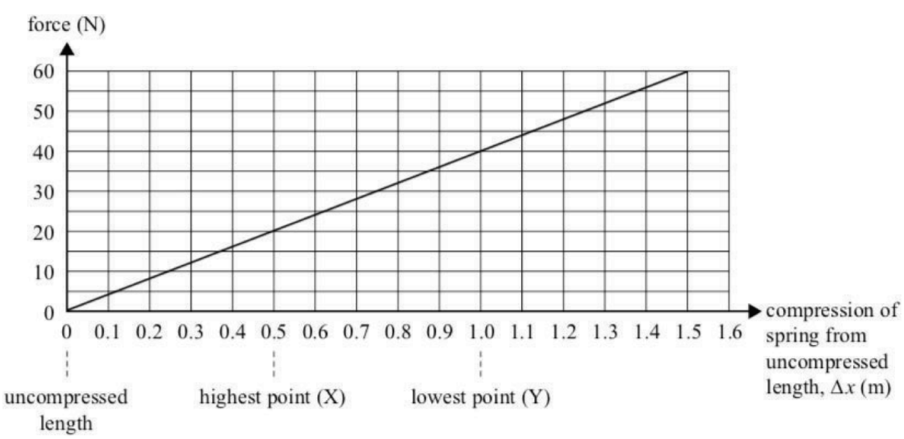
Question 22/ 52

[VCAA 2018 SB Q9]

A spring launcher is used to project a rubber ball of mass 2.0 kg vertically upwards. The arrangement is shown below. The ball is driven by a spring, which is compressed and released. When the spring reaches the top, point X, it is held stationary, but is still partly compressed as the ball leaves the launcher. Assume the spring has no mass.



The force–distance graph of the spring is below, on which the lower and upper positions of the spring in the spring launcher are marked.



a. Calculate the spring constant, *k*, of the spring.

(2 marks)

b. Calculate the change in spring potential energy of the spring as it goes from the lowest point, Y, to the highest point, X.

(3 marks)

c. The spring, with a ball in place, is released from Y. It moves up to X, where it is stopped and the ball is launched. Calculate the speed of the ball when it leaves the spring launcher. Show the steps in your working.

(4 marks)

Solution

a $40\ \mathrm{N\ m^{-1}}$ Gradient of graph.

b 15 J Area of graph between extension of 0.5 and 1.0 (or use $\frac{1}{2}k{x_1}^2 - \frac{1}{2}k{x_2}^2$).

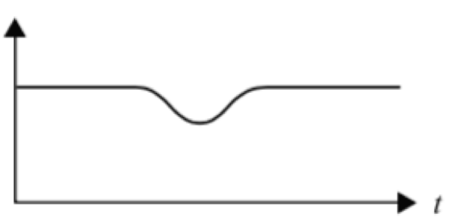
c $2.3\ \mathrm{m\ s^{-1}}$ Use energy conservation. Take GPE zero at lowest point, where KE is also zero, and $\mathrm{EPE} = 20\ \mathrm{J}$. At highest point, EPE is 5.0 J, GPE is 9.8 J, so $\mathrm{KE} = 5.2\ \mathrm{J}$ (5.0 J if g is taken as $10\ \mathrm{N\ kg^{-1}}$; this gives answer as $2.2\ \mathrm{m\ s^{-1}}$.). Use $\frac{1}{2}mv^2$.

Question 23/ 52

(Adapted VCAA 2017 Sample SB Q11)

Students observe two trolleys collide elastically on a horizontal surface.

They know that the collision is elastic but are unsure how the kinetic energy varies with time. One student, Pat, thinks that it will vary as shown in the left-hand graph below. Another student, Alex, thinks that it will vary as shown in the right-hand graph below. Who is correct? Explain your answer.



(2 marks)

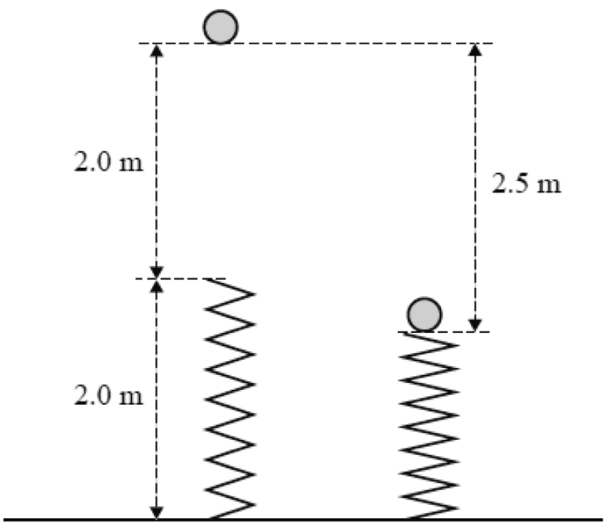
Solution

Pat is correct. Some energy is stored in the spring during the collision and then released again so that the final KE is equal to the initial KE.

Question 24/ 52

[VCAA 2018 SB Q6]

A ball of mass 2.0 kg is dropped from a height of 2.0 m above a spring, as shown below. The spring has an uncompressed length of 2.0 m. The ball and the spring come to rest when they are at a distance of 0.50 m below the uncompressed position of the spring.



a. Use $g = 9.8 \text{ N kg}^{-1}$ to show the spring constant, *k*, is equal to 392 N m^{-1}. Show your working.

(3 marks)

b. Determine the acceleration of the ball when it reaches its maximum speed. Explain your answer.

(2 marks)

c. Calculate the compression of the spring when the ball reaches its maximum speed. Show your working.

(2 marks)

Solution

a During the fall of the ball, it loses GPE given by $mgh = 2 \times 9.8 \times 2.5 = 49 \text{ J}$. Equate this to the gain in $\text{EPE} = \frac{1}{2}k(0.5)^2$.

b $0\ \mathrm{m\ s^{-2}}$ At maximum speed, the rate of change of velocity is zero.

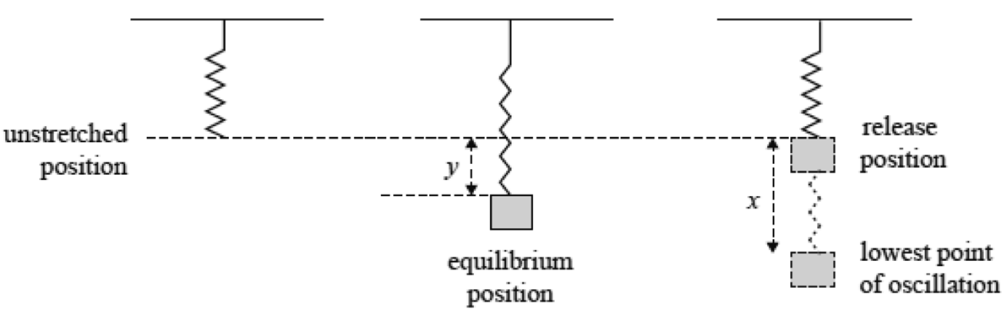
c 0.05 m When $a = 0$, forces are balanced (net force = 0) and mass is travelling at max. speed. Here, f $\text{orce down} = mg = 19.6 = \text{force up} = kx = 392x$

Question 25/ 52

[Adapted VCAA 2019 SB Q5]

Students conduct an experiment in which a mass of 2.0 kg is suspended from a spring with spring constant $k = 100\ \mathrm{N\ m^{-1}}$. Ignore the mass of the spring.

Take the gravitational field, *g*, to be $10\ \mathrm{N\ kg^{-1}}$. Take the zero of gravitational potential energy when the mass is at its lowest point. The experimental arrangement is shown below.



The mass is raised to the unstretched length of the spring and released so that it oscillates vertically.

a. Determine the distance, *x*, from the release position to the point at which the mass momentarily comes to rest at the lowest point of oscillation. Ignore frictional losses. Show your working.

(2 marks)

b. Calculate the maximum speed of the mass. Show your working.

(4 marks)

Solution

a 0.40 m Use energy conservation. KE is zero at top and bottom, so $\mathrm{GPE_{TOP}} = \mathrm{EPE_{BOTTOM}}$. Hence

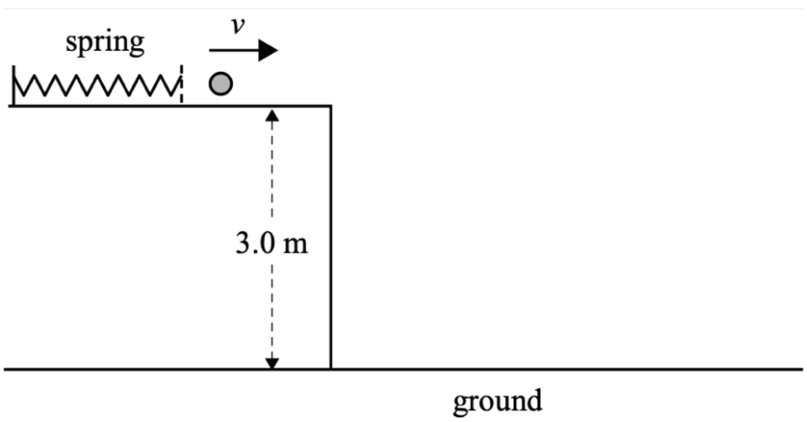
$mgx = \frac{1}{2}kx^2$ and $x =$. Alternatively, could use symmetry of oscillating motion about the equilibrium point, where $y = 0.20\ \mathrm{m}$.

b $1.4\ \mathrm{m\ s^{-1}}$ Easiest method is to observe that maximum speed occurs when $a = 0$, i.e. at the equilibrium point. Now use $\mathrm{GPE_{INITIAL}} = \mathrm{GPE_{EQUILIBRIUM\ POINT}} + \frac{1}{2}ky^2\ (\mathrm{EPE}) + \mathrm{KE_{MAXIMUM}}$. Hence $\mathrm{KE_{MAXIMUM}} = mg\,(x - y) - \frac{1}{2}ky^2 = 4 - 2 = 2 = \frac{1}{2}mv_{\mathrm{MAX}}{}^2$.

Question 26/ 52

[Adapted VCAA 2020 SB Q9]

An ideal spring is compressed by 0.15 m. A ball of mass 0.20 kg is placed in contact with the compressed spring. The spring is then released, causing the ball to move horizontally, with a velocity of *v*, across a smooth surface, as shown below.



If the spring constant is $1250\ \mathrm{N\ m^{-1}}$, show that the magnitude of the initial velocity, *v*, of the ball is $12\ \mathrm{m\ s^{-1}}$, correct to two significant figures. Show your working.

(2 marks)

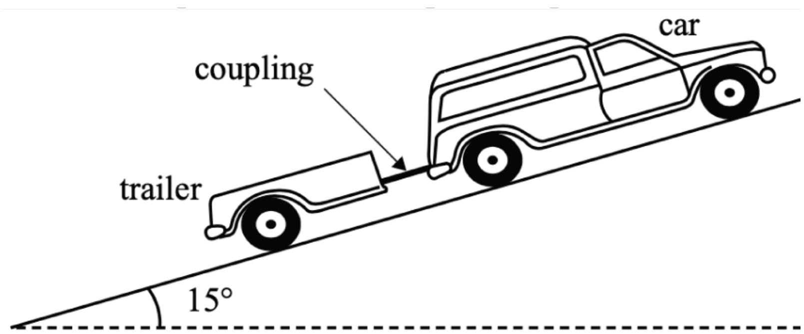
Solution

The elastic potential energy stored in the compressed spring is $0.5kx^2 = 14\ \mathrm{J}$. Since the spring is ideal, all this energy is converted into KE. Use $14 = 0.5mv^2$ to give $v = 12\ \mathrm{m\ s^{-1}}$ (to two significant figures).

Question 27/ 52

[Adapted VCAA 2021 NHT SB Q8]

A car is driving up a uniform slope with a trailer attached, as shown below. The slope is angled at 15° to the horizontal. The trailer has a mass of 200 kg and the car has a mass of 750 kg. Ignore all retarding friction forces down the slope. The car and trailer are travelling at a constant speed of $8 \mathrm{~m} \mathrm{~s}^{-1}$ up the slope.



Calculate the gravitational potential energy gained by the car and trailer when they have travelled 100 m along the slope. Show your working.

(3 marks)

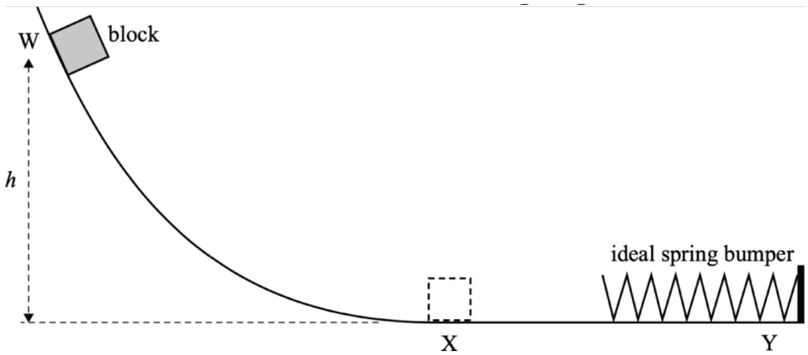
Solution

482 kJ The vertical $\text{height gained} = 200 \times \sin 15 = 51.8 \mathrm{~m}$; now use $\Delta\text{GPE} = mgh = 950 \times 9.8 \times 51.8 = 482 \mathrm{~kJ}$.

Question 28/ 52

[VCAA 2021 SB Q9]

In a model of a proposed ride at a theme park, a 5.0 kg smooth block slides down a ramp from point W and into an ideal spring bumper without any friction or air resistance, as shown below. The final section of the ramp, between points X and Y, is horizontal. The block comes to an instantaneous stop at point Y.



The maximum compression of the spring is measured as 3.0 m and its spring constant, *k*, is $100\ \mathrm{N\ m}^{-1}$. Calculate the release height, *h*. Show your working.

(3 marks)

Solution

9.2 m The loss in $\mathrm{GPE} = mgh = \mathrm{gain}$ in elastic $\mathrm{PE} = 0.5kx^2$. Equate.

Question 29/ 52

[Adapted VCAA 2021 SB Q18]

A small rubber ball of mass 50 g falls vertically from a given height and rebounds from a hard floor. Just before the ball hits the floor, it has a certain amount of kinetic energy, E_k. The ball's speed immediately before impact is $3.6\ \mathrm{m\ s}^{-1}$ and it rebounds upward at a speed of $3.3\ \mathrm{m\ s}^{-1}$. At one instant when the ball is in contact with the floor, it is stationary before it rebounds. Explain what has happened to the kinetic energy, E_k, of the ball when it is stationary.

(2 marks)

Solution

All the kinetic energy that the ball had when moving will be transformed into other forms, such as elastic potential energy, thermal energy and some sound energy. When it rebounds a part of the elastic PE will be transformed back into KE. This will be partial as the rebound speed is less than the impact speed.

Question 30/ 52

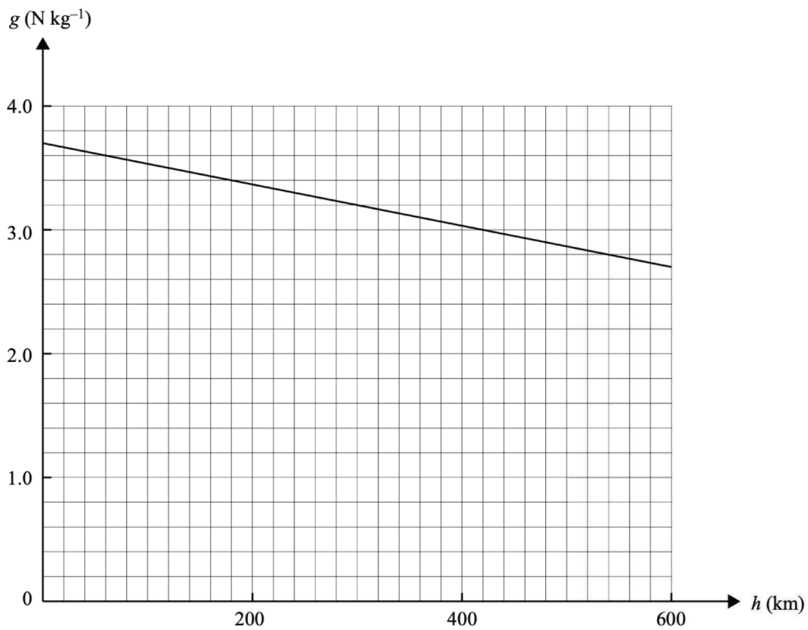
[Adapted VCAA 2021 SB Q8]

On 18 February 2021, the Perseverance rover space capsule, travelling at 20000 km h^{-1}, entered Mars's atmosphere at an altitude of 300 km above the surface of Mars. The mass of the capsule was 1000 kg.

a. Calculate the kinetic energy of the capsule at this point. Show your working.

(2 marks)

The graph below shows the gravitational field strength of Mars (*g*) versus altitude (*h*).



b. Calculate the gravitational potential energy of the capsule relative to the surface of Mars at an altitude of 300 km. Show your working.

(3 marks)

c. The capsule used aerodynamic braking as it descended through Mars's atmosphere to reduce its speed from 20000 km h^{-1} to 1600 km h^{-1}. The capsule was then at an altitude of 10 km above the surface of Mars and had ~1% of its original combined gravitational potential energy and kinetic energy remaining. Describe how ~99% of the gravitational potential energy and kinetic energy of the capsule was transformed and dissipated as the capsule descended from an altitude of 300 km above the surface of Mars to an altitude of 10 km above the surface of Mars. No calculations are required.

(3 marks)

Solution

a 1.54×10^{10} J Convert speed to $\mathrm{m\ s^{-1}}$ (divide $\mathrm{km\ h^{-1}}$ by 3.6), then use $\frac{1}{2}mv^2$.

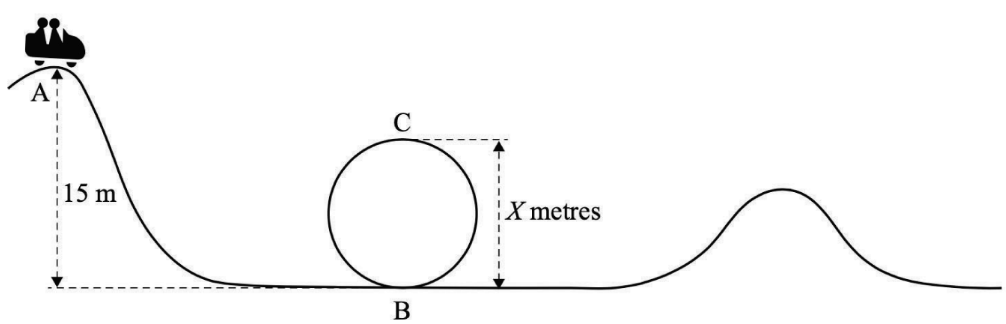
b 1.04×10^{9} J Find area under graph between 0 and 300 km, then multiply by 1000 kg (mass of capsule).

c Energy is neither created nor destroyed but may be transformed from one kind into another. Aerodynamic braking transforms the KE and GPE into thermal energy which can then be dissipated into the environment – in this case into the casing of the capsule and the Martian atmosphere.

Question 31/ 52

[Adapted VCAA 2021 SB Q9]

Abbie and Brian are about to go on their first loop-the-loop roller-coaster ride.



The highest point of the roller-coaster (point A) is 15 m above point B and the car starts at rest from point A. Assume that there is negligible friction between the car and the track. What is the speed of the car at point B? Show your working.

(2 marks)

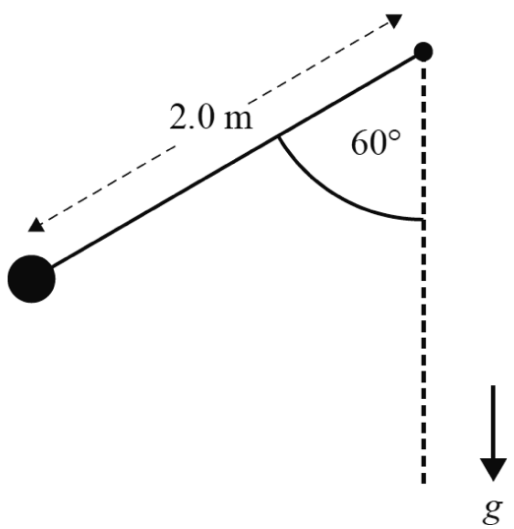
Solution

$17\ \mathrm{m\ s^{-1}}$ There is no KE at point A, only GPE. This is converted into KE at point B. Use $mgh = \frac{1}{2}mv^2$.

Question 32/ 52

[VCAA 2022 NHT SB Q7]

A spherical mass of 2.0 kg is attached to a piece of string with length of 2.0 m. The spherical mass is pulled back until it makes an angle of 60° with the vertical, as shown below. The spherical mass is then released. Ignore the mass of the string.



a. Show that the maximum speed of the spherical mass is $4.4\ \mathrm{m\ s^{-1}}$.

(2 marks)

b. At what part of its path is the spherical mass at its maximum speed? Explain your reasoning.

(2 marks)

Solution

a Use $mg\Delta h = \frac{1}{2}mv^2$; $\Delta h = 2.0\ \cos 60^\circ = 1.0$; Simplify $mg\Delta h = \frac{1}{2}mv^2$ to $v^2 = 2gh =$

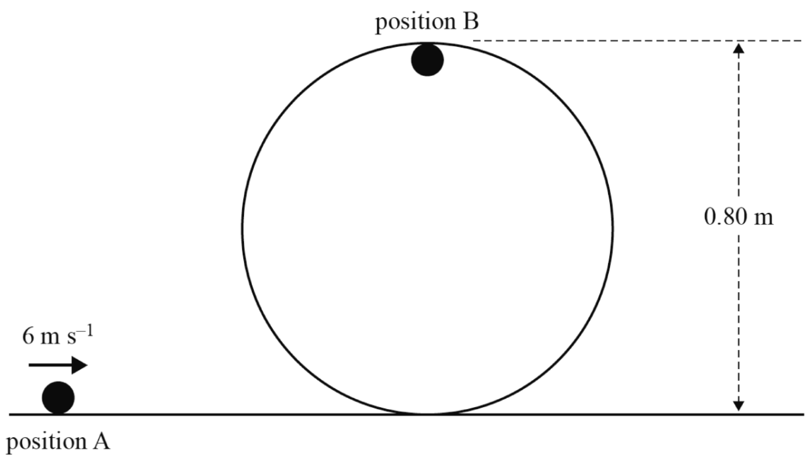
19.6, so $v = 4.4 \text{ m s}^{-1}$.

b Mass has lost most of its GPE at the bottom of its swing, so it has gained the most KE at this point.

Question 33/ 52

[Adapted VCAA 2022 NHT SB Q9]

A small ball of mass 0.30 kg travels horizontally at a speed of 6 m s^{-1}. It enters a vertical circular loop of diameter 0.80 m, as shown below. Assume that the radius of the ball and that the frictional forces are negligible.



Show that the kinetic energy of the ball at position A is 5.4 J.

(1 mark)

Solution

$$\text{KE} = \frac{1}{2} \text{ m v}^2 = 0.5 \times 0.3 \times 6^2 = 5.4 \text{ J}.$$

Chapter 4 Momentum and collisions

Question 1/ 20

Two rollerbladers (Jack and Jill) are skating with very little frictional resistance to their motion. Jack rolls up to Jill, who is skating more slowly in the same direction. They join hands and roll on in the same direction, without accelerating.

Which of the following describes the physics of this ‘collision’ best?

A The combined momentum and KE has not changed.

B The combined KE has remained constant.

C The combined momentum has remained constant.

D Both the combined momentum and KE have changed.

Solution

C Momentum is always conserved, but energy not always.

Question 2/ 20

Two snooker balls of unknown quality travel directly towards each other, as shown below. They have the same mass.

Which one of the combinations in the table below is *impossible* immediately after the collision? Take right as positive.

Velocity of ball A ($\mathrm{ms^{-1}}$) **Velocity of ball B ($\mathrm{ms^{-1}}$)**

Velocity of ball A (ms^{-1})	Velocity of ball B (ms^{-1})
$+4$	-1.0
-3.0	0.0
-1.5	-1.5
-5.5	$+2.5$

Solution

A Violates momentum conservation (momentum is a vector).

Question 4/ 20

In one instance, the blocks stick together after the collision, due to (very) quick-acting glue. Their speed after the collision is closest to

A $1.0 \mathrm{~m~s}^{-1}$

B $1.2 \mathrm{~m~s}^{-1}$

C $1.5 \mathrm{~m~s}^{-1}$

D $1.8 \mathrm{~m~s}^{-1}$

Solution

A Use conservation of momentum.

Question 5/ 20

On another occasion, the blocks collide elastically. The speed of the two blocks is closest to the following speeds (the 1.2 kg block speed is written first; the units are $\mathrm{m\ s^{-1}}$).

A (2, 1)

B (1, 2)

C (1.5, 1.5)

D (0, 1.5)

Solution

B Conservation of momentum and energy but you have to assume that the 1.2 kg block moves left after the collision.

Question 6/ 20

A golf club head (mass 250 g) travelling at $30\ \mathrm{m\ s^{-1}}$ strikes a stationary golf ball (mass 50 g). During the collision, the golf club head slows to $22\ \mathrm{m\ s^{-1}}$. Which of the following is closest to the impulse acting on the golf ball during the collision?

A 0.2 N s

B 0.4 N s

C 2 N s

D 4 N s

Solution

C Same as impulse on club head $(= 0.25 \times 8)$.

Question 7/ 20

The speed of the golf ball after the collision is closest to

A $22 \mathrm{~m} \mathrm{~s}^{-1}$

B $28 \mathrm{~m} \mathrm{~s}^{-1}$

C $40 \mathrm{~m} \mathrm{~s}^{-1}$

D $240 \mathrm{~m} \mathrm{~s}^{-1}$

Solution

C $\text{Impulse} = 2 = 0.05 \times v$

Question 8/ 20

The collision could best be described as

A elastic, with no loss of KE.

B inelastic, with a loss of 12 J.

C inelastic, with a loss of 40 J.

D inelastic, with a loss of 60 J.

Solution

B Calculate KE before and after.

Question 9/ 20

In a collision between two objects, where they stick together after the collision, it is true to say that

A all the KE is always lost to other forms.

B sometimes all the KE is lost to other forms.

C sometimes the collision is elastic.

D sometimes some of the momentum is changed to other forms.

Solution

B C and D false; A can only occur in some head-on collisions.

Question 11/ 20

[VCAA 2017 SA Q7]

Which of the following best gives the magnitude of the impulse given to the car by the rocket motor in the first 5.0 s?

A 4.0 N s

B 8.0 N s

C 20 N s

D 40 N s

Solution

C $\quad$ Use impulse $= F \times t$

Question 12/ 20

[VCAA 2017 SA Q9]

With the same rocket motor, the car accelerates from rest for 10 s. Which one of the following best gives the final speed?

A 6.3 m s^{-1}

B 10 m s^{-1}

C 20 m s^{-1}

D 40 m s^{-1}

Solution

C $\quad$ Impulse $(40 \times 10) = m\Delta v$

Question 13/ 20

An X-ray photon with a momentum of 6.0×10^{-23} N s collides with a stationary electron. The electron's momentum gain is 1.0×10^{-22} N s, and it is in the same direction as the X-ray photon. Which of the following is closest to the magnitude of the momentum of the scattered photon?

A 4×10^{-11} N s

B 4×10^{-17} N s

C 4×10^{-23} N s

D 4×10^{-30} N s

Solution

C Conservation of momentum (scattered backwards)

Question 14/ 20

Two atoms travelling at the same speed towards each other collide and bounce off at the same speed, going in opposite directions. Which of the following statements is correct?

A The collision increases the total amount of energy.

B Kinetic energy is conserved throughout the collision.

C The collision reduces the total momentum.

D The total momentum before the collision is zero.

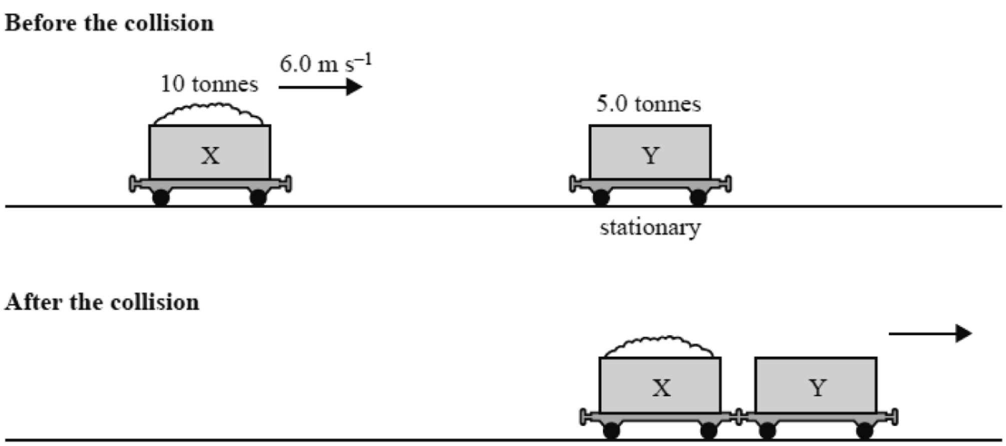
Solution

D Momentum is a vector quantity.

Question 15/ 20

[VCAA 2018 SA Q8]

A railway truck X of mass 10 tonnes, moving at $6.0\ \mathrm{m\ s^{-1}}$, collides with a stationary railway truck Y of mass 5.0 tonnes. After the collision, the trucks are joined together and move off as one. The situation is shown below.



The final speed of the joined railway trucks after the collision is closest to

A $2.0\ \mathrm{m\ s^{-1}}$

B $3.0\ \mathrm{m\ s^{-1}}$

C $4.0\ \mathrm{m\ s^{-1}}$

D $6.0\ \mathrm{m\ s^{-1}}$

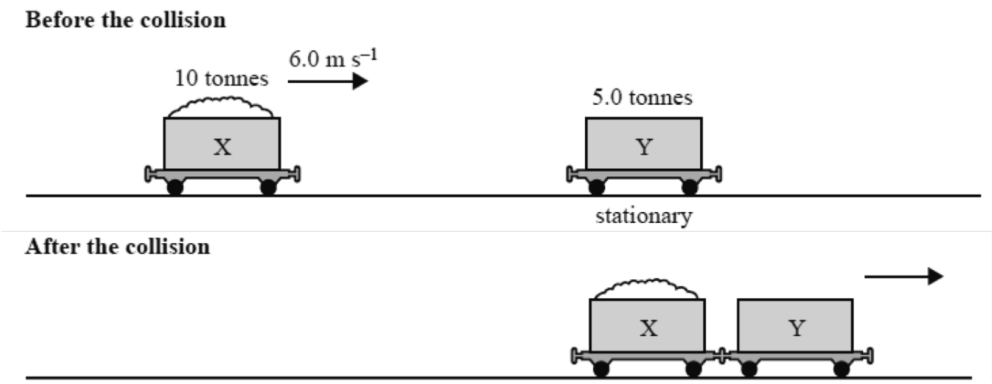
Solution

C $\quad$ $\text{Momentum before} = 10\ 000 \times 6 = \text{momentum after} = 15\ 000 \times v$

Question 16/ 20

[VCAA 2018 SA Q9]

A railway truck X of mass 10 tonnes, moving at 6.0 m s^{-1}, collides with a stationary railway truck Y of mass 5.0 tonnes. After the collision, the trucks are joined together and move off as one. The situation is shown below.



The collision of the railway trucks is best described as one where

A kinetic energy is conserved but momentum is not conserved.

B kinetic energy is not conserved but momentum is conserved.

C neither kinetic energy nor momentum is conserved.

D both kinetic energy and momentum are conserved.

Solution

B   Momentum is always conserved in isolated systems; in ‘sticky‘ collisions KE is not conserved.

Question 17/ 20

[VCAA 2019 SA Q20]

As part of their Physics course, Anna, Bianca, Chris and Danshirou investigate the physics of car crashes. On an internet site that describes what happens during car crashes, they find the following statement.

> *It happens in a flash: your car goes from driving to impacting … As the vehicle crashes into something, it stops or slows very abruptly, and at the point of impact the car's structure will bend or break. That crumpling action works to absorb some of the initial crash forces, protecting the passenger compartment to some degree.*

Source: Kathleen Poling, 'Crash Dynamics for Dummies', Car Seats for the Littles, 3 January 2018, www.csftl.org/crash-dynamics-dummies/

The students disagree about the use of the word 'forces' in the statement,

'That crumpling action works to absorb some of the initial crash forces, protecting the passenger compartment to some degree'.

Which one of the following students best identifies the physics of how the crumpling action protects the passengers?

A Anna '*to absorb some of the initial crash speed, protecting …*'

B Bianca '*to absorb some of the initial crash kinetic energy, protecting …*'

C Chris '*to absorb some of the initial crash momentum, protecting …*'

D Danshirou '*to absorb some of the initial crash forces, protecting …*'

Solution

B Kinetic energy can be transformed into other forms (e.g. sound energy, thermal energy). Momentum (and forces) are always passed on; they are not 'absorbed'.

Question 18/ 20

[VCAA 2021 SA Q3]

A 45 g golf ball, initially at rest, is hit by a golf club. The contact time between the club and the ball is 0.50 ms. The magnitude of the final velocity of the ball is 41 m s^{-1}. Which one of the following is closest to the average force experienced by the golf ball?

A 0.18 kN

B 0.37 kN

C 1.8 kN

D 3.7 kN

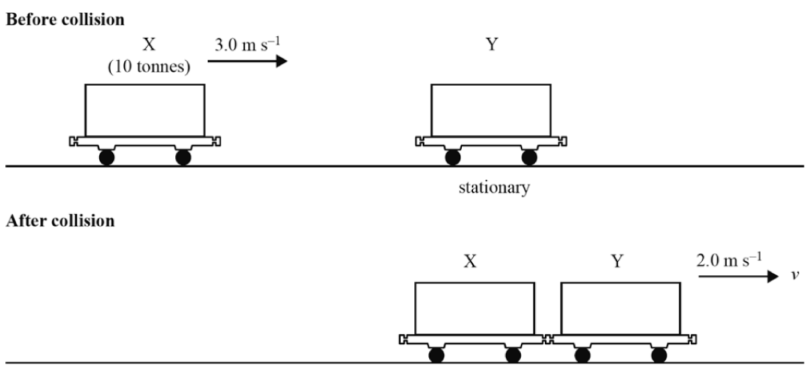
Solution

D Use $F\Delta t = m\Delta v$; make F the subject.

Question 19/ 20

[VCAA 2022 SA Q6]

A railway truck (X) of mass 10 tonnes, moving at $3.0\ \mathrm{m\ s^{-1}}$, collides with a stationary railway truck (Y), as shown in the diagram below. After the collision, they are joined together and move off at speed $v = 2.0\ \mathrm{m\ s^{-1}}$.



Which one of the following is closest to the mass of railway truck Y?

A 3 tonnes

B 5 tonnes

C 6.7 tonnes

D 15 tonnes

Solution

B $\text{Momentum before} = 30 = \text{Momentum after} = (10 + m_{\text{Y}}) \times 2$; solve for m_{Y}.

Question 20/ 20

[VCAA 2022 SA Q7]

Which one of the following best describes the force exerted by the railway truck X on the railway truck $\text{Y}\ (F_{X\ on\ Y})$ and the force exerted by the railway truck Y on the railway truck $\text{X}\ (F_{Y\ on\ X})$ at the instant of collision?

A $F_{\text{X on Y}} < F_{\text{Y on X}}$

B $F_{\text{X on Y}} = F_{\text{Y on X}}$

C $F_{\text{X on Y}} = -F_{\text{Y on X}}$

D $F_{\text{X on Y}} > F_{\text{Y on X}}$

Solution

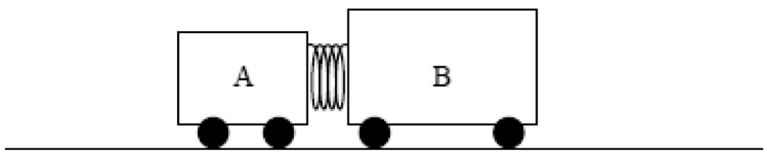
B Apply Newton's third law.

Question 21/ 20

[Adapted VCAA NHT 2023 SA Q9]

The diagram below shows two stationary trolleys on a smooth surface, with an ideal spring compressed between them. Trolley A has mass of 1.0 kg and Trolley B has mass of 2.5 kg. The spring is released and the trolleys move off in opposite directions. The spring falls straight down.

Trolley A moves to the left at $0.80\ \mathrm{m\ s^{-1}}$.



Which one of the following is closest to the speed of Trolley B?

A $0.32\ \mathrm{m\ s^{-1}}$

B $0.80\ \mathrm{m\ s^{-1}}$

C $2.0\ \mathrm{m\ s^{-1}}$

D $3.1\ \mathrm{m\ s^{-1}}$

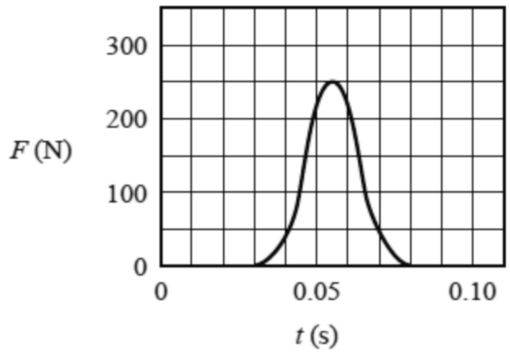
Solution

A Conservation of momentum $(1 \times 0.8) = (2.5 \times v)$

Question 22/ 20

[VCAA 2023 SA Q4]

The diagram below shows the force versus time graph of the force on a tennis ball when it is hit by a tennis racquet. The tennis ball is stationary when the tennis racquet first comes into contact with the ball.



Which one of the following is closest to the impulse experienced by the tennis ball as it is hit by the tennis racquet?

A 0.50 N s

B 5.0 N s

C 10 N s

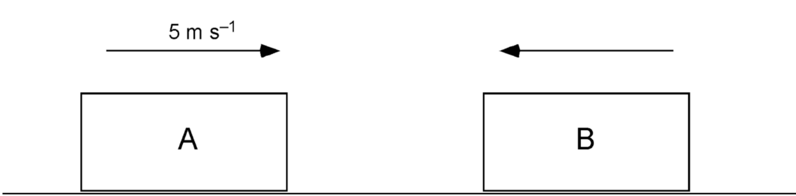
D 50 N s

Solution

B The impulse is given by the area under the force vs time graph. Using a triangle gives 5 N s.

Question 1/ 46

Students are studying collisions between blocks of wood on a flat frictionless table. The blocks slide towards each other as shown in the diagram.



Block A is travelling to the right at $5\ \mathrm{m\ s^{-1}}$; block B is moving to the left. Block A has a mass of 4 kg, and block B has a mass of 8 kg. After they collide, block A moves to the *left* with a speed of $5\ \mathrm{m\ s^{-1}}$, and block B is stationary.

a. Calculate the speed of block B *before* the collision. Show your reasoning.

(2 marks)

b. Does this collision conserve kinetic energy? You must justify your conclusion with calculations.

(2 marks)

Solution

a $5\ \mathrm{m\ s^{-1}}$ Balance momentum before and after – remember direction!

b No $\mathrm{KE\ before} = 150\ \mathrm{J}; \mathrm{KE\ after} = 50\ \mathrm{J}$

Question 2/ 46

A 500 kg car travelling at $5\ \mathrm{m\ s^{-1}}$ runs into a stationary truck of mass 3.0 t. The truck moves forward at $1.0\ \mathrm{m\ s^{-1}}$, and the car rebounds in the opposite direction. What is the speed of the car straight after the collision? (Ignore external forces during the collision.)

(3 marks)

Solution

$1.0\ \mathrm{m\ s^{-1}}$ $\mathrm{Momentum\ before} = +2500 = 3000 - 500u$

Question 3/ 46

The collision between two snooker balls can be modelled by two isolated masses colliding.

Show that momentum is conserved in this collision.

(2 marks)

Solution

Take the mass of each $\text{ball} = m; \text{mom}_{\text{BEFORE}} = 2m = (1.5 + 0.5)m = \text{mom}_{\text{AFTER}}$.

Question 4/ 46

Two rollerbladers (Jack and Jill) are skating with good skates on a surface that has virtually no frictional resistance to their rolling. Jack has a mass of 55 kg. He rolls up to Jill at 5 m s^{-1}. Jill has a mass of 45 kg, and she is rolling at 1 m s^{-1} in the same direction as Jack.

a. They join hands and roll on in the same direction. They do not skate. How fast will they be moving?

(2 marks)

b. Without pushing or pulling, Jack and Jill let go of each other. Describe what happens immediately after they let go. Justify your description with relevant physics.

(3 marks)

Solution

a 3.2 m s^{-1} $\text{Momentum}_{\text{BEFORE}} = 55 \times 5 + 45 \times 1 = 320 = 100u$

b Both will roll on at the same speed. They have not exerted any forces on each other; therefore, they cannot have accelerated (or use momentum conservation).

Question 5/ 46

A car travelling at $6 \mathrm{~m~s^{-1}}$ crashes into two stationary cars. All the cars have the same mass (150 kg). They stick together and travel in the same direction as before. There is very little friction and no injuries.

a. How fast are they all travelling after the crash?

(2 marks)

b. How much momentum has the first car lost in the crash?

(2 marks)

c. What impulse did the first car exert on the other two cars?

(2 marks)

Solution

a $2 \mathrm{~m~s^{-1}}$ Conservation of momentum.

b $600 \mathrm{~kg~m~s^{-1}}$ $m\Delta v$

c $600 \mathrm{~kg~m~s^{-1}}$ Impulse = change in momentum.

Question 6/ 46

Two cars, both travelling at $U \text{ m s}^{-1}$, collide head on and lock together. The right-hand car has mass *M* and the left-hand car has mass *m*.

Straight after the collision, the wreckage travels *left* at $V \text{ m s}^{-1}$.

a. What is the magnitude of the total momentum before the collision? (Give your answer in terms of *M*, *m*, and *U*.) (2 marks)

b. Derive an expression for *V* in terms of *U, m* and *M*. (2 marks)

Solution

a $U\,(M - m)$ Positive taken to the right, otherwise $U\,(M - m)$; momentum conservation.

b Equate $U\,(M - m)$ to $(M + m)\,V$.

Question 7/ 46

In a car, the driver's head collides horizontally with an airbag at 8.0 m s^{-1}. The driver's head stops in 0.16 s. This can be modelled as a horizontal collision between the head (mass 7.0 kg) and the airbag.

a. Calculate the magnitude of the impulse that the airbag exerts on the driver's head during this collision.

(2 marks)

b. Compare the impulse that the airbag exerts on the driver's head with the impulse that the driver's head exerts on the airbag.

(1 mark)

Solution

a 56 N s Use $\text{Impulse} = m\Delta v$.

b The impulse will be exactly the same (i.e. 56 N s) from Newton's third law.

Question 8/ 46

[Adapted VCAA 2016 SB Q8]

An X-ray photon with a momentum of $6.6 \times 10^{-23}\ \text{N s}$ collides with a stationary electron. The electron's momentum gain is $1.1 \times 10^{-22}\ \text{N s}$ in the same direction as the incident X-ray photon. Calculate the magnitude of the momentum of the photon after the collision.

(2 marks)

Solution

4.4×10^{-23} N s $6.6 \times 10^{-23}\ (p_{\text{BEFORE}}) = 11 \times 10^{-23} + x(p_{\text{AFTER}})$; solve for *x* (will be negative, i.e. to left).

Question 9/ 46

A basketball is bounced on a floor, striking the floor at 8 m s^{-1}, and rebounding at 6 m s^{-1}. Its mass is 400 g. The collision takes 80 ms.

a. What is the change in velocity of the ball during its bounce?

(2 marks)

b. What is the impulse of the net force on the ball during its bounce?

(2 marks)

c. What is the average net force exerted on the ball during its bounce?

(2 marks)

Solution

a 14 m s^{-1} (up) $\Delta v = 8 - (-6)$: velocity is a vector quantity.

b 5.6 N s Equate impulse to change in momentum $m\Delta v$.

c 70 N $\text{Impulse} = F\Delta t$

Question 10/ 46

Airbags in cars are designed to lengthen the time of collisions of people with parts of the car in accidents. Explain why this should lead to fewer injuries to people in cars.

(4 marks)

Solution

$F = \frac{m\Delta v}{\Delta t}$; hence, if Δt is extended, the average force is lowered. Collisions with an airbag have a longer Δt than collisions with harder objects.

Question 11/ 46

A mass collides with another mass in deep space (where $g = 0$). Magnets ensure the masses stick together. They move off at the same speed (conservation of momentum). In a similar collision on a table on Earth, both masses come to a stop quickly.

Explain why.

(3 marks)

Solution

Conservation of momentum applies to a whole system; when external forces are involved (e.g. in the second case) other masses are involved.

Question 12/ 46

The law of conservation of momentum applies in *isolated* systems. Explain what is meant by an isolated system.

(2 marks)

Solution

An *isolated system* is not acted upon by external forces; every force in the system has an equal and opposite *action–reaction* force in the system. Every impulse is balanced by an equal and opposite impulse, hence conservation of momentum in the system.

Question 13/ 46

[Adapted VCAA 2016 SA Q1]

An engine of mass 20 tonnes and moving at $3.0\ \mathrm{m\ s^{-1}}$ collides with a stationary wagon of mass 10 tonnes. They couple together and move off at $2.0\ \mathrm{m\ s^{-1}}$, as shown.

Determine whether the collision is elastic or inelastic. Show your working.

(2 marks)

Solution

Inelastic $\mathrm{KE_{BEFORE}} = \frac{1}{2}mu^2 = 90\ 000\ \mathrm{J}; \mathrm{KE_{AFTER}} = 60\ 000\ \mathrm{J}$

Question 14/ 46

A physics student, Sam K, is playing soccer.

a. Calculate the impulse she gives to a stationary soccer ball of mass 400 g that is kicked and moves off at a speed of $30\ \mathrm{m\ s^{-1}}$ ($108\ \mathrm{km\ h^{-1}}$).

(2 marks)

b. Determine the average force of her kick if the impact between her foot and the soccer ball lasts 6.0 ms.

(2 marks)

Solution

a 12 N s Impulse on soccer $\text{ball} = m\Delta v = (0.4)\,(30) = 12\ \text{N s}$.

b 2000 N Average force on soccer $\text{ball} = m\Delta v/\Delta t = 12/\,(0.06) = 2000\ \text{N}$

Question 15/ 46

[Adapted VCAA 2016 SA Q1]

An engine of mass 20 t moving at $3.0\ \text{m s}^{-1}$, collides with a stationary wagon of mass 10 t. They couple and move off together, as shown.

a. Calculate the speed of the engine and the wagon after the collision.

(2 marks)

b. In another situation the engine, moving to the right at $2.0\ \text{m s}^{-1}$, collides with but does not couple with the stationary wagon. After the collision, the wagon moves off to the right at $2.0\ \text{m s}^{-1}$. Calculate the velocity (speed and direction) of the engine after the collision. Show your working.

(3 marks)

Solution

a $2.0\ \text{m s}^{-1}$ Use conservation of momentum.

b $1.0\ \text{m s}^{-1}$; to right Use conservation of momentum; take v_{LEFT} as negative.

Question 16/ 46

[Adapted VCAA 2016 SA Q4]

A toy car of mass 4.0 kg is held against a compressed spring, and released. Friction is negligible. The car moves off at $2.0\ \mathrm{m\ s^{-1}}$.

Calculate the impulse given to the car by the spring. Include a unit.

(2 marks)

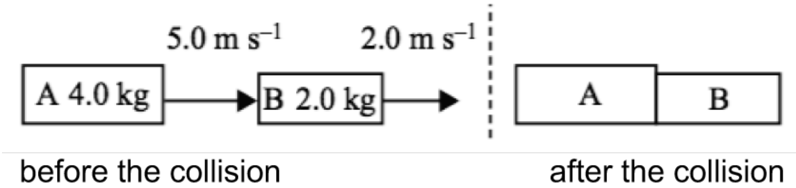
Solution

$8.0\ \mathrm{N\ s}\ \left(\mathrm{kg\ m\ s^{-1}}\right)$ Use $I = F\Delta t = m\Delta v$.

Question 17/ 46

[VCAA 2017 SB Q12]

Students are using two trolleys, Trolley A of mass 4.0 kg and Trolley B of mass 2.0 kg, to investigate kinetic energy and momentum in collisions. Before the collision, Trolley A is moving to the right at $5.0\ \mathrm{m\ s^{-1}}$ and Trolley B is moving to the right at $2.0\ \mathrm{m\ s^{-1}}$, as shown in the diagram. The trolleys collide and lock together, as shown on the next page.



Determine, using calculations, whether the collision is elastic or inelastic. Show your working and justify your answer.

(3 marks)

Solution

Use conservation of momentum to show speed after collision is 4.0 m s^{-1}. Then compare KE before the collision (54 J) with KE after the collision (48 J). Hence, the collision is inelastic.

Question 18/ 46

[VCAA 2017 Sample SB Q11]

Students conduct an experiment using two trolleys, A and B, of mass 6.0 kg and 2.0 kg respectively. In the experiment, Trolley A moves at 2.0 m s^{-1} and Trolley B is stationary before they collide. There is a spring between the two trolleys, attached to Trolley B. When the trolleys collide, they compress the spring and then move apart. After the collision, Trolley A moves at 1.0 m s^{-1}. The experimental set-up is shown below. Ignore the mass of the spring.

Calculate the speed of Trolley B immediately after the collision.

(2 marks)

Solution

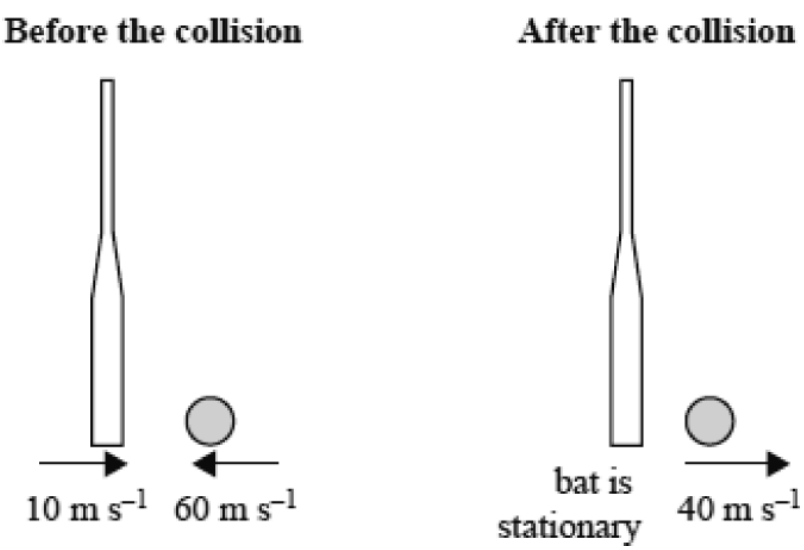
$3.0\ \mathrm{m\ s^{-1}}$ Use conservation of momentum; $\mathrm{p_{BEFORE}} = 12\ \mathrm{N\ s}$ (to the right); $\mathrm{p_{AFTER}} = 6 + 2v_{\mathrm{B}}$. All quantities are to the right.

Question 19/ 46

[VCAA 2019 NHT SB Q7]

Students use high-speed photography to analyse a collision between a bat and ball. The experiment is arranged so that the bat and ball are both moving horizontally just before and just after the collision, as shown below. Assume that the bat and ball are point masses. The students record the following.

- $\text{Mass of bat} = 2.0\ \text{kg}$
- $\text{Mass of ball} = 0.20\ \text{kg}$
- $\text{Speed of bat immediately before collision} = 10\ \text{m s}^{-1}$ (bat is stationary after collision)
- $\text{Speed of ball immediately before collision} = 60\ \text{m s}^{-1}$ (towards bat)
- $\text{Speed of ball immediately after collision} = 40\ \text{m s}^{-1}$ (away from bat)
- $\text{Time ball is in contact with bat} = 0.010\ \text{s}$



a. Calculate the magnitude of the impulse given by the bat to the ball. Include an appropriate unit. Show your working.

(3 marks)

b. Calculate the average force of the bat on the ball during the collision. Show your working.

(2 marks)

c. Use calculations to determine whether the collision between the bat and the ball is elastic or inelastic. Show your working.

(2 marks)

Solution

a 20 N s $\text{Impulse } I = \text{change in momentum of ball} = 0.2 \times 100$. Remember p is a vector.

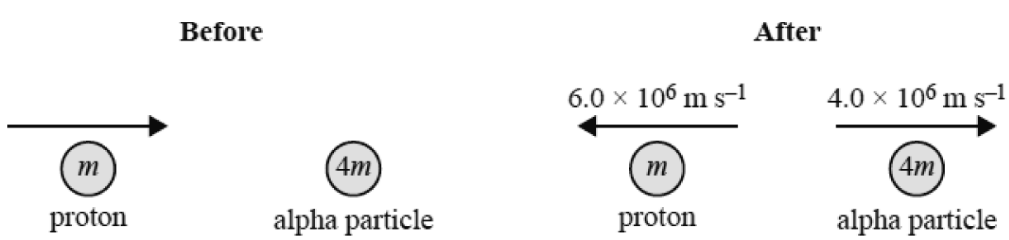
b 2000 N $\text{Impulse on ball} = F_{\text{AVERAGE}} \times t$, so $F_{\text{AVERAGE}} = \frac{20}{0.01}$.

c Inelastic Total $\text{KE}_{\text{BEFORE}} = 460 \text{ J}$ is greater than $\text{KE}_{\text{AFTER}} = 160 \text{ J}$.

Question 20/ 46

[VCAA 2019 SB Q9]

A proton in an accelerator collides head-on with a stationary alpha particle, as shown below. After the collision, the alpha particle travels at a speed of $4.0 \times 10^6 \text{ m s}^{-1}$. The proton rebounds at $6.0 \times 10^6 \text{ m s}^{-1}$.



Find the proton speed before the collision. Model the alpha particle mass as 4*m*, and the proton mass as *m*. Show your working. Ignore relativistic effects.

(3 marks)

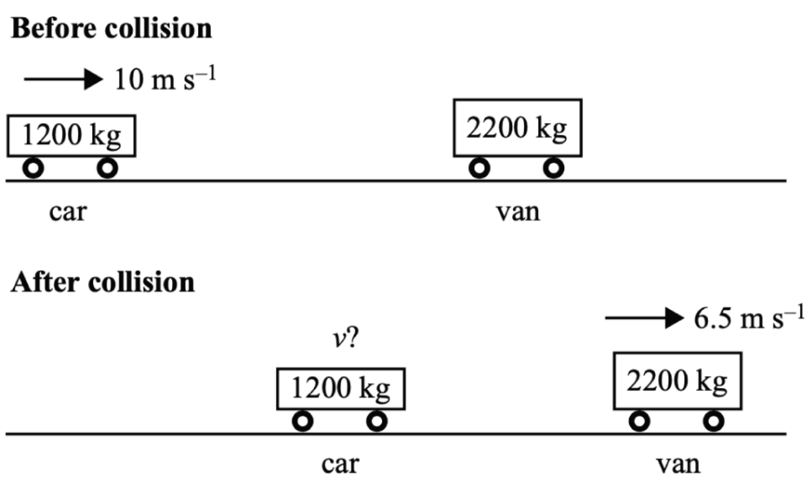
Solution

1.0×10^7 m s^{-1} Momentum before $= mv$ is equal to the momentum afterwards $= 4m \times 4.0 \times 10^6 - m \times 6.0 \times 10^6$; solve for *v*. Note the need for a minus sign to indicate vector nature of momentum.

Question 21/ 46

[VCAA 2020 SB Q10]

Jacinda designs a computer simulation program as part of her practical investigation into the physics of vehicle collisions. She simulates colliding a car of mass 1200 kg, moving at 10 m s^{-1}, into a stationary van of mass 2200 kg. After the collision, the van moves to the right at 6.5 m s^{-1}. The situation is shown below.



a. Calculate the speed of the car after the collision and indicate the direction it would be travelling in. Show your working.

(4 marks)

b. Explain, using appropriate physics, why this collision represents an example of either an elastic or an inelastic collision.

(3 marks)

c. i. The collision between the car and the van takes 40 ms. Calculate the magnitude and indicate the direction of the average force on the van by the car.

(3 marks)

ii. Calculate the magnitude and indicate the direction of the average force on the car by the van.

(2 marks)

Solution

a $1.9\ \mathrm{m\ s}^{-1}$, leftwards Momentum is conserved, hence $p_{\text{BEFORE}} = 12\ 000 = p_{\text{AFTER}} = 12v - 22 \times 6.5$. Solve for *v*. Minus sign indicates leftward motion.

b Inelastic KE before $\left(\text{using } 0.5\,mv^2\right) = 6.0 \times 10^4\ \text{J; KE after} = 4.9 \times 10^4\ \text{J}$.

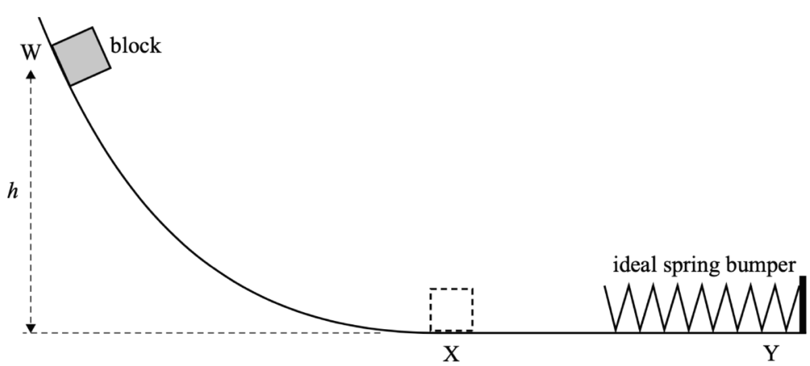
ci 358 kN; rightwards Use $F_{\text{AVERAGE}} = \frac{\Delta p}{\Delta t} = \frac{2200 \times 6.5}{0.04} = 358\ \text{kN}$.

cii 358 kN; leftwards Follows directly from Newton's third law. No calculation needed.

Question 22/ 46

[Adapted VCAA 2021 SB Q9]

In a model of a proposed ride at a theme park, a 5.0 kg smooth block slides down a ramp from point W and into an ideal spring bumper without any friction or air resistance, as shown below. The final section of the ramp, between points X and Y, is horizontal. The block comes to an instantaneous stop at point Y. The maximum compression of the spring is 3.0 m and the spring constant is $100\ \mathrm{N\ m}^{-1}$.



a. Calculate the magnitude of the maximum momentum of the block. Show your working.

(2 marks)

b. When the block comes to rest, its momentum is zero. In terms of the principle of conservation of momentum, state what has happened to the momentum of the block as it comes to rest.

(1 mark)

Solution

a 67 kg m s^{-1} First find speed at point X from $0.5mv^2 = 0.5kx^2$; this gives $v_{\text{MAX}} = 13.4 \text{ m s}^{-1}$. So $\text{maximum momentum} = 67 \text{ kg m s}^{-1}$.

b The momentum of the block is transferred to the compressed spring and whatever the spring is fixed to.

Question 23/ 46

[Adapted VCAA 2021 NHT SB Q18]

A small rubber ball of mass 50 g falls vertically from a given height and rebounds from a hard floor. Just before the ball hits the floor, it has a certain amount of vertical momentum, *p*. At one instant when the ball is in contact with the floor, it is stationary before it rebounds.

What has happened to the vertical momentum, *p*, of the ball when it is stationary?

(1 mark)

Solution

The momentum of the block is transferred to the floor, then the building and finally, Earth.

Question 24/ 46

[Adapted VCAA 2021 SB Q17]

A 'space sail' on a tiny interstellar cylindrical probe relies on the momentum of photons from a nearby star to exert a propulsive force, as shown.

Missing Image

2.0×10^{18} photons strike the sail at 90° to its surface every second and reflect elastically. The photons have a momentum of $1.55 \times 10^{-26}\ \mathrm{kg\ m\ s^{-1}}$. Calculate the force that the reflecting photons exert on the space sail. Show your working. Give your answer correct to two significant figures.

(3 marks)

Solution

$6.2 \times 10^{-8}\mathrm{N}$ The impulse exerted by the reflecting $\mathrm{photons} = F\Delta t = \Delta p$.

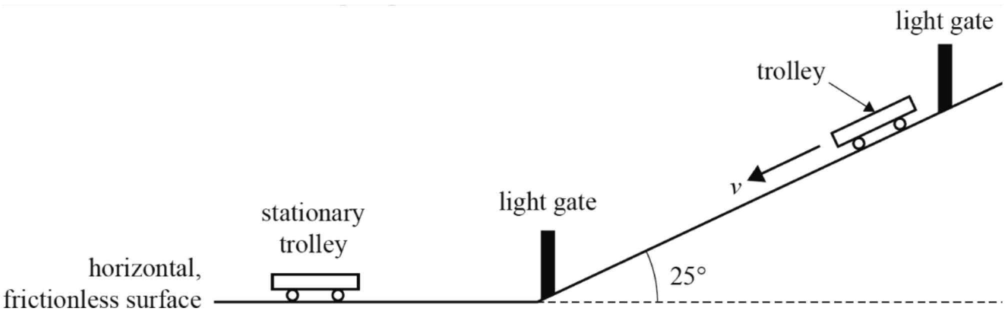
The change in $\mathrm{momentum} = 2p = 3.10 \times 10^{-26}$, $N = 2.0 \times 10^{18}$ and $\Delta t = 1$.

$F = \frac{(2\times10^{18})(3.10\times10^{-26})}{1} = 6.2 \times 10^{-8}\ \mathrm{N}$.

Question 25/ 46

[Adapted VCAA 2022 SB Q7]

Kym and Kelly are experimenting with trolleys on a ramp inclined at 25°, as shown below. They release a trolley with a mass of 2.0 kg from the top of the ramp. The trolley moves down the ramp, through two light gates and onto a horizontal, frictionless surface. Kym and Kelly calculate the acceleration of the trolley to be $3.2\ \mathrm{m\ s^{-2}}$ using the information from the light gates.



When it reaches the bottom of the ramp, the trolley travels along the horizontal, frictionless surface at a speed of 4.0 m s^{-1} until it collides with a stationary identical trolley. The two trolleys stick together and continue in the same direction as the first trolley.

a. Calculate the speed of the two trolleys after the collision. Show your working and clearly state the physics principle that you have used.

(3 marks)

b. Determine, with calculations, whether this collision is an elastic or inelastic collision. Show your working.

(3 marks)

Solution

a 2.0 m s^{-1} Use conservation of momentum.

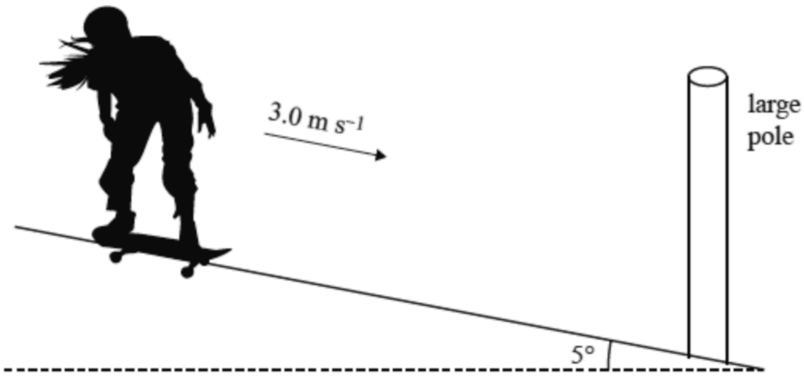
b Inelastic KE before $\left(\text{using } 0.5mv^2\right) = 16.0 \text{ J; KE after} = 8.0 \text{ J.}$

Question 26/ 46

[Adapted VCAA 2023 SB Q8]

Maia is at a skatepark. She stands on her skateboard as it rolls in a straight line down a gentle slope at a constant speed of 3.0 m s^{-1}, as shown. The slope is 5° to the horizontal.

The combined mass of Maia and the skateboard is 65 kg.



Near the bottom of the ramp, Maia takes hold of a large pole and comes to a complete rest while still standing on the skateboard. Maia and the skateboard now have no momentum or kinetic energy.

Explain what happened to both the momentum and the kinetic energy of Maia and the skateboard. No calculations are required.

(2 marks)

Solution

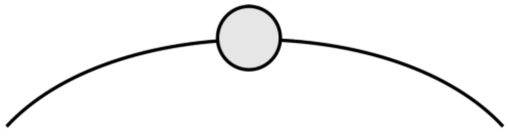
Maia's momentum is transferred to the Earth.

Maia's kinetic energy eventually transforms into heat/sound.

Chapter 5 Projectile motion

Question 1/ 15

A netball is thrown towards the net. It is shown below at the highest point of its flight. Air resistance is negligible.



Which one or more of the following best describes the ball at its highest point?

A It is travelling at the fastest speed of its flight.

B At this point it stops momentarily.

C The net force on the ball is vertically downward.

D At this point there is no net force on the ball.

Solution

C Only force acting is gravity.

Question 3/ 15

The other angle is closest to

A 65°

B 60°

C 55°

D 50°

Solution

C Follows from the fact that $\sin\ (2 \times 35) = \sin\ (2 \times 55)$.

Question 4/ 15

They also find that, for a given value of *v*, the angle that gives the greatest range is closest to

A 0°

B 30°

C 45°

D 60°

Solution

C Greatest range when sin2θ is a maximum.

Question 5/ 15

For $v = 20 \text{ m s}^{-1}$ and $\theta = 30^{\circ}$, which of the following is closest to the time for the complete flight shown above?

A 1.0 s

B 1.8 s

C 2.0 s

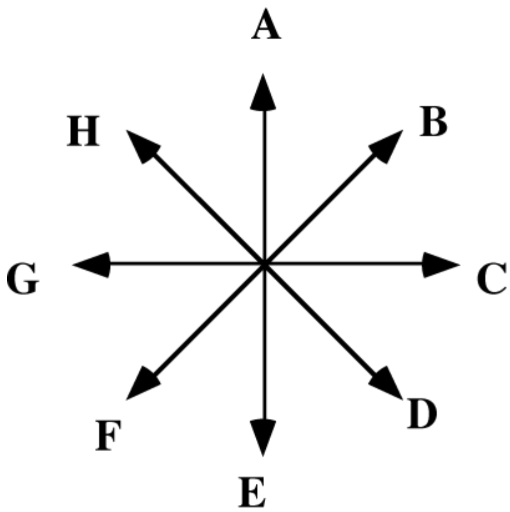
D 3.5 s

Solution

C Vertical component is 10 m s^{-1}; $\text{time up} = 1.0 \text{ s} = \text{time down}$.

Question 6/ 15

If air resistance was significant and taken into account, the shape of the trajectory would change. Which of the following arrows would best describe the direction of the resultant force acting on the ball at the highest point in its flight?

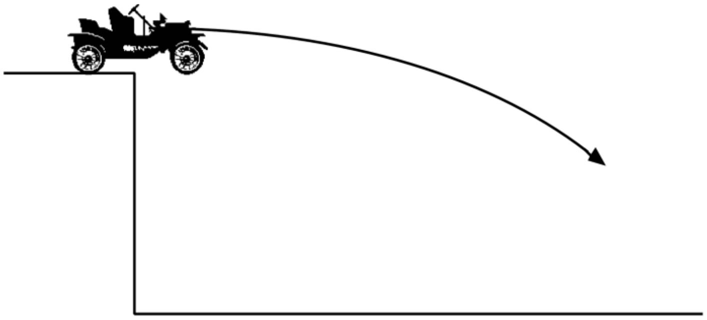


Solution

F Vector addition of gravity and air resistance.

Question 7/ 15

A car is demonstrating its safety features. Air resistance is very small. It follows a parabolic path before crashing.



Throughout the flight, its horizontal component of velocity remains very close to $10 \mathrm{~m} \mathrm{~s}^{-1}$. This means that

A the force of gravity is very small.

B air resistance is very small.

C there is a strong wind against the car.

D air resistance is balanced by the force of the car's engine.

Solution

B Constant horizontal component implies this.

Question 9/ 15

Which of the following is closest to the time that it takes him to strike the water?

A 1.1 s

B 1.2 s

C 1.3 s

D 1.4 s

Solution

B Use $s = ut + \frac{1}{2}at^2$ with $u = 0$.

Question 10/ 15

Which of the following is closest to the horizontal distance (from the end of the pier) that he strikes the water?

A 11 m

B 12 m

C 13 m

D 14 m

Solution

B Horizontal motion: $s = ut$.

Question 11/ 15

A second student reaches the end of the pier at $8 \mathrm{~m~s^{-1}}$. Which of the following is closest to the time it takes her to strike the water?

A 1.1 s

B 1.2 s

C 1.3 s

D 1.4 s

Solution

B Vertical motion is unaffected by horizontal motion.

Question 13/ 15

Which of the following is closest to the speed it is thrown at?

A $20\ \mathrm{m\ s^{-1}}$

B $30\ \mathrm{m\ s^{-1}}$

C $40\ \mathrm{m\ s^{-1}}$

D $60\ \mathrm{m\ s^{-1}}$

Solution

B It takes gravity 3.0 seconds to stop it; hence $\mathrm{speed} = 30\ \mathrm{m\ s^{-1}}$.

Question 14/ 15

Which of the following is closest to the distance it travels before it returns to a height of 1.0 m?

A 30 m

B 45 m

C 60 m

D 90 m

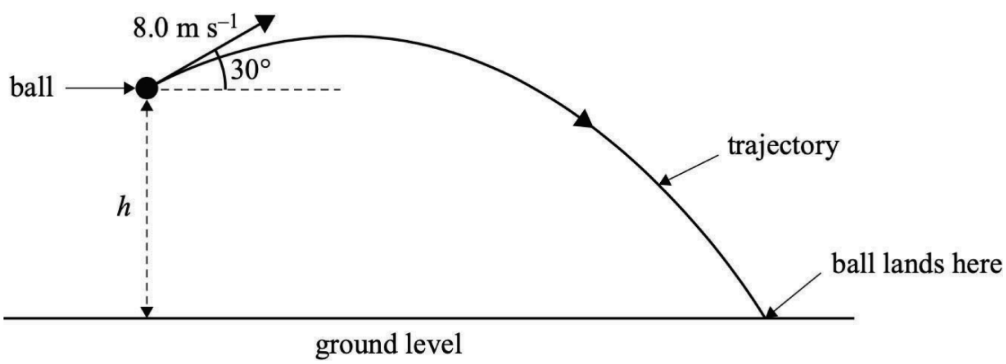
Solution

D Use $v^2 = u^2 + 2as$ for the journey up and double *x*.

Question 15/ 15

[VCAA 2021 NHT SA Q10]

Melissa launches a ball from height *h* above the ground at a speed of 8.0 m s^{-1} and at an angle of 30° above the horizontal. The time of the ball's flight is 1.0 s. The diagram below shows the trajectory of the ball.



Ignoring air resistance, which one of the following is closest to the horizontal distance that the ball landed from Melissa?

A 4.6 m

B 5.0 m

C 6.9 m

D 8.0 m

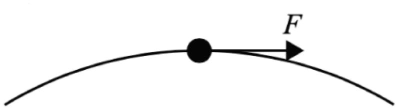
Solution

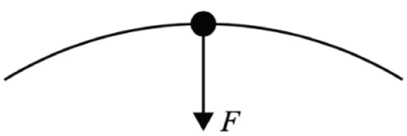
C $v_{\text{HORIZ}} = 8 \times \cos 30^\circ = 6.9 \text{ m s}^{-1}$; time of $\times$ flight is 1.0 s.

Question 16/ 15

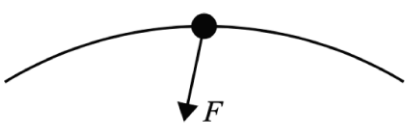
[VCAA 2021 NHT SA Q11]

Which one of the following diagrams best shows the direction of the resultant force, *F*, on the ball at the position of maximum height in the real situation where air resistance is *not* ignored?

A 

B 

C Missing Image

D 

Solution

D   Net force is vector sum of gravity (downwards) and tangential (horizontal leftwards).

Question 18/ 15

[VCAA 2021 SA Q9]

Which one of the following expressions correctly gives the distance *d*?

A $0.8t$

B $6t$

C $5t^2$

D $6t + 5t^2$

Solution

B Horizontal movement is $\text{constant speed} = \text{speed}\ (6) \times \text{time}\ (t)$.

Question 19/ 15

[VCAA 2021 SA Q10]

Which one of the following is closest to the time taken, *t*, for Lucy to reach the water below?

A 0.8 s

B 1.1 s

C 1.3 s

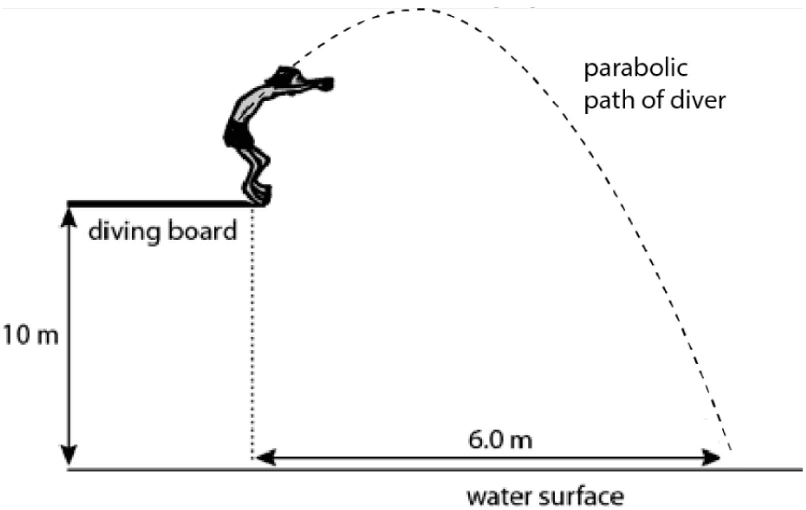
D 1.6 s

Solution

C Consider vertical motion; use $s = ut + \frac{1}{2}\ gt2$ with $u = 0$.

Question 1/ 35

Jim (50 kg) dives off a diving board 10 m above the water surface. He hits the water 2.0 s later, a horizontal distance of 6.0 m from his starting point. The situation is shown in the diagram below. Air resistance forces are negligible.



a. Calculate the horizontal component of Jim's velocity during his flight.

(2 marks)

b. Calculate the magnitude of the vertical component of Jim's velocity at the time he jumps off the board.

(3 marks)

c. Calculate Jim's total energy $(\mathrm{PE} + \mathrm{KE})$ just before he hits the water.

(3 marks)

Solution

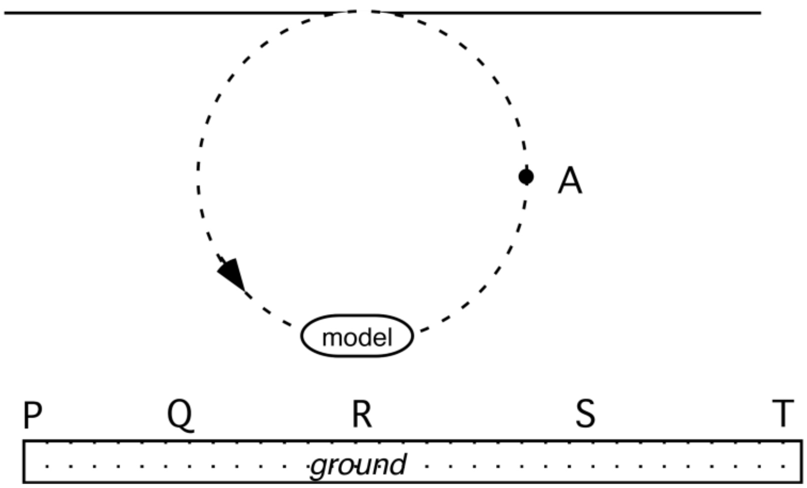
a $3.0 \mathrm{~m~s}^{-1}$ Use $x = vt$ applied to the horizontal motion.

b $4.8 \mathrm{~m~s}^{-1}$ Apply $x = ut + \frac{1}{2}at^2$ to the vertical motion (watch signs!).

c 5.7 kJ Equal to $\mathrm{KE} + \mathrm{PE}$ at $\mathrm{start} = \frac{1}{2}mv^2 + mgh$; $v^2{}_{\mathrm{start}} = 32 \mathrm{~m~s}^{-1}$.

Question 2/ 35

A model aeroplane flies an upside-down ‘loop the loop’. A metal part comes loose from the model, at point A. Later it strikes the ground.



Which point (P, Q, R, S, T) is closest to where it strikes the ground? Justify your answer.

(2 marks)

Solution

S It travels vertically upwards from A.

Question 3/ 35

A 60 kg high jumper leaves the ground with 1860 J of kinetic energy. At the top of her flight she has a kinetic energy of 660 J. Her centre of mass is now higher than it was on take-off from the ground. Give all your answers to two significant figures.

a. By how much has the height of her centre of mass increased from take-off to the top of her flight?

(2 marks)

b. At what speed is she travelling at the top of her flight?

(2 marks)

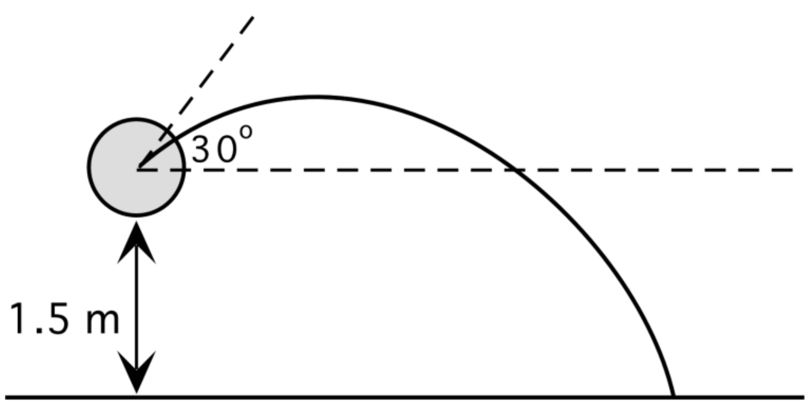
Solution

a 2.0 m She has 'lost' 1200 J of KE; this has been transformed to GPE. Now use $\mathrm{GPE} = mgh$ to find *h*.

b $4.7\ \mathrm{m\ s^{-1}}$ Obtain directly from $\mathrm{KE} = 660 = 0.5mv^2$.

Question 4/ 35

Kirsty is throwing a shotput from shoulder height, about 1.5 m above the ground. She launches at $6.5\ \mathrm{m\ s^{-1}}$ at an angle of 30°.



a. What is the vertical displacement of the ball between launch and where it strikes the ground? Give size and direction.

(2 marks)

b. Calculate the time of travel for the ball. Show your working.

(3 marks)

c. Calculate the range of the ball. Show your working.

(3 marks)

Solution

a 1.5 m downwards Vertical displacement.

b 0.98 s Use $s = ut + 0.5gt^2$ (vertical quantities only).

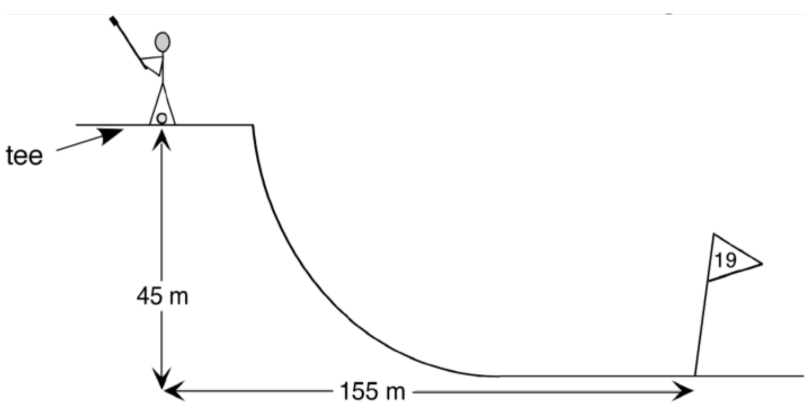
Take $u = -6.5\sin 30°$, $g = 9.8$, $s = 1.5$ (down positive).

c 5.5 m $R = \text{horizontal component of velocity} \times \text{travel time}$.

Horizontal component = $u\cos 30°$.

Question 5/ 35

A golfer hits off from an elevated tee, as shown in the diagram.



The ball leaves the tee horizontally and lands in the hole. The horizontal distance between the tee and the hole is 155 m; the vertical distance is 45 m. There is a tailwind that cancels any air resistance.

a. Calculate the speed of the ball leaving the tee.

(2 marks)

As a result of another shot, a ball flies off the same tee at a speed of $50\ \mathrm{m\ s^{-1}}$, travelling at 30° to the horizontal. Ignore air resistance.

b. How high does it go above the tee?

(2 marks)

c. How long is it in the air?

(2 marks)

d. What is the horizontal distance of the shot?

(2 marks)

Solution

a $51\ \mathrm{m\,s^{-1}}$ Use $v = \frac{s}{t}$, with time of flight for drop of 45 m.

b 32 m Use $v^2 = u^2 + 2ax$; with $v = 0$.

c 6.5 s Use $s = ut + 0.5gt^2$; $u = -25$; $g = 9.8$; $s = 45$.

d 282 m $\text{Horizontal velocity} \times \text{time}$.

Question 6/ 35

The table below gives data from the flight of a soccer ball. Positive readings mean velocity directed upwards (vertical components) or to the right (horizontal components). There is some air resistance present.

Time (s)	Vertical velocity ($\mathrm{ms^{-1}}$)	Horizontal velocity ($\mathrm{ms^{-1}}$)
0.00	20.0	20.0
0.10	18.6	19.6
0.20	17.3	19.2
0.30	16.1	18.9
0.40	14.9	18.6
0.50	13.8	18.4

a. At what angle to the horizontal is the ball moving at time $t = 0$ s?

(2 marks)

b. What was the speed of the ball at time $t = 0.50$ s?

(2 marks)

Solution

a 45° Equal horizontal and vertical components.

b 23 m s^{-1} Add components using Pythagoras.

Question 7/ 35

Tam throws a ball a horizontal distance of 100 m. She throws it at an angle of 30°. It lands at the same height. (Ignore air resistance.) Give all your answers to two significant figures.

a. At what speed does the ball leave her hand?

(2 marks)

b. If she throws it at 45° to the horizontal, how fast will she have to throw it to ensure that it still travels 100 m?

(2 marks)

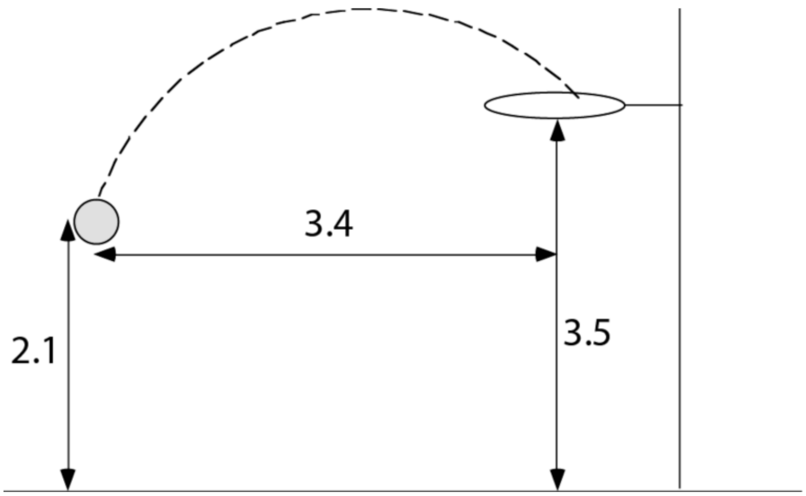
Solution

a 34 m s^{-1} $vt \cos 30° = 100$, $\frac{2v \sin 30°}{9.8}$. Solve.

b $31\ \mathrm{m\ s^{-1}}$ Use $R = \frac{v^2 \sin 2\theta}{g}$. (range formula).

Question 8/ 35

A netball player shoots for goal.



a. What is the vertical displacement involved in the throw?

(2 marks)

b. What is the total displacement involved in the throw?

(2 marks)

c. The ball takes 1.1 s for the journey. What is the horizontal component of its velocity?

(2 marks)

d. What is the vertical component of its launch velocity?

(2 marks)

e. What is its launch speed?

(2 marks)

f. What angle to the horizontal was it launched at?

(2 marks)

Solution

a 1.4 m (up) $= 3.5 - 2.1$.

b 3.7 m Use Pythagoras' theorem.

c $3.1\ \mathrm{m\ s^{-1}}$ $v = \frac{\Delta s}{\Delta t}$

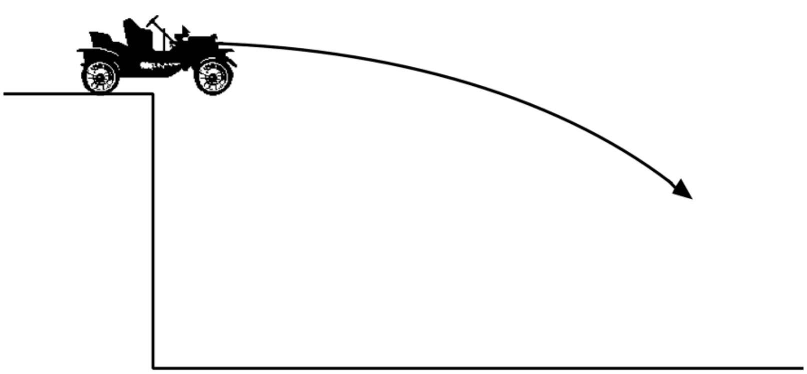
d $6.7\ \mathrm{m\ s^{-1}}$ Use $x = ut + 0.5at^2$ for vertical components of motion.

e $7.3\ \mathrm{m\ s^{-1}}$ Vector addition, and Pythagoras' theorem.

f 65° $\tan^{-1}\left(\frac{V_y}{V_x}\right)$

Question 9/ 35

A car in a 'diving' demonstration is demonstrating its safety features. It takes a parabolic path before crashing to the ground, 1.8 s later. No-one is in the car.



a. What is the initial vertical velocity component of the car?

(2 marks)

b. What is the vertical component of the car's velocity just before it hits the ground?

(2 marks)

c. What is the vertical distance that the car falls through?

(2 marks)

Solution

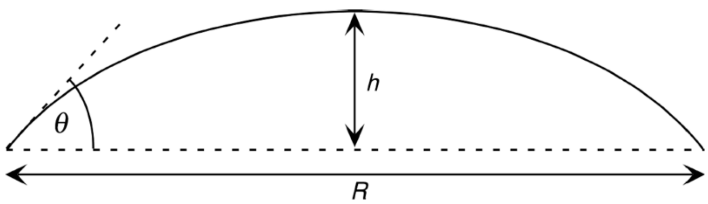
a Zero It is travelling horizontally.

b $18 \mathrm{~m~s}^{-1}$ Use $v_{\mathrm{y}} = gt$.

c 16 m Use $s = \frac{1}{2} gt^2$.

Question 10/ 35

A ball flies through the air following the path shown in the diagram.



The ball's mass is 550 g. Its initial kinetic energy is 110 J. The initial angle is θ and maximum height is h.

a. What is the speed of the ball at the start of its flight?

(2 marks)

b. If $h = 8.0$ m, calculate the KE of the ball at maximum height.

(2 marks)

c. Calculate the speed of the ball at maximum height.

(2 marks)

d. Calculate the angle θ.

(2 marks)

Solution

a 20 m s^{-1} Total energy at the start is 110 J; hence $0.5mv^2 = 110$.

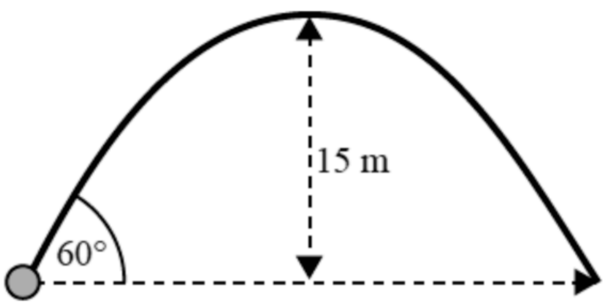
b 67 J Difference between 110 J and GPE at maximum h.

c 15.6 m s^{-1} $E_\text{k} = \frac{1}{2}mv^2$.

d 39° Use the maximum height to find u_y; $\tan\theta = \frac{u_y}{u_x}$.

Question 11/ 35

Charlie kicks a football at an angle of 60° to the horizontal on level ground. It rises a vertical distance of 15 m above the point from where he kicks it as shown in the diagram. Ignore air resistance.



a. Calculate the initial speed of the football.

(2 marks)

b. Calculate the time the football is in the air.

(2 marks)

c. Calculate the horizontal distance the ball travels.

(2 marks)

Solution

a 20 m s^{-1} Vertically: $v^2 = u^2 + 2as$ so $u = \sqrt{2 \times 10 \times 15} = 17.3 \text{ m s}^{-1}$.

Speed $= 17.3/\sin(60°) = 20$ m s^{-1}.

b 3.5 s Calculate *t* from vertical motion up, $t = 17.3/10 = 1.73$ s, then total time in air $= 1.73 \times 2 = 3.5$ s.

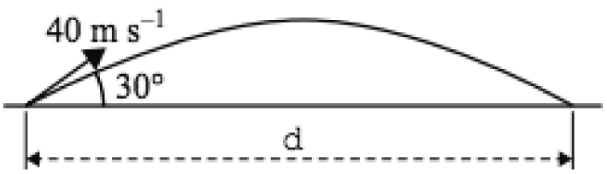
c 35 m Range = horizontal component of velocity × time in air

$= 20 \cos(60°)\, 3.5 = 35$ m.

Question 12/ 35

[VCAA 2016 SA Q5]

A ball is projected from the ground at an angle of 30° to the horizontal and at a speed of 40 m s^{-1}, as shown. Ignore any air resistance.

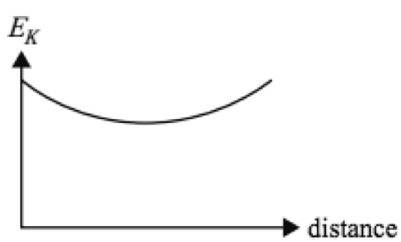


a. Calculate the distance, *d*, to the point where the ball hits the ground. Show your working.

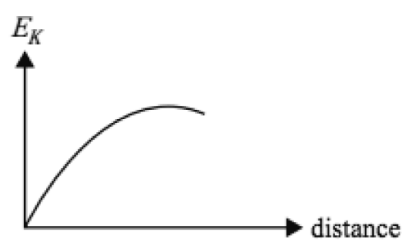
(3 marks)

b. Which one of the graphs below best shows the kinetic energy of the ball as a function of horizontal distance, *d*, from the launching point? Explain your answer.

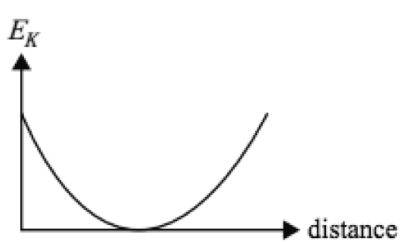
A.



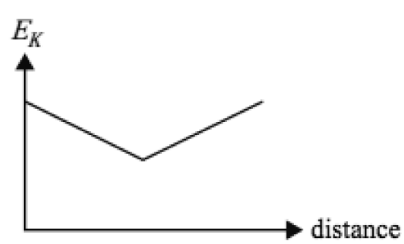
B.



C.



D.



(2 marks)

Solution

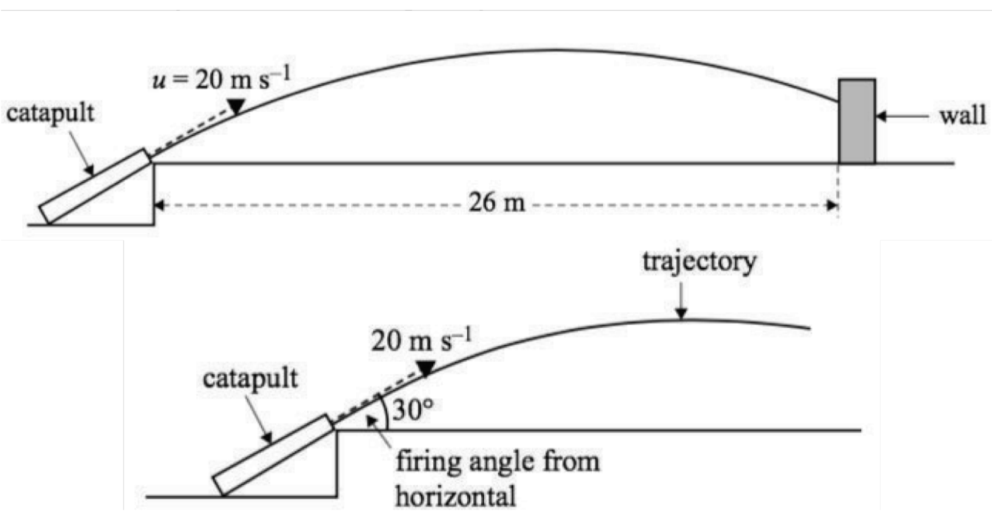
a 141 m Simplest to use range formula here: $R = \frac{v^2 \sin 2\theta}{g}$.

b A KE minimum at top of flight, but graph cannot be linear.

Question 13/ 35

[Adapted VCAA 2017 SB Q9]

Students use a catapult to investigate projectile motion. A ball of mass 0.10 kg is fired from the catapult at an angle of 30° to the horizontal. The ball leaves the catapult at ground level with a speed of 20 m s^{-1}. Instead of reaching the ground, the ball strikes a wall 26 m from the launching point, as shown in the first diagram. The second diagram shows an enlarged view of the catapult. Ignore air resistance.



Calculate the height of the ball above the ground when it strikes the wall. Show your working.

(3 marks)

Solution

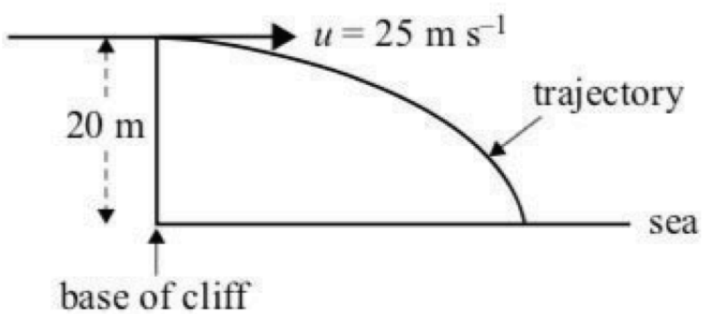
4.0 m Find time of flight from horizontal motion (use $s = vt$, where s is 26 m and $v = 20\cos 30°$; this gives $t = 1.5\,(0)$ s. Now apply

$s = ut + \frac{1}{2}at^2$ where $u = 20\sin 30°$, $a = -9.8$ and $t = 1.50$.

Question 14/ 35

[VCAA 2018 NHT SB Q6]

A rock of mass 2.0 kg is thrown horizontally from the top of a vertical cliff 20 m high with an initial speed of 25 m s^{-1}, as shown.



a. Calculate the time taken for the rock to reach the sea. Show your working.

(3 marks)

b. Calculate the horizontal distance from the base of the cliff to the point where the rock reaches the sea. Show your working.

(2 marks)

c. Calculate the kinetic energy of the rock as it reaches the surface of the sea. Show your working.

(2 marks)

Solution

a 2.0 s (2 s.f.) Consider vertical motion only. Use $u = 0$, $s = 20$ and $a = 9.8$; use $s = ut + \frac{1}{2}at^2$.

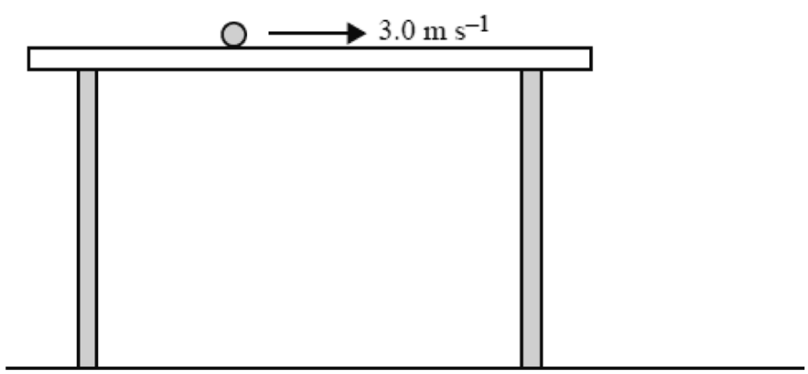
b 51 m Consider horizontal motion only: use $s = ut = 51$ (if 3 s.f. carried through; 50 would probably be accepted).

c 1.0 kJ Total energy at $\text{start} = mgh + \frac{1}{2}mv^2 = 1017\text{ J} = \text{energy}$ at end.

Question 15/ 35

[VCAA 2018 SB Q7]

A small ball of mass 0.20 kg rolls on a horizontal table at 3.0 m s^{-1}, as shown. The ball hits the floor 0.40 s after rolling off the edge of the table. The radius of the ball may be ignored. In this question, take the value of g to be 10 m s^{-2}.



a. Calculate the horizontal distance from the right-hand edge of the table to the point where the ball hits the floor.

(1 mark)

b. Calculate the height of the table. Show your working.

(2 marks)

c. Calculate the speed at which the ball hits the floor. Show your working.

(3 marks)

Solution

a 1.2 m Horizontal component of velocity is constant (at 3.0 m s^{-1}); use $s = v_{\text{H}}t$.

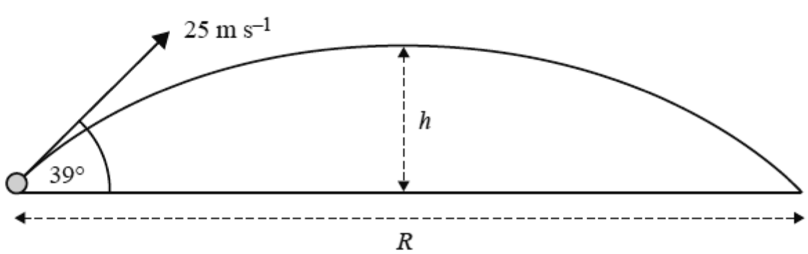
b 0.80 m Apply $s = ut + \frac{1}{2}at^2$ to vertical motion ($\text{initial vertical component of velocity} = 0$).

c 5.0 m s^{-1} Calculate horizontal and vertical components of velocity at time of impact; $v_\text{H} = 3.0 \text{ m s}^{-1}$ and $v_\text{V} = 4.0 \text{ m s}^{-1}$; (find v_V from $v = u + at$); vector addition gives 5.0 m s^{-1}.

Question 16/ 35

[VCAA 2019 SB Q10]

A projectile is launched from the ground at an angle of 39° and at a speed of 25 m s^{-1}, as shown below. The maximum height that the projectile reaches above the ground is labelled *h*.



a. Ignoring air resistance, show that the projectile's time of flight from the launch to the highest point is equal to 1.6 s. Give your answer to two significant figures. Show your working and indicate your reasoning.

(2 marks)

b. Calculate the range, *R*, of the projectile. Show your working.

(2 marks)

Solution

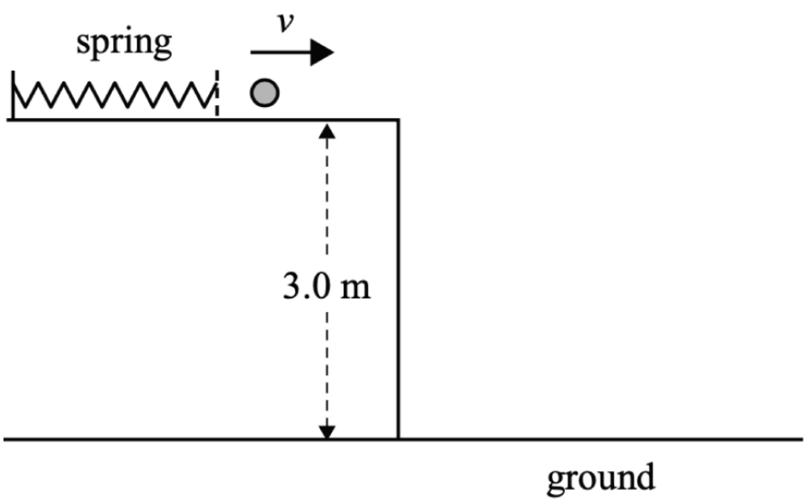
a Consider only vertical components of motion. $u = 25 \sin 39° = 15.7$. Now use $v = u + at$ where $a = -9.8$; hence $t = \frac{15.7}{9.8} = 1.60 \text{ s}$.

b 62 m Consider only horizontal components of motion. $a = 0$, $u = 25 \cos 39° = 19.4$. Now use $s = ut = 62 \text{ m}$.

Question 17/ 35

[Adapted VCAA 2020 SB Q9]

An ideal spring is compressed by 0.15 m. A ball, mass 0.20 kg, is placed in contact with a compressed spring. The spring is then released, making the ball move horizontally with a speed of 12 m s^{-1} across a smooth surface, as shown.



Calculate the speed of the ball after it has fallen a vertical distance of 2.5 m. Show your working.

(3 marks)

Solution

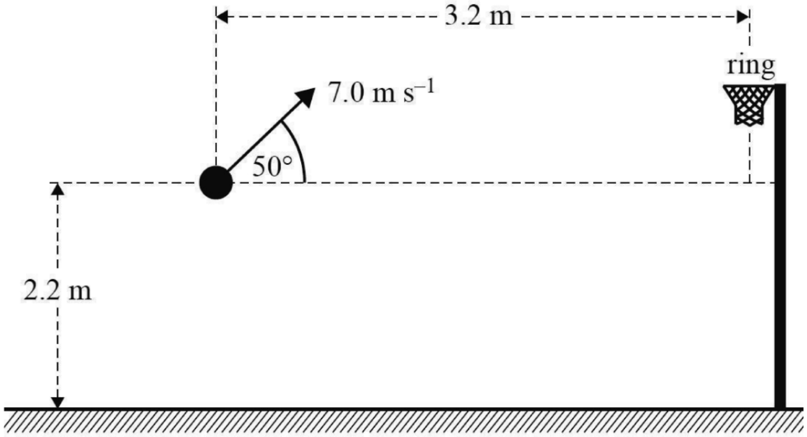
14 m s^{-1} First calculate v_{VERT} from $v^2 = u^2 + 2gx$, this gives 7 m s^{-1}.

Now combine v_{VERT} and v_{HORIZ} using Pythagoras.

Question 18/ 35

[VCAA 2022 NHT SB Q10]

A basketball player throws a ball with an initial velocity of 7.0 m s^{-1} at an angle of 50° to the horizontal, as shown on below. The ball is 2.2 m above the ground when it is released. By the time the ball passes through the ring at the top of the basket, it has travelled a horizontal distance of 3.2 m. Ignore air resistance.



a. Show that the time taken for the ball's flight from launch to passing through the ring is 0.71 s. Show your working.

(2 marks)

b. How far above the ground is the ring at the top of the basket? Show your working.

(4 marks)

Solution

a $\text{Horizontal component of velocity} = 7\cos 50^\circ = 4.50$; use $t = \frac{x}{v} = \frac{3.2}{4.50} = 0.71$ s.

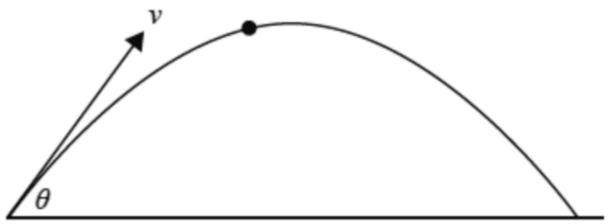
b 3.5 m $\text{Vertical component of velocity} = 7\sin 50^\circ = 5.36$. Now use $x = ut + \frac{1}{2}at^2 = 1.34$. $\text{Top of ring} = 1.3 + 2.2 = 3.5$ m.

Question 19/ 35

[VCAA 2023 NHT SB Q12]

Two students investigate the physics of long jumps. They analyse a video of their friend Jemina as she runs along a track and then jumps. She lands in a sand pit that is level with the track.

Jemina's horizontal speed at the moment she jumps is 8.0 m s^{-1}. She is in the air for 0.6 s before landing in the sand pit. The students use $g = 10 \text{ m s}^{-2}$ for their calculations. The motion is modelled as that of a point mass, as shown below.



a. Calculate the horizontal distance that Jemina would be expected to travel if her motion were modelled as a projectile with point mass, as shown above.

(2 marks)

b. Calculate Jemina's vertical speed as she takes off from the track.

(2 marks)

c. Calculate Jemina's velocity as she launches. Include both the magnitude and the angle from the horizontal of her velocity at take-off.

(3 marks)

d. The students use a tape measure to check the horizontal distance that Jemina actually jumps, and find that it is less than the distance they calculated in part **a**. Suggest one possible reason for this.

(1 mark)

Solution

a 4.8 m $D = v_{\text{H}} \times t = 8.0 \times 0.6 = 4.8 \text{ m}$.

b 3.0 m s^{-1} $v_{\text{V}} = a \times t = 10 \times 0.3 = 3.0 \text{ m s}^{-1}$

c $\theta = 21^\circ$

8.5 m s^{-1} $\tan(\theta) = \frac{3.0}{8.0}$

$\theta = 20.6^\circ$ and $v = \sqrt{3^2 + 8^2} = 8.5 \text{ m s}^{-1}$.

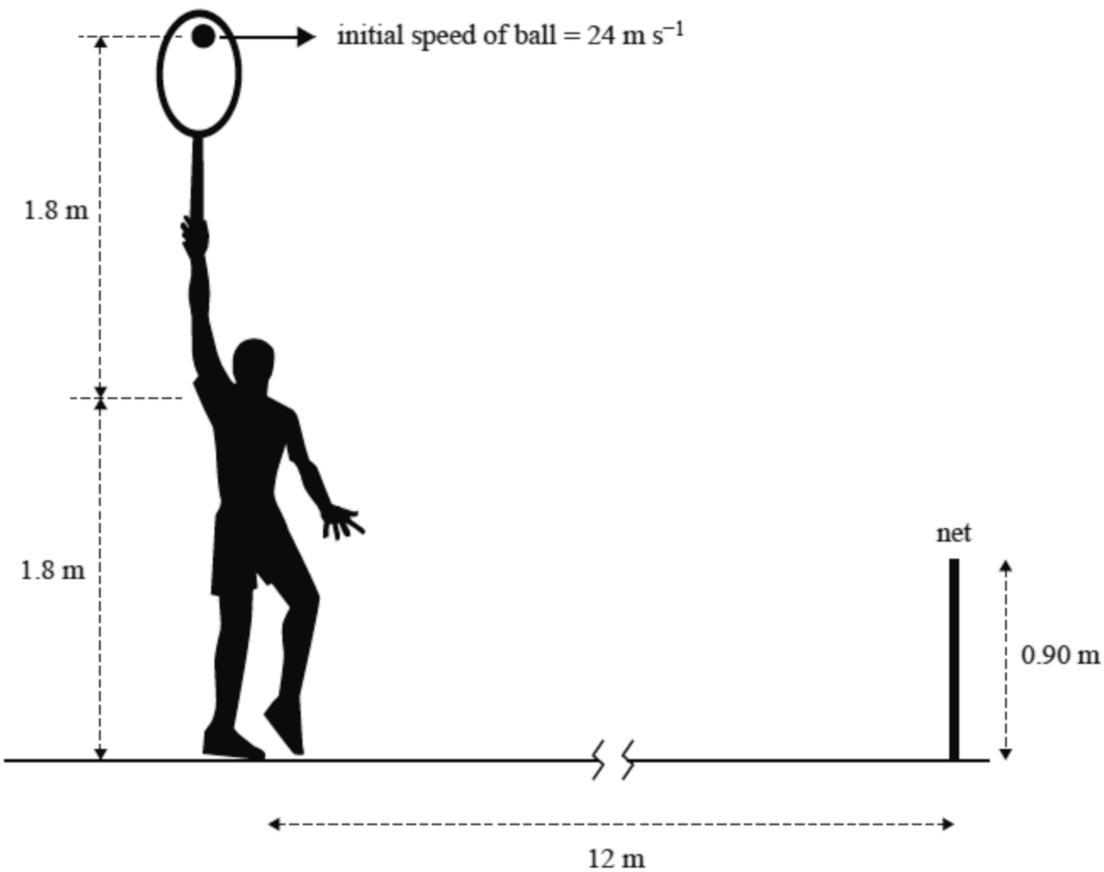
d Air resistance

Question 20/ 35

[Adapted VCAA 2023 SB Q9]

Giorgos is practising his tennis serve using a tennis ball of mass 56 g.

The ball leaves Giorgos's racquet with an initial speed of 24 m s^{-1} in a horizontal direction, as shown below.



How far above the net will the ball be when it passes above the net? Assume that there is no air resistance. Show your working.

(3 marks)

Solution

1.5 m Time to reach the net 0.5 s travel (12 m at 24 m s^{-1}). The ball will fall a distance in vertical direction using $s = ut + \frac{1}{2}gt^2$

$s = 1.225 \text{ m}$. It starts from a height of 3.6 m, so it will be $3.6 - 1.225 = 2.375$ m above the ground. The net is 0.9 m high so the ball will clear the net by 1.475 m.

Chapter 6 Circular motion

Question 1/ 13 [VCAA 2023 SA Q9]

In uniform circular motion of an object travelling at constant speed, which of the following statements is true?

A The object is travelling with zero acceleration.

B The object is travelling with constantly changing velocity.

C The object is accelerating away from the centre of the circle.

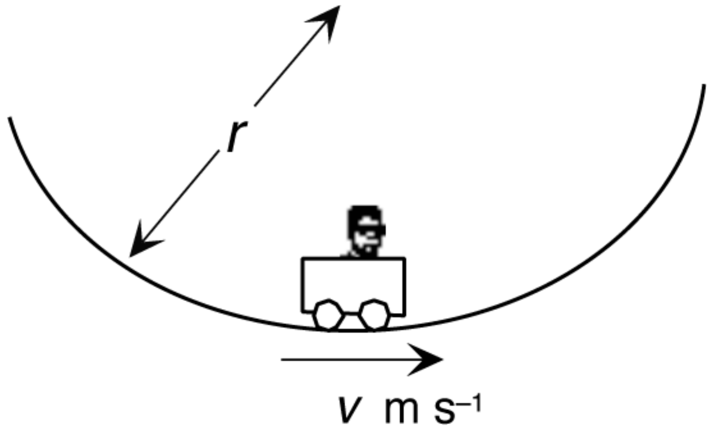
D The kinetic energy of the object is changing in direction.

Solution

B Direction of velocity is changing.

Question 2/ 13 [VCAA 2023 SA Q9]

In the sketch, Jim is sitting in a carriage going through a ‘valley’ on a rollercoaster.



In the ‘valley’, Jim feels heavier than usual. This is because

A his mass has increased.

B his weight has increased.

C the normal reaction force from the seat has increased.

D he is accelerating downwards.

Solution

C Needs to be larger than mg for net centripetal force.

Question 4/ 13 [VCAA 2023 SA Q9]

Which of the following gives the magnitude of the net force on the car towards the centre of the corner at this speed?

A mg cos15

B mg sin15

C N cos15

D N sin15

Solution

D Component of *N* supplies the required centripetal force.

Question 5/ 13 [VCAA 2023 SA Q9]

Which of the following gives the best relationship between *N* and *mg*?

A $mg \cos 15 = N$

B $N \cos 15 = mg$

C $N \sin 15 = mg$

D $mg \sin 15 = N$

Solution

B Resolve forces vertically; they must balance.

Question 7/ 13 [VCAA 2023 SA Q9]

Which of the following is closest to the speed of the planet in its circular orbit?

A 60 m s^{-1}

B 600 m s^{-1}

C 6000 m s^{-1}

D $60\,000 \text{ m s}^{-1}$

Solution

C Use $v = \frac{2\pi R}{T}$.

Question 8/ 13 [VCAA 2023 SA Q9]

Which of the following is closest to the gravitational force between the planet and the star?

A 4×10^3 N

B 4×10^4 N

C 4×10^5 N

D 4×10^6 N

Solution

B $\frac{mv^2}{R}$ must equal centripetal force (gravity).

Question 9/ 13 [VCAA 2023 SA Q9]

A section of a rollercoaster is sketched below.

Students compare the normal reaction force between the rollercoaster car and the rails at the top of the 'hills' to the normal reaction force in the 'valleys'. Which of the following student opinions is accurate?

A The two normal reaction forces are the same; they are equal to the gravitational force on the car in both cases.

B The normal reaction force on the hills is the same as that in the valleys; they are both equal centripetal forces.

C The normal reaction force on the hills is greater than that in the valleys; the centripetal accelerations are in different directions.

D The normal reaction force in the valleys is greater than that on the hills; the centripetal accelerations are in different directions.

Solution

D In the valleys $N > mg$; on the hills $N < mg$.

Question 10/ 13 [VCAA 2023 SA Q9]

Which of the following identifies a centripetal force?

A the outward force felt by car passengers whilst rounding a corner

B the force on the Moon that balances gravity

C the force that sends a car skidding off the road on a sharp corner

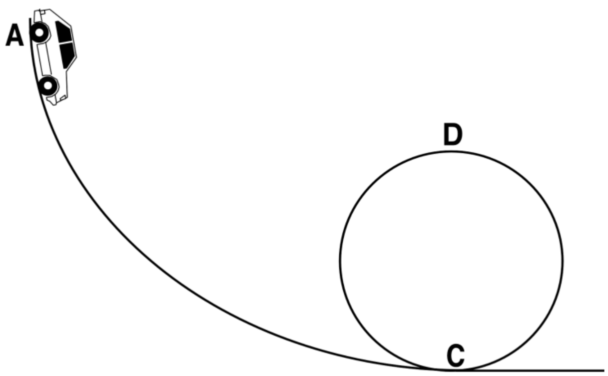
D the tension in a string whirling a stone in a circle

Solution

D Centripetal forces point towards the centre.

Question 11/ 13 [VCAA 2023 SA Q9]

A toy car does a loop the loop in the apparatus sketched below.



Which of the following best describes the conditions that ensure that the car does not fall off at the point D?

A The gravitational force on the car must be greater than the centripetal force on the car.

B The reaction force from the rails must be equal to the centripetal force on the car minus the weight of the car.

C The reaction force from the rails must be equal to the centripetal force on the car plus the weight of the car.

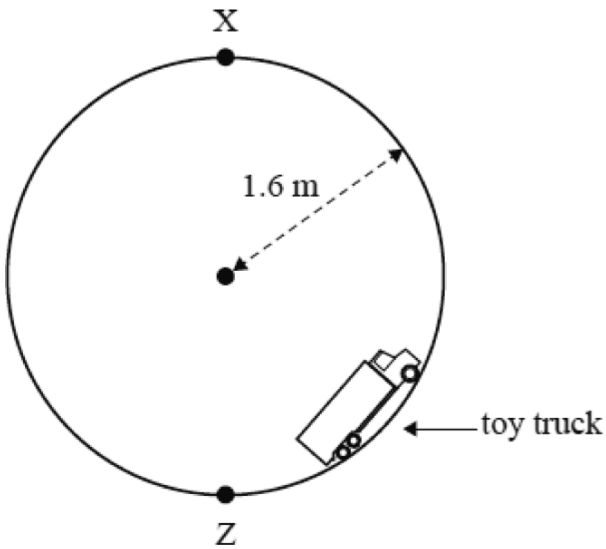
D The reaction force on the car must be directed upwards.

Solution

B Follows from $N + mg = \frac{mv^2}{R}$.

Question 12/ 13 [VCAA 2023 SA Q9]

A toy truck travels on a track around a vertical loop of radius 1.6 m, as shown below. Assume that the toy truck is a point mass.



The minimum speed at which the toy truck must be moving at point X for it to stay on the track is closest to

A $1.6 \mathrm{~m} \mathrm{~s}^{-1}$

B $3.2 \mathrm{~m} \mathrm{~s}^{-1}$

C $4.0 \mathrm{~m} \mathrm{~s}^{-1}$

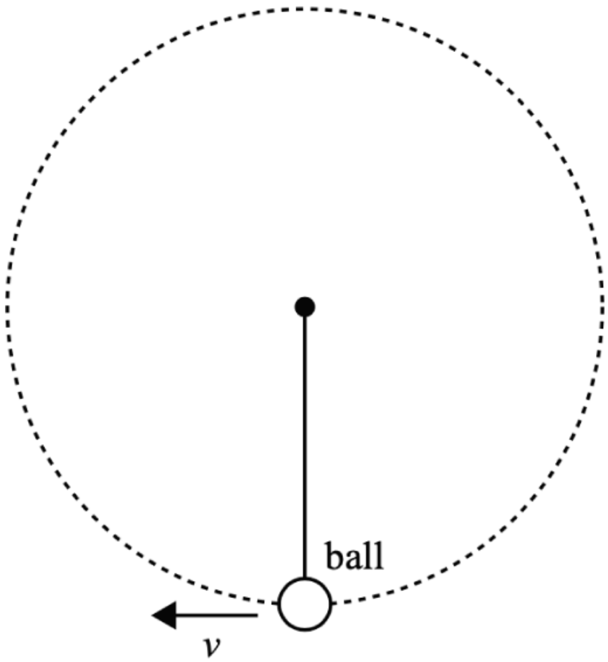
D $16 \mathrm{~m} \mathrm{~s}^{-1}$

Solution

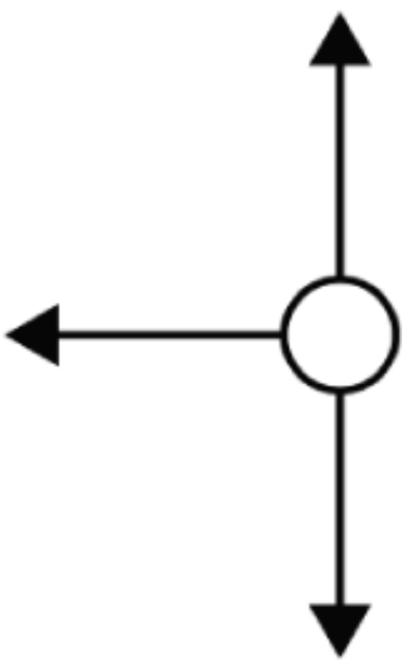
C Minimum speed when $N=0$, so $\frac{m v^2}{R}=m g$.

Question 13/ 13 [VCAA 2023 SA Q9]

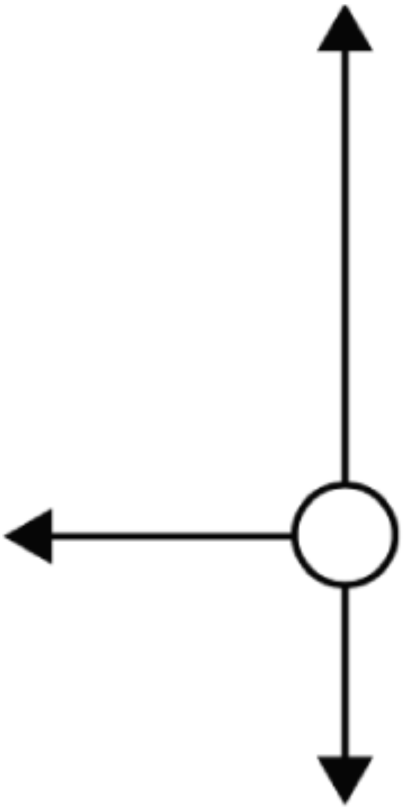
A ball is attached to the end of a string and rotated in a circle at a constant speed in a vertical plane, as shown in the diagram below.



The arrows in options **A.** to **D.** below indicate the direction and the size of the forces acting on the ball. Ignoring air resistance, which one of the following best represents the forces acting on the ball when it is at the bottom of the circular path and moving to the left?



A



B

C

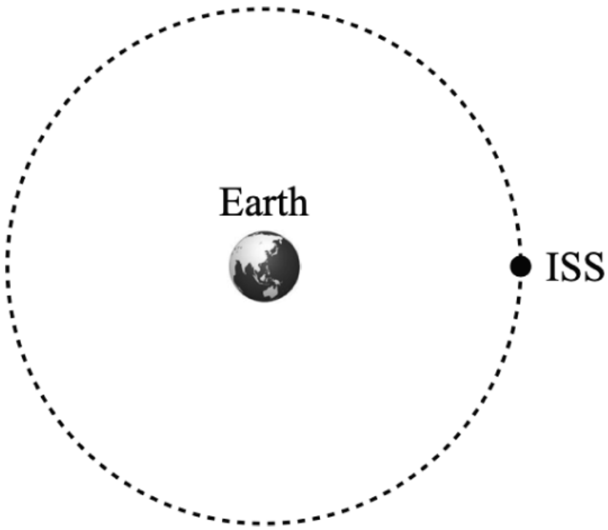
D

Solution

D The ball is moving at constant speed so there must be a net force towards the centre of the circle.

Question 14/ 13 [VCAA 2023 SA Q9]

The International Space Station (ISS) is travelling around Earth in a stable circular orbit, as shown in the diagram below.



Which one of the following statements concerning the momentum and the kinetic energy of the ISS is correct?

A Both the momentum and the kinetic energy vary along the orbital path.

B Both the momentum and the kinetic energy are constant along the orbital path.

C The momentum is constant, but the kinetic energy changes throughout the orbital path.

D The momentum changes, but the kinetic energy remains constant throughout the orbital path.

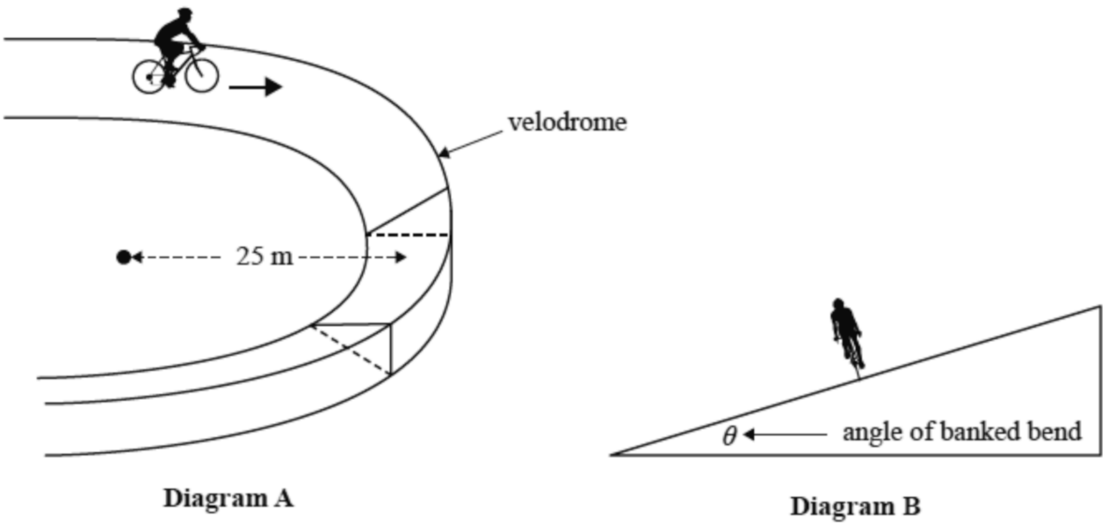
Solution

D The speed is constant, so the KE is constant. Momentum is a vector and it is changing in direction throughout the orbit.

Question 15/ 13 [VCAA 2023 SA Q9]

An engineer is designing a banked circular curve of radius 25 m in a new bicycle velodrome.

Diagram A shows the bicycle approaching the banked section, and diagram B shows the front view of a bicycle moving out of the page as it rounds the banked bend.



The bicycle is travelling at $11\ \mathrm{m\ s^{-1}}$ on the banked section. At this speed there are no sideways frictional forces between the wheels and the road surface.

Which one of the following is closest to the angle of the banked bend?

A 2.6°

B 10°

C 26°

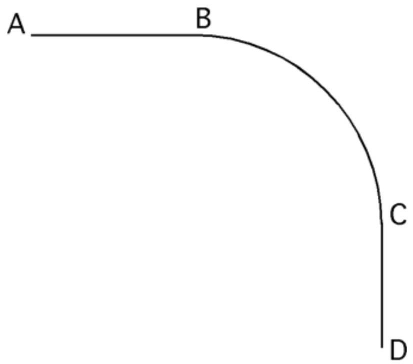
D 30°

Solution

C Using $\tan\ \theta = \frac{v^2}{Rg}$ gives $\theta = 26.28^0$

Question 1/ 41 [Adapted VCAA 2023 SB Q9]

A cyclist of mass 60 kg is riding along the path shown in the diagram. From point A to B the path is a straight line, from B to C the path is circular, and from C to D it is a straight line. She rides at a constant speed of 10 m s^{-1} throughout. Between points B and C, the cyclist is accelerating at 5.0 m s^{-2}.



a. Explain how the cyclist can be accelerating between B and C when she is travelling at constant speed.

(2 marks)

b. Calculate the radius of the circular section between B and C.

(2 marks)

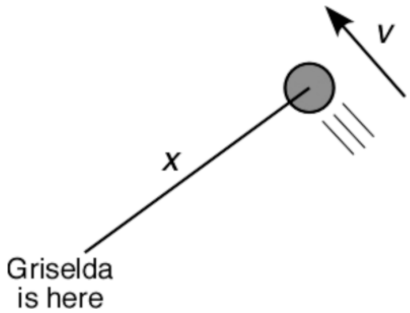
Solution

a Direction of velocity changes even though speed is constant. It means there is a constantly changing velocity and so an acceleration $\left(a = \frac{\Delta v}{\Delta t}\right)$.

b 20 m Use $a = \frac{v^2}{r}$; make *r* the subject.

Question 2/ 41 [Adapted VCAA 2023 SB Q9]

Griselda throws the *hammer* (a mass on the end of a chain) in an athletic contest. Just before she lets go, it is moving in a circle, as shown (from above). The length of the chain between Griselda and the mass is 1.2 m, the tension in the chain is 720 N and the mass is 4.0 kg. Just before she lets go, the mass is moving at $v \text{ m s}^{-1}$.



a. Describe the direction of the net force acting on the round ball of the hammer. Assume that the chain is horizontal.

(2 marks)

b. Find *v*.

(2 marks)

c. Describe the horizontal motion of the centre of mass of the hammer after release.

(1 mark)

Solution

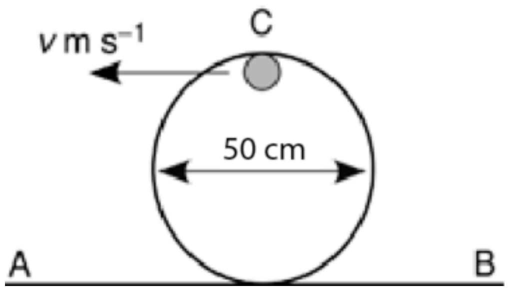
a The ball is travelling in a circle, so the net force must be towards its centre.

b 15 m s^{-1} Use $F_{\text{net}} = 720 = \frac{mv^2}{r}$.

c It moves in a straight line (horizontally) on release.

Question 3/ 41 [Adapted VCAA 2023 SB Q9]

In a ‘loop the loop’ novelty ball game, a ball is fired along the track below. The ball has a mass of 50 g.



a. What is the minimum speed it needs to have at point C?

(3 marks)

b. In another trial, the ball is travelling at 2.0 m s^{-1} at point C. What is the reaction force between the track and the ball at point C?

(2 marks)

Solution

a 1.6 m s^{-1} $N + mg = \frac{mv^2}{r}$; *N* cannot be < 0. Set $N = 0$ for min. speed.

b 0.31 N Use $N + mg = \frac{mv^2}{r}$, make *N* the subject.

Question 4/ 41 [Adapted VCAA 2023 SB Q9]

Kermit Cookie rides his pony in a very tight circle of radius 5 m. The friction force between the pony's hooves and the ground cannot exceed 8000 N. The mass of the pony and Kermit is 400 kg. What is the maximum speed they can achieve without slipping during this turn?

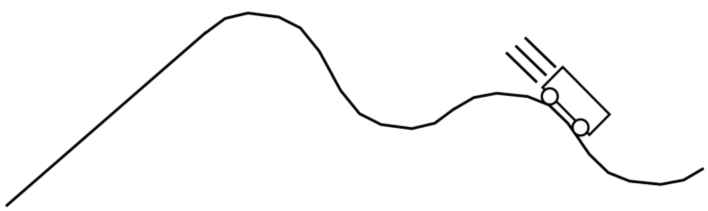
(2 marks)

Solution

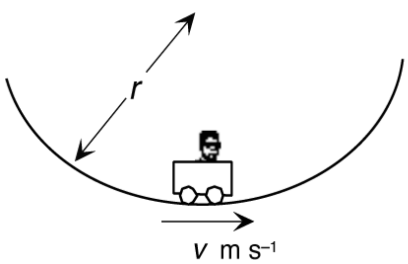
10 m s^{-1} $F_{\max} = \frac{mv_{\text{MAX}}^2}{r}$.

Question 5/ 41 [Adapted VCAA 2023 SB Q9]

Rollercoaster rides often have a high hill at the start, followed by a series of smaller ones. At the tops of the hills, passengers feel lighter than usual; at the bottom of the valleys, they feel heavier.



In the sketch, Jim is sitting in a car going through one of the valleys. Jim has a mass of 65 kg, and the valley is close to circular, with a radius of 20 m. The carriage he is sitting in is travelling at 10 m s^{-1}. The gravitational field is *g*.



a. Draw arrows on the diagram to represent the forces acting on Jim. Label the arrows clearly so that it is clear what force each arrow represents.

(3 marks)

b. What is the magnitude of Jim's acceleration at the bottom of the valley?

(2 marks)

c. Describe how 'heavy' Jim feels at the bottom of the valley, compared to his normal weight.

(2 marks)

d. A little later, Jim travels over a hill on the rollercoaster. He feels lighter than usual. Explain why. Include a force diagram in your explanation.

(3 marks)

Solution

a • A normal reaction force (*N*) upwards on Jim from the seat.

• A weight force downwards $(W = mg)$.

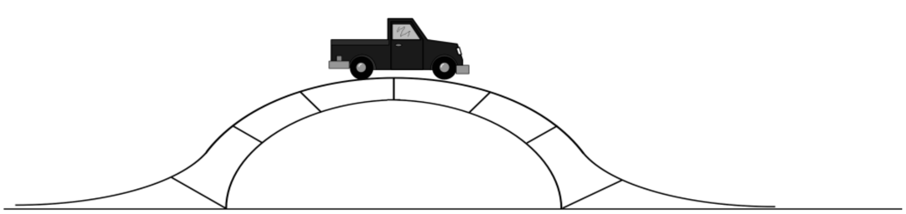
b $5 \mathrm{~m~s}^{-2}$ $a = \frac{v^2}{r}$.

c $N = 962$ N (from $N - mg = \frac{mv^2}{r}$), about 50% more than normal.

d The net acceleration is downwards (centripetal), and the net force in this direction is $mg - R\ (> 0)$. Hence *R* is less than *mg*, so Jim is less squashed against the seat and he feels lighter.

Question 6/ 41 [Adapted VCAA 2023 SB Q9]

A circular humpback bridge has a sign warning that 'Cars may lose contact with the road surface at the crest if they exceed a speed of $36 \mathrm{~km~h}^{-1}$.



The bridge radius (at its crest) is 10 m.

a. What would be the acceleration of the truck if it travelled at 10 m s^{-1} at the crest of the bridge (and did not lose contact with the surface)?

(2 marks)

b. Explain why the truck is likely to lose contact with the road surface at a speed of $10 \mathrm{~m~s}^{-1}$.

(4 marks)

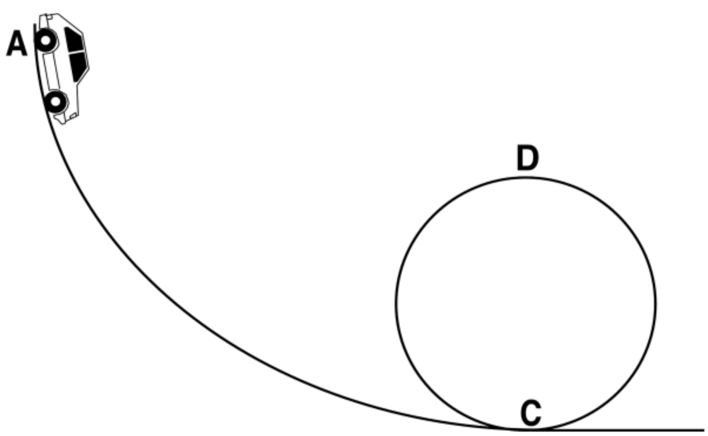
Solution

a 10 m s^{-2} down Use $a = \frac{v^2}{r}$.

b Motion is circular, $\therefore mg - N = \frac{mv^2}{r}$; $\therefore N = mg - \frac{mv^2}{r}$; this gives $N < 0$. Contact is on the verge of being 'lost' when $N = 0$. (Need to convert 36 km h^{-1} into m s^{-1}.)

Question 7/ 41 [Adapted VCAA 2023 SB Q9]

A ride at an amusement park involves passengers 'looping the loop' in a car, as shown. The car starts from rest at A, which is 22 m above C. The car and its passengers have a combined mass of 250 kg. The circular part of the track (with C at the bottom and D at the top) has a radius of 8.0 m.



a. Calculate the speed of the car at C. Ignore friction and air resistance.

(2 marks)

b. What speed will the car be going at D (if the car stays on the track)?

(2 marks)

c. What will be the normal reaction on the car from the track at D?

(2 marks)

d. The passengers feel lighter than usual at D. Explain why this is so. Include an estimate of their perceived percentage weight reduction.

(4 marks)

Solution

a $21\ \mathrm{m\ s^{-1}}$ $\Delta E_{\mathrm{k}} = 0.5mv^2 = mg\Delta h\,(\Delta h = 22)$.

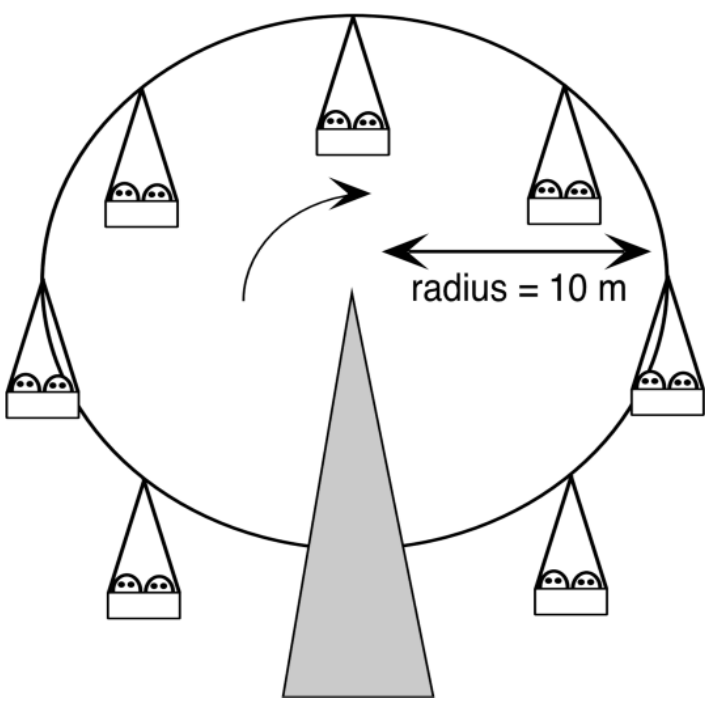
b $11\ \mathrm{m\ s^{-1}}$ As above (use $\Delta h = 6\ \mathrm{m}$).

c 1250 N $N + mg = \frac{mv^2}{r}$.

d Reduced 50% Normal reaction force from rails is 50% of the 2500 N on the flat. Reaction force from seat on passenger is also reduced.

Question 8/ 41 [Adapted VCAA 2023 SB Q9]

Jemima and Fred are riding a Ferris wheel at a park. These are large vertical wheels that rotate slowly. This Ferris wheel is, however, travelling faster than normal. It completes a whole revolution in 20 s, and it has a radius of 10 m.



a. What speed is the perimeter of the wheel travelling at?

(2 marks)

b. What is the net force acting on a 60 kg passenger who is 10 m from the centre of the wheel?

(2 marks)

c. Jemima and Fred notice that they feel lighter at the top of the wheel, compared with the bottom of the wheel. Give physics reasons to explain their observations.

(4 marks)

Solution

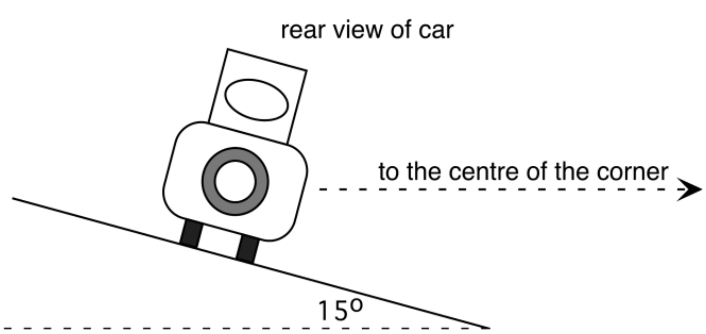
a 3.1 m s^{-1} Use $v = \frac{2\pi r}{T}$.

b 59 N Use $F_{\text{NET}} = \frac{mv^2}{r}$.

c At top of the wheel's rotation $F_{\text{NET}} = mg - R = \frac{mv^2}{r}$; hence $R < mg$; at bottom of rotation $F_{\text{NET}} = R - mg = \frac{mv^2}{r}$; hence $R > mg$; when wheel stationary $R = mg$.

Question 9/ 41 [Adapted VCAA 2023 SB Q9]

High-speed roads are often banked to assist cars when cornering. A view *behind* a car on the corner of a high-speed road shows banking of 15°.



The car is going fast enough so that there is friction between the tyres and the road acting *down* the slope *sideways*. The bend it is taking is approximately circular and has a radius of 167 m.

a. Draw arrows representing the following forces acting on the car:

• weight, *mg*

• normal reaction, *N*

• friction, *Fr*.

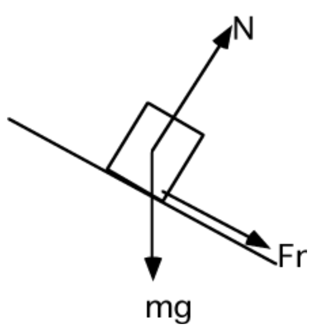
(3 marks)

The car now slows, until it travels at the speed where sideways friction is no longer needed to assist the car to turn the corner; at this speed $Fr = 0$.

b. Calculate the speed required to reduce the sideways friction to zero. The radius of the curve is 167 m.

(2 marks)

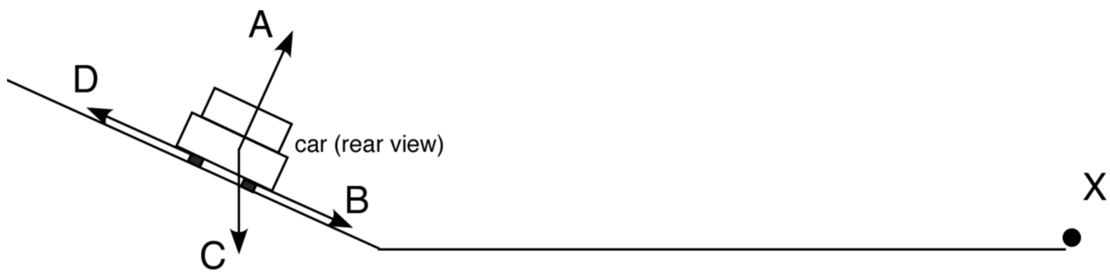
Solution

a 

b $21\ \mathrm{m\ s^{-1}}$ Use $N \sin 15° = F_{\mathrm{NET}} = \frac{mv^2}{r}$. Combine with $N \cos 15° = mg$.

Question 10/ 41 [Adapted VCAA 2023 SB Q9]

The diagram shows the *rear* view of a car travelling around a corner on a banked road. The car is travelling away from us (into the page). The banking has been designed so that cars that travel at $28\ \mathrm{m\ s^{-1}}$ *do not require* any sideways frictional force between their tyres and the road to travel around the corner safely.



a. When the car is travelling *faster* than the recommended speed, which of the arrows above best corresponds to the direction of these forces?

• Gravity force on the car

• Normal reaction force of the road on the car

• The sideways frictional force on the tyres from road

(3 marks)

b. When the car is travelling *slower* than the recommended speed, which of the arrows above best corresponds to the direction of these forces?

• Gravity force on the car

• Normal reaction force of the road on the car

• The sideways frictional force on the tyres from road

(3 marks)

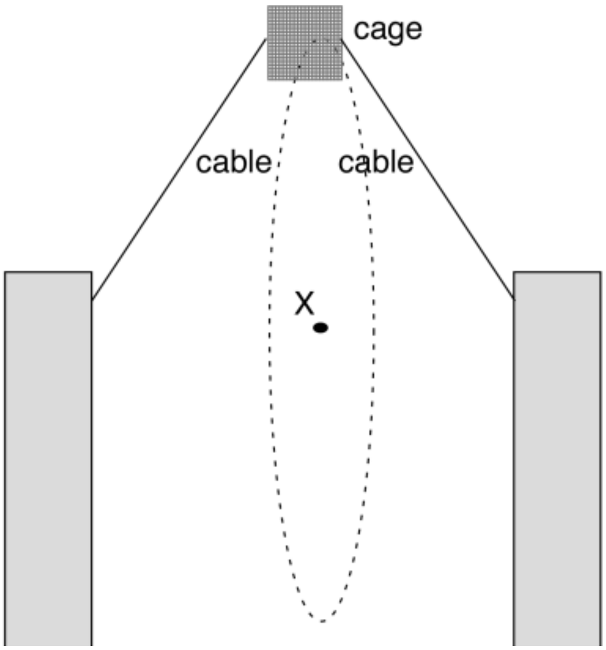
Solution

a $\mathrm{B} = \text{friction, C} = \text{gravity, A} = \text{normal reaction.}$

b $\mathrm{D} = \text{friction, C} = \text{gravity, A} = \text{normal reaction.}$

Question 11/ 41 [Adapted VCAA 2023 SB Q9]

In an adventure ride, riders are strapped in a cage moving in a vertical circle on cables. These are at an angle of 30° to the vertical. The radius of the circle is 8.0 m. The cage has a total mass of 250 kg.



At the top of the circular path, the cage is travelling at $10\ \mathrm{m\,s^{-1}}$.

a. Calculate the net force acting on the cage at this point.

(2 marks)

b. Show that the tension in each of the cables at the top of the circle is close to 390 N.

(2 marks)

c. At the bottom of the circle, the gravitational potential energy (GPE) of the car has decreased. This loss in GPE has been converted to KE. Calculate the speed of the car at the bottom of the circular path.

(2 marks)

d. The owners of the ride are concerned that the cables are safe. They believe that the tension in the cables will be greater at the bottom of the circular path. Are they correct? Justify your answer with reasons drawn from your knowledge of physics principles.

(3 marks)

e. As the ride slows to a stop, it is travelling at $8\ \mathrm{m\,s^{-1}}$ at the lowest point of the circular path. Calculate the tension in the cables at this point.

(2 marks)

Solution

a 3.1 kN Use $F_{\text{NET}} = \frac{mv^2}{R}$.

b Use $2T \cos\theta + mg = 3125$; make *T* the subject.

c 20 m s^{-1} Use $mgh + 0.5mu^2 = 0.5mv^2$.

d At top, $T_{\text{TOP}} = \frac{\left(\frac{mu^2}{R} - mg\right)}{2\cos\theta}$, at bottom $T_{\text{BOTTOM}} = \frac{\left(\frac{mu^2}{R} + mg\right)}{2\cos\theta}$, since $v > u$ (since loss in GPE and gain in KE); hence $T_{\text{TOP}} < T_{\text{BOTTOM}}$.

e 2.6 kN Use $T_{\text{BOTTOM}} = \frac{\left(\frac{mu^2}{R} + mg\right)}{2\cos\theta}$.

Question 12/ 41 [Adapted VCAA 2023 SB Q9]

A small car of mass 600 kg travels in a horizontal circle of radius 20.0 m at a constant speed of 10 m s^{-1}.

a. Calculate the magnitude of the centripetal acceleration acting on the car.

(2 marks)

b. Calculate the magnitude of the centripetal force acting on the car.

(2 marks)

c. In which direction does the centripetal force on the car act?

(2 marks)

Solution

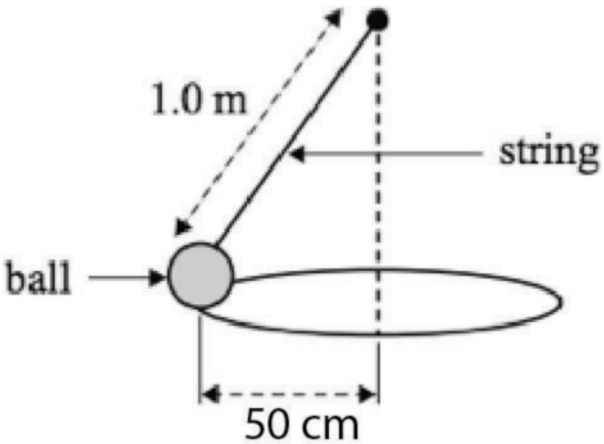
a 5 m s^{-2} Use $a = \frac{v^2}{r} = \frac{10^2}{20} = 5 \text{ m s}^{-2}$

b 3000 N Use $F = ma = (600)(5) = 3000 \text{ N}$.

c Towards the centre of the circle.

Question 13/ 41 [Adapted VCAA 2023 SB Q9]

A steel ball of mass 2.0 kg is swinging in a circle of radius 0.50 m at a constant speed of $1.7 \mathrm{~m~s^{-1}}$ at the end of a 1.0 m long string, as shown.



a. Draw all the forces acting on the ball as lines with arrows. Also draw the resultant force as a dotted line (with arrow), labelled F_{R}.

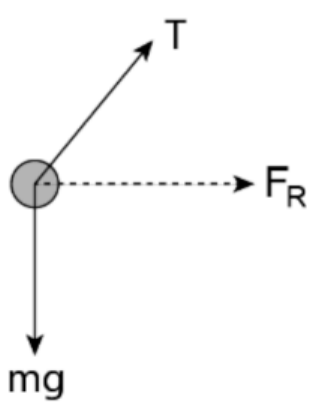
(2 marks)

b. Calculate the tension in the string. Show your working.

(3 marks)

Solution

a



b 23 N Easiest is to set $T\cos\theta = mg$ (where θ is angle between vertical and string; find θ from

$\sin\theta = 0.5$) or use $\tan\theta = \frac{v^2}{rg}$.

Question 14/ 41 [Adapted VCAA 2023 SB Q9]

According to one model of the atom, the electron in the ground state of a hydrogen atom moves around the stationary proton in a circular orbit with a radius of 53 pm (53×10^{-12} m). The force acting between the proton and the electron at this separation is equal to 8.2×10^{-8} N. Calculate the speed of the electron in this circular path. The mass of the electron is 9.1×10^{-31} kg.

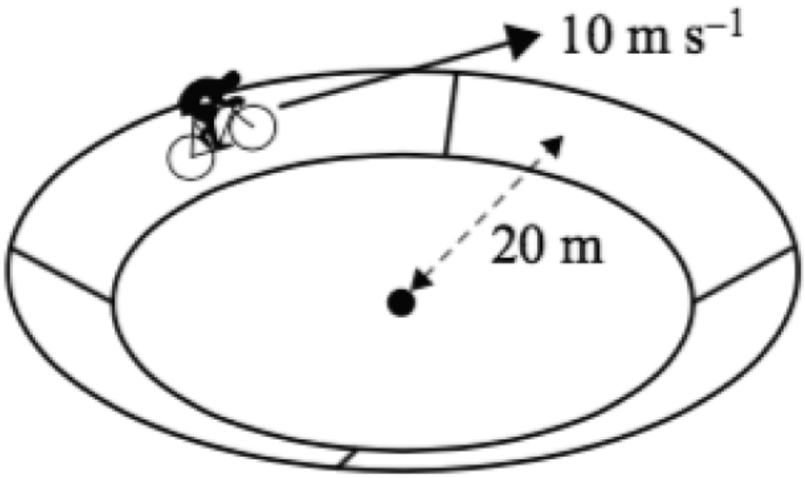
(3 marks)

Solution

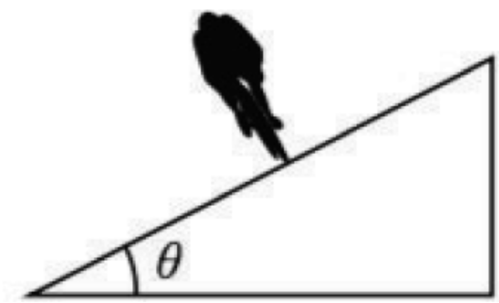
$2.2 \times 10^6 \text{ m s}^{-1}$ Set $F(8.2 \times 10^{-8}) = \frac{mv^2}{r}$ and make *v* the subject.

Question 15/ 41 [Adapted VCAA 2023 SB Q9]

A bicycle and its rider have a total mass of 100 kg and travel around a circular banked track at a radius of 20 m and at a constant speed of 10 m s^{-1}, as shown. The track is banked so that there is no sideways friction force applied by the track on the wheels.



a. On the diagram below, draw all the forces on the rider and the bicycle, considered as a single object, as arrows. Draw the net resultant force as a dashed arrow labelled F_{NET}.



(2 marks)

b. Calculate the correct angle of bank for there to be no sideways friction force applied by the track on the wheels. Show your working.

(2 marks)

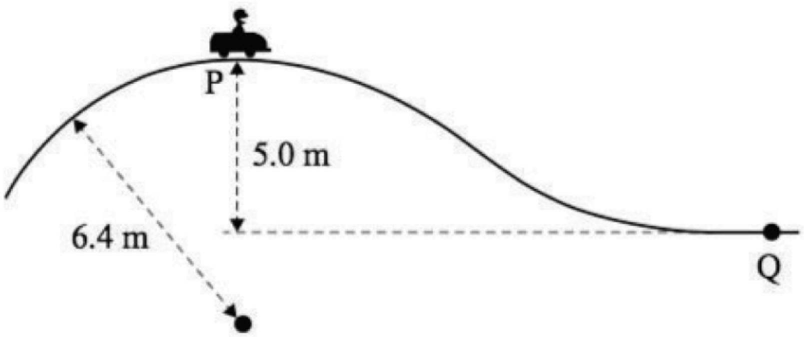
Solution

a Missing Image

b 27° Easiest to use $\tan\theta = \frac{v^2}{rg}$ and make *v* the subject.

Question 16/ 41 [Adapted VCAA 2023 SB Q9]

A roller-coaster is arranged so that the normal reaction force on a rider at the top of the circular arc at point P, shown below, is briefly zero. The section of the track at point P has a radius of 6.4 m.



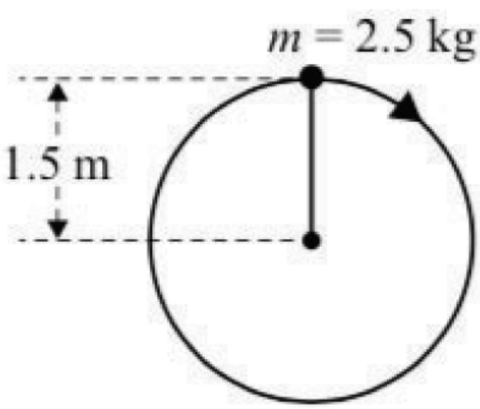
Calculate the speed that the car needs to have to achieve a normal reaction force on the rider at point P. (2 marks)

Solution

$7.9\ \mathrm{m\ s^{-1}}$ If normal reaction $\text{force} = 0$ then $mg = \frac{mv^2}{r}$; calculate *v*.

Question 17/ 41 [Adapted VCAA 2023 SB Q9]

In an experiment, a ball of mass 2.5 kg is moving in a vertical circle at the end of a string, as shown. The string has a length of 1.5 m.



a. Calculate the minimum speed the ball must have at the top of its arc for the string to remain tight (under tension). (2 marks)

b. In another experiment, the ball is moving at $6.0 \mathrm{~m~s}^{-1}$ at the top of its arc. Calculate the speed of the ball at the lowest point.

(3 marks)

Solution

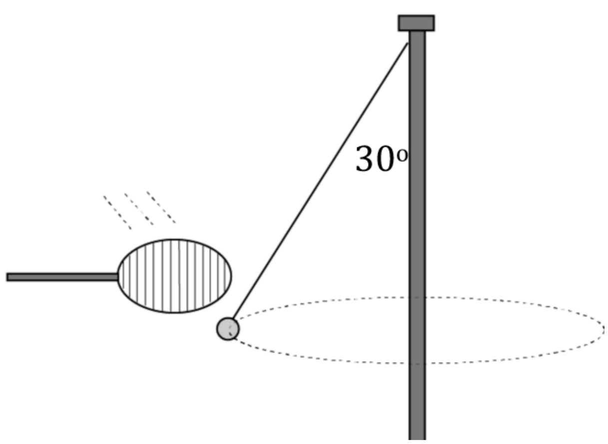
a $3.8 \mathrm{~m~s}^{-1}$ At top of circle, centripetal $\text{force} = T + mg = \frac{mv^2}{R}$.

Minimum speed occurs when $T = 0$. Hence, $\frac{mv^2}{R} = mg$.

b $9.7 \mathrm{~m~s}^{-1}$ Conservation of energy: $E_{\text{top}} = \frac{1}{2} m v_{\text{TOP}}{}^2 + mgh = \frac{1}{2} m v_{\text{BOTTOM}}{}^2$. Note $h = 3.0 \mathrm{~m}$.

Question 18/ 41 [Adapted VCAA 2023 SB Q9]

A 600 g ball swings in a horizontal circle on the end of a 1.5 m cord attached to a pole, as shown below. The string makes an angle of 30° with the vertical pole.



a. Calculate the magnitude of the tension in the cord.

(2 marks)

b. Calculate the size of the centripetal acceleration of the ball.

(3 marks)

c. Calculate the speed of the ball.

(3 marks)

Solution

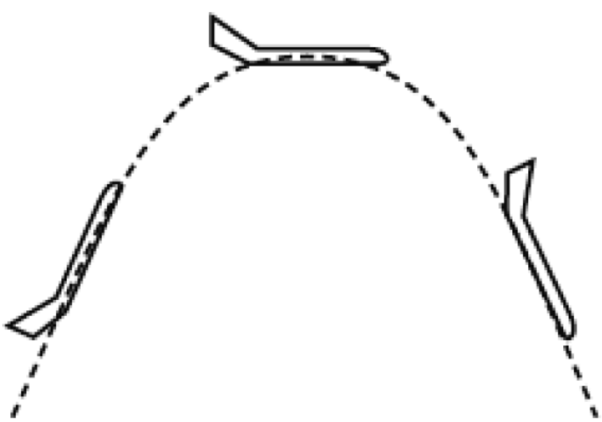
a 6.8 N Balance weight of ball (*mg*) with *T*cos30°.

b 5.7 m s^{-2} $\text{Centripetal force} = T\sin 30°$; divide by *m* to obtain acceleration.

c 2.1 m s^{-1} Use $a = \frac{v^2}{R}$ where $R = \text{cord length} \times \sin 30°$.

Question 19/ 41 [Adapted VCAA 2023 SB Q9]

Members of the public can now pay to take zero gravity flights in specially modified jet aeroplanes that fly at an altitude of 8000 m above Earth's surface. A typical trajectory is shown below. At the top of the flight, the trajectory can be modelled as an arc of a circle.



a. Calculate the radius of the arc that would give passengers zero gravity at the top of the flight if the jet is travelling at 180 m s^{-1}. Show your working.

(2 marks)

b. Is the force of gravity on a passenger zero at the top of the flight? Explain what 'zero gravity experience' means.

(2 marks)

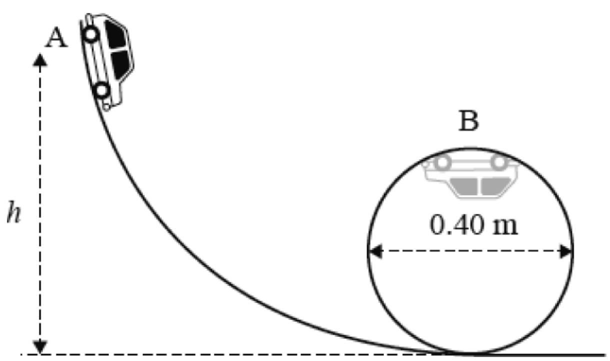
Solution

a $3.3 \times 10^3 \mathrm{m}$ Use $R = \frac{v^2}{g}$.

b No, gravity acts throughout. A ‘zero gravity experience’ is due to the reduction of the normal reaction force *N* to zero in free fall.

Question 20/ 41 [Adapted VCAA 2023 SB Q9]

A 250 g toy car performs a loop in the apparatus shown below.



The car starts from rest at point A and travels along the track without any air resistance or retarding frictional forces. The radius of the car’s path in the loop is 0.20 m. When the car reaches point B it is travelling at a speed of $3.0 \mathrm{~m~s}^{-1}$.

a. Calculate the value of *h*. Show your working.

(3 marks)

b. Calculate the magnitude of the normal reaction force on the car by the track when it is at point B. Show your working.

(3 marks)

c. Explain why the car does not fall from the track at point B, when it is upside down.

(3 marks)

Solution

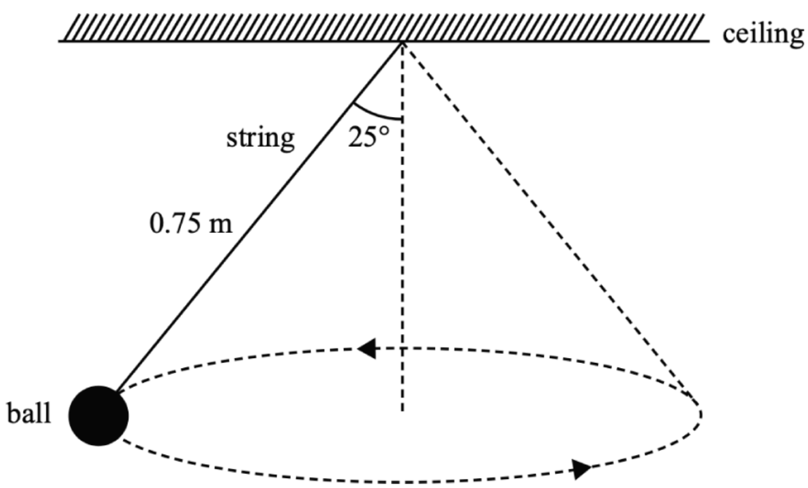
a 0.86 m Use conservation of energy. $\text{GPE lost} = mg\,(h - 0.40); \text{KE gained} = 0.5mv^2$; equate and solve for h.

b 8.8 N At point B, net force is downwards and equal to $(N + mg)$. This must equal $\frac{mv^2}{r}$; hence $N = m(\frac{v^2}{r} - g)$.

c As long as the normal reaction from the track is > 0, the toy car will be pushing upwards on the track (Newton's third law) and it will not fall off. As it slows, the normal reaction force will get smaller; when it reduces to zero, the car is on the verge of falling off.

Question 21/ 41 [Adapted VCAA 2023 SB Q9]

The diagram below shows a small ball of mass 1.8 kg travelling in a horizontal circular path at a constant speed while suspended from the ceiling by a 0.75 m long string.



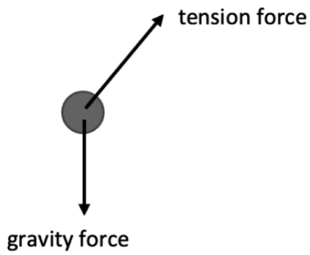
a. Use labelled arrows to indicate on the diagram the two physical forces acting on the ball.

(2 marks)

b. Calculate the speed of the ball. Show your working.

(4 marks)

Solution



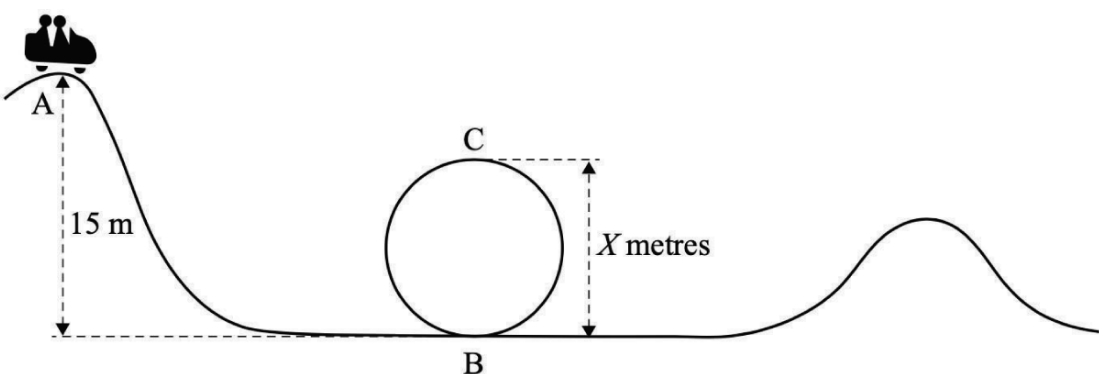
a

Note that the centripetal force is not regarded as a physical force in this question.

b $1.2\ \mathrm{m\ s^{-1}}$ $F_{\mathrm{NET}} = mg \times \tan 25° = \frac{mv^2}{r}$ where $r = 0.75 \sin 25°$. Solve for *v*.

Question 22/ 41 [Adapted VCAA 2023 SB Q9]

Abbie and Brian are about to go on their first loop-the-loop roller-coaster ride. As competent Physics students, they are working out if they will have enough speed at the top of the loop to remain in contact with the track while they are upside down at point C, shown below. The radius of the loop CB is *r*.



The highest point of the roller-coaster (point A) is 15 m above point B and the car starts at rest from point A. Assume that there is negligible friction between the car and the track.

a. By considering the forces acting on the car, show that the condition for the car to just remain in contact with the track at point C is given by $v^2/r = g$. Show your working.

(2 marks)

b. What is the maximum height of the loop (*X* metres) that will ensure that the car stays in contact with the track at point C? Show your working.

(3 marks)

c. If friction is taken into account, will Abbie and Brian need to increase or decrease their predicted value for the radius of the loop? Explain your answer.

(3 marks)

Solution

a For the car to stay in contact with the track the normal force (*N*) minimum must be zero.

At this point $F_{\text{NET}} = \frac{mv^2}{r} = mg + N$. When $N = 0$ this gives $\frac{v^2}{r} = g$.

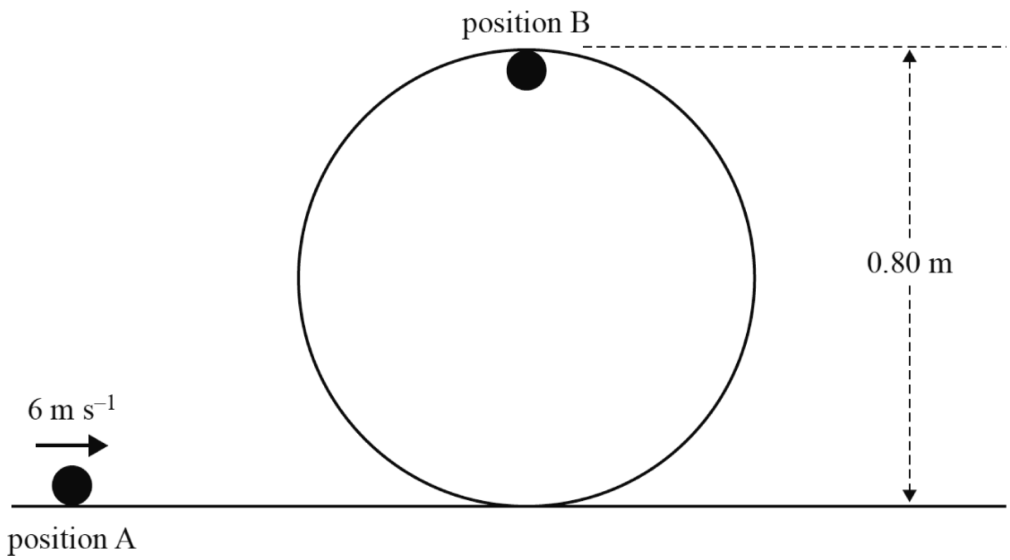
b 12 m GPE Change between A and C is $mg(15 - X) = \text{KE} = \frac{1}{2}mv^2$;

So $v^2 = 2g\,(15 - X)$. The condition $\frac{v^2}{r} = g$ must apply, so $v^2 = rg$. So, $2g\,(15 - X) = rg$ or $30 - 2X = r = \frac{X}{2}$. Solve for *X*.

c The radius of the loop will have to decrease. You must show how and why the initial equation of forces $\left(\frac{mv^2}{r} = mg + F_{\text{N}}\right) \rightarrow \frac{mv^2}{r} = mg \rightarrow \frac{v^2}{r} = g$ for full marks. Friction will cause the velocity to decrease and since the radius is related to the velocity by $r = \frac{v^2}{g}$, if the velocity decreases the radius will have to decrease as well.

Question 23/ 41 [Adapted VCAA 2023 SB Q9]

A small ball of mass 0.30 kg travels horizontally with a kinetic energy of 5.4 J. It enters a vertical circular loop of diameter 0.80 m, as shown below. Assume that the radius of the ball and that the frictional forces are negligible.



Will the ball remain on the track at the top of the loop at position B? Give your reasoning.

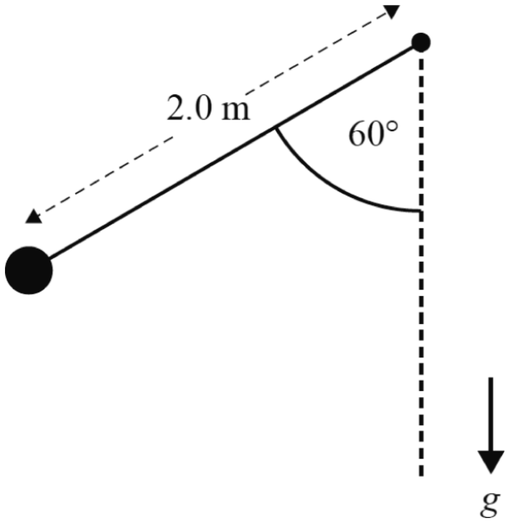
(4 marks)

Solution

The ball will stay on the track. The slowest it can go and stay on the track is when the normal force is just zero. This occurs when $mg = \frac{mv^2}{r}$, or $v^2 = gr$; this gives $v = 1.98 \text{ m s}^{-1}$. Find the actual speed at B using conservation of energy; that is, KE at $\text{B} = 5.4 - mg\Delta h$, where $\Delta h = 0.80$. This gives *v* at $\text{B} = 4.5 \text{ m s}^{-1}$.

Question 24/ 41 [Adapted VCAA 2023 SB Q9]

A spherical mass of 2.0 kg is attached to a piece of string of length of 2.0 m. The spherical mass is pulled back until it makes an angle of 60° with the vertical, as shown below.



The spherical mass is then released. Ignore the mass of the string. The maximum speed of the spherical mass is 4.4 m s^{-1}. Calculate the maximum tension in the string.

(3 marks)

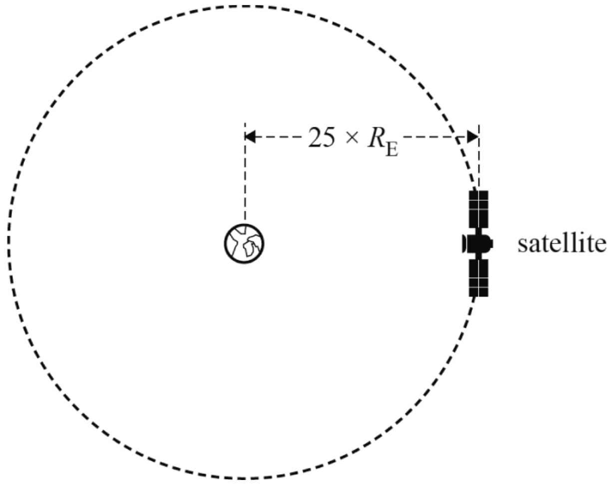
Solution

40 N Identify that the maximum tension and speed occurs at the bottom of the swing. At this point, net force is $T - mg = \frac{mv^2}{r}$.

Make *T* the subject: $T = mg + \frac{mv^2}{r} = 39.6$ N.

Question 25/ 41 [Adapted VCAA 2023 SB Q9]

A satellite is moving in a stable circular orbit 25 Earth radii from the centre of Earth, as shown below. The period of the satellite is *T*.



Indicate the direction of the acceleration of the satellite by drawing an arrow on the satellite in the diagram above.

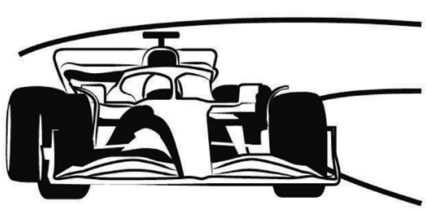
(1 mark)

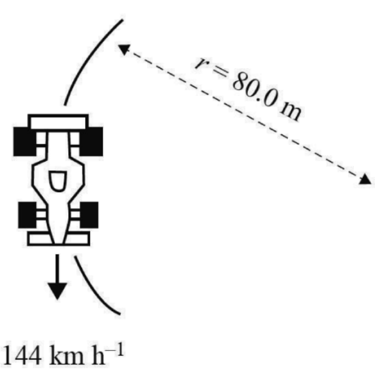
Solution

An arrow from the satellite towards Earth, at the centre of the circular orbit.

Question 26/ 41 [Adapted VCAA 2023 SB Q9]

A Formula 1 racing car is travelling at a constant speed of 144 km h^{-1} (40 m s^{-1}) around a horizontal corner of radius 80.0 m. The combined mass of the driver and the car is 800 kg. The left-hand diagram below shows a front view and the right-hand diagram shows a top view.





a. Calculate the magnitude of the net force acting on the racing car and driver as they go around the corner.

(2 marks)

b. On the right-hand diagram, draw the direction of the net force acting on the racing car using an arrow.

(1 mark)

c. Explain why the racing car needs a net horizontal force to travel around the corner and state what exerts this horizontal force.

(2 marks)

Solution

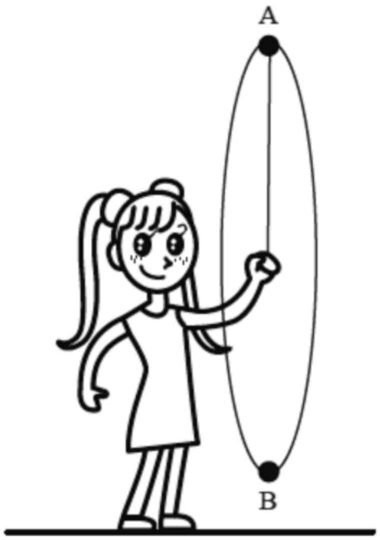
a 1.6×10^4 N This force is the centripetal force, given by $\frac{mv^2}{R}$.

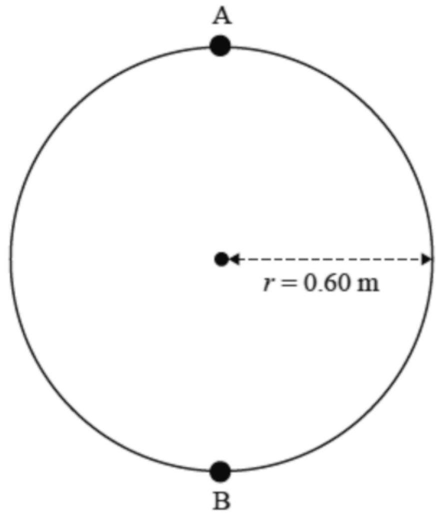
b An arrow from the racing car pointing towards the centre of the circle.

c The car is continuously changing its horizontal direction; it is thus accelerating, so there must be a net force on it. This force is supplied by the friction between the tyres and the road.

Question 27/ 41 [Adapted VCAA 2023 SB Q9]

Lee ties a small ball of mass 100 g to a string and rotates it in a vertical circle, as shown in the left-hand diagram below. Assume that the ball is rotated at a constant speed of 3.0 m s^{-1}. The radius, *r*, of the circle is 0.60 m. The right-hand diagram below shows a side view.





a. On the right-hand diagram, draw arrows to represent each of the forces acting on the small ball at position A, at the top of the circle, and at position B, at the bottom of the circle. Label each arrow clearly and use the lengths of the arrows to show the relative approximate magnitudes of the forces. No calculations are required.

(4 marks)

b. Calculate the tension force in the string when the ball is at position B.

Use $g = 10\ \mathrm{m\ s^{-2}}$.

(2 marks)

c. Lee now increases the speed of the ball to a new constant speed, which is greater than $3.0\ \mathrm{m\ s^{-1}}$, and notices that the string breaks when the ball is at position B. Explain why the string is more likely to break at position B than at position A.

(3 marks)

Solution

a *mg* down equally at A and B, *T* at A down, *T* at B up & $> mg$ at B, $T_{\mathrm{B}} > T_{\mathrm{A}}$

b 2.5 N $F_{\mathrm{c}} = T_{\mathrm{B}} - mg = \frac{mv^2}{r} \therefore T_{\mathrm{B}} = mg + \frac{mv^2}{r}$

$= 0.10 \times 10 + \left(\frac{0.10 \times 3.0^2}{0.6}\right)$

c Tension increases (at all points) as speed increases.

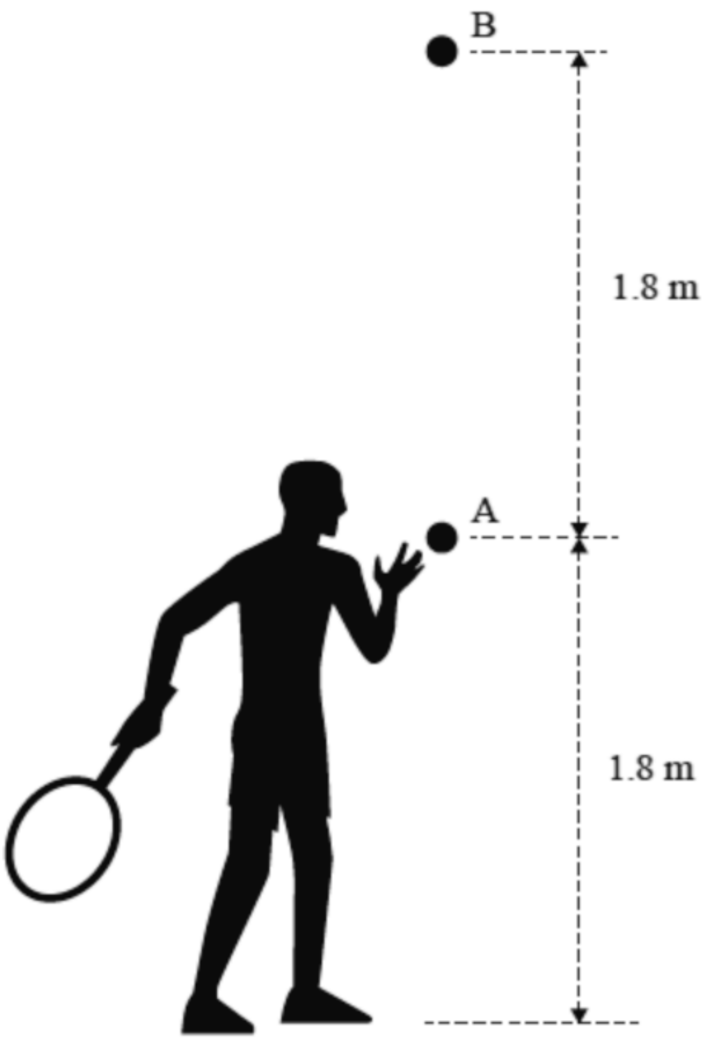
*F*c constant at top and bottom.

$T_B > T_A$ (due to gravity).

Question 28/ 41 [Adapted VCAA 2023 SB Q9]

Giorgos is practising his tennis serve using a tennis ball of mass 56 g.

a. Giorgos practises throwing the ball vertically upwards from point A to point B, as shown below.

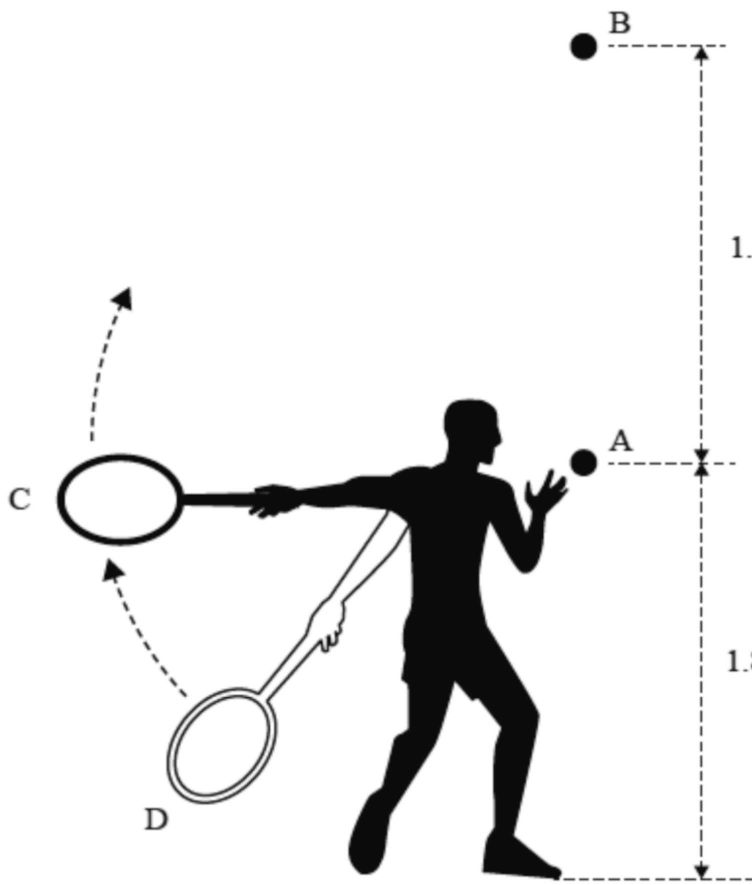


His daughter Eka, a physics student, Models the throw, assuming that the ball is at the level of Giorgos's shoulder, point A, both when it leaves his hand and also when he catches it again. Point A is 1.8 m from the ground. The ball reaches a maximum height, point B, 1.8 m above Giorgos's shoulder.

Show that the ball is in the air for 1.2 s from the time it leaves Giorgos's hand, which is level with his shoulder, until he catches it again at the same height.

(2 marks)

b. Giorgos swings his racquet from point D through point C, which is horizontally behind him at shoulder height, as shown below, to point B. Eka models this swing as circular motion of the racquet head. The centre of the racquet head moves with constant speed in a circular arc of radius 1.8 m from point C to point B.



The racquet passes point C at the same time that the ball is released at point A and then the racquet hits the ball at point B.

Calculate the speed of the racquet at point C.

(2 marks)

Solution

a Calculate the time taken for the ball of fall 1.8m using $s = ut + \frac{1}{2}gt^2$ gives $t = 0.606$ s

The total time is twice this $t = 1.2$ s as required.

b 4.7 m s^{-1} Time to travel one quarte of a circle is 0.6 s.

Use $v = \frac{2\pi R}{T} = 4.7 \text{ m s}^{-1}$

Chapter 7 Fields and their patterns

Question 1/ 18

Which of the following best describes the force between two isolated positive point charges?

A There is an attractive force caused by the direct interaction of the two charges.

B There is a repulsive force caused by the direct interaction of the two charges.

C There is an attractive force caused by the interaction of the electric field of one charge with the other charge.

D There is a repulsive force caused by the interaction of the electric field of one charge with the other charge.

Solution

D Standard knowledge.

Question 2/ 18

A key difference between the electrostatic forces between two positive charges and magnetic forces between two bar magnets is that

A electrostatic forces rely on electric fields, but magnetic forces are direct interactions between magnets.

B the electrostatic forces can be either attractive or repulsive, but the magnetic forces are always attractive.

C the electrostatic force will always be positive, but the magnetic force can be attractive or repulsive.

D both forces can be attractive or repulsive, but magnetic forces only work at short ranges.

Solution

C Standard knowledge.

Question 3/ 18

At the time of writing this question, magnetic monopoles have not been observed. However, if they were discovered, the pattern of their magnetic field would likely be most similar to the field pattern of

A a moving isolated electric charge.

B a bar magnet.

C an isolated point mass.

D a closely spaced pair of positive and negative electric charges.

Solution

C A magnetic monopole (e.g. an isolated N pole) would have a field similar to an isolated point mass (or charge).

Question 4/ 18

The following kinds of monopoles have **not** yet been observed.

A positive electric

B negative electric

C magnetic north

D gravitational

Solution

C Standard knowledge.

Question 5/ 18

Which of the following statements is correct?

A Electrostatic and magnetic fields are vector fields; gravitational fields are not.

B Electrostatic and gravitational fields are vector fields; magnetic fields are not.

C Magnetic and gravitational fields are vector fields; electrostatic fields are not.

D Electrostatic, magnetic and gravitational fields are all vector fields.

Solution

D Standard knowledge.

Question 6/ 18

Which of the following is closest to a uniform field?

A the electric field between two large charged parallel plates

B the electric field close to an isolated positive charge

C the magnetic field close to a current in a long straight wire

D none of the above is close to a uniform field

Solution

A Standard knowledge.

Question 7/ 18

The inverse square law does *not* apply to which of the following?

A the gravitational field of a point mass

B the electric field of an isolated positive charge

C the electric field of an isolated negative charge

D the magnetic field of a bar magnet

Solution

D Bar magnets have dipole fields.

Question 8/ 18

Which of the following could be described as a static field?

A the gravitational field of the Moon as it passes overhead

B the electric field of a vibrating positive charge

C the magnetic field around a coil carrying AC current

D the magnetic field around a coil carrying DC current

Solution

D The others all change with time.

Question 9/ 18

Which of the following interactions always produces repulsive forces?

A electrostatic charges of opposite sign

B electrostatic charges of same sign

C two bar magnets

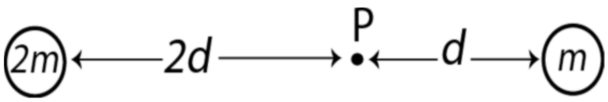
D masses of matter and anti-matter

Solution

B Standard knowledge.

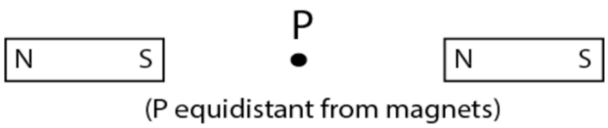
Question 10/ 18

Which of the following diagrams shows the situation in which the vector sum of fields produces a zero field at P? Diagram A shows two masses, diagrams B and C show electric charges, and diagram D shows two bar magnets.

A


B


C


D


Solution

B C and D clearly have a non-zero field at P; in A the *inverse square law* means that the fields do not cancel.

Question 11/ 18

Which of the following statements best summarises current information about monopoles and dipoles?

A Dipoles are only possible in electric fields.

B Monopoles are never observed in gravitational fields.

C Monopoles are not observed in electric fields.

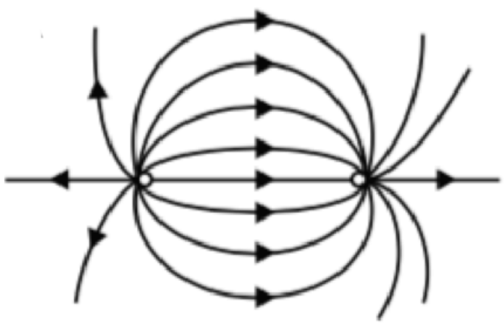
D Dipoles exist in electric and magnetic fields.

Solution

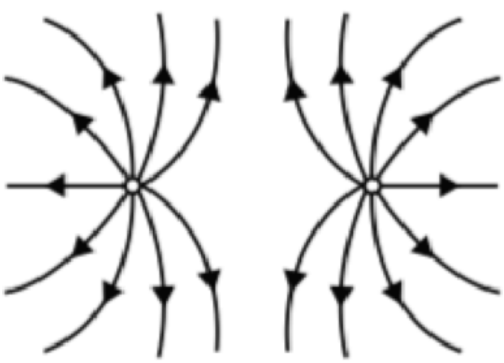
D Magnetic monopoles (at the time of print) have not been observed.

Question 12/ 18

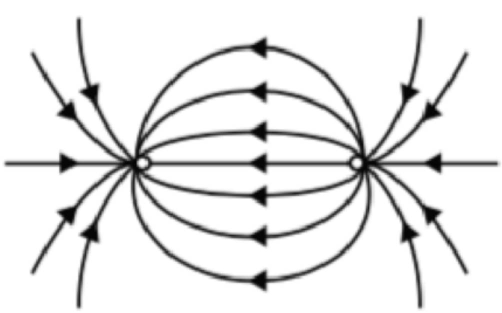
Which one of the following diagrams best shows the electric field pattern surrounding two equal, positive point charges?



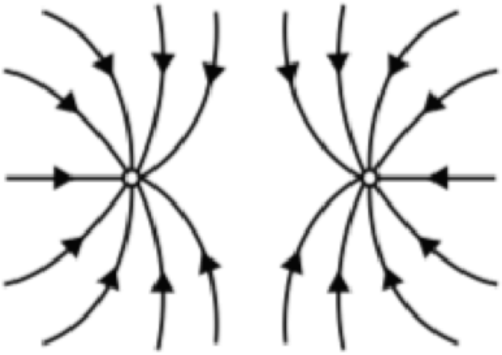
A



B



C

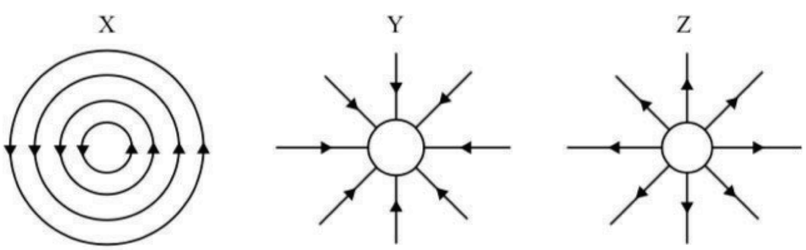
D 

Solution

B Standard knowledge of field patterns.

Question 13/ 18

The three diagrams X, Y and Z below represent different types of fields.



Which one of the following statements about these diagrams is correct?

A X could be an electric field, Y could be a gravitational field and Z could be a magnetic field.

B X could be a gravitational field, Y could be an electric field and Z could be a magnetic field.

C X could be a magnetic field, Y could be a gravitational field and Z could be an electric field.

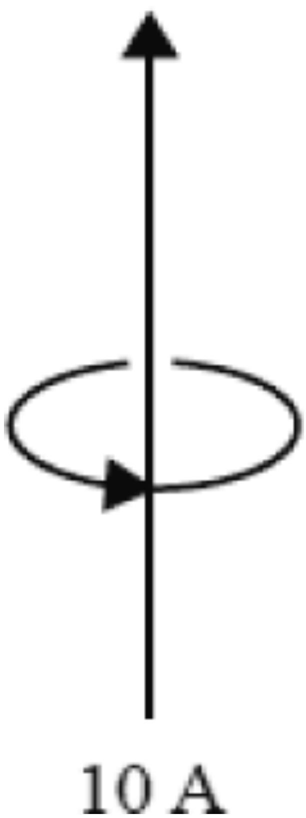
D X could be a gravitational field, Y could be a magnetic field and Z could be an electric field.

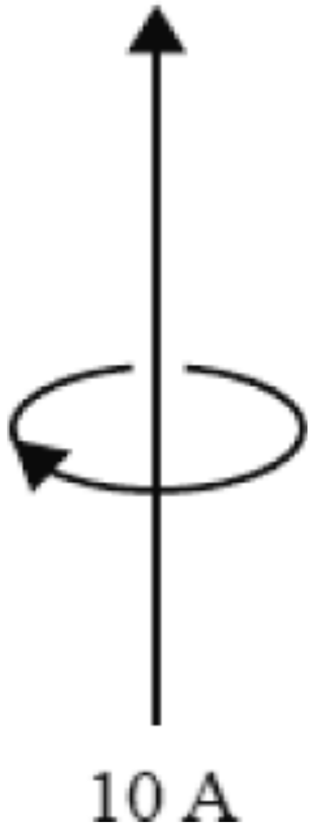
Solution

C   Closed loop field patterns must be magnetic; gravitational fields must be attractive; electric field patterns can be repulsive or attractive.

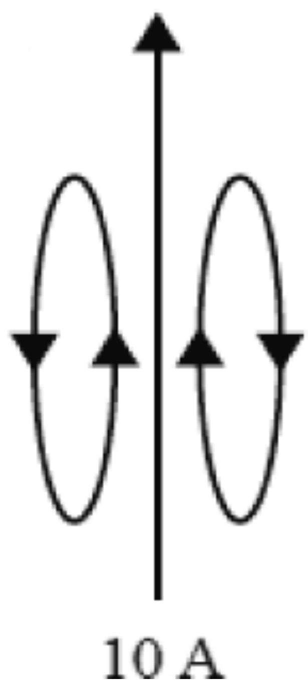
Question 14/ 18

A straight wire carries a current of 10 A. Which one of the following diagrams best shows the magnetic field associated with this current?

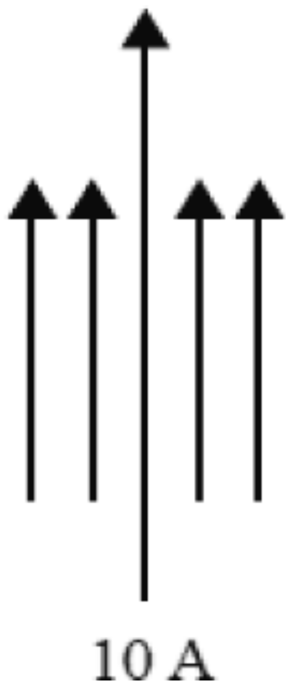
A 



B



C



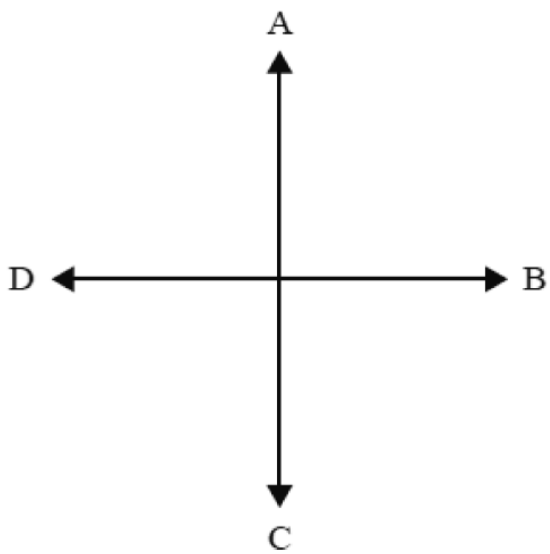
D

Solution

A Right-hand grip rule using conventional current.

Question 15/ 18

Two identical bar magnets are placed end to end, as shown below. Point X is midway between the bar magnets. Which direction best shows the direction of the magnetic field at point X?



A A

B B

C C

D D

Solution

B Fields from N and S poles add, both are to the right.

Question 16/ 18

Magnetic and gravitational forces have a variety of properties. Which of the following best describes the attraction/repulsion properties of magnetic and gravitational forces?

Magnetic forces **Gravitational forces**

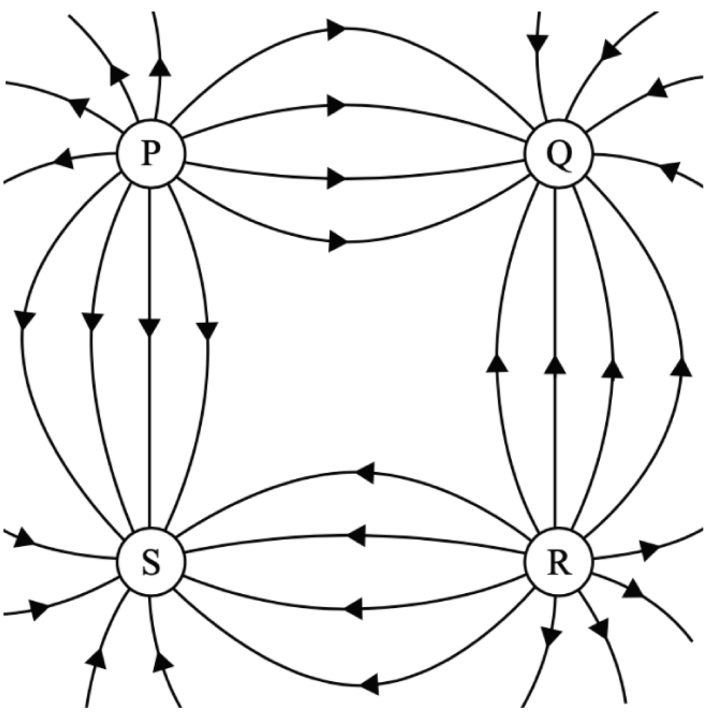
Magnetic forces	Gravitational forces
either attract or repel	only attract
only repel	neither attract nor repel
only attract	only attract
either attract or repel	either attract or repel

Solution

A Standard knowledge.

Question 17/ 18

The diagram below shows the electric field lines between four charged spheres: P, Q, R and S. The magnitude of the charge on each sphere is the same.



Which of the following correctly identifies the type of charge (+ positive or − negative) that resides on each of the spheres P, Q, R and S?

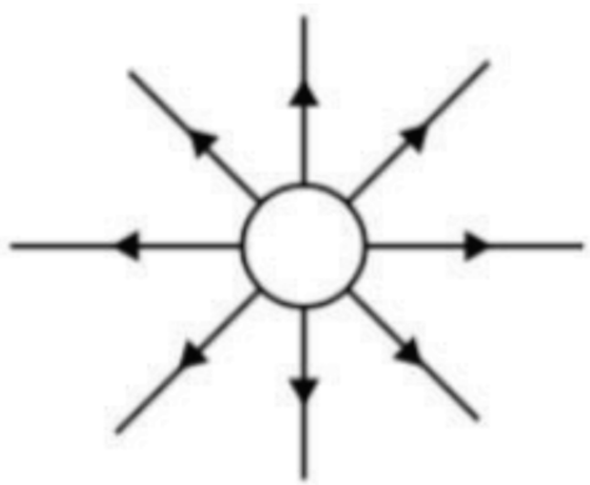
P	Q	R	S
−	+	−	+
+	−	+	−
−	−	+	+
+	+	−	−

Solution

B A small test $+\text{ve}$ electric charge will be attracted to Q and S and repelled by P and R.

Question 18/ 18

Consider the diagram below, which shows a stationary object with field lines that extend outwards from the object.



The field shown is most likely to be identified as an example of

A an electric field that is uniform.

B an electric field that is non-uniform.

C a gravitational field that is uniform.

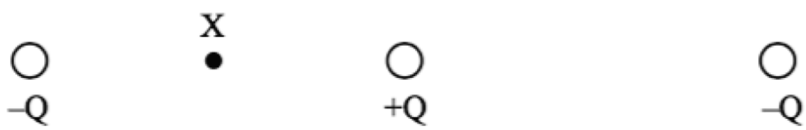
D a gravitational field that is non-uniform.

Solution

B Non-uniform and repulsive (gravity would be attractive).

Question 1/ 29 [VCAA 2020 SB Q1]

Three charges are arranged in a line, as shown below.



Draw an arrow at point X to show the direction of the resultant electric field at X. If the resultant electric field is zero, write the letter ‘N’ at X.

(1 mark)

Solution

Draw a horizontal arrow to the left at the point X. The field of the two left-hand charges combine towards the left; their combined effect is much greater than the effect of the right-hand charge.

Question 2/ 29 [VCAA 2020 SB Q1]

Two small equal masses are shown in the diagram below. They can be considered to be point masses.

a. Identify any point(s) where the combined gravitational field of the two masses is zero, by marking it on the diagram.

(1 mark)

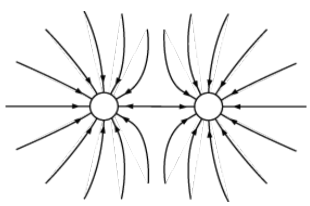
b. Sketch the pattern of the gravitational field between the masses, using at least four field lines. Mark each field line with an appropriate arrow to show the direction of the field.

(2 marks)

Solution

a Midway between the two masses.

b



Question 3/ 29 [VCAA 2020 SB Q1]

Two small charges of opposite sign are shown in the diagram below. They can be considered to be point charges.

a. Sketch the pattern of the electric field between the charges, using at least four field lines. Mark each field line with an appropriate arrow to show the direction of the field.

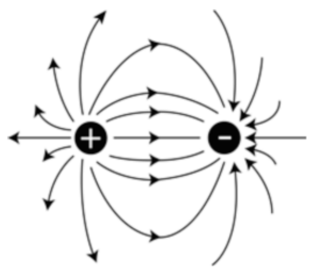
(2 marks)

b. Students are debating whether the point midway between the two charges is a point of zero field strength.

Give your judgement on this, including reasons.

(2 marks)

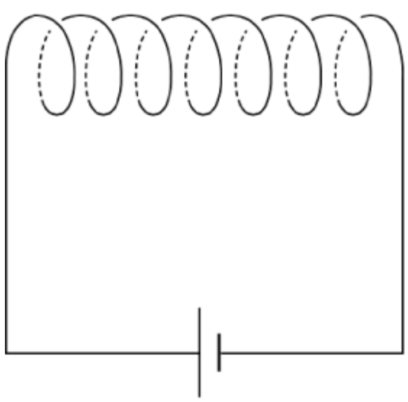
Solution

a 

b It won't be. The field from the LH +ve charge will be directed to the R, as will the field from the negative charge.

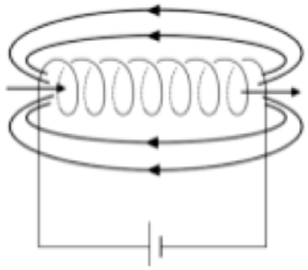
Question 4/ 29 [VCAA 2020 SB Q1]

The diagram below shows a solenoid. Draw five lines with arrows to show the magnetic field of the solenoid.



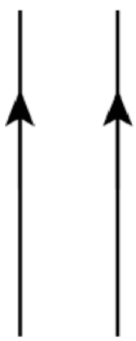
(2 marks)

Solution



Question 5/ 29 [VCAA 2020 SB Q1]

Two long straight wires are parallel, as shown in the left-hand diagram below. Viewed from *below*, they can be shown as in the right-hand diagram. Note that the currents are in the same direction.



a. Sketch the pattern of the magnetic field lines as seen from below the wires. Use six (or more) lines.

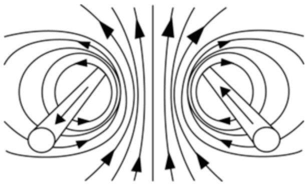
(2 marks)

b. The current in *one* wire is reversed. Sketch the field pattern now.

(2 marks)

Solution

a Missing Image

b 

Question 6/ 29 [VCAA 2020 SB Q1]

a. Give an example of a non-uniform magnetic field. Include a pattern of field lines.

(2 marks)

b. Give an example of a non-uniform electrostatic field. Include a pattern of field lines.

(2 marks)

c. Give an example of a non-uniform gravitational field. Include a pattern of field lines.

(2 marks)

Solution

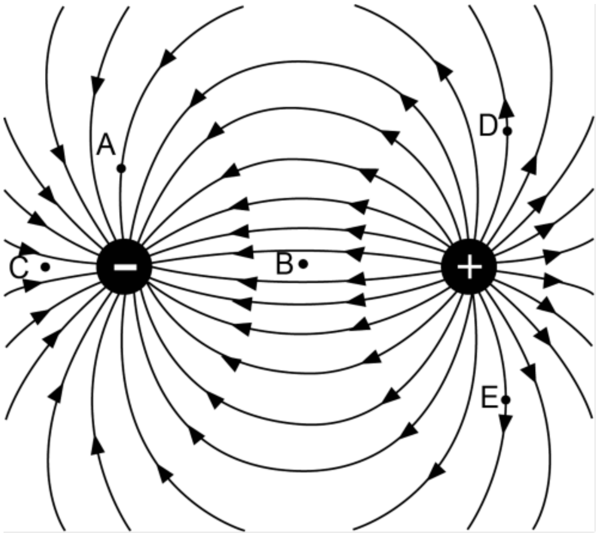
a See answer to Q23a or Q23b.

b See answer to Q21a.

c See answer to Q20b.

Question 7/ 29 [VCAA 2020 SB Q1]

An electrostatic field line pattern is shown below.



a. Use the field pattern to compare the direction of the field at points A and E. Explain your reasoning.

(2 marks)

b. Use the field pattern to compare the direction of the field at points B and C. Explain your reasoning.

(2 marks)

c. Use the field pattern to compare (qualitatively) the strength of the field at points B and D. Explain your reasoning.

(2 marks)

Solution

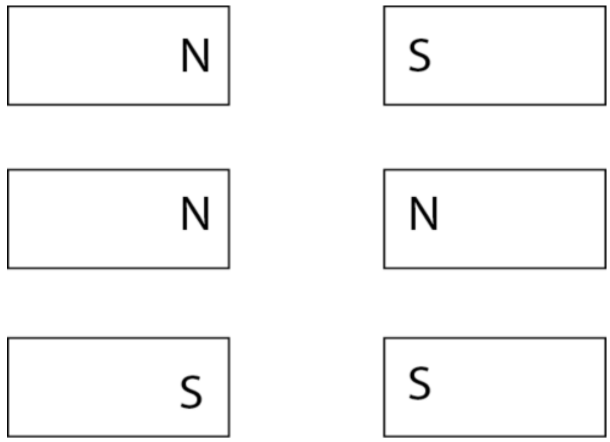
a At A, vertically down (tangent to field line at point); at E the same.

b At B, horizontally left (tangent to field line at point); at C horizontally right.

c The field at B is stronger than at D because the density of field lines is greater.

Question 8/ 29 [VCAA 2020 SB Q1]

Two bar magnets are arranged in three different ways, as shown.



In the space between the magnets in each arrangement, draw *at least four* magnetic field lines. Attach arrowheads to each field line, showing its direction.

(3 marks)

Solution

Missing Image

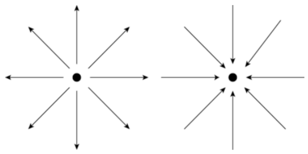
Question 9/ 29 [VCAA 2020 SB Q1]

Compare and contrast the shapes and directions of the fields from a single isolated positive point charge and a single isolated point mass.

(3 marks)

Solution

The fields of both are radial in direction, and their strengths drop off according to an inverse square law. However, the gravitational field is always attracive and its direction is directed inwards to the point mass (right-hand diagram below), while the electric field is directed outwards from the point charge (left-hand diagram).



Question 10/ 29 [VCAA 2020 SB Q1]

Gravitation, magnetism and electricity can be explained using a field model. According to our understanding of physics and current experimental evidence, these three field types can be associated with only monopoles, only dipoles or both monopoles and dipoles. In the table below, indicate whether each field type can be associated with only monopoles, only dipoles or both monopoles and dipoles by ticking the appropriate box.

Field type	Only monopoles	Only dipoles	Both monopoles and dipoles
gravitation			
magnetism			
electricity			

(3 marks)

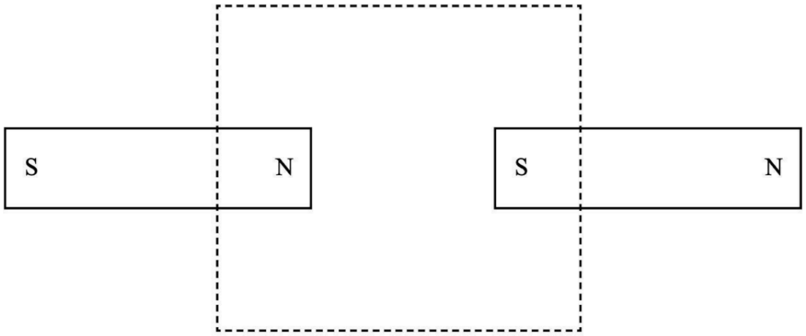
Solution

Gravitation – only monopoles; Magnetism – only dipoles; Electricity – both monopoles and dipoles.

Question 11/ 29 [VCAA 2020 SB Q1]

Two bar magnets are placed close to each other, as shown below.

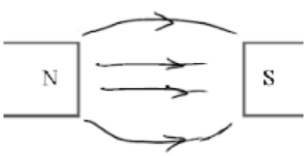
Sketch the shape and the direction of *at least four* magnetic field lines between the two poles within the dashed border shown.



(2 marks)

Solution

The examiners report suggests something like the following:



Chapter 8 Gravitational fields

Question 1/ 24

Which of the below gives the correct units for *G*?

A $\mathrm{N\ kg^{-1}}$

B $\mathrm{m^3 s^{-2}\ kg^{-1}}$

C $\mathrm{N\ m\ kg^{-2}}$

D none of the above

Solution

B Deduce from $F = \frac{Gm_1m_2}{R^2}$.

Question 2/ 24

Scientists want to put a satellite into an orbit where the gravitational field of Earth is half its value at Earth's surface. The altitude of this orbit above Earth's surface will be

A 3*R*

B $\sqrt{2}R - R$

C 4*R*

D $\sqrt{2}R$

Solution

B Deduce from $g \propto \frac{1}{R^2}$.

Question 3/ 24

If the Moon were to be put into a new orbit of twice its current radius, its potential energy would

A increase.

B decrease.

C remain unchanged.

D increase or decrease, depending on its speed in the new orbit.

Solution

A PE increased; if it stopped moving would hit Earth faster.

Question 4/ 24

Two satellites are in orbit at the same height around Earth. Satellite 1 has a mass 10 times that of satellite 2. Determine which option is closest to the ratio:

$\frac{period\ of\ satellite\ 1}{period\ of\ satellite\ 2}$

A 100

B 10

C 1

D 0.10

Solution

C All satellites at same height have same *v* and *T*.

Question 5/ 24

A Moon transfer vehicle has a weight of 625 000 N on Earth's surface. On the surface of the Moon a *possible* value for its approximate weight could be

A 0 N

B 625 000 N

C 62 500 kg

D 100 000 N

Solution

D g on Moon's surface must be less than on Earth.

Question 6/ 24

The acceleration due to gravity on the surface of Mars is close to $3.8\ \mathrm{m\ s^{-2}}$. Which of the following is closest to the weight of an object on Mars that weighs 76 N on Earth?

A 7.6 kg

B 29 N

C 290 N

D 760 N

Solution

B   Use $W = mg_{\mathrm{MARS}}$.

Question 7/ 24

Which of the following best describes the forces acting on a satellite in stable orbit around Earth?

A The gravity force from Earth

B The gravity force from Earth, balanced by an equal outwards force

C No force is required; conservation of momentum ensures its motion

D A force from the engines of the satellite

Solution

A Gravity supplies the required centripetal force.

Question 8/ 24

A satellite in orbit around Earth is at a height where the value of $g = 4.9 \text{ m s}^{-2}$. Which of the following is closest to the centripetal acceleration of the satellite while in this orbit?

A 0 m s^{-2}

B 4.9 m s^{-2}

C 9.8 m s^{-2}

D 19.6 m s^{-2}

Solution

B The only force is $\text{gravity} = mg = ma$.

Question 9/ 24

Which of the following is closest to the period of a geostationary satellite?

A 12 hours

B 86 400 s

C 1 year

D 0 s because it is stationary

Solution

B $1 \text{ day} = 86\ 400 \text{ s}$.

Question 10/ 24

Two satellites are in orbit at the same height. Satellite 1 has a mass of 100 kg; satellite 2 has a mass of 1000 kg. Which statement below is correct?

A They have the same potential energy and orbital period.

B They have different potential energies and the same orbital period.

C They have the same potential energy and different orbital periods.

D They have the different potential energies and orbital periods.

Solution

B   *T* and *v* are the same (at same radius); PE depends on mass.

Question 11/ 24

[VCAA 2018 NHT SA Q2]

DATA

$\text{Mass of Mercury} = 3.34 \times 10^{23}\ \text{kg}$

$\text{Radius of Mercury} = 2.44 \times 10^{6}\ \text{m}$

$\text{Universal gravitational constant } G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$

The gravitational field strength at the surface of Mercury (assumed spherical and uniform) is close to

A $9.00 \times 10^{6}\ \text{N kg}^{-1}$

B $9.81\ \text{N kg}^{-1}$

C $3.74\ \text{N kg}^{-1}$

D $3.74 \times 10^{-2}\ \text{N kg}^{-1}$

Solution

C   Use $g = \frac{GM}{r^2}$.

Question 12/ 24

Two satellites in circular orbits around Earth have different masses but are travelling at the same speed. This means that

A they will travel at different radii.

B they will circle Earth with different periods.

C they will have the same potential energy.

D the gravitational force on them will be different.

Solution

D Radii and periods the same PE different (masses different).

Question 13/ 24

[VCAA 2018 SA Q7]

At one point on Earth's surface at a distance *R* from the centre of Earth, the gravitational field strength is measured as 9.76 N kg^{-1}. Which one of the following is closest to Earth's gravitational field strength at a distance 2*R* above the surface of Earth at that point?

A 1.08 N kg^{-1}

B 2.44 N kg^{-1}

C 3.25 kg^{-1}

D 4.88 N kg^{-1}

Solution

B It will be $\frac{1}{4}$ of the surface value (inverse square law).

Question 14/ 24

[VCAA 2019 NHT SA Q4]

The gravitational field strength at the surface of Mars is $3.7 \mathrm{~N} \mathrm{~kg}^{-1}$. Which one of the following is closest to the change in gravitational potential energy when a 10 kg mass falls from 2.0 m above Mars's surface to Mars's surface?

A 3.7 J

B 7.4 J

C 37 J

D 74 J

Solution

D Use $\Delta \mathrm{GPE}$ change $=m g \Delta h$.

Question 15/ 24

[VCAA 2019 SA Q4]

The magnitude of the acceleration due to gravity at Earth's surface is *g*. Planet Y has twice the mass and half the radius of Earth. Both planets are modelled as uniform spheres. Which one of the following best gives the magnitude of the acceleration due to gravity on the surface of Planet Y?

A $\frac{1}{2} g$

B $1 g$

C $4g$

D $8g$

Solution

D Use $g = \frac{GM}{r^2}$; mass increase causes increase $\times$ 2; radius decrease causes increase $\times$ 4; combine effect $\times$ 8.

Question 16/ 24

[VCAA 2020 SA Q2]

Jupiter's moon Ganymede is its largest satellite. Ganymede has a mass of 1.5×10^{23} kg and a radius of 2.6×10^{6}m. Which one of the following is closest to the magnitude of Ganymede's surface gravity?

A 0.8 m s^{-2}

B 1.5 m s^{-2}

C 3.8 m s^{-2}

D 9.8 m s^{-2}

Solution

B Use $g = \frac{GM}{r^2}$.

Question 17/ 24

[VCAA 2021 NHT SA Q4]

A person has a mass of 60.0 kg. Which one of the following is closest to the weight of this person on Earth's surface?

A 60.0 kg

B 60.0 N

C 588 kg

D 588 N

Solution

D Weight is a force; use $F_{\mathrm{g}} = mg$ since $g = 9.8\ \mathrm{N\ kg^{-1}}$.

Question 18/ 24

[VCAA 2021 NHT SA Q5]

When a spacecraft orbits Earth, its orbital period is not a function of the

A mass of Earth.

B mass of the spacecraft.

C velocity of the spacecraft.

D height of the spacecraft above Earth.

Solution

B None of the equations for T contain the mass m of the orbiter.

Question 19/ 24

[VCAA 2021 SA Q4]

The planet Phobetor has a mass four times that of Earth. Acceleration due to gravity on the surface of Phobetor is $18 \mathrm{~m} \mathrm{~s}^{-2}$. If Earth has a radius R, which one of the following is closest to the radius of Phobetor?

A R

B $1.5R$

C $2R$

D $4R$

Solution

B Rearrange $g=\frac{G M_2}{R^2}$ to $R^2=\frac{G M}{g}$; so $R \propto \sqrt{\frac{M}{g}}$. From here $\frac{R_{\mathrm{P}}}{R_{\mathrm{E}}}=\sqrt{\frac{M_{\mathrm{P}} \times g_{\mathrm{E}}}{M_{\mathrm{E}} \times g_{\mathrm{P}}}}=\sqrt{\frac{4}{1.8}}=1.5$

Question 20/ 24

[VCAA 2022 NHT SA Q3]

The gravitational field strength at the surface of a uniform spherical planet of radius R is $g \mathrm{~N} \mathrm{~kg}^{-1}$. At a distance of $3R$ above the planet's surface, the strength of gravity will be closest to

A 0

B $\frac{g}{3}$

C $\frac{g}{9}$

D $\frac{g}{16}$

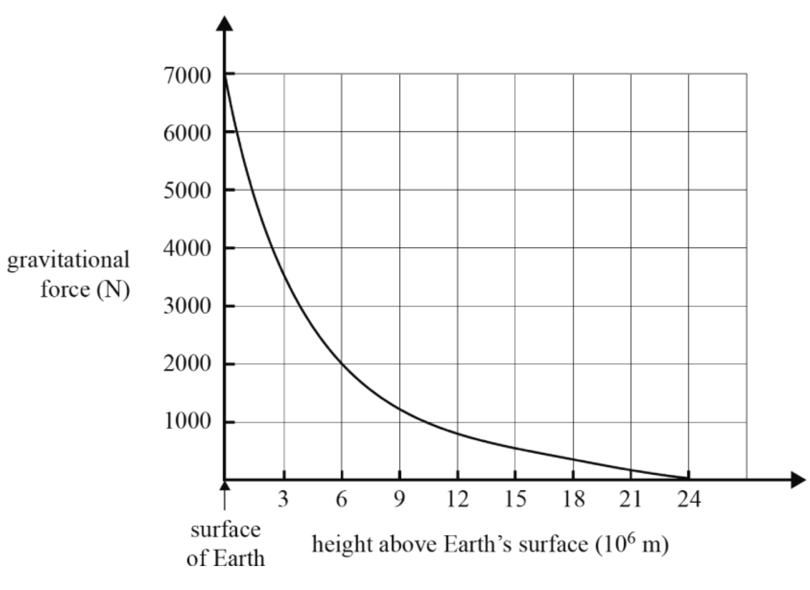
Solution

C Use $F \propto \frac{1}{R^2}$.

Question 21/ 24

[VCAA 2022 NHT SA Q4]

The Mars *Odyssey* spacecraft was launched from Earth to explore Mars. The graph below shows the gravitational force acting on the 700 kg Mars *Odyssey* spacecraft plotted against its height above Earth's surface.



Which one of the following is closest to the minimum launch energy needed for the Mars Odyssey spacecraft to 'escape' Earth's gravitational attraction?

A 4.0×10^4 J

B 1.5×10^5 J

C 4.0×10^{10} J

D 1.5×10^{11} J

Solution

C Total up area under graph by counting squares. There are close to 12 squares; each one is worth 3×10^9 J.

Question 22/ 24

[VCAA 2023 NHT SA Q3]

Two identical satellites, S_1 and S_2, each of mass *m*, are placed into two circular orbits around Earth. Satellite S_1 has an orbital radius of 5*R*. Satellite S2 has an orbital radius of *R*.

Which one of the following best gives the value of $\frac{\text{gravitational force exerted on S}_1\text{ by Earth}}{\text{gravitational force exerted on S}_2\text{ by Earth}}$?

A $\frac{1}{25}$

B $\frac{1}{10}$

C 10

D 25

Solution

A $F \propto \frac{1}{R^2}$.

Question 23/ 24

[VCAA 2023 NHT SA Q8]

Saturn has 83 moons. One of them, Enceladus, has a mass 1.08×10^{20} kg and a circular orbit of radius 2.38×10^{8} m.

The mass of Saturn is 5.68×10^{26} kg.

Which one of the following is closest to the gravitational force of attraction between Enceladus and Saturn?

A 0 N

B 1300 N

C 4.9×10^{8} N

D 7.2×10^{19} N

Solution

D Use $F = \frac{Gm_1m_2}{R^2}$.

Question 24/ 24

[VCAA 2023 SA Q3]

Space scientists want to place a satellite into a circular orbit where the gravitational field strength of Earth is half of its value at Earth's surface.

Which one of the following expressions best represents the altitude of this orbit above Earth's surface, where R is the radius of Earth?

A $(\sqrt{2}\mathrm{R}/\bar{2})$ - R

B $\sqrt{2}\mathrm{R}$

C $(\sqrt{2}\mathrm{R})-\mathrm{R}$

D $2\mathrm{R}-\sqrt{2}\mathrm{R}$

Solution

C Use $g \propto \frac{1}{r^2}$ then new radius from centre of earth $= \sqrt{2}\mathrm{R}$ and subtract earth's radius R.

Question 1/ 56

Calculate the gravitational force attracting two masses of 1 kg, separated by 0.40 m.

(2 marks)

Solution

$4.2 \times 10^{-10}\ \mathrm{N}$ Use $F=\frac{Gm_1m_2}{R^2}$.

Question 2/ 56

A space shuttle of mass 200 t is in circular orbit around Earth, at a height of 200 km.

DATA: mass of $\mathrm{Earth} = 6.0 \times 10^{24}\ \mathrm{kg}$; radius of $\mathrm{Earth} = 6.4 \times 10^{6}\ \mathrm{m}$

Calculate the kinetic energy of the space shuttle in this orbit. Show your working.

(4 marks)

Solution

6.1×10^{12} J Use $\mathrm{KE} = \frac{GMm}{2R}$.

Question 3/ 56

From the frame of reference of Earth, the Moon orbits it once every 27.3 days. The orbit circumference (assumed circular) is equal to 2.4×10^6 km. Calculate the acceleration of the Moon in this frame of reference. Show your working.

(3 marks)

Solution

$0.0027 \mathrm{~m~s}^{-2}$ Use $v = \frac{2\pi R}{T}$ and then $a = \frac{v^2}{R}$.

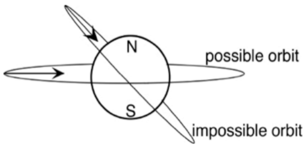
Question 4/ 56

A geosynchronous satellite is one with a period of 24 h positioned exactly above the equator. It appears motionless viewed from the surface of Earth. Explain why it must be in an orbit above the equator.

(4 marks)

Solution

Satellite orbits must lie in planes passing through Earth's centre. If not above the equator, its orbit must alternate from N to S hemispheres, and it cannot stay directly above a given point on Earth's surface.



Question 5/ 56

A rocket is disabled at a height of nine Earth radii above the surface of Earth. It is at rest. By how much will its velocity change in the next 200 s?

(Take g at Earths surface $= 10 \text{ m s}^{-2}$; assume g does not change in 200 s.)

(2 marks)

Solution

20 m s^{-1} $v = gt$, with $g = 0.1$ from the inverse square law.

Question 6/ 56

Between the Sun and Earth, there will be a point where the sum of their gravitational fields will be zero. This point is a distance x from the centre of Earth, and the radius of Earth's orbit about the Sun is R. Write down an equation that would enable you to find x, in terms of R, M_e (the mass of Earth), and M_s (the mass of the Sun). Do not attempt to solve the equation.

(2 marks)

Solution

$\frac{M}{R-X^2} = \frac{M_e}{X^2}$ Gravitational fields due to Sun and Earth are equal and opposite.

Question 7/ 56

A small satellite orbits Mars. It has a kinetic energy of 3.0×10^{10} J, and it is at a constant distance of 8.0×10^7 m from the centre of Mars. What is the *weight* of the satellite at this height? Show your working.

(3 marks)

Solution

750 N $W = mg = \frac{mv^2}{r} = \frac{2E_k}{r}$.

Question 8/ 56

An Earth-calibrated balance, which compares a known mass with an unknown mass by a balancing mechanism, will work satisfactorily on the Moon but not in a satellite in stable orbit. Explain why this is so.

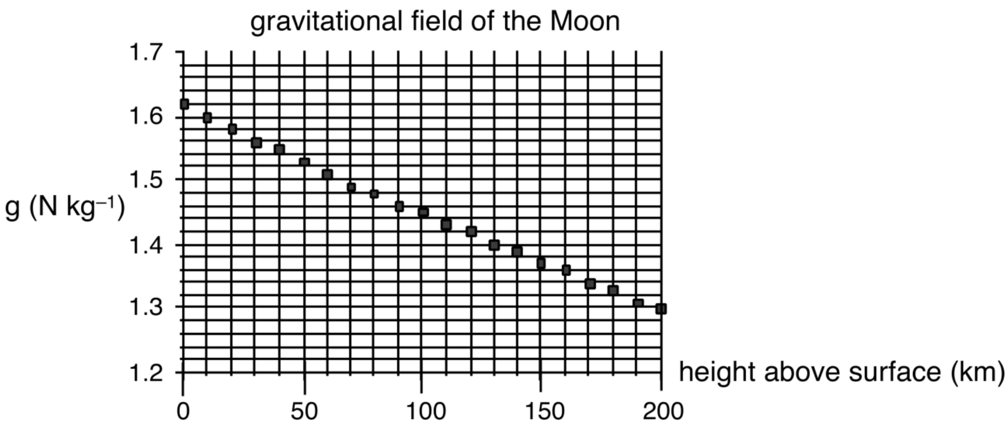
(4 marks)

Solution

Balancing mechanisms don't work in satellites as they rely on reaction forces. In a satellite everything is in free fall and reaction forces are zero.

Question 9/ 56

An experiment fires a mass of 50 kg vertically from the surface of the Moon to a maximum height of 180 km. There is no air resistance.



Use the graph to deduce the velocity of the mass. Explain your method.

(4 marks)

Solution

$\approx 730\ \mathrm{m\ s^{-1}}$ Equate area under the graph to 180 km, times the mass, to the KE. Note: in calculating area, you need to take into account the 'hidden' area below $g = 1.2\ \mathrm{N\ kg^{-1}}$.

Question 10/ 56

One of Kepler's laws for planetary motion of planets around the Sun can be expressed in the form $T^2 \propto R^3$. Show that this holds for planets in circular orbits around the Sun.

(3 marks)

Solution

Use $\frac{GMm}{R^2} = \frac{4\pi^2 mR}{T^2}$; rearrange to make T^2 the subject.

Question 11/ 56

Read the following extract.

Jupiter, the largest planet in the solar system, has several moons. Galileo discovered four of them in 1610/11 AD. They are Io, Europa, Ganymede and Callisto; more details about them are shown in the table below.

Moon name	Distance from centre of Jupiter	Mass (relative units)	Period of rotation (days)
Io	4.2×10^8 m	1.0	1.77
Europa	6.7×10^8 m	0.7	3.55
Ganymede	1.1×10^9 m	3.7	7.16
Callisto	1.87×10^9 m	2.6	

a. Explain why the period of rotation of the three closest moons increases with the distance from the centre of Jupiter, and it is *not* related to the masses of the moons involved.

(4 marks)

b. Calculate the period of rotation of Callisto. Express your answer to two significant figures. Show your working.

(4 marks)

Solution

a T for a satellite is given by $\frac{4\pi^2 r}{T^2} = \frac{GM}{r^2}$. This equation does not include the mass of the satellite, so T is independent of the mass of the satellite.

b 16 days Kepler's law: $\frac{T^2}{r^3}$ is the same for all moons. Take the average.

Question 12/ 56

a. Calculate the gravitational field g on the surface of Phobos (a moon of Mars). Assume it is uniform and spherical. Show your working.

DATA: mass of Phobos: 1.07×10^{16} kg; radius of Phobos: 11.3 km

(2 marks)

b. Assuming constant density, state g at the centre of Phobos.

(1 mark)

Solution

a $0.0056\ \mathrm{N\ kg^{-1}}$ Use $g = \frac{GM}{R^2}$.

b $0\ \mathrm{N\ kg^{-1}}$ All the attraction from mass balances out at the centre.

Question 13/ 56

Calculate the mass of Earth from the following data. Show your working.

$$\text{Radius of Moons orbit} = 3.8 \times 10^8 \text{ m; period of Moon} = 28 \text{ days}$$

(3 marks)

Solution

5.5×10^{24} kg Use $\frac{GM_E}{R^2} = \frac{4\pi^2 R}{T^2}$.

Question 14/ 56

Show that two satellites of different mass with the same radius orbit about Earth must have the same speed and period. Assume circular orbits.

(3 marks)

Solution

$T^2 = \left(\frac{4\pi^2}{GM}\right) R^3$ demonstrates periods are the same; $v = \frac{2\pi R}{T}$ shows speeds are the same.

Question 15/ 56

A spacecraft is placed in orbit around Saturn so that it always over the same point on Saturn's surface on its equator.

$$\text{Saturns mass} = 5.68 \times 10^{26} \text{ kg, Saturns period of rotation} = 10.25 \text{ h}$$

a. Calculate the period, in seconds, of the spacecraft's orbit.

(1 mark)

b. Calculate the radius of the orbit of the spacecraft. Show your working.

(3 marks)

Solution

a 36 900 s $10\ \mathrm{h} = 3600 \times 10; 15\ \mathrm{min} = 15 \times 60$, add.

b $1.09 \times 10^8 \mathrm{m}$ Rearrange $\frac{GMm}{R^2} = \frac{4\pi^2 mR}{T^2}$ with *R* as subject.

(NB: m cancels).

Question 16/ 56

Two students discuss the gravitational field *inside* Earth (assumed to be a uniform sphere). Jacinta says that the field will increase towards the centre of Earth, but Josie says that it will decrease to zero. Evaluate these statements.

(4 marks)

Solution

If Earth were a uniform sphere, the vector sum of the fields from all parts of Earth would cancel. However, these forces would tend to stretch any object at the centre equally in all directions.

Question 17/ 56

[VCAA 2016 SA Q6]

a. Explain the conditions for a satellite to be in a geostationary orbit (that is, stationary over a fixed point on Earth's surface). There is no need to calculate the actual radius of the orbit.

(3 marks)

b. Roger states that there are a number of situations on or near Earth's surface where a person may feel 'weightless'. Emily states that this is impossible. It is only possible to feel 'weightless' in deep space where there is no, or very little, gravitational force on a person. Is Emily correct or incorrect? Explain your answer.

(3 marks)

Solution

a (1) Period of 24 h (86 400 s) (2) in the same plane as the equator (3) in a stable near-circular orbit (4) rotating in same direction as Earth.

b Emily is incorrect, as one can *feel* weightless in any situation where the normal reaction force drops to zero, e.g. in free fall. One would, of course also feel weightless in a situation where $g = \text{zero}$ (e.g. in deep space).

Question 18/ 56

[VCAA 2017 SB Q4]

Charon, a moon of Pluto, has a circular orbit.

DATA

$$\text{Mass of Pluto} = 1.3 \times 10^{22}\ \text{kg; radius of Pluto} = 1.2 \times 10^{6}\ \text{m}$$

$$\text{Mass of Charon} = 1.6 \times 10^{21}\ \text{kg; radius of Charons orbit} = 1.8 \times 10^{7}\ \text{m}$$

$$\text{Universal gravitational constant } (G) = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$$

Assume that Pluto is a uniform sphere.

a. Calculate the gravitational field strength on the surface of Pluto. Show your working and include an appropriate unit.

(3 marks)

b. Calculate the period of orbit of Charon. Show your working.

(3 marks)

c. Scientists wish to place a spacecraft, of mass 1000 kg, in an orbit of the same radius as Charon. Three students, Rick, Melissa and Nam, are discussing the situation and have different opinions. Rick says as the spacecraft is lighter, it will have to move at a greater speed than Charon to achieve the same orbit. Melissa says the spacecraft would need to move at the same speed as Charon. Nam says the spacecraft would need only to move at a lower speed as it is lighter than Charon. Evaluate these three opinions. Detailed calculations are *not* necessary.

(3 marks)

Solution

a 0.60 N kg^{-1} Use $g = \frac{GM}{R^2}$.

b $5.2 \times 10^5 \text{s}$ Use and rearrange with *T* the subject.

c Melissa is correct; the others are wrong. The speed of the orbiting spacecraft is given by where *M* is the mass of Pluto; the mass of the spacecraft is irrelevant.

Question 19/ 56

[Adapted VCAA 2018 SB Q1]

A 1500 kg satellite is in a circular orbit around Earth at an altitude of 850 km.

$\text{Earths radius} = 6400 \text{ km}$; its $\text{mass} = 6.0 \times 10^{24} \text{ kg}; G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$.

a. Calculate the period of the satellite in seconds.

(3 marks)

b. The controllers of the satellite use its motors to move the satellite into a higher, but still stable, orbit.

i. Will this increase, decrease or have no effect on the speed of the satellite? Justify your answer.

(3 marks)

ii. Will this increase, decrease or have no effect on the gravitational potential energy of the satellite? Take the surface of Earth as the zero of gravitational potential energy. Justify your answer.

(3 marks)

Solution

a 6131 s Use and rearrange with *T* as the subject.

bi In circular orbits, $a = g = \frac{GM}{r^2} = \frac{mv^2}{r}$; hence $v = \sqrt{\frac{GM}{r}}$, so *v* will decrease as *r* increases.

bii The gravitational potential energy (GPE), with the zero set at Earth's surface, will be equal to the work done against the gravitational force to raise the satellite to its orbit height; clearly this implies an increase in the GPE is required.

Question 20/ 56

In December 2003, a spacecraft was put into orbit around Mars. The orbital period was 7.5 h. Assume that the orbit was circular, and use the data below.

$\text{Mass of Mars} = 6.4 \times 10^{23}\ \text{kg; radius of Mars} = 3.4 \times 10^{6}\ \text{m.}$

a. Calculate the speed of the spacecraft when in orbit around Mars. Show the steps of your working.

(3 marks)

b. Calculate gravitational field due to Mars acting on the spacecraft. Show your working.

(3 marks)

c. Calculate the *height* of the orbiting spacecraft above the surface of Mars. Show your working.

(4 marks)

Solution

a 2150 m s^{-1} Use $v^3 = \frac{2\pi GM}{T}$ or first use *R* from $R^3 = \left(\frac{GM}{4\pi^2}\right) T^2$ and then use $v^2 = \frac{GM}{R}$.

b 0.50 N kg^{-1} Use $g = \frac{v^2}{R}$ (but this needs *R* obviously – see part **c**.

c $5.8 \times 10^6 \text{m}$ Use $R^3 = \left(\frac{GM}{4\pi^2}\right) T^2$ and then subtract radius of Mars.

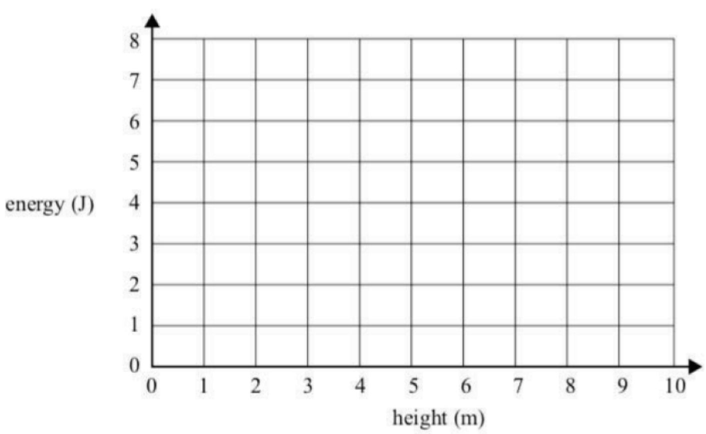
Question 21/ 56

[Adapted VCAA 2017 Sample SB Q1]

A probe of mass 0.20 kg is released from 10 m above Mars's surface. Assume the gravitational field strength is uniform (the same as at the surface). Ignore air resistance. Graph the probe's gravitational potential energy against the height above the Martian surface on the grid below: label it as U_g. Take potential energy at the surface of Mars as zero. Include the initial potential energy value. On the same axes, sketch the kinetic energy of the probe; label this as E_K.

DATA

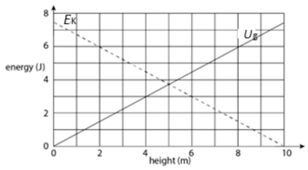
$\text{Mass}_{\text{MARS}} = 6.4 \times 10^{23} \text{ kg}; \text{Radius}_{\text{MARS}} = 3.4 \times 10^6 \text{ m}; G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$.



(3 marks)

Solution

Need to calculate *g* at surface of Mars (use $g = \frac{GM_{\text{MARS}}}{R^2} = 3.7 \text{ N kg}^{-1}$); then use $\text{GPE} = mgh = 7.4 \text{ J}$ at 10 m height. Then draw the graph.



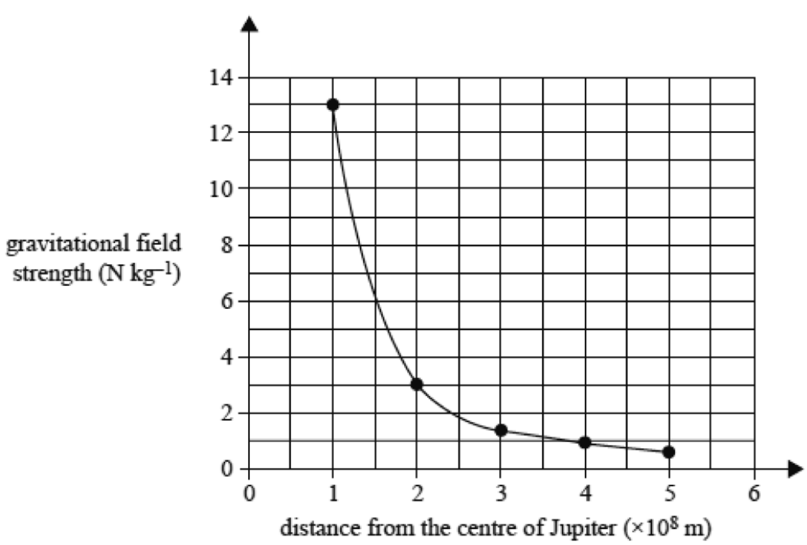
Question 22/ 56

[VCAA 2018 SB Q9]

The spacecraft *Juno* has been put into orbit around Jupiter. The table below contains information about the planet Jupiter and the spacecraft Juno. The graph below shows gravitational field strength (N kg^{-1}) as a function of distance from the centre of Jupiter.

Data

mass of Jupiter	1.90×10^{27} kg
radius of Jupiter	7.00×10^{7} m
mass of spacecraft *Juno*	1500 kg



a. Calculate the gravitational force acting on Juno by Jupiter when Juno is at a distance of 2.0×10^8 m from the centre of Jupiter. Show your working.

(2 marks)

b. Use the graph on the previous page to estimate the magnitude of the change in gravitational potential energy of the spacecraft Juno as it moves from a distance of 2.0×10^8 m to a distance of 1.0×10^8 m from the centre of Jupiter. Show your working.

(3 marks)

c. Europa is a moon of Jupiter. It has a circular orbit of radius 6.70×10^8 m around Jupiter. Calculate the period of Europa's orbit. Show your working.

(3 marks)

Solution

a 4.5×10^3 N Simplest method is to multiply the mass of *Juno* by the *g* value (3.0 N kg^{-1}) from the graph. Alternatively, use $g = \frac{GM}{R^2}$ to give 3.17 N kg^{-1} and $F_G = 4752$ N. Both answers would be marked correct.

b 1.05×10^{12}J kg^{-1} Use area under graph between these two distance values and multiply by the mass of *Juno*. Area is approximately equal to 14 squares; one square $= 5 \times 10^7$J kg^{-1}. Some allowance would be given for variations.

c 3.06×10^5s Use standard relationship $\frac{GM}{R^2} = \frac{4\pi^2 R}{T^2}$; make *M* the subject.

Question 23/ 56

[VCAA 2019 NHT SB Q10]

A spacecraft with astronauts on board is in orbit around Mars at an altitude of 1.6×10^6 m above the surface of Mars. The mass of Mars is 6.4×10^{23} kg and its radius is 3.4×10^6 m. Take the universal gravitational constant, *G*, to be 6.7×10^{-11} N m^2 k g^{-2}. The mass of the spacecraft is 2.0×10^4 kg.

a. Calculate the period of orbit of the spacecraft around Mars. Show your working.

(4 marks)

b. The altitude of the spacecraft above the surface of Mars is doubled so that the spacecraft is now in a new stable orbit. Will the speed of the spacecraft be greater, the same or lower in this new orbit? Explain your reasoning.

(2 marks)

Solution

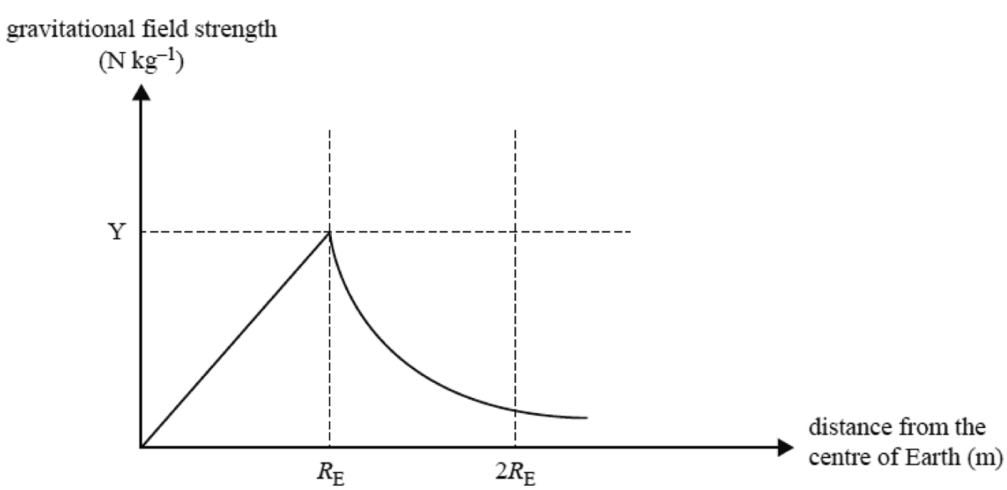
a $1.1 \times 10^4 \text{s}$ Use $\frac{GMm}{R^2} = \frac{4\pi^2 mR}{T^2}$ with T as the subject.

b Lower. Speed in a stable orbit is given by $v = \sqrt{\frac{GM}{r}}$; since G and M are constant, v must be smaller.

Question 24/ 56

[VCAA 2019 SB Q4]

Assume that a journey from approximately 2 Earth radii ($2R_E$) down to the centre of Earth is possible. The radius of Earth (R_E) is 6.37×10^6 m. Assume that Earth is a sphere of constant density. A graph of gravitational field strength versus distance from the centre of Earth is shown below.



a. What is the numerical value of Y?

(1 mark)

b. Explain why the gravitational field strength is 0 N kg^{-1} at the centre of Earth.

(2 marks)

c. Calculate the increase in potential energy for a 75 kg person hypothetically moving from the centre of Earth to the surface of Earth. Show your working.

(2 marks)

Solution

a 9.8 N kg^{-1} Average value of gravitational field at Earth's surface.

b At Earth's centre, the vector sum of gravitational fields from all parts of Earth's mass equals zero.

c $2.3\,(4) \times 10^{9}$ J The GPE change required is equal to the work done against the gravity force. This is equal to the area under the graph. This is a simple triangle area calculation.

Question 25/ 56

[VCAA 2019 SB Q5]

Navigation in vehicles or on mobile phones uses a network of global positioning system (GPS) satellites. The GPS consists of 31 satellites that orbit Earth. In December 2018, one satellite of mass 2270 kg, from the GPS Block IIIA series, was launched into a circular orbit at an altitude of 20 000 km above Earth's surface.

a Identify the type(s) of force(s) acting on the satellite and the direction(s) in which the force(s) must act to keep the satellite orbiting Earth.

(2 marks)

b Calculate the period of the satellite to three significant figures. You may use data from the table below in your calculations. Show your working.

(3 marks)

Data

mass of satellite	2.27×10^{3} kg

mass of Earth	5.98×10^{24} kg
radius of Earth	6.37×10^{6} m
altitude of satellite above Earth's surface	2.00×10^{7} m
gravitational constant	6.67×10^{-11} N m^2 kg^{-2}

Solution

a The force is a gravitational force caused by Earth's gravitational field. The direction of this force is towards the centre of mass of Earth.

b 4.26×10^4s Use $\frac{GMm}{R^2} = \frac{4\pi^2 mR}{T^2}$ with T as the subject.

Question 26/ 56

[VCAA 2020 SB Q4]

The Ionospheric Connection Explorer (ICON) space weather satellite, constructed to study Earth's ionosphere, was launched in October 2019. ICON will study the link between space weather and Earth's weather at its orbital altitude of 600 km above Earth's surface. Assume that ICON's orbit is a circular orbit. Use $R_{\text{E}} = 6.37 \times 10^6$ m.

a. Calculate the orbital radius of the ICON satellite.

(1 mark)

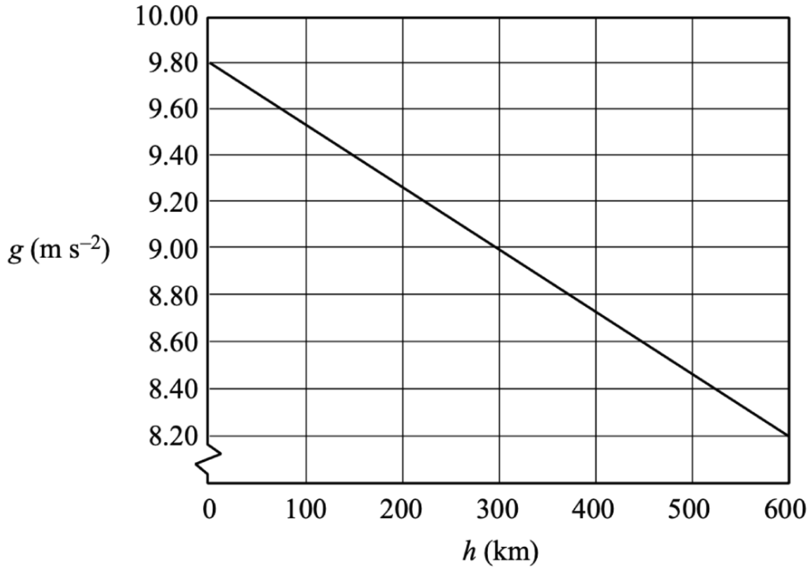
b. Calculate the orbital period of the ICON satellite correct to three significant figures. Show your working.

(4 marks)

c. Explain how the ICON satellite maintains a stable circular orbit without the use of propulsion engines.

(2 marks)

d. The graph on the next page shows the strength of Earth's gravitational field, *g*, as a function of orbital altitude, *h*, above the surface of Earth.



Determine the change in gravitational potential energy of the ICON satellite as it travels from Earth's surface to its orbital altitude of 600 km above Earth's surface. The mass of the ICON satellite is 288 kg.

(3 marks)

Solution

a $6.97 \times 10^6 \mathrm{m}$ Add the altitude to the radius of Earth.

b 5788 s Use $T^2 = \frac{4\pi^2}{GM} \times R^3$.

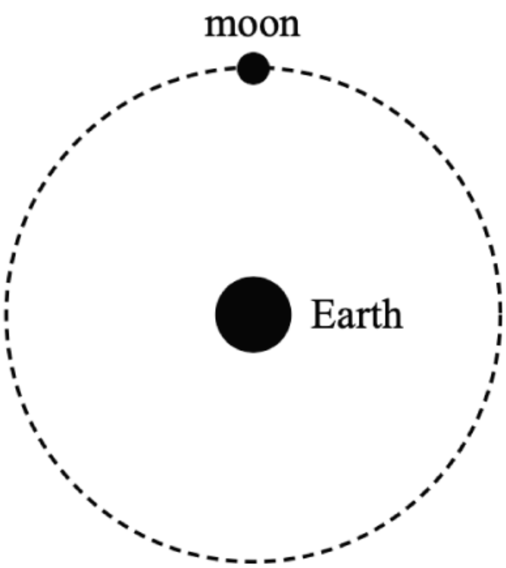
c The ICON satellite is subject only to a gravitational force towards Earth. Further, this force is constant in magnitude. This is why the satellite maintains a stable circular orbit.

d 1.56×10^9 J First find area under graph – take care with the broken *y*-axis. (Easiest to use rectangle $(6 \times 10^5 \times 8.2)$ plus triangle $\frac{6\times10^5\times1.6}{20}$. The multiply area of 5.4×10^6 by satellite mass (288 kg).

Question 27/ 56

[VCAA 2021 NHT SB Q3]

The motion of Earth's moon can be modelled as a circular orbit around Earth, as shown below.



Data:

mass of Earth	5.98×10^{24} kg
mass of the moon	7.35×10^{22} kg
radius of the moon's orbit around Earth	3.84×10^{8} m
universal gravitational constant (G)	6.67×10^{-11} N m^2 kg^{-2}

a. Calculate the magnitude of the gravitational force that Earth exerts on the orbiting moon. Give your answer correct to three significant figures. Show your working.

(3 marks)

b. The average orbital period of Earth's moon is 27.32 days. The moon is moving slightly further away from Earth at an average rate of 4 cm per year. Given this information, will the average orbital period of Earth's moon decrease, stay the same or increase? Explain your answer.

(3 marks)

Solution

a 1.99×10^{20} N Use $F_g = \frac{GMm}{R^2}$ and round to three significant figures.

b The orbital period will increase, as T^2 is proportional to R^3 (from $T^2 = \frac{4\pi^2}{GM} \times R^3$).

Question 28/ 56

[VCAA 2021 SB Q3]

To calculate the mass of distant pulsars, physicists use Newton's law of universal gravitation and the equations of circular motion. The planet Phobetor orbits pulsar PSR $\mathrm{B1257+12}$ at an orbital radius of $6.9 \times 10^{10}\ \mathrm{m}$ and with a period of $8.47 \times 10^{6}\ \mathrm{s}$. Assuming that Phobetor follows a circular orbit, calculate the mass of the pulsar.

Show all your working.

(3 marks)

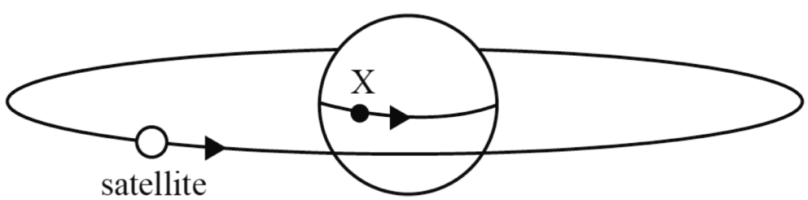
Solution

$2.7 \times 10^{30}\ \mathrm{kg}$ Use $\frac{GMm}{R^2} = \frac{4\pi^2 mR}{T^2}$ with M as the subject.

Question 29/ 56

[VCAA 2022 SB Q2]

There are over 400 geostationary satellites above Earth in circular orbits. The period of orbit is one day (86 400 s). Each geostationary satellite remains stationary in relation to a fixed point on the equator. The diagram below shows an example of a geostationary satellite that is in orbit relative to a fixed point, X, on the equator.



a. Explain why geostationary satellites must be vertically above the equator to remain stationary relative to Earth's surface.

(2 marks)

b. Using $G = 6.67 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}$, $M_\mathrm{E} = 5.98 \times 10^{24}\ \mathrm{kg}$ and $R_\mathrm{E} = 6.37 \times 10^{6}\ \mathrm{m}$, show that the altitude of a geostationary satellite must be equal to $3.59 \times 10^{7}\ \mathrm{m}$.

(4 marks)

c. Calculate the speed of an orbiting geostationary satellite.

(3 marks)

Solution

a Satellites in circular orbits have a gravitational force directed towards Earth's centre. To remain stationary relative to the surface of Earth, they must be in an equatorial orbit because if they were in a non-equatorial orbit, they would move relative to the surface of Earth.

b $3.59 \times 10^{7}\mathrm{m}$ First find geostationary orbit radius and then subtract the radius of Earth. Find radius from $\frac{GM}{R^2} = \frac{4\pi^2 R}{T^2}$ with *R* as the subject; this is $4.225 \times 10^{7}\mathrm{m}$. Now subtract $6.37 \times 10^{6}\mathrm{m}$.

c $3.07 \times 10^{3}\mathrm{m}$ Use $v = \frac{2\pi R}{T}$ with $T = 86\ 400$ s.

Question 30/ 56

[VCAA NHT 2023 SB Q5]

The diagram below shows the sun, the moon and Earth.

The mass of the sun is approximately 3.3×10^{5} times the mass of Earth.

The distance from the sun to the moon is approximately 390 times the distance from Earth to the moon.

Missing Image

Calculate $\frac{\text{magnitude of the sun's gravitational force on the moon}}{\text{magnitude of Earth's gravitational force on the moon}}$.

(3 marks)

Solution

2.2 Use $F_g = \frac{GMm}{R^2}$

$$\begin{aligned}
&= \frac{F_{\text{SM}}}{F_{\text{EM}}} = \frac{GM_{\text{S}}m}{{R_{\text{SM}}}^2} \times \frac{{R_{\text{EM}}}^2}{GM_{\text{E}}m} \\
&= \frac{M_{\text{S}}}{{R_{\text{SM}}}^2} \times \frac{{R_{\text{EM}}}^2}{M_{\text{E}}} \\
&= \frac{M_{\text{S}}}{M_{\text{E}}} \times \frac{{R_{\text{EM}}}^2}{{R_{\text{SM}}}^2} \\
&= 3.3 \times 10^5 \times \frac{1}{390^2} \\
&= 2.17
\end{aligned}$$

Question 31/ 56

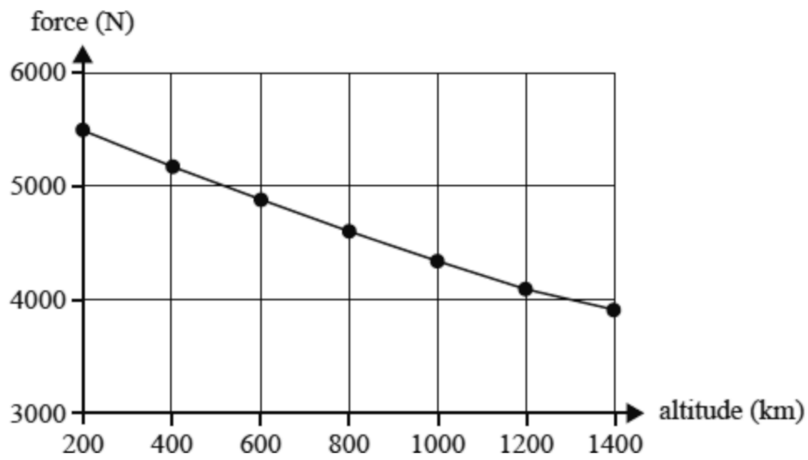
[VCAA NHT 2023 SB Q6]

Measuring very small changes in Earth's surface mass, the 600 kg satellite GRACE-FO1 is in a circular orbit around Earth at an altitude of 500 km. The radius of Earth is 6.37×10^6 m.

a. Calculate the magnitude and direction of the satellite's centripetal acceleration. Give your answer correct to three significant figures.

(3 marks)

b. The diagram below shows a graph of the gravitational force that would act on GRACE-FO1 for a range of altitudes.



Estimate the energy required to lift the satellite from its present orbit at an altitude of 500 km to a new orbit at an altitude of 1400 km.

(2 marks)

Solution

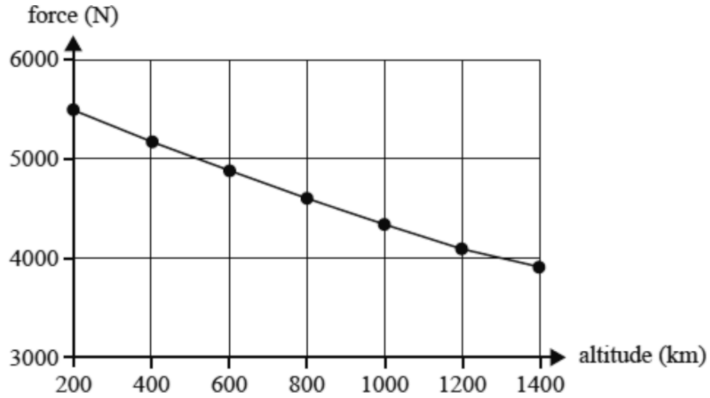
a 8.45 m s^{-2} towards Earth

$$\begin{aligned} a &= \frac{GM}{R^2} \\ &= \frac{\left(6.67 \times 10^{-11}\right)\left(5.98 \times 10^{24}\right)}{\left(6.37 \times 10^6 + 5.00 \times 10^5\right)^2} \\ &= 8.45 \text{ m s}^{-2} \text{ towards Earth's centre.} \end{aligned}$$

b 4.1×10^9 J * Area under graph (from 500 km to 1400 km) is

$\left(\frac{5050+3950}{2}\right) \times (1400 - 500) \times 10^3 = 4.05 \times 10^9$ J

Note the graph given (below) does not have origins shown.



Alternative approach:

- 6.5 visible squares
- 13.5 invisible squares.
- 20 squares total @ $2 \times 10^8 \text{J sqr}^{-1} = 4 \times 10^9$ J.
- Acceptable range $3.9 \times 10^9 \text{J to } 4.2 \times 10^9$ J.

Question 32/ 56

[VCAA 2023 SB Q2]

Phobos is a small moon in a circular orbit around Mars at an altitude of 6000 km above the surface of Mars. The gravitational field strength of Mars at its surface is 3.72 N kg^{-1}. The radius of Mars is 3390 km.

a. Show that the gravitational field strength 6000 km above the surface of Mars has a value of 0.48 N kg^{-1} .

(2 marks)

b. Calculate the orbital period of Phobos. Give your answer in seconds.

(3 marks)

c. Phobos is very slowly getting closer to Mars as it orbits.

Will the orbital period of Phobos become shorter, stay the same or become longer as it orbits closer to Mars? Explain your reasoning.

(2 marks)

Solution

a Calculate ratio of gravity at the orbit height (r_o) compared to the radius of Mars (r_m)

$\frac{g_o}{g_m} = (\frac{r_m}{r_o})^2$

$g_o = 3.72(\frac{3390}{9390})^2$

b 2.77×10^4 s Which is 0.48 N kg^{-1} as required.

Use expression for period of orbit T

$T = \sqrt{\frac{4\pi^2 R}{g}}$

$T = \sqrt{\frac{4\pi^2 (9.39 \times 10^6)}{0.48}}$

c Shorter period *T* As *R* decreases *T* must also decrease as R^3/T^2 is a constant for Mars.

Chapter 9 Electric fields

Question 1/ 25

Two equal positive isolated electric charges separated by a distance *d* and exert a force *F* on each other. To decrease the force to *F*/3, the distance would have to increase to

A 3*d*

B $\sqrt{3}d$

C 9*d*

D $\frac{d}{3}$

Solution

B This follows from $F = \frac{kQ_1Q_2}{R^2}$ (inverse square relationship).

Question 2/ 25

Two equal positive isolated electric charges of value q are separated by a distance d and exert a force F on each other. One of the charges is increased to $2q$; the other is increased to $3q$. The force will change to

A $6F$

B $3F$

C $2F$

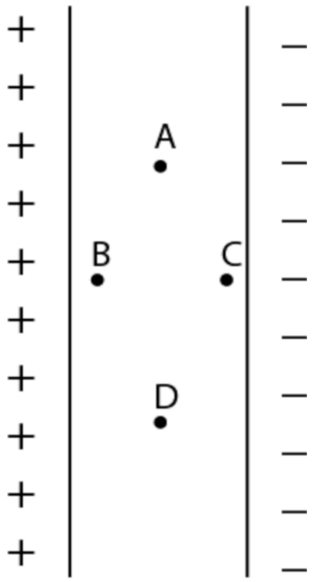
D $3\frac{F}{2}$

Solution

A Follows directly from $F = \frac{kQ_1Q_2}{R^2}$.

Question 3/ 25

A uniform electric field can be produced by two large parallel conducting plates with a small spacing between them, as shown in the diagram below. Points A and D are midway between the plates.



The direction of the field between the plates at points A, B, C and D is best described as

A towards the right at all points.

B towards the left at all points.

C zero at points A and D, but towards the right at B and C.

D zero at points A and D; towards the left at B and towards the right at C.

Solution

A Uniform field, standard knowledge.

Question 4/ 25

The potential energy of a negative charge would

A increase as charge moves from B to C.

B decrease as charge moves from B to C.

C decrease as charge moves from A to D.

D increase as charge moves from A to D.

Solution

A Standard knowledge.

Question 5/ 25

The size of the electrostatic force acting on a small negative charge at each of the points A, B, C and D can be described as

A largest at B, zero at A and D, and smallest at C.

B largest at C, zero at A and D, and smallest at B.

C largest at B, equal at A and D, and smallest at C.

D equal at all four points.

Solution

D This is a uniform field.

Question 6/ 25

The direction of the electrostatic force acting on a small positive charge at each of the points A, B, C and D can be described as

A to the right at B, zero at A and D, and to the left at C.

B to the right at C, zero at A and D, and to the left at B.

C to the right at all four points.

D to the left at all four points.

Solution

C Force on a positive charge is in same direction as field.

Question 7/ 25

Two large parallel conducting plates are separated by 15 cm. A potential difference of 225 V is applied across the plates. Which of the following best describes the electric field in the space between the plates?

A There is a uniform field of $1500\ \mathrm{V\ m^{-1}}$ from the $+$ plate to the $-$ plate.

B There is a uniform field of $1500\ \mathrm{V\ m^{-1}}$ from the $-$ plate to the $+$ plate.

C There is a uniform field of $15\ \mathrm{V\ m^{-1}}$ from the $+$ plate to the $-$ plate.

D There is a uniform field of $15\ \mathrm{V\ m^{-1}}$ from the $-$ plate to the $+$ plate.

Solution

A Use $E = \frac{V}{d}$; direction is away from $+\mathrm{ve}$ charges.

Question 8/ 25

An alpha particle ($\text{charge} = +3.2 \times 10^{-19}\text{C}, \text{mass} = 6.6 \times 10^{-27}$ kg) is placed midway between the plates. Which of the following best describes the force on the particle?

A There is a force of 7.2×10^{-17} N towards the $-$ plate.

B There is a force of 7.2×10^{-17} N towards the $+$ plate.

C There is a force of 4.8×10^{-16} N towards the $-$ plate.

D There is a force of 4.8×10^{-16} N towards the $+$ plate.

Solution

C Use $F = qE$.

Question 9/ 25

The magnitude of the acceleration of the alpha particle described in the previous two questions is closest to

A 1.1×10^{10} m s^{-2}

B 7.3×10^{10} m s^{-2}

C 1.4×10^{-19} m s^{-2}

D 3.0×10^{8} m s^{-2}

Solution

B Use $a = \frac{F}{m}$.

Question 10/ 25

If a stationary alpha particle were placed at the positive plate, it would

A remain there, as it is a position of minimum potential energy.

B move at a constant speed of $1500 \mathrm{~m} \mathrm{~s}^{-1}$ towards the negative plate.

C move towards the negative plate and gain $7.2 \times 10^{-17} \mathrm{J}$ of kinetic energy.

D oscillate about the midpoint, with a kinetic energy of $7.2 \times 10^{-17} \mathrm{J}$.

Solution

C Use $\Delta E = qV$ to verify the KE value.

Question 11/ 25

Electrons are accelerated from rest in an electron gun by a potential difference of 50 kV. What is their final speed? (Ignore relativistic effects.)

A $1.0 \times 10^{5} \mathrm{~m} \mathrm{~s}^{-1}$

B $4.7 \times 10^{7} \mathrm{~m} \mathrm{~s}^{-1}$

C $1.3 \times 10^{8} \mathrm{~m} \mathrm{~s}^{-1}$

D $2.9 \times 10^{8} \mathrm{~m} \mathrm{~s}^{-1}$

Solution

C Use $qV = \frac{1}{2}mv^2$.

Question 12/ 25

[VCAA 2017 SA Q2]

Millikan, a famous scientist, measured the size of the electron charge by balancing an upwards electric force with a gravitational force on a small oil drop. In a repeat of this experiment, an oil drop with a charge of 9.6×10^{-19} C was placed in an electric field of 10^4 V m^{-1}. Which one of the following is closest to the electrical force on the oil drop?

A 9.6×10^{-14} N

B 9.6×10^{-15} N

C 9.6×10^{-22} N

D 9.6×10^{-23} N

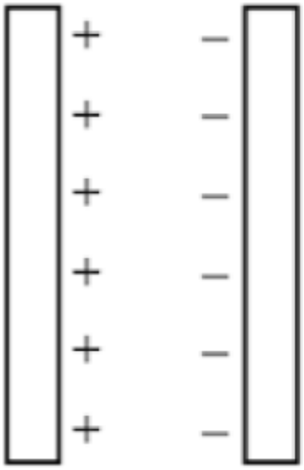
Solution

B Use $F = qE$.

Question 13/ 25

[VCAA 2017 SA Q3]

Two large charged plates with equal and opposite charges are placed close together, as shown in the diagram below. A distance of 5.0 mm separates the plates. The electric field between the plates is equal to 1000 N C^{-1}.



Which one of the following is closest to the voltage difference between the plates?

A 5.0 V

B 200 V

C 5000 V

D 5 000 000 V

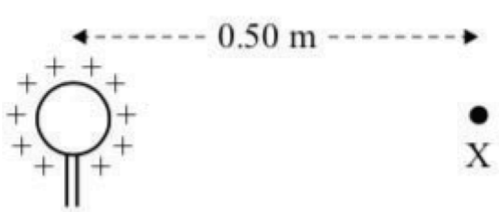
Solution

A Use $V = Ed$.

Question 14/ 25

[Adapted VCAA 2018 NHT SA Q3]

A Van de Graaff generator, a piece of electric field demonstration equipment, consists of a small electrically charged sphere, as shown in the diagram.



A Van de Graaff generator has a sphere with a charge of 5.0×10^{-7} coulombs on it. Take the Coulomb's law constant as $k = 9.0 \times 10^9\ \mathrm{N\ m^2\ C^{-2}}$. Which one of the following best gives the magnitude of the electric field at point X in the diagram above, 0.50 m from the sphere?

A $1.8 \times 10^{-2}\ \mathrm{V\ m^{-1}}$

B $3.6 \times 10^{-2}\ \mathrm{V\ m^{-1}}$

C $1.8 \times 10^{4}\ \mathrm{V\ m^{-1}}$

D $3.6 \times 10^{4}\ \mathrm{V\ m^{-1}}$

Solution

C Use $E = \frac{kQ}{R^2}$.

Question 15/ 25

An electron is accelerated to a speed of $3.0 \times 10^7\ \mathrm{m\ s^{-1}}$ in a vacuum by a voltage V.

Which of the following is closest to the value of V? (Ignore relativistic effects.)

A 250 V

B 2500 V

C 25 000 V

D 250 000 V

Solution

B Use $V = \frac{mv^2}{2q}$; answer is 2559 V.

Question 16/ 25

[Adapted VCAA 2017 Sample SA Q5]

A small sphere with a charge of $+1.0 \times 10^{-9}$ C is placed 30 cm from a metal sphere with a charge of $+1.0 \times 10^{-8}$ C on it. Both act as point charges. Which of the following best gives the magnitude of the force between the spheres? Take $k = 9.0 \times 10^{9}$ N $\mathrm{m}^2\mathrm{C}^{-2}$.

A 1.1×10^{-14} N

B 1.0×10^{-6} N

C 3.0×10^{-6} N

D 3.0×10^{-5} N

Solution

B Use $F = \frac{kQq}{R^2}$.

Question 17/ 25

[VCAA 2018 SA Q4]

A small sphere has a charge of 2.0×10^{-6}C. Take $k = 8.99 \times 10^{9}$ N m^2 C^{-2}. The strength of the electric field due to this charge at a point 3.0 m from the sphere is best given by

A 2.9×10^{-3} V m^{-1}

B 6.0×10^{-3} V m^{-1}

C 9.0×10^{-3} V m^{-1}

D 2.0×10^{3} V m^{-1}

Solution

D Use $E = \frac{kQ}{R^2}$.

Question 18/ 25

[VCAA 2019 SA Q2]

The electric field between two parallel plates that are 1.0×10^{-2}m apart is 2.0×10^{-4} N C^{-1}. Which one of the following is closest to the voltage between the plates?

A 2.0×10^{-8} V

B 2.0×10^{-6} V

C 2.0×10^{-4} V

D 1.0×10^{-2} V

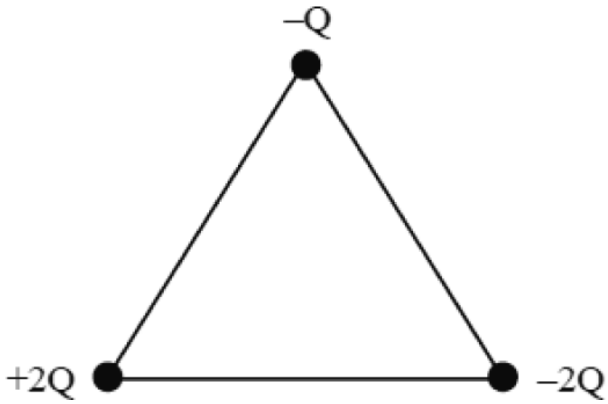
Solution

B Use $V = Ed$.

Question 19/ 25

[VCAA 2019 SA Q3]

Three charges $(-\mathrm{Q}, \ +2\mathrm{Q}, \ -2\mathrm{Q})$ are placed at the vertices of an isosceles triangle, as shown below.



Which one of the following arrows best represents the direction of the net force on the charge $-\mathrm{Q}$?

A 

B 


C


D

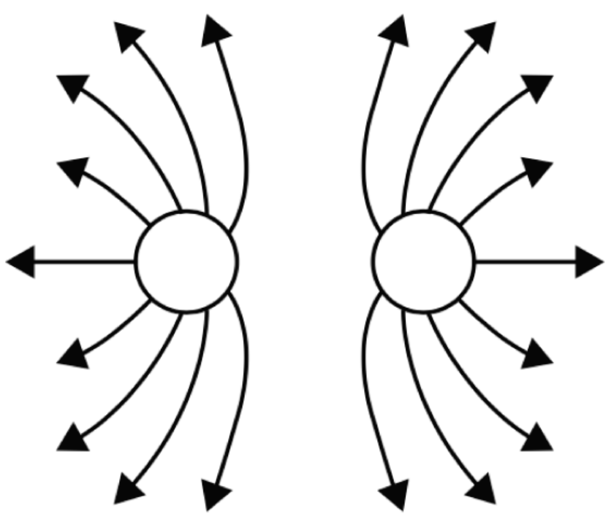
Solution

A The electric force from the $-2\mathrm{Q}$ charge is repulsive and equal in magnitude to the attractive force from the $+2\mathrm{Q}$ charge; draw a vector diagram.

Question 20/ 25

[VCAA 2020 SA Q1]

The diagram below shows the electric field lines between two charges of equal magnitude.



The best description of the two charges is that the

A charges are both positive.

B charges are both negative.

C charges can be either both positive or both negative.

D left-hand charge is positive and the right-hand charge is negative.

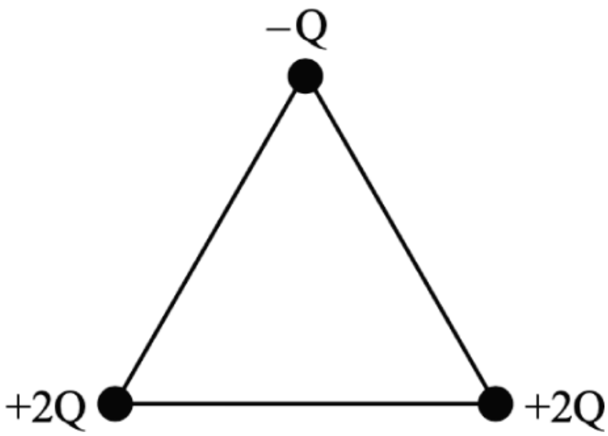
Solution

A Symmetry tells us both charges are the same sign; the direction of the field lines tells us they are positive.

Question 21/ 25

[VCAA 2021 SA Q2]

Three charges, $-Q$, $+2Q$ and $+2Q$, are placed at the vertices of an equilateral triangle, as shown below.



Which one of the following arrows best represents the direction of the net force on the charge $-Q$?


A


B

C 

D 

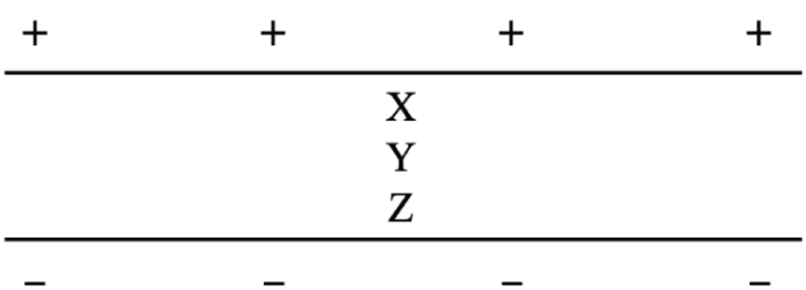
Solution

B The $+2Q$ charges exert attractive forces whose horizontal components cancel each other, leaving two downwards components.

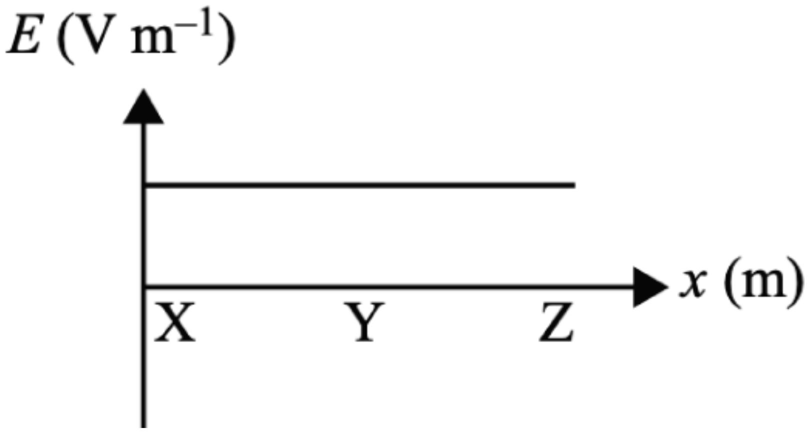
Question 22/ 25

[VCAA 2021 SA Q3]

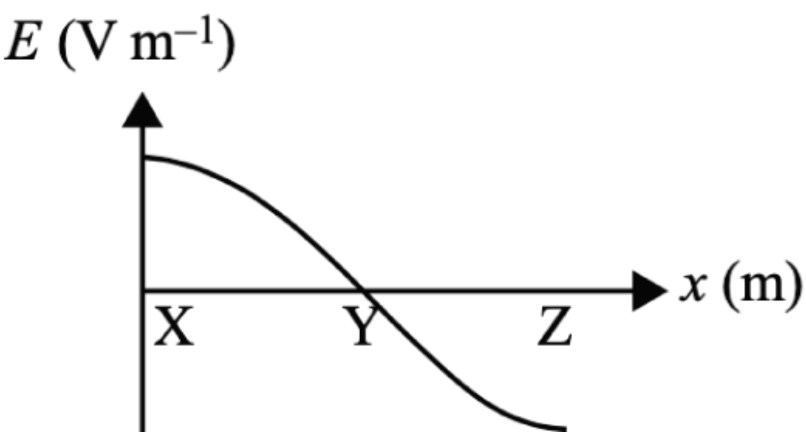
The diagram below shows two parallel metal plates with opposite charges on each plate. X, Y and Z represent different distances from the positive plate.



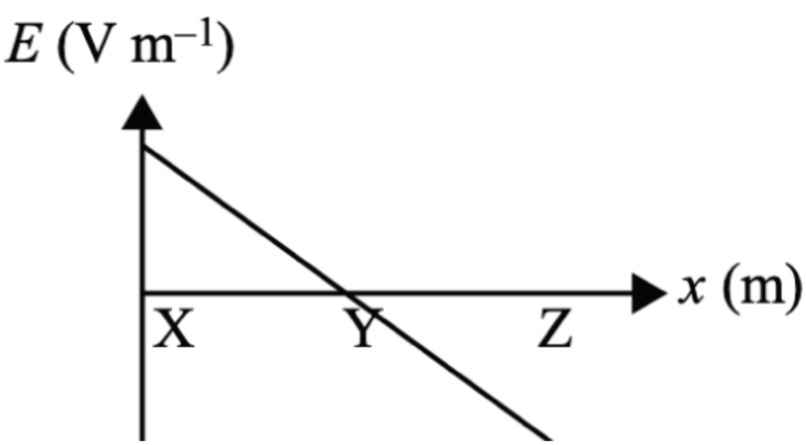
Which one of the graphs below best shows the electric field strength, *E*, versus the position, x, between the two parallel plates?



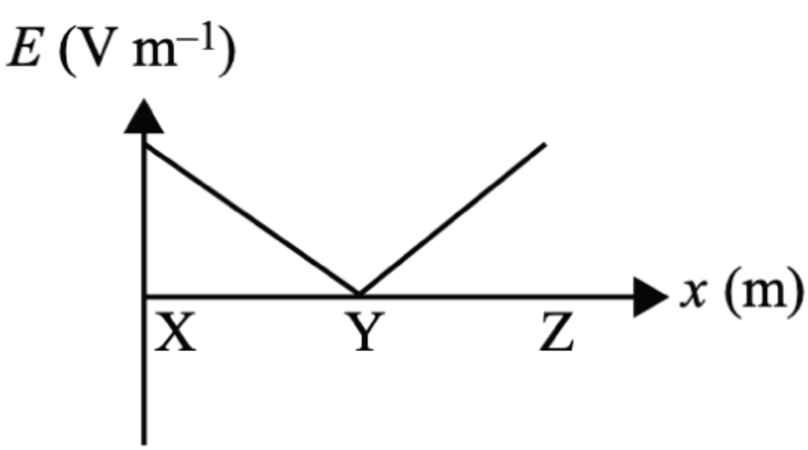
A



B



C



D

Solution

A The field between close parallel plates is constant in magnitude and direction.

Question 23/ 25

[VCAA 2022 NHT SA Q1]

Two parallel plates that are 10 mm apart have a potential difference of 5.0 kV between them. Which one of the following best gives the strength of the electric field between the plates?

A $5.0 \times 10^{-1}\ \mathrm{V\ m^{-1}}$

B $5.0 \times 10^{1}\ \mathrm{V\ m^{-1}}$

C $5.0 \times 10^{2}\ \mathrm{V\ m^{-1}}$

D $5.0 \times 10^{5}\ \mathrm{V\ m^{-1}}$

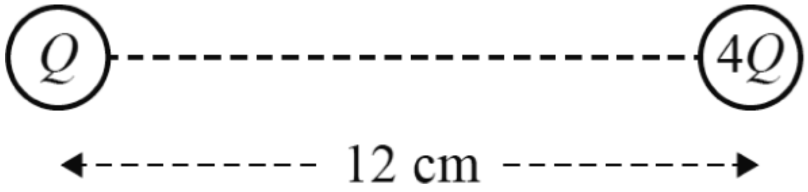
Solution

D Use $E = V/d$.

Question 24/ 25

[VCAA 2022 SA Q4]

Two point charges, Q and $4Q$, are placed 12 cm apart, as shown in the diagram below.



On the straight line between the charges Q and $4Q$, the electric field is

A non-zero everywhere.

B zero at a point 2.4 cm from Q.

C zero at a point 3 cm from Q.

D zero at a point 4 cm from Q.

Solution

D Both charges have the same sign so the fields from each will be in opposite directions. The field will be zero when the fields are equal in magnitude and opposite in direction. This will happen when $kQ/r^2 = 4kQ/(12-r)^2$.

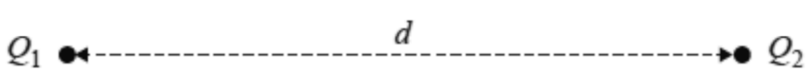
This reduces to $12 - r = 2r$.

Solving gives $r = 4$ cm.

Question 25/ 25

[VCAA 2023 SA Q2]

The diagram below shows two charges, Q_1 and Q_2, separated by a distance, *d*.



There is a force, *F*, acting between the two charges.

Which one of the following is closest to the magnitude of the force acting between the two charges if both d and the charge on Q_1 are halved?

A $F/4$

B F

C $2F$

D $4F$

Solution

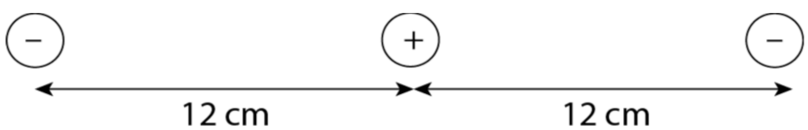
C Use $F = \frac{k\ Q_1 Q_2}{d^2}$

When d is halved, F will increase by a factor of 4.

When Q_1 is halved, F will decrease by a factor of 2. Overall effect is an increase by a factor of 2.

Question 1/ 46

Three point charges, each of 6 μC, are separated along a line, as shown in the diagram.



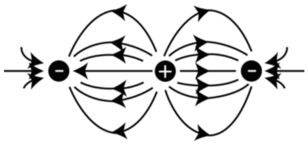
a. Sketch the shape of the electric field in the vicinity of these three charges, using field lines. There should be at least four lines starting or finishing on each of the charges.

(3 marks)

b. The two left-hand charges are secured in place. Calculate the force acting on the right-hand charge, giving its direction. Show your working.

(3 marks)

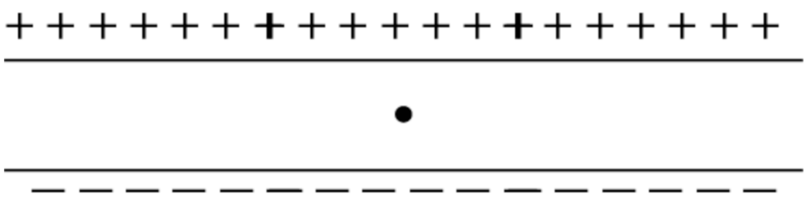
Solution

a 

b 16.9 N, left To left: $F = \frac{kQ_2}{R^2}$ with $R_1 = 0.12$; to right with $R_2 = 0.24$.

Question 2/ 46

A tiny charged oil drop is suspended by the electric field midway between two large parallel plates, as shown in the diagram below.



a. State the sign of the charge on the oil drop.

(1 mark)

b. The electric field has strength 10000 V m^{-1} and the charge on the particle is 3.2×10^{-12} C. Calculate the mass of the charged particle. Show your working.

(3 marks)

c. One student (Amy) discussing the experiment suggests that if the particle were closer to either plate, the particle would accelerate upwards. Her friend (Xu) disagrees and says that the particle would still remain suspended. Evaluate these two responses.

(3 marks)

d. The distance between the plates in 2.0 cm. Calculate the potential difference between the two plates.

(2 marks)

Solution

a Negative Electric force is upwards to balance gravity.

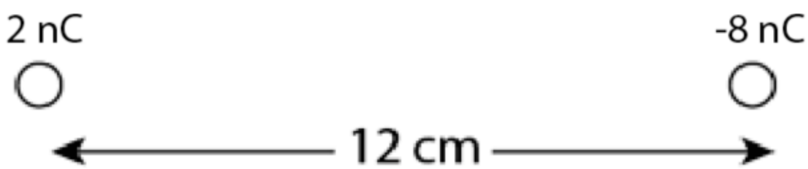
b 3.3×10^{-9} kg Use $qE = mg$.

c Xu is correct; the electric field is uniform, and the force is the same everywhere.

d 200 V Use $E = \frac{V}{d}$.

Question 3/ 46

Two point charges, of $+2\ \mathrm{nC}$ and $-8\ \mathrm{nC}$, are placed 12 cm apart as shown in the diagram below.



a. Calculate the strength of the electric field at a point exactly midway between the two charges. Show your working.

(3 marks)

b. Describe the direction of the electric field at this point.

(1 mark)

c. There is a point *x* cm to the *left* of the $+2\ \mathrm{nC}$ charge where the electric field is zero. Show that this point is given by $x = 12\ \mathrm{cm}$.

(3 marks)

d. If the charges were moved towards each other, would the total potential energy increase, decrease or remain the same? Explain.

(3 marks)

Solution

a $25\ 000\ \mathrm{N\ C^{-1}}$ Use $E = \frac{kQ}{d^2}$ twice and add; note both fields are to the right.

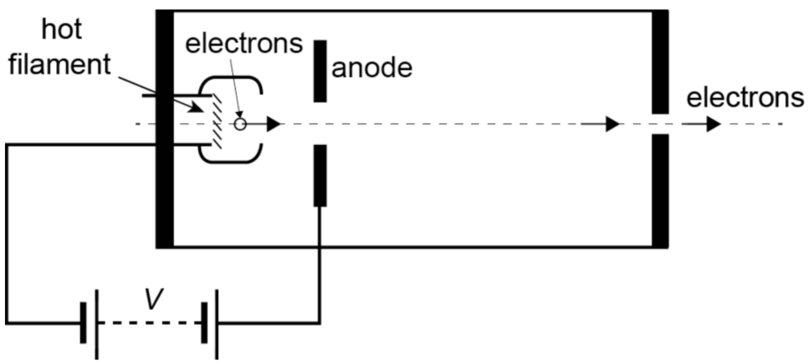
b To the right See above.

c *E* from $2\ \mathrm{nC}\ \text{(to the left)} = E$ from $-8\ \mathrm{nC}$ (to the right). Distance from $2\ \mathrm{nC} = x$; from $-6\mathrm{nC} = (12 + x)$; now use $\frac{2k}{x^2} = \frac{8k}{(x+12)^2}$. Simplify and insert $x = 12$.

d Decrease The force between them is attractive. If they were released and free to move, they would now convert less energy into KE.

Question 4/ 46

A schematic diagram of the injector into a synchrotron is shown below.



The electrons are emitted from the hot filament at very low speeds and can be considered to be at rest. The electric field between the anode and the filament can be considered uniform. The space between the anode and the filament is 4.0 cm. (Relativistic effects can be ignored in this question.)

a. If the accelerating voltage between the anode and the filament is 2500 V, calculate the speed of the electrons as the reach the anode.

(2 marks)

b. Calculate the size of the electric field acting on the electrons when they are emitted from the filament.

(1 mark)

c. Calculate the acceleration of the electrons between the filament and the anode.

(2 marks)

d. A scientist proposes increasing the distance between the anode and the filament but leaving the accelerating voltage unchanged. Discuss the effect on the electrostatic force on the electrons, their acceleration, and their speed as they reach the anode.

(3 marks)

Solution

a 2.96×10^7 m s^{-1} Use $qV = \frac{1}{2}mv^2$.

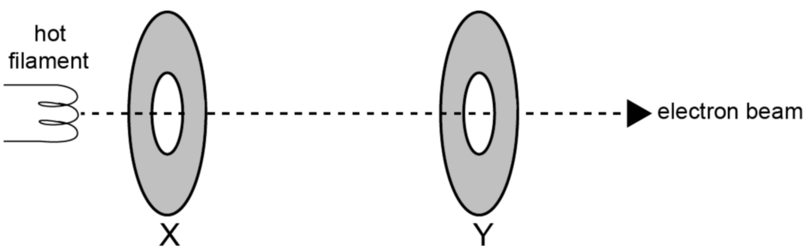
b 62 500 N c^{-1} Use $E = \frac{V}{d}$.

c 1.10×10^{16}m s^{-2} Use $a = \frac{qE}{m}$.

d This will reduce the field *E* and hence the electrostatic force *F* and acceleration *a* but leave the final speed unchanged.

Question 5/ 46

The diagram below shows part of a linear electron accelerator.



The electrons pass through plate X with a speed of 5.0×10^6 m s^{-1}. They reach plate Y with a speed of 1.0×10^7 m s^{-1}.

a. Calculate the magnitude of the potential difference between plates X and Y.

(2 marks)

b. If the distance between plates X and Y is 1.5 mm, and the electric field is uniform, calculate the magnitude of the field in this region.

(2 marks)

Solution

a 213 V Use $\Delta \text{KE} = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = qV$.

b 1.42×10^5 N C^{-1} Use $E = \frac{V}{d}$.

Question 6/ 46

In an electrostatic paint sprayer, droplets of paint are accelerated by an electric field onto the paint target. In one application, the droplets have a mass of 5.0 mg and each are given a kinetic energy of 15 J. The accelerating field is uniform and covers a distance of 1.2 cm. The charge on the droplets is 3.2×10^{-5} C.

a. Calculate the strength of the electric field acting on the paint droplets.

(2 marks)

b. Calculate the accelerating voltage involved.

(2 marks)

Solution

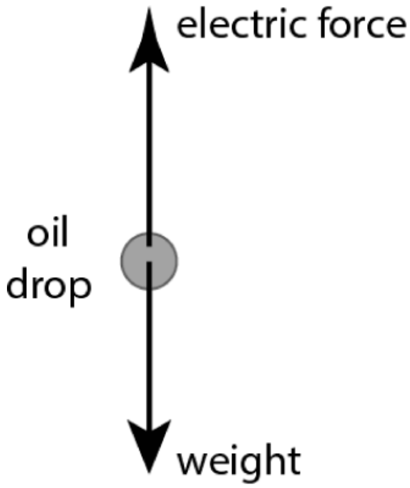
a 3.9×10^7 N C^{-1} Work done $= Fx = qEx = 15$; make E the subject.

b 468 kV Use $V = Ed$.

Question 7/ 46

In a variation of Millikan's famous experiment to determine the quantum of charge (the charge on a single electron), a charged oil drop is held stationary against gravity in an electric field.

A drop of mass 1.6×10^{-6} kg is held stationary by an electric field of 1.0×10^{12} V m^{-1}, directed downwards.



a. State whether the oil drop has excess electrons or a shortage of electrons, giving a reason for your answer.

(2 marks)

b. Calculate the number of excess or shortage of electrons on the oil drop.

(3 marks)

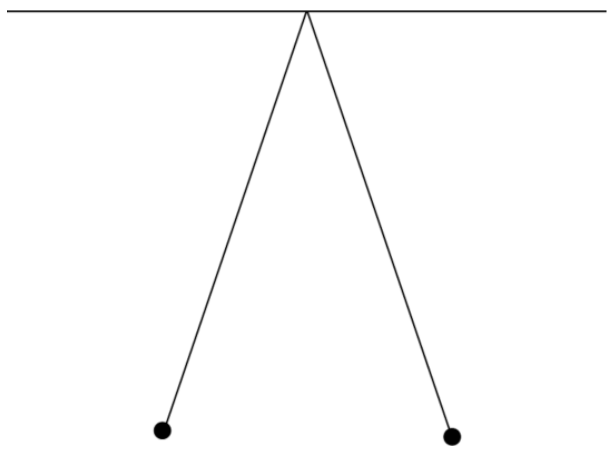
Solution

a Excess electrons Field is down, force is up, charge must be negative.

b 98 Use $mg = qE$.

Question 8/ 46

Students are conducting an experiment with two equally charged particles suspended on insulating strings, as shown in the diagram below. There is a tension, *T*, acting in each string.



a. Sketch the direction of the two electrostatic forces acting as arrows attached to the particles.

(1 mark)

b. The angle between the two strings is equal to 30°. If the mass of each particle is 0.5 mg, calculate the tension in each string. Show your working.

(3 marks)

c. Show that the size of the electrostatic force, F_E, on each particle is given by $F_E = T \sin 15$.

Show your reasoning clearly and in detail.

(3 marks)

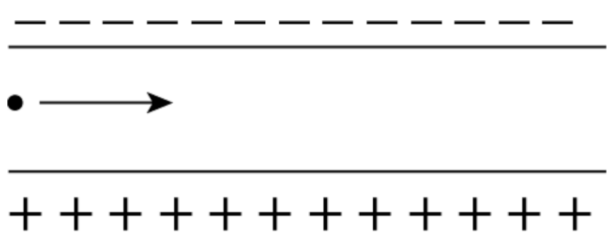
Solution

a 

b 0.0051 N Use $\text{weight} = mg = T \cos 15$.

c Resolving horizontally: $T \sin 15 = F_E$.

An electron is fired between two charged parallel plates, as shown in the diagram below. The electron is travelling horizontally to the right with a speed of $5.0 \times 10^6 \text{ m s}^{-1}$.



a. Calculate the kinetic energy of the electron in eV to two significant figures.

(2 marks)

b. The voltage across the two plates is 5000 V; their spacing is 0.25 cm. State the magnitude and direction of the electric field between the plates.

(2 marks)

c. Calculate the magnitude of the acceleration of the electrons when they are between the plates.

(2 marks)

d. Describe (in words) the direction of the acceleration of the electrons while they are between the plates.

(1 mark)

Solution

a 71 eV $\text{KE} = \frac{1}{2}mv^2$; then convert to eV.

b 2.0 MV m^{-1} Use $E = \frac{V}{d}$.

c $3.5 \times 10^{17} \text{m s}^{-2}$ Use $a = \frac{qE}{m}$.

d Electrons will have 0 acceleration horizontally, and $3.5 \times 10^{17} \text{m s}^{-2}$ vertically down.

Question 10/ 46

[Adapted VCAA 2016 SB Q2]

In the electron gun of a synchrotron, electrons are accelerated from rest to reach a final speed of $8.0 \times 10^7 \text{ m s}^{-1}$. Ignore relativistic effects.

a. Calculate the electron gun accelerating voltage in kilovolts.

(2 marks)

A magnetic field of $4.0 \times 10^{-4} \text{ T}$ causes these electrons to turn through a part of a circle.

b. Calculate the radius of the circle.

(2 marks)

c. Calculate the magnitude of the force acting on these electrons.

(2 marks)

Solution

a 18.2 kV Use $qV = \frac{1}{2}mv^2$.

b 1.1 m Use $R = \frac{mv}{qB}$.

c $5.1 \times 10^{-15} \text{ N}$ Use $F = qvB$.

Question 11/ 46

[Adapted VCAA 2017 SB Q2]

According to one model of the atom, the electron in the ground state of a hydrogen atom moves around the stationary proton in a circular orbit with a radius of 53 pm $(53 \times 10^{-12} \text{ m})$. Show that the magnitude of the force acting between the proton and the electron at this separation equals $8.2 \times 10^{-8} \text{ N}$. Take $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$ and the magnitude of the electron and proton charges as $1.6 \times 10^{-19} \text{ C}$. Show all the steps of your working.

(2 marks)

Solution

Use $F = \frac{kQ_1Q_2}{R^2}$.

Question 12/ 46

[VCAA 2018 NHT SB Q2]

The electron gun of a particle accelerator accelerates electrons between two plates that are 10 cm apart and have a potential difference of 5000 V between them.

DATA

mass of electron	9.1×10^{-31} kg
charge on electron	-1.6×10^{-19} C

a. Calculate the magnitude of the electric field between the plates. Include an appropriate unit.

(2 marks)

b. Calculate the magnitude of the force on an electron between the plates.

(2 marks)

c. Calculate the speed of the electrons as they exit the electron gun. Ignore relativistic effects. Assume that the initial speed of the electrons is zero.

(2 marks)

Solution

a $5.0 \times 10^4 \mathrm{V\ m}^{-1}$ Use $E = \frac{V}{d}$.

b 8.0×10^{-15} N Use $F = qE$.

c 4.2×10^7 m s^{-1} Rearrange $qV = \frac{1}{2} mv^2$ *to* $v = \sqrt{\frac{2qV}{m}}$.

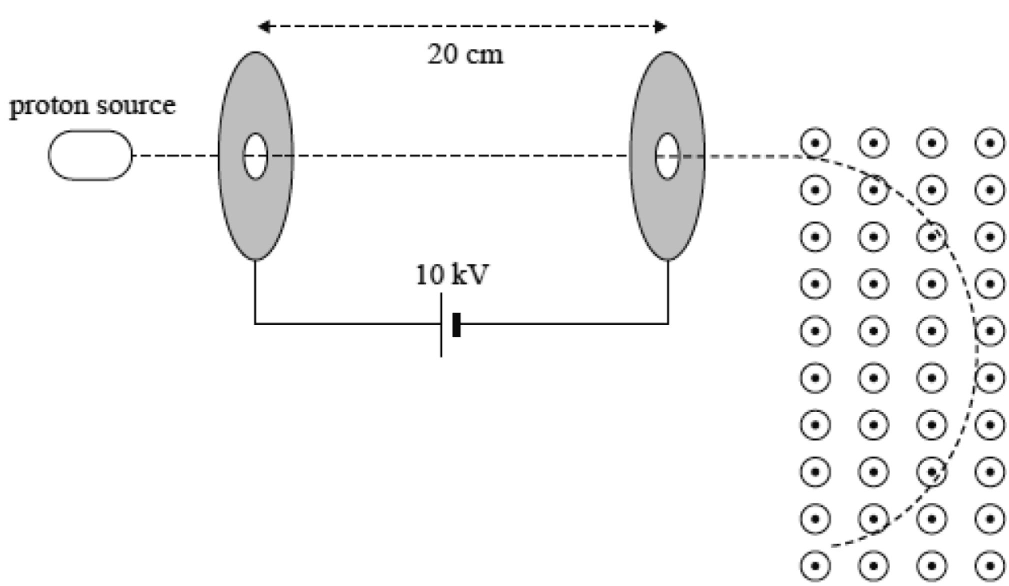
Question 13/ 46

[Adapted VCAA 2018 SB Q1]

An electric field accelerates a proton between two plates. The proton exits into a region of uniform magnetic field at right angles to its path, directed out of the page, as shown on the next page.

Data

mass of proton	1.7×10^{-27} kg
charge on proton	$+1.6 \times 10^{-19}$ C
accelerating voltage	10 kV
distance between plates	20 cm
strength of magnetic field	2.0×10^{-2} T



a. Calculate the strength of the electric field between the plates.

(1 mark)

b. Calculate the speed of the proton as it leaves the electric field. Show your working.

(2 marks)

Solution

a $5.0 \times 10^4 \text{V m}^{-1}$ Use $E = \frac{V}{d}$.

b $1.4 \times 10^6 \text{ m s}^{-1}$ Use $qV = \frac{1}{2}mv^2$ with *v* as the subject.

Question 14/ 46

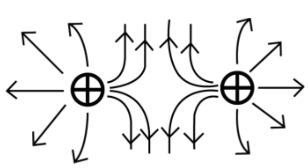
[VCAA 2019 SB Q2]

The diagram below shows two equal positive stationary charges placed near each other.

Sketch on the diagram the shape and direction of the electric field lines. Use at least *eight* field lines.

(2 marks)

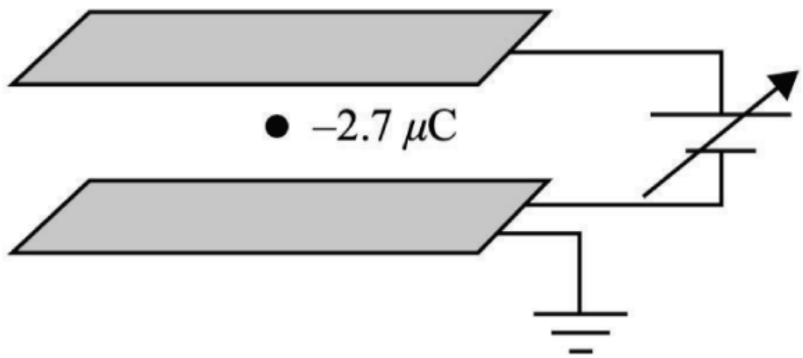
Solution



Question 15/ 46

[VCAA 2021 NHT SB Q1]

A small sphere carrying a charge of $-2.7\mu\text{C}$ is placed between charged parallel plates, as shown below. The potential difference between the plates is set at 15.5 V, which just holds the sphere stationary. The electric field between the plates is uniform.



a. In which direction (up, down, right, left) will the sphere move if the voltage is increased?

(1 mark)

b. Calculate the value of the electric force that is holding the sphere stationary if the plates are 2.0 mm apart. Show your working.

(2 marks)

Solution

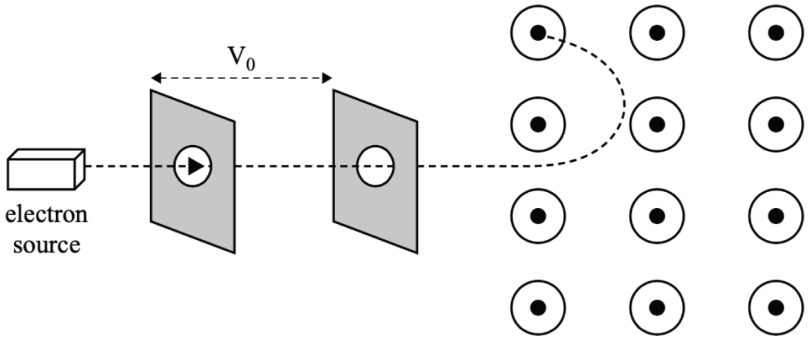
a Up The electric field will increase and the negatively charged sphere will move opposite to the field direction.

b 0.021 N Use $F = qE = \frac{qV}{d}$.

Question 16/ 46

[Adapted VCAA 2021 NHT SB Q2]

An electron is accelerated from rest by a potential difference of V_0. It emerges at a speed of $2.0 \times 10^7 \mathrm{~m~s}^{-1}$ into a magnetic field.



Calculate the value of the accelerating voltage, V_0. Show your working.

(3 marks)

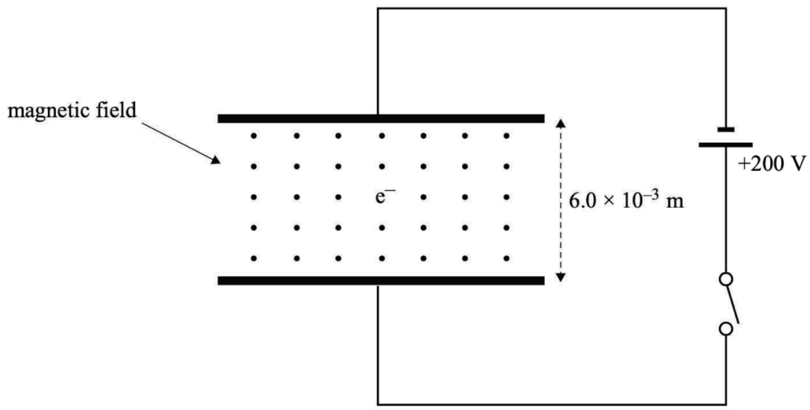
Solution

1.1(4) kV Rearrange $qV_0 = \frac{1}{2}mv^2$ with V_0 as the subject.

Question 17/ 46

[Adapted VCAA 2021 SB Q5]

The diagram following shows a stationary electron $(\mathrm{e}-)$ in a uniform magnetic field between two parallel plates. The plates are separated by a distance of $6.0 \times 10^{-3} \mathrm{~m}$, and they are connected to a 200 V power supply and a switch. Initially, the plates are uncharged. Assume that gravitational effects on the electron are negligible.



The switch is closed. Determine the magnitude and the direction of any electric force now acting on the electron. Show your working.

(3 marks)

Solution

5.3×10^{-15} N Use $F = qE = \frac{qV}{d} = \frac{1.6 \times 10^{-19} \times 200}{6.0 \times 10^{-3}}$.

Question 18/ 46

[VCAA 2022 NHT SB Q1]

A particle with mass *m* and charge *q* is accelerated from rest by a potential difference, *V*. The only force acting on the particle is due to the electric field associated with this potential difference.

a. Show that the speed of the particle is given by $v = \sqrt{\frac{2qV}{m}}$ and state the principle of physics used in your answer.

(2 marks)

b. Calculate the speed of an electron accelerated from rest by a potential difference of 200 V.

(2 marks)

Solution

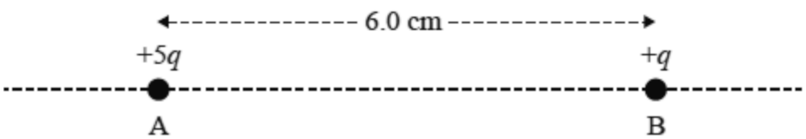
a Conservation of energy is the principle. $\text{EPE} = qV = \text{KE} = \frac{1}{2}mv^2$; make v the subject.

b $8.4 \times 10^6 \text{ m s}^{-1}$ Substitute values into $v = \sqrt{\frac{2qV}{m}}$.

Question 19/ 46

[VCAA 2023 NHT SB Q1]

Two small charges, A and B, are placed 6.0 cm apart in a straight line, as shown below.



Charge A has a magnitude of $+5q$ coulombs and charge B has a magnitude of $+q$ coulombs.

If the force exerted by charge A on charge B is 5.1×10^{-24} N to the right, determine the value of q.

(3 marks)

Solution

$6.4 \times 10^{-19}\text{C}$ $F = \frac{kq_1q_2}{r^2}$

$5.1 \times 10^{-24} = \frac{8.99 \times 10^9 \times 5q \times q}{(6.0 \times 10^{-2})^2}$

$5q^2 = 2.04 \times 10^{-36}$

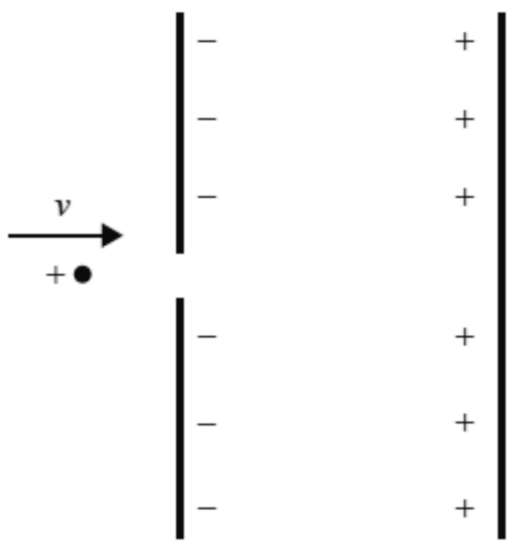
$q = 6.39 \times 10^{-19}\text{C}$.

Question 20/ 46

[VCAA 2023 NHT SB Q2]

A positively charged particle carrying a charge of $+1.5 \times 10^{-8}$ C enters a region between two large, charged plates with opposite charges, as shown below.

The potential difference between the plates is 2.0 kV, and the kinetic energy of the charged particle as it enters the hole is 2.8×10^{-5} J. Ignore gravitational effects and air resistance.



Ariel and Jamie discuss what they think will happen to the particle after it enters the region between the two equally but oppositely charged plates.

Ariel says that the particle has insufficient kinetic energy to reach the positively charged plate and will travel part of the way before returning towards the negatively charged plate.

Jamie says that the particle will collide with the positively charged plate and then head back towards the negatively charged plate.

Evaluate Ariel and Jamie's statements, giving clear reasons for your answer.

(3 marks)

Solution

Work done by field to slow down positively charged particle

$$= qV$$
$$= (1.5 \times 10^{-8})(2.0 \times 10^{3})$$
$$= 3.0 \times 10^{-5}\ \text{J}$$

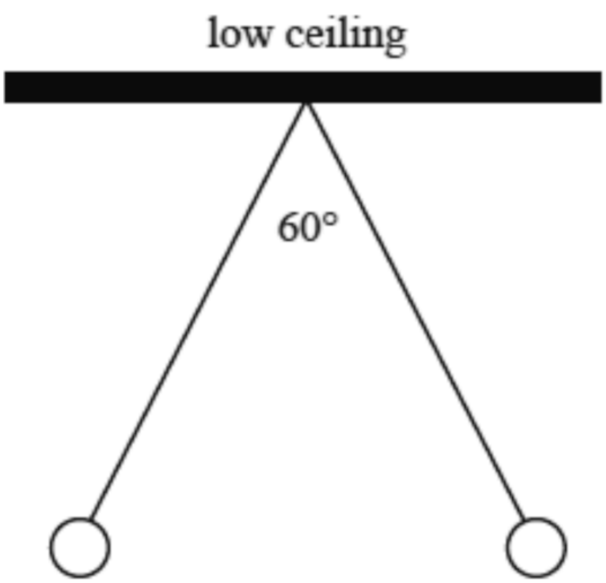
Ariel is correct as the particle's kinetic energy $< 3.0 \times 10^{-5}$ J and therefore insufficient to reach the positively charged plate.

Question 21/ 46

[VCAA 2023 SB Q1]

Some physics students are conducting an experiment investigating both electrostatic and gravitational forces. They suspend two equally charged balls, each of mass 4.0 g, from light, non-conducting strings suspended from a low ceiling.

The charged balls repel each other with the strings at an angle of 60°, as shown below.



There are three forces acting on each ball:

• a tension force, T

• a gravitational force, F_g

• an electrostatic force, F_E

a. On the diagram shown above, using the labels T, F_g and F_E, draw each of the three forces acting on each of the charged balls.

(2 marks)

b. Show that the tension force, *T*, in each string is 4.5×10^{-2} N. Use $g = 9.8$ N kg^{-1}.

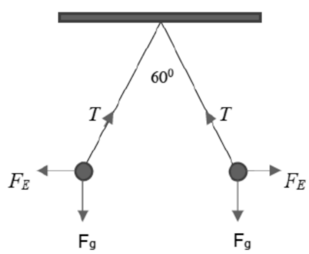
(2 marks)

c. Calculate the magnitude of the electrostatic force, F_E.

(2 marks)

Solution

a



b $T \cos(30°) = 4.0 \times 10^{-3}(9.8)$

$T = 4.5 \times 10^{-2}$ N as required.

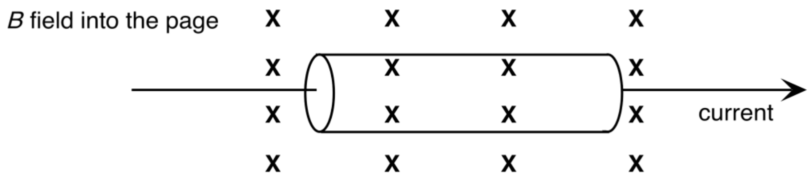
c 2.3×10^{-2} N $F_E = T \cos(60°) = 4.5 \times 10^{-2}(0.500)$

$F_E = 2.3 \times 10^{-2}$ N

Chapter 10 Magnetic fields

Question 1/ 23

Electrons moving through a resistor experience a force if the resistor is in a magnetic field. A resistor is oriented east–west as shown, with Earth's magnetic field into the page. The current is to the right.



An electron travelling through the resistor will experience a force due to the magnetic field; the direction of the force will be

A up.

B down.

C into page.

D out of page.

Solution

A Use right-hand slap rule or Fleming's rule.

Question 2/ 23

A vertical lightning conductor gets a 'bolt from the blue' – a discharge from thunderclouds above. This sends electrons in the conductor rushing downwards. Assume Earth's magnetic field is horizontal. In which direction does Earth's magnetic field push the lightning conductor?

A North

B South

C East

D West

Solution

D Use right-hand slap rule or Fleming's rule.

Question 3/ 23

The Earth's magnetic field in Question 2 is horizontal and has a value of 2×10^{-5} T, and the lightning conductor is 2.5 m long; the current in the conductor is close to 200 000 A. The magnetic force is closest to

A 10 N

B 1.6 N

C 1.0×10^{-4} N

D 2.5×10^{-10} N

Solution

A Use $F = BIl$.

Question 4/ 23

During a severe storm, the lightning conductor is tipped over towards the north, so that it now makes an angle of 30° to the horizontal and is no longer at right angles to the magnetic field. Which of the following best describes the new magnetic force on the lightning conductor when a current of around 10^4 A flows through it?

A It is the same as before.

B It is greater than before.

C It is less than before, but not zero.

D There is now no magnetic force on the conductor.

Solution

C Only equal to $F = BIl$ when B and l are at right angles.

Question 5/ 23

When a wire is pushed by a magnetic force perpendicular to the field, which of the following can you be sure about?

A A current is flowing in the wire.

B The force F on the wire is given by the formula $F = BI$.

C The force on the wire is equal to the sum of all the magnetic forces on the protons inside the wire.

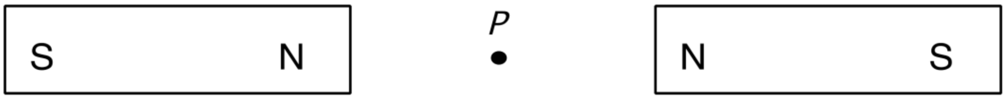
D The wire is in the same direction as the magnetic field.

Solution

A This is why there is a force; the interaction of B and I.

Question 6/ 23

Jon is investigating fields produced by magnets as research for a model electric motor. One arrangement of magnets is shown. The magnets are identical; P is exactly midway between the two N poles.



Which of the following best describes the magnetic field at *P*?

A It is stronger than the field due to one magnet only.

B It is about the same as the field due to one magnet only.

C It is weaker than the field due to one magnet only.

D It is close to zero.

Solution

D Vector addition of fields at the point.

Question 8/ 23

What is the direction of the force on the side KL in each of the three orientations?

A

Orientation 1	***Orientation 2***	***Orientation 3***
up	up	zero

B

down down down

C

up down zero

D

up up up

Solution

B Use right-hand slap rule or Fleming's rule.

Question 9/ 23

Is the force on side LM ever zero?

A In all three orientations

B In orientation number 1

C In orientation number 2

D In orientation number 3

Solution

D In orientation 3, field is parallel to current.

Question 10/ 23

A group of students is considering how to create a magnetic monopole. Which one of the following is correct?

A Break a bar magnet in half.

B Pass a current through a long solenoid.

C Pass a current through a circular loop of wire.

D It is not known how to create a magnetic monopole.

Solution

D Standard knowledge.

Question 11/ 23

An electron is travelling in a circle of radius 1.0 cm at right angles to a magnetic field of 5 mT. Which of the following is closest to its speed?

A 10^5 m s^{-1}

B 10^6 m s^{-1}

C 10^7 m s^{-1}

D 10^8 m s^{-1}

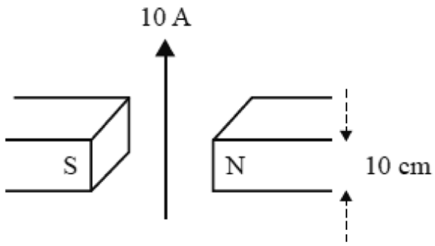
Solution

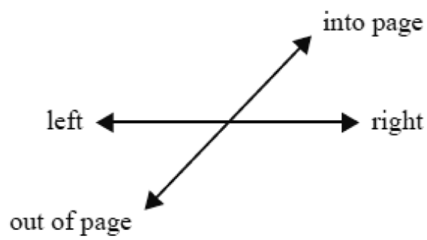
C Use $v = \frac{BqR}{m}$; answer $= 8.8 \times 10^6 \text{ m s}^{-1}$.

Question 12/ 23

[VCAA 2018 SA Q1]

A wire carrying a current of 10 A is placed in a uniform magnetic field of $B = 4.0 \times 10^{-4}$ T, as shown below. 10 cm of the wire is in the field.





Which one of the following best gives the magnitude of the force acting on the wire?

A 4.0×10^{-2} N

B 4.0×10^{-4} N

C 1.6×10^{-8} N

D 4.0×10^{-12} N

Solution

B Use $F = BIl$.

Question 13/ 23

[VCAA 2018 SA Q2]

Which one of the following best gives the direction of the force acting on the wire?

A out of page

B into page

C right

D left

Solution

A Use right-hand slap rule or Fleming’s rule.

Question 15/ 23

[VCAA 2019 NHT SA Q2]

Which one of the following best gives the direction of the electromagnetic force on the powerline?

A horizontally west

B horizontally north

C vertically upwards

D vertically downwards

Solution

D Use right-hand slap rule or Fleming’s rule.

Question 16/ 23

[VCAA 2019 NHT SA Q3]

The magnitude of the force on each metre of the powerline is best given by

A 5.0×10^3 N

B 5.0×10^{2} N

C 5.0×10^{-2} N

D 5.0×10^{-5} N

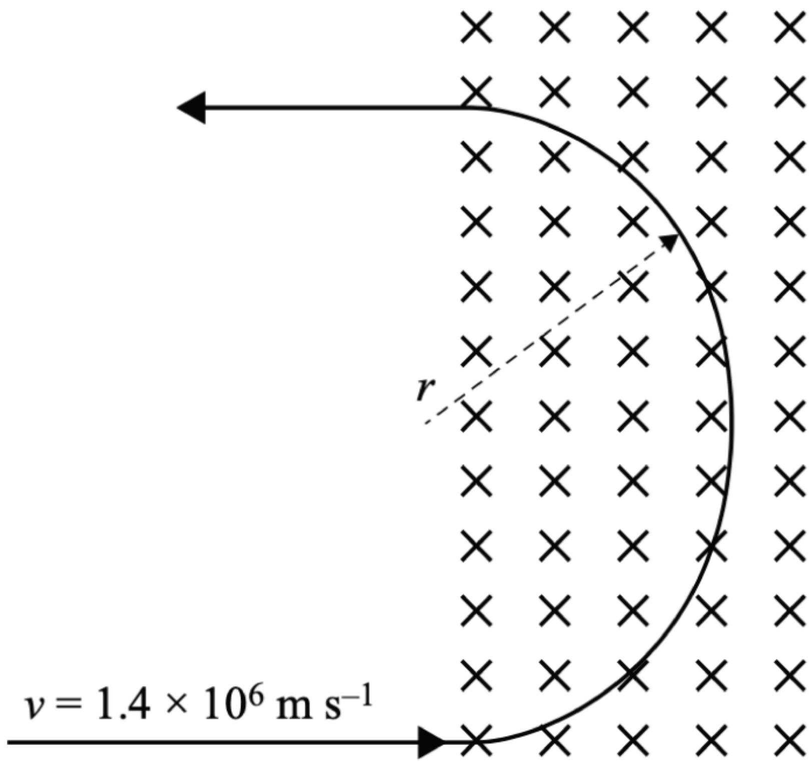
Solution

C   Use $F = BIl$ with $l = 1$.

Question 17/ 23

[VCAA 2020 SA Q3]

A positron with a velocity of 1.4×10^{6} m s^{-1} is injected into a uniform magnetic field of 4.0×10^{-2} T, directed into the page, as shown in the diagram below. It moves in a vacuum in a semicircle of radius *r*. The mass of the positron is 9.1×10^{-31} kg and the charge on the positron is 1.6×10^{-19} C. Ignore relativistic effects.



Which one of the following best gives the speed of the positron as it exits the magnetic field?

A 0 m s^{-1}

B much less than $1.4 \times 10^{6} \text{ m s}^{-1}$

C $1.4 \times 10^{6} \text{ m s}^{-1}$

D greater than $1.4 \times 10^{6} \text{ m s}^{-1}$

Solution

C   No work is done on the positron by the magnetic force as it is perpendicular to the velocity of the positron.

Question 18/ 23

[VCAA 2020 SA Q4]

The speed of the positron is changed to $7.0 \times 10^5 \text{ m s}^{-1}$. Which one of the following best gives the value of the radius r for this speed?

A $\frac{r}{4}$

B $\frac{r}{2}$

C r

D $2r$

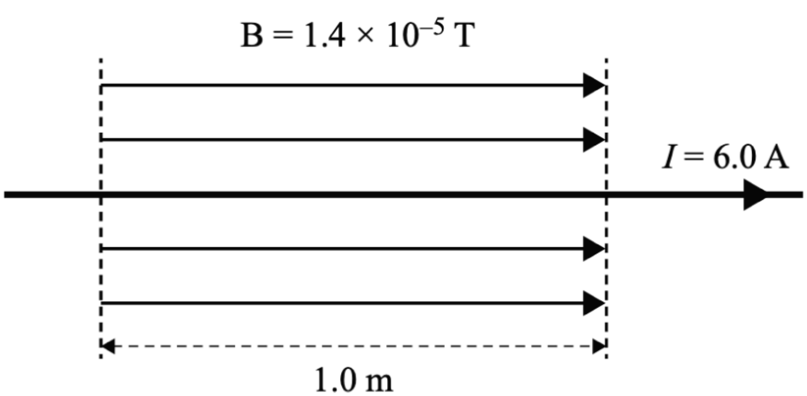
Solution

B The radius is given by $r = \frac{mv}{qB}$. The speed of the positron is halved, so the radius is also halved.

Question 19/ 23

[VCAA 2021 NHT SA Q1]

A wire carrying a current, *I*, of 6.0 A passes through a magnetic field, *B*, of strength 1.4×10^{-5} T, as shown below. The magnetic field is exactly 1.0 m wide.



The magnitude of the force on the wire is closest to

A 0 N

B 2.3×10^{-6} N

C 8.4×10^{-5} N

D 4.3×10^{5} N

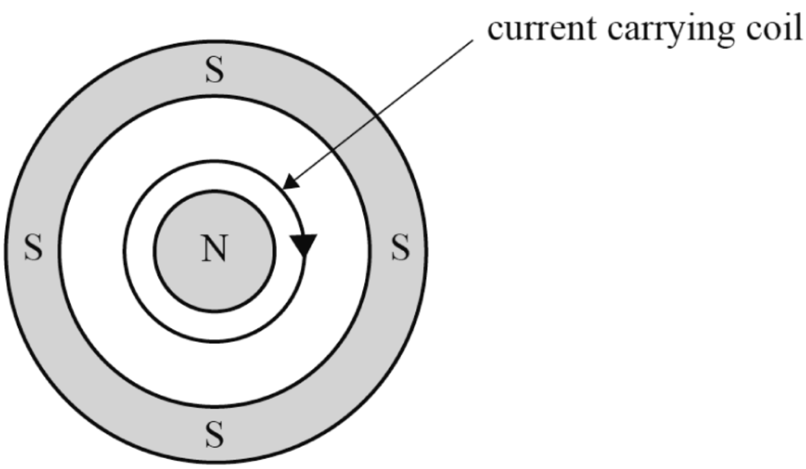
Solution

A There is no magnetic force when the current is parallel to the magnetic field.

Question 20/ 23

[VCAA 2022 NHT SA Q2]

A loudspeaker consists of a current carrying coil within a radial magnetic field, as shown in the diagram below. The direction of the current in the coil is also shown.



Which one of the following best describes the direction of the force on the coil?

A out of the page

B down the page

C into the page

D up the page

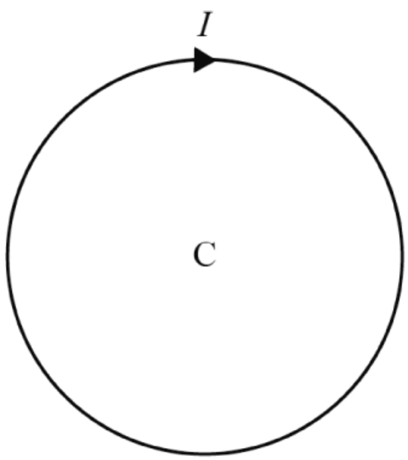
Solution

A Use the right-hand slap rule or Fleming’s rule.

Question 21/ 23

[VCAA 2022 SA Q1]

A single loop of wire carries a current, *I*, as shown in the diagram below.



Which one of the following best describes the direction of the force on the coil?

A to the left

B to the right

C into the page

D out of the page

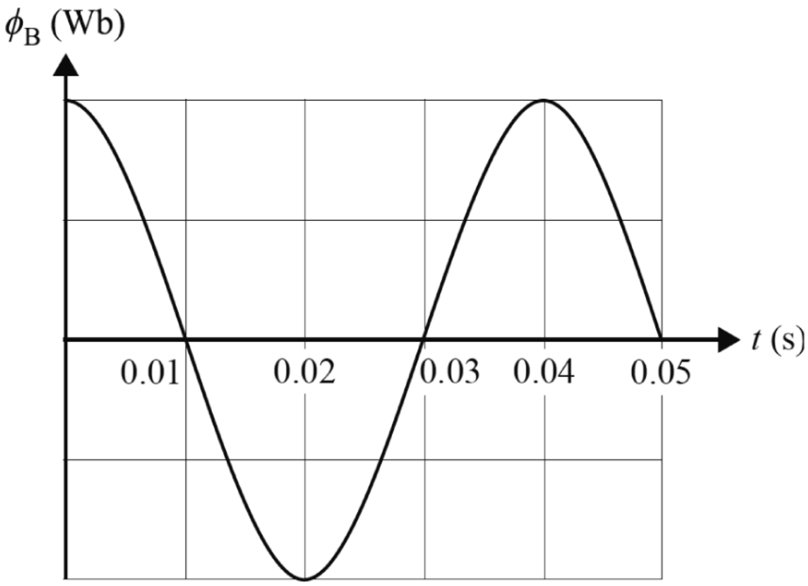
Solution

C Use right hand grip rule with thumb in the direction of the current.

Question 22/ 23

[VCAA 2022 SA Q2]

The diagram below shows the magnetic flux variation through the coil of an AC generator.



Which one of the following is closest to the frequency of the magnetic flux variation through the coil of the AC generator?

A 0.04 Hz

B 10 Hz

C 20 Hz

D 20 Hz

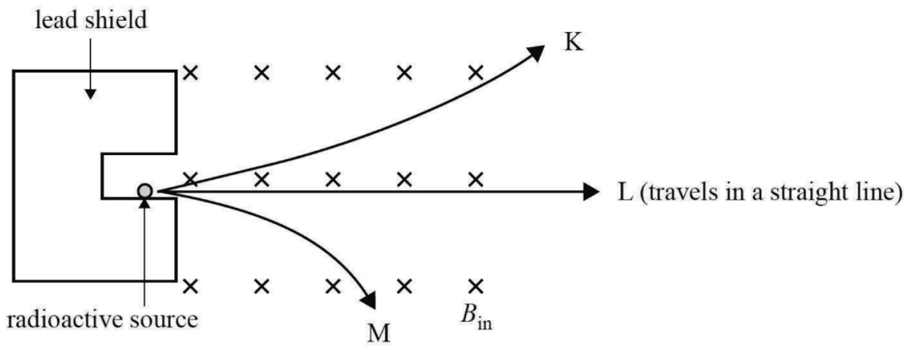
Solution

D Use $f = 1/T$.

Question 23/ 23

[VCAA 2022 SA Q3]

Particles emitted from a radioactive source travel through a magnetic field, B_{in}, directed into the page, as shown schematically in the diagram below. Three particles, K, L and M, follow the paths indicated by the arrows.



Which of the following correctly identifies the charges on particles K, L and M?

K	**L**	**M**
positive	no charge	negative
positive	negative	negative
negative	no charge	positive
no charge	no charge	no charge

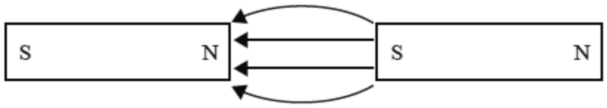
Solution

A L must be uncharged; K is positive and M is negative (right-hand slap rule).

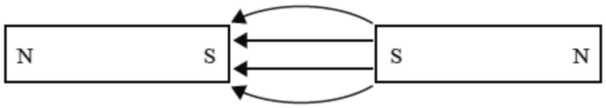
Question 24/ 23

[VCAA NHT 2023 SA Q3]

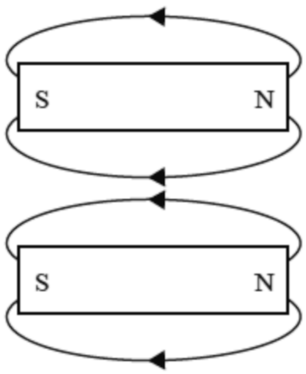
Which one of the following diagrams best represents the magnetic field between two magnets?



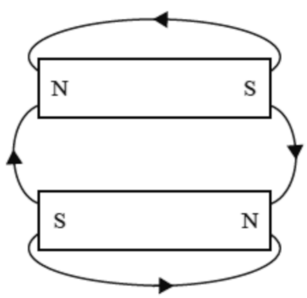
A



B



C



D

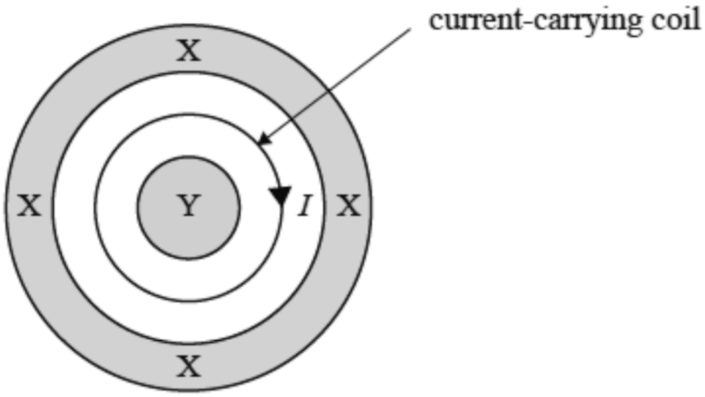
Solution

C Magnetic field lines run from north (N) to south (S).

Question 25/ 23

[VCAA 2023 SA Q1]

One type of loudspeaker consists of a current-carrying coil within a radial magnetic field, as shown in the diagram below. X and Y are magnetic poles, and the direction of the current, *I*, in the coil is clockwise as shown.



The force, F, acting on the current-carrying coil is directed into the page.

Which one of the following statements correctly identifies the magnetic polarities of X and Y?

A X is a north pole and Y is a south pole.

B X is a south pole and Y is a north pole.

C Both X and Y are north poles.

D Both X and Y are south poles.

Solution

A Right hand slap rule.

Question 1/ 48

A bending magnet in an accelerator causes a beam of electrons moving at $1.5 \times 10^7 \text{ m s}^{-1}$ to move in a circular path of radius 0.25 m. Calculate the magnitude of the magnetic field.

(2 marks)

Solution

3.4×10^{-4}T Use $B = \frac{mv}{qR}$.

Question 2/ 48

A wire of length 2 m in a magnetic field of 0.15 T experiences a sideways magnetic force of 3 N. What is the current flowing in it?

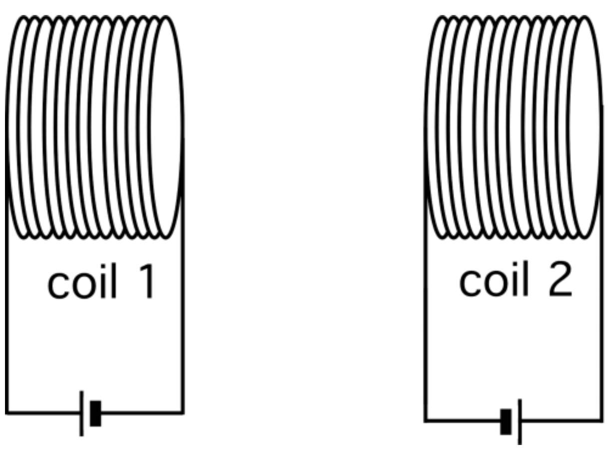
(2 marks)

Solution

10 A Use $F = BIl$.

Question 3/ 48

Two coils, shown below, provide separate magnetic fields. A current is flowing through both coils. As a result, they exert forces on each other.



What is the direction of the force on coil 1? Show your reasoning.

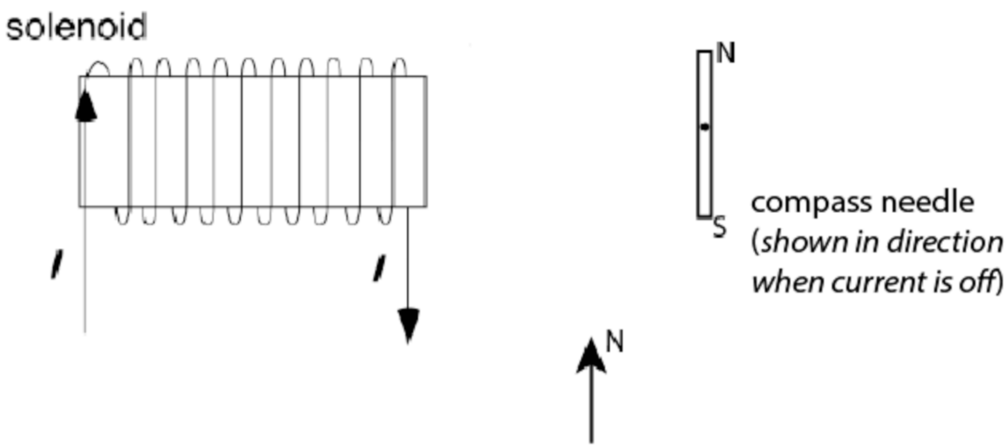
(3 marks)

Solution

To the right The two coils have S poles facing each other (right-hand grip).

Question 4/ 48

Students measure the field of a current-carrying solenoid by comparing it to Earth's magnetic field. A balanced compass needle is pivoted about its centre and put in the position shown below. With the current *off*, the needle points to north.



a. When the current is switched *on*, the needle turns through 30°. Describe, with reasons, the direction it turns.

(2 marks)

b. Earth's magnetic field at the location is 30 μT. Calculate the strength of the magnetic field of the solenoid at the position of the compass needle. Show your working.

(3 marks)

Solution

a Anticlockwise Field from solenoid points W; vector sum.

b 17.3 μT Using components, $F = 30 \times \tan 30\ \mu\text{T}$.

Question 5/ 48

The Aurora Australis is a display of light above the south pole, caused by the spiralling paths of charged particles emitting photons. A proton travels at $40\ \text{km s}^{-1}$, at right angles to a magnetic field of $5.0 \times 10^{-5}\ \text{T}$. The mass of a proton is $1.7 \times 10^{-27}\ \text{kg}$, and its charge is $+1.6 \times 10^{-19}\ \text{C}$.

a. Calculate the magnetic force acting on the proton.

(2 marks)

b. Calculate the radius of the circular path of the proton.

(2 marks)

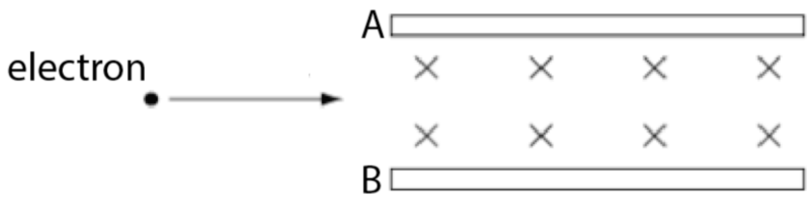
Solution

a $3.2 \times 10^{-19}\ \text{N}$ Use $F = qvB$.

b 8.5 m Use $R = \frac{mv}{qB}$.

Question 6/ 48

The speed of charged particles can be measured by passing them through a combination of electric and magnetic fields at right angles to each other. An electron is shown entering the space between two parallel charged plates, where there is such a combination of fields.



a. Determine which plate, A or B, must be at the highest potential if the electron is to pass though the space undeflected. Show your reasoning.

(2 marks)

b. At a speed of $200\ 000\ \mathrm{m\ s^{-1}}$, the electron passes through undeflected. If the magnetic field is of strength 0.2 T, calculate the strength of the electric field between the plates.

(2 marks)

c. The voltage across the plates is equal to 1000 V. Calculate the spacing of the plates.

(2 marks)

d. Suppose an alpha particle (charge: $+3.2 \times 10^{-19}\ \mathrm{C}$; mass: $6.6 \times 10^{-27}\ \mathrm{kg}$) replaces the electron and is travelling at the same speed. Discuss the changes required to ensure that it also remains undeflected.

(3 marks)

Solution

a Plate A Plate A must be positive to balance the downwards magnetic force (use RHS or Fleming's rule).

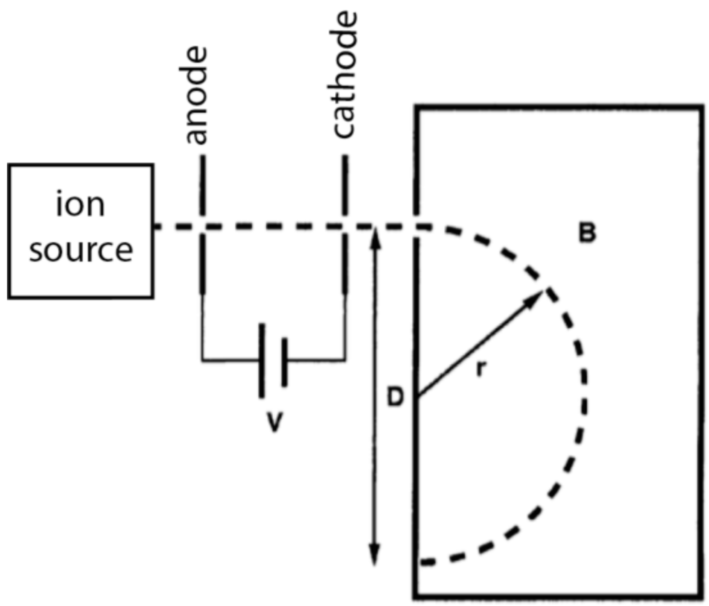
b $40\ 000\ \mathrm{N\ C^{-1}}$ Use $E = vB$.

c 2.5 cm Use $E = \frac{V}{d}$.

d No changes The electric force qE must still balance Bqv; hence $E = vB$ still.

Question 7/ 48

The outline of a simple mass spectrometer is sketched below. An ion source provides ionised atoms that are then accelerated through a potential difference of V volts, as shown. The ions then enter a region of uniform magnetic field and are bent into a circular path (region B). (The whole apparatus is evacuated.)



a. State the sign of the ions in this arrangement, giving a reason for your answer.

(2 marks)

b. Explain why the ions travel in a circular path in region B.

(3 marks)

c. Identify the direction of the uniform magnetic field in region B. Give a reason for your answer.

(2 marks)

d. In a particular experiment, ions of mass 11.6×10^{-27} kg carrying one electronic charge are accelerated by a voltage of 4000 V. Calculate the speed that they enter region B. (Assume that their speed is zero as they pass through the anode and constant from the point they leave the hole in the cathode.) Show your working.

(3 marks)

e. The ions strike the detecting plate a distance $D = 2r$ from their entry into region B, as shown in the diagram. In one experiment $D = 12.8$ cm. Calculate the value of the magnetic field in region B. Include a unit. Show your working.

(4 marks)

f. In another experiment, the speed of the ions entering region B and the strength of the magnetic field in region B both remain the same, but the value for *D* halves. Students discussing this result suggest the following possibilities:

Student A: these ions have the same mass but double the charge.

Student B: these ions have the same charge but half the mass.

Student C: these ions have both double the charge and half the mass.

Evaluate these responses.

(4 marks)

Solution

a Positive Follows as the cathode is connected to the negative potential.

b The only force is the magnetic *Bqv*; it is constant and perpendicular to the motion. The result is uniform circular motion.

c Out of the page Use right-hand slap rule or Fleming's rule.

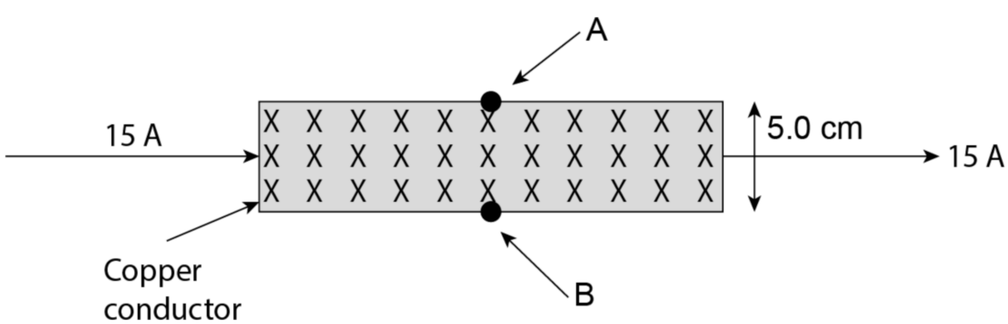
d $3.32 \times 10^5 \text{ m s}^{-1}$ Use $qV = \frac{1}{2}mv^2$.

e 0.376 T Use $R = \frac{mv}{qB}$.

f Use $R = \frac{mv}{qB}$; students A and B are correct, but C's idea would reduce *D* by ×4.

Question 8/ 48

Scientists investigate magnetic forces acting on electrons flowing through a conductor in a magnetic field. The conductor, a bar of copper of width 5.0 cm, and the magnetic field are at right angles to each other, as shown below. The magnetic field is 0.75 T.



When the scientists connect a sensitive voltmeter between points A and B, they measure a voltage, but only when a magnetic field is present.

a. Explain why the voltage occurs across the conductor only when a magnetic field is present, in terms of the electrons in the conductor.

(3 marks)

b. Identify whether point A or point B is at the higher potential, giving reasons.

(2 marks)

c. The voltage they measure is equal to 0.75 μV. Calculate the electric field across the conductor, between points A and B, assuming a uniform field.

(2 marks)

d. Assume that the force on the electrons from the electric field (*qE*) balances the magnetic force on the electrons to show that the voltage, *V*, between A and B is equal to *Bvd*, where *d* is the distance between A and B, and *v* is the speed of the electrons flowing in the conductor. Show your reasoning.

(2 marks)

e. Use the result in part **d.** to calculate the speed of the electrons.

(2 marks)

Solution

a, b The current consists of electrons moving perpendicular to the *B* field. They experience a *Bqv* force, moving them towards the lower side of the conductor. So point B will be negative compared to A, so there is a voltage across the conductor. Eventually the *Bqv* force is balanced by an opposing electric force, $F = qE$.

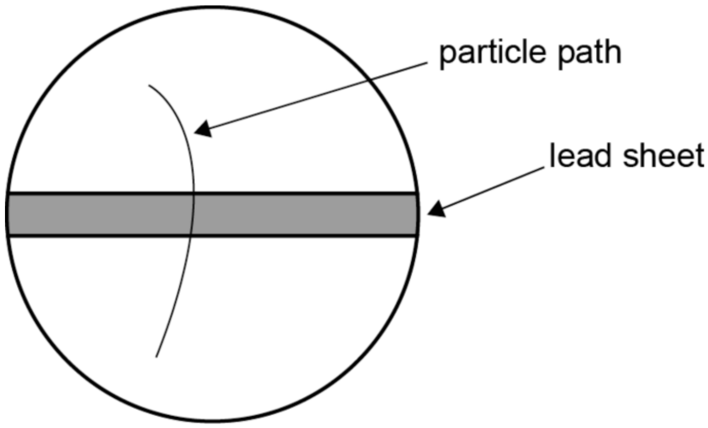
c 1.5×10^{-5} N C^{-1} Use $E = \frac{V}{d}$.

d When the electric and magnetic forces balance, $Bqv = qE = q\frac{V}{d}$. Rearrange.

e 2.0×10^{-5} m s^{-1} Use $v = \frac{V}{Bd}$, from the previous question.

Question 9/ 48

The path of a charged particle in a particle detector is shown in the diagram below. There is a strong uniform magnetic field at right angles to the page, directed into the page, and the particle travels through a piece of lead, where it loses some kinetic energy.



a. The particle is moving upwards. Explain why this must be the case, using physics principles.

(3 marks)

b. Determine the sign of the charge of the particle, giving a reason for your answer.

(2 marks)

c. The radius of the curvature of the path (r) can be measured, as can the strength of the magnetic field (B) and the charge of the particle (q). Write an equation for the momentum of the particle in terms of these variables. Show your reasoning.

(3 marks)

Solution

a The particle making the track is going more slowly in the upper half; this is because the track is more curved, although the magnetic field is the same ($R = \frac{mv}{qB}$, this implies that v is less).

b Positive This follows from the direction of the magnetic force (RHS or Fleming's right-hand rule).

c $p = Bqr$ Follows from $Bqv = \frac{mv^2}{r}$; implies $Bq = \frac{mv}{r} = \frac{p}{r}$.

Question 10/ 48

[Adapted VCAA 2016 SA Q13]

A 3.0 m long, vertical, copper lightning conductor is located in a region where Earth's magnetic field is horizontal and pointing north. A current of 2000 A flows down the conductor to Earth during an electrical storm. Force detectors measure a force on the lightning conductor of 0.32 N.

a. Calculate the magnitude of Earth's magnetic field acting on the lightning conductor.

(2 marks)

b. Describe the direction of the force on the lightning conductor. Explain your reasoning.

(2 marks)

Solution

a 5.3×10^{-5} T Use $F = BIl$.

b East Use the RHS rule or Fleming's rule.

Question 11/ 48

[VCAA 2018 NHT SB Q3]

A uniform electric field accelerates protons from rest to a speed of 5.00×10^{7} m s^{-1}.

DATA

mass of proton	1.67×10^{-27} kg
charge on proton	$+1.60 \times 10^{-19}$ C

a. The protons then pass into a region of uniform magnetic field that is at right angles to their velocity. They are bent into a circular path. Explain why the path is circular in shape.

(3 marks)

b. The strength of the uniform magnetic field is 500 mT. Calculate the magnitude of the magnetic force on the protons.

(3 marks)

Solution

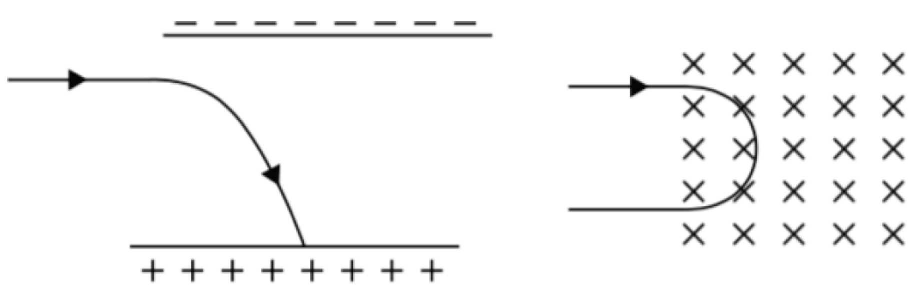
a The magnetic force (Bqv) is always directed at right angles to the velocity of the charged particle involved. Since the strength of the B field is constant, this means a constant sideways force; this acts as a centripetal force and guides the protons into a circular path.

b 4.0×10^{-12} N Use $F = Bqv$.

Question 12/ 48

[Adapted VCAA 2017 Sample SB Q2]

A beam of electrons travelling in a particle accelerator are deflected by a uniform electric field (left-hand diagram below). In another situation they are deflected by a uniform magnetic field (right-hand diagram below).



Explain why the paths of the electrons in the two situations have different shapes.

(2 marks)

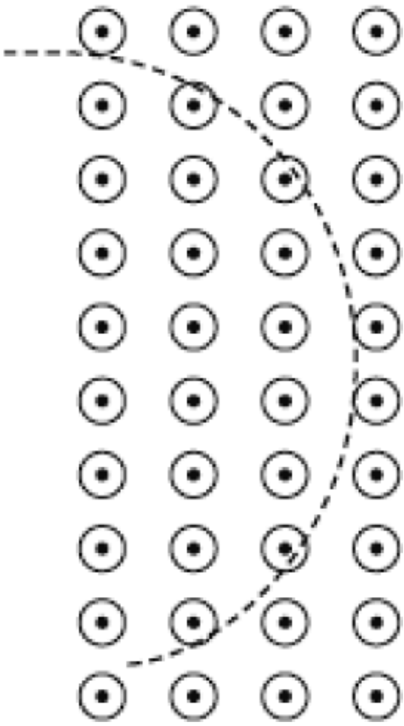
Solution

The uniform electric field in the left-hand diagram causes a constant force downwards, causing a parabolic path; the magnetic force in the right-hand diagram causes a constant magnitude force at right angles to the electrons path; this causes a circular path.

Question 13/ 48

[Adapted VCAA 2018 SB Q1]

A proton enters a region of uniform magnetic field with a speed of $1.0 \times 10^6 \text{ m s}^{-1}$ and moves in a circular path.



Calculate the radius of the path of this proton in the magnetic field. Show your working. (Use $B = 20 \text{ mT}$, $\text{proton charge} = 1.6 \times 10^{-19} \text{ C}$, $\text{proton mass} = 1.7 \times 10^{-27} \text{ kg}$.

(2 marks)

Solution

0.53 m Use $Bqv = \frac{mv^2}{r}$ with r as the subject.

Question 14/ 48

[Adapted VCAA 2019 NHT SB Q1]

Electrons move into a region of uniform magnetic field. The field is perpendicular to the velocity of the electrons. Will their path be a straight line, part of a parabola or part of a circle? Give a reason for your answer.

(2 marks)

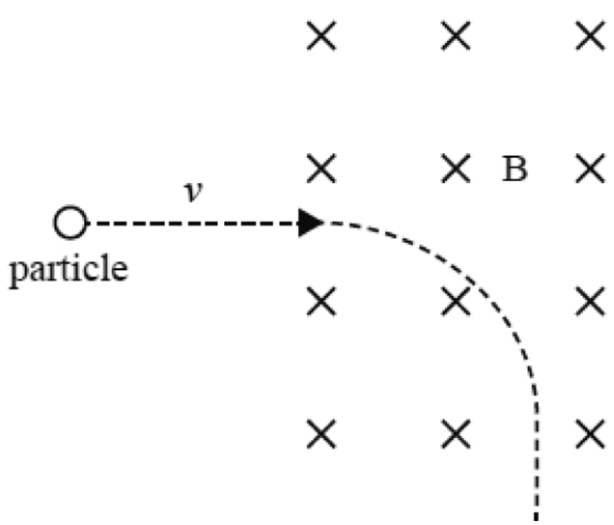
Solution

The electrons will follow a circular path as the magnetic force acting on them (Bqv) will be constant and at right angles to their velocity and act as a centripetal force.

Question 15/ 48

[VCAA 2019 SB Q1]

A particle of mass *m* and charge *q* travelling at velocity *v* enters a uniform magnetic field B, as shown below.



a Is the charge *q* positive or negative? Give a reason for your answer.

(1 mark)

b Explain why the path of the particle is an arc of a circle while the particle is in the magnetic field.

(2 marks)

Solution

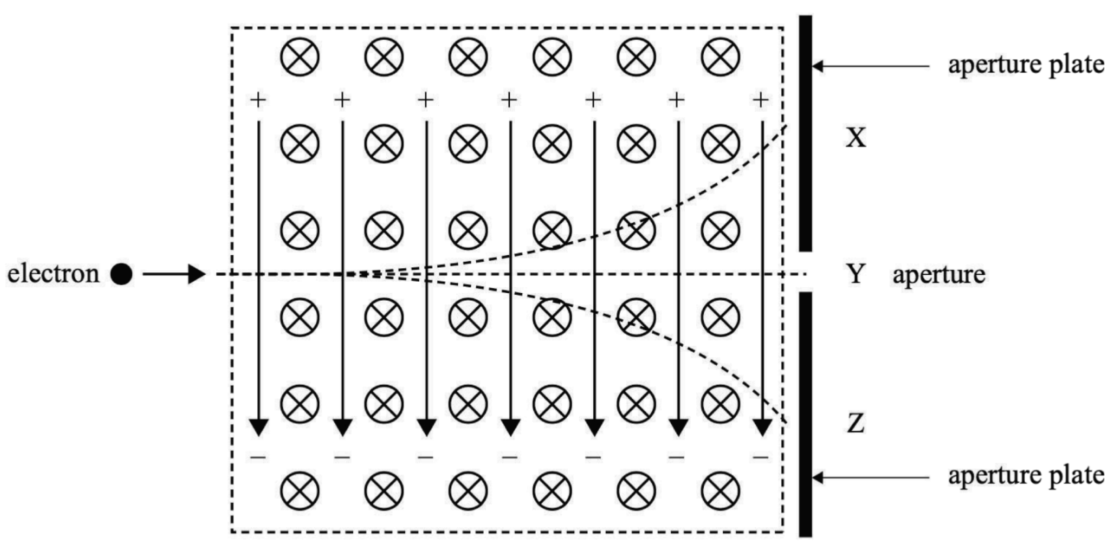
a Negative Use the RHS rule of Fleming's rule; the magnetic force points initially downwards and thereafter towards the centre of the circular arc.

b The magnetic force will be perpendicular to the velocity and constant in magnitude, since B, q and v are all constant. This kind of force produces circular motion.

Question 16/ 48

[VCAA 2020 SB Q3]

Electron microscopes use a high-precision electron velocity selector consisting of an electric field, E, perpendicular to a magnetic field, B. Electrons travelling at the required velocity, v_0, exit the aperture at point Y, while electrons travelling slower or faster than the required velocity, v_0, hit the aperture plate, as shown below.



a. Show that the velocity of an electron that travels straight through the aperture to point Y is given by $v_0 =$

$\frac{E}{B}$.

(1 mark)

b. Calculate the magnitude of the velocity, v_0, of an electron that travels straight through the aperture to point Y if $E = 500\ \text{kVm}^{-1}$ and $B = 0.25\ \text{T}$. Show your working.

(2 marks)

c. i. At which of the points – X, Y or Z – in the diagram could electrons travelling faster than v_0 arrive?

(1 mark)

ii. Explain your answer to part **c.i.**

(2 marks)

Solution

a The electric force qE must equal the magnetic force Bqv. Make v the subject.

b $2.0 \times 10^6\ \text{m s}^{-1}$ Substitute into the relationship given in part **a**.

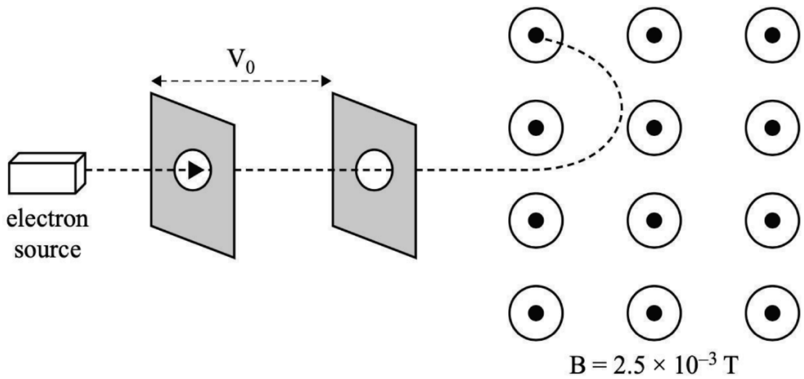
ci Z

cii F_E will be unchanged since the velocity of the electrons does not affect it, but F_B will increase since $F_\text{B} = Bqv$. This results in a net downwards force.

Question 17/ 48

[Adapted VCAA 2021 NHT SB Q2]

An electron is accelerated from rest by a potential difference of V_0. It emerges at a speed of $2.0 \times 10^7\ \text{m s}^{-1}$ into a magnetic field, B, of strength $2.5 \times 10^{-3}\ \text{T}$ and follows a circular arc, as shown below.



a. Explain why the path of the electron in the magnetic field follows a circular arc.

(2 marks)

b. Calculate the radius of the path travelled by the electron. Show your working.

(3 marks)

Solution

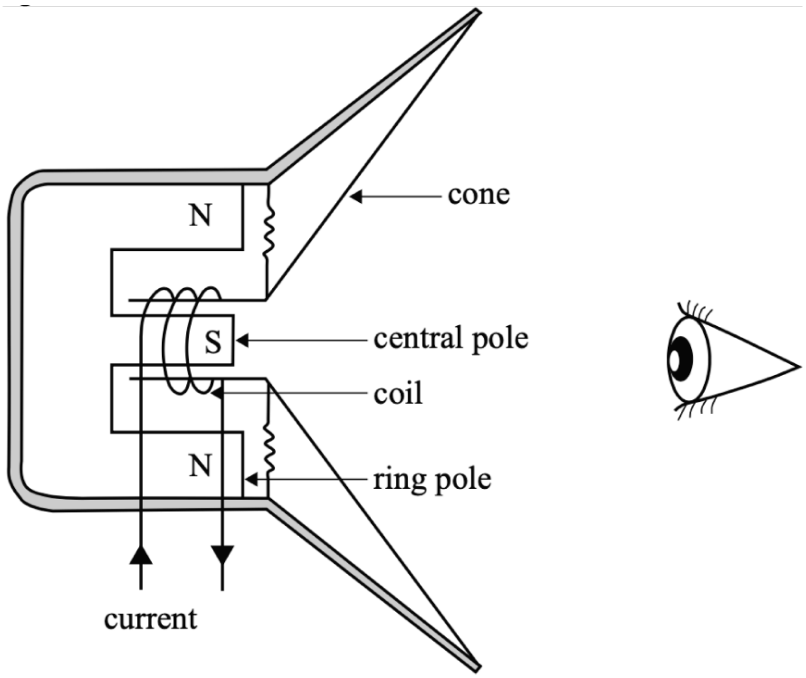
a The magnetic force is always perpendicular to the velocity and is constant in magnitude. This produces a circular path.

b 0.045(5) m Use $Bqv = \frac{mv^2}{r}$ with *r* as the subject.

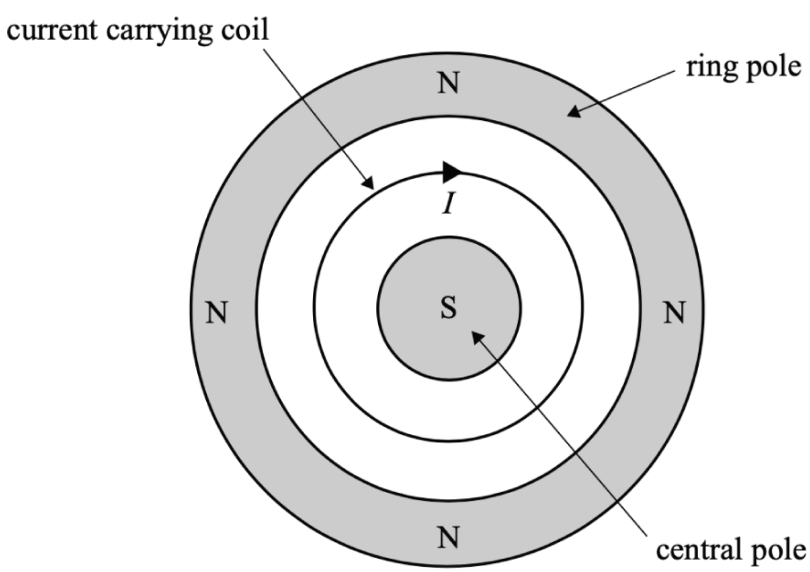
Question 18/ 48

[VCAA 2021 SB Q2]

A schematic side view of one design of an audio loudspeaker is shown in the diagram below. It uses a current carrying coil that interacts with permanent magnets to create sound by moving a cone in and out.



The diagram below shows a schematic view of the loudspeaker from the position of the eye shown in in the previous diagram. The direction of the current is clockwise, as shown.



a. Draw four magnetic field lines on the diagram above, showing the direction of each field line using an arrow.

(1 mark)

b. Which one of the following gives the direction of the force acting on the current carrying coil?

A left

B right

C up the page

D down the page

E into the page

F out of the page

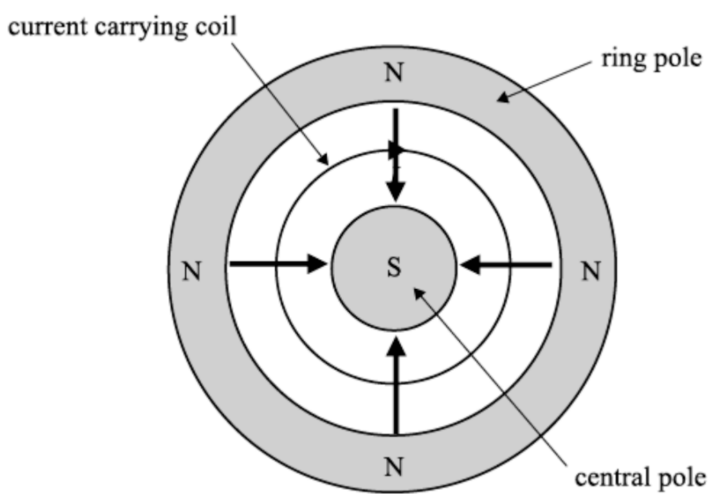
(1 mark)

c. The current carrying coil has a radius of 5.0 cm and 20 turns of wire, and it carries a clockwise current (*I*) of 2.0 A. Its magnetic field strength (*B*) is 200 mT. Calculate the magnitude of the force, *F*, acting on the current carrying coil. Show your working.

(2 marks)

Solution

a



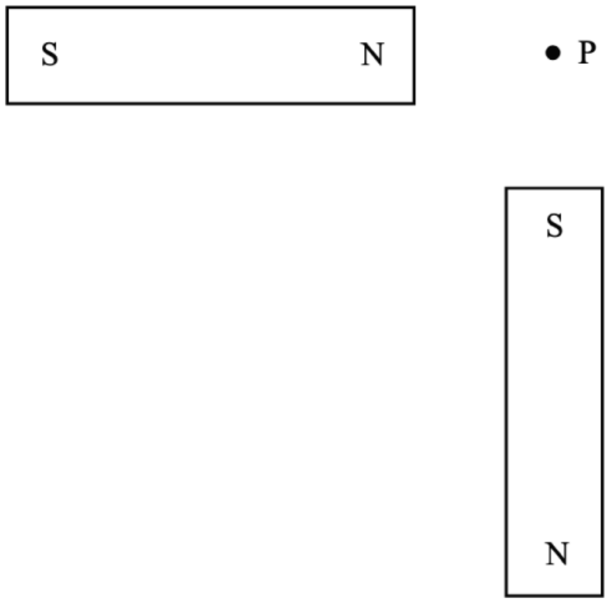
b E Use RHS rule or Fleming's rule

c 2.5 N Use $F = nBil$ with $n = 20, B = 0.200 \text{ T}, I = 2.0, l = 2\text{p} \times 5.0 \text{ cm}$

Question 19/ 48

[VCAA 2021 SB Q1]

Two identical bar magnets of the same magnetic field strength are arranged at right angles to each other and at the same distance from point P, as shown.



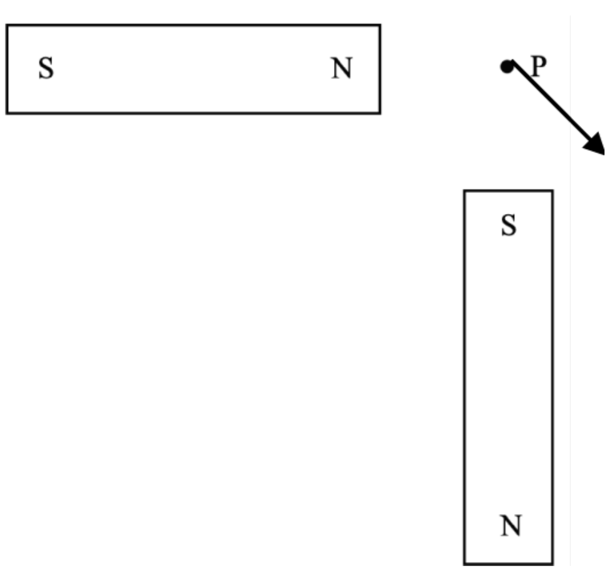
a. At point P on the diagram above, draw an arrow indicating the direction of the combined magnetic field of the two bar magnets.

(1 mark)

b. Calculate the magnitude of the combined magnetic field strength of the two bar magnets if each bar magnet has a magnetic field strength of 10.0 mT at point P.

(2 marks)

Solution



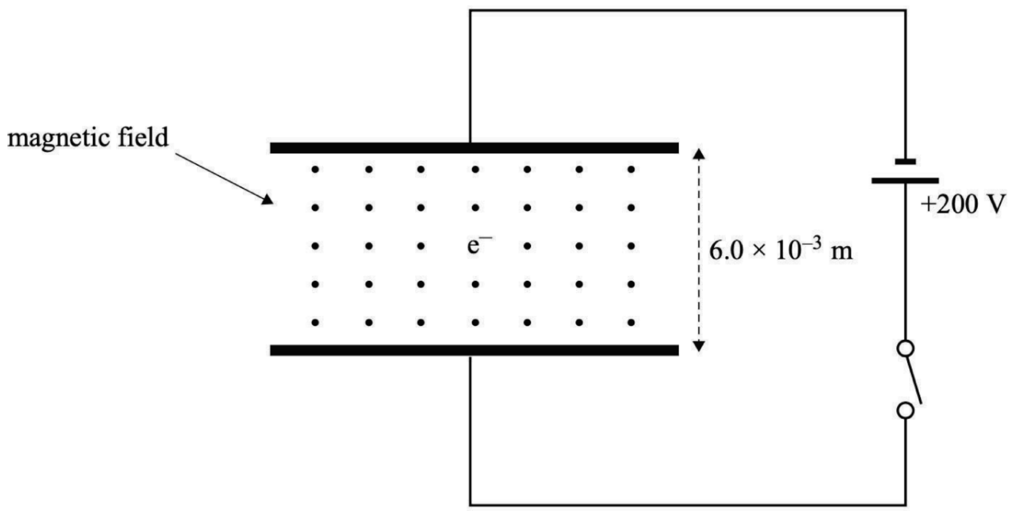
a

b 14.1 mT Use Pythagoras to combine the two vector fields of 10.0 mT.

Question 20/ 48

[Adapted VCAA 2021 SB Q5]

The diagram below shows a stationary electron $(\mathrm{e}-)$ in a uniform magnetic field between two parallel plates. The plates are separated by a distance of $6.0 \times 10^{-3}\mathrm{m}$, and they are connected to a 200 V power supply and a switch. Initially, the plates are uncharged. Assume that gravitational effects on the electron are negligible.



a. Explain why the magnetic field does not exert a force on the electron. Justify your answer with an appropriate formula.

(2 marks)

b. Ravi and Mia discuss what they think will happen to the size and direction of the magnetic force on the electron after the switch is closed. Ravi says that there will be a magnetic force of constant magnitude, but it will be continually changing direction. Mia says that there will be a constantly increasing magnetic force, but it will always in the same direction. Evaluate these two statements, giving clear reasons for your answer.

(4 marks)

Solution

a The magnetic force on a charges is given by $F_{\mathrm{B}} = Bqv$; here $v = 0$.

b Ravi is correct saying that the magnetic force will be changing direction, as it will be always at right angles to the direction of motion of the charge (which will now be moving because of the electric force on it). However, he is incorrect in saying that the magnitude of the magnetic force will be constant (as the speed of the electron will be increasing and this will cause the magnetic force also to increase in magnitude). Mia is correct in saying that the magnetic force will be increasing in magnitude but incorrect in saying that it will always be acting in the same direction.

Question 21/ 48

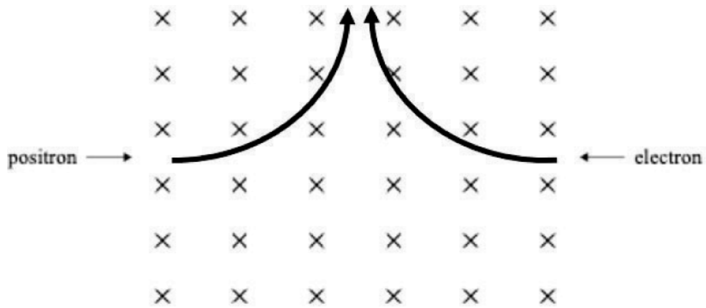
[VCAA 2022 NHT SB Q3]

A positron and an electron are fired one at a time into a strong uniform magnetic field in an evacuated chamber. They are fired at the same speed but from opposite sides of the chamber. Their initial velocities are initially perpendicular to the magnetic field and opposite in direction to each other, as shown in the diagram below. A positron has the same mass as an electron $(9.1 \times 10^{-31}\ \mathrm{kg})$ and has the same magnitude of electric charge as an electron $(-1.6 \times 10^{-19}\ \mathrm{C})$ but is positively charged $(+1.6 \times 10^{-19}\ \mathrm{C})$.

On the diagram, sketch and label the respective paths that the positron and the electron will take while in the uniform magnetic field.

Solution

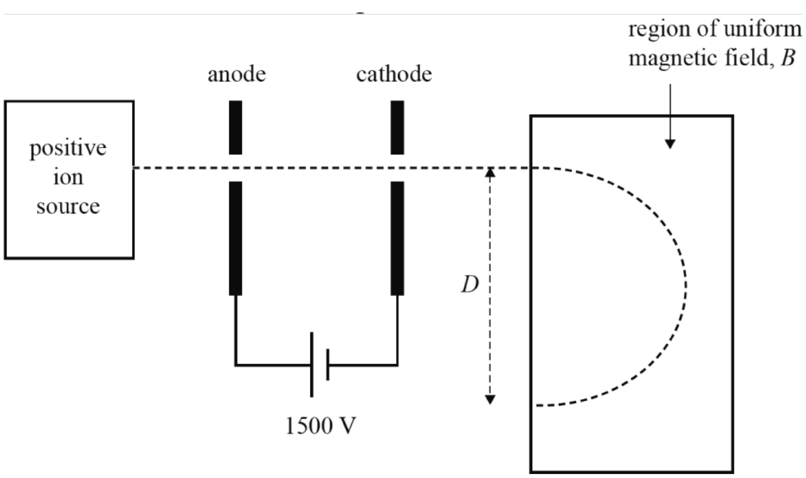
Both particles move in circular path of the same radius. The electron path bends upwards; so does the positiron.



Question 22/ 48

[VCAA 2022 SB Q3]

A schematic diagram of a mass spectrometer that is used to deflect charged particles to determine their mass is shown in the diagram below. Positive singly charged ions (with a charge of $+1.6 \times 10^{-19}\mathrm{C}$) are produced at the ion source. These are accelerated between an anode and a cathode. The potential difference between the anode and the cathode is 1500 V. The ions pass into a region of uniform magnetic field, *B*, and are directed by the field into a semicircular path of diameter *D*.



a. Calculate the increase in the kinetic energy of each ion as it passes between the anode and the cathode. Give your answer in joules.

(2 marks)

b. Each ion has a mass of 4.80×10^{-27} kg. Show that each ion has a speed of $3.16 \times 10^{5}\ \mathrm{m\ s^{-1}}$ when it exits the cathode. Assume that the ion leaves the ion source with negligible speed. Show your working.

(2 marks)

c. The current carrying coil has a radius of 5.0 cm and 20 turns of wire, and it carries a clockwise current (*I*) of 2.0 A. Its magnetic field strength (*B*) is 200 mT. Calculate the magnitude of the force, *F*, acting on the current carrying coil. Show your working.

(3 marks)

Solution

a 2.4×10^{-16} J Use $\text{work done} = \text{gain in KE} = qV$.

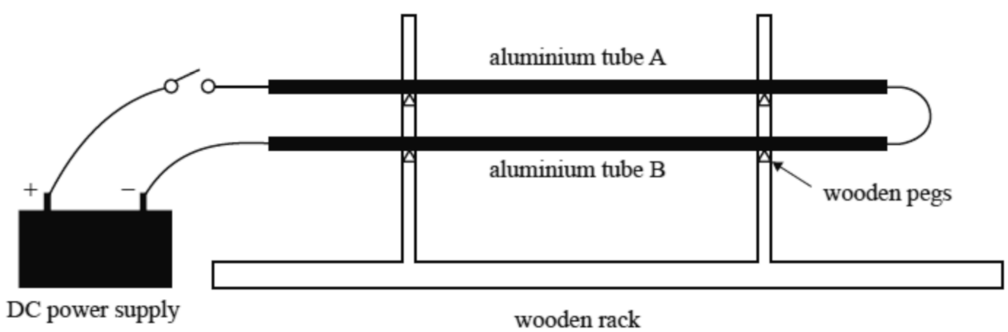
b $3.16 \times 10^{5}\ \text{m s}^{-1}$ $\text{KE} = \frac{1}{2}mv^2$; hence $2.4 \times 10^{-16} = \frac{1}{2} \times 4.80 \times 10^{-27} \times v^2$. Solve.

c 0.19 m Use $F = Bqv = \frac{mv^2}{R}$; hence $r = \frac{mv}{Bq}$.

Question 23/ 48

[VCAA NHT 2023 SB Q3]

Two thin, light aluminium tubes, A and B, are supported in a vertical wooden rack, as shown below. Both of the aluminium tubes rest horizontally on wooden pegs.



The two thin, light aluminium tubes form a series circuit with a DC power supply. It was observed that one of the tubes jumped upwards when the DC power supply was switched on.

Identify which tube jumped upwards and explain why this occurred.

(3 marks)

Solution

Tube A An indication that the two fields are into the page between the tubes. Two like fields in the same region repel / Greater flux density between tubes causes repulsion.

Applying right-hand grip rule the magnetic field produced by tube A will be into the page at tube B’s location. Similarly, the magnetic field produced by current flowing through tube B will be into the page at tube A’s location.

Applying the right-hand slap rule (or similar), at tube A current to the right and field into the page indicates that tube A would be pushed upward with no resistance. Similarly, tube B pushed down but resistance is present.

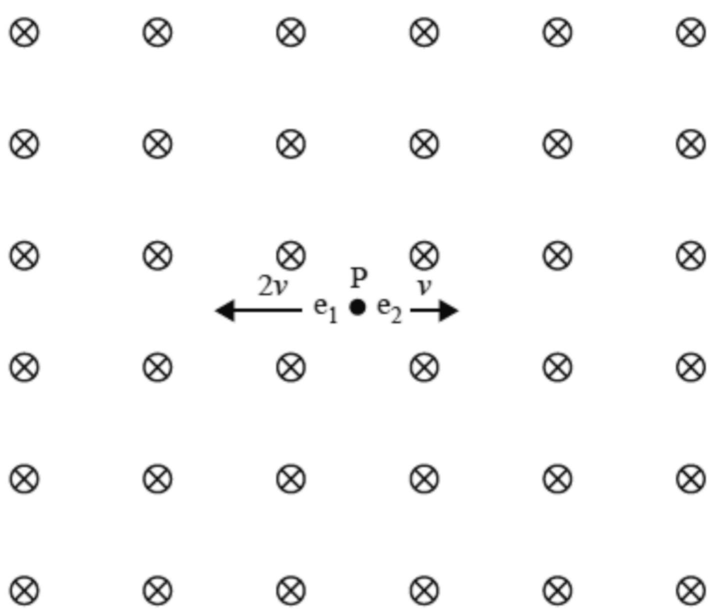
Question 24/ 48

[VCAA NHT 2023 SB Q4]

Two electrons, e_1 and e_2, are emitted, one after the other, from point P in a uniform magnetic field, as shown below.

Both electrons travel perpendicular to the magnetic field, but in opposite directions. Throughout their journey, both electrons remain within the magnetic field.

Electron e_1 travels at twice the speed of e_2. Relativistic effects can be ignored as both electrons are travelling at low speeds. Electrostatic effects at point P can be ignored as the two electrons are emitted at different times.



Which one of the following three outcomes occurs?

• Outcome 1 – Electron e_1 returns to point P in the shortest time.

• Outcome 2 – Electron e_2 returns to point P in the shortest time.

• Outcome 3 – Both electrons take the same time to return to point P.

Explain your answer.

(3 marks)

Solution

Outcome 3 – both return at same time.

The centripetal force F_C is provided by the magnetic force F_M.

$$F_M = F_C$$

$$qvB = \frac{mv^2}{R}$$

$$qB = \frac{mv}{R}$$

Since $v = \frac{2\pi R}{T}$

$$qB = \frac{2\pi m}{T}$$

i.e. the period $T = \frac{2\pi m}{qB}$

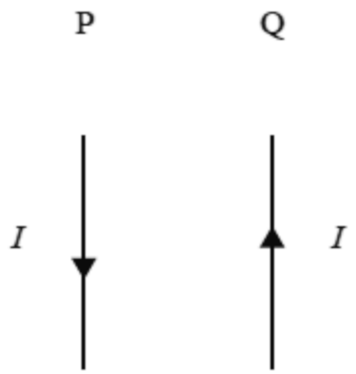
As T is independent of speed or as T is only dependent on mass, charge and magnetic field strength, all which are identical for the two electrons, both return at the same time.

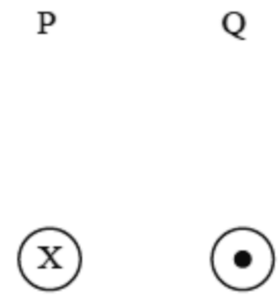
Question 25/ 48

[VCAA 2023 SB Q3]

Two long, straight current-carrying wires, P and Q, are parallel, as shown below (left diagram). The current in the wires is the same in magnitude and opposite in direction.

The diagram on the right shows the wires as viewed from above.





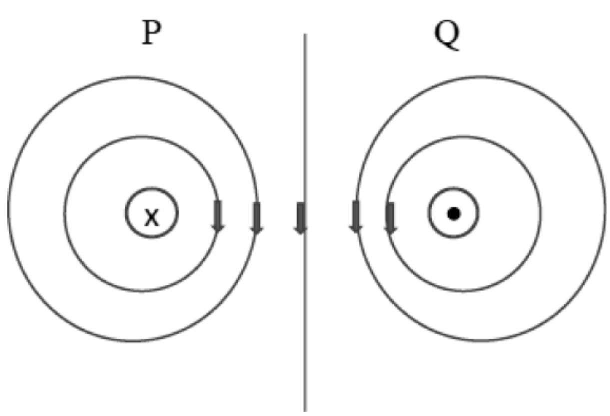
a. On the right hand diagram, sketch the magnetic field around the wires, showing the direction of the magnetic field. Use at least five field lines.

(3 marks)

b. Do the two wires, P and Q, attract or repel each other? Explain your reasoning.

(2 marks)

Solution



a

A complete circle around each wire

Direction of magnetic field correct

Field shape correct using at least 5 lines

b Repel Right hand slap rule.

Chapter 11 DC electric motors

Question 2/ 7

When current flows through the coil, the coil will (viewed from above)

A rotate clockwise.

B rotate anticlockwise.

C rotate either way, depending on the initial direction of motion.

D not rotate, it will simply vibrate about the position shown.

Solution

B Use RHS rule or Fleming's rule.

Question 3/ 7

Which of the following would be likely to *increase* the speed of the motor? (Assume that the coil is very light.)

A Decrease the number of turns of the rotating coil.

B Increase the area of the rotating coil.

C Decrease the area of the rotating coil.

D Decrease the current in the rotating coil.

Solution

B Increasing the area increases the torque (twisting effect) of the magnetic forces on the coil.

Question 4/ 7

If the permanent magnets were replaced by DC electromagnets with the same poles, which of the changes below would be necessary to keep the motor rotating as above?

A Replace the commutator with sliprings.

B Rectify the DC current.

C Reverse the direction of the poles.

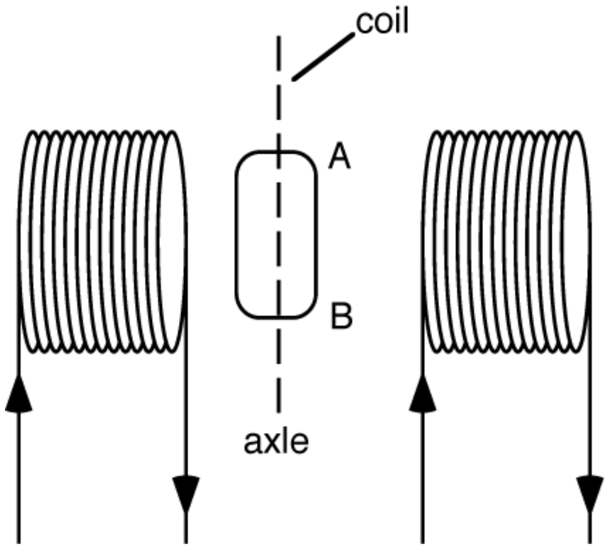
D No changes are required.

Solution

D The magnetic field would be the same as before.

Question 5/ 7

A coil on an axle is placed between the poles of an electromagnet.



A current is flowing in the coil between the electromagnets. The coil is rotating like a motor (a commutator is fitted). Side AB of the coil is rotating towards us. Which of the following best describes the current in the coil?

A It is flowing from A to B along this side.

B It must be alternating.

C It is flowing from B to A along this side.

D It could be flowing in either direction, one cannot tell.

Solution

C Use right-hand slap rule or Fleming's rule.

Question 7/ 7

With the coil in the position shown, and with the current flowing as shown, the coil is likely to

A remain in the position shown, as the BIl forces are balanced.

B rotate in a clockwise direction (viewed from the battery), due to opposite BIl forces on sides XW and YZ.

C rotate in an anticlockwise direction (viewed from the battery), due to opposite BIl forces on sides XW and

YZ.

D rotate only if one of the magnets is reversed in direction.

Solution

C Use right-hand slap rule or Fleming's rule.

Question 8/ 7

The primary function of the split-ring commutator is to

A prevent the wires from the power supply becoming tangled.

B increase the size of the turning force on the coil.

C convert the DC from the battery into an AC voltage.

D ensure that the coil rotates continuously in one direction.

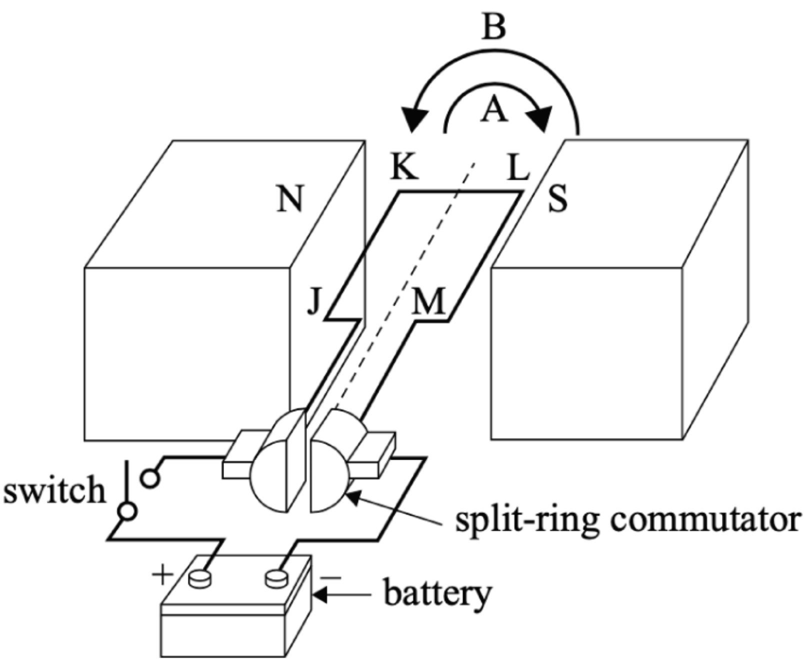
Solution

D Standard DC motor theory.

Question 9/ 7

[VCAA 2021 SA Q5]

The diagram below shows a small DC electric motor, powered by a battery that is connected via a split-ring commutator. The rectangular coil has sides KJ and LM. The magnetic field between the poles of the magnet is uniform and constant.



The switch is now closed, and the coil is stationary and in the position shown in the diagram. Which one of the following statements best describes the motion of the coil when the switch is closed?

A The coil will remain stationary.

B The coil will rotate in direction A, as shown in the diagram.

C The coil will rotate in direction B, as shown in the diagram.

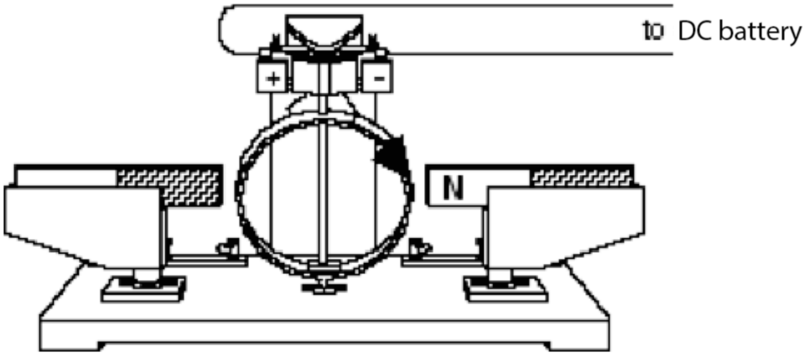
D The coil will oscillate regularly between directions A and B, as shown in the diagram.

Solution

C Apply RHS or Fleming's rule to side JK when current is flowing from J to K. Alternatively, apply rule to side LM when current is flowing from L to M.

Question 1/ 19

A simple DC motor, like the one shown below, has one rotating coil. Its field is supplied by permanent magnets.



Jimmy thinks that reversing the poles of *one* of the magnets would increase the magnetic field and hence the speed of the motor. Analyse this idea.

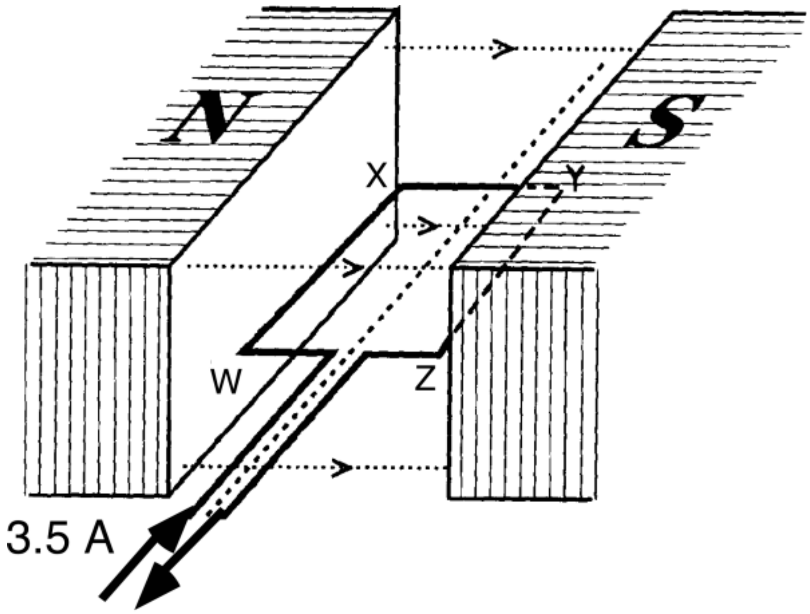
(2 marks)

Solution

Reversing one of the magnets would decrease the magnetic field around the coil, and the forces on each side of the coil would prevent continuous rotation.

Question 2/ 19

The coil and permanent magnets of a DC motor are sketched below.



The magnets shown above have a field of 45 mT between the poles. The 30-turn coil WXYZ has a current of 3.5 A in each turn. WX and $\mathrm{YZ} = 10\ \mathrm{cm}$, and XY and $\mathrm{ZW} = 5\ \mathrm{cm}$.

a. Describe the directions of the forces acting on the sides WX and YZ.

(2 marks)

b. Calculate the magnitude of the total force on the side WX.

(2 marks)

c. Calculate the magnitude of the total force on the side XY.

(2 marks)

d. For the coil to continue to rotate, a *commutator* is needed between points WZ and the DC supply. Explain its *function*.

(3 marks)

Solution

a The magnetic force on WX is downwards, on YZ, it is upwards.

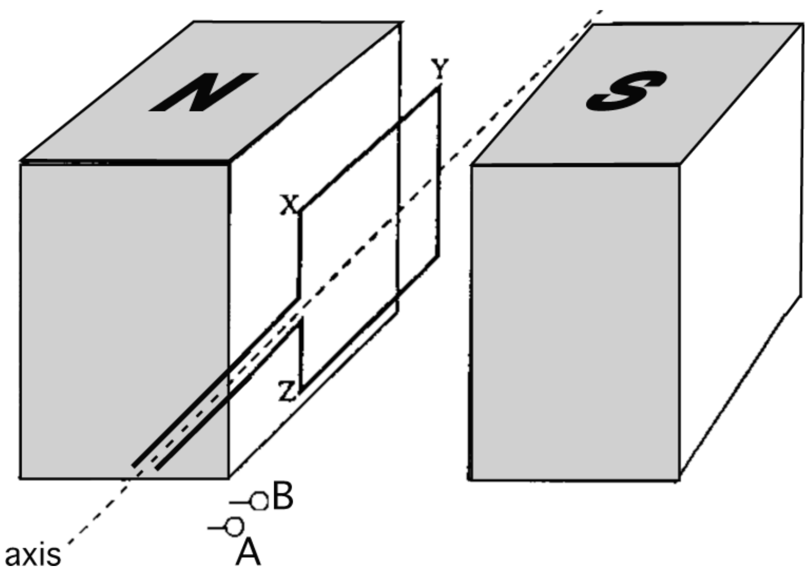
b 0.47 N Use $F = nBIl$.

c 0 N The field and the current are parallel.

d The function of the commutator is to reverse the direction of the current in the rotating coil every half rotation. This ensures that the torque on the rotating coil is always in the same direction, so that it keeps rotating in the same direction.

Question 3/ 19

The diagram below shows a coil free to rotate about a horizontal axis with little friction. The coil is completely immersed in a uniform magnetic field.



If the points A and B are connected to a source of DC current, and suitable connections are made between A and B and the coil (not shown), a DC motor can be constructed. Outline the *function* of these connections.

(3 marks)

Solution

The function of the commutator (which is what is required) is to reverse the direction of the current in the rotating coil every half rotation. This ensures that the torque on the rotating coil is always in the same direction, so that it keeps rotating in the same direction. In the stem to Q10 there is a clear diagram of a commutator.

Question 4/ 19

Explain what would happen to the torque, (τ), of a simple DC motor if the current, *I*, external magnetic field, *B*, and the number of loops of wire in the coil, *N*, were all in turn increased.

(3 marks)

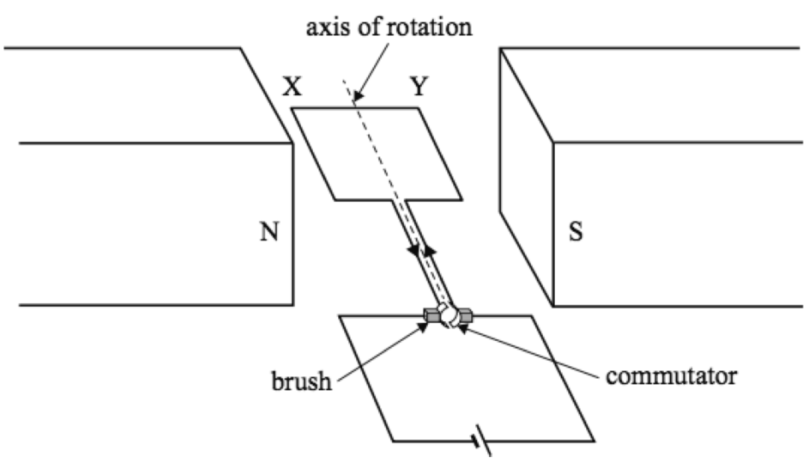
Solution

The torque, (τ), of a simple DC motor would increase if the current, *I*, increased; if the external magnetic field, *B*, increased; and if the number of loops of wire in the coil, *N*, increased.

Question 5/ 19

[Adapted VCAA 2016 SA Q14]

Students build a simple electric motor, as shown.



a. Describe the position(s) where the magnetic force on side XY is zero.

(2 marks)

b. The students discover that the motor starts moving more readily from some positions that from others. Describe the best orientation(s) for starting the motor to move from rest, and explain why.

(2 marks)

c. To increase the speed of the motor, the students suggest a number of improvements. The following improvements are suggested:

i increase the battery voltage

ii replace the single turn coil with a multiple turn coil

iii increase the resistance of the coil

iv reverse one of the poles of the permanent magnets.

Evaluate these suggestions.

(4 marks)

Solution

a When the coil is horizontal and XY is parallel to the magnetic field.

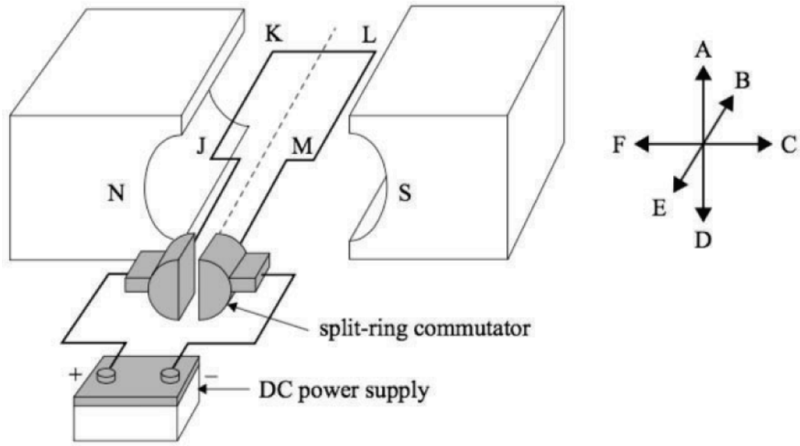
b The twisting effect of the magnetic forces (torque) on the coil will be greatest when the coil is horizontal.

c Suggestions **i** and **ii** will increase the size of the forces and hence their twisting effect. Suggestion **i** will increase the current and hence *F* (from $F = BIl$); suggestion **ii** will do the same (from $F = nBIl$); the other two suggestions will decrease the forces; **iii** will reduce the current, and **iv** will reduce *B*.

Question 6/ 19

[VCAA 2017 SB Q3]

A schematic diagram of a simple DC motor is shown below. It consists of two magnets, a single 9.0 V DC power supply, a split-ring commutator and a rectangular 10 loop coil of wire. The resistance of the coil of wire is 6.0 Ω. The length of the side JK is 12 cm and the length of the side KL is 6.0 cm. The strength of the uniform magnetic field is 0.50 T.



a. Determine the size and direction (A–F) of the force acting on side JK.

(3 marks)

b. What is the size of the force acting on the side KL in the orientation shown in the diagram above? Explain your answer.

(2 marks)

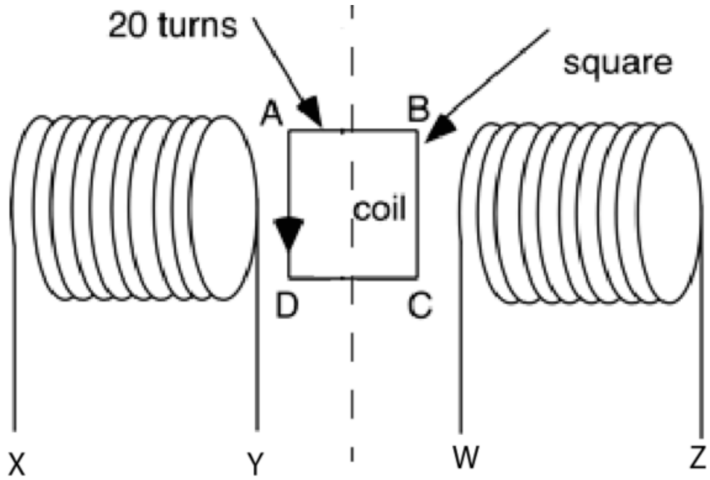
Solution

a 0.90 N; direction D Use $F = nBIl$; use RHS rule for direction.

b Zero force. This is because the current and the magnetic field are parallel in this orientation.

Question 7/ 19

A diagram of a simple DC motor is shown below. It has a 20-turn square coil free to rotate in a uniform magnetic field. Two electromagnets supply the field. The commutator and brushes are not shown. The arrow shows the current in the rotating coil.



a. At one time, side AD moves *out of the page*, and BC is moves *into the page*. What is the direction of the current in the two electromagnets?

(2 marks)

b. The uniform magnetic field between the electromagnet coils is 200 mT. The square coil has a 5.0 cm side. Calculate the maximum and minimum values of the size of the magnetic flux through the square coil during a full rotation of the coil. Include a unit in your answer.

(3 marks)

c. When the coil is in the position shown, the current flowing in the coil is 1.2 A. Calculate the size of the force on side AD, the size of the net force on the square coil, and the size of the force on the side AB.

(3 marks)

Solution

a Current in LH electromagnet goes from Y to X; in RH coil it is from Z to W.

b 0; 0.5 mWb Minimum value when coil parallel to field; maximum value when at right angles $(\Phi_{\text{MAX}} = BA)$.

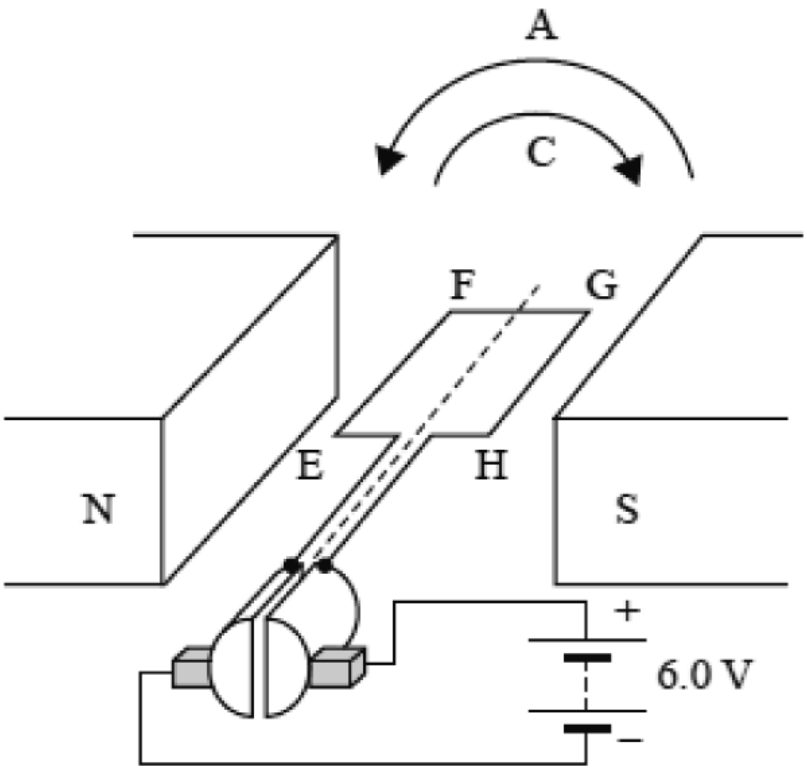
c • 0.24 N: use $F = nBIl$.

- 0 N: forces on sides AD and BC are equal and opposite.
- 0 N: no force when current is parallel to the B field.

Question 8/ 19

[VCAA 2018 SB Q3]

Students build a model of a simple DC motor, as shown below.



a. The motor is set with the coil horizontal, as shown, and the power source is applied. Will the motor rotate in a clockwise (C) or anticlockwise (A) direction? Explain your answer.

(3 marks)

b. One student suggests that slip rings would be easier to make than a commutator and that they should use slip rings instead. Explain the effect that replacing the commutator with slip rings would have on the operation of the motor, if no other change was made.

(2 marks)

Solution

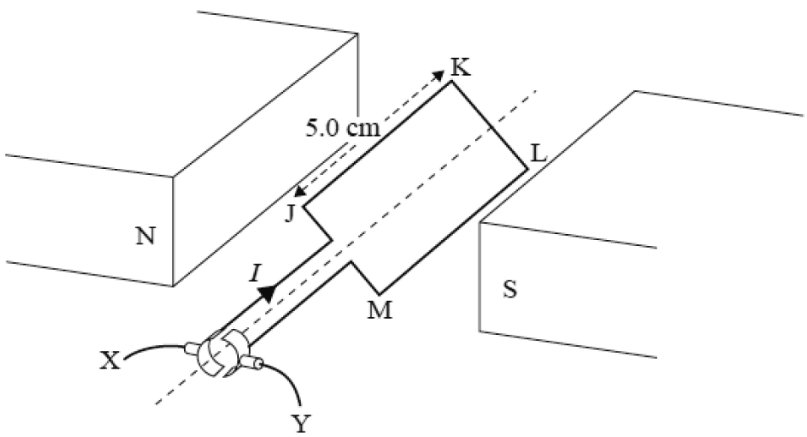
a C – clockwise. Current flows in direction HGFE. RH slap rule predicts downward force on HG and upwards force on FE, resulting in clockwise rotation.

b Coil will rotate through 90° from position shown in that diagram and stop there as slip rings do not reverse direction of the torque on the armature coil.

Question 9/ 19

[VCAA 2019 SB Q3]

The diagram below shows a schematic of a DC motor. The motor has a coil, JKLM, consisting of 100 turns. The permanent magnets provide a uniform magnetic field of 0.45 T. The commutator connectors, X and Y, provide a constant DC current, *I*, to the coil. The length of the side JK is 5.0 cm. The current *I* flows in the direction shown in the diagram.



a. Which terminal of the commutator is connected to the positive terminal of the current supply?

(1 mark)

b. Draw an arrow on the diagram to indicate the direction of the magnetic force acting on the side JK.

(1 mark)

c. Explain the role of the commutator in the operation of the DC motor.

(2 marks)

d. A current of 6.0 A flows through the 100 turns of the coil JKLM. The side JK is 5.0 cm in length. Calculate the size of the magnetic force on the side JK in the orientation shown in the diagram. Show your working.

(2 marks)

Solution

a Terminal X. This follows from the direction of the current shown in the diagram.

b An arrow pointing vertically downwards. You should attach the arrow to the side JK. This follows from the RHS (or Fleming's rule).

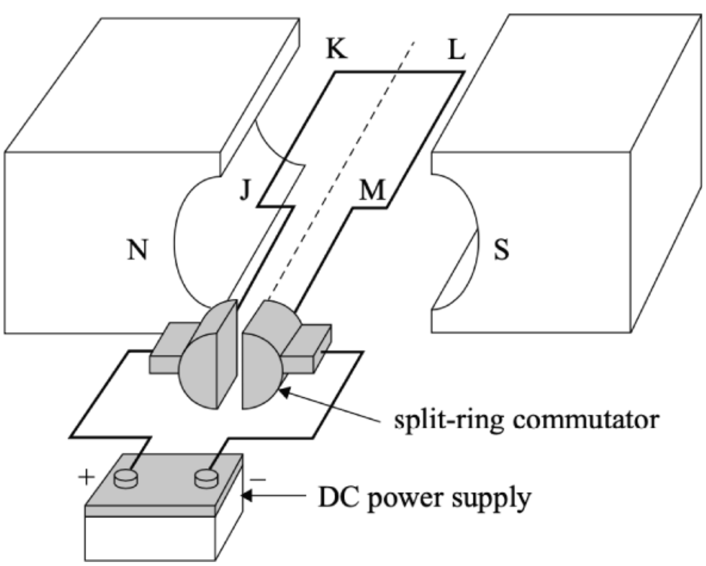
c The function of the commutator is to reverse the direction of the current in the rotating coil every half rotation. This ensures that the torque (twisting effect of the magnetic force) on the rotating coil is always in the same direction, so that it keeps rotating in the same direction.

d 13.5 N Use $F = nBIl = 100 \times 0.45 \times 6.0 \times 0.05 = 13.5 \text{ N}$

Question 10/ 19

[VCAA 2021 SB Q4]

The diagram below shows a schematic diagram of a simple one-coil DC motor. A current is flowing through the coil.



a. Draw an arrow on the diagram to indicate the direction of the force acting on the side JK of the coil.

(1 mark)

b. Explain the purpose of the split-ring commutator.

(2 marks)

Solution

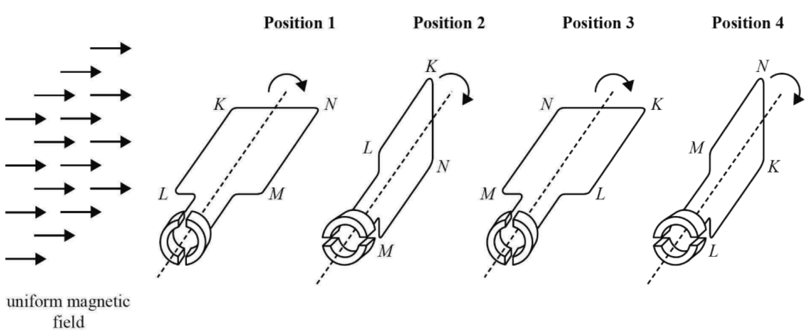
a Vertically downwards. Use the RHS rule or Fleming's rule.

b The purpose of the commutator is to reverse the direction of the current in the rotating coil every half rotation. This ensures that the torque (twisting effect of the magnetic force) on the rotating coil is always in the same direction, so that it keeps rotating in the same direction.

Question 11/ 19

[VCAA 2022 SB Q1]

The diagram below shows four positions (1, 2, 3 and 4) of the coil of a single-turn, simple DC motor. The coil is turning in a uniform magnetic field that is parallel to the plane of the coil when the coil is in Position 1, as shown. When the motor is operating, the coil rotates about the axis through the middle of sides LM and NK in the direction indicated. The coil is attached to a commutator. Current for the motor is passed to the commutator by brushes that are not shown in the diagram.



a. When the coil is in Position 1, in which direction is the current flowing in the side KL – from K to L or from L to K? Justify your answer.

(2 marks)

b. When the coil is in Position 3, in which direction is the current flowing in the side KL – from K to L or from L to K?

(1 mark)

c. The side KL of the coil has a length of 0.10 m and experiences a magnetic force of 0.15 N due to the magnetic field, which has a magnitude of 0.5 T. Calculate the magnitude of the current in the coil.

(2 marks)

Solution

a The motor is rotating clockwise. Apply the right-hand slap (or Fleming's) rule to deduce that the current is flowing from K to L.

b The current direction will have reversed from that in position 1 so as to maintain the direction of rotation; hence L to K.

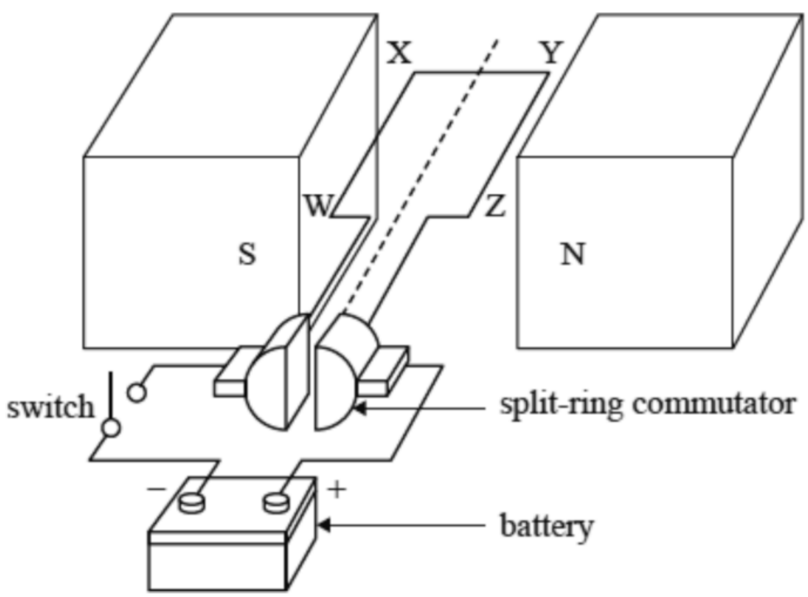
c 3.0 A Use $F = nBIl$ with I as the subject.

Question 12/ 19

[VCAA NHT 2023 SB Q7]

A schematic diagram of a simple DC motor, powered by a battery is shown below.

The motor has a rectangular coil, WXYZ, consisting of 45 turns. The side WX has a length of 6.0 cm and the side XY has a length of 4.0 cm. The coil is connected to a split-ring commutator. Two permanent magnets provide a uniform magnetic field of 80 mT. Both the coil and the commutator are free to turn. The switch is now closed.



a. Will the motor spin clockwise, spin anticlockwise or remain stationary when viewed from the battery side?

(1 mark)

b. Calculate the magnitude of the force on the side YZ if a current of 3.2 A flows through the coil.

(2 marks)

Solution

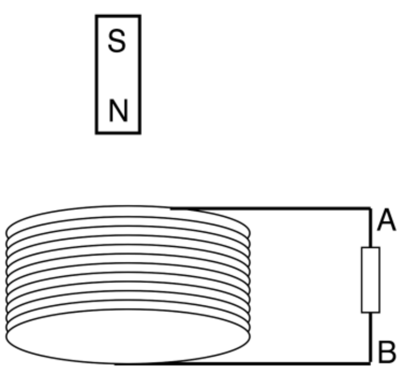
a Anticlockwise.

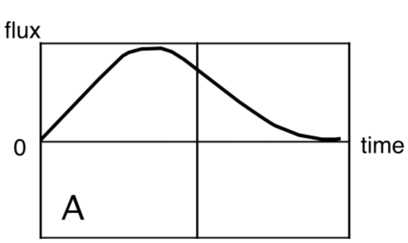
b 0.69 N $F = nIlB = 45 \times 3.2\left(6.0 \times 10^{-2}\right)\left(80 \times 10^{-3}\right) = 0.69$ N.

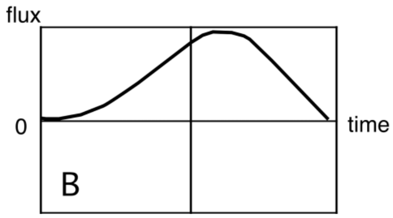
Chapter 12 Generation principles

Question 1/ 22

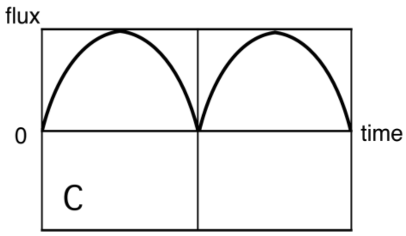
A magnet drops through a coil of area $0.2\ \mathrm{m}^2$. Which of the graphs below best describes how the flux through the coil changes with time?



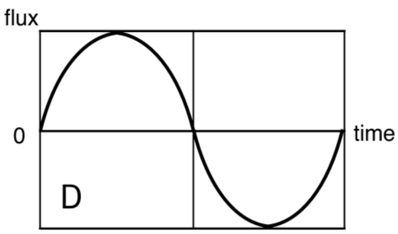
A 



B



C



D

Solution

B Flux increases to a maximum but decreases more rapidly as the magnet accelerates.

Question 2/ 22

Which of the following best describes how the emf changes with time?

A It rises from zero to a maximum and then drops back to zero.

B It rises from zero to a maximum and then drops back to zero. It does this twice.

C It rises from zero to a negative maximum, drops back to zero, increases to a maximum in the opposite direction, and then drops back to zero.

D It rises from zero to a maximum and stabilises on that value.

Solution

C   Negative as the gradient of flux–time graph is positive and then positive as gradient is negative (Lenz's law).

Question 4/ 22

If spun by hand, it produces an output voltage. The best reason for this is that

A the flux through the coil changes.

B the attraction of the two permanent magnets forces electrons to move.

C this action will cause an equal and opposite reaction.

D friction generates heat which accelerates the electrons.

Solution

A   From Faraday's law.

Question 5/ 22

The connection between the coil and the output is a split-ring commutator. This means that the output voltage is best described as a

A sinusoidal voltage.

B steady DC voltage.

C varying AC voltage.

D DC voltage whose size varies with time.

Solution

D There is an AC emf in the coil; the commutator rectifies it.

Question 6/ 22

If the commutator were replaced with slip-rings, which of the following would now best describe the output voltage?

A A sinusoidal AC voltage

B A steady DC voltage

C A varying AC voltage

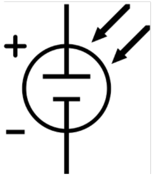
D A DC voltage whose size varies with time

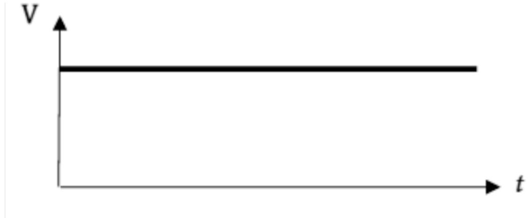
Solution

A The flux changes sinusoidally producing an AC voltage.

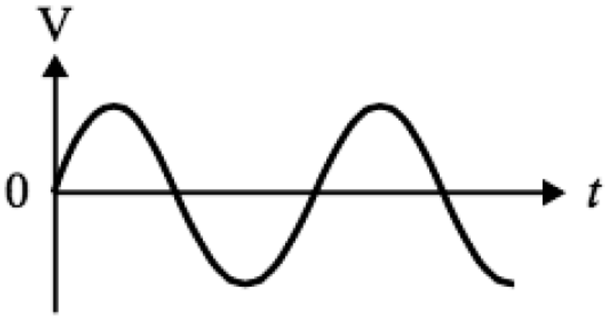
Question 7/ 22

The DC output of a photovoltaic cell (left) is shown below (right).

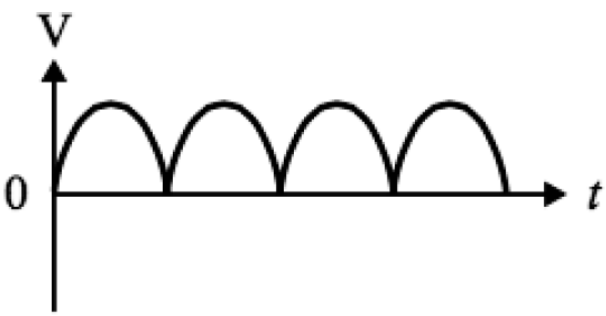




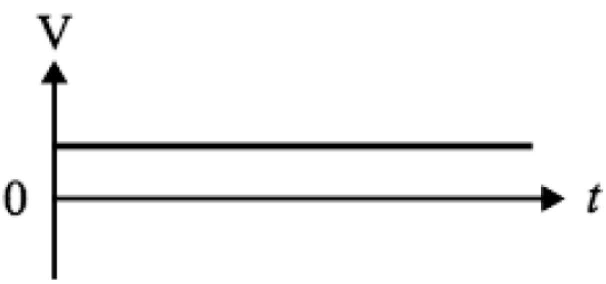
The output of the photovoltaic cell is now connected to an *inverter* in a household rooftop system. Which one of the following graphs best represents the output of the inverter?



A



B



C

D

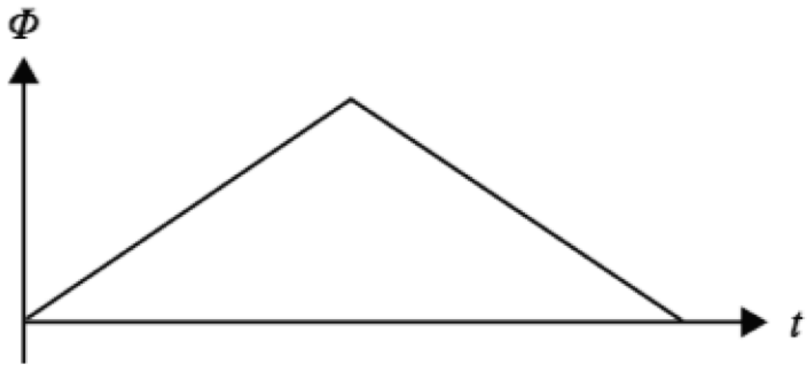
Solution

A There function of an *inverter* is to produce AC electricity.

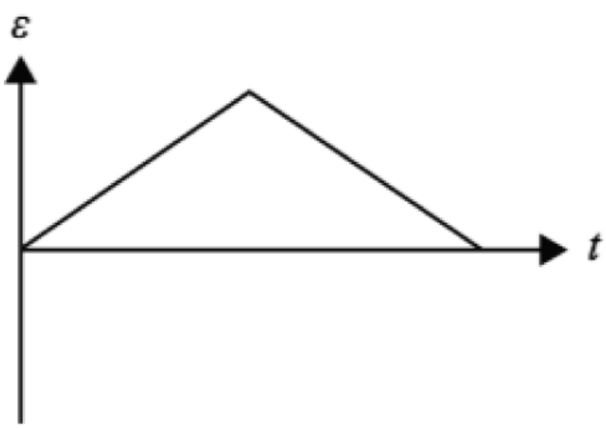
Question 8/ 22

[VCAA 2017 SA Q6]

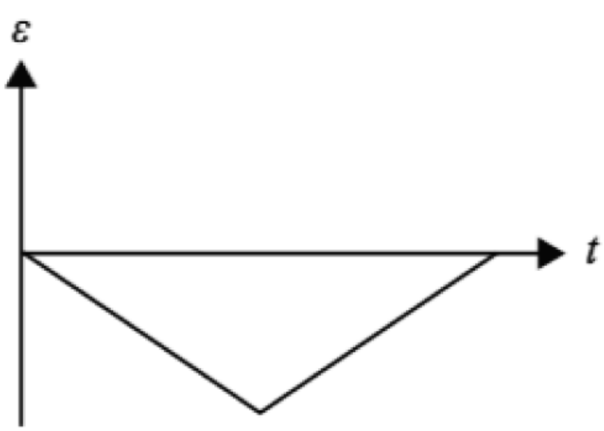
The graph below shows the change in magnetic flux (Φ) through a coil of wire as a function of time (*t*).



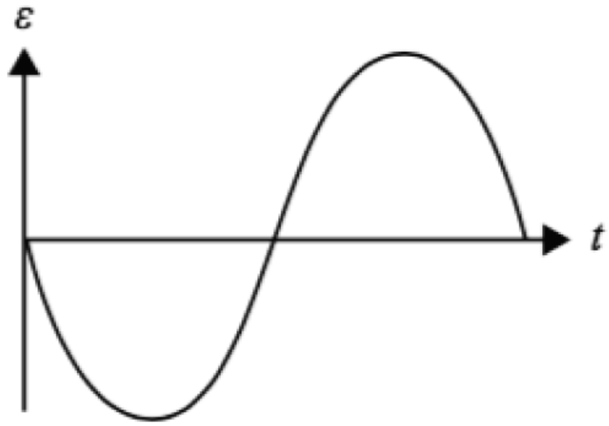
Which one of the following graphs best represents the induced EMF (*ε*) across the coil of wire as a function of time (*t*)?



A



B



C

D Missing Image

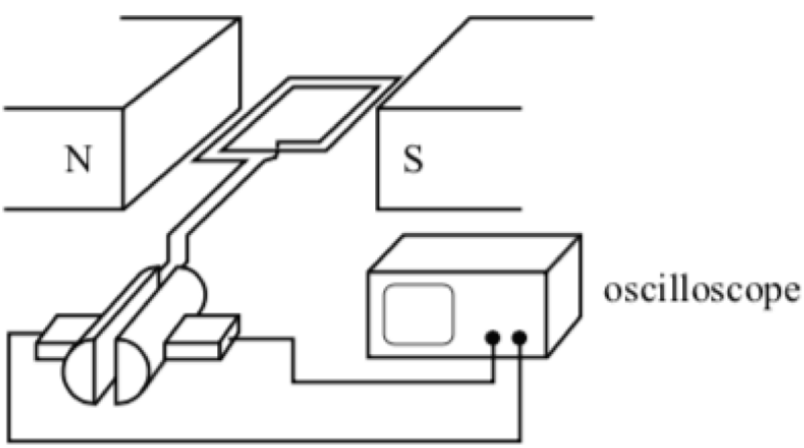
Solution

D The EMF is equal to the (negative) gradient of the magnetic flux.

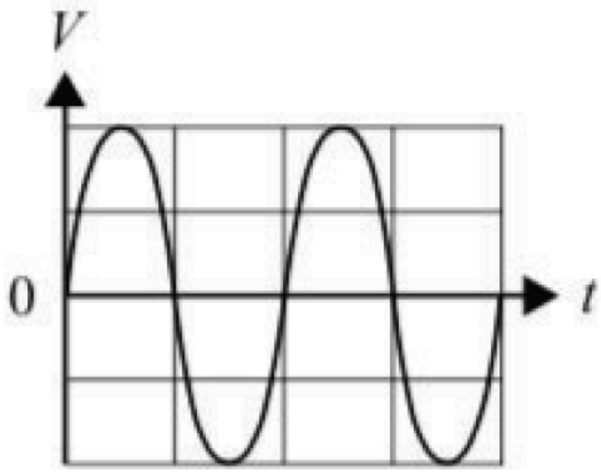
Question 9/ 22

[VCAA 2018 NHT SA Q4]

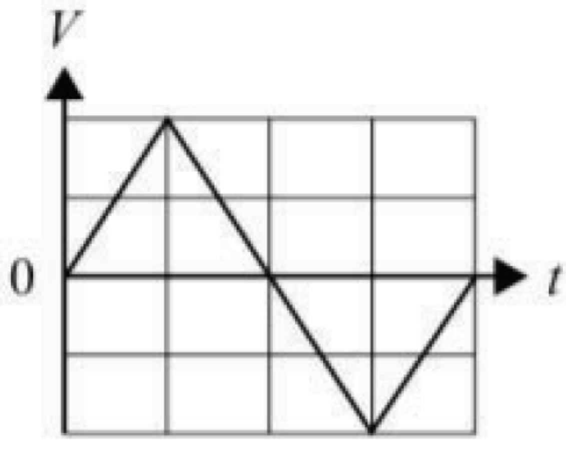
A simple DC generator consists of two magnets that produce a uniform magnetic field, in which a square loop of wire of 100 turns rotates at constant speed, and a commutator, as shown in the diagram below.



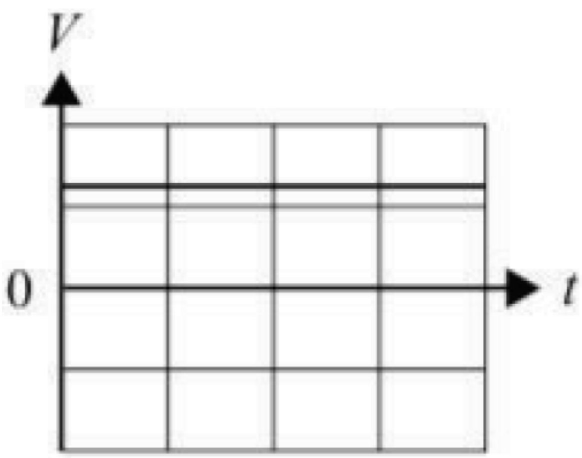
Which one of the following graphs on the next page best shows the display observed on the oscilloscope?



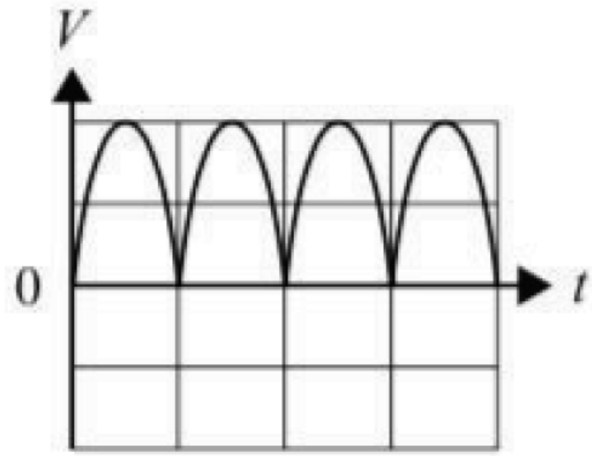
A



B



C

D 

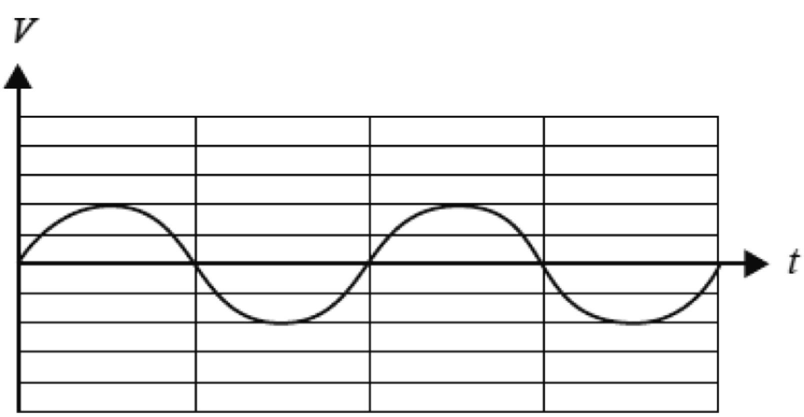
Solution

D The split-ring commutator rectifies the induced AC produced in the rotating coil.

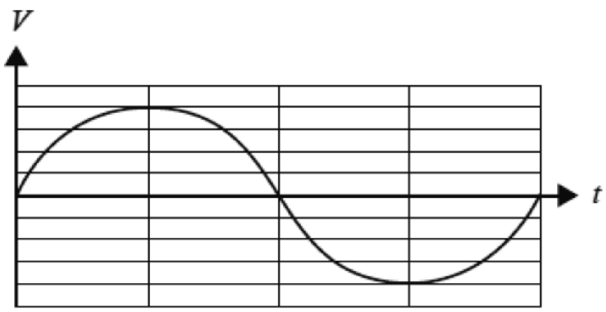
Question 10/ 22

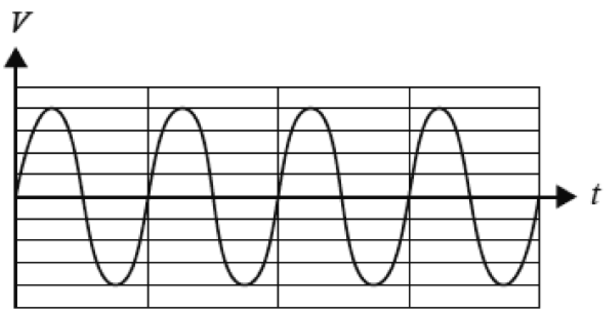
[VCAA 2019 NHT SA Q7]

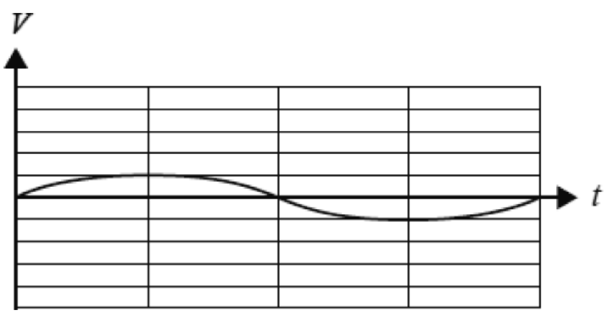
An alternator is rotating at 10 revolutions per second. Its output is measured by an oscilloscope. The signal produced is shown below.

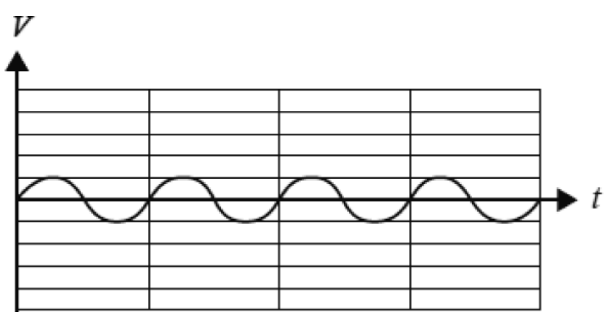


The alternator is then slowed so that it rotates at five revolutions per second. Which one of the following graphs best shows the display observed on the oscilloscope?

A 

B 

C 

D 

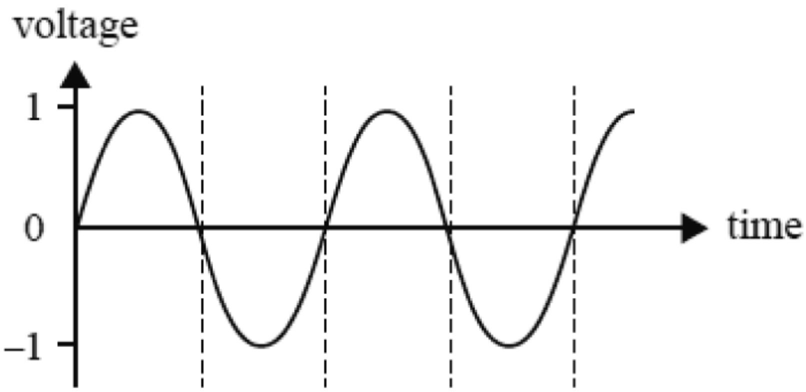
Solution

C The period will double, and the amplitude will halve.

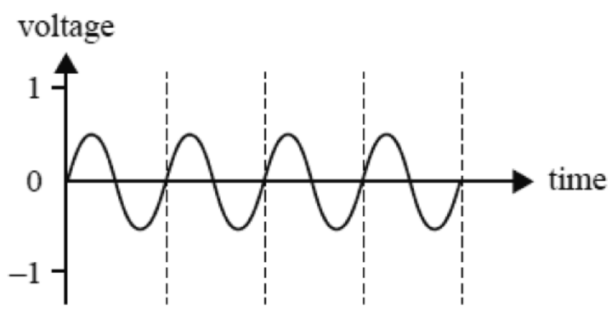
Question 11/ 22

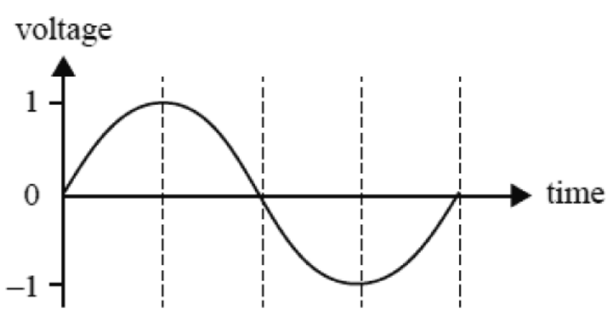
[VCAA 2019 SA Q7]

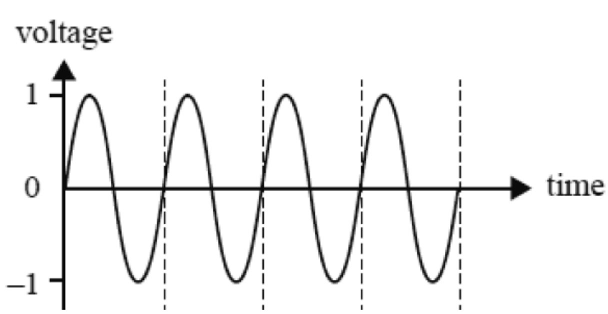
The coil of an AC generator completes 50 revolutions per second. A graph of output voltage versus time for this generator is shown below.

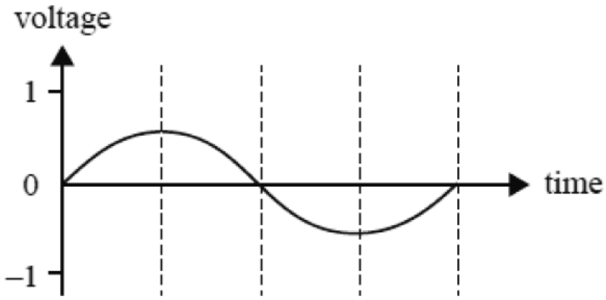


Which one of the following graphs best represents the output voltage if the rate of rotation is changed to 25 revolutions per second?

A


B


C


D 

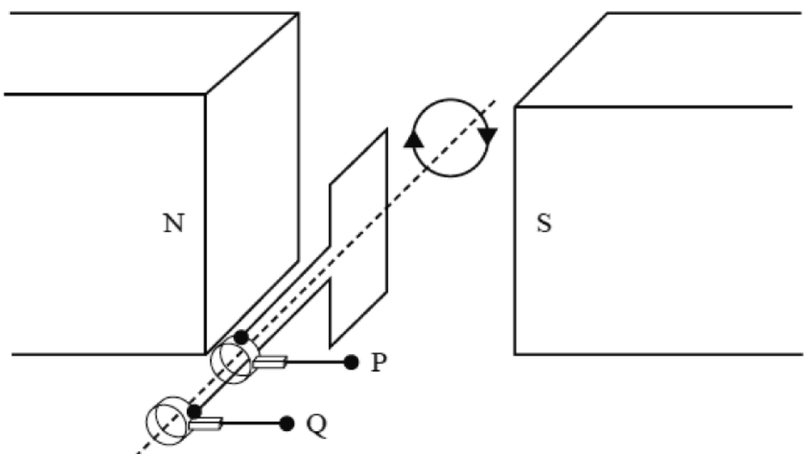
Solution

D The period will double, and the amplitude will halve.

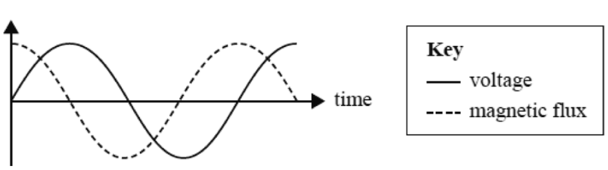
Question 12/ 22

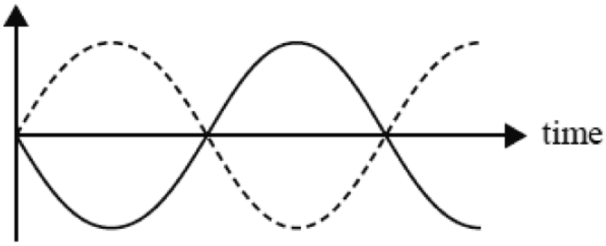
[VCAA 2019 SA Q8]

An electrical generator is shown in the diagram below. The generator is turning clockwise.

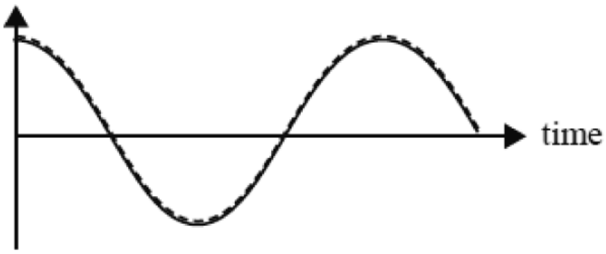


The voltage between P and Q and the magnetic flux through the loop are both graphed as a function of time, with voltage versus time shown as a solid line and magnetic flux versus time shown as a dashed line. Which one of the following graphs on the next page best shows the relationships for this electrical generator?

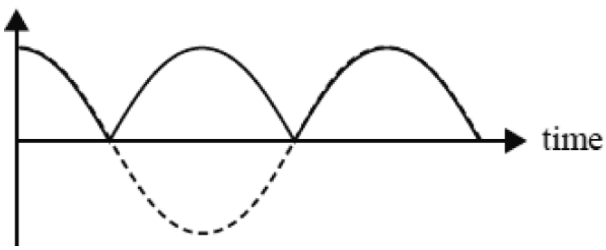
A 



B



C



D

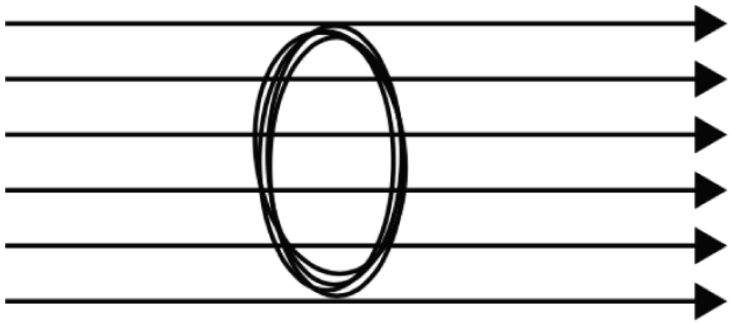
Solution

A When the flux is at a maximum, the emf is at zero (from the gradient of the flux–time graph).

Question 13/ 22

[VCAA 2020 SA Q5]

A coil consisting of 20 loops with an area of $10\ \text{cm}^2$ is placed in a uniform magnetic field *B* of strength 0.03 T so that the plane of the coil is perpendicular to the field direction, as shown in the diagram below.



What is the value of the flux through the coil?

A 0 Wb

B 3.0×10^{-5} Wb

C 6.0×10^{-4} Wb

D 3.0×10^{-1} Wb

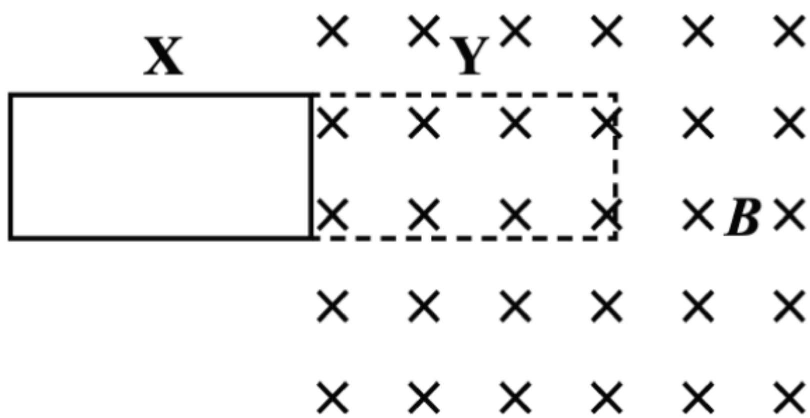
Solution

B Use $\text{flux} = B \times A$. Note that the number of turns is irrelevant.

Question 14/ 22

[VCAA 2020 SA Q6]

A single loop of wire moves into a uniform magnetic field B of strength 3.5×10^{-4} T over time $t = 0.20$ s from point X to point Y, as shown in the diagram below. The area A of the loop is $0.05\ \text{m}^2$.



The magnitude of the average induced EMF in the loop is closest to

A 0 V

B 3.5×10^{-6} V

C 8.8×10^{-5} V

D 8.8×10^{3} V

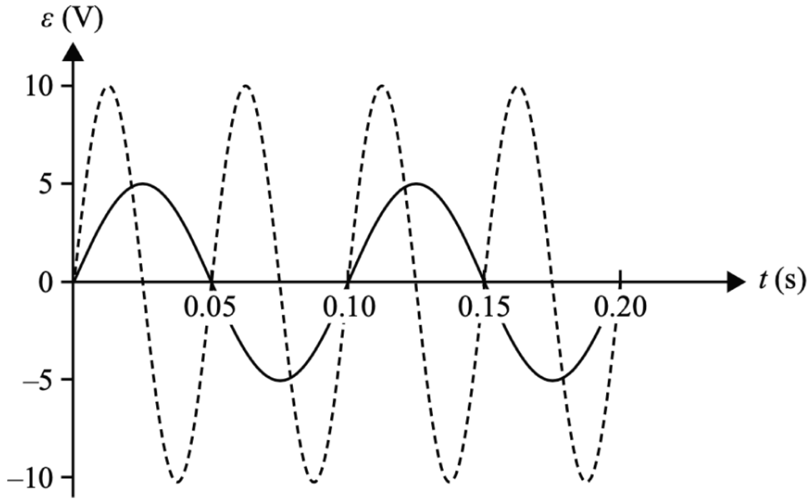
Solution

C Use $\text{emf} = B \times (\Delta A / \Delta t)$

Question 15/ 22

[VCAA 2021 NHT SA Q8]

In the diagram below, the solid line represents the graph of output EMF, ε, versus time produced by an AC generator. A single change is made to the AC generator and its operation, and the new graph of output EMF, ε, versus time is shown as a dashed line.



Which one of the following best describes the change made to the AC generator?

A The area of the coil was doubled.

B The speed of rotation was halved.

C The speed of rotation was doubled.

D The number of turns of the wire in the coil was doubled.

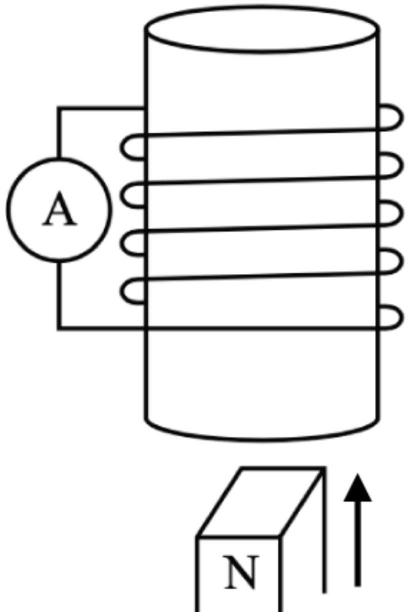
Solution

C The frequency must have doubled as the new period is halved; this will also cause the amplitude to double.

Question 16/ 22

[VCAA 2021 SA Q9]

The diagram below shows a bar magnet moving upward into a coil. Which of the following correctly identifies the direction of the induced current, as viewed from the top of the coil, and the direction of the magnetic field produced by the induced current inside the coil?



Current direction	Magnetic field direction
clockwise	↓
clockwise	↑
anticlockwise	↑
anticlockwise	↓

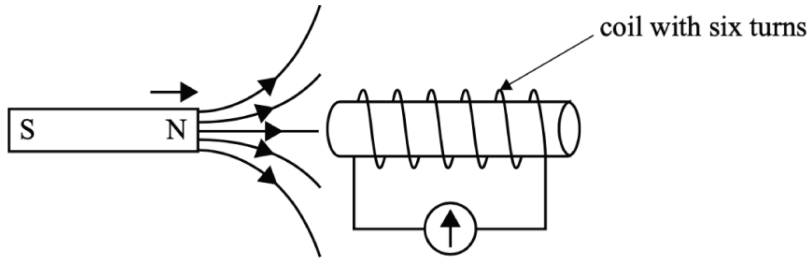
Solution

A The upwards flux will increase; the response will be the generation of a downwards flux due to the induced emf; use the RH Grip rule (or similar) to find induced current direction.

Question 17/ 22

[VCAA 2021 SA Q6]

A magnet approaches a coil with six turns, as shown in the diagram below. During time interval Δt, the magnetic flux changes by 0.05 Wb and the average induced EMF is 1.2 V.



Which one of the following is closest to the time interval Δt?

A 0.04 s

B 0.01 s

C 0.25 s

D 0.50 s

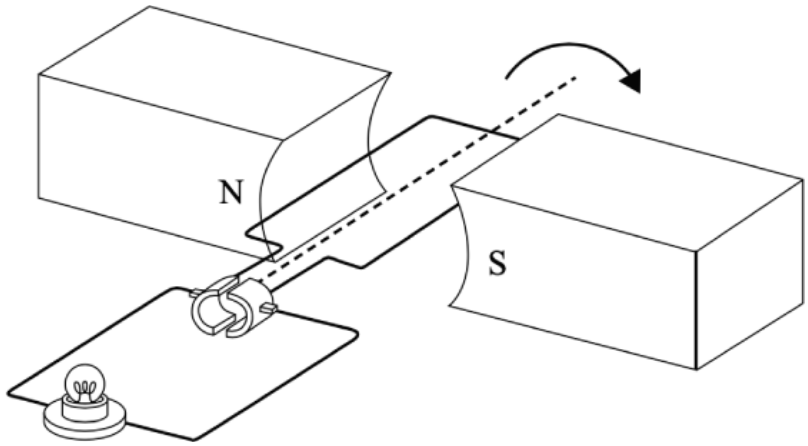
Solution

C Use $\text{emf} = -\frac{n\Delta\phi}{\Delta t}$ with $n = 6, \text{emf} = 1.2, \text{flux change} = 0.05$.

Question 18/ 22

[VCAA 2021 SA Q8]

The diagram below shows a simple electrical generator consisting of a rotating wire loop in a magnetic field, connected to an external circuit with a light globe, a split-ring commutator and brushes. The direction of rotation is shown by the arrow.



Which one of the following best describes the function of the split-ring commutator in the external circuit?

A It delivers a DC current to the light globe.

B It delivers an AC current to the light globe.

C It ensures the force on the side of the loop nearest the north pole is always up.

D It ensures the force on the side of the loop nearest the north pole is always down.

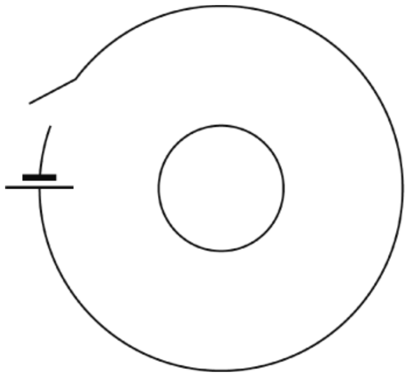
Solution

A The AC generated in the rotating coil reverses direction every half cycle; the split ring commutator reverses this.

Question 19/ 22

[VCAA 2022 NHT SA Q6]

Two concentric loops of conducting wire are placed on a flat horizontal surface. The outer loop contains an open switch and a battery cell. The inner loop consists of a single closed loop of wire. The diagram below shows the arrangement of the two loops, as viewed from above. Which one of the following best describes the induced current in the inner loop when the switch is closed in the outer loop, as viewed from above?



A a steady clockwise current

B a steady anticlockwise current

C a momentary clockwise current

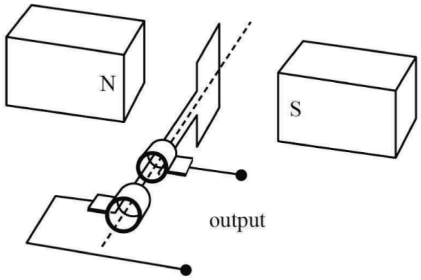
D a momentary anticlockwise current

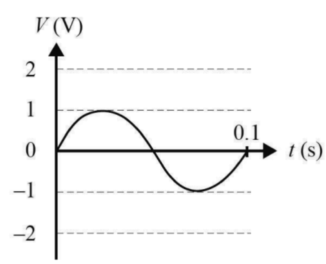
Solution

C As the current in the outer loop builds up from zero there will be an increasing magnetic flux out of the page in the inner loop. This will induce a clockwise current in the inner loop causing an opposing flux into the page.

Question 20/ 22

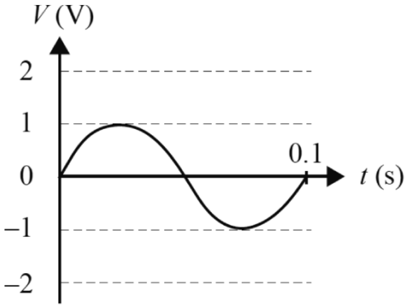
A simple electricity generator is shown in the diagram below. When the coil is rotated, the output voltage across the slip rings is measured. The graph shows how the output voltage varies with time.



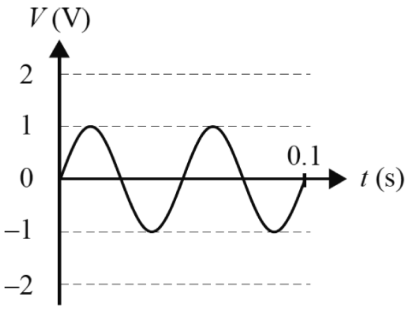


The frequency of rotation of the generator is now doubled. Which one of the following graphs best represents the output voltage measured across the slip rings?

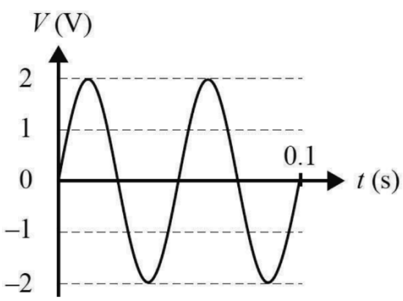
A



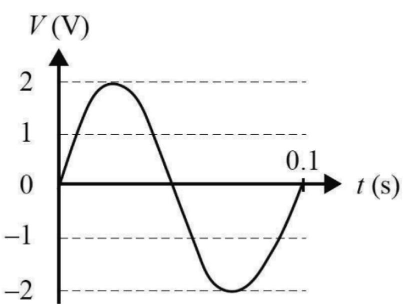
B



C



D



Solution

C Doubling the rotation rate will double the peak voltage and halve the rotation period.

Question 21/ 22

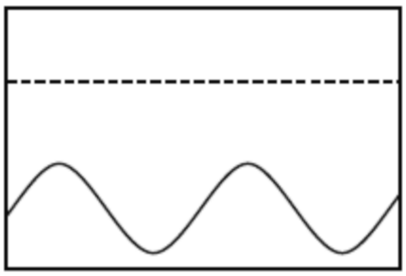
[VCAA 2023 NHT SA Q7]

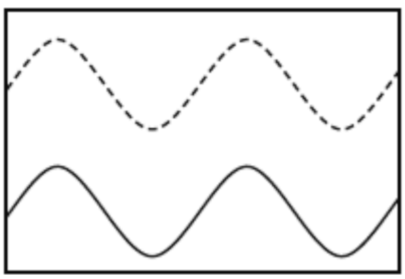
Electrical generators may use slip rings or split-ring commutators when generating electricity. When operating at equal frequencies, the output voltages of these two types of generators can be displayed together on an oscilloscope screen.

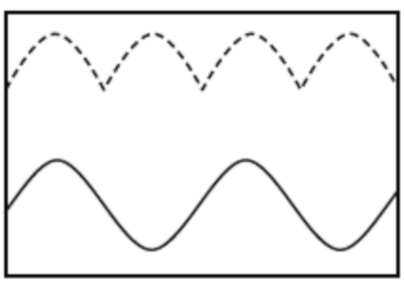
The output of the split-ring commutator is displayed as a dotted line.

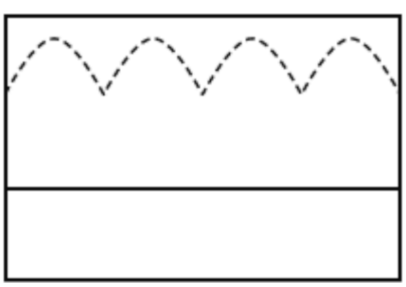
The output of the slip rings is displayed as a solid line.

Which one of the following diagrams best represents the two outputs?


A


B


C


D

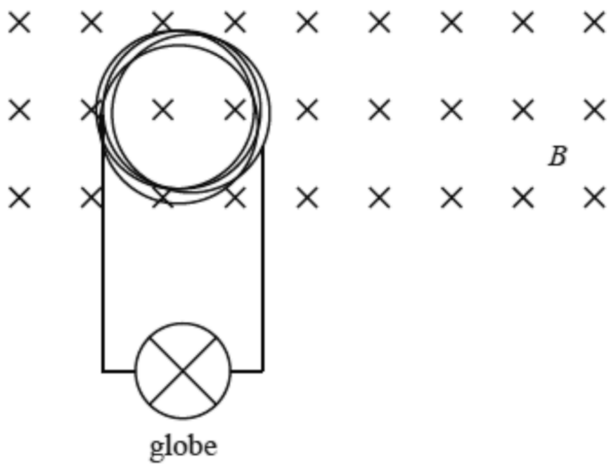
Solution

C   Split ring produces rectified DC and slip rings AC.

Question 22/ 22

[VCAA 2023 SA Q5]

The diagram below shows a stationary circular coil of conducting wire connected to a low-resistance globe in a uniform, constant magnetic field, *B*.



The magnetic field is switched off.

Which one of the following best describes the globe in the circuit before the magnetic field is switched off, during the time the magnetic field is being switched off and after the magnetic field is switched off?

Before	**During**	**After**
Off	On	Off
On	On	Off
On	Off	Off
Off	On	On

Solution

A The current will flow when there is an induced EMF due to the changing flux through the circular coil. This only occurs during the process of turning the switch on or off.

Question 23/ 22

[VCAA 2023 SA Q6]

The radius of the coil is 5 cm and the magnetic field strength is 0.2 T. The coil has 100 loops. Assume that the magnetic field is perpendicular to the area of the coil.

Which one of the following is closest to the magnitude of the magnetic flux through the coil of wire when the magnetic field is switched on?

A 0.0016 Wb

B 0.16 Wb

C 16 Wb

D 1600 Wb

Solution

A When the flux through the coil is constant, the globe will not be on.

Use $\phi = BA$

Question 1/ 50

A coil is stationary in a steady 0.15 T magnetic field (at right angles to its area). The strength of the field changes to 0.10 T in a time of 0.15 s. The area of the coil is 0.20 m^2 and it has 100 turns. Calculate the average emf induced during this time. Show your working.

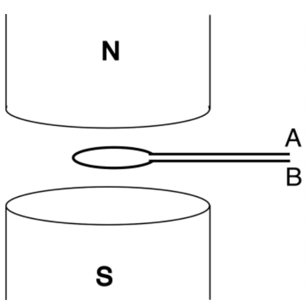
(3 marks)

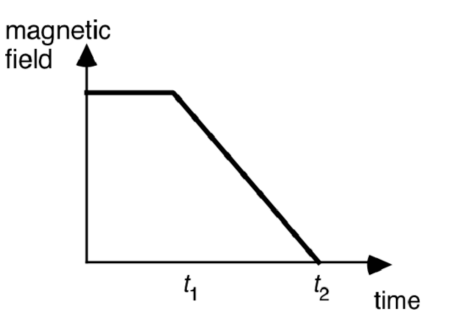
Solution

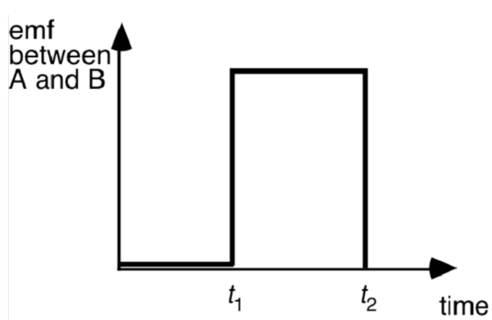
6.7 V Use $emf = -n\Delta\phi/\Delta t$ with $n = 100$, $\Delta t = 0.15$ flux change $= 0.01$.

Question 2/ 50

A single coil of area 0.15 m^2 of wire lies flat between the poles of an electromagnet, as shown. The field of the magnet changes as shown in the left-hand graph below. The emf between A and B is also shown as a function of time.







a. Explain why the induced voltage varies with time as shown.

(3 marks)

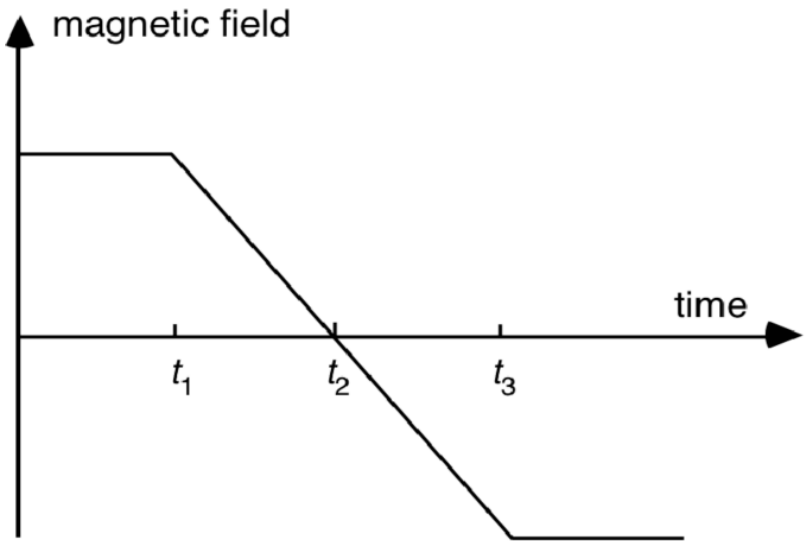
b. In a second experiment, the magnetic field is exactly *halved*, and the time interval between t_1 and t_2 is exactly *doubled*. Sketch the graph of the emf between A and B as a function of time.

(3 marks)

c. If the time interval between t_1 and t_2 is 25 ms and the initial value of the magnetic field is 200 mT, calculate the maximum value of the emf between A and B.

(2 marks)

In a third experiment, the field in the electromagnet is reduced to zero, reversed and increased again, as shown in the graph below.



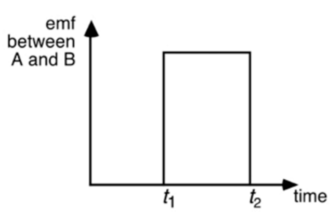
d. Sketch the shape of the emf induced between A and B in this case and explain your answer.

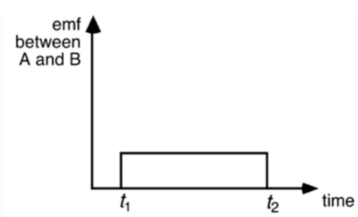
(4 marks)

Solution

a The emf is proportional to the negative of the gradient of the graph of the flux against time (from Faraday's law: $\text{emf} = -\frac{n\Delta\phi}{\Delta t}$). Between t_1 and t_2 the gradient is negative and constant (hence, the emf); at other times the gradient is zero and so is the emf.

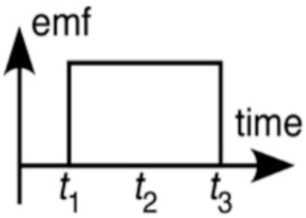
b The graph was at first: The new graph will look like:





The change occurs simply because the gradient of the flux graph will be one-quarter of what it was before.

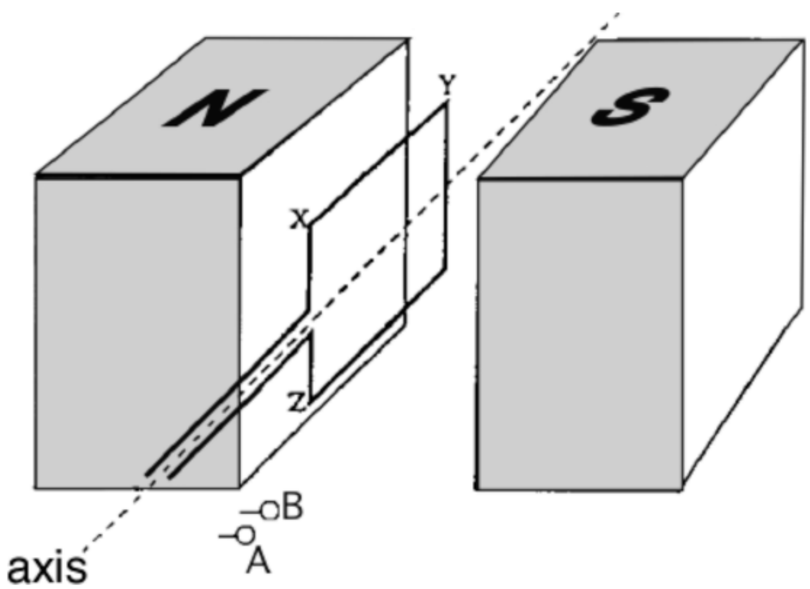
c 1.2 V Use Faraday's law: $\text{emf} = -\frac{n\Delta\phi}{\Delta t}$.



d The emf induced between t_1 and t_3 is constant because of the constant slope of B. Whether B is positive or negative does not matter.

Question 3/ 50

The diagram below shows a coil free to rotate about an axis with little friction. The coil is completely immersed in a uniform magnetic field.



a. If the coil is made to spin by an external force, the arrangement can produce an AC voltage between A and B. Such an arrangement is described as an *alternator*. Outline the nature of the connections between A and B and the coil for this to occur.

(3 marks)

b. Alternatively, with another kind of connection, a *DC* voltage can be produced between A and B. Outline the nature of the connections between the coil and A and B for this to occur.

(3 marks)

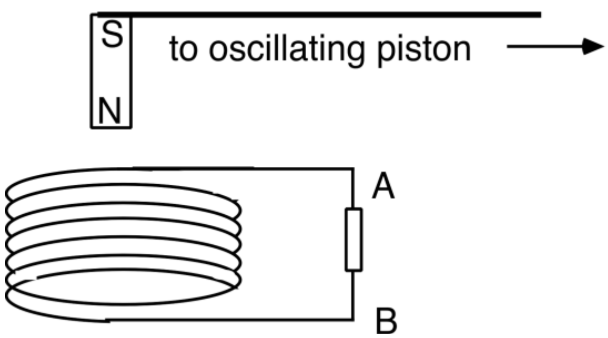
Solution

a *Slip rings* are required; these connect each end of the coil continuously to the same point in the external circuit.

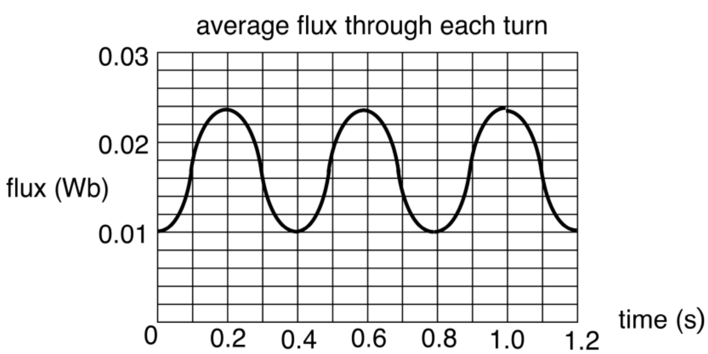
b A *commutator* (exactly like the arrangement for a DC motor) is required. This reverses direction of the current from the coil every half turn.

Question 4/ 50

A magnet on the end of a lever oscillates up and down through a coil, as shown. The coil has an area of 0.20 m^2 and 50 turns.



The graph on the next page shows how the magnetic flux through the coil changes with time as the magnet moves into and out of the coil.



a. Sketch the emf across the coil against time, from $t = 0$ to $t = 0.4$ s.

(3 marks)

b. Calculate the *average* emf between $t = 0.4$ s and $t = 0.6$ s.

(2 marks)

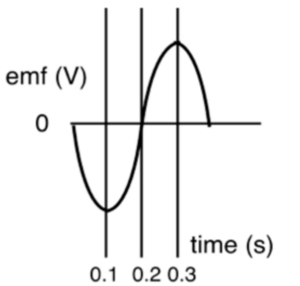
c. If the generator is attached to a load of resistance 4.5 Ω, find the average current. The resistance of the coil is very low.

(2 marks)

Solution

a Something close to the diagram on the right.

The graph is the negative slope of the flux graph. The emf will be large at $t = 0$ and cross the axis at 0.2 s when the flux peaks (points of zero gradient).



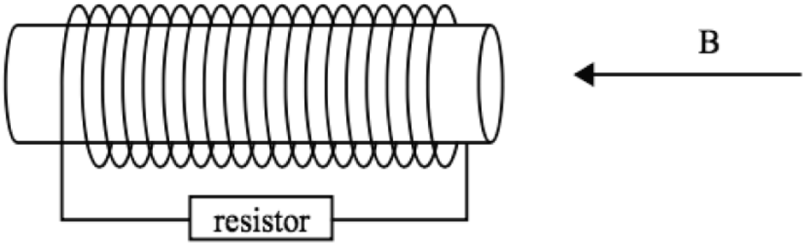
b 3.5 V Use $\varepsilon = -\frac{n\Delta\phi}{\Delta t} = 50 \times \frac{0.014}{0.2}$.

c 0.78 A Use $I = \frac{\varepsilon}{R}$.

Question 5/ 50

[VCAA 2016 SA Q15]

A coil is wound around a cardboard cylinder, as shown in the diagram.



The cross-sectional area of the coil is $0.0060\ \mathrm{m}^2$. There are 1000 turns in the coil. The coil is immersed in a uniform external magnetic field of strength 0.0050 T. Its direction is shown by the arrow labelled B in the diagram.

a. Calculate the magnitude of the flux through the first turn of the coil. Include an appropriate unit.

(2 marks)

b. The external magnetic field is now reduced to zero. This results in an emf in the coil. Describe the direction of the current in the resistor during this time (use the words 'left' and 'right'). Give reasons for your answer.

(3 marks)

Solution

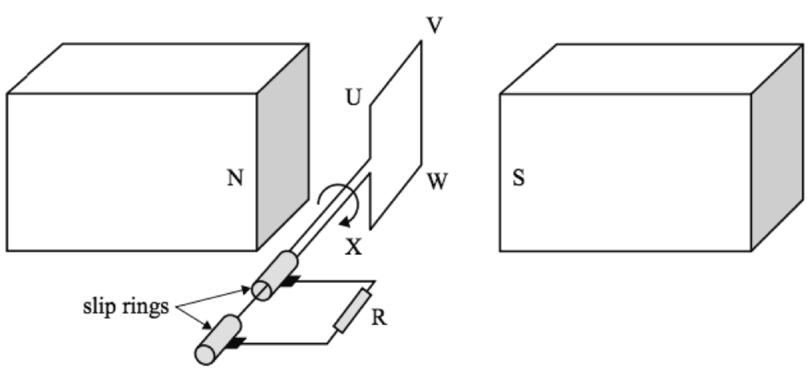
a $3.0 \times 10^{-5}\mathrm{Wb}$ Use $\phi = BA$. Can also use $\mathrm{T\ m^2}$ as an appropriate unit.

b Induced current in resistor to the **left**. As the field decreases, so does the flux. The current will oppose this change and generate field in the same direction as the arrow B. Use right-hand grip rule to predict current (or make RH end of coil a south pole).

Question 6/ 50

[VCAA 2016 S Q17]

Samira and Mark construct a simple slip-ring alternator, as shown.



When the coil is rotating steadily, it takes 40 ms for each complete rotation and produces a peak emf of 3.5 V.

a. Calculate the frequency of the AC emf.

(2 marks)

b. Calculate the RMS value of the AC emf.

(1 mark)

c. Describe the orientation of the rotating coil when the magnitude of the emf is a maximum. Give reasons for your answer.

(2 marks)

d. To increase the magnitude of the emf produced by the alternator, a student suggests making a number of changes to the alternator. He suggests these changes:

• increase the number of turns in the rotating coil

• increase the frequency of the rotating coil

• increase the strength of the permanent magnets

• reduce the resistance of the resistor R.

Evaluate these responses.

(4 marks)

Solution

a 25 Hz Use $f = \frac{1}{T}$.

b 2.47 V Divide peak voltage (emf) by $\sqrt{2}$.

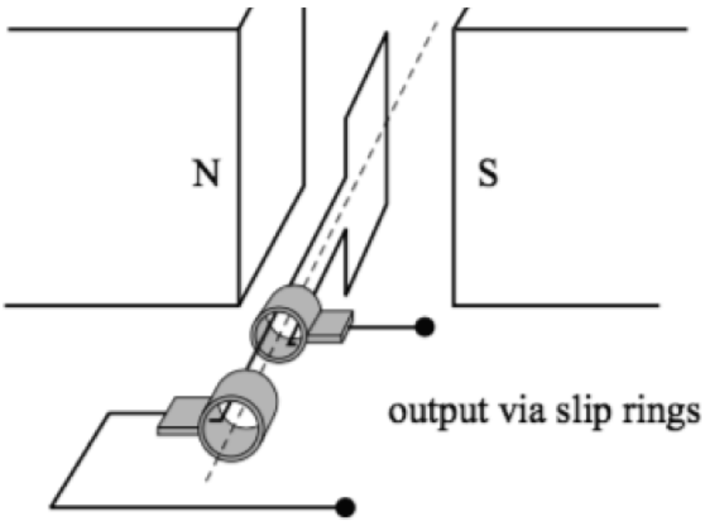
c Maximum emf will occur when the flux through the coil is changing most rapidly; this is when the coil is **horizontal**.

d All except the last. The key equation is $\varepsilon = -n\left(\frac{\Delta\phi}{\Delta t}\right)$; increasing *f* decreases Δt; increasing *B* increases $\Delta\phi$. The last suggestion only affects the current, not the emf.

Question 7/ 50

[Adapted VCAA 2017 SB Q5]

The alternator in the diagram has a 10 turn rectangular coil with sides of 0.30 m and 0.40 m. The coil rotates four times a second in a uniform magnetic field. The magnetic flux through the coil in the position shown is 0.20 Wb.



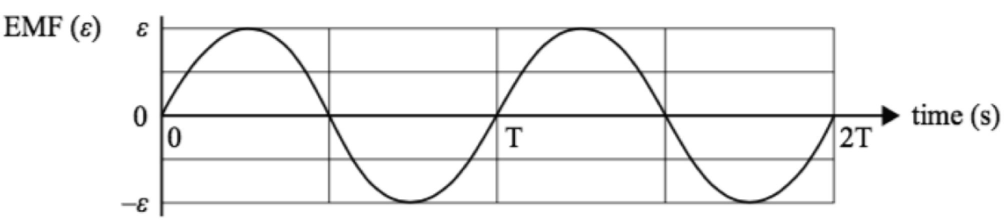
a. Calculate the magnitude of the magnetic field. Include an appropriate unit.

(3 marks)

b. Calculate the magnitude of the average EMF (ε) generated in a quarter of a turn. Show all the steps of your working.

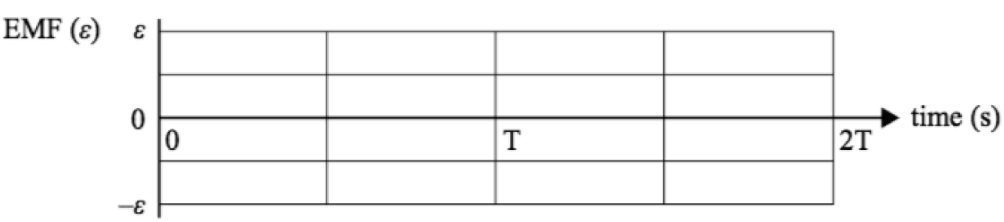
(3 marks)

c. The graph below shows the output EMF (ε) versus time graph of the alternator for two complete cycles.



The two slip rings are now replaced with a split-ring commutator.

On the diagram below, sketch the EMF (ε) versus time graph of this new arrangement for two complete cycles.

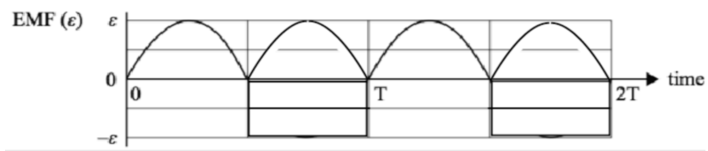


(2 marks)

Solution

a $1.7\ \mathrm{T}\ \left(\mathrm{Wb\ m^{-2}}\right)$ Use $\Phi = BA$ with B as the subject.

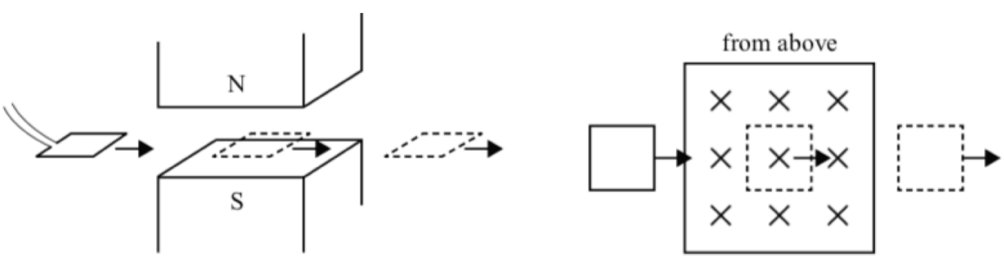
b 32 V $\mathrm{EMF} = \varepsilon = -n\left(\frac{\Delta\phi}{\Delta t}\right)$; with $\Delta t = \text{time}$ for $\frac{1}{4}$ $\text{turn} = 0.0625$ s.

c 

Question 8/ 50

[VCAA 2018 NHT SB Q4]

Students move a square loop of wire of 100 turns and of cross-sectional area $4.0 \times 10^{-4}\mathrm{m}^2$. The loop moves at constant speed from outside left, into, through and out of a magnetic field, as shown in the left-hand diagram. The area between the poles has a uniform magnetic field of magnitude $2.0 \times 10^{-3}\mathrm{T}$. The right-hand diagram shows the view from above.



a. On the axes provided below, sketch the magnetic flux, Φ_{B}, through the loop as it moves into, through and out of the magnetic field.

(2 marks)

b. On the axes provided below, sketch the EMF induced through the loop as it moves into, through and out of the magnetic field.

(2 marks)

c. The loop takes 2.0 s to move from completely outside to completely inside the magnetic field. Calculate the magnitude of the induced EMF in the loop as it moves into the magnetic field.

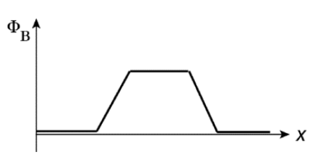
(2 marks)

d. Determine the direction of the induced current in the loop as it moves into the magnetic field as viewed from above (clockwise or anticlockwise). Justify your answer.

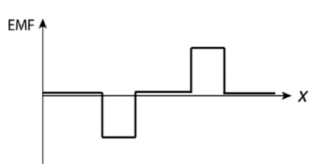
(3 marks)

Solution

a



b



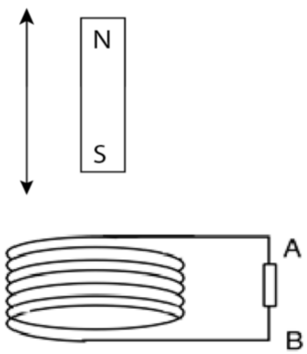
c 4.0×10^{-5}V EMF $= \varepsilon = -n\left(\frac{\Delta\phi}{\Delta t}\right)$; $\Delta t = 2.0, n = 100$ and

$\Delta\Phi = BA = 8.0 \times 10^{-7\,\text{Wb}}$.

d The change in the magnetic flux is an increase downwards. This change will be opposed by the induced current; it will flow so as to create flux upwards. To do this it must flow **anticlockwise** (RH grip rule).

Question 9/ 50

A generator coil of area 0.2 m^2 with 7 turns, has an associated magnet that oscillates up and down through it, as shown in the diagram.



a. Describe the direction of the induced current through the resistor between A and B when the magnet is travelling down towards the coil.

(2 marks)

b. The graph below shows how the average flux through each turn changes with time. Identify when the magnet is momentarily stationary. Give your answers to one significant figure.

(2 marks)

Missing Image

c. Sketch the variation of the current in the resistor between A and B as a function of time (no need to indicate *direction* through the resistor).

(2 marks)

d. Calculate the *average* emf across the coil between time $t = 0.4 \text{ s}$ and $t = 0.6 \text{ s}$.

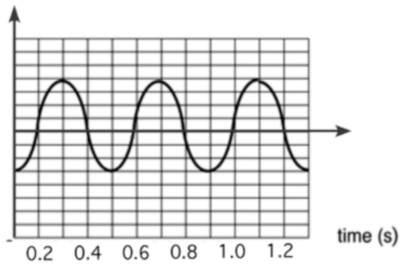
(2 marks)

Solution

a The induced current will flow through the resistor AB from B to A.

b Induced current will be zero at 0, 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 s; (when gradient of flux–time graph is zero).

c

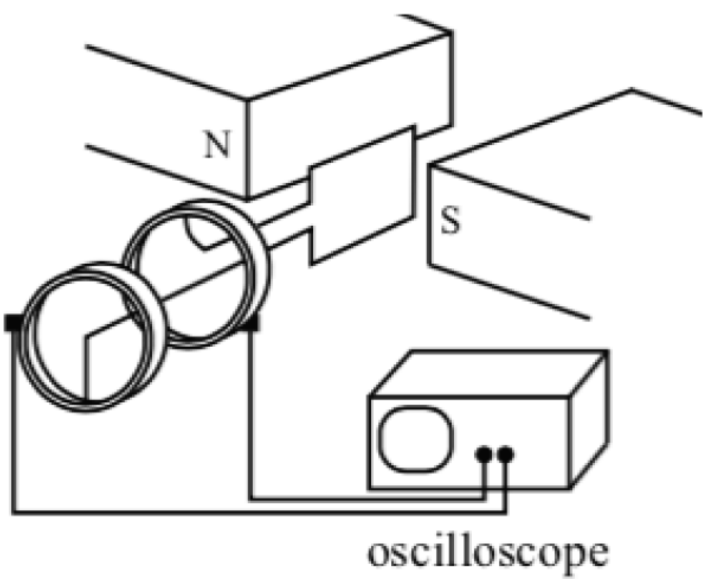


d 0.49 V Use $emf_{\text{AVERAGE}} = n \times \frac{\Delta\phi}{\Delta t} = 7 \times \frac{(0.014)}{(0.02)}$

Question 10/ 50

[VCAA 2017 Sample SB Q4]

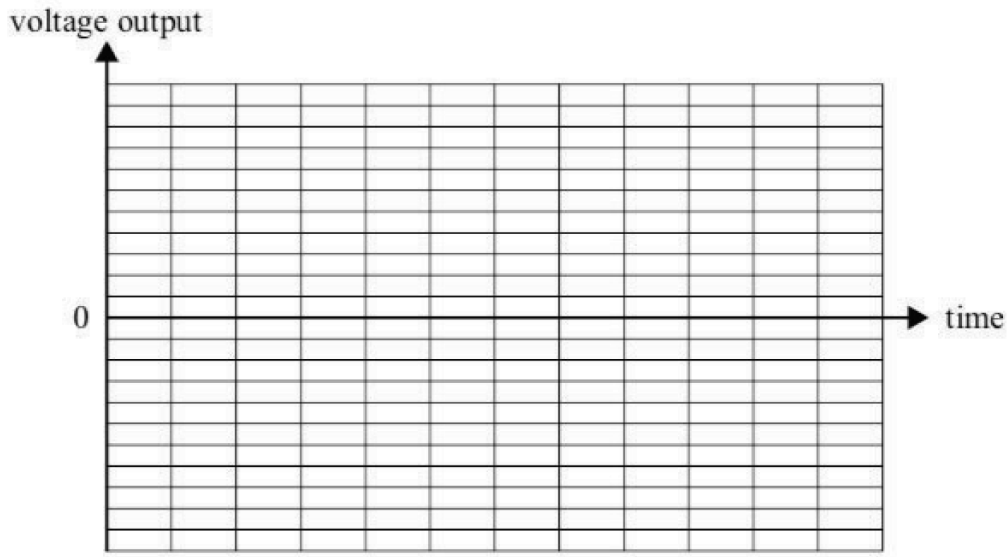
The diagram below shows a simple alternator. The strength of the magnetic field is 0.50 T, the loop has 20 turns, the area of the loop is $0.020\ \mathrm{m}^2$ and the rate of rotation is 10 Hz.



a. Calculate the magnitude of the average EMF induced as the loop turns from the instant shown to a point one-quarter of a period later. Show your working and include an appropriate unit.

(3 marks)

b. The alternator gradually slows to a stop. On the grid provided below, sketch the voltage output expected. Scale values are not required on the axes.

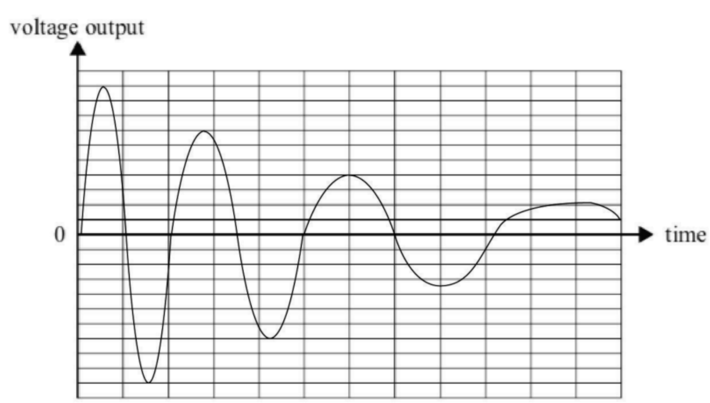


(3 marks)

Solution

a 8.0 V Use $emf_{\text{AVERAGE}} = n \times \frac{\Delta\phi}{\Delta t} = 20 \times \frac{(0.50)(0.02)}{(0.025)}$

b

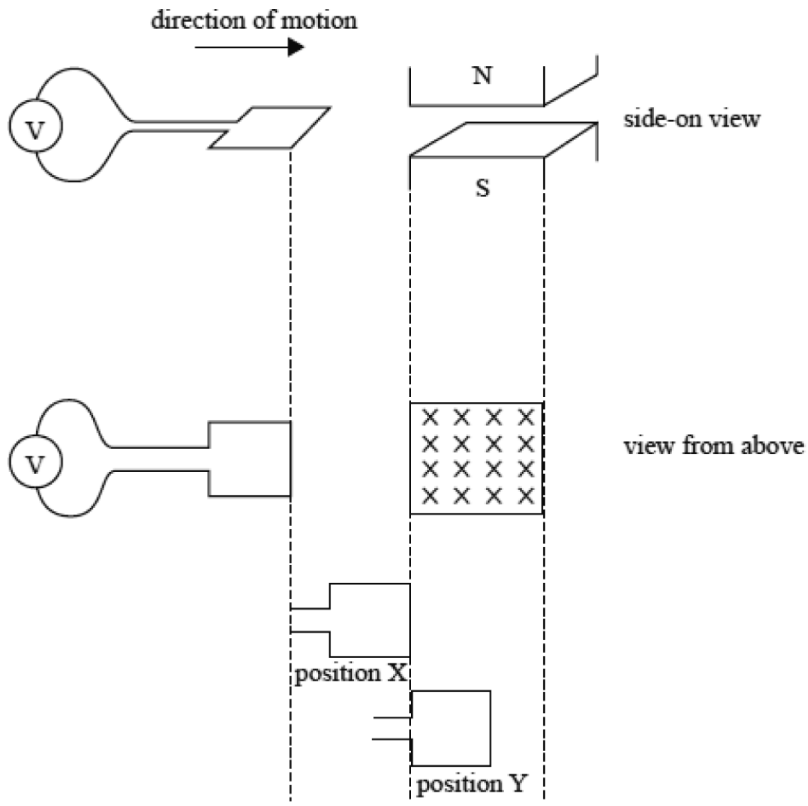


Note that the period lengthens, and the amplitude decreases.

Question 11/ 50

[VCAA 2018 SB Q2]

A square loop of wire of 10 turns with a cross-sectional area of $1.6 \times 10^{-3}\ \mathrm{m}^2$ passes at a constant speed into, through and out of a magnetic field of magnitude $2.0 \times 10^{-2}\ \mathrm{T}$, as shown below. The loop takes 0.50 s to go from position X to position Y.

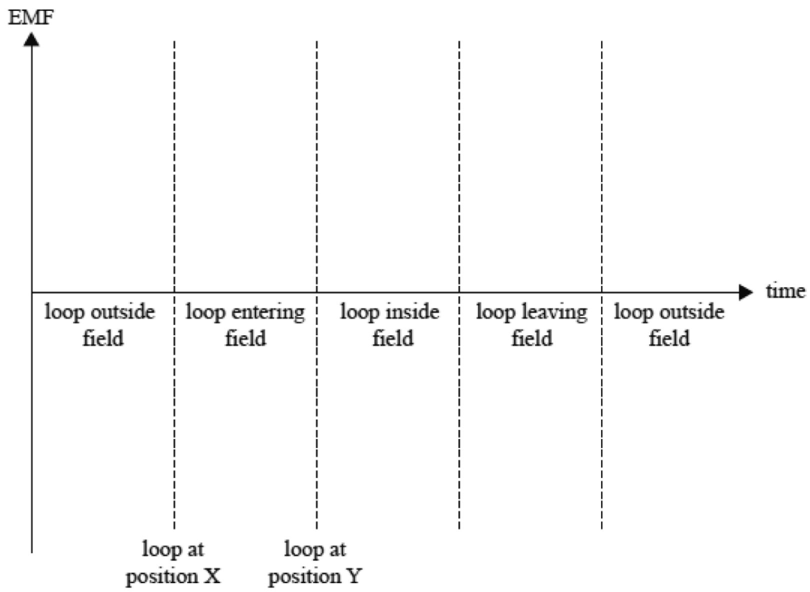


a. Calculate the average EMF induced in the loop as it passes from just outside the magnetic field at position X to just inside the magnetic field at position Y. Show your working.

(3 marks)

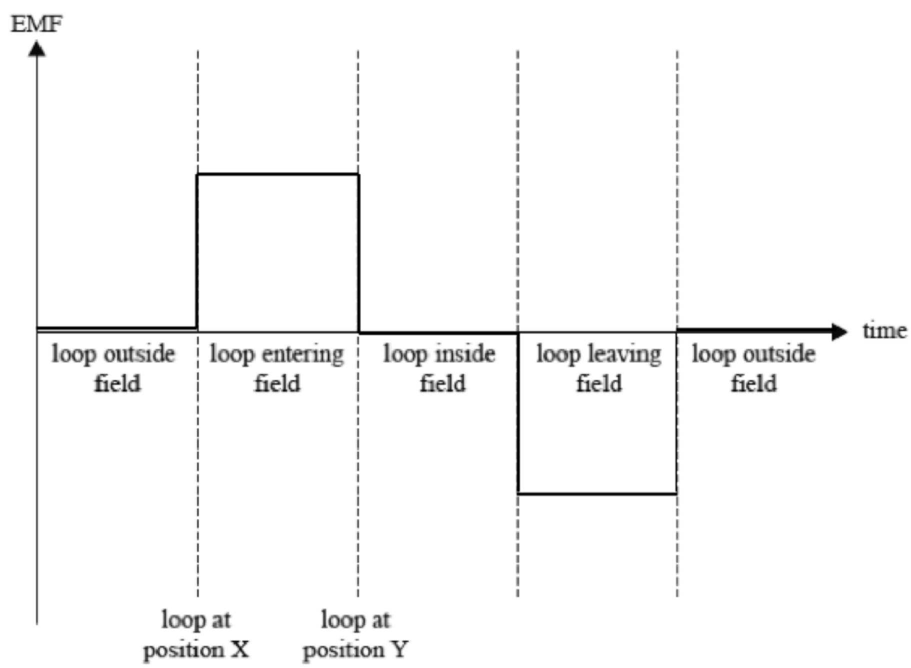
b. Sketch the EMF induced in the loop as it passes into, through and out of the magnetic field. You do not need to include values on the axes.

(3 marks)



Solution

a $6.4 \times 10^{-4}\mathrm{V}$ Use Faraday's Law for magnitude of the EMF, hence $\mathrm{EMF} = \varepsilon = -n\left(\frac{\Delta\phi}{\Delta t}\right)$; in position X flux through coil is 0; in position Y it is $2 \times 10^{-2} \times 1.6 \times 10^{-3} = 3.2 \times 10^{-5}\mathrm{Wb}$.



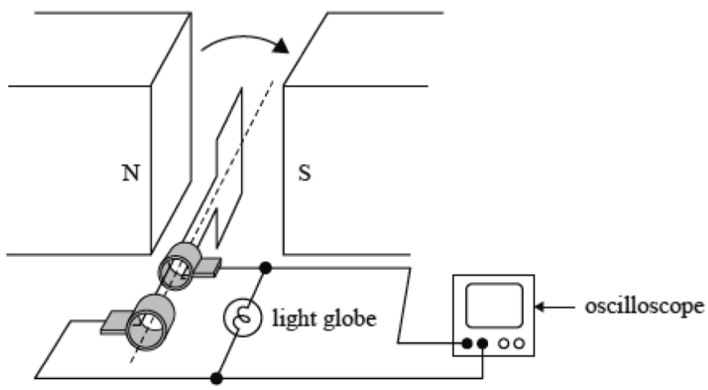
b

(Answer could be inverted.)

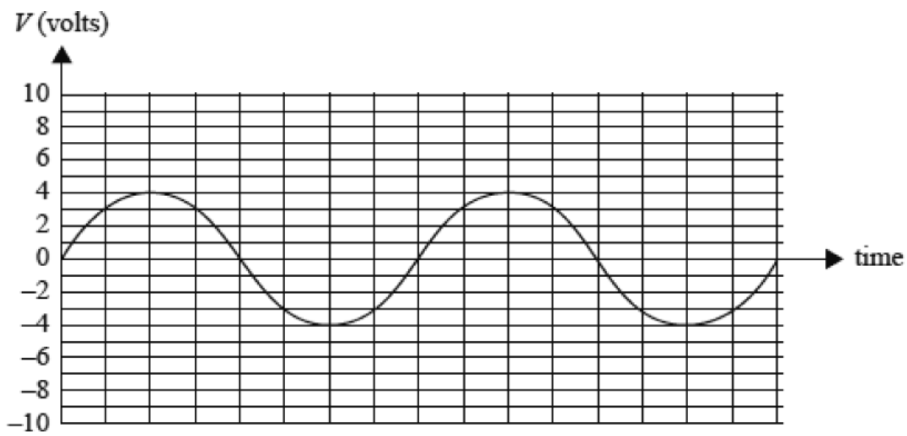
Question 12/ 50

[VCAA 2018 SB Q4]

The diagram shows a simple AC alternator with the output connected to an oscilloscope and a light globe. The oscilloscope can be considered as having a very large resistance. The coil is rotated, as shown.



The output on the oscilloscope is shown in the diagram below.

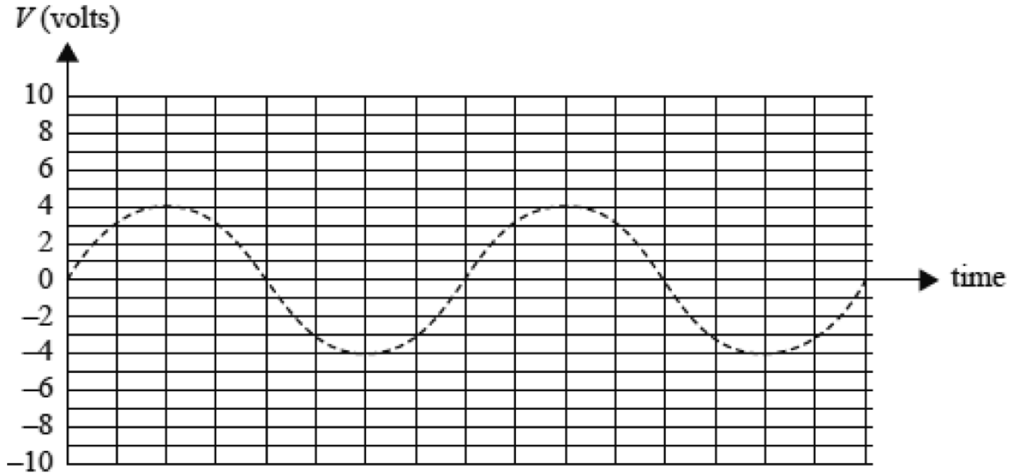


a. The AC alternator is to be replaced with a battery. What voltage should the battery have for the light globe to light up with the same average brightness as it did with the alternator? Show your working.

(2 marks)

b. The rate of rotation of the loop is doubled. On the diagram below, sketch the output that will now be seen on the oscilloscope. The original waveform is shown as a dashed line.

(2 marks)



Solution

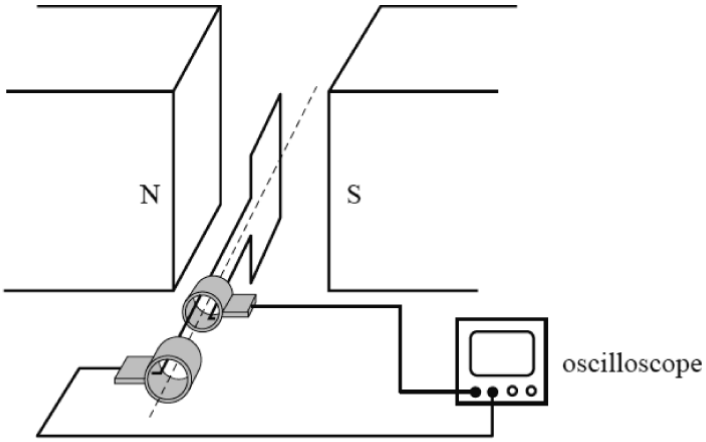
a 2.8 V Required $\text{DC volts} = \text{AC peak}$ value divided by $\sqrt{2}$.

b Same shape as original output (sinusoidal but double the amplitude and half the period (twice the frequency).

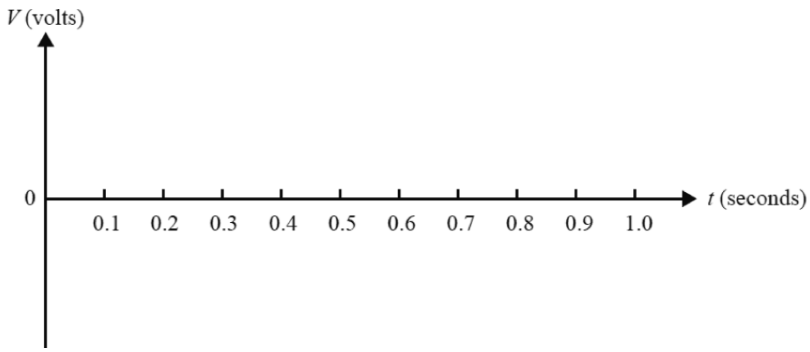
Question 13/ 50

[Adapted VCAA 2019]

A square loop of wire with a cross-sectional area of $0.010\ \text{m}^2$ and 20 turns rotates in a magnetic field of strength $4.0 \times 10^{-2}\ \text{T}$. The wires of the loop are connected to two slip rings and an oscilloscope, as shown below.

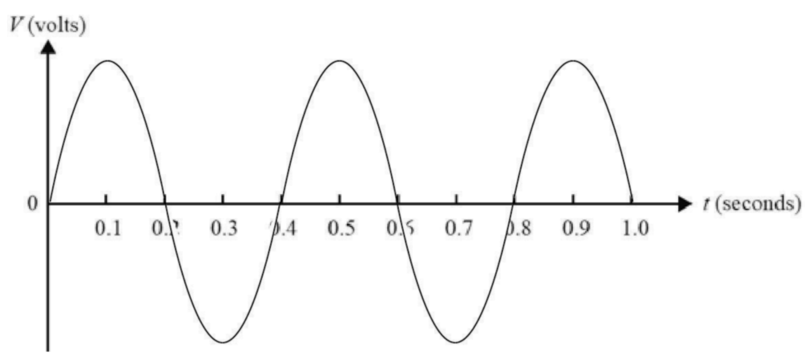


The loop takes 0.10 s to make a quarter rotation (from a position at right angles to the field to a position parallel to the field). On the axes provided below, sketch the output signal that would be displayed on the oscilloscope over 1.0 s. A value or scale on the *y* axis is not necessary. Take the position of the loop at $t = 0$ to be that shown in the diagram above.



(2 marks)

Solution

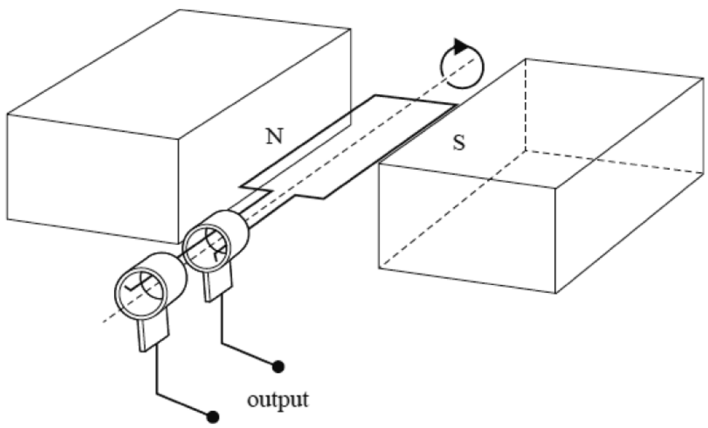


(The graph could be inverted if the coil is travelling in the opposite direction.)

Question 14/ 50

[VCAA 2019 SB Q7]

Students in a Physics practical class investigate the piece of electrical equipment shown below. It consists of a single rectangular loop of wire that can be rotated within a uniform magnetic field. The loop has dimensions $0.50\ \mathrm{m} \times 0.25\ \mathrm{m}$ and is connected to the output terminals with slip rings. The loop is in a uniform magnetic field of strength 0.40 T.



a. Circle the name that best describes the piece of electrical equipment shown in the diagram.

alternator DC generator DC motor AC motor

(1 mark)

b. i. What is the magnitude of the flux through the loop when it is in the position shown in the diagram?

(1 mark)

ii. Explain your answer to part **bi**.

(1 mark)

The students connect the output terminals of the piece of electrical equipment to an oscilloscope. One student rotates the loop at a constant rate of 20 revolutions per second.

c. Calculate the period of rotation of the loop.

(1 mark)

d. Calculate the maximum flux through the loop. Show your working.

(2 marks)

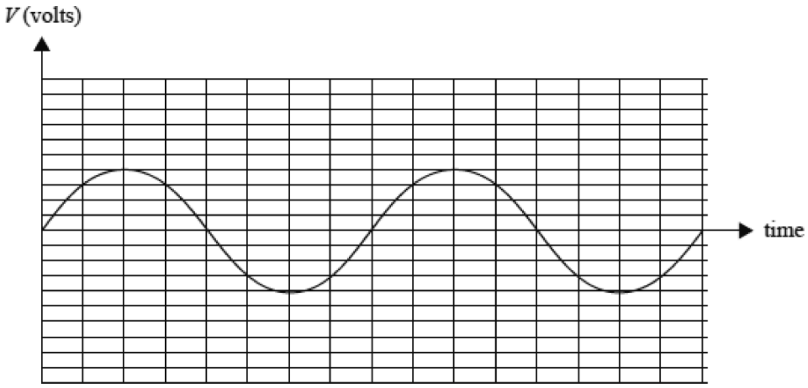
e. The loop starts in the position shown in the diagram. What is the average voltage measured across the output terminals for the first quarter turn? Show your working.

(2 marks)

f. State two ways that the amplitude of the voltage across the output terminals can be increased.

(2 marks)

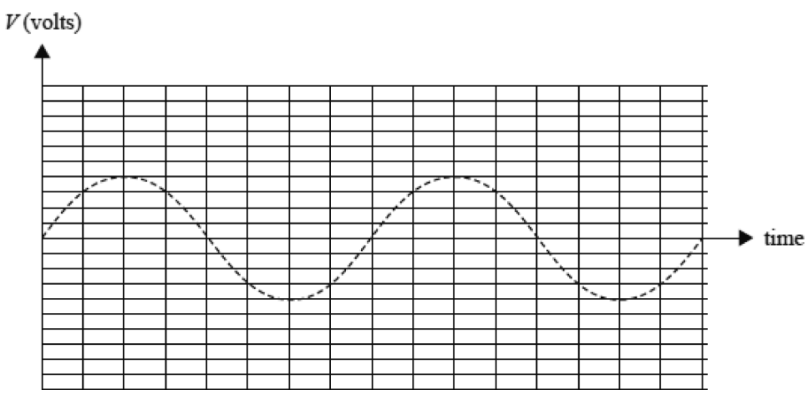
g. The diagram below shows the output voltage graph shown on the oscilloscope for two cycles.



The students now replace the slip rings in the earlier diagram with a split-ring commutator.

On the diagram below, sketch with a *solid* line the output that the students will now observe on the oscilloscope. Show two complete revolutions. The original output is shown with a *dashed* line.

(1 mark)



Solution

a alternator The output of the rotating coil will be AC and this is not changed by the slip ring output arrangement.

bi 0 Wb

bii The magnetic field is parallel to the plane of the rectangular loop.

c 0.05 s $T = \frac{1}{f}$

d 0.05 Wb $\text{Maximum } \Phi = 0.40 \times 0.50 \times 0.25 \text{ Wb}$

e 4.0 V $\text{Average emf} = \frac{\text{flux change}}{\text{time taken}} = \frac{0.050}{0.0125} \text{ V}$

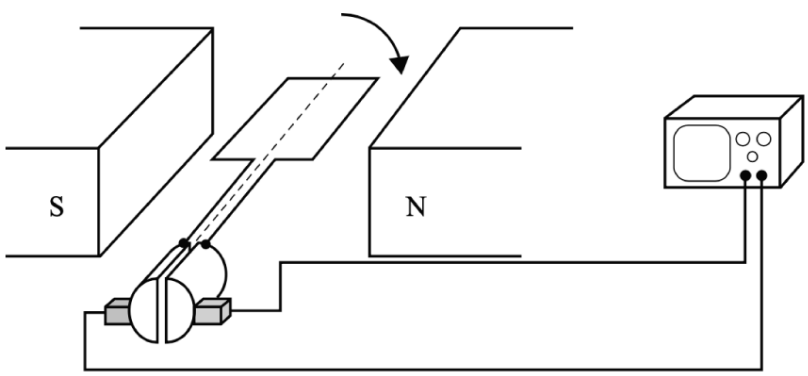
f There are more than two ways, including the following. Increase rotation rate of coil, increase the number of turns of the coil, increase the strength of the magnetic field, increase the area of the coil.

g The direction of the negative parts of the curve will be reversed (the emf will be 'rectified').

Question 15/ 50

[VCAA 2020 SB Q5]

A rectangular wire loop with dimensions $0.050 \text{ m} \times 0.035 \text{ m}$ is placed between two magnets that create a uniform magnetic field of strength 0.2 mT. The loop is rotated with a frequency of 50 Hz in the direction shown in the diagram. The ends of the loop are connected to a split-ring commutator to create a DC generator. The loop is initially in the position shown in the diagram.



a. In which direction – clockwise or anticlockwise – will the induced current travel through the loop for the first quarter turn as seen from above?

(1 mark)

b. Calculate the average EMF measured in the loop for the first quarter turn.

(3 marks)

c. On the axes provided below, sketch the output EMF versus time, *t*, for the first two rotations. Include a scale on the horizontal axis.

(3 marks)

d. Suggest two modifications that could be made to the apparatus shown in the initial diagram that would increase the output EMF of the DC generator.

(2 marks)

Solution

a Anticlockwise. The flux though the loop will be increasing and the induced current will be generating flux in the opposite direction.

b $7 \times 10^{-5}\text{V Average emf} = \frac{N \times BA}{\Delta t} = \frac{1 \times 0.0002 \times 0.050 \times 0.035}{0.005}$

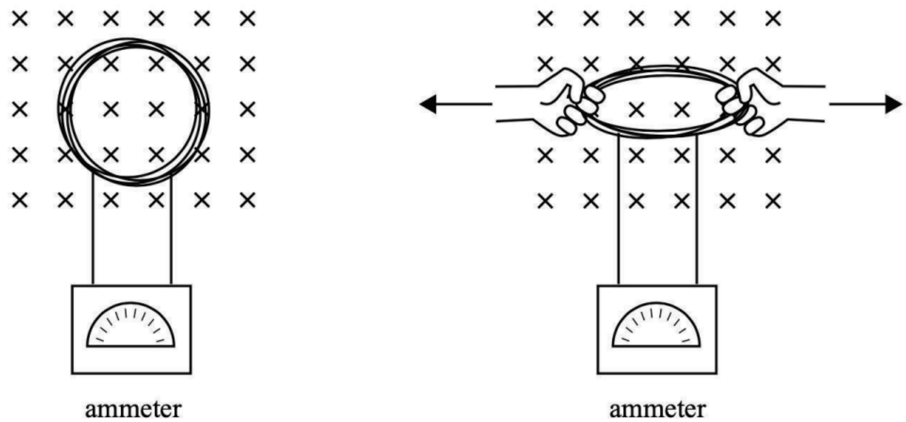
c Missing Image

d A range of possibilities include: increasing the field strength, the coil area, the frequency (or decreasing the period of rotation).

Question 16/ 50

[VCAA 2020 SB Q6]

Two Physics students hold a coil of wire in a constant uniform magnetic field, as shown in the left-hand diagram. The ends of the wire are connected to a sensitive ammeter. The students then change the shape of the coil by pulling each side of the coil in the horizontal direction, as shown in the right-hand diagram. They notice a current register on the ammeter.



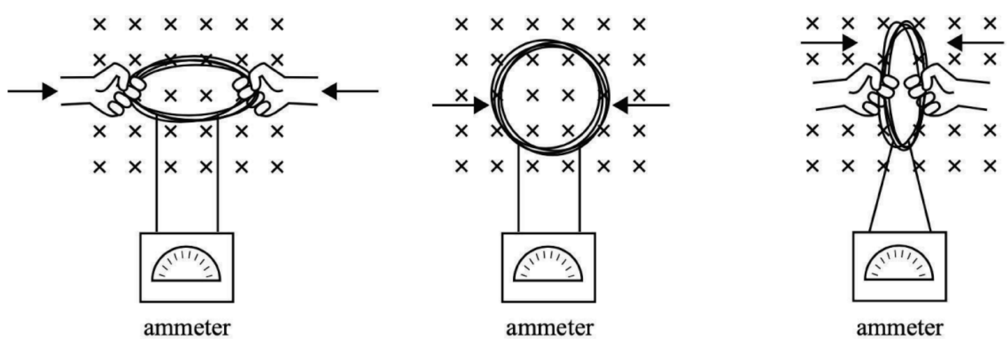
a. Will the magnetic flux through the coil increase, decrease or stay the same as the students change the shape of the coil?

(1 mark)

b. Explain, using physics principles, why the ammeter registered a current in the coil and determine the direction of the induced current.

(3 marks)

c. The students then push each side of the coil together, as shown in the diagram below, so that the coil returns to its original circular shape, as shown, and then changes to the shape shown in right-hand diagram below.



Describe the direction of any induced currents in the coil during these changes. Give your reasoning.

(2 marks)

Solution

a Decrease. The area through which the magnetic field passes is smaller.

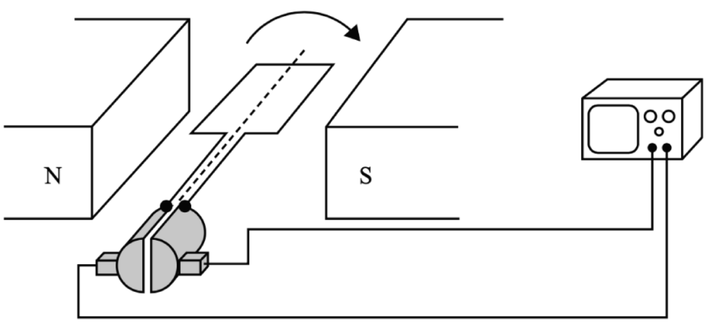
b The flux into the page decreases. From Lenz's law the induced current produces a flux (increasing) into the page. Using the right-hand grip rule (or similar) the induced current will flow clockwise.

c When the coil changes to the circular shape there is an increasing flux into the page. Applying the right-hand grip rule, this means an induced current will flow anticlockwise around the loop. Then when the loop shape reduces in the final diagram, the flux decreases, and the induced current will flow clockwise around the loop.

Question 17/ 50

[VCAA 2021 NHT SB Q5]

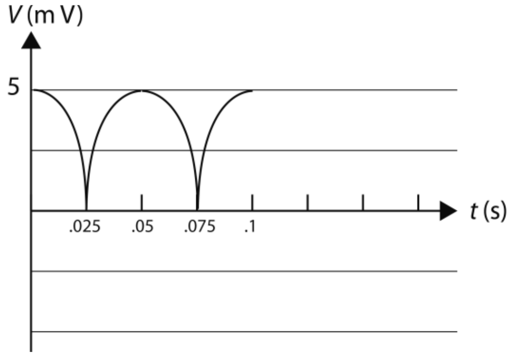
Physics students who are investigating the generation of electricity spin a coil at a constant 10 rotations per second in a uniform magnetic field. They observe the output on an oscilloscope. The experimental set-up is shown on the next page. The peak voltage produced by the coil is 5 mV.



On the axes below, sketch the voltage versus time graph observed on the screen of the oscilloscope for one complete rotation of the coil from the position shown in the diagram. Include appropriate scales on each axis.

(3 marks)

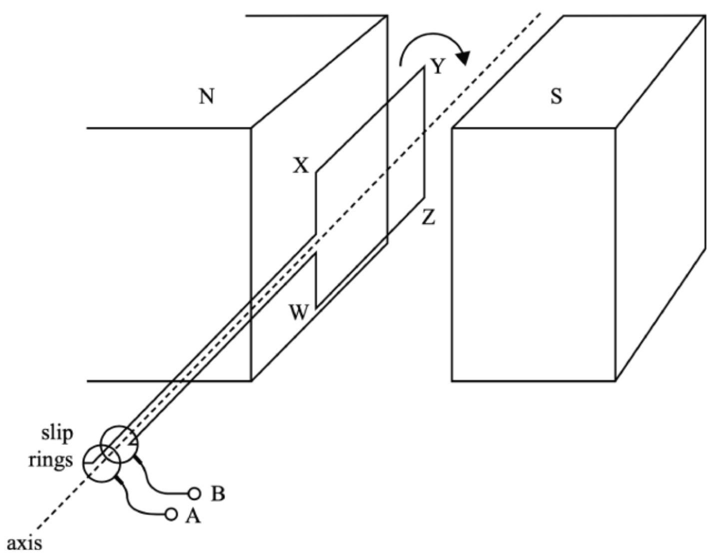
Solution



Question 18/ 50

[VCAA 2021 NHT SB Q6]

Gir and Kau are investigating electromagnetic induction. They have a single wire loop of dimensions $\mathrm{XY} = 0.030\ \mathrm{m}$ long and $\mathrm{YZ} = 0.020\ \mathrm{m}$ wide, which is placed in a uniform magnetic field of strength 0.20 T. The loop is rotated clockwise about an axis, as shown below.



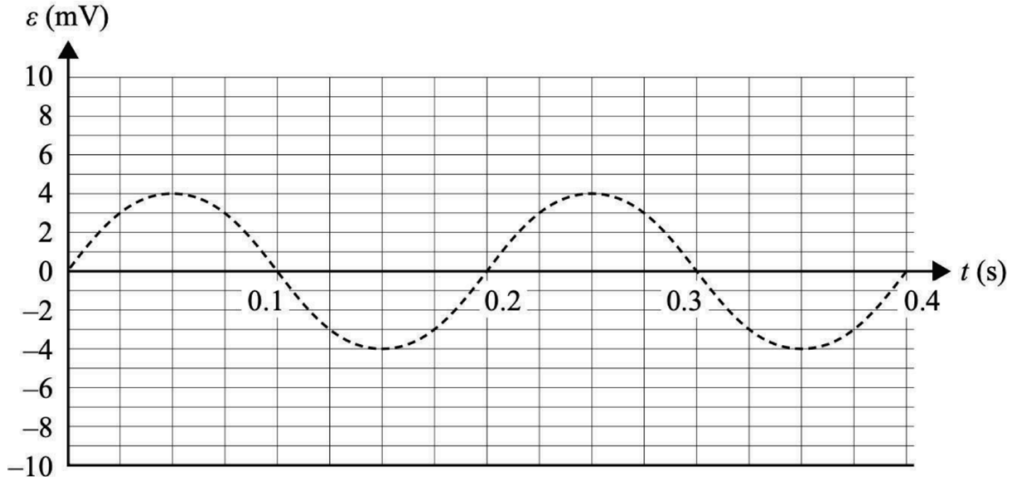
a. Explain the purpose of the slip rings in the apparatus shown in the diagram above.

(2 marks)

b. Calculate the size of the magnetic flux through the loop when it is oriented as shown in the diagram above. Show your working.

(2 marks)

The loop is rotated by Kau at a constant frequency, f, and an EMF, ε, is generated. The diagram below shows the generated EMF versus time trace observed on the screen of an oscilloscope.

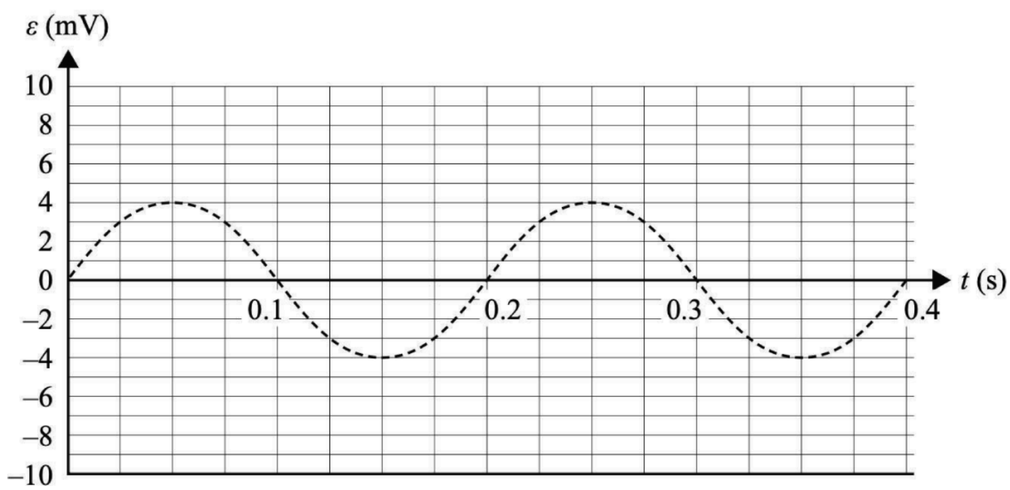


c. Calculate the frequency of the rotation from the oscilloscope trace shown in the diagram above.

(1 mark)

d. Gir now doubles the number of turns in the loop from one turn to two turns, creating two loops. The loops are again rotated at the same constant frequency, *f*. On the diagram on the next page, sketch a graph that shows the resulting variation of the EMF with time between points A and B. The original output is shown as a dashed line.

(2 marks)



Solution

a The slip rings are in continuous contact with the rotating coil and contacts A and B. Hence the AC current/emf generated in the rotating coil is connected to external circuits via A and B.

b 1.2×10^{-4} Wb Magnetic flux $= B \times A$

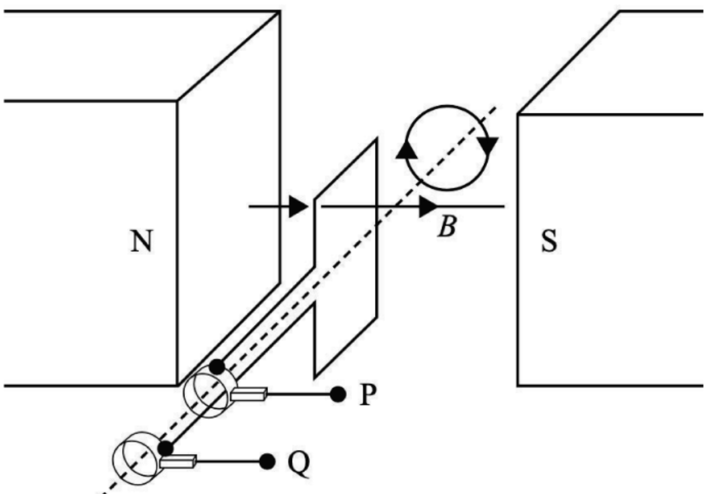
c 5.0 Hz $\text{Period (from graph)} = 0.2$ s; now use $f = \frac{1}{T}$.

d The required graph has the same period but double the amplitude. The extra coil just doubles the output voltage.

Question 19/ 50

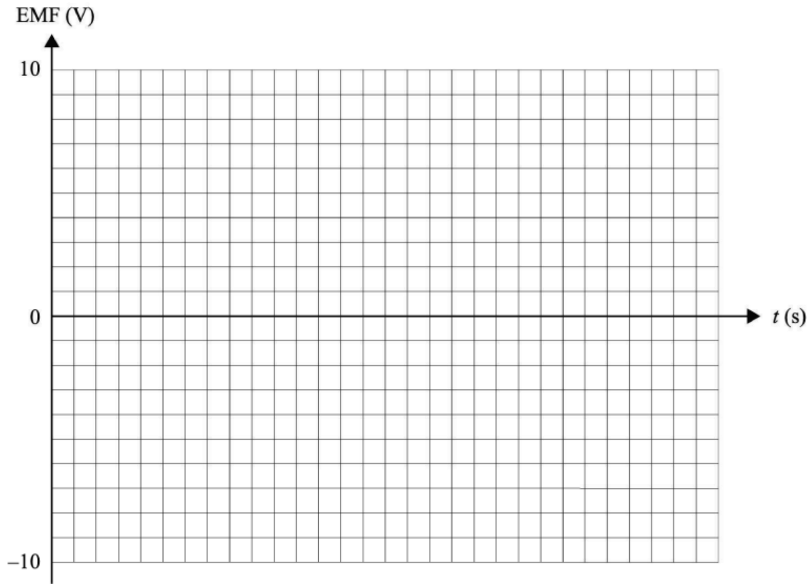
[VCAA 2021 SB Q6]

The diagram below shows a simple AC generator. A mechanical energy source rotates the loop smoothly at 50 revolutions per second and the loop generates an RMS voltage of 4.25 V. The magnetic field, *B*, is constant and uniform. The direction of rotation is as shown in in the diagram below.



a. Sketch the output EMF between P and Q versus time, *t*, on the grid below, starting with the loop in the position shown in in the diagram. Show at least two complete revolutions, and include the maximum voltage on the vertical axis and a time scale on the horizontal axis.

(4 marks)



b. Describe the function of the slip rings shown in the diagram.

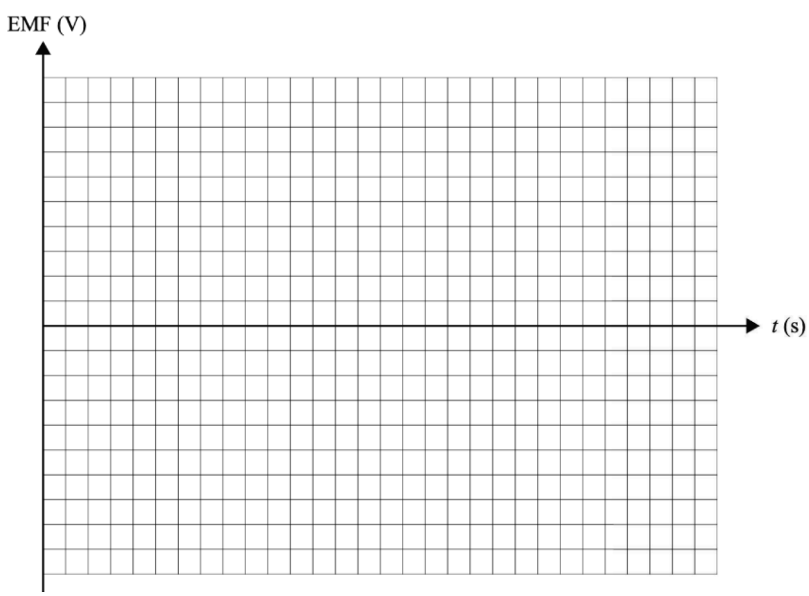
(1 mark)

c. i. How could the AC generator shown be changed to a DC generator?

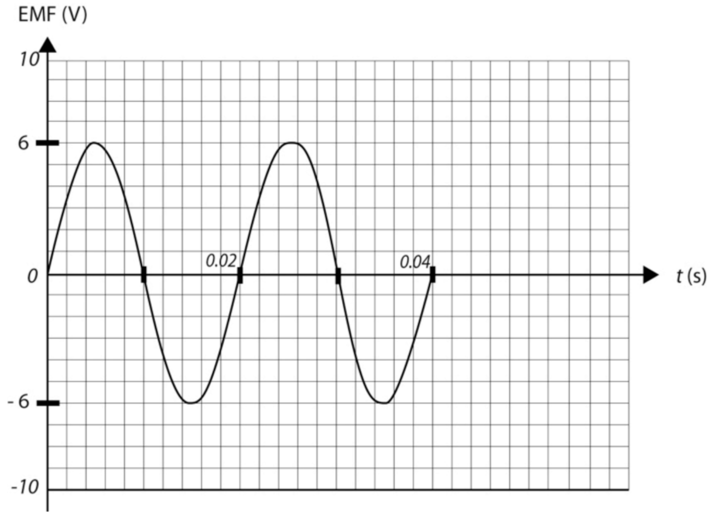
(1 mark)

ii. Sketch the output EMF versus time, t, for this DC generator *for at least two* complete revolutions on the grid below. Include a time scale on the horizontal axis. No scale is required for the vertical axis.

(2 marks)



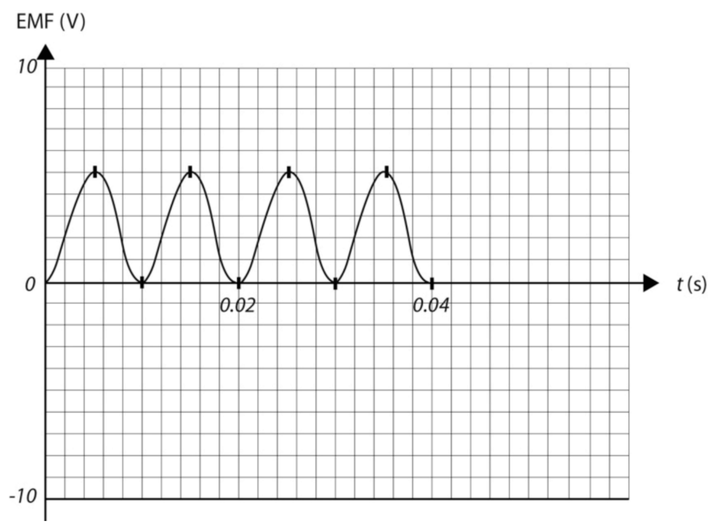
Solution

a 

A sinusoidal graph with peaks at $+6.0\mathrm{V}$ and $-6.0\mathrm{V}$ and period of 0.02 s. 4.25 V_{RMS} has a peak value of 6.0 V.

b The slip rings provide continuous contact between the rotating loop and the output of the generator so that the AC voltage produced in the loop can be used.

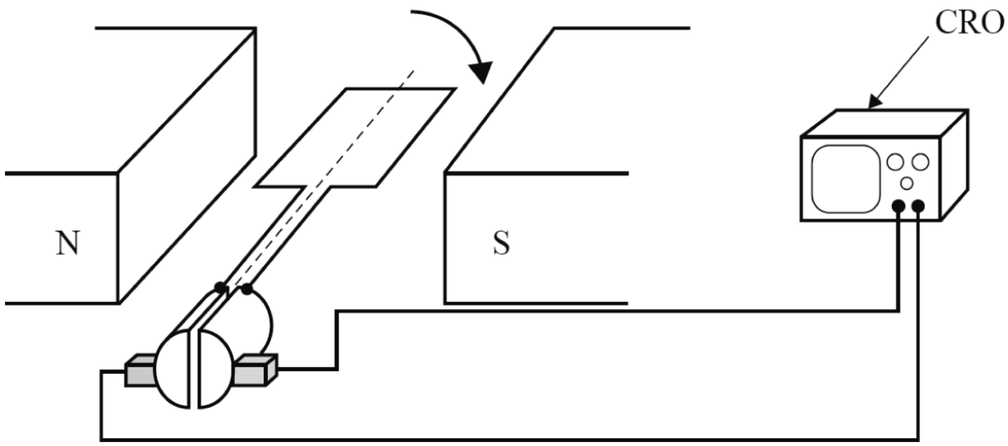
ci Replace the slip rings with a split ring commutator; this will rectify the AC and produce pulsed DC.

cii 

Question 20/ 50

[VCAA 2022 NHT SB Q4]

The diagram below shows a schematic diagram of a simple DC generator with the output connected to a cathode ray oscilloscope (CRO). The DC generator consists of a rectangular wire coil of 200 turns placed in a uniform magnetic field of strength 5.0 mT. The coil is rotated with a frequency of 60 Hz in the direction shown in the diagram The average EMF generated in the coil for the first quarter turn is 35 mV. The coil is initially in the position shown in the diagram.



a. When viewed from above, will the induced current in the coil be clockwise or anticlockwise during the first quarter turn?

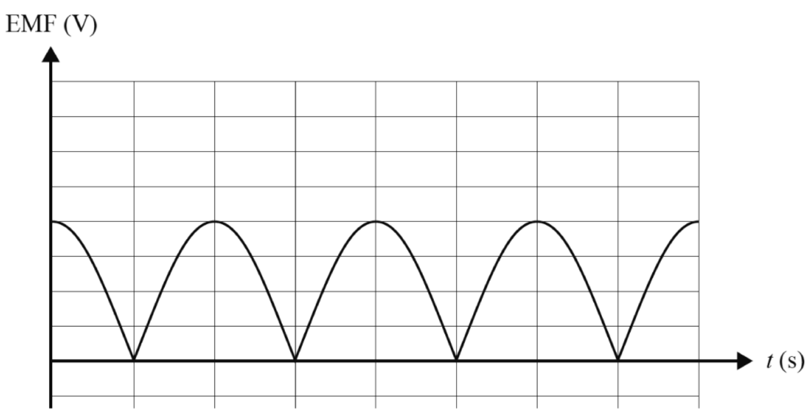
(1 mark)

b. Calculate the area of one loop of the rectangular wire coil. Show your working.

(3 marks)

c. The graph on the next page shows the EMF induced in the coil over two full turns. On the same axes, sketch the output EMF that would result if the number of turns in the coil is changed to 100 turns and the frequency of rotation is changed to 30 Hz.

(2 marks)

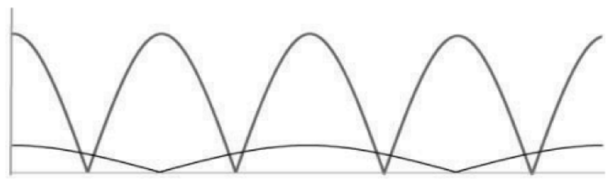


Solution

a Clockwise. The flux thourgh the loop in the position shown is inrceasing; the indused current will flow in a direction to oppose this chage (Lenz's law).

b $1.5 \times 10^{-4}\mathrm{m}^2$ $\Delta t = 0.25 \times \left(\frac{1}{60}\right) = 0.0042$; $\mathrm{emf} = \frac{nBA}{\Delta t}$; make A the subject.

$A = \text{average } emf \times \frac{\Delta t}{nB} = 0.035 \times \frac{0.0042}{(200 \times 0.005)}$.

c 

Note that the amplitude is one quarter of the original due to changes in the turns and the frequency; and the period is doubled due to that frequency change.

Question 21/ 50

[VCAA 2022 NHT SB Q5]

A bar magnet is moved towards a single closed loop of conducting wire with the bar magnet's south pole closest to the loop, as shown in the diagram below. The loop is stationary.

The area and the shape of the loop remain constant and the magnet is not changed. Explain, in terms of magnetic flux, how a current is induced in the loop.

(2 marks)

Solution

As the magnet moves towards the loop the magnetic field through the loop and consequently the flux increase. Faraday's law describes these as the conditions for an induced emf; $\mathrm{emf} = -n\left(\frac{\Delta\phi}{\Delta t}\right)$.

Question 22/ 50

[VCAA 2022 SB Q4]

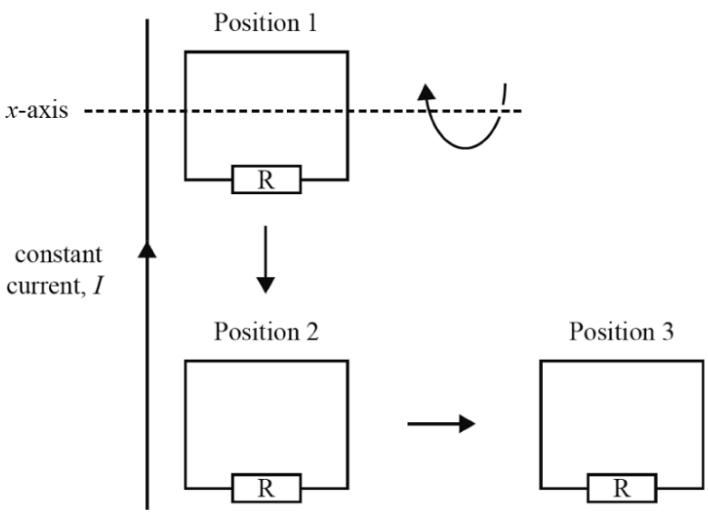
A square loop of wire connected to a resistor, R, is placed close to a long wire carrying a constant current, *I*, in the direction shown in the diagram below.

The square loop is moved three times in the following order:

• Movement A – Starting at Position 1 in the diagram, the square loop rotates one full rotation at a steady speed about the *x*-axis. The rotation causes the resistor, R, to first move out of the page.

• Movement B – The square loop is then moved at a constant speed, parallel to the current carrying wire, from Position 1 to Position 2 in the diagram.

• Movement C – The square loop is moved at a constant speed, perpendicular to the current carrying wire, from Position 2 to Position 3 in the diagram.

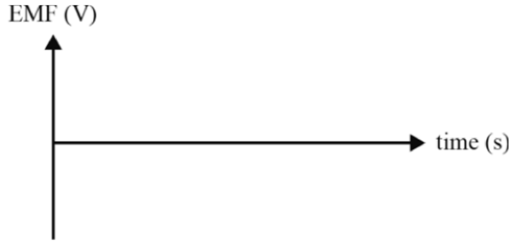
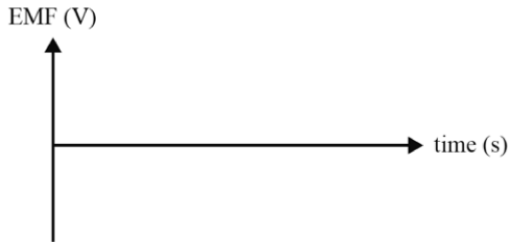


Complete the table below to show the effects of each of the three movements by:

• sketching any EMF generated in the square loop during the motion on the axes provided (scales and values are not required)

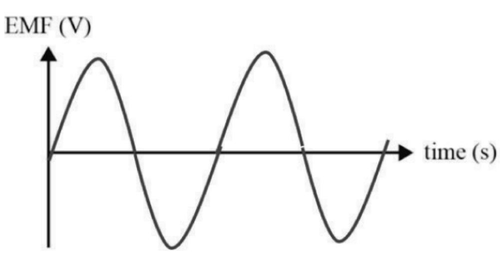
• stating whether any induced current in the square loop is ‘alternating’, ‘clockwise’, ‘anticlockwise’ or has ‘no current’.

Movement	Possible induced EMF	Direction of any induced current (alternating/clockwise /anticlockwise/no current)

Movement	Possible induced EMF	Direction of any induced current (alternating/clockwise /anticlockwise/no current)
A rotation about x-axis		
B moving from Position 1 to Position 2		
C moving from Position 2 to Position 3		

Solution

Movement A:



Current is alternating.

Movement B:

Current is zero (flux is constant).

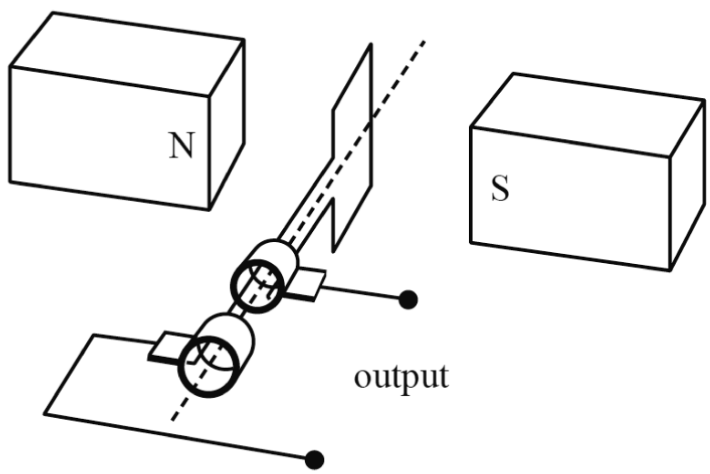
Movement C:

Current is clockwise.

Question 23/ 50

[VCAA 2022 SB Q6]

The diagram below shows a simple alternator consisting of a rectangular coil of area 0.060 m^2 and 200 turns, rotating in a uniform magnetic field. The magnetic flux through the coil in the vertical position shown in diagram is $1.2 \times 10^{-3}\text{Wb}$.



a. Calculate the strength of the magnetic field in the diagram. Show your working.

(2 marks)

b. The rectangular coil rotates at a frequency of 2.5 Hz. Calculate the average induced EMF produced in the first quarter of a turn. Begin the quarter with the coil in the vertical position shown in the diagram.

(3 marks)

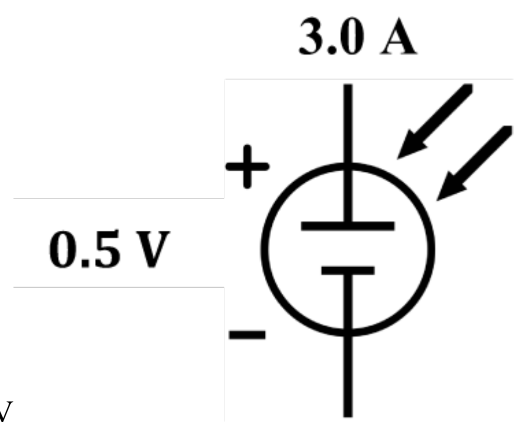
Solution

a $B = 2.0 \times 10^{-2}$ T Use $\text{flux} = BA$ with *B* as the subject.

b 2.4 V Use $\text{EMF} = \frac{n\Delta\phi}{\Delta t}$ with $n = 200$, $\Delta\phi = 1.2 \times 10^{-3}$ and $\Delta t = 0.1\ (= \frac{0.4}{4})$.

Question 24/ 50

One particular photovoltaic (PV) cell, shown below, produces 0.5 V and generates a current, in full sunlight, of 3.0 A.



0.5 V

a. Calculate the power output of a single photovoltaic (PV) cell operating at optimum conditions.

(2 marks)

b. Draw a circuit showing two of these PV cells wired in series. Calculate the output voltage, current and power of this series combination.

(2 marks)

c. Draw a circuit showing two of these PV cells wired in parallel. Calculate the output voltage, current and power of this parallel combination.

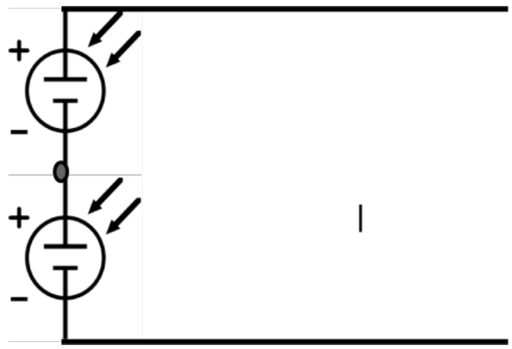
(2 marks)

d. How many PV cells, and in what configuration (series or parallel), would you need to generate 36 W at 3.0 A and 12.0 V?

(2 marks)

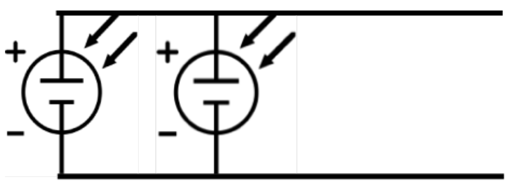
Solution

a 1.5 W Use $P = IV$.



b

c In series, $\text{output voltage} = 1.0\text{ V}, \text{output current} = 3.0\text{ A}, \text{output power} = 3.0\text{ W}.$



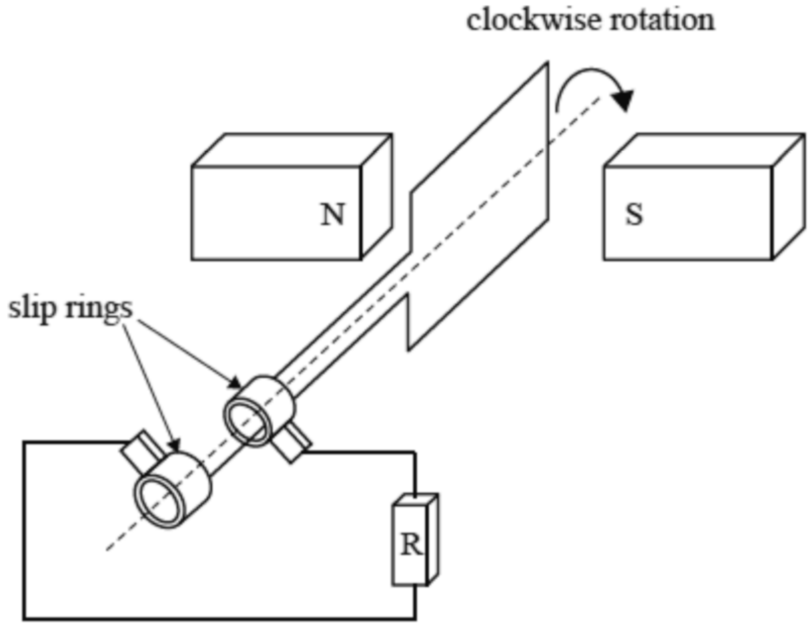
In parallel, $\text{output voltage} = 0.5\text{V}, \text{output current} = 6.0\text{ A}, \text{output power} = 3.0\text{ W}.$

d 24 PV cells in series $(24 \times 0.5 = 12.0\text{ V})$. In series, current is the same (3.0 A).

Question 25/ 50

[VCAA NHT 2023 SB Q8]

Sarah and Raminda construct a simple alternator, as shown below.



When the coil is rotating steadily, it takes 50.0 ms to complete one revolution and the peak EMF generated is 4.30 V.

a. Calculate the frequency of the alternator.

(1 mark)

b. Calculate the EMF, V_{RMS}, generated. Show your working and give your answer correct to three significant figures.

(2 marks)

c. To increase the magnitude of the EMF produced by the alternator, Raminda suggests making a number of changes to the alternator.

Sarah insists that each change be investigated one at a time.

In the spaces provided, indicate whether each suggestion will increase, decrease or have no effect on the EMF produced by the alternator.

Suggested change	**Effect on EMF (increases, decreases or has no effect)**
reduce the resistance of resistor R	
increase the strength of the permanent magnets	
reduce the period of rotation of the coil to 25 ms	
increase the number of turns of the rotating coil	

(4 marks)

Solution

a 20 Hz $T = 50 \times 10^{-3}\text{s}.\ f = \frac{1}{T} = \frac{1}{50 \times 10^{-3}} =\ 20\ \text{Hz}.$

b 3.04 V $V_{\text{RMS}} = \frac{V_n}{\sqrt{2}} = \frac{4.30}{\sqrt{2}} = 3.04\ \text{V}.$

c

Suggested change	emf (increases, decreases or no effect)
Reduce the resistance of resistor R	no effect
Increase the strength of the permanent magnets	increases
Reduce the period of rotation of the coil to 60 ms	increases
Increase the number of turns of the rotating coil	increases

Question 26/ 50

[VCAA NHT 2023 SB Q10]

A single rectangular loop of wire containing a cut out section labelled EF moves to the right at a constant speed of $2.4\ \text{m s}^{-1}$, as shown below. At time $t = 0$, the right-hand edge of the loop enters a constant magnetic field into the page.

Missing Image

The induced EMF produced as a function of time is shown in the graph below.

Missing Image

While the loop enters, and is partially within, the field, an EMF is generated between points E and F.

a. Which point, E or F, is positive?

(1 mark)

b. Explain why the induced EMF is constant during the time period 0.00 s to 0.025 s.

(2 marks)

c. Calculate the strength of the magnetic field through which the rectangular loop travels.

(3 marks)

Solution

a E Use Lenz's law.

b The emf generated is proportional to the RATE of CHANGE of flux.

Because the loop is travelling at constant speed, rate of change is constant thus emf generated is constant.

c 0.33 T $\text{emf} = -\frac{\text{N}\Delta\phi_B}{\Delta t} = 0.04 = \frac{1B(0.06\times0.05)}{0.025}$

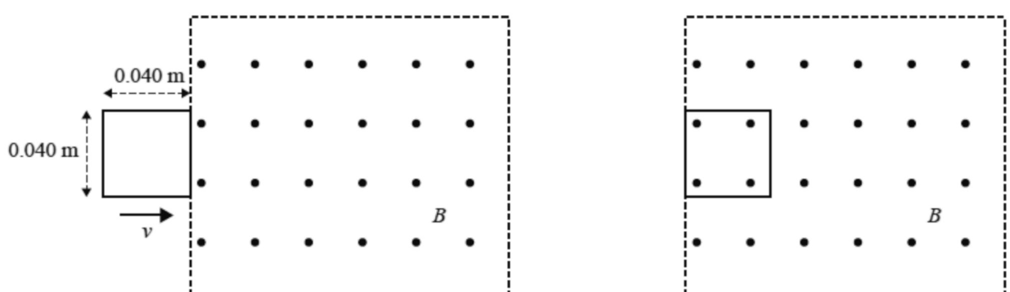
$\therefore B = 0.33\ \text{T}$

Question 27/ 50

[Adapted VCAA 2023 SB Q5]

The diagram below (left) shows a single square loop of conducting wire placed just outside a constant uniform magnetic field, *B*. The length of each side of the loop is 0.040 m. The magnetic field has a magnitude of 0.30 T and is directed out of the page.

Over a time period of 0.50 s, the loop is moved at a constant speed, *v*, from completely outside the magnetic field to completely inside the magnetic field as shown below.

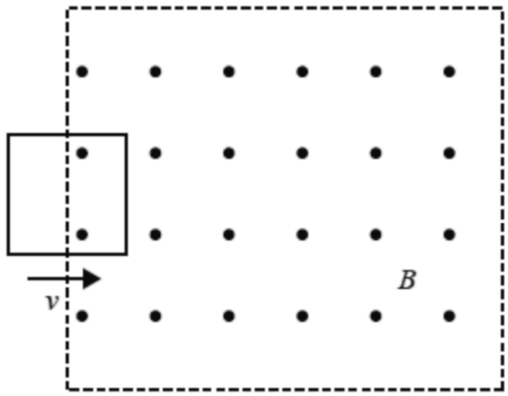


a. Calculate the average EMF produced in the loop as it moves from the position just outside the region of the field to the position completely within the area of the magnetic field. Show your working.

(2 marks)

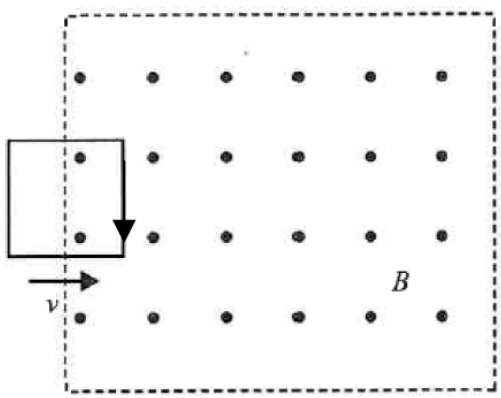
b. On the small square loop in the diagram below, show the direction of the induced current as the loop moves into the area of the magnetic field.

(1 mark)



Solution

a 9.6×10^{-4} V $EMF = \frac{0.3 \times (0.04)^2}{0.5}$



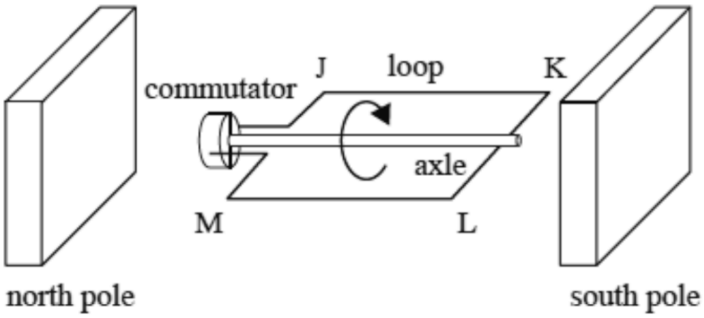
b Clockwise

Question 28/ 50

[VCAA 2023 SB Q6]

Kim and Charlie are attempting to create a DC generator and have arranged the magnets along the axis of rotation of the wire loop, J, K, L and M, as shown below. They are having some trouble getting it to work.

They rotate the loop in the direction of the arrow, as shown.



a. Using physics concepts, explain why this orientation of the magnets will not generate an *EMF*.

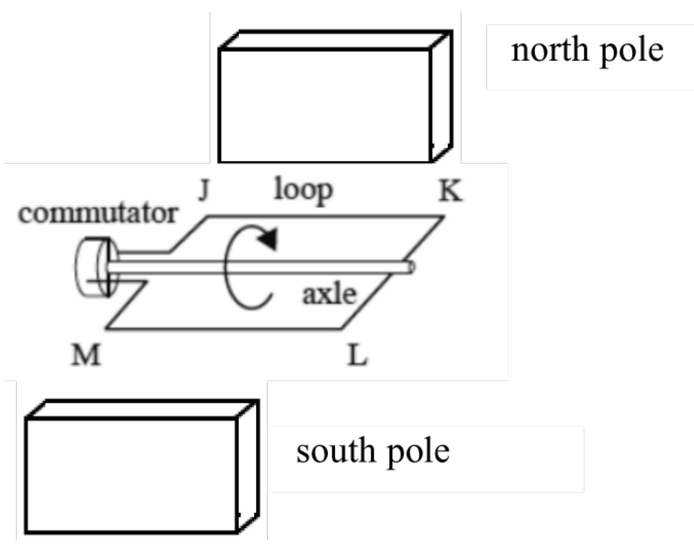
(2 marks)

b. Kim and Charlie decide to move the magnets so that an *EMF* is generated. On the diagram above draw the positions of the magnets to ensure that an *EMF* is generated.

(1 mark)

Solution

a An *EMF* is generated when there is a change in flux in the loop. The field is parallel to the loop - there is no magnetic flux passing through it. Therefore, no change in flux.



b Rotate the two magnets by 90°.

Chapter 13 Transformers and transmission

Question 1/ 28

The key principle involved in the operation of an electrical transformer is

A electromagnetic induction.

B Ohm's law.

C conservation of energy.

D conservation of momentum.

Solution

A Standard knowledge.

Question 3/ 28

The ratio of primary turns/secondary turns is closest to

A 0.03

B 0.3

C 3

D 30

Solution

D Use $\frac{V_1}{V_2} = \frac{N_1}{N_2}$.

Question 4/ 28

When a current of 600 mA flows in the primary coil, the current in the secondary is equal to (without energy losses)

A 18 mA

B 20 mA

C 18 A

D 20 A

Solution

C Step-down transformer; current increases; $\frac{V_1}{I_1} = \frac{V_2}{I_2}$.

Question 5/ 28

210 V_{RMS} is equal to

A 149 V_{PEAK}

B 297 V_{PEAK}

C 297 $V_{PEAK\text{-}PEAK}$

D 594 V_{PEAK}

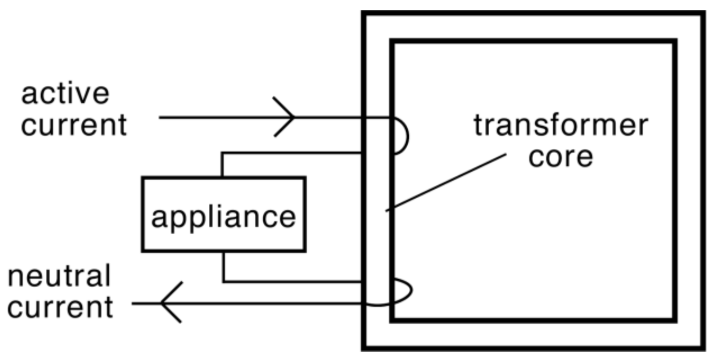
Solution

B $V_{\text{PEAK}} = \sqrt{2} \times V_{\text{RMS}}$.

Question 6/ 28

One form of household safety device, sometimes described as RCI, relies on detecting an *inequality* between the active and neutral currents in a circuit.

One method of detecting any inequality is shown in the diagram following. The active and neutral wires are both wound around the transformer core in opposite directions to each other.



When the AC active current is greater than the AC neutral current, which of the following best describes the situation in the transformer core?

A There is no flux through the transformer core.

B There is an increasing flux through the transformer core.

C There is a decreasing flux through the transformer core.

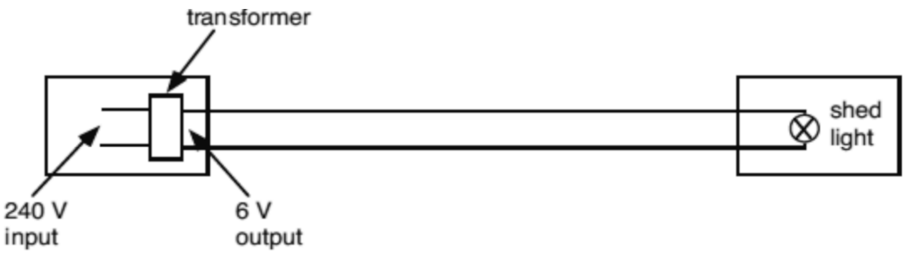
D There is a changing flux through the transformer core.

Solution

D One AC flux (from active current) $>$ AC flux from neutral current.

Question 7/ 28

Electricity for a light in a shed is supplied via a long piece of 2-core flex connecting the light to a 6 V transformer output.



When the shed light is turned on, it draws a current of 3.5 A RMS. Which of the following best describes the current in the shed light?

A A steady current of 3.5 A

B A varying current with a peak value of $+3.5$ A

C A varying current $(\text{peak value} \sim 5\ \text{A})$ but an average of 0 A

D A varying current $(\text{peak value} \sim 5\ \text{A})$ but an average of 3.5 A

Solution

C Current will be AC with an average of 0 and a peak value of 4.95 A.

Question 8/ 28

A DC motor with $R = 0.80\ \Omega$ needs at least 15 kW of electric power. Which of the following voltage values would be suitable?

A 24 V

B 60 V

C 90 V

D 120 V

Solution

D   Must be at least 109.5 V (from $P = \frac{V^2}{R}$).

Question 9/ 28

High AC voltages are used for the long-distance transmission of a fixed amount of electrical energy primarily because

A high voltages deter damaging bird strikes on the equipment.

B high voltages can mean higher currents and lower losses.

C high AC voltages are efficiently obtained using transformers.

D high voltages can mean lower currents and lower losses.

Solution

D   C is true but not the primary reason.

Question 10/ 28

Which one of the following voltage and current combinations would produce a power output closest to 120 W_{RMS}?

A 12 V DC and 10 A DC

B 12 V_{PEAK} AC and 10 A_{PEAK} AC

C 18 V_{PEAK} AC and 15 A_{PEAK} AC

D $34\ V_{P-P}$ AC and $10\ A_{P-P}$ AC

Solution

A The DC values are equivalent to RMS values.

Question 12/ 28

[VCAA 2017 SA Q4]

Which one of the following best gives the ratio of the number of turns, $N_{primary}$: $N_{secondary}$?

A 1:4

B 1:20

C 4:1

D 20:1

Solution

D Use $\frac{V_1}{V_2} = \frac{N_1}{N_2}$.

Question 13/ 28

[VCAA 2017 SA Q5]

The transformer delivers 48 W_{RMS} to a resistor. The transformer is ideal. Which one of the following best gives the peak current in the secondary coil?

A 0.2 A

B 4.0 A

C 5.7 A

D 11.3 A

Solution

C For ideal transformers, $N_1 I_1 = N_2 I_2$; then convert the RMS value to a peak value.

Question 15/ 28

[VCAA 2018 NHT SA Q5]

Which one of the following best gives the peak voltage of the input to the transformer?

A 171 V

B 240 V

C 339 V

D 480V

Solution

C $\text{Peak value} = \sqrt{2} \times \text{RMS}$ value.

Question 16/ 28

[VCAA 2018 NHT SA Q6]

The ratio of turns in the primary (input) to turns in the secondary (output) is best given by

A 15:1

B 1:15

C 24:1

D 1:24

Solution

A Use $\frac{V_1}{V_2} = \frac{N_1}{N_2}$.

Question 17/ 28

[VCAA 2018 NHT SA Q7]

The power input to the primary of the transformer is 30 W. Which one of the following best gives the RMS current in the secondary (output)?

A 0.50 A

B 1.9 A

C 8.0 A

D 15 A

Solution

B $\text{Power}_{\text{IN}} = \text{Power}_{\text{OUT}} = V_{\text{RMS}} \times I_{\text{RMS}}; 30 = 16I.$

Question 18/ 28

A proposed transformer will take 220 kV AC power and transform it to 66 kV, with an output power of 100 kW. There are 120 turns in the secondary coil. Which of the following gives the closest values for the number of turns in the primary coil, and the current in the secondary coil? (All values are RMS.)

A 36 turns, 1.5 A

B 400 turns, 1.5 A

C 400 turns, 0.7 A

D 36 turns, 0.7 A

Solution

B Use $\frac{V_1}{V_2} = \frac{N_1}{N_2}$ and $\text{Power}_{\text{IN}} = \text{Power}_{\text{OUT}} = V_{\text{RMS}} \times I_{\text{RMS}}.$

Question 19/ 28

Which of the following combinations will give a value of output power closest to 100 W (RMS)?

A 70 V (peak) and 2 A (RMS)

B 50 V (RMS) and 1.4 A (peak)

C 50 V (peak) and 2 A (peak)

D 100 V (peak to peak) and 2 A (peak)

Solution

A Convert values to RMS and use $P = VI$ (gives 99 W_{RMS}).

Question 20/ 28

When a DC supply (instead of AC) is connected to the primary coil of a transformer, there will be no continuous voltage generated in the secondary coil. The best reason for this is that

A the flux in the primary coil does not transfer to the secondary coil.

B the flux transfers to the secondary coil, but it does not vary with time.

C AC is required in the primary to generate any flux at all.

D DC causes a very high resistance in the coils as it is not time varying.

Solution

B Constant DC magnetic flux does not induce an emf.

Question 21/ 28

[Adapted VCAA 2019 NHT SA Q6]

A light globe operates correctly at 12 V_{RMS} AC power supply. If the light globe is operated using a battery instead of the mains supply, what voltage should the battery have for the light globe to operate correctly?

A 12 V

B 17 V

C 8.5 V

D 6.0 V

Solution

A This follows from the definition of RMS.

Question 23/ 28

[VCAA 2019 SA Q5]

Which of the following correctly identifies the parts labelled X and Y, and the function of the transformer?

A

Part X	Part Y	Function of transformer
primary coil	secondary coil	step-down

B

primary coil	secondary coil	step-up

C

secondary coil   primary coil   step-down

D

secondary coil   primary coil   step-up

Solution

B   Clearly X is the primary coil (input coil) and the larger number of turns in the secondary coil identifies the transformer as a step-up device.

Question 24/ 28

[VCAA 2019 SA Q6]

Which one of the following is closest to the RMS current in the primary circuit?

A 0.04 A

B 0.20 A

C 1.20 A

D 1.50 A

Solution

C   Assume the input power = output power (an ideal transformer), hence $40 \times I_P = \frac{240^2}{1200}$.

Question 25/ 28

[VCAA 2020 SA Q7]

An ideal transformer has an input DC voltage of 240 V, 2000 turns in the primary coil and 80 turns in the secondary coil. The output voltage is closest to

A 0 V

B 9.6 V

C $6.0 \times 10^3 \mathrm{V}$

D $3.8 \times 10^7 \mathrm{V}$

Solution

A Transformers do not work with DC voltages.

Question 26/ 28

[VCAA 2021 NHT SA Q6]

The mains voltage in a particular part of Australia is AC with a voltage of 240 V_{RMS}. Which one of the following is closest to the peak-to-peak voltage, $\mathrm{V}_{\mathrm{p-p}}$, for this mains voltage?

A 170 V

B 340 V

C 480 V

D 680 V

Solution

D   To find peak-to-peak voltage, multiply V_{RMS} by $2\sqrt{2}$.

Question 27/ 28

[VCAA 2021 NHT SA Q7]

Electrical power stations are often situated far from the cities that require the power that they generate. Which one of the following best describes the reason for the high-voltage transmission of electrical energy?

A Transformers can be used to increase the voltage in the cities.

B High voltages reduce the energy losses in the transmission lines.

C High voltages provide the large currents needed for efficient transmission.

D High voltages can reduce the overall total resistance in the transmission lines.

Solution

B   High voltage can reduce the current in the transmission lines and hence the I^2R losses.

Question 28/ 28

[VCAA 2021 SA Q7]

A mobile phone charger uses a step-down transformer to transform 240 V AC mains voltage to 5.0 V. The mobile phone draws a current of 3.0 A while charging. Assume that the transformer is ideal and that all readings are RMS.

Which one of the following is closest to the current drawn from the mains during charging?

A 48 A

B 16 A

C 1.2 A

D 0.06 A

Solution

D Use power in $(240 \times i) = \text{power out } (5.0 \times 3.0)$.

Question 29/ 28

[Adapted VCAA 2022 NHT SA Q5]

The ratio of the number of turns in an ideal step-up transformer is 1:350. An alternating RMS current of 30.0 mA is supplied to the primary coil. The RMS current in the output will be closest to

A 0 mA

B 0.086 mA

C 30.0 mA

D $1.1 \times 10^4 \text{mA}$

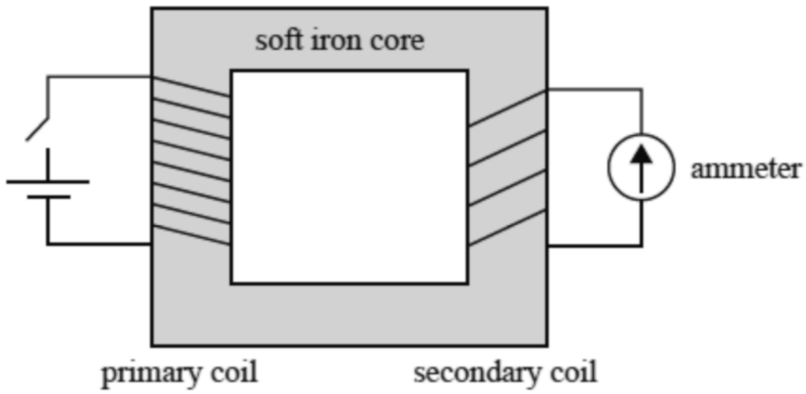
Solution

B Ideal step-up transformers will reduce the current; $N_1 I_1 = N_2 I_2$.

Question 30/ 28

[VCAA 2023 NHT SA Q5]

The diagram below shows an ideal transformer in which the primary coil is connected to a battery and a switch. An ammeter is connected to the secondary coil.



When the switch is closed, the pointer on the ammeter momentarily deflects. How could the deflection on the ammeter be made larger?

A decrease the number of primary coils

B decrease the number of secondary coils

C increase the number of secondary coils

D place a resistor in series with the ammeter

Solution

B $\text{Power in} = \text{Power out}$. Secondary coil voltage less (decrease in number of turns) so current larger.

Question 31/ 28

[VCAA 2023 NHT SA Q6]

An RMS current of 15.6 A is equivalent to a peak-to-peak current of

A 11.0 A

B 22.1 A

C 44.1 A

D 55.2 A

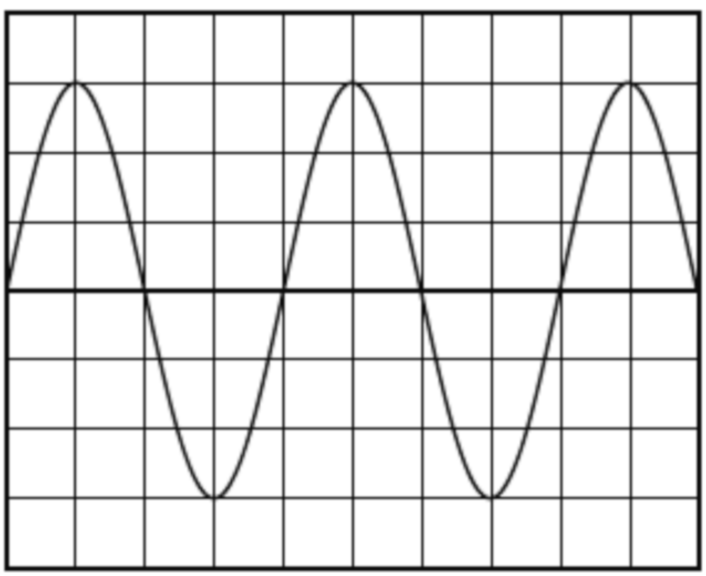
Solution

C To find peak-to-peak voltage, multiply V_{RMS} by $2\sqrt{2}$.

Question 32/ 28

[VCAA 2023 SA Q7]

An oscilloscope is connected to a sinusoidal AC voltage source. The resulting trace on the oscilloscope screen is shown on the next page. One vertical division on the oscilloscope screen represents a potential difference of 20 V, and one horizontal division represents a time interval of 10 ms.



Which one of the following is closest to both the peak-to-peak voltage and the frequency of the signal shown in the diagram?

A 42 V and 10 Hz

B 60 V and 25 Hz

C 120 V and 10 Hz

D 120 V and 25 Hz

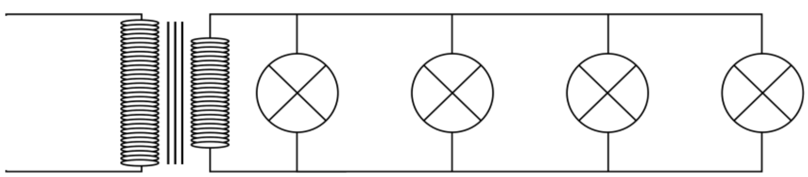
Solution

D The period is 4 divisions, therefore 40 ms, so the frequency must be 25 Hz.

The peak-to-peak voltage is 6 divisions, therefore 120 V.

Question 1/ 54

A transformer is used to provide a low voltage supply for decorative lighting on a tree in Syd's backyard. The circuit is represented below.



The input of the transformer is connected to 240 V AC. The globes in the circuit are designed to operate properly from 12 V AC.

a. If the transformer can be considered ideal, calculate the ratio:

$$\frac{\text{primary turns}}{\text{secondary turns}}$$

(2 marks)

b. Explain why the input of the transformer *must* be AC rather than smooth DC. Refer to the basic principle of physics involved.

(3 marks)

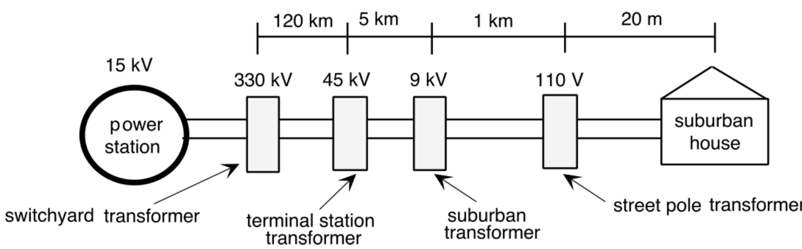
Solution

a 20 Use $\frac{V_1}{V_2} = \frac{N_1}{N_2}$.

b In the secondary coil, a changing flux is needed to cause an induced emf in it (Faraday's law), so the current in the primary must be AC to cause a changing flux in the transformer core.

Question 2/ 54

Electric power is delivered to an overseas city with a range of different transmission voltages. All the voltages and currents are RMS.



The power station generator produces energy at 15 kV. In the adjacent switchyard this is stepped up to 330 kV before transmission to the outer suburban area. The diagram shows the output voltages of the various transformers before delivery to each household at 110 V.

a. Calculate the value of the ratio:

$$\frac{\text{number of turns on secondary of switchyard transformer}}{\text{number of turns on primary of switchyard transformer}}$$

(1 mark)

At the primary of the street pole transformer, the current is 1.5 A, and the voltage is very close to 9 kV. The transformer can be assumed to have no significant power losses within it.

b. What RMS current flows in the secondary of the street pole transformer?

(2 marks)

c. Although the switchyard transformer produces electricity at 330 kV, the input voltage to the next transformer is 325 kV. Explain why this occurs, quoting relevant formulas. Use the symbol *R* for the resistance of the transmission lines.

(2 marks)

Solution

a 22 Use $\frac{V_1}{V_2} = \frac{N_1}{N_2}$.

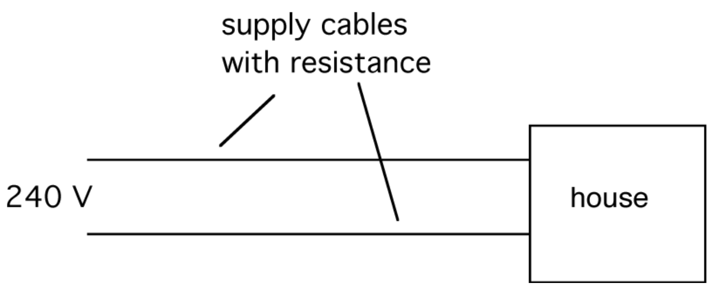
b 123 A Use $V_1 I_1 = V_2 I_2$.

c There are resistive losses in the transmission lines; the relevant formula is

$V_{\text{LOSS}} = I_{\text{LINES}} R$.

Question 3/ 54

A house in the country receives its electricity some kilometres from the main supply cables. The cables involved have resistance, which means that some voltage is ‘lost’ along them. The diagram below outlines the situation.



a. The voltage received at the country house changes, depending on the current being drawn by the house. Explain why this occurs.

(3 marks)

b. On one occasion, the voltage received at the house is measured as 225 V_{RMS}. The current being drawn at the time is 45 A_{RMS}. Calculate the resistance of the supply cables.

(2 marks)

Solution

a • The voltage at the house will be less than 240 V by an amount $V = IR$.

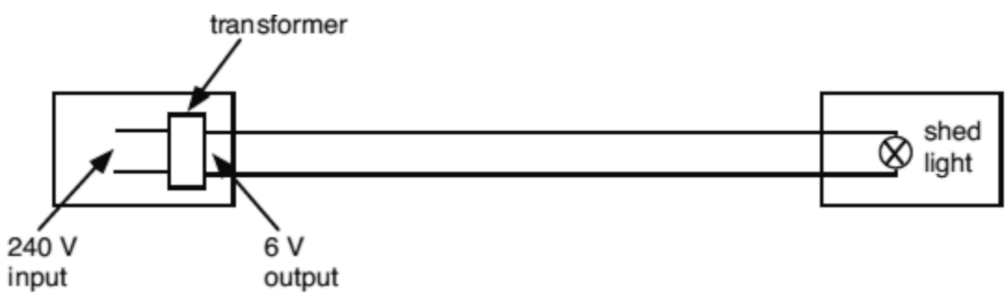
• I is the current drawn by the house; R the resistance of the supply cables.

- As the current varies, so will the voltage at the house.

b 0.33 Ω V_{loss} in $\text{wires} = 15\text{ V}$; use $V_{\text{loss}} = IR_{\text{wires}}$.

Question 4/ 54

Electricity for a light in a shed is supplied via a long piece of 2-core flex connecting the light to a 6 V transformer, whose output power is 21 W.



a. If the transformer input coil contains 960 turns, how many turns are there on the output coil?

(1 mark)

b. The wires to the shed have some resistance, with the result that the shed light operates off *less* than 6.0 V. The voltage at the light is 5.0 V. Calculate the total resistance of the wires leading out to the shed.

(2 marks)

c. Calculate the power dissipated in the wires leading out to the shed when the shed light is switched on.

(2 marks)

Solution

a 24 turns From $\frac{V_1}{V_2} = \frac{N_1}{N_2}$.

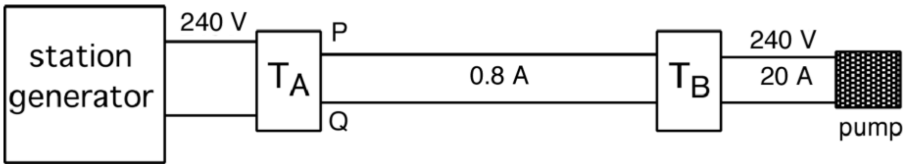
b 0.29 Ω The voltage drop in the wires (ΔV) is 1.0 V; find *I* from

$P(21) = V_{\text{OUTPUT}}\,(6) \times I$; then use $\Delta V = IR_{\text{WIRES}}$.

c 3.5 W Use $P = I^2R$ or $P = \Delta V \times I$.

Question 5/ 54

A system for delivering power to an isolated pump from the 240 V generator that supplies a cattle station is shown below.



Transformers T_A and T_B were installed to reduce the power loss in transmission (assume no power is lost in the transformers).

a. Explain why T_A and T_B increase the fraction of generator output power transferred to the pump. Your answer should clearly show the nature (step-up or step-down) of the transformers, and the physics involved.

(3 marks)

b. The RMS current in the transmission wires is 0.8 A. What is the output voltage V_{PQ} from T_A?

(2 marks)

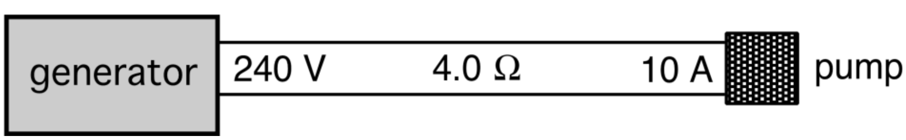
c. The primary coil of T_A consists of 100 turns of wire. How many turns of wire are in the secondary coil of T_A?

(2 marks)

d. If the transmission wires have a combined resistance of 4.0 Ω, what power is dissipated in these?

(2 marks)

Before the transformers were installed, wires connected the generator and pump directly. In this arrangement the pump drew 10 A.



e. Under this arrangement, how much power was lost in the cables?

(2 marks)

Solution

a Transformers allow power to the pump to be delivered at a higher voltage; so less current is flows along the wires, so less power I^2R is lost as heat in the wires.

T_A: step-up, T_B: step-down.

b 6000 V Power to $T_{\mathrm{B}} = \mathrm{power}$ to the pump. $V \times 0.8 = 240 \times 20$.

c 2500 turns $\frac{N_P}{N_S} = \frac{V_P}{V_S}$ giving $N_p = 100 \times \frac{6000}{240}$.

d 2.6 W Use $P = I^2R$.

e 400 W Use $P = I^2R$.

Question 6/ 54

A step-down transformer has a turns ratio of 20:1. It is designed to operate from the mains supply (240 V). It is used to produce higher currents than would normally be available from the mains supply.

a. The mains supplies 10 A_{RMS} at 240 V_{RMS}. What is the maximum RMS current the step-down transformer could supply from its secondary coil?

(2 marks)

b. It is undesirable to connect the secondary of such a transformer to high resistance loads if large currents are required. Explain why.

(3 marks)

Solution

a 200 A Use $V_1I_1 = V_2I_2$.

b A high resistance across the low-voltage secondary coil will restrict the maximum current (from Ohm's law).

Question 7/ 54

Explain why high voltages are used for the transmission of AC electricity over long distances.

(2 marks)

Solution

Power losses are minimised using high transmission voltages (and consequently lower currents, to keep total power the same); $P_{\text{LOSS}} = I^2R$ is the key formula.

Question 8/ 54

Transformers are often treated as being 'ideal' transformers.

a. With regard to the ratio of the power in: power out for a transformer, what is meant by saying a transformer is an 'ideal' transformer?

(2 marks)

b. A typical transformer for a smart phone feels warm when in use. Explain why this smart phone transformer is not an 'ideal' transformer.

(2 marks)

Solution

a $P_{\text{IN}} = P_{\text{OUT}}$. There is no loss of power in an ideal transformer.

b As some of the input power is lost as heat $(P_{\text{IN}} > P_{\text{OUT}})$ so the smart phone transformer cannot be considered as ideal.

Question 9/ 54

Early domestic electricity was supplied as DC. AC soon became preferred. Outline one key advantage that AC has over DC for domestic power supplies.

(2 marks)

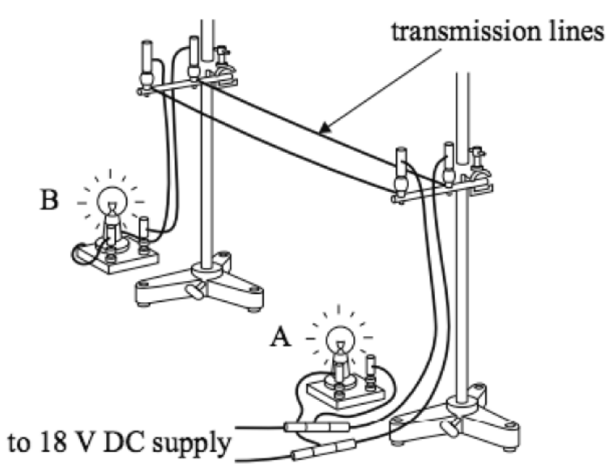
Solution

It is easy to change AC voltage size efficiently using transformers. It is also easier to transmit AC over long distances with low energy losses.

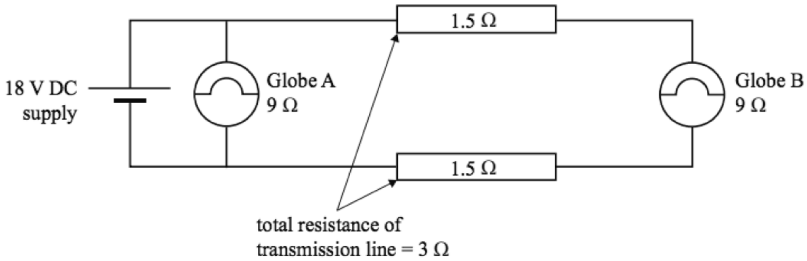
Question 10/ 54

[Adapted VCAA 2016 SA Q16]

Ruby and Max investigate transmission of electric power with a model system.



The circuit of the arrangement is shown below.



Ruby and Max use an 18 V DC power supply, as shown. The transmission lines have a *total* resistance of 3.0 Ω. The resistance of the globes is a constant 9.0 Ω, and that the other connecting wires have zero resistance.

a. Calculate the power delivered to Globe A.

(2 marks)

b. Calculate the total voltage drop over the transmission lines. Show your working.

(2 marks)

c. Calculate the power delivered to Globe B.

(3 marks)

Ruby notices the voltage supply to houses is AC and there are transformers used (on street poles and at the city edge). Ruby and Max next investigate the use of transformers to reduce power losses in transmission. They have two transformers – a 1:10 step-up transformer and a 10:1 step-down transformer.

d. Redraw the circuit above with an 18 V AC supply and with the transformers correctly connected. Label the transformers as step up and step down.

(2 marks)

e. Explain why transformers would reduce transmission losses. Your answer should include reference to key physics formulas and principles.

(3 marks)

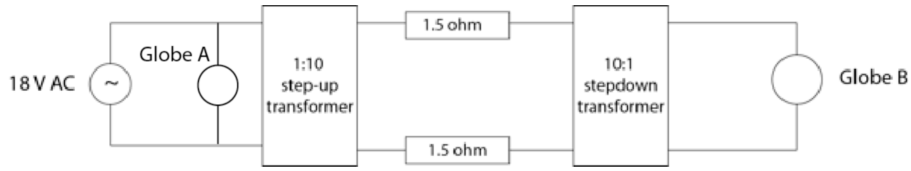
Solution

a 36 W Use $P = \frac{V^2}{R}$.

b 4.5 V $V_{\text{LOSS}} = I_{\text{LINES}} \times R_{\text{LINES}}; I_{\text{LINES}} = \frac{18}{12} = 1.5\ A$.

c 20(.25) W Easiest to use $P_{\text{LOSS}} = I^2 R = 1.5^2 \times 9$.

d



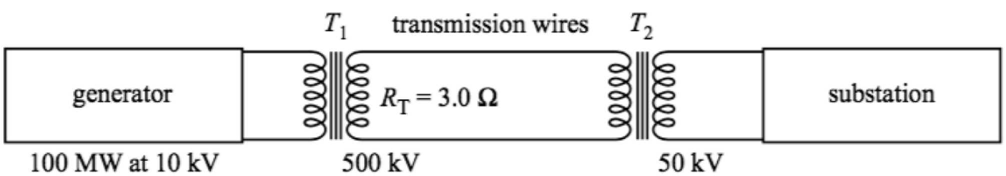
e Increased voltage means reduced current in lines for same power

$(P_{\text{IN}} = V_1 I_1 = V_2 I_2 = P_{\text{OUT}})$; lower I in lines means reduced $P_{\text{LOSS}} (= I_{\text{LINES}}{}^2 \times R_{\text{LINES}})$.

Question 11/ 54

[VCAA 2017 SB Q6]

The diagram shows a generator at an electrical power station that generates 100 MW_{RMS} of power at a voltage of 10 kV_{RMS} AC. Transformer T_1 steps the voltage up to $500 \text{kV}_{\text{RMS}}$ AC for transmission through transmission wires that have a total resistance, R_{T}, of 3.0 Ω. Transformer T_2 steps the voltage down to $50\ \text{kV}_{\text{RMS}}$ AC at the substation. Assume that both transformers are ideal.



a. The current in the transmission lines is 200 A. Calculate the total electrical power loss in the transmission wires.

(2 marks)

b. Transformer T_1 stepped the voltage up to $250\ \text{kV}_{\text{RMS}} \text{AC}$ instead of $500\ \text{kV}_{\text{RMS}}\ \text{AC}$. By what factor would the power loss in the transmission lines increase?

(2 marks)

Solution

a 120 kW Use $P = I^2 R$.

b $\times 4$ Calculate new current from $P = VI$; now recalculate power loss.

Question 12/ 54

A computer transformer rated at 140 W_{RMS} is connected to the mains 240 V_{RMS} electricity. It transforms the voltage to 28 V_{RMS}. Assume the transformer is ideal.

a. Calculate the current supplied to the transformer by the mains electricity.

(2 marks)

b. Calculate the current supplied to the computer by the transformer.

(2 marks)

Solution

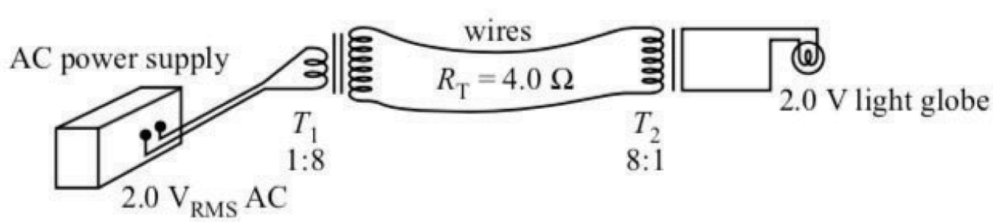
a 0.58 A $P = IV.\,140 = I\,(240).\,I = \ 0.58\text{A}.$

b 5.0 A Assuming no power lost $P = IV.\,140 = I\,(28).\,I = 5.0\ \text{A}.$

Question 13/ 54

[VCAA 2018 NHT SB Q5]

Students construct a model to show the transmission of electricity in transmission lines. The apparatus is shown below.



The students use two transformers, T_1 and T_2, with ratios of 1:8 and 8:1 respectively, and a 2.0 V_{RMS} AC power supply. Assume that the transformers are ideal. The students use a light globe that operates correctly when there is a voltage of 2.0 V across it. The wires of the transmission lines have a total resistance of 4.0 Ω. The students measure the current in the wires to be 0.50 A.

a. Calculate the power loss in the wires.

(2 marks)

b. Calculate the voltage across the light globe.

(4 marks)

c. The light globe does not operate correctly, as it would with a voltage of 2.0 V. Describe **one** change the students could make to the model to make the light globe operate correctly.

(2 marks)

Solution

a 1.0 W $\text{Power loss} = I^2R = 0.5^2 \times 4.$

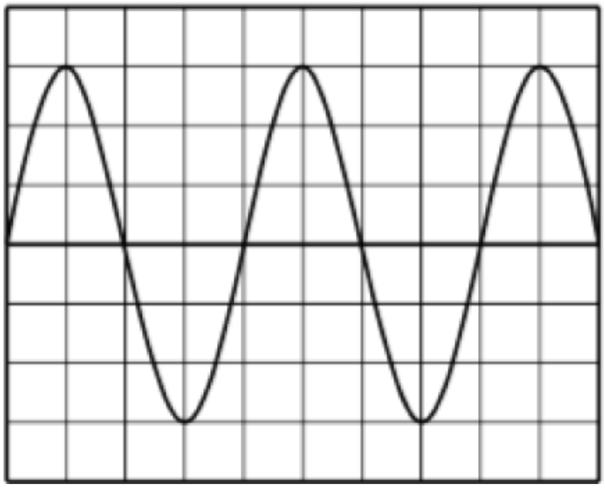
b 1.8 V (1.75) After first transformer, voltage is 16 V_{RMS}. Voltage loss in transmission lines is 2.0 V (from $V_{\text{LOSS}} = IR_{\text{LINES}}$). The final transformers then step this down from 14 V to $\frac{14}{8}$.

c Some changes include higher input voltage at start; lower resistance transmission lines, higher voltage in transmission lines using different transformers. All focus on keeping the final voltage at 2.0 V either by higher input or lower transmission losses.

Question 14/ 54

[Adapted VCAA 2017 Sample SB Q5]

An oscilloscope is connected to a sinusoidal AC source. The trace obtained on the oscilloscope screen, where one horizontal division represents a time of 20 ms and one vertical division represents 10 V, as shown below.



a. Calculate the RMS voltage for the signal shown in the diagram.

(2 marks)

b. Calculate the frequency for the signal shown in the diagram.

(1 mark)

Solution

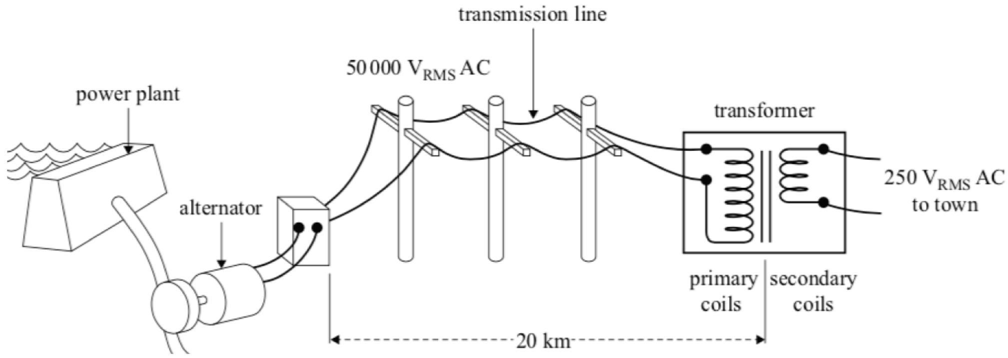
a 21 V $\text{Peak voltage} = 30\ \text{V}$; now divide by $\sqrt{2}$.

b 12 Hz Reciprocal of the period (80 ms).

Question 15/ 54

[Adapted VCAA 2017 Sample SB Q10]

A rural town is supplied with electricity from a small hydro-electric power plant 20 km from the town. The alternator generates electricity at 5000 V. This is stepped up in a transformer to 50 000 V. Electricity is transmitted to the town through a two-wire high-voltage transmission line. The input voltage to the transmission line at the alternator end is $50000\ \text{V}_{\text{RMS}}\text{AC}$. The current in the line is 15 A_{RMS}. At the edge of the town, a transformer converts the voltage to 250 V_{RMS} AC for use in the town. The total resistance of the transmission line is 40 Ω. The system is shown on the next page. The transformers are ideal.



a. Calculate the total power loss in the transmission line. Show your working.

(3 marks)

b. Calculate the voltage input from the transmission line to the step-down transformer at the town end of the line.

(3 marks)

c. Explain why AC rather than DC is generally used for long-distance power transmission. Include the steps involved in the process of long-distance power transmission.

(3 marks)

Solution

a 9000 W $\text{Power loss} = I^2R = 15^2 \times 40$.

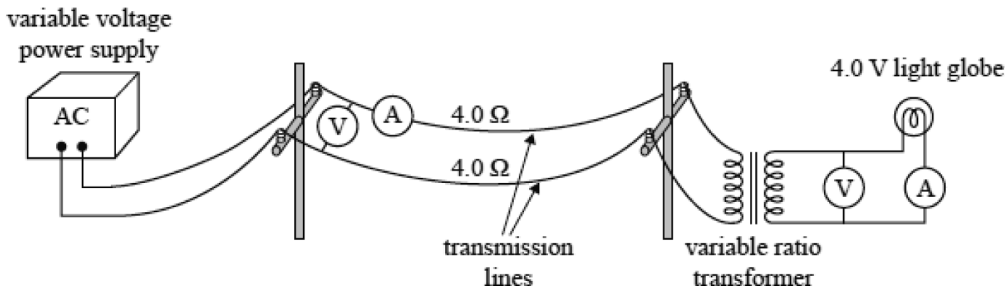
b 49.4 kV V drop in $\text{lines} = IR_{\text{WIRES}} = 600\text{ V}$.

c High voltages and low currents for the same power $(P = VI)$ reduce power losses $(P_{\text{LOSS}} = I^2R)$. One then needs to change the voltage down for domestic uses. However, whilst it is difficult to change DC voltages up and down, it is relatively easy and efficient to do this with AC by using transformers.

Question 16/ 54

[VCAA 2018 SB Q5]

A Physics class is investigating power loss in transmission lines. The students construct a model of a transmission system. They first set up the model as shown below. The model consists of a variable voltage AC power supply, two transmission lines, each of $4.0\ \Omega$ $(\text{total resistance} = 8.0\ \Omega)$, a variable ratio transformer, a light globe and meters as needed. The purpose of the model is to operate the 4.0 V light globe. A variable ratio transformer is one in which the ratio of turns in primary windings to turns in secondary windings can be varied. The resistance of the connecting wires can be ignored.



In their first experiment, the transformer is set on a ratio of 4:1 and the current in the transmission lines is measured to be 3.0 A. The light globe is operating correctly, with $4.0\ \mathrm{V_{RMS}}$ across it.

a. Calculate the power dissipated in the light globe. Show your working.

(2 marks)

b. Calculate the voltage output of the power supply. Show your working.

(3 marks)

c. Calculate the total power loss in the transmission lines. Show your working.

(2 marks)

In a second experiment, the students set the variable ratio of the transformer at 8:1 and adjust the variable voltage power supply so that the light globe operates correctly, with $4.0\ \mathrm{V_{RMS}}$ across it.

d. Calculate the total power loss in the transmission lines in this second experiment. Show your working.

(3 marks)

e. Suggest two reasons why high voltages are often used for the transmission of electric power over long distances.

(2 marks)

Solution

a 48 W Current in globe must be 12 A $(\text{input transformer current} \times 4)$; now use $P = V_{\mathrm{RMS}} \times I$.

b 40 W Voltage drop in lines = IR_{WIRES} = 24 V; V across input to $\text{transformer} = 4 \times 4.0 = 16\text{ V}$; add these values.

c 72 W $\text{Power loss in lines} = I^2R = 3.0^2 \times 8.0$.

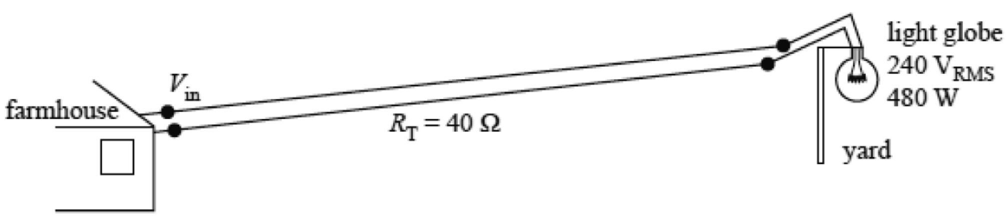
d 18 W Current in globe still 12 A; hence current in lines $= \frac{12}{8} = 1.5\text{A}$; now use $I^2R = 18$.

e Any two of the following: to reduce the current in the lines; to reduce power losses in the lines; to be able to use lighter (thinner) wires in the lines; to be able to use cheaper but higher resistance wires.

Question 17/ 54

[VCAA 2019 NHT SB Q4]

An electrician is installing a power supply to a yard located 500 m from a farmhouse in order to operate a 240 V_{RMS}, 480 W light globe, as shown in the diagram. The connecting wires have a total resistance, R_{T}, of 40 Ω. At the farmhouse, the electrician provides the required input voltage, V_{in}, to the connecting wires for the light globe to operate at 240 V_{RMS} and 480 W.



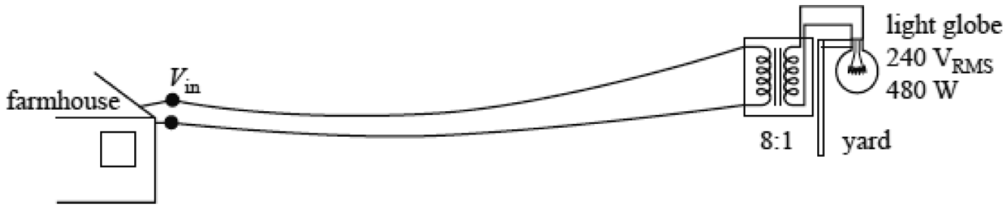
a. When the light globe is operating at 240 V_{RMS} and 480 W, what is the power loss in the connecting wires? Show your working.

(2 marks)

b. Calculate the RMS voltage of V_{in}. Show your working.

(3 marks)

c. To reduce the power loss in the connecting wires, the electrician changes the input voltage, V_{in}, and installs an 8:1 step-down transformer at the yard. After these changes, the light globe still operates at 240 V_{RMS} and 480 W, as shown in the diagram below.



Calculate the RMS power loss in the connecting wires for this new situation. Show your working.

(3 marks)

Solution

a 160 W Current in the light $\text{globe} = \frac{P}{V} = 2\ \text{A}$. Now use $P_{\text{loss}} = I^2R$.

b 320 V_{RMS} Voltage loss in $\text{wires} = IR_{\text{wires}} = 80\ V_{\text{RMS}}$.

c 2.5 W Current input to transformer must be $\frac{1}{8}$ of the current output $(\text{ideal transformer}) = 0.25\ \text{A}$. Now use $P_{\text{loss}} = I^2R$.

Question 18/ 54

[VCAA 2019 SB Q6]

A home owner on a large property creates a backyard entertainment area. The entertainment area has a low-voltage lighting system. To operate correctly, the lighting system requires a voltage of $12\ \text{V}_{\text{RMS}}$. The lighting system has a resistance of 12 Ω.

a. Calculate the power drawn by the lighting system.

(1 mark)

To operate the lighting system, the home owner installs an ideal transformer at the house to reduce the voltage from $240\ \text{V}_{\text{RMS}}$ to $12\ \text{V}_{\text{RMS}}$. The home owner then runs a 200 m long heavy-duty outdoor extension lead, which has a total resistance of 3 Ω, from the transformer to the entertainment area.

b. The lights are a little dimmer than expected in the entertainment area. Give one possible reason for this and support your answer with calculations.

(4 marks)

c. Using the same equipment, what changes could the home owner make to improve the brightness of the lights? Explain your answer.

(2 marks)

Solution

a 12 W Use $P = \frac{V^2}{R} = \frac{144}{12} = 12\text{ W}$.

b One of the following.

- The resistance of the system has increased by 3 Ω, now being 15 Ω rather than 12 Ω,, so the current will now change from 1.0 A_{RMS} down to 0.8 A_{RMS} through the lighting system, resulting in a power output of 7.68 W (using I^2R) rather than 12 W.

- The 12 V_{RMS} voltage will now be shared between the lighting system and the extension lead; the lighting system will now only receive 9.6 V, resulting in a smaller power output of $\frac{9^2}{12} = 7.68\text{ W}$.

Other methods are possible.

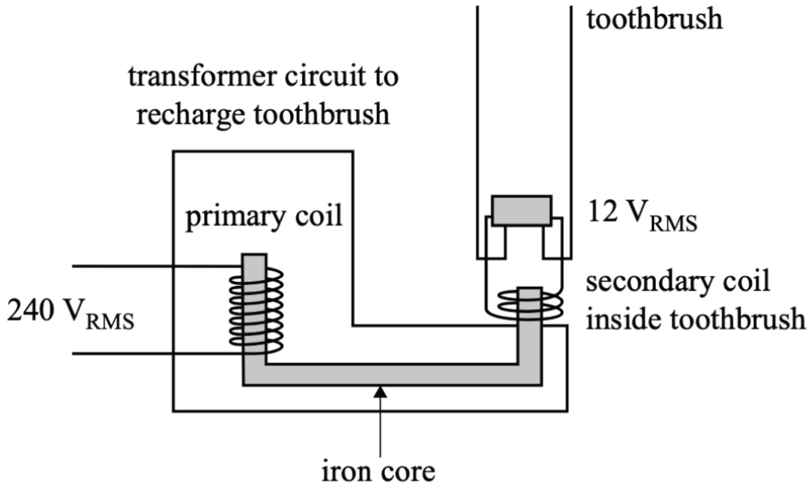
c Several possibilities, as follows.

- Use a lower resistance extension lead, reducing voltage/power losses in the lead.
- Connect a step-up transformer at the lighting system end of the lead, raising the voltage back to 12 V_{RMS}.
- Use lower voltage globes in the lighting system that have a higher power rating.

Question 19/ 54

[VCAA 2020 SB Q7]

A rechargeable electric toothbrush uses a transformer circuit, as shown in the diagram below. A secondary coil inside the toothbrush is connected, via an iron core, to a primary coil that is connected to the mains power supply. The mains power is 240 V_{RMS} and the toothbrush recharges at $12\ V_{RMS}$. The average power delivered by the transformer to the toothbrush is 0.90 W. Assume that the transformer is ideal.



a. Calculate the peak voltage in the secondary coil. Show your working.

(2 marks)

b. Determine the ratio of the number of turns $\frac{N_p}{N_s}$.

(1 mark)

c. Calculate the RMS current in the primary coil while the toothbrush is charging. Show your working.

(2 marks)

Solution

a 17 V Multiply V_{RMS} by $\sqrt{2}$.

b 20 Use $\frac{N_p}{N_s} = \frac{V_p}{V_s}$.

c 3.8 mA Use $P = V_p \times I_p$.

Question 20/ 54

[VCAA 2021 NHT SB Q7]

Angela and Janek are installing two low-voltage lights in their outdoor garden. They have a $240\ V_{RMS}$ AC transformer with an output voltage of $12\ \mathrm{V_{RMS}}$ AC. Each light has a constant resistance of 6.0 Ω. For the purposes of calculations, assume that the transformer is ideal.

a. Describe what is meant by an ideal transformer in terms of the input power and the output power.

(1 mark)

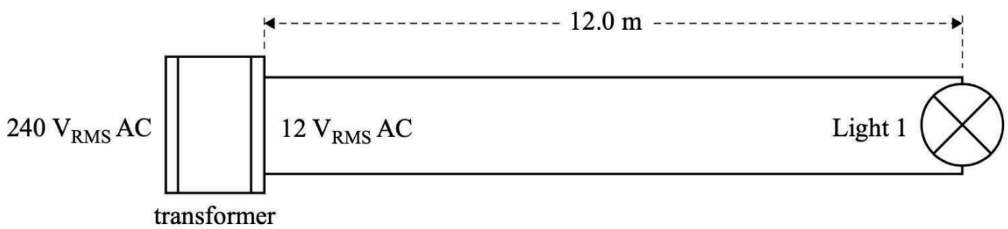
b. Calculate the ratio of the number of turns of the primary coil to the number of turns of the secondary coil.

(1 mark)

c. Each light is designed to operate at $12\ \mathrm{V_{RMS}}$. Calculate the power dissipated in one light when it is operated at $12\ \mathrm{V_{RMS}}$. Show your working.

(2 marks)

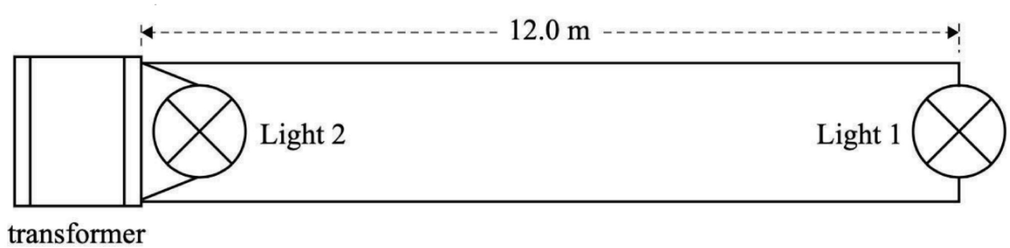
Angela and Janek now connect the first light, Light 1, to the transformer using two wires, each 12.0 m long, as shown below. Each wire has a resistance of 0.05 Ω per metre.



d. Calculate the RMS voltage across Light 1. Show your working.

(3 marks)

e. Angela and Janek now connect the second light, Light 2, directly across the secondary of the transformer, as shown below.



They thought that with the circuit shown above, Light 1 and Light 2 would be equally bright. However, they observed that Light 2 was brighter than Light 1.

Explain why Light 2 was observed to be brighter than Light 1.

(3 marks)

Solution

a In ideal transformers, the output power is equal to the input power.

b 20 Use $\frac{N_p}{N_s} = \frac{V_p}{V_s}$.

c 24 W Use $P = \frac{V^2}{R} = \frac{144}{6} = 24$ W.

d 10 V The 12 V is now shared between 1.2 Ω for the wires and 6 Ω for Light 1; this means Light 1 has 10 V and the wires 2 V. Alternatively, calculate the current ($I = \frac{12}{7.2}$) and then apply $V = IR$ to the light; $V = 12 \times \frac{6}{7.2} = 10$ V.

e The voltage across Light 2 is 12 V but the voltage across Light 1 is only 10 V.

Question 21/ 54

[VCAA 2021 SB Q7]

The generator of an electrical power plant delivers 500 MW to external transmission lines when operating at 25 kV. The generator's voltage is stepped up to 500 kV for transmission and stepped down to 240 V 100 km away (for domestic use). The overhead transmission lines have a total resistance of 30.0 Ω. Assume that all transformers are ideal.

a. Explain why the voltage is stepped up for transmission along the overhead transmission lines.

(2 marks)

b. Calculate the current in the overhead transmission lines. Show your working.

(2 marks)

c. Determine the maximum power available for domestic use at 240 V. Show all your working.

(3 marks)

Solution

a Transmission losses in the transmission lines are proportional to I^2, so transmitting power at lower currents reduced losses. However, to keep the same amount of power transmitted it is necessary to increase the voltage, which can be done by using a step-up transformer.

b 1.0 kA The transformer is ideal, so power in = power out. Hence, $500 \times 10^6 = 500 \times 10^3 \times I$.

c 470 MW Available power = input power – transmission losses. $\text{Losses} = I^2R = 1000^2 \times 30 = 30 \text{ MW}$.

Question 22/ 54

[Adapted VCAA 2022 NHT SB Q6]

A laptop computer requires a transformer to reduce the voltage to its rechargeable battery while the battery is charging. The power point supplies an RMS voltage of 240 V and delivers an RMS current of 0.35 A. The transformer converts the voltage to an RMS voltage of 8.0 V. Assume that the transformer is ideal.

a. Calculate the ratio of the number of turns $N_{\text{primary}}/N_{\text{secondary}}$. Show your working.

(2 marks)

b. Calculate the RMS current delivered by the power point while the battery is charging.

(2 marks)

Solution

a 30:1 Step-down transformer. Use $\frac{N_P}{N_S} = \frac{V_S}{V_P} = \frac{240}{8} = 30$.

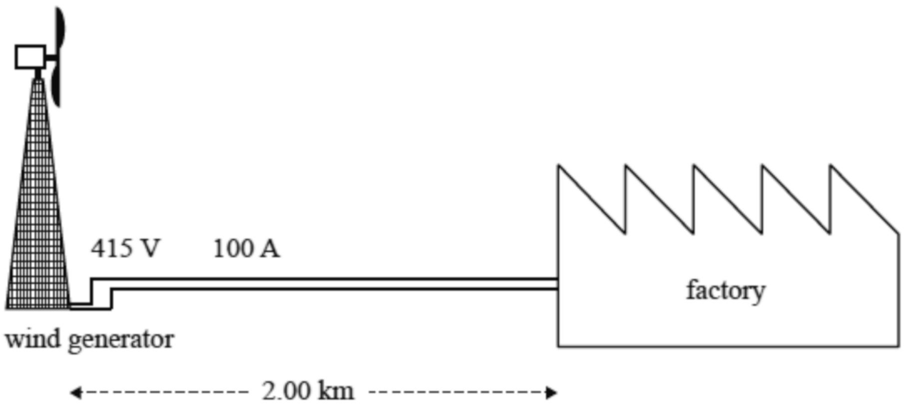
b 0.012 A $\text{Power in} = \text{power out}$; use $V_\text{P} I_\text{P} = V_\text{S} I_\text{S} = 240 \times I_\text{P} = 8 \times 0.35$.

Question 23/ 54

[VCAA 2022 SB Q5]

A wind generator provides power to a factory located 2.00 km away, as shown below.

When there is a moderate wind blowing steadily, the generator produces an RMS voltage of 415 V and an RMS current of 100 A. The total resistance of the transmission wires between the wind generator and the factory is 2.00 Ω.



a. Calculate the power, in kilowatts, produced by the wind generator when there is a moderate wind blowing steadily.

(1 mark)

b. To operate correctly, the factory's machinery requires a power supply of 40 kW. Determine whether the energy supply system, as shown, will be able to supply power to the factory when the moderate wind is blowing steadily. Justify your answer with calculations.

(3 marks)

c. The factory's owner decides to limit transmission energy loss by installing two transformers: a step-up transformer with a turns ratio of 1:10 at the wind generator and a step-down transformer with a turns ratio of 10:1 at the factory. Each transformer can be considered ideal. With the installation of the transformers, determine the power, in kilowatts, now supplied to the factory.

(3 marks)

Solution

a 41.5 kW $P = VI = 415 \times 100 = 41.5\ \mathrm{kW}.$

b No $P_{\text{loss}} = I^2R = (100)^2 \times 2 = 20\ \mathrm{kW}.$

$\text{Power at factory} = 41.5 - 20 < 40\ \mathrm{kW}.$

c 41.3 kW $I = 10\ \mathrm{A};\ P_{\text{loss}} = I^2R = 10^2 \times 2 = 200\ \mathrm{W}.$

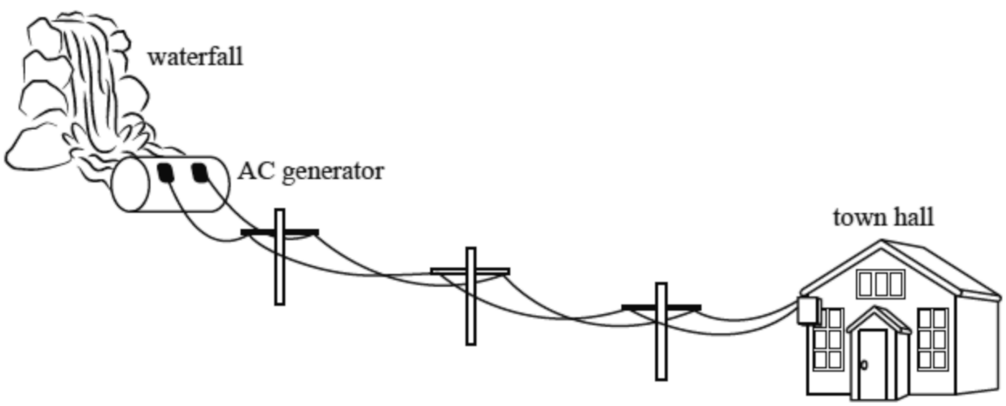
Power at factory $= 41.5 - 0.2 = 41.3$ kW.

Question 24/ 54

[VCAA NHT 2023 SB Q9]

A local community wishes to power its town hall using hydro-electricity. A waterfall drives an AC generator, with power delivered to the hall via transmission lines, as shown below.

The generator has an RMS power output of 4.2 kW when operating normally.



The town hall's electrical loads have a total resistance of 20 Ω and require 2.6 kW of RMS power when operating normally.

a. Calculate the RMS voltage at the town hall under these conditions. Show your working.

(2 marks)

b. Calculate the resistance of the transmission lines.

(3 marks)

c. Suggest two changes the community could make to the system that would reduce power losses without changing the output of the AC generator or the load at the town hall.

(2 marks)

Solution

a 228 V $P = \frac{V^2}{R} \rightarrow V = \sqrt{PR} = \sqrt{\left(2.60 \times 10^3\right)(20.0)} = 228 \text{ V.}$

b 12.3 Ω I in $\text{lines} = I$ at town $\text{hall} = \frac{V}{R} = \frac{228}{20.0} = 11.4 \text{ A.}$

$\text{Power loss across lines} = 4200 - 2600 = 1600 \text{ W.}$

$P_{\text{loss}} = I^2 R \rightarrow R = \frac{P}{I^2} = \frac{1600}{11.4^2} = 12.3\ \Omega.$

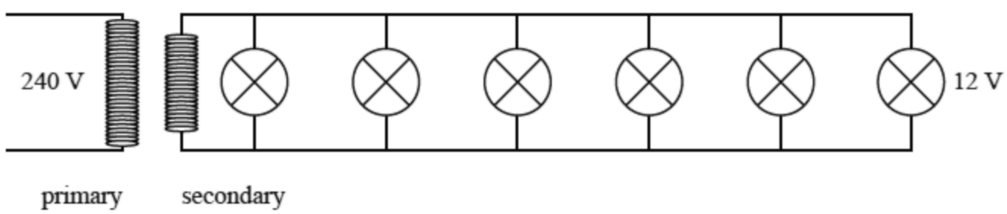
c • Use transmission lines of lower resistance.

• Use a step-up transformer at the generator end and a step-down transformer at the community hall end.

Question 25/ 54

[VCAA 2023 SB Q4]

A transformer is used to provide a low-voltage supply for six outdoor garden globes. The circuit is shown below. Assume there is no power loss in the connecting wires. All voltage values are RMS values.



The input of the transformer is connected to a power supply that provides an AC voltage of 240 V. The globes in the circuit are designed to operate with an AC voltage of 12 V. Each globe is designed to operate with a power of 20 W.

a. Assuming that the transformer is ideal, calculate the ratio of primary turns to secondary turns of the transformer.

(1 mark)

The globes are turned on.

b. Calculate the current in the primary coil of the transformer.

(2 marks)

c. Explain why the input current to the primary coil of the transformer must be AC rather than constant DC for the globes to shine.

(2 marks)

Solution

a 20 240 V: 12 V

b 0.5 A 6 globes @ $20 \text{ W} = 120 \text{ W}$

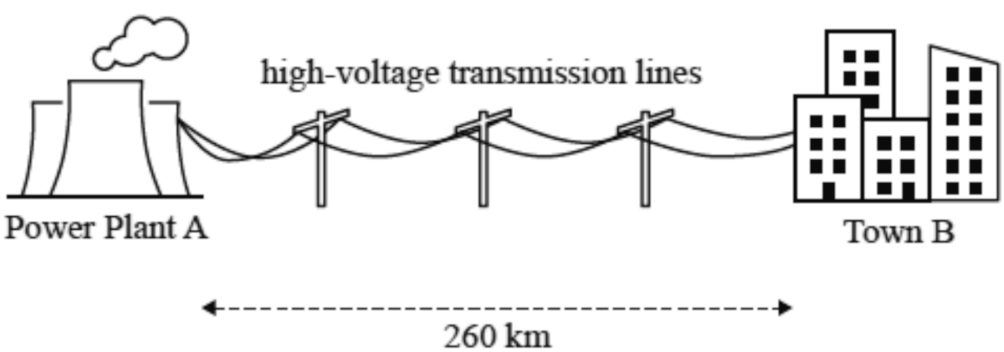
Use $P = IV \quad 120 = I(240)$

c Changing magnetic flux is required. Alternating current, AC, provides a changing magnetic flux but a constant direct current, DC, does not.

Question 26/ 54

[VCAA Adapted 2023 SB Q7]

Two high-voltage transmission lines span a distance of 260 km between Power Plant A and Town B, as shown on the next page. Power Plant A provides 350 MW of power. The potential difference at Power Plant A is 500 kV. The current in the transmission lines has an RMS value of 700 A and the power loss in the transmission lines is 20 MW.



a. Show, using calculations, that the total resistance of the two transmission lines is 41 Ω

(2 marks)

b. Town B needs a minimum of 480 kV.

Determine whether 480 kV will be available to Town B. Show your working.

(3 marks)

c. Explain what would happen if the electricity between Power Plant A and Town B were to be transmitted at 50 kV instead of 500 kV. Assume that the resistance of the transmission lines is still 41 Ω and the power supplied by Power Plant A is 350 MW.

(2 marks)

Solution

a $P_{LOSS} = I^2 R$

$R = \frac{(2 \times 10^7)}{700^2} = 40.8\ \Omega$

b No Voltage at Power Plant A is 500 kV

Voltage drop across wires is $= 700 \times 41 = 28.7\ \text{kV}$

$500 - 28.7 = 471.3\ \text{kV}$

Voltage at Town B is $471\ \text{kV} < 480\ \text{kV}$

c If power is constant then a lower a voltage increases current $(P = IV)$ so more power loss as $P_{LOSS} = I^2$ R.

Chapter 14 Interference, diffraction, standing waves

Question 1/ 30

When two sound waves meet, they

A pass through each other without being changed.

B reflect off each other.

C pass through each other, combining effects when they overlap.

D diffract off each other.

Solution

C Standard knowledge.

Question 2/ 30

A very large pipe in a science museum is open at both ends, as shown. It is large enough for people to walk inside it. A large loudspeaker faces one end. Jin is walking along the pipe.

During a demonstration, one frequency resonates strongly in the pipe.

Which of the following best explains the cause of this resonance?

A A standing wave is generated in the loudspeaker.

B Waves moving to the left from the loudspeaker reflect from Jin.

C Waves moving to the left from the loudspeaker reflect from the far end.

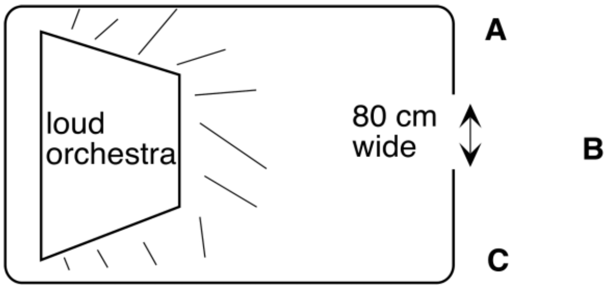
D Odd harmonics are formed in the pipe.

Solution

C Standard standing wave formation.

Question 3/ 30

An orchestra is playing in a hall with an open door; it is 80 cm wide. The speed of sound is $320 \mathrm{~m} \mathrm{~s}^{-1}$. Which of the following statements is likely to be true?



A Listeners at A and C can hear all notes below 400 Hz clearly.

B Listeners at B can only hear frequencies above 400 Hz.

C Listeners at A and C can hear all frequencies clearly.

D Listeners at A and C can only hear frequencies above 400 Hz.

Solution

A Low frequencies diffract strongly from doorway.

Question 4/ 30

Telescopes observing distant stars produce sharper images when the diameter of their viewing aperture is increased. This is likely to because

A they gather sharper light.

B the larger aperture reduces spread due to diffraction.

C the larger area smooths out minor fluctuations.

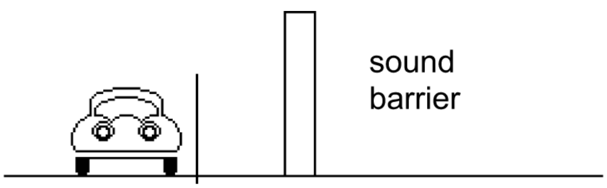
D the larger aperture prevents interference effects.

Solution

B Standard diffraction theory.

Question 5/ 30

Sound barriers at the side of freeways are more effective at reducing high-frequency sounds (e.g. 2000 Hz sirens) than low-frequency noises (e.g. 200 Hz noises from trucks). Which *one or more* of the following best explains this?



A Sounds of 200 Hz have a relatively long wavelength.

B Sounds of 200 Hz have a relatively short wavelength.

C Short wavelength sounds diffract easily around the barrier.

D Long wavelength sounds diffract easily around the barrier.

Solution

A, D Standard diffraction theory.

Question 7/ 30

[Adapted VCAA 2015 SB Q10]

The students increase the frequency to 3000 Hz. Which one of the following is most likely to be observed?

A The edge of the pattern will still be about 1.5 m from the centre line.

B The edge of the pattern will be closer to the centre line.

C The edge of the pattern will be further out than 1.5 m.

D There will now be no edge of the pattern.

Solution

B Standard diffraction theory.

Question 8/ 30

[VCAA 2015 B Q11]

The students now repeat the experiment in their classroom, but do not observe such a clear edge to the pattern. Which one of the following is the most likely reason for this?

A The room is too big for the wavelength.

B The room is too small for the wavelength.

C The doorway allowed a proportion of the sound to escape and so destructive interference did not occur completely.

D Reflection from walls and ceiling of the classroom mean that destructive interference does not occur completely at the edge of the pattern.

Solution

D Only possible option.

Question 9/ 30

The distance from Earth to the Moon is measured using a laser beam focused by a mirror. The beam is aimed at a reflector on the Moon surface; the time for the journey is measured. When the beam leaves Earth, it is a few metres wide, but when it reaches the Moon it is over 6 km wide. The best explanation is that

A the vacuum of space allows the beam to spread over the long distance.

B the aperture of the focusing mirror gives rise to diffraction.

C there is a limit to the ability of the mirror to focus.

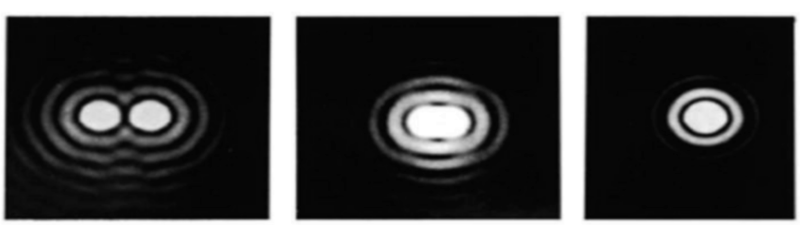
D the diameter of the focusing mirror is too great.

Solution

B Standard diffraction theory.

Question 10/ 30

When cars with two headlights are a long way away on a straight road, it is hard to tell that there are *two* headlights; our eyes cannot resolve the two objects.



close for away

If the headlights gave out *violet* light, they would be easier to resolve, because

A the wavelength of violet light is less than the average wavelength of white light.

B the wavelength of violet light is longer than the average wavelength of white light.

C the speed of violet light is the faster than the speed of white light.

D the speed of violet light is slower than the speed of white light.

Solution

A There is less diffraction at shorter wavelengths.

Question 11/ 30

A beam of electromagnetic radiation of frequency $1 \times 10^{15} \mathrm{Hz}$ is directed at a hole of diameter 0.1 mm. A circular diffraction pattern is detected 10 m from the hole, with a diameter of 6 mm. When the hole is changed for one of diameter of 0.2 mm, and the radiation is changed to a frequency $5 \times 10^{14} \mathrm{Hz}$, the pattern is likely to be circular, with a diameter close to

A 3 mm

B 6 mm

C 12 mm

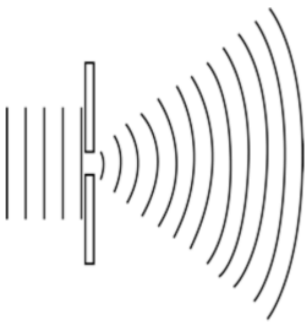
D 60 mm

Solution

B Standard diffraction theory.

Question 12/ 30

When small water waves are directed at a barrier with a small gap, diffraction results, as shown in the somewhat idealised diagram below.



Students decrease the period of the water waves. Which of the following best describes what they are now likely to see in the waves to the right of the gap?

A The pattern will be unchanged.

B The pattern will spread further.

C The pattern will become narrower.

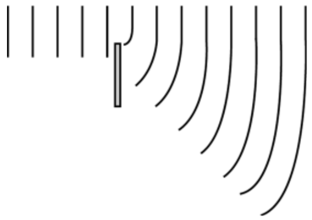
D The wavelength will increase, but the spread will remain the same.

Solution

B Both wavelength and diameter have increased by ×2.

Question 13/ 30

Water waves striking a barrier can change direction, as in the diagram below.



This is most likely an example of

A diffraction

B refraction

C reflection

D dispersion

Solution

C   Shorter period means higher frequency means shorter λ.

Question 14/ 30

Plucking a guitar string causes a resonance in that string. This is due to a

A standing wave in the string due to superposition of longitudinal waves.

B standing wave in the string due to superposition of transverse waves.

C transverse and a longitudinal wave superimposing.

D string being of a special length.

Solution

B   Standing wave formation in strings works like this.

Question 15/ 30

Marching soldiers crossing bridges are asked to ‘break step’ to avoid large amplitude oscillations. Which of the following best describes the conditions for this?

A Such resonances only occur when the bridge is of a special length.

B A large number of people walking can, on its own, cause resonances.

C A regular marching frequency always causes resonances of this kind.

D The marching frequency corresponding to the natural vibration frequency.

Solution

D Standard conditions for resonance.

Question 16/ 30

Which of the following best describes what happens to a two-slit interference pattern when the slits are moved apart?

A The dark and light bands become less widely separated.

B The dark and light bands become more widely separated.

C The wavelength of the light is increased.

D The wavelength of the light is reduced.

Solution

A Use $\Delta x = \frac{\lambda L}{D}$.

Question 17/ 30

Which *one or more* of the options above describes what happens to a two-slit interference pattern when the medium is changed to one of greater refractive index (for example, air is changed to water)?

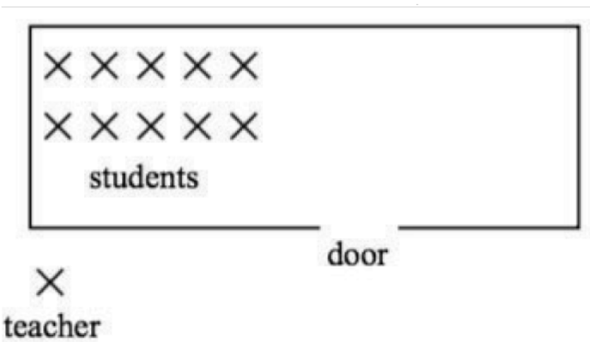
Solution

A, D Wavelength is shorter, apply $\Delta x = \frac{\lambda L}{D}$.

Question 18/ 30

[VCAA 2017 SA Q14]

A teacher stands in the corridor a short distance from the open door of her classroom, as shown in the diagram. She can hear the students, but cannot see them.



Which one of the following best explains why the teacher can hear her students?

A The speed of sound is much greater than the speed of light.

B The speed of sound is comparable with the speed of light.

C Sound diffracts because the wavelength of sound is much smaller than the width of the door.

D Sound diffracts because the wavelength of sound is comparable with the width of the door.

Solution

D Diffraction causes the necessary spreading of the sound; the greater the wavelength the more the diffraction; the wavelength of sound is much larger than that of light and is also comparable with the doorway width.

Question 19/ 30

Jannie is standing between two loudspeakers at a sporting ground. They are being tested with a note of a single frequency of 340 Hz. The loudspeakers emit sound reasonably well in all directions.

When she stands midway between the speakers the sound is quite loud, but as she moves away from this point towards either speaker the sound gets softer. Which of the following best helps explain why this happens?

A Waves from each speaker arrive at the central point in phase.

B Waves from each speaker have a path difference of an exact whole number of wavelengths everywhere.

C Waves from each speaker have a path difference of exactly zero everywhere.

D The speakers are specially designed to keep in phase everywhere.

Solution

A The central point is one of constructive interference; when she moves from here destructive interference starts to occur.

Question 21/ 30

[VCAA 2017 Sample SA Q15]

Which one of the following statements best indicates how we interpret the motion of the guitar string shown above?

A It is the result of two transverse waves travelling along the string in the same direction.

B It is the result of two transverse waves travelling along the string in opposite directions.

C It is the result of two longitudinal waves travelling along the string in the same direction.

D It is the result of two longitudinal waves travelling along the string in opposite directions.

Solution

B Standard knowledge.

Question 22/ 30

[VCAA 2017 Sample SA Q16]

S is a point on the guitar string, as on the previous page. For the instant *immediately after* that shown on the previous page, the direction in which point S on the guitar string will move is

A upwards.

B to the left.

C to the right.

D downwards.

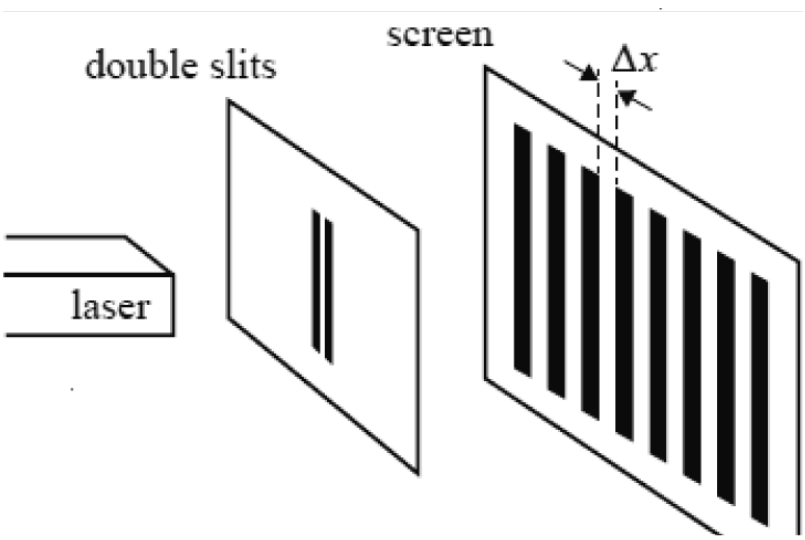
Solution

D It has reached the point of maximum displacement from zero and is about to travel downwards.

Question 23/ 30

[VCAA 2018 SA Q12]

A teacher sets up an apparatus to demonstrate Young's double-slit experiment. A pattern of bright and dark bands is observed on the screen, as shown below.



Which one of the actions below will increase the distance, Δx, between the adjacent dark bands in this interference pattern?

A Decrease the distance between the slits and the screen.

B Decrease the wavelength of the light.

C Decrease the slit separation.

D Decrease the slit width.

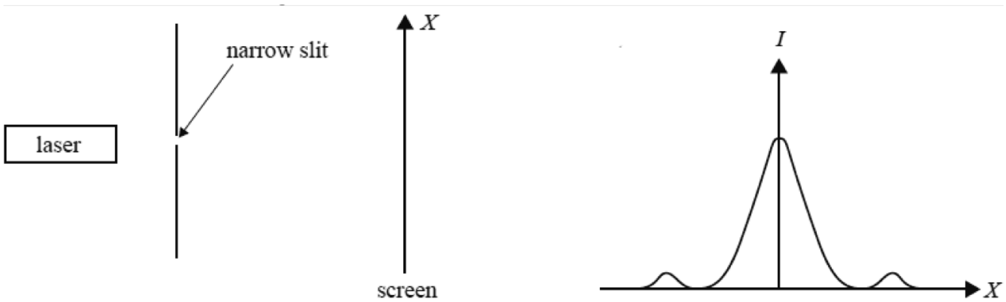
Solution

D Use approximate relationship $\Delta x = \frac{\lambda L}{D}$.

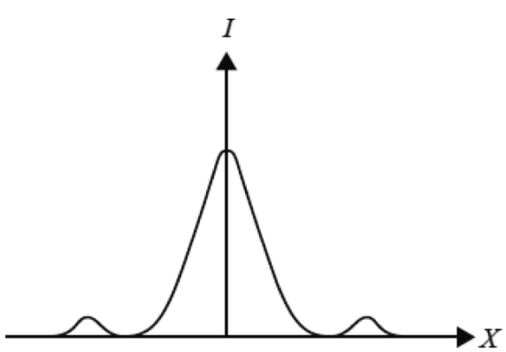
Question 24/ 30

[VCAA 2019 NHT SA Q15]

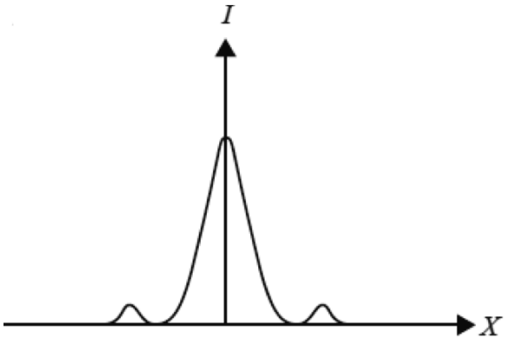
Monochromatic laser light of wavelength 600 nm shines through a narrow slit. The intensity of the transmitted light is recorded on a screen some distance away, as shown below in the diagram on the left. The intensity graph of the pattern seen on the screen is shown below on the right.



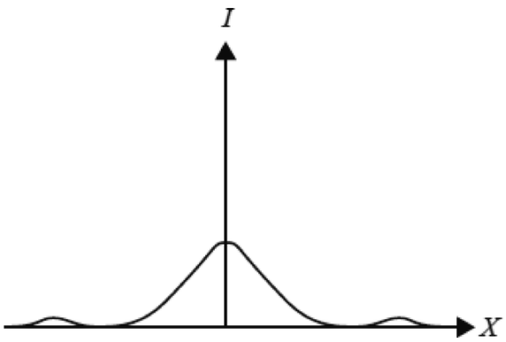
Which one of the following intensity graphs best represents the pattern that would be seen if a slightly wider slit were used?

A


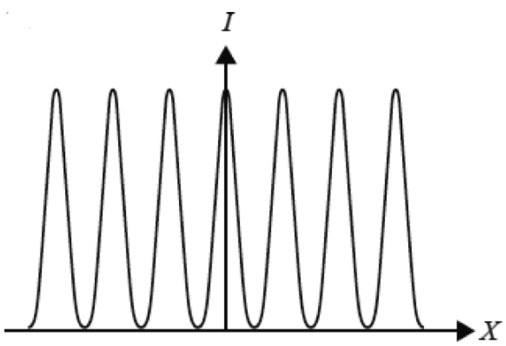
B



C



D



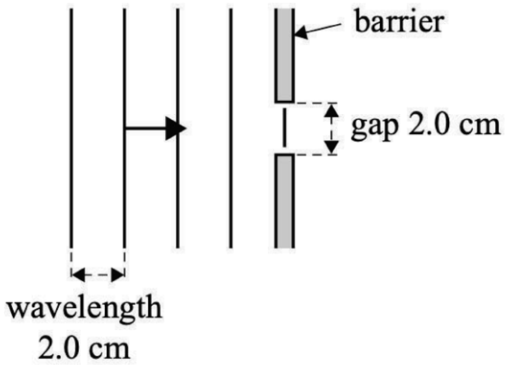
Solution

B Standard situation; wider slit means narrower pattern.

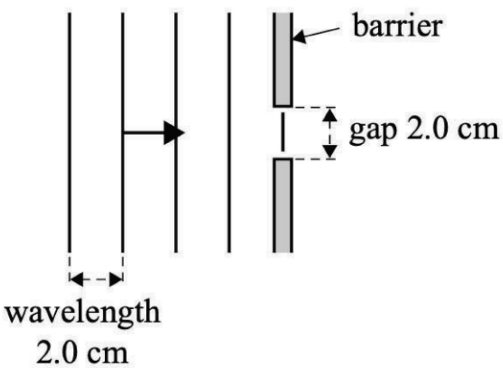
Question 25/ 30

[VCAA 2020 SA Q14]

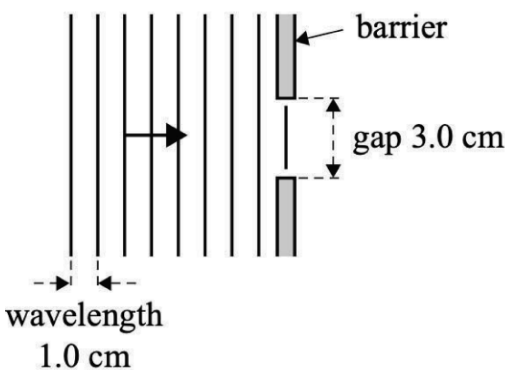
Students are investigating the diffraction of waves using a ripple tank. Water waves are directed towards barriers with gaps of different sizes, as shown below. In which one of the following would the greatest diffraction effects be observed?



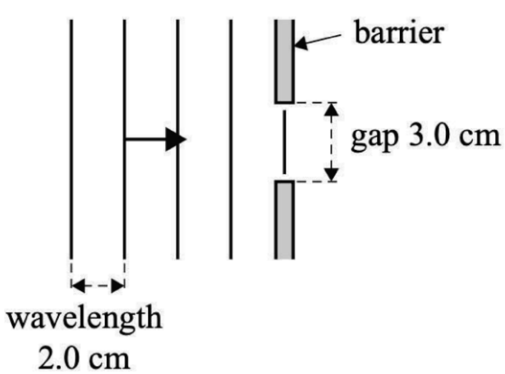
A



B



C



D

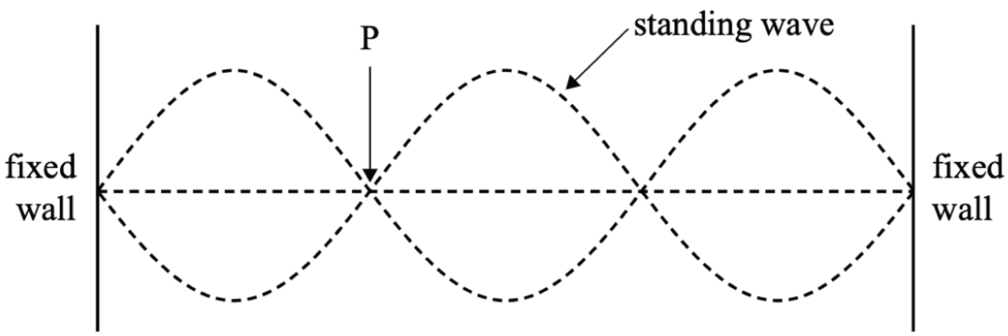
Solution

B   The amount of diffraction is proportional to the ratio $\frac{\lambda}{w}$.

Question 26/ 30

[VCAA 2021 NHT SA Q14]

The diagram below represents a standing wave.



The point P on the standing wave is

A a node resulting from destructive interference.

B a node resulting from constructive interference.

C an antinode resulting from destructive interference.

D an antinode resulting from constructive interference.

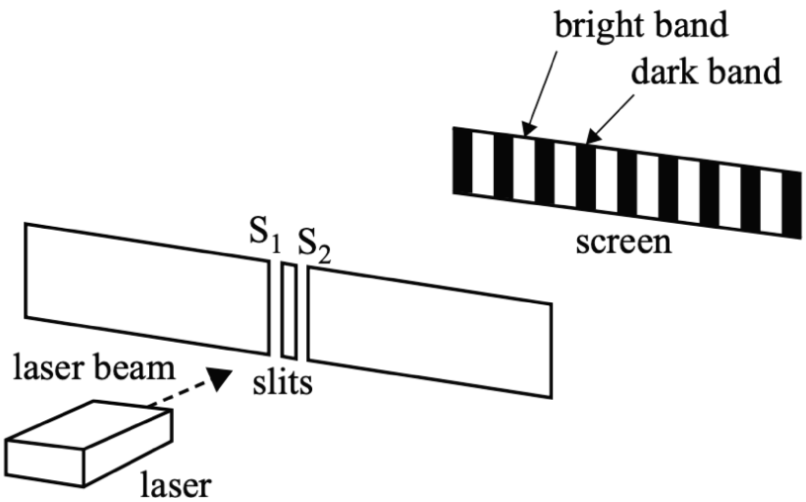
Solution

A   The point P is a node where destructive interference occurs between waves travelling from the left and waves travelling from the right.

Question 27/ 30

[VCAA 2021 NHT SA Q16]

A red laser used in a double-slit experiment creates an interference pattern on a screen, as shown below.



The red laser is replaced with a green laser. Which one of the following best explains what happens to the spacing between adjacent bright bands when the green laser is used?

A The spacing increases.

B The spacing decreases.

C The spacing stays the same.

D The spacing cannot be determined from the information given.

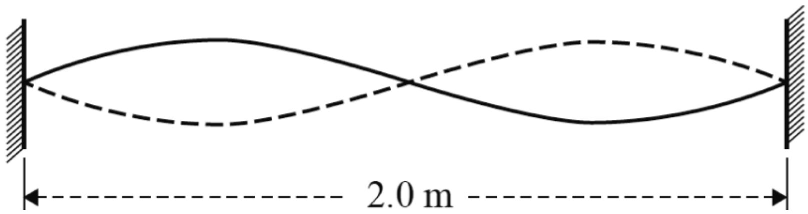
Solution

B Green light has a shorter wavelength than red light, so the interference will be less spread out.

Question 28/ 30

[VCAA 2022 NHT SA Q12]

The diagram below represents a standing wave on a string fixed at both ends, with a node at the centre. The wave has a frequency of 5.0 Hz and the distance between the two fixed ends is 2.0 m.



A 0.40 m s^{-1}

B 2.5 m s^{-1}

C 5.0 m s^{-1}

D 10 m s^{-1}

Solution

D Identify $\lambda = 2.0 \text{ m}$ (standing wave pattern), then use $v = f\lambda$.

Question 29/ 30

[VCAA 2022 NHT SA Q19]

Diffraction is a property of waves. Electrons display wave-like properties when producing diffraction patterns. This is because electrons

A always carry an electric charge.

B can move around nuclei in fixed orbits.

C have a wavelength related to their momentum.

D can jump between energy levels within an atom.

Solution

C Electrons have a de Bröglie wavelength given by $\lambda = \frac{h}{p}$.

Question 30/ 30

[VCAA 2022 SA Q13]

A travelling wave produced at point A is reflected at point B to produce a standing wave on a rope, as represented in the diagram below.

The distance between points A and B is 2.4 m. The period of vibration of the standing wave is 1.6 s. The speed of the travelling wave along the rope is closest to

A 0.75 m s^{-1}

B 1.0 m s^{-1}

C 1.5 m s^{-1}

D 2.0 m s^{-1}

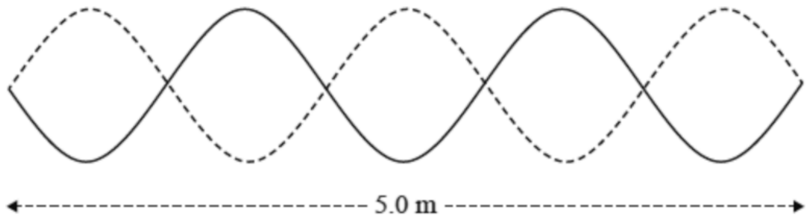
Solution

A $v = \frac{\lambda}{T} = \frac{1.2}{1.6} = 0.75 \text{ m s}^{-1}$.

Question 31/ 30

[VCAA 2022 NHT SA Q19]

A standing wave is produced on a flexible string, as shown in the diagram below. The diagram shows the wave at two different times – the solid line represents what the wave looks like at a particular time and the dotted line represents what the wave looks like exactly half a cycle later.



Which one of the following is closest to the wavelength of the standing wave?

A 0.5 m

B 1.0 m

C 1.5 m

D 2.0 m

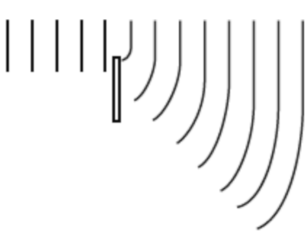
Solution

D $2.5\lambda = 5.0$ m.

Question 32/ 30

[VCAA 2023 SA Q16]

Water waves travelling at constant speed and hitting a barrier can change direction, as shown in the diagram below.



Which one of the following best identifies this phenomenon?

A diffraction

B dispersion

C refraction

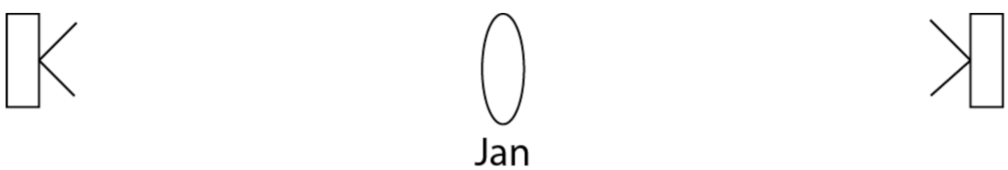
D resonance

Solution

A The change of direction of a wavefront as it moves past a barrier is called diffraction.

Question 1/ 67

Jan is standing midway between two speakers. They are emitting sound in phase, at 175 Hz, and she hears a loud sound of that frequency. Assume that Jan does not have any effect on the sound waves.



The speakers are 10 m apart. As she moves to the left, the sound intensity falls. When she is 4.5 m from the left-hand speaker, the intensity reaches a minimum.

a. Explain why the intensity drops to a minimum.

(3 marks)

b. Calculate the wavelength of the 175 Hz sound.

(2 marks)

c. Use this data to calculate the speed of sound.

(2 marks)

d. Describe the nature of the sound wave that forms in the space between the two loudspeakers.

(2 marks)

Solution

a This is a point of destructive interference with path $\text{difference} = \frac{1}{2}\lambda$.

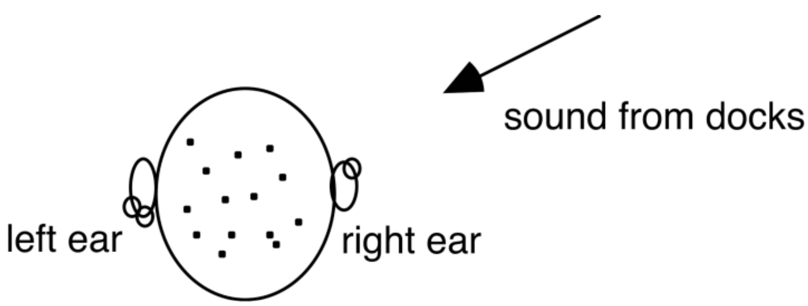
b 2.0 m If $\frac{1}{2}\lambda = 1.0\ \text{m}$, then $\lambda = 2.0\ \text{m}$.

c $350\ \text{m s}^{-1}$ Use $v = f\lambda$.

d A standing wave is formed; two equal waves travelling in opposite directions superpose.

Question 2/ 67

Dan is listening to a ship whistle coming from the docks.



Dan can tell where the sound is coming from by comparing the intensities in each of his ears. Explain why Dan would find it harder to locate low-frequency sound than high-frequency sound.

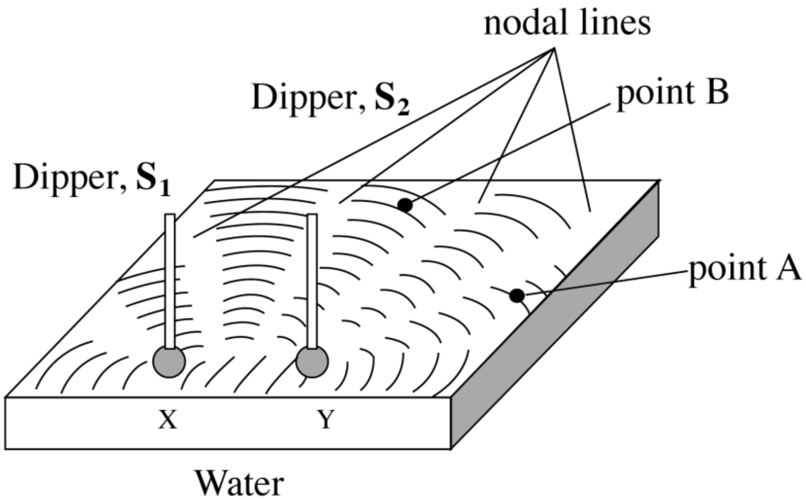
(2 marks)

Solution

The low frequency sounds will diffract easily around his head and reach the more ‘distant’ ear; the high frequency sounds will not do this.

Question 3/ 67

Two dippers make circular waves in phase in a shallow tank of water, as shown.



The dark lines in the diagram show areas of water where there is no wave motion in the water. Between these dark lines (nodal lines), water waves are travelling away from the dippers; the bright sections are wave crests. Point B is equidistant from X and Y.

a. Explain why there are travelling waves in some parts of the tank and flat water in other parts.

(3 marks)

X is the point where dipper S_1 touches the water, and Y the point where S_2 touches. The wavelength of the travelling water waves is 1 cm.

b. Find the distance $(AX - AY)$ in cm.

(1 mark)

c. Describe the movement of the water along the line joining points X and Y, giving your reasoning.

(3 marks)

d. The speed of the water waves is $5\ \text{cm s}^{-1}$. Calculate the period of the dippers (in seconds).

(2 marks)

e. Discuss the effect on the pattern of nodal lines if each of these changes was implemented:

• reducing the distance XY

• increasing the frequency of the dippers.

(4 marks)

Solution

a There are travelling waves where there is constructive interference between the waves from the two dippers; these correspond to path differences of a whole number of wavelengths. The flat areas are where there is destructive interference; here the path difference is an odd number of half wavelengths.

b 2 cm A is on the second constructive line of interference from the central line (that B is on); therefore, the path difference is two whole wavelengths.

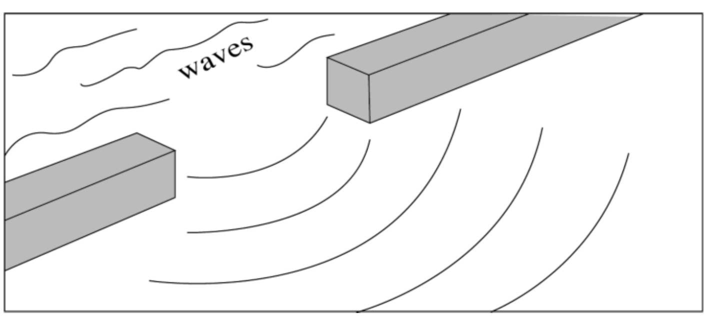
c There will be a standing wave along this line, as two equal and opposite waves are superposing. There will be nodes (flat spots) every 0.5 cm.

d 0.2 s Use $v = \frac{\lambda}{T}$.

e Reducing the distance XY would cause a broadening of the pattern of nodal lines (flat water) and antinodal lines (travelling waves). Increasing the frequency of the dippers would have the opposite effect, narrowing the spread.

Question 4/ 67

Straight water waves are incident on a narrow opening at a harbour, as shown.



Boat owners in the harbour would like to reduce the amount that the waves spread out as they travel through the opening. Some suggest that a narrower opening would reduce both the spreading and the amount of wave energy entering the harbour. Evaluate this response.

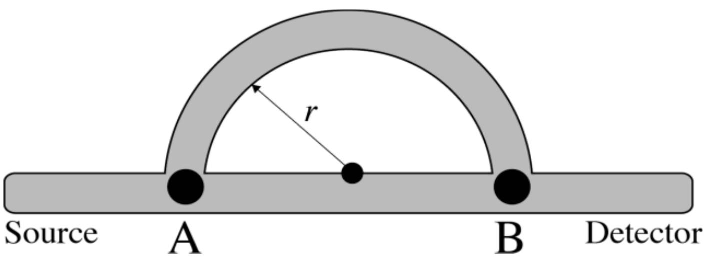
(3 marks)

Solution

A narrower opening would increase the diffraction of the water waves (as the ratio would increase, but there would be less total wave energy entering the harbour.

Question 5/ 67

Sound travels along a tube sketched below. At point A, about half the sound travels along the curved section, the other half is undeflected at this point, and at point B the two paths rejoin. The radius of the curved section, *r*, is 80 cm.



a. Show that the path difference for the two pathways is equal to 1.14*r*.

(2 marks)

b. As the sound frequency from the source changes, the detector measures varying degrees of loudness. A sound of frequency 372 Hz is generated. The speed of sound at the time is 340 m s^{-1}. Evaluate whether the sound is likely to be close to a maximum or a minimum. Show your working.

(3 marks)

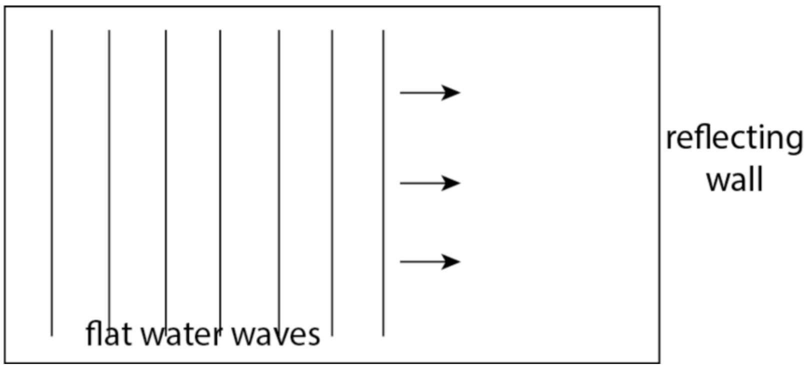
Solution

a $\text{Curved distance} = \pi r; \text{straight distance} = 2r; \text{difference} = \pi - 2 = 1.14r.$

b $\lambda = \frac{340}{372} = 0.91 \text{ m}; \text{path difference} = 1.14\pi = 0.91$; constructive interference.

Question 6/ 67

Plane water waves in a ripple tank are directed towards the flat wall of the tank.



The waves are moving at 6.0 cm s^{-1} towards the right. The frequency of the waves is 3.0 Hz.

a. Calculate the wavelength of the waves.

(2 marks)

b. When the waves reach the wall, they reflect (without loss), and travel back to left, interfering with waves travelling right. Describe the resulting waves that form in the tank (including quantitative details).

(4 marks)

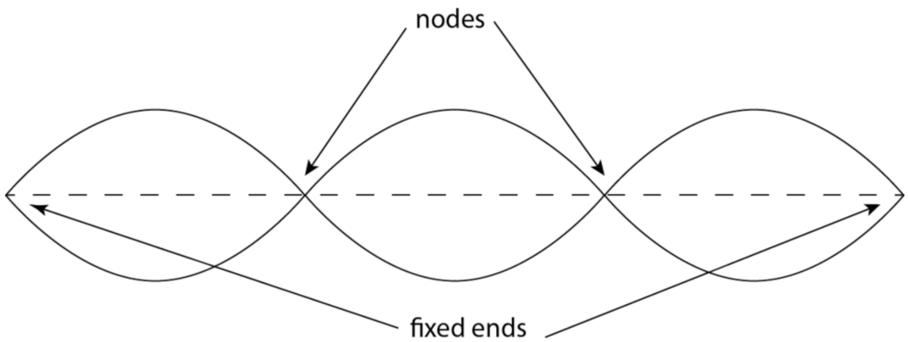
Solution

a 2.0 cm Use $v = f\lambda$.

b Standing waves form (equal and opposite waves superposing); distance between $\text{nodes} = 1.0 \text{ cm } (\frac{1}{2}\lambda)$; amplitude double the original waves.

Question 7/ 67

A violin string is played forming a 900 Hz sound standing wave. The string is fixed at the ends, and a strobe photo of the vibrating string reveals regions of no vibration (nodes), as shown below. The distance between the fixed ends is 30 cm. The dashed line shows the string's position when it is not vibrating.



a. Describe the mechanism leading to the formation of the standing wave.

(3 marks)

b. Calculate the period of the standing wave.

(2 marks)

c. Calculate the speed of a transverse wave along the violin string. Show your working.

(3 marks)

d. The violin player finds that they can play two other lower frequency notes on the 30 cm length string, with the string otherwise unchanged. Calculate the frequency of these two notes, showing your working.

(3 marks)

Solution

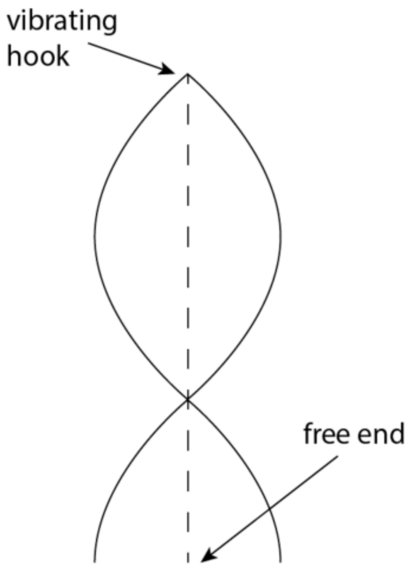
a Superposition of equal and opposite travelling waves.

b 1.11 ms Period $T = \frac{1}{f}$.

c 180 m s^{-1}. Use $v = f\lambda,\ \lambda = 2 \times \text{distance}$ between nodes.

d 300 Hz & 600 Hz Fundamental and second harmonic (1 & 2 loops).

A light cord is hanging from a vibrating hook in the ceiling. This sets up standing waves in the cord. The hook can be considered to be stationary, and the hanging end can be considered free. *One* of the possible standing waves is sketched below. The dashed line shows the position of the cord when it is not vibrating. The wave shown has a frequency of 150 Hz. The vertical distance between the hook and the free end is 45 cm.



a. Sketch the shape of two other standing waves, labelling the nodes and antinodes.

(4 marks)

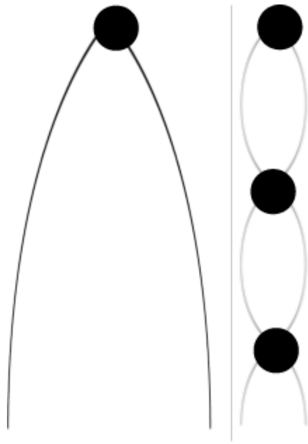
b. Calculate the frequency of the two standing waves that you have sketched. Show your working.

(3 marks)

c. Calculate the speed of a transverse wave along the hanging cord.

(2 marks)

Solution

a 

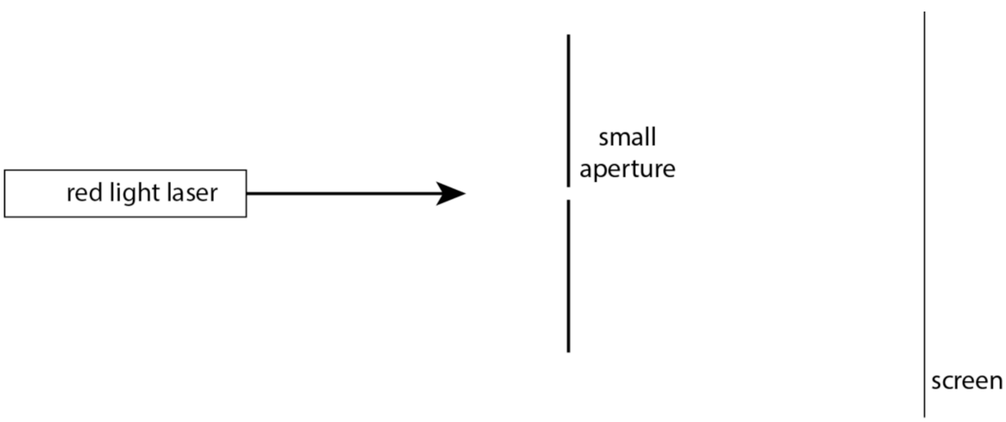
Fundamental & third harmonic. Dots are nodes, antinodes at max. displacement.

b 50 Hz and 250 Hz Find $v = f\lambda = 150 \times 0.6 = 90 \text{ m s}^{-1}$ (from data in stem); and use new λ values $(\lambda = 2 \times \text{distance between nodes})$.

c 90 m s^{-1} See explanation for part **b**.

Question 9/ 67

A red laser is directed at a very small width vertical slit in an opaque barrier. This is similar to a Young's two-slit experiment with only one slit. Diffraction effects are clearly seen. The diagram shows the apparatus viewed from above.



a. Describe the pattern seen on the screen.

(2 marks)

b. Describe the change in the pattern if the screen is moved towards the slit.

(1 mark)

c. The red laser is replaced by a green laser. Describe the pattern now. Explain your reasoning.

(2 marks)

d. The laser is now replaced with a narrow beam of white light from an incandescent light globe. Describe the pattern now. Explain your reasoning.

(3 marks)

Solution

a The laser beam will spread out in inverse proportion to the width of the slit. (On either side of this broadened beam there will be a fainter pattern of interference bands.)

b The width of the broadened beam will decrease (as will the interference pattern).

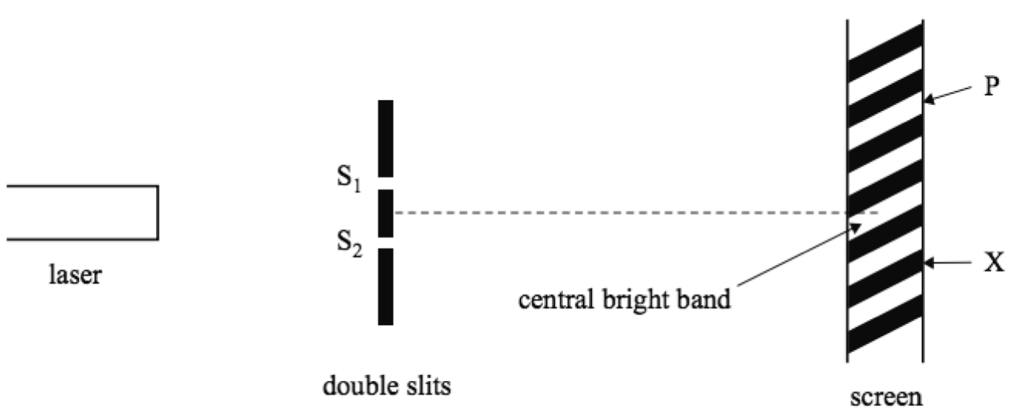
c The width of the broadened beam will decrease (as will the interference pattern). This is due to the shorter wavelength of green photons.

d There will be a central white broad beam (and fainter interference side bands); the central beam (and side bands) will be fringed with narrow coloured spectral bands, from blue out to red.

Question 10/ 67

[Adapted VCAA 2016 SA Q18]

Amelia and Rajesh conduct an experiment to study interference using a laser and double slits, as shown. X is a dark band as shown.



The path difference $S_1X - S_2X$ is found to be 750 nm.

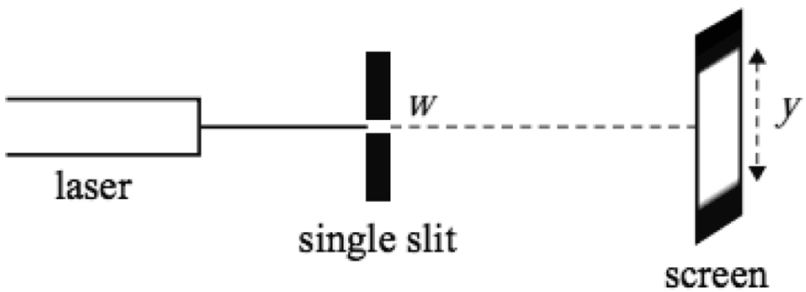
a. Calculate the wavelength of the laser.

(2 marks)

b. P is a bright band. Calculate the path difference $S_2P - S_1P$. Show your working.

(2 marks)

Amelia and Rajesh replace the double slits with a single slit of width *w*, as shown. They find that the width of the central maximum of the diffraction pattern is *y*.



They replace the single slit with another single slit of width 2*w*.

c. Describe the expected change in the width of the central maximum, including your reasoning.

(2 marks)

Solution

a 500 nm $750 \text{ nm} = 1.5$ wavelengths (point X is the second dark band).

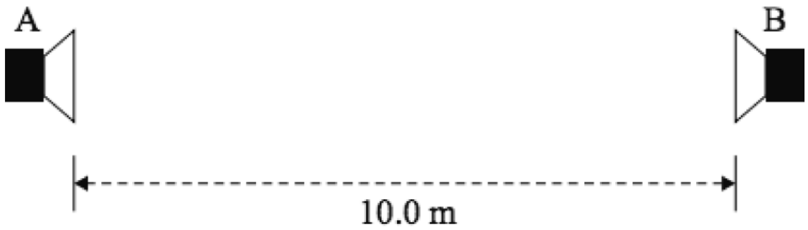
b 1000 nm P is second bright band from centre.

c The wider slit will result in less diffraction spread (from the $\frac{\lambda}{w}$ ratio).

Question 11/ 67

[Adapted VCAA 2016 SB Q7]

Yasmin and Paul set up the following experiment in a large open area. They connect two speakers that face each other, as shown.



The speakers are 10 m apart and connected to the same signal generator, and produce a sound with a wavelength of 1.0 m. Yasmin stands in the centre, equidistant to speakers A and B. She then moves towards Speaker B and experiences a sequence of loud and quiet regions. She stops at the second region of quietness. How far is she from Speaker B? Show your working.

(3 marks)

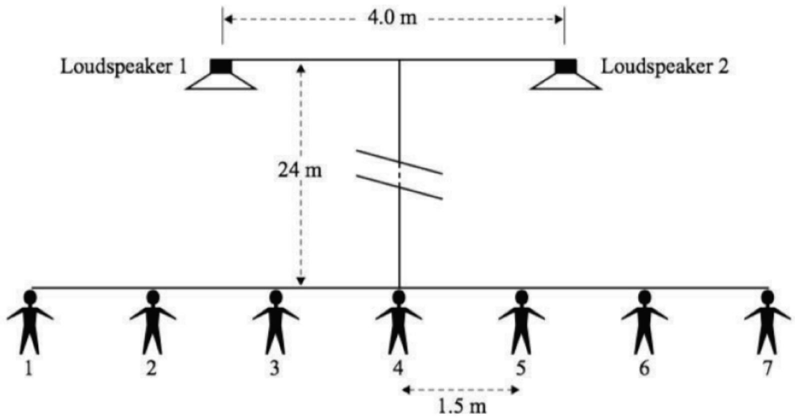
Solution

4.25 m Loud spots (antinodes) are $\frac{\lambda}{2}$ apart; nodes are midway between antinodes.

Question 12/ 67

[Adapted VCAA 2017 SB Q15]

A Physics teacher is demonstrating wave phenomena to her students. She takes her students to the school oval to listen to 680 Hz sound. The speed of sound in air is 340 m s^{-1}. The teacher sets up two loudspeakers placed 4.0 m apart with the 680 Hz sound in phase. Seven students are placed in a row 24 m from the loudspeakers, as shown in the diagram below. Each student is 1.5 m away from the next student. Student 4 is in the middle and is exactly the same distance from each loudspeaker. When a single loudspeaker is sounding, all the students hear very close to the same intensity.



The teacher now connects both loudspeakers. One student, Elli, predicts that now they will all hear a similar sound of double the intensity. Another student, Sam, disagrees. He says the intensity of the sound will depend on each student's relative distance from each speaker.

a. Evaluate Elli's and Sam's responses.

(3 marks)

b. Will students 2 and 5 in the diagram on the previous page hear similar or different sound intensities? If you predict that one of the students will hear a higher sound intensity, state which student and justify your prediction. Show your working.

(3 marks)

Solution

a Sam is correct and Elli is incorrect. There will be interference between the waves for the two speakers, similar to a Young's experiment for light. The path difference between the sound from the speakers will determine whether each student is closer to a node in the interference pattern or an antinode.

b Easiest way to determine the nodes and antinodes is to use the approximate formula for the nodal spacing: $\Delta x = \frac{\lambda L}{d}$ (can use precise method with Pythagoras, but results are very close). This gives that the spacing of antinodes is 3.0 m; hence student 2 is at an antinode (maximum sound) and student 5 is at a node (minimum sound).

Question 13/ 67

[VCAA 2017 SB Q16]

Standing waves are formed on a string of length 4.0 m that is fixed at both ends. The speed of the waves is 240 m s^{-1}.

a. Calculate the wavelength of the lowest frequency resonance.

(2 marks)

b. Calculate the frequency of the second-lowest frequency resonance.

(2 marks)

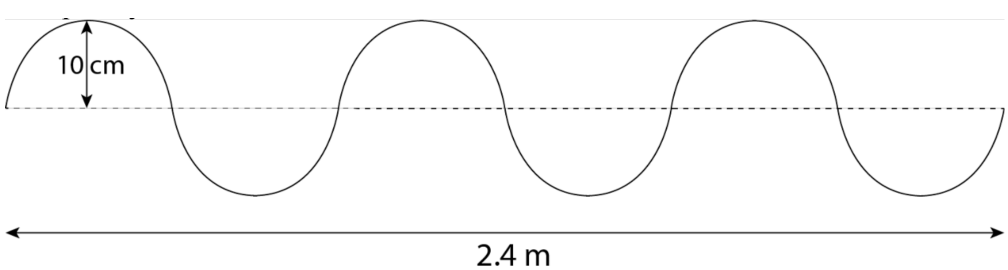
Solution

a 8.0 m Lowest resonance (fundamental) will have $\lambda = 2L$.

b 60 Hz Fundamental is at 30 Hz (from $v = f\lambda$) or find λ first.

Question 14/ 67

Students create a standing wave in an elastic cord 2.4 m long. They take video shots of the vibrating cord. The diagram below shows the cord at one extreme of its vibration (maximum amplitude). The dashed line shows the 'at rest' position of the elastic cord. The frequency of the wave is 100 Hz.



a. State the wavelength of the standing wave.

(1 mark)

b. Sketch the position of the cord at a time 7.5 ms after that shown.

(2 marks)

c. Calculate the speed of a transverse wave along the cord.

(2 marks)

Solution

a 0.80 m Three wavelengths are 2.4 m.

b Zero displacement

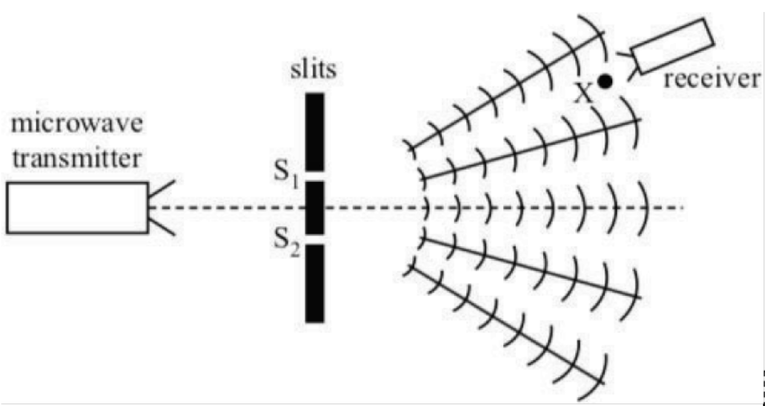
(flat) $T = 10\ \mathrm{ms}$; 7.5 ms is $\frac{3}{3}$ period.

c $80\ \mathrm{m\ s^{-1}}$ Use $v = f\lambda$.

Question 15/ 67

[Adapted VCAA 2018 NHT SB Q11]

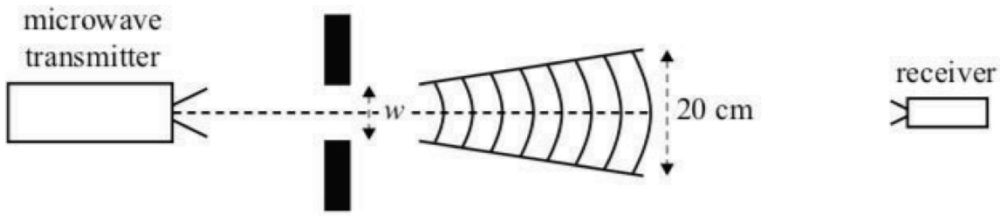
Students use a microwave set to study wave interference. The set consists of a transmitter set to transmit waves of $\lambda = 3.0$ or 6.0 cm, a receiver measuring the intensity and wavelength of the received signal, plates to make single or double slits and a ruler. The speed of the waves is $3.0 \times 10^8\ \mathrm{m\ s^{-1}}$. The students set up the equipment using 3.0 cm microwaves, placing the receiver at X on the second nodal line (minimum) out from the centre, as shown.



a. Calculate the path difference $\mathrm{S_2X - S_1X}$. Show your working.

(2 marks)

The students now replace the two slits with a single slit of width *w*, as shown.



b. With the transmitter set to a wavelength of 3.0 cm, the width of the diffraction pattern is 20 cm at a fixed distance from the slit. They then change the wavelength to 6.0 cm. What effect will this have on the width of the pattern? Explain your answer.

(2 marks)

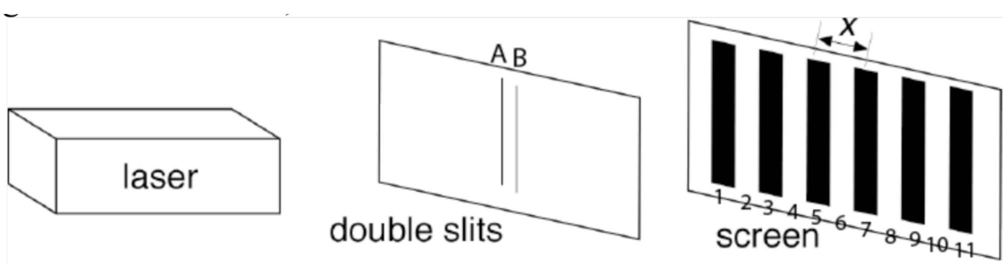
Solution

a 4.5 cm First nodal line; hence path $\text{difference} = 1.5\lambda$.

b Longer wavelength means a broader pattern (ratio of $\frac{\lambda}{w}$ is greater).

Question 16/ 67

Students perform a Young's double-slit experiment. The diagram below shows the arrangement. Two narrow slits (A and B) let light from a laser pass through them. The result is a pattern of light and dark bands on a screen. The bands are numbered. The spacing between the bands, *x*, as also shown.



a. One of the bands is *equidistant* from slit A and slit B. Explain why it is not possible for bands 1, 3, 5, 7, 9 or 11 to be that band.

(2 marks)

b. The students measure that the distance from slit A to band 11 is longer than the distance from slit B to band 11 by 1.5 μm. Use this information to calculate the wavelength of the light from the laser. (*Assume that* *band 6 is the central band.*)

(2 marks)

c. Identify *two* changes to the apparatus that would increase the spacing, *x*. Explain your changes in terms of a wave model of light.

(2 marks)

d. Explain why *narrow* slits (A and B) are necessary if the light from the slits is to spread out and overlap after passing through them.

(2 marks)

Solution

a The dark bands are points of destructive interference between the light from the two slits; this means there must be a path difference equal to an odd number of half wavelengths; path difference can't be zero (central band must have $\mathrm{PD} = 0$).

b 0.6 μm Band 11 is the third dark band from the centre; this means a path difference of $2.5\lambda = 1.5\mu\mathrm{m}$.

c • Increase wavelength of the light from laser (bands would move further apart because of the greater wavelength).

• Move slits closer together (bands would move further apart in order to obtain the path difference required for constructive or destructive interference).

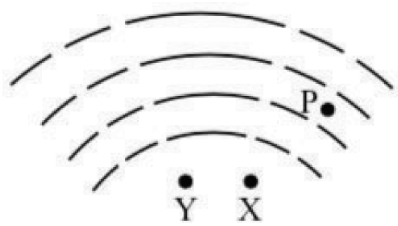
• Increase distance between the slits and the screen (angular spread stays the same, but as the distance increases the spacing *x* increases).

d For interference to occur, the light from the two slits must spread out; this occurs because of diffraction; the narrower the slits, the more the diffraction (the amount is proportional to $\frac{\lambda}{w}$, where *w* is the width of the slit(s)).

Question 17/ 67

[Adapted VCAA 2017 Sample SB Q6]

Juan conducts an experiment using a shallow tray of water of waves. He uses two point sources of wavelength 10 cm and frequency 5 Hz to investigate a two point source interference pattern, as shown below.



He observes lines of maxima and minima in the resultant pattern, as shown above. The lines on the diagram represent wave crests. Point P is on a nodal line of minima. Juan measures the distance from source X to point P as 16.0 cm. Determine the distance from source Y to point P.

(2 marks)

Solution

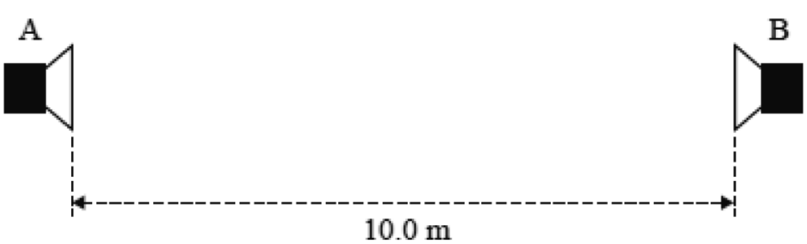
31 cm The distance must be 1.5λ greater than the distance PX.

Question 18/ 67

[Adapted VCAA 2018 SB Q11]

The diagram following shows two speakers, A and B, facing each other. The speakers are connected to the same signal generator/amplifier and the speakers are simultaneously producing the same 340 Hz sound.

Take the speed of sound to be 340 m s^{-1}.



A student stands in the centre, equidistant from speakers A and B. He then moves towards speaker B and experiences a sequence of loud and quiet regions. He stops at the second region of quietness. How far has the student moved from the centre? Explain your reasoning.

(3 marks)

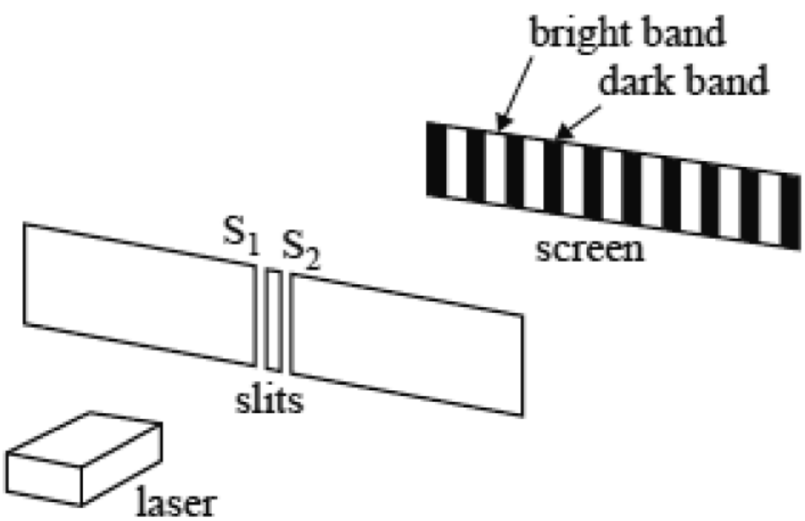
Solution

0.75 m A standing wave is formed between the speakers; nodes are spaced $\frac{\lambda}{2}\ (= 0.50\ \mathrm{m})$ apart. The distance between a node and an antinode is thus 0.25 m. Hence, he moves 0.75 m.

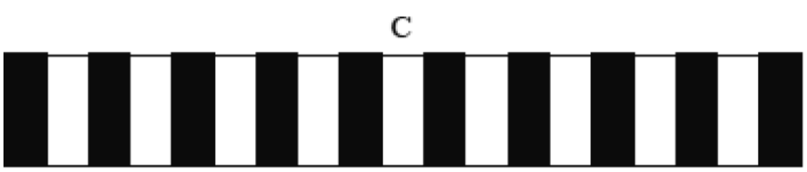
Question 19/ 67

[Adapted VCAA 2018 SB Q13]

Physics students studying interference set up a double-slit experiment using a 610 nm laser, as shown in the diagram below.



A section of the interference pattern observed by the students is shown in the diagram below. There is a bright band at point C, the centre point of the pattern.



a. Explain why point C is in a bright band rather than in a dark band.

(2 marks)

b. Another point on the pattern to the right of point C is further from $\mathrm{S_1}$ than $\mathrm{S_2}$ by a distance of $2.14 \times$

$10^{-6}\mathrm{m}$. Mark this point on the diagram by writing an X above the point. You must use a calculation to justify your answer.

(2 marks)

Solution

a C is a point of constructive interference because the path difference between light from S_1 and S_2 is zero.

b $2.14 \times 10^{-6}\mathrm{m}$ is equal to 3.5λ; hence the point is an antinode and is the centre of the fourth dark band to the right or left of C.

Question 20/ 67

[VCAA 2019 NHT SB Q11]

Kym and Roger conduct an experiment to observe an electron diffraction pattern. 5000 eV electrons are projected through a diffracting grid and the resulting pattern is observed on a screen. Kym and Roger want to calculate the wavelength of X-rays that would produce a similarly spaced diffraction pattern. Kym says that they will need X rays of 5000 eV. Roger says that X-rays of a different energy will be needed.

a. Explain why Roger is correct.

(2 marks)

b. Showing each working step involved, calculate the X-ray energy that would be required to produce the similarly spaced diffraction pattern.

(4 marks)

Solution

a Diffraction is a wave phenomenon, and for similar patterns the wavelength of the X-rays must be the same as the de Bröglie wavelength of the electrons. This will mean that the energy of the photons will not be equal to the KE of the electrons.

b 71.5 keV 1. p of 5000 eV $\text{electrons} = \sqrt{(2mE)} = 3.82 \times 10^{-23}$N s.

2. de Bröglie $\text{wavelength} = \frac{h}{p} = \ 1.74 \times 10^{-11}$m.

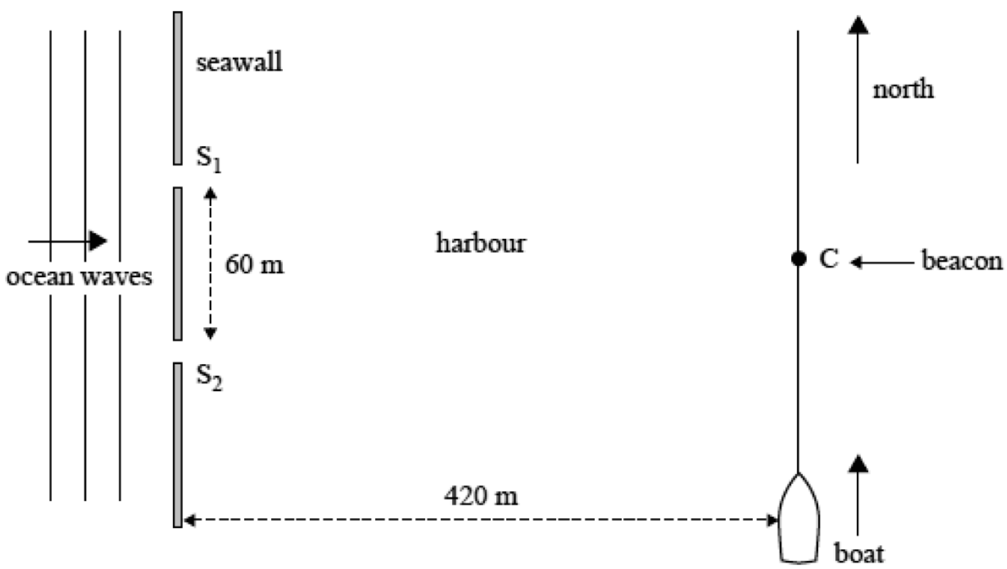
3. Energy of these $\text{photons} = \frac{hc}{\lambda} = 1.14 \times 10^{-14}$ J.

4. Convert to eV.

Question 21/ 67

[VCAA 2019 NHT SB Q13]

A seawall that is aligned north–south protects a harbour of constant depth from large ocean waves, as shown in the diagram on the next page. The seawall has two small gaps, S_1 and S_2, which are 60 m apart. Inside the harbour, a small boat sails north parallel to the seawall at a distance of 420 m from the seawall. At point C sits a beacon, equidistant from the two gaps in the seawall. The boat's captain notices that, at about every 42 m, there is calm water, while there are large waves between those calm points.



a. Will the beacon at point C be in calm water or large waves? Give a reason for your answer.

(2 marks)

b. Calculate the wavelength of the ocean waves. Show your working.

(2 marks)

Solution

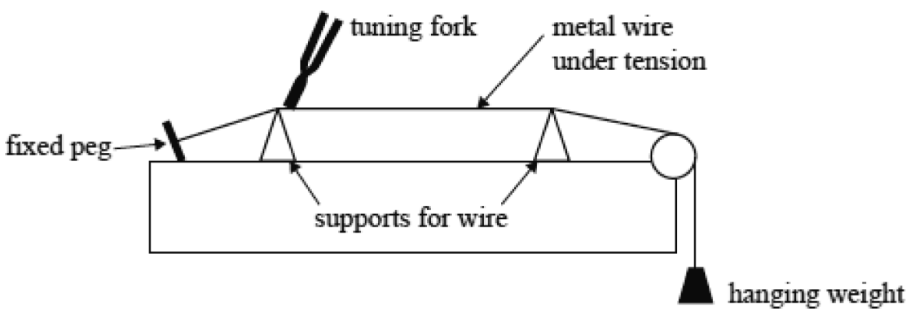
a Large waves The point C is an antinode, a point of constructive interference, where the path difference of the waves from S_1 and S_2 is zero.

b 6.0 m Use the approximate formula for the spacing of antinodes $x = \lambda$, where $x = 42$, $L = 420$ and $d = 60$.

Question 22/ 67

[VCAA 2019 NHT SB Q14]

The diagram below shows a simple apparatus that can be used to determine the frequency of a tuning fork.



The apparatus consists of two supports and a metal wire that is stretched between a fixed peg and a hanging weight. The wire is under tension. The tuning fork is set vibrating and is then touched onto the wire close to the left-hand support, which makes the wire vibrate at the same frequency as the tuning fork.

a. Draw a diagram of the simplest standing wave pattern that can exist on the vibrating section of the wire (the fundamental) between the two supports.

(2 marks)

b. When the distance between the supports is 0.92 m, the fundamental frequency resonates in the wire. Calculate the wavelength of the fundamental. Show your working.

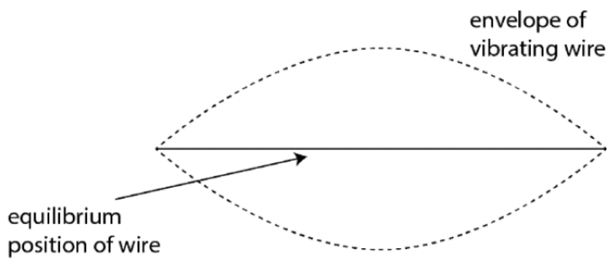
(2 marks)

c. Calculate the frequency of the tuning fork if the speed of the waves in the wire is 224 m s^{-1}. Show your working.

(2 marks)

Solution

a



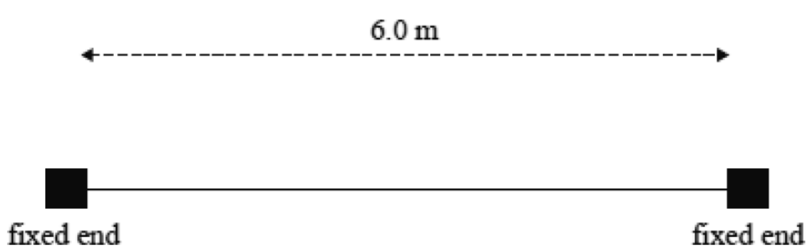
b 1.8(4) m Wavelength of standing wave is double the node spacing.

c 122 Hz Use $v = f\lambda$ with *f* as the subject.

Question 23/ 67

[Adapted VCAA 2019 SB Q13]

In an experimental set-up used to investigate standing waves, a 6.0 m length of string is fixed at both ends, as shown in the diagram. The string is under constant tension, ensuring that the speed of the wave pulses created is a constant 40 m s^{-1}.



In an initial experiment, a continuous transverse wave of frequency 7.5 Hz is generated along the string. Will a standing wave form? Give a reason for your answer.

(2 marks)

Solution

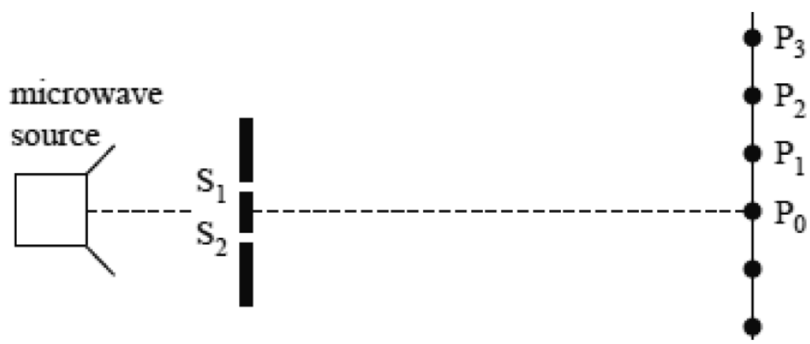
No The wavelength of the waves in the stretched string is 5.33 m. For a standing wave to form, the length has to be an integer multiple of half wavelengths, i.e. $\frac{60}{267}$ $(= 2.23)$ would need to be an integer. Clearly it isn't.

Question 24/ 67

[VCAA 2019 SB Q14]

Students have set up a double-slit experiment using microwaves. The beam of microwaves passes through a metal barrier with two slits, shown as S_1 and S_2 in the diagram. The students measure the intensity of the resulting beam at points along the line shown in the diagram below.

They determine the positions of maximum intensity to be at the points labelled P_0, P_1, P_2 and P_3. Take the speed of electromagnetic radiation to be $3.00 \times 10^8 \mathrm{~m~s}^{-1}$.



The distance S_1 to P_3 is 72.3 cm and the distance S_2 to P_3 is 80.6 cm.

a. What is the frequency of the microwaves transmitted through the slits? Show your working.

(2 marks)

b. The signal strength is at a minimum approximately midway between points P_0 and P_1. Explain the reason why the signal strength would be a minimum at this location.

(2 marks)

Solution

a $1.08 \times 10^{10} \mathrm{Hz}$ Path difference to $\mathrm{P}_3 = 0.083 \mathrm{~m} = 3$ whole wavelengths.

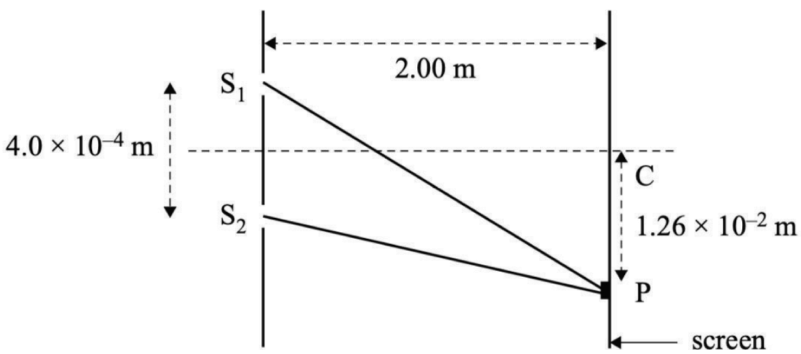
Hence $\lambda = 2.77\text{cm}$; now use $f = \frac{c}{\lambda} = 1.08 \times 10^{10}\text{Hz}$.

b This is a point where destructive interference occurs, as the path difference is equal to half a wavelength. The waves from the two slits arrive out of phase.

Question 25/ 67

[VCAA 2020 SB Q12]

In a Young's double-slit interference experiment, laser light is incident on two slits, S_1 and S_2, that are 4.0×10^{-4} m apart, as shown in the diagram below.



Rays from the slits meet on a screen 2.00 m from the slits to produce an interference pattern. Point C is at the centre of the pattern. The diagram below shows the pattern obtained on the screen.

a. There is a bright fringe at point P on the screen. Explain how this bright fringe is formed.

(2 marks)

b. The distance from the central bright fringe at point C to the bright fringe at point P is $1.26 \times 10^{-2}\text{m}$. Calculate the wavelength of the laser light. Show your working.

(3 marks)

Solution

a The bright fringe at P is the fourth bright fringe from C. Constructive interference must be occurring so the path difference is four wavelengths.

b 630 nm Use $4 \times \Delta x = \frac{\lambda L}{d}$ with λ as the subject.

Question 26/ 67

[Adapted VCAA 2021 NHT SB Q16]

2.0 nm X-rays are incident on a single narrow slit of width $5 \times 10^{-8}\mathrm{m}$. Would a diffraction pattern be observed? Justify your answer.

(3 marks)

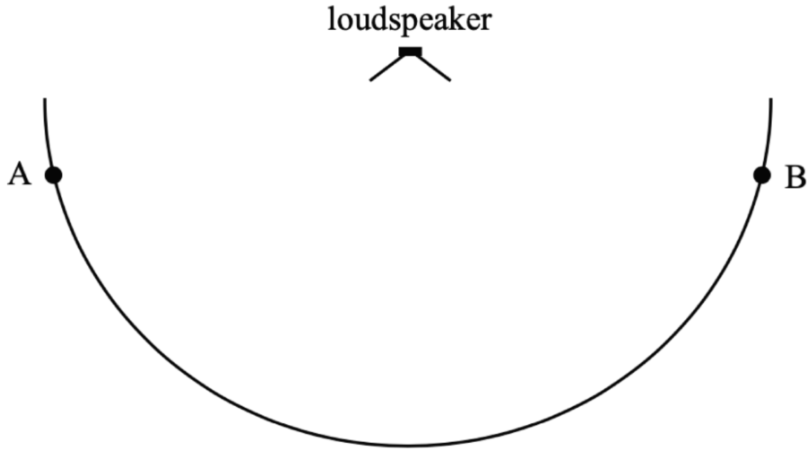
Solution

The ratio $\frac{\lambda}{w}$ is proportional to the amount of diffraction 'spreading'; in this case, this ratio is equal to 0.04, hence there would be very little spreading. Whether it is *observable* or not would depend on the quality of the instruments used to detect the X-rays.

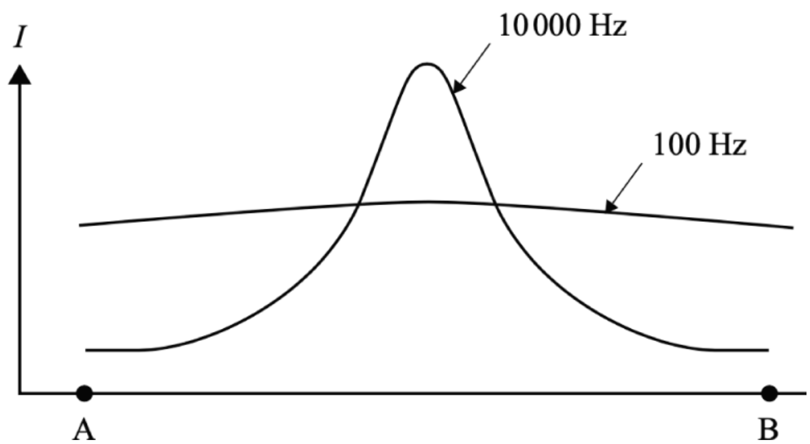
Question 27/ 67

[VCAA 2021 NHT SB Q14]

To explain different aspects of mechanical waves, a Physics teacher sets up a demonstration in a Physics laboratory using a 0.80 m wide loudspeaker and a microphone. The microphone measures the sound intensity at different positions on a circle around the speaker from position A to position B, as shown in the diagram below.



The speed of sound in the Physics laboratory is $334\ \mathrm{m\ s^{-1}}$. Measurements are made at frequencies of 100 Hz and 10 000 Hz. The loudspeaker emits the 100 Hz and 10 000 Hz frequencies with equal intensity. The graph below shows the intensity, *I*, measured for each frequency at positions on the semicircular line shown in the diagram above between positions A and B.



Explain why the response at 10 000 Hz has a greater intensity directly in front of the loudspeaker, while the response at 100 Hz is nearly the same at all positions.

(2 marks)

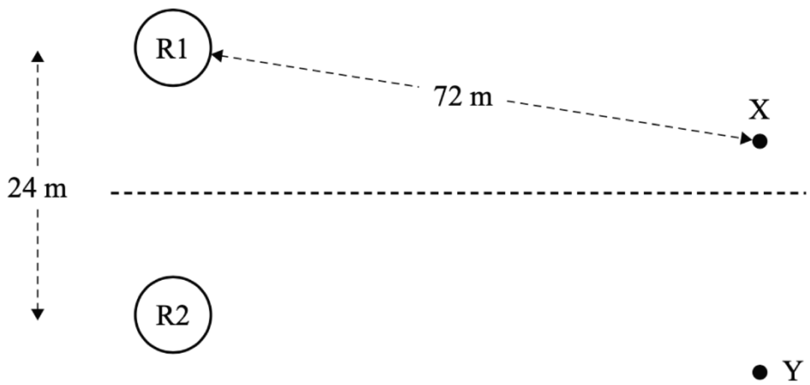
Solution

The diffraction 'spreading' is proportional to the ratio $\frac{\lambda}{w}$; here *w* is the diameter of the loudspeaker and λ is the wavelength of the two frequencies. The 100 Hz sound will have a much longer wavelength than the 10 000 Hz sound, hence the different shapes of the two graphs.

Question 28/ 67

[VCAA 2021 NHT SB Q12]

Students are testing two identical radio transmitters, R1 and R2, on a football field. The transmitters are positioned 24 m apart, as shown in the diagram below. The transmitters are in phase, both emitting crests simultaneously, and emit waves of wavelength 18 m in all directions. The students are standing at point X, which is located 72 m away from the nearest transmitter, R1.



a. During testing, the radio signal received at point X is detected to be a minimum. Calculate the shortest distance that point X could be from R2. Show your working.

(2 marks)

b. At another location on the football field, point Y, the students detect a maximum. Explain why the two observations at points X and Y would support the wave model of light.

(3 marks)

Solution

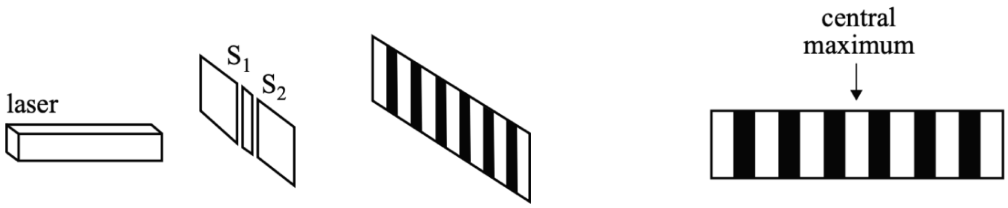
a 81 m There is constructive interference at point X; the shortest distance will correspond to a path difference of $\frac{\lambda}{2}$ $(= 9\ \text{m})$. Clearly X is further from R2 than from R1. Add 9 m to 72 m.

b The point Y must be a point of constructive interference, due to a path difference of $n\lambda$. Two wave sources would produce just this kind of pattern of constructive and destructive interference. Hence the radio sources can be modelled with a wave model. Light can therefore also be modelled with waves, as it shares this kind of behaviour as well.

Question 29/ 67

[Adapted VCAA 2021 SB Q13]

In a Young's double-slit experiment, the distance between two slits, S_1 and S_2, is 2.0 mm. The slits are 1.0 m from a screen on which an interference pattern is observed, as shown in the left-hand diagram. The right-hand diagram shows the position of the central maximum of the observed interference pattern.



If a laser with a wavelength of 620 nm is used to illuminate the two slits, what would be the distance between two successive dark bands? Show your working.

(2 marks)

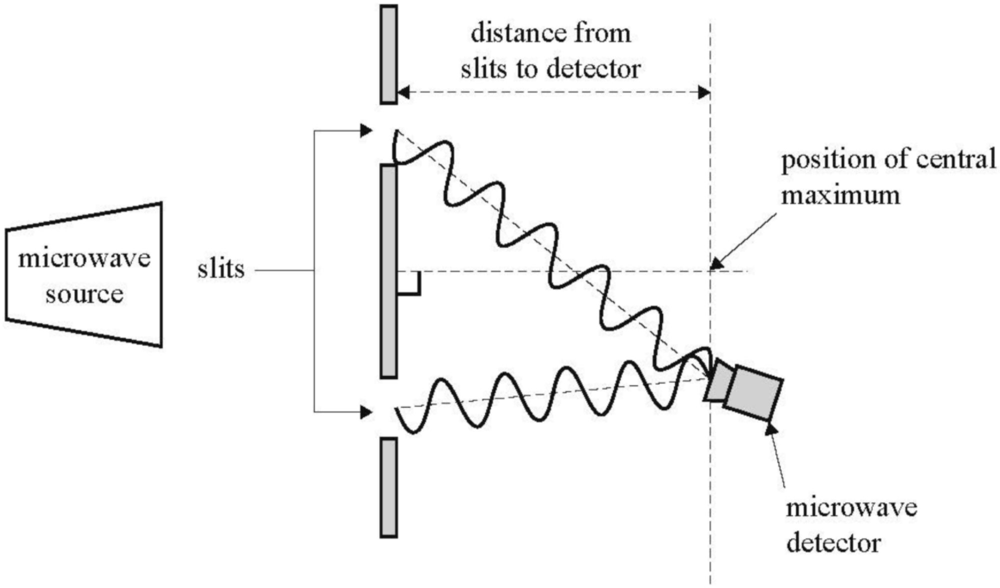
Solution

0.31 mm Use $\Delta x = \frac{\lambda L}{d}$.

Question 30/ 67

[VCAA 2022 NHT SB Q13]

Students are investigating the interference of waves using a source of coherent microwaves, two narrow slits and a microwave detector. The diagram below shows the microwaves travelling from the slits to the detector.



a. The frequency of the microwaves is 12.0 GHz. Calculate the wavelength of the microwaves. Show your working.

(2 marks)

b. Using the information in the diagram and your answer to part **a.**, calculate the path difference between the two waves arriving at the detector. Give your reasoning.

(2 marks)

c. Will the intensity of the microwaves at the detector's position, as shown in the diagram, be a maximum or a minimum? Justify your answer.

(2 marks)

d. The frequency of the microwaves is now halved and the position of the detector is not changed. Describe any changes in the intensity of the microwaves at the detector. Explain your answer.

(3 marks)

Solution

a 2.5 cm Use $f = \frac{c}{f} = \frac{3.0\times10^8}{12\times10^9} = 25 \text{ cm}.$

b 2.5 cm Count the wavelengths from the diagram.

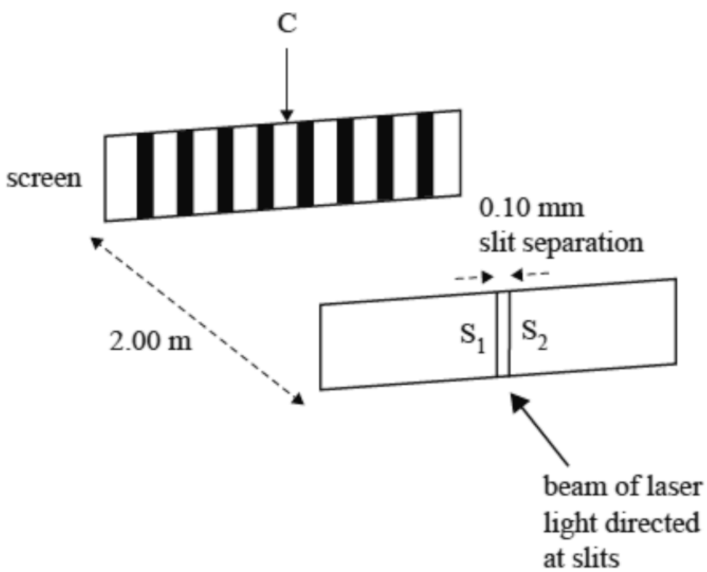
c The intensity will be at a maximum, as the path difference will be one whole wavelength.

d The intensity will now be at a minimum. The wavelength will be doubled (from$\lambda = \frac{c}{f}$) so the path difference will now be one half wavelength, and destructive interference will occur at the point on the screen.

Question 31/ 67

[VCAA 2022 SB Q12]

Students conduct an experiment in a Physics laboratory using a laser light source, two narrow slits and a screen, as shown.



Point C is at the centre of the pattern of light and dark bands on the screen. The slit separation is 0.10 mm and the distance between the two slits and the screen is 2.00 m.

a. The band at point C is a bright band. Explain why the band at point C is bright and why there is a dark band to the left of the centre.

(2 marks)

b. The experiment performed by the students is often described as Young's double-slit experiment. Explain how this experiment gave support to those who argued that light has a wave-like nature.

(2 marks)

c. The frequency of the laser light is 6.00×10^{14} Hz. Calculate the spacing of the dark bands on the screen. Show your working.

(2 marks)

d. The students decide to safely immerse the entire apparatus in a liquid. The refractive index of the liquid is unknown but it is greater than the refractive index of air. Using the same laser light, they notice that the spacing of the bands changes. Describe the change observed in the spacing of the bands and explain why this change occurred.

(2 marks)

Solution

a Same distance for light to travel to the bright band at C where there is constructive interference and a path difference of zero. For dark band to the left of centre, there is destructive interference and a path difference of $\frac{\lambda}{2}$.

b An interference pattern is observed and interference is a property of waves.

c 0.01 m $\Delta x = \frac{\lambda L}{d} = \frac{cL}{fd} = \frac{\left(3.00\times10^{8}\right)(2.00)}{(6.00\times10^{14})(1.00\times10^{-4})} = 0.01\text{ m}.$

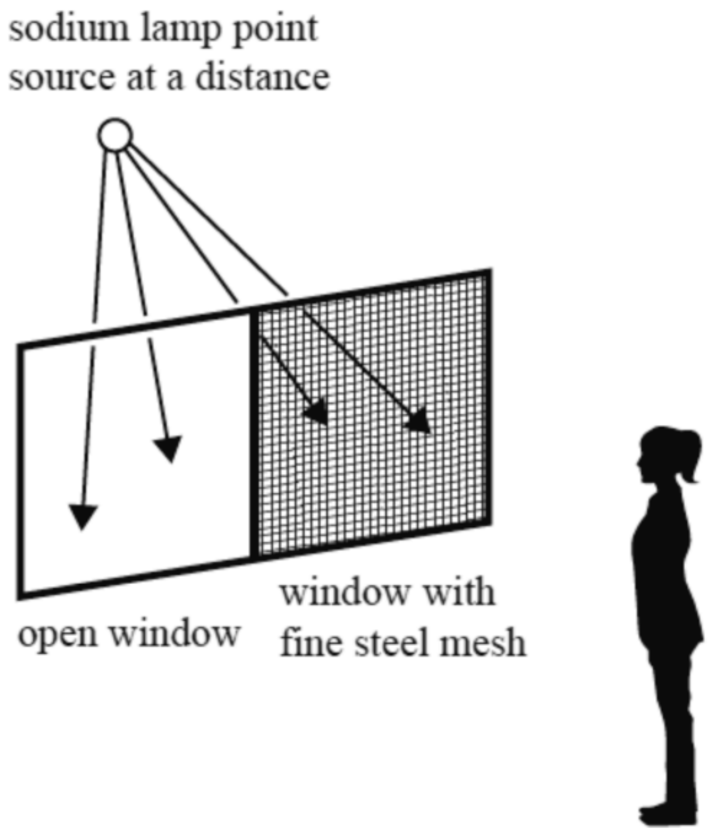
d Speed reduces, frequency remains the same, wavelength reduces therefore spacing decreases. $\Delta x = \frac{\lambda L}{d}$
.

Question 32/ 67

[VCAA 2022 SB Q16]

A small sodium lamp, emitting light of wavelength 589 nm, is viewed at night through two windows from across a street. The glass of one window has a fine steel mesh covering it and the other window is open, as shown. Assume that the sodium lamp is a point source at a distance.

A Physics student is surprised to see a pattern formed by the light passing through the steel mesh but no pattern for the light passing through the open window. She takes a photograph of the observed pattern to show her teacher, who assures her that it is a diffraction pattern.



a. State the condition that the fine steel mesh must satisfy for a diffraction pattern to form.

(1 mark)

b. Explain why the condition stated in **part a**. does not apply to the open window.

(2 marks)

Solution

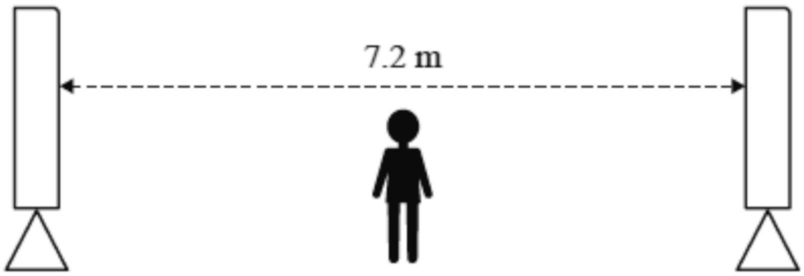
a There are gap sizes in the fine steel mesh such that diffraction occurs $\left(\frac{\lambda}{w} \approx 1\right)$.

b The window width is much larger than the λ of the light.

Question 33/ 67

[VCAA NHT 2023 SB Q15]

Nialle is standing between two loudspeakers on the school oval, as shown below. Sound of a single frequency of 200 Hz is being emitted equally from both speakers. The distance between the speakers is 7.2 m.



When Nialle stands exactly halfway between the speakers, the sound is quite loud. Nialle begins to walk towards one speaker and notices that the sound gets quieter and then louder.

a. Calculate the wavelength of the 200 Hz sound, taking the speed of sound to be 360 m s^{-1}.

(1 mark)

b. Nialle decides that this observation must be due to interference.

Explain how interference accounts for the loud and quiet points.

(3 marks)

c. Calculate the spacing between two adjacent quiet points.

(2 marks)

Solution

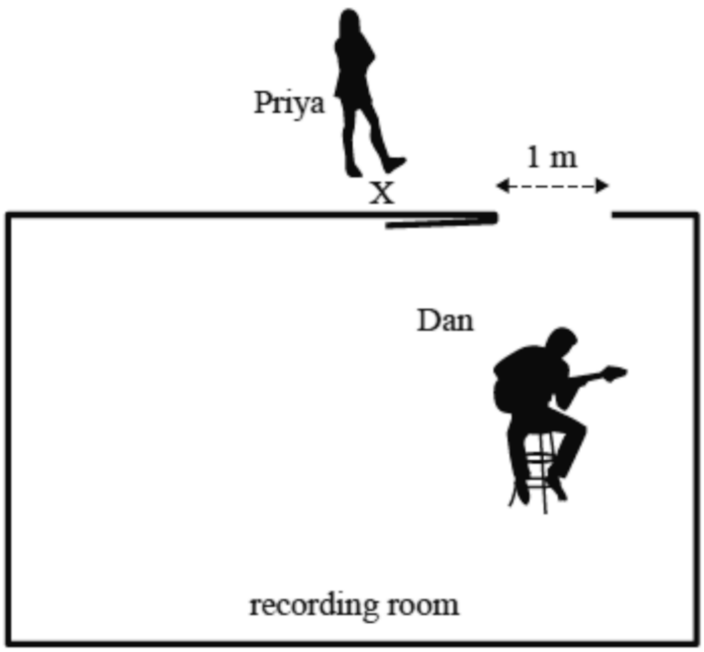
a 1.80 m

b Volume depends on location between speakers. Describe constructive and destructive interference in terms of path difference. Regions of constructive interference result in loud sound while regions of destructive interference result in quiet sound.

c 0.90 m A standing wave formed therefore distance between$\text{nodes} = \frac{\lambda}{2}$.

[Adapted VCAA NHT 2023 SB Q16]

Priya and Dan are playing music in a soundproof recording room. Priya leaves the room while Dan is still playing. She notices that when she is standing at point X with the door open, as shown below, she can still hear the music. The music is not only softer, but some of the frequencies also seem to be relatively much softer. The door to the recording room is 1 m wide.



Outline in what way the music sounds different to Priya and explain why.

(3 marks)

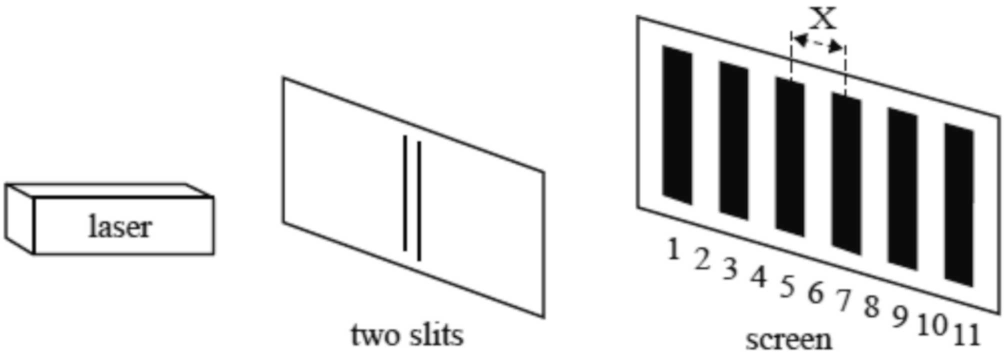
Solution

The reason why there is a difference in the sound is due to diffraction through the door opening. Longer wavelengths diffract more than shorter wavelengths and so the shorter wavelengths will sound softer relative to the longer wavelengths.

Question 35/ 67

[VCAA NHT 2023 SB Q18]

Students carry out a Young’s double-slit experiment using the experimental set-up shown below. Laser light passes through two closely spaced narrow slits and forms a pattern of light and dark bands on a screen. The bands are numbered – the even numbers are bright bands and the odd numbers are dark bands. The band spacing is X. Band 6 is equidistant from each of the two slits.



a. Using a wave model of light, explain why Band 3 is dark.

(2 marks)

b. The two slits are 1.00 m from the screen. The spacing between the two slits is 0.100 mm. The wavelength of the laser is 600 nm.

Calculate the band spacing, X, in millimetres.

(2 marks)

c. The whole apparatus is now immersed in an insulating liquid of refractive index 1.2. The spacing of the bands changes.

Explain why the spacing of the bands changes and include a calculation of the new band spacing.

(2 marks)

Solution

a Band 3 is a point of destructive interference because the path difference of the light rays from the two slits is $\frac{3\lambda}{2}$.

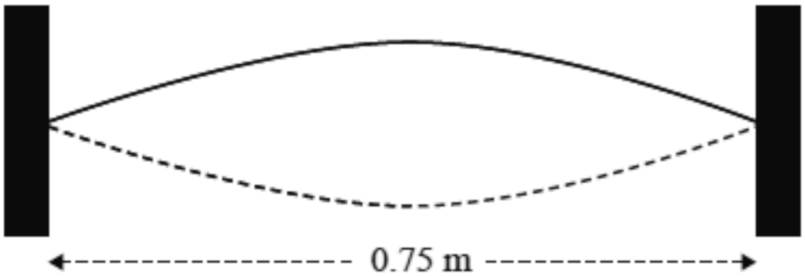
b 6.00 mm Use $\mathrm{X} = \frac{\lambda L}{d} = \frac{600 \times 10^{-9}}{10^{-4}} = 0.006 \text{ m} = 6.00 \text{ mm}$.

c 5.00 mm As the refractive index increases, wavelength decreases.

Question 36/ 67

[VCAA 2023 SB Q11]

A guitar string of length 0.75 m and fixed at both ends is plucked and a standing wave is produced. The envelope of the standing wave is shown below.



The speed of the wave along the string is $393\ \mathrm{m\ s^{-1}}$.

a. What is the frequency of the wave?

(1 mark)

b. Describe how the standing wave is produced on the string fixed at both ends.

(2 marks)

Solution

a 262 Hz $v = f\lambda$

$393 = f(0.75 \times 2)$

$f = 262\ \mathrm{Hz}$

b When the string is plucked, the wave travels to both fixed ends. A standing wave is formed when the wave that is travelling along the string is reflected at each end. The two waves combine (principle of superposition) to form an interference pattern.

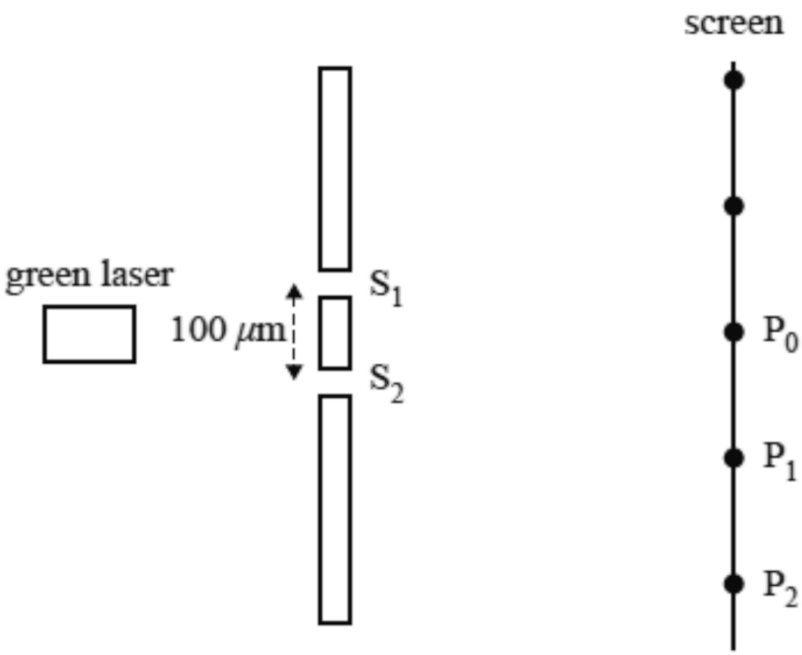
Question 37/ 67

[VCAA 2023 SB Q13]

A group of physics students undertake a Young's double-slit experiment using the apparatus shown below. They use a green laser that produces light with a wavelength of 510 nm.

The light is incident on two narrow slits, S_1 and S_2.

The distance between the two slits is 100 µm.



An interference pattern is observed on a screen with points P_0, P_1 and P_2 being the locations of adjacent bright bands as shown above. Point P_0 is the central bright band.

a. Calculate the path difference between S_1P_2 and S_2P_2. Give your answer in metres.

(2 marks)

b. The green laser is replaced by a red laser.

Describe the effect of this change on the spacing between adjacent bright bands.

(1 mark)

c. Explain how Young's double-slit experiment provides evidence for the wave-like nature of light and not the particle-like nature of light.

(3 marks)

Solution

a 1.02×10^{-6} m $\mathrm{PD} = 2\lambda$

$= 2 \times 510 \times 10^{-9}$

$= 1.02 \times 10^{-6}$ m

b Increase The red laser light has a longer wavelength than the green laser light. This will increase the distance between adjacent bright bands as $\Delta x = \frac{\lambda L}{d}$

c Young's double slit experiment can only be explained if light is modelled as a wave. The two slits give an interference pattern, due to constructive and destructive interference. Interference is a property of waves.

Particles will not create an interference pattern and would only form 2 bands.

Chapter 15 Particle properties of light, models of light

Question 1/ 21

A searchlight beams out green light, of wavelength 520 nm. The momentum of a single 520 nm photon is closest to

A 3.9×10^{-19}N s

B 1.3×10^{-27}N s

C 6.6×10^{-37}N s

D 3.4×10^{-60}N s

Solution

B Use $p = \frac{h}{\lambda}$

Question 2/ 21

The searchlight power is 5.0 kW. These photons are focused onto a perfectly reflecting mirror. The average force on the mirror is closest to

A 1.7×10^{-5} N

B 3.3×10^{-5} N

C 5.0×10^{3} N

D 1.0×10^{4} N

Solution

B $\text{Find } n \text{ (number per second)} = \frac{P}{hf} = \frac{P\lambda}{hc}$. Each photon causes an impulse of $\frac{2h}{\lambda}$. Total impulse per $\text{second} = F = \frac{2nh}{\lambda} = \frac{2P}{c}$

Question 3/ 21

If the mirror in the previous question was replaced by a perfectly *absorbing* surface, then the force would

A increase by a factor of 2

B decrease by a factor of 2.

C remain the same.

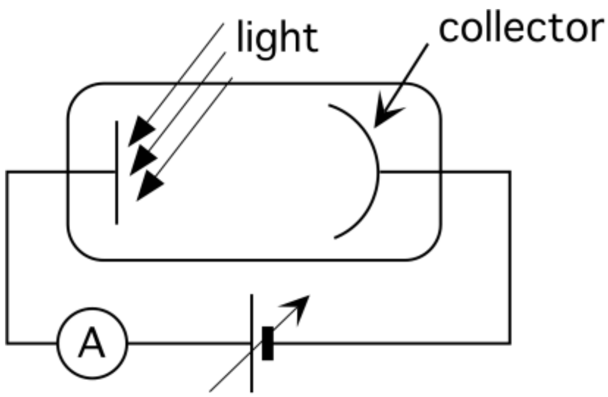
D change, but not by a factor of 2.

Solution

B Absorbed photon has $\frac{1}{2}$ the momentum change.

Question 4/ 21

A photocell is sketched below. This apparatus can be used to determine the maximum energy of emitted photoelectrons. Which of the following values best describes the key measurement for this?



A the maximum current through the ammeter

B the maximum voltage at maximum current

C the smallest voltage to just achieve maximum current

D the smallest voltage to just achieve minimum current

Solution

D This is the stopping voltage.

Question 5/ 21

Einstein's explanation of the photoelectric effect contributed a particular insight, namely that

A more intense light carries more energy.

B the energy carried by light can be transferred to electrons.

C different frequency light has different wavelengths.

D the energy that light carries is in discrete quantities.

Solution

D Quantisation of light energy.

Question 6/ 21

A dark region in a two-slit interference pattern for light happens because

A the photons annihilate each other at that point.

B the photons involved are not able to be detected.

C the energy of the photons is greatly reduced due to interference.

D the photons cannot be detected at that point.

Solution

D The probability of photons being detected there is zero.

Question 7/ 21

Which of the following best describes what happens when the intensity of the source of light for the interference pattern is reduced greatly?

A The number of photons is reduced greatly.

B The energy of the photons is reduced greatly.

C The frequency of the photons is reduced greatly.

D The speed of the photons is reduced greatly.

Solution

A Standard knowledge.

Question 8/ 21

Photoelectrons are emitted almost immediately from the metal surface after light of a suitable wavelength strikes it. The best explanation for this is that

A only one photon is required to liberate one electron.

B very few photons are required to liberate electrons**.**

C the electrons resonate strongly to the frequency of the incident photons.

D even weak light sources contain lots of energy to liberate electrons.

Solution

A The Einstein equation $(\mathrm{KE}_{\mathrm{MAX}} = hf - W)$ assumes that single photons have the energy to liberate single electrons.

Question 9/ 21

[VCAA 2018 NHT SA Q16]

When light of a specific frequency strikes a particular metal surface, photoelectrons are emitted. If the light intensity is increased but the frequency of the light remains the same, which of the following is correct?

Number of photoelectrons emitted	Maximum kinetic energy of the photoelectrons
remains the same	remains the same
remains the same	increases
increases	remains the same
increases	increases

Solution

C Electrons are emitted because the photon energy is greater than the work function; this excess energy is given to the electrons as KE. More photons will not change this value but will mean that more electrons are emitted.

Question 10/ 21

A metal surface has a work function of 2.0 eV. The minimum energy of an incoming photon required to eject a photoelectron is

A 3.2×10^{-19} J

B 1.6×10^{-19} J

C 8.0×10^{-20} J

D 4.0×10^{-20} J

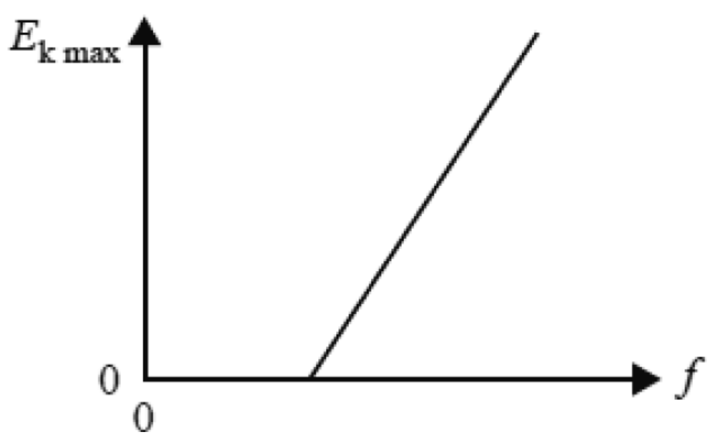
Solution

A Standard knowledge.

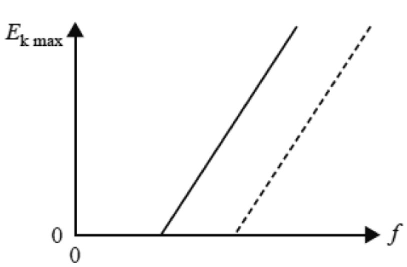
Question 11/ 21

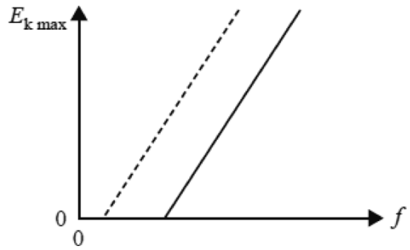
[VCAA 2018 SA Q17]

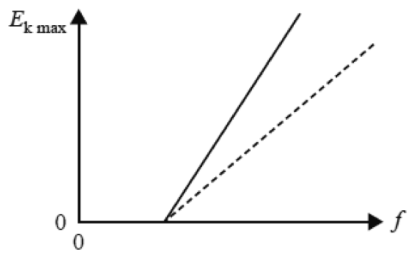
The results of a photoelectric experiment are displayed in the graph below. The graph shows the maximum kinetic energy (E_k max) of photoelectrons versus the frequency (*f*) of light falling on the metal surface.

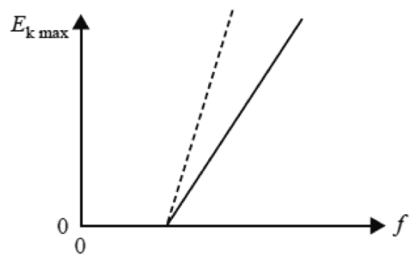


A second experiment is conducted with the original metal surface being replaced by one with a larger work function. The original data is shown with a solid line and the results of the second experiment are shown with a dashed line. Which one of the graphs below shows the results from the second experiment?

A 

B 

C 

D 

Solution

A Must have same gradient (h) but greater value of the x-intercept.

Question 12/ 21

[VCAA 2019 SA Q16]

Students are conducting a photoelectric effect experiment. They shine light of known frequency onto a metal and measure the maximum kinetic energy of the emitted photoelectrons. The students increase the intensity of the incident light. The effect of this increase would most likely be

A lower maximum kinetic energy of the emitted photoelectrons.

B higher maximum kinetic energy of the emitted photoelectrons.

C fewer emitted photoelectrons but of higher maximum kinetic energy.

D more emitted photoelectrons but of the same maximum kinetic energy.

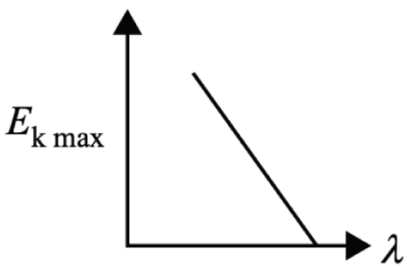
Solution

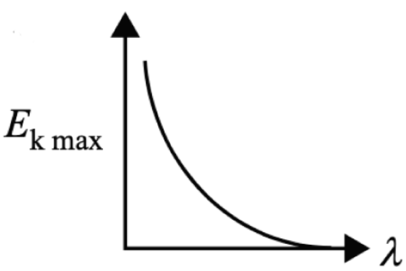
D More incident photons will cause more photoelectrons but the energy of the photoelectrons depends only on the frequency of the incident light.

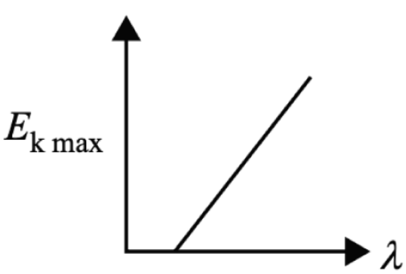
Question 13/ 21

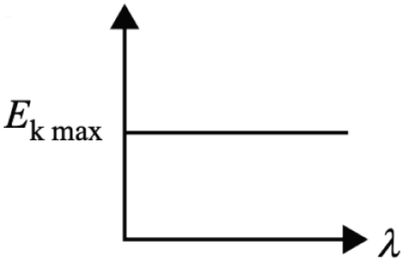
[VCAA 2020 SA Q20]

When photons with energy E strike a metal surface, electrons may be emitted. The maximum kinetic energy, $E_{\text{k max}}$, of the emitted electrons is given by $E_{\text{k max}} = E - W$, where W is the work function of the metal. Which one of the following graphs best shows the relationship between the maximum kinetic energy of these electrons, $E_{\text{k max}}$, and the wavelength of the photons, λ?

A 

B 

C 

D 

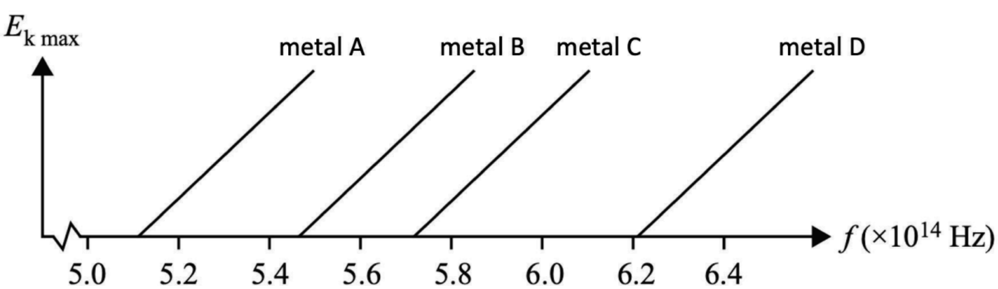
Solution

B Follows from $E_{k\ max} = \frac{hc}{\lambda} - W$.

Question 14/ 21

[Adapted VCAA 2020 SA Q16]

The diagram below shows a plot of maximum kinetic energy, $E_{k\ max}$, versus frequency, *f*, for various metals capable of emitting photoelectrons.



Which one of the following correctly ranks these metals in terms of their work function, from highest to lowest in numerical value?

A Metal A

B Metal B

C Metal C

D Metal D

Solution

D   Cut-off frequency f_0 is related to the work function by

$W = hf_0$.

Question 15/ 21

[VCAA 2021 NHT SA Q18]

Experiments on the photoelectric effect involve shining light onto a metal surface. Measurements are made of the number of emitted electrons and their maximum kinetic energy from the metal surface. This is done for different frequencies and intensities of light. Which one of the following statements would not be one of the experimental findings?

A The ability to eject electrons from this metal depended only on the frequency of light.

B The stopping potential for the photoelectrons was independent of the light intensity.

C The maximum kinetic energy of the photoelectrons depended only on the light intensity.

D At frequencies below the threshold frequency, no electrons were ejected from this metal no matter how high the light intensity was.

Solution

C   Wave models for light predicted that this should occur; the discovery that it did not was crucial in establishing a photon model.

Question 16/ 21

[VCAA 2021 NHT SA Q15]

The polarisation of light supports

A the wave model of light.

B the particle model of light.

C both the wave model and the particle model of light.

D neither the wave model nor the particle model of light.

Solution

A The electromagnetic theory of light is founded on a wave model.

Question 17/ 21

[VCAA 2021 SA Q16]

The diagram below shows a circuit that is used to study the photoelectric effect.

Missing Image

Which one of the following is essential to the measurement of the maximum kinetic energy of the emitted photoelectrons?

A the level of brightness of the light source

B the wavelengths that pass through the filter

C the reading on the voltmeter when the current is at a minimum value

D the reading on the ammeter when the voltage is at a maximum value

Solution

C When the PD across the photocell just stops all the photoelectrons, then the most energetic photoelectrons are being stopped.

Question 18/ 21

[VCAA 2022 NHT SA Q16]

When light of a specific frequency strikes a metal surface, photoelectrons are emitted. If the light intensity is increased but the frequency of the light remains the same, which of the following would be correct?

Number of photoelectrons emitted	Maximum kinetic energy of photoelectrons
increases	remains the same
remains the same	increases
increases	decreases
remains the same	remains the same

Solution

A More photons will release more photoelectrons but the of the photoelectron energy depends only on the light frequency.

Question 19/ 21

[VCAA 2022 SA Q15]

Which one of the following best provides evidence of light behaving as a particle?

A photoelectric effect

B white light passing through a prism

C diffraction of light through a single slit

D interference of light passing through a double slit

Solution

A   Standard knowledge.

Question 20/ 21

[VCAA 2023 NHT SA Q15]

Violet light shines on a metal surface and electrons are emitted. The maximum kinetic energy of electrons emitted is measured to be 0.120 eV.

This energy, when expressed in joules, is closest to

A 1.33×10^{-20} J

B 1.92×10^{-20} J

C 1.33×10^{-18} J

D 1.92×10^{-18} J

Solution

B   Convert eV to J using 1.6×10^{-19}.

Question 21/ 21

[VCAA 2023 NHT SA Q18]

Light of wavelength 300 nm is just able to cause the photoelectric emission of electrons from a lead surface. If light of twice this wavelength were incident on a lead surface

A no photoelectric emission would occur.

B half as many electrons would be ejected per second.

C the same number of electrons would be ejected per second, with twice the energy.

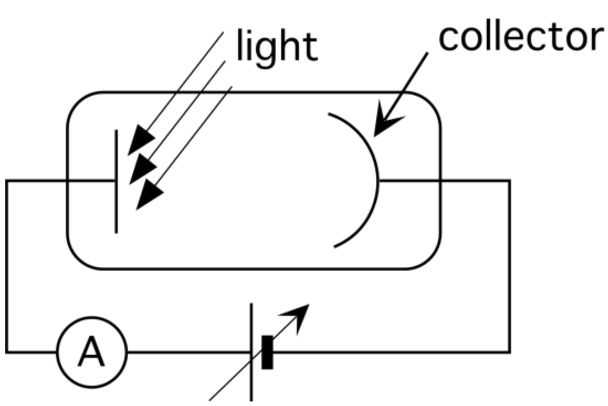
D the same number of electrons would be ejected per second, with more energy but not necessarily twice as much energy.

Solution

A Twice the wavelength implies half the frequency – below threshold frequency.

Question 1/ 49

A photocell is sketched in the diagram below. This apparatus can be used to determine the maximum energy of emitted electrons. The maximum KE of the photoelectrons depends on the frequency of the light falling on the metal surface, but not on its intensity.



Explain why this observation caused difficulties for the proponents of a wave model of light.

(2 marks)

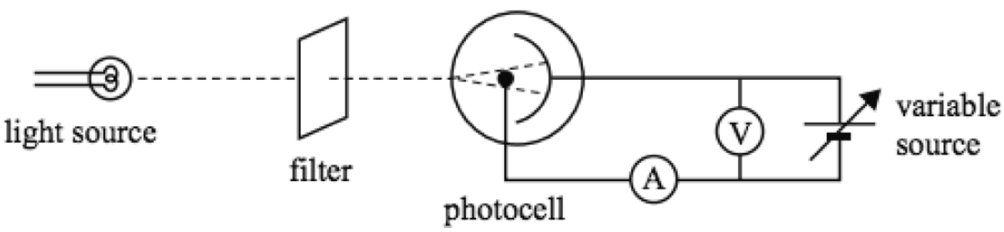
Solution

The wave theory of light links energy to intensity and cannot explain the frequency dependence of the emitted electron energy.

Question 2/ 49

[VCAA 2016 SA Q19]

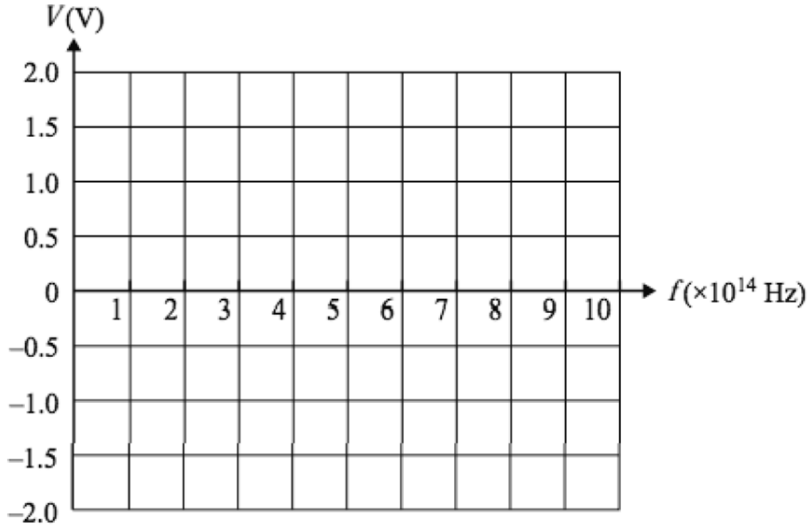
Emily is conducting an experiment to investigate the photoelectric effect. The apparatus is shown below. It consists of a light source, a filter and a photocell (a metal plate with a collecting electrode in a vacuum tube).



Emily uses various filters to shine a particular wavelength on the photocell. She increases the voltage (V) until the current just goes to zero and records this voltage. Emily repeats this process for different frequencies. Her results are shown in the table on the next page.

Frequency (Hz)	Voltage (V)
6.0×10^{14}	0.16
7.0×10^{14}	0.52
8.0×10^{14}	0.88
9.0×10^{14}	1.20

a. On the axes below, plot Emily’s data and draw the graph of voltage against frequency.



(2 marks)

b. From the graph, determine the value that Emily would have found for each of the following:

i. Planck's constant

ii. threshold frequency

iii. work function of the metal.

(3 marks)

c. Explain how the recorded voltage measurements give information about the emitted photoelectron.

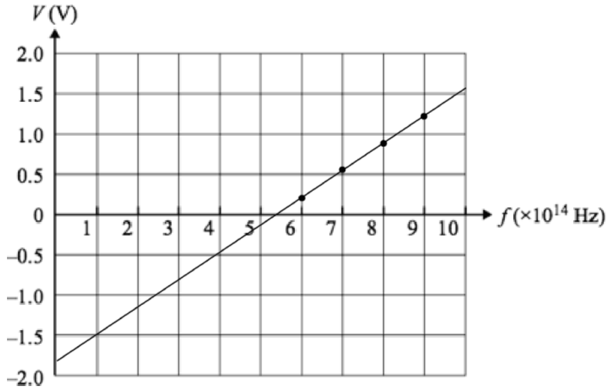
(2 marks)

d. For each frequency, Emily doubles the intensity of the incident light.

Describe the graph Emily will now obtain in comparison with the original graph. Do these two graphs support the wave model or particle model of light? Justify your answer.

(3 marks)

Solution

a 

b From graph: **i** $h = 3.5 \pm 0.2 \times 10^{-15}$eV s; **ii** $f_{\text{threshold}} = \ 5.5 \pm 0.3 \times 10^{14}$Hz;

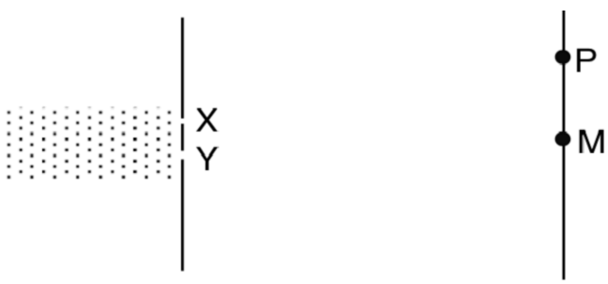
iii $\phi = 1.9 \pm 0.2$ eV.

c The voltage readings (converted to eV) give the maximum KE of the photoelectrons.

d Graph will be the same; this supports the particle model of light. The increased intensity produces more photons, but the photons (and hence the photoelectrons) have the same energy (from $E = hf$).

Question 3/ 49

A two-slit experiment is successfully performed with light.



Light and dark bands are seen on the screen on the right. M is the midpoint of the pattern. It is opposite the midpoint of XY. The point P in the diagram is the third dark band upwards from M. Explain this in terms of a wave model.

(3 marks)

Solution

M is equidistant from X and Y; the light waves arrive in phase at *M* giving constructive interference (bright band); at P the path difference between the waves starting at Y and X is 2.5 wavelengths; so there is destructive interference (a dark band).

Question 4/ 49

Calculate the momentum change involved when a single photon of wavelength 1.0×10^{-8} m is reflected from a mirror.

(2 marks)

Solution

1.3×10^{-25}N s Use $2p = \frac{2h}{\lambda}$.

Question 5/ 49

When very weak light sources are used, photoelectrons are produced almost immediately when the light strikes the metal. This fact tends to support a particle model of light rather than a wave model. Explain.

(3 marks)

Solution

Wave theory says it takes time for low intensity light to give enough energy to eject an electron. Photon theory says that at low intensities, one photon can free an electron, since electrons are released because electrons interact with single photons.

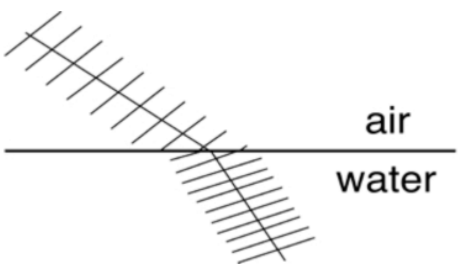
Question 6/ 49

The speed of light in water is slower than the speed of light in air. A wave theory of light used this to explain refraction. Use a diagram to show this.

(3 marks)

Solution

Draw a wavefront diagram, as shown.



Wave theory explains refraction towards the normal by assuming that the wave speed in water is less than in air, implied by the shorter wavelength in water. Confirmed by experimental results.

Question 7/ 49

In a photoelectric experiment, a metal with a work function of 1.8 eV is illuminated with light of $\lambda = 5 \times 10^{-7}$ m. Is electron emission possible? Give quantitative reasons.

(2 marks)

Solution

Yes The photons have energy 2.5eV, greater than 1.8 eV.

Question 8/ 49

Physicists use the expression 'wave-particle duality' as light sometimes behaves like particles and sometimes like waves. What evidence is there that light behaves like particles? Explain how this evidence supports a particle model.

(4 marks)

Solution

Evidence for particle-like behaviour of light can be found in the results of the photoelectric effect. Light falling on a metal plate can release electrons from the metal, as follows:

- frequency must be large enough
- energy of photoelectrons only depends on light frequency, not on intensity
- photoelectrons are emitted promptly, even at very low intensities.

This evidence is most simply interpreted as light comprised of tiny energy packets ('quanta' – now called photons) each with energy *hf*; the KE of photoelectrons being given by $\mathrm{KE} = hf - W$; *W* the 'release energy' or *work function* of the metal. Each photoelectron is released by interaction with a single photon, which explains the release at very low intensities.

Question 9/ 49

Compare the ratio of the number of photons produced per second by a 5.0 W monochromatic light source of wavelength 400 nm and a 5.0 W monochromatic light source of wavelength 600 nm.

(2 marks)

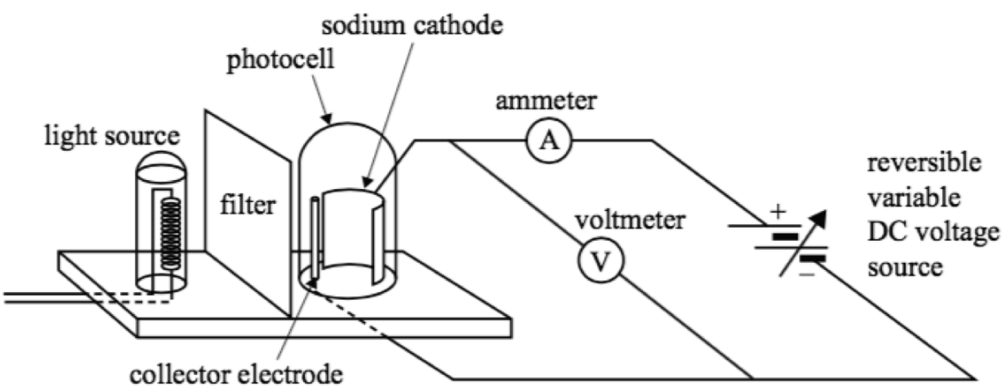
Solution

Energy of a single photon $E = hf = hc/\lambda$. Therefore, fewer shorter wavelength photons (400 nm) are required than the longer wavelength photons (600 nm) to produce the same amount of energy ($5.0\ \text{W} = 5.0\ \text{J s}^{-1}$) in the ratio of 2:3.

Question 10/ 49

[VCAA 2017 SB Q17]

In an experiment, blue light of frequency 6.25×10^{14} Hz is shone onto the sodium cathode of a photocell. The apparatus is shown below.



The graph of photoelectric current versus potential difference across the photocell is shown in the graph on the next page.

The threshold frequency for sodium is 5.50×10^{14} Hz.

a. What is the cut-off potential, V_o, when light of frequency 6.25×10^{14} Hz (blue light) is shone onto the sodium cathode of the photocell in the diagram on the previous page?

(2 marks)

b. On the graph of photoelectric current versus potential difference shown above, sketch the curve expected if the light is changed to *ultraviolet* with a significantly *higher* intensity than the original blue light.

(2 marks)

c. The results of photoelectric effect experiments in general provide strong evidence for the particle-like nature of light. Outline *two* aspects of these results that provide the strong evidence that is not explained by the wave model of light, and explain why.

(5 marks)

Solution

a 0.31 V Use $V = h\left(f - f_o\right) = 4.14 \times 10^{-15} \times (6.25 - 5.5) \times 10^{14}$

b Cut-off voltage to the left (greater magnitude); *y*-intercept higher if the increased intensity is significant.

c Possible relevant aspects of the results of photoelectric experiments supporting the particle-like nature of light rather than wave-like nature include:

- the dependence of the electron KE on the frequency of the incident light, and its explanation by the Einstein equation; this implies that the incident energy arrives in the form of discrete quanta of energy (hf) rather than a steady build-up of energy from a wavefront.

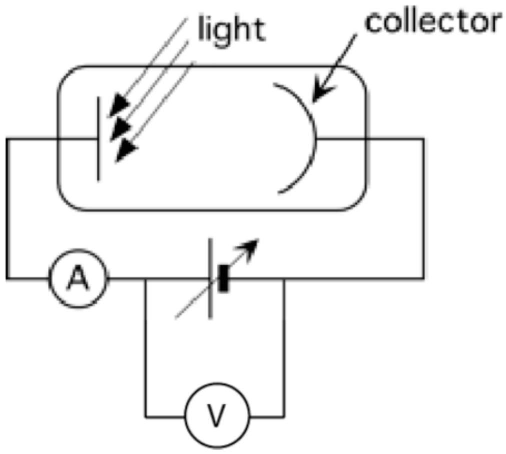
- the lack of time delay between the arrival of light on the photoelectric surface and the emission of photoelectrons, even for very weak light sources; this too implies the arrival of energy in discrete quanta.

- the lack of correlation between the intensity of incident light and the KE of the photoelectrons; more intense light of the same frequency just results in more photoelectrons rather than photoelectrons with higher

KE.

Question 11/ 49

The photoelectric effect was first observed in the 19th century. An evacuated photoelectric cell is shown in the diagram below, connected into a circuit.



Electrons are emitted from the left-hand metal plate when light of a sufficiently short wavelength strikes the metal plate. They can then travel around the circuit, provided that the voltage of the battery is not too large.

a. Explain how adjusting the battery voltage, reading the voltmeter, and observing the ammeter can be used to measure the energy of the most energetic photoelectrons.

(3 marks)

b. Einstein's equation for the photoelectric effect can be written as follows:

$E_{K\ max} = hf - W$. Explain the physical meaning of the term *W*.

(2 marks)

c. Determine a value for *W* if the most energetic electrons have an energy of 1.9 eV, and the incident light has a wavelength of $4.14 \times 10^{-7}\text{m}$.

(2 marks)

Solution

a If light of a short enough wavelength falls on the plate, electrons are emitted. These travel across the tube, and if they reach collector plate travel around circuit, causing a current. However, they only reach collector if KE is greater than ΔPE due to the battery in the circuit. To measure KE of the most energetic emitted electrons, the experimenter just raises the variable battery voltage until these electrons are just prevented from reaching the collector. The KE of these electrons is then given by: $\mathrm{KE} = e \times V_{\mathrm{BATTERY}}$.

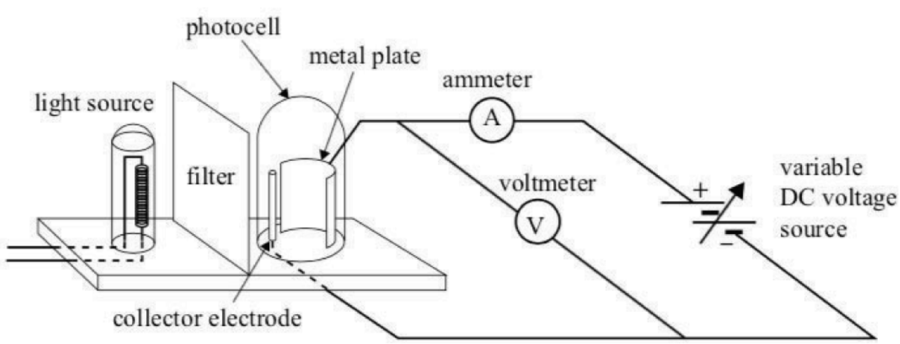
b *W* is the work function of the metal involved; it is the minimum energy required to remove electrons from that metal surface.

c 1.1 eV The incident photons have energy of 3 eV; ($E = \frac{hc}{\lambda}$); hence $W = 1.1$ eV.

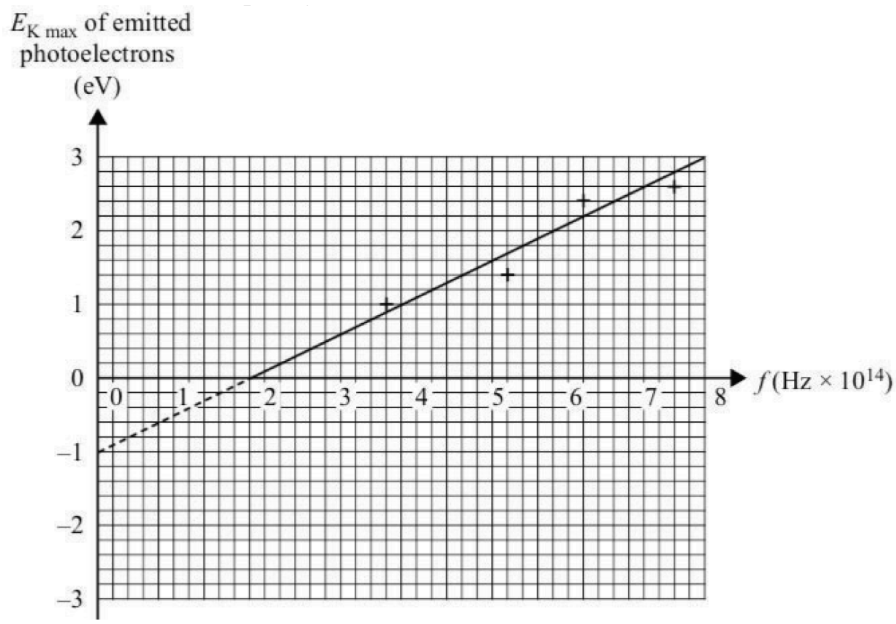
Question 12/ 49

[VCAA 2018 NHT SB Q16]

Students are investigating the photoelectric effect. The apparatus used by the students is shown below. A light source shines light through a filter that only allows one frequency of light to pass through. This monochromatic light shines onto a metal plate and photoelectrons are emitted. Different filters allow different frequencies to strike the metal plate. For each frequency, the maximum kinetic energy of the emitted photoelectrons is measured by using a stopping voltage.



The graph of the data the students collected for the maximum kinetic energy of emitted photoelectrons versus frequency is shown below. A line of best fit has been drawn.



a. Determine the value of Planck's constant, h, that the students would have obtained from this graph.

(2 marks)

b. Determine the value of the minimum frequency, or cut-off frequency, f_0, that the students would have obtained from this graph.

(1 mark)

c. Determine the value of the work function of the metal in the plate that the students would have obtained from this graph.

(1 mark)

d. The students replace the photocell with one that has a different metal plate with a work function of 2.5 eV. On the grid above, draw in the graph they would now expect.

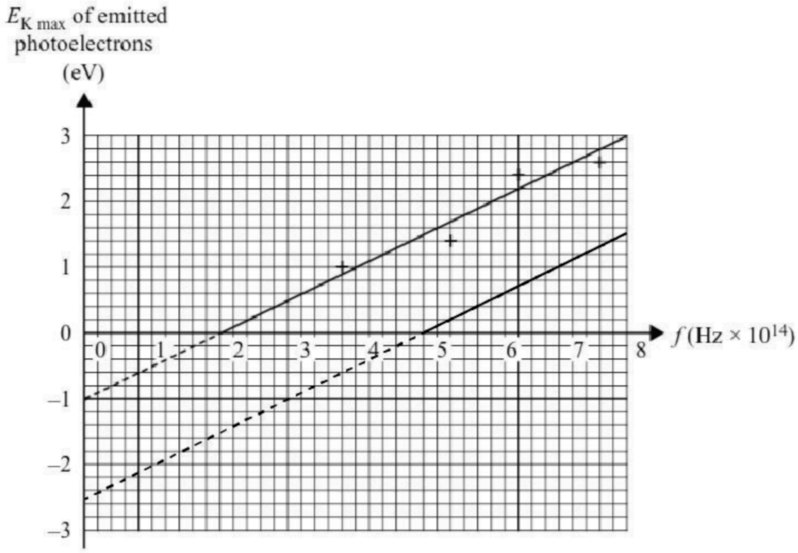
(2 marks)

Solution

a $5.0 \times 10^{-15}\text{eV s}$ h is the gradient of the graph.

b $2.0 \times 10^{14}\text{Hz}$ Read the x-intercept from the graph.

c 1.0 eV Read the y-intercept from the graph.

d 

Question 13/ 49

[VCAA 2018 NHT SB Q17]

The results of photoelectric effect experiments provide evidence for the particle-like nature of light. Outline *one* aspect of the results that would provide this evidence. Your response should explain:

• why a wave model of light cannot satisfactorily explain this aspect of the results

• how the photon theory does explain this aspect of the results.

(6 marks)

Solution

Several possibilities include:

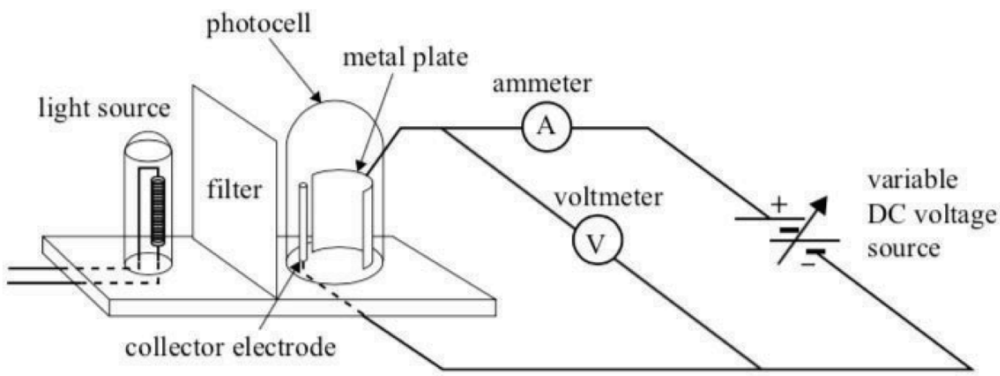
• the almost instantaneous emission of photoelectrons even at very low light intensities (wave theory would expect a delay dependent on intensity); photon theory explains from assumption that only one photon of sufficient energy (hf) is enough to release an electron.

• the proportionality between photon frequency and KE of photoelectrons and independence with intensity (wave theory would predict that increasing intensity would increase the KE of the photoelectrons).

Question 14/ 49

[Adapted VCAA 2017 Sample SB Q17]

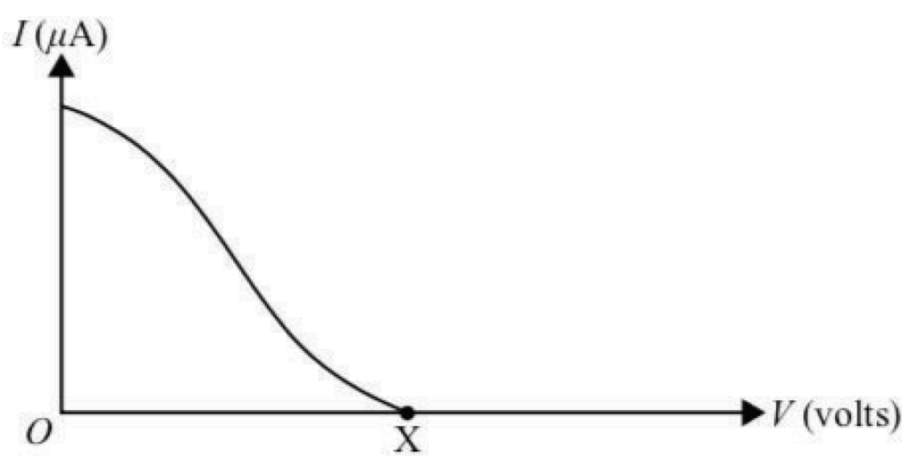
Students set up the apparatus shown below to study the photoelectric effect; in particular, the relationship between the frequency and intensity of incoming light and the maximum kinetic energy of emitted photoelectrons. Assume that all the filters give light of the same intensity.



The apparatus consists of

- a source of white light
- a set of filters, each of which allows only light of a one wavelength to pass
- a photocell with a metal plate and a collector electrode in an evacuated glass case
- a voltmeter, an ammeter and a variable DC voltage source in a circuit, as shown.

With one filter in place and the same light source, the students slowly increase the voltage (measured by the voltmeter V) from zero. They plot the current measured by the ammeter A as a function of the voltage. This is shown below.



a. Explain why the current drops to zero at point X.

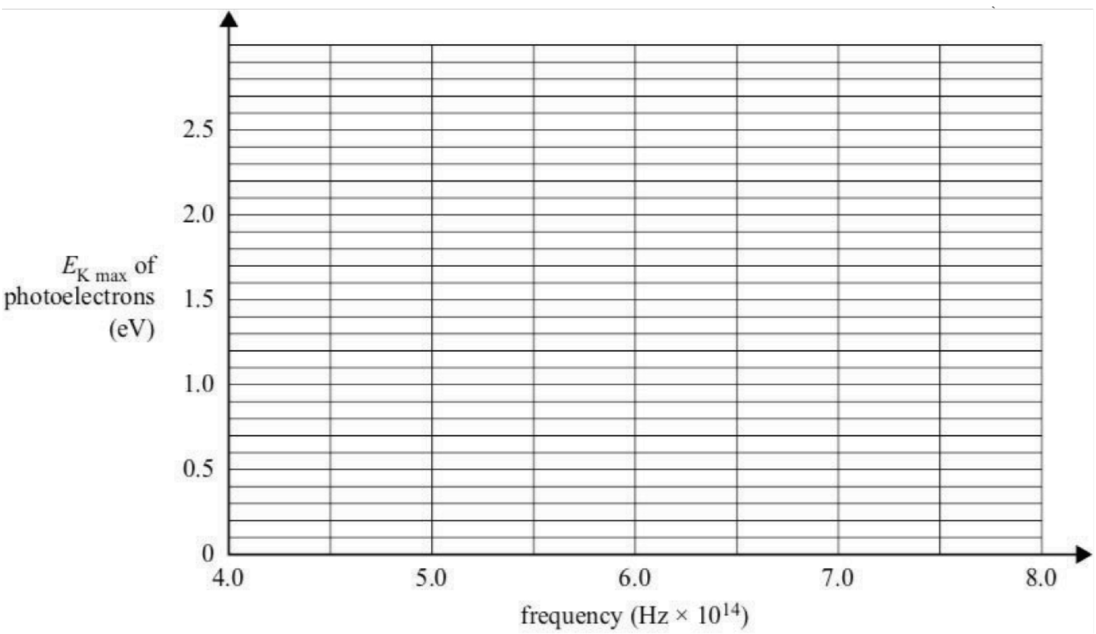
(2 marks)

The students next use five filters to give five frequencies of light falling on the metal plate and measure the stopping voltage on the voltmeter for each frequency. The data collected is shown in the table below.

Frequency $(\mathbf{Hz}) \times \mathbf{10^{14}}$	**Stopping voltage (eV)**
4.5	1.3
5.0	1.5
6.1	2.0
6.9	2.5
7.6	2.8

b. Plot the data given in the table above on the axes provided below, then draw a line of best fit to show maximum kinetic energy of the emitted photoelectrons versus frequency of light falling on the metal plate.

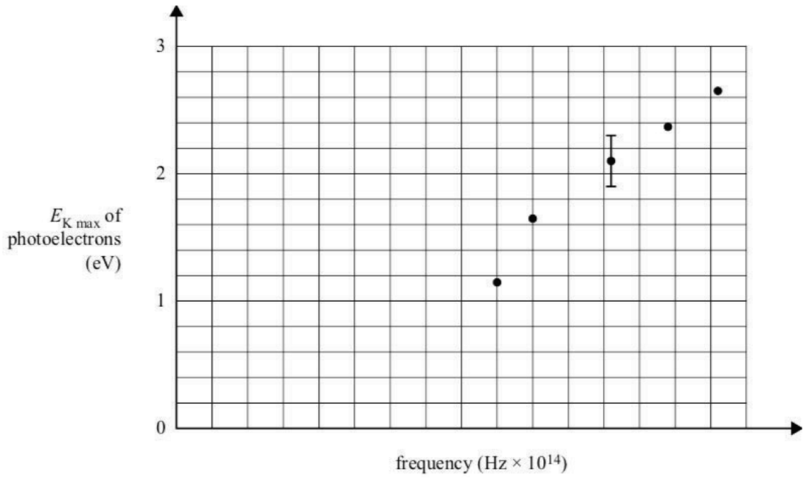
(3 marks)



c. From the graph plotted above, determine the value of Planck's constant, *h*, that the students would have obtained. Give your answer to two significant figures.

(2 marks)

Students perform a photoelectric experiment on another metal determine the uncertainty in their measurements for the maximum kinetic energy of the photoelectrons. This is represented by a vertical bar drawn on one data point in the graph on the next page. (Uncertainties in frequency values can be neglected.)

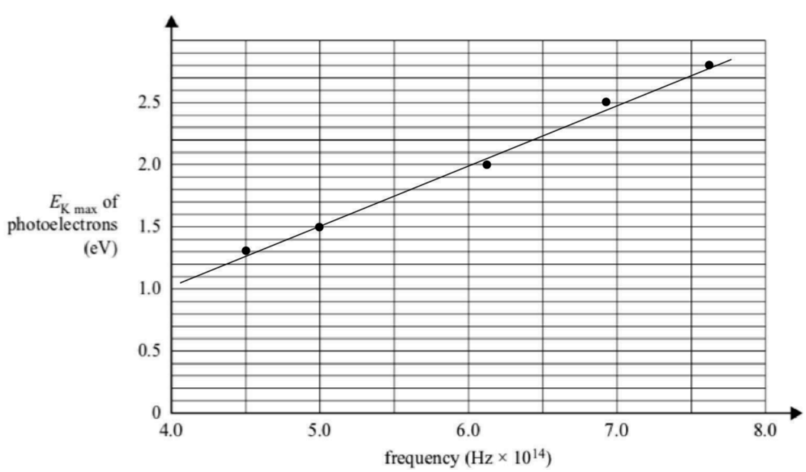


d. On the graph above, show the steps needed to determine whether the data points may be fitted by a straight line. Explain your reasoning.

(3 marks)

Solution

a Ejected photoelectrons move across the phototube provided their KE is greater than the potential energy of the reversed DC voltage source. As the value of this voltage is steadily increased, fewer and fewer of the photoelectrons have sufficient KE, until eventually the most energetic electrons are stopped, at point X.



b

c $4.8 \times 10^{-15}\text{eV s}$ Gradient of graph gives *h*.

d Fit uncertainty bars to all the points (same size as indicated); then see if a straight line of best fit passes through the extent of these bars.

Question 15/ 49

[Adapted VCAA 2017 Sample SB Q18]

Outline the conclusions about the nature of light that Albert Einstein made from the observations of photoelectric experiments. Include how these conclusions arose from the experimental observations and why these conclusions contradicted the simple wave model.

(5 marks)

Solution

Einstein proposed the following conclusions about the nature of light.

- A beam of light consists of a beam of 'light quanta' – now called photons.

- The energy of each $\text{photon} = hf$ (first proposed by Planck).

- The equation $\text{KE} = hf - W$ describes the photoelectric effect accurately, where the *work function* (*W*) is the minimum amount of energy required to release a photoelectron for a metal surface.

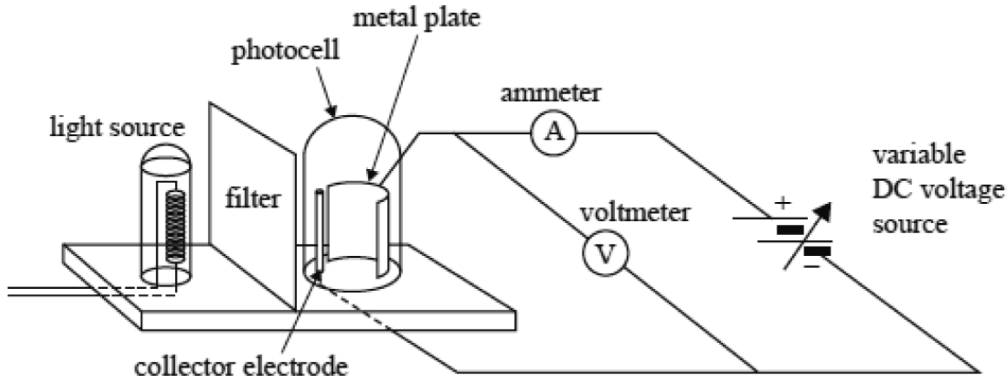
- This model explains the frequency dependency of the most energetic photoelectrons; the immediacy of release of photoelectrons even from very faint light sources of sufficient energy; the independence of KE on the intensity of the light falling on the metal.

- The simple wave model predicted that the light intensity would affect the energy of photoelectrons and that there should be a delay of photoelectron emission for very faint light sources.

Question 16/ 49

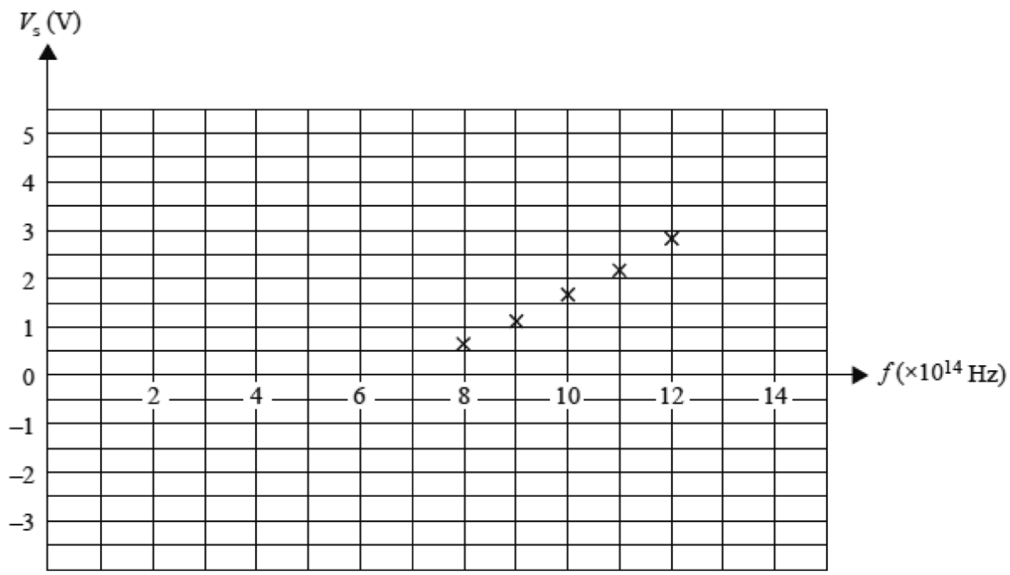
[VCAA 2018 SB Q17]

To investigate the photoelectric effect, Sai and Kym set up an experiment. The apparatus is shown below.



With the light source on and a filter in place, Sai and Kym measure the maximum kinetic energy of emitted photoelectrons by gradually changing the collector voltage until the current measured by the ammeter just falls to zero.

They record this voltage (the stopping voltage) for each frequency of the incident light and plot their results in a graph of stopping voltage, V_s, versus frequency, $f(\times\ 10^{14}\text{Hz})$, of the incident light, as shown on the next page.



With $6.0\times 10^{14}\text{Hz}$ light, the ammeter always shows zero. Sai wants to repeat the experiment for this frequency with a much brighter light source and wants to expose the metal to the light for much longer. Kym says photoelectrons will never be ejected with this frequency of light.

a i. Who is correct – Sai or Kym?

(1 mark)

ii. What explanation might Sai give to support her opinion that by waiting longer and using a brighter light source, photoelectrons could be ejected from the metal with light of a frequency of 6.0×10^{14} Hz?

(2 marks)

b. Use the graph to calculate Planck's constant. Show your working.

(2 marks)

c. Determine the work function of the metal from the graph. Give your reasoning.

(2 marks)

Solution

ai Kym. This is a fundamental experimental fact of the photoelectric effect.

aii • Light is a wave; increasing the brightness will increase the energy carried by the wave and will eventually release electrons if it is bright enough.

• The wave nature of light will continuously transfer energy onto the metal surface; eventually enough energy will be transferred to release electrons.

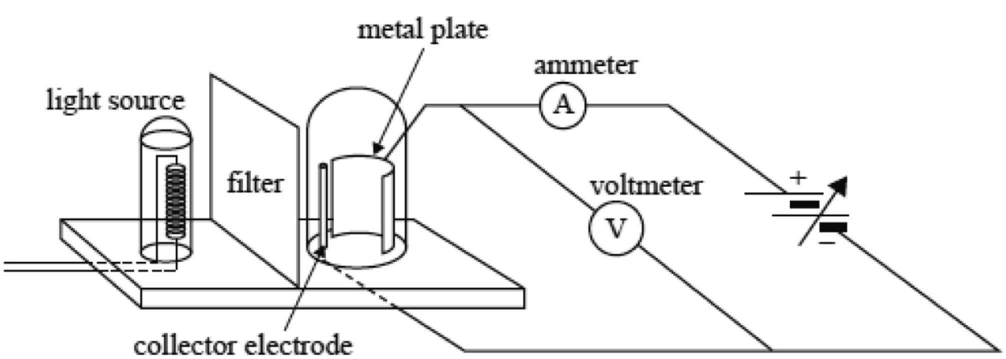
b $(5.5 \pm 0.5) \times 10^{-15} \mathrm{eVs}$. Measure the gradient of the graph.

c 3.5 ± 0.5 eV *y*-intercept of graph

Question 17/ 49

[VCAA 2019 NHT SB Q16]

April sets up the apparatus shown below to investigate the photoelectric effect. She can change the frequency of the light incident on the metal plate by changing the filter and she can change the type of metal of which the plate is made.



a. For her first experiment, April chooses a filter that gives light of frequency 7.13×10^{14} Hz and a metal plate made of caesium with a work function of 1.95 eV. April adjusts the voltage of the collector electrode so that the current becomes smaller and smaller. When the ammeter, A, reaches zero, April records the voltage shown on the voltmeter, V. Use calculations to determine this voltage.

(3 marks)

b. For her second experiment, April uses a metal plate made of zinc. Zinc has a threshold frequency for emission of photoelectrons of 1.04×10^{15} Hz. Photoelectrons are emitted. Calculate the maximum wavelength, in nanometres, of the light for photoelectrons to be emitted from the zinc plate. Show your working.

(2 marks)

c. For her third experiment, April changes the metal plate from the zinc plate used in the second experiment to a plate made of platinum. Platinum has a threshold frequency of 1.53×10^{15} Hz. April uses light of frequency 7.13×10^{14} Hz but does not make any other changes. Photoelectrons are not emitted. April observes for a longer time and then increases the intensity of the light beam but still finds that photoelectrons are not emitted. Explain how April's observations support the particle model of light but do not support the wave model of light in explaining the photoelectric effect.

(3 marks)

Solution

a 1.00 V Photon $\text{energy} = hf = 2.95 \text{ eV}$. Subtract work function $W\ (= 1.95 \text{ eV})$.

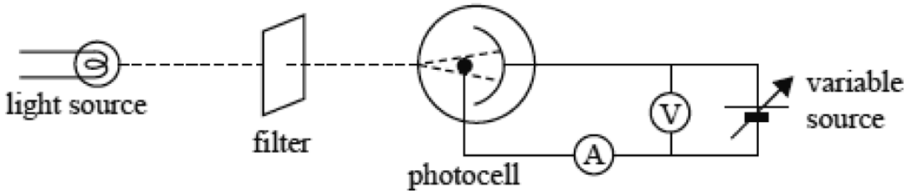
b 288 nm Maximum wavelength means minimum (threshold) photon energy; hence use $c = f\lambda$. Convert answer to nm.

c The Einstein explanation of the photoelectric effect assumes that each photoelectron is emitted due to the energy of a single photon. The number of photons per second (intensity) simply cause the emission of more electrons if the photon energy is above the threshold. If not, no electrons can be emitted. Thus her observations are consistent with a particle model of light. The wave model assumes that the wavefronts falling on the metal plate transfer enough energy to liberate the electrons, so as time goes by, enough energy should eventually cause photoelectric emission. This does not happen, so the wave model is not supported.

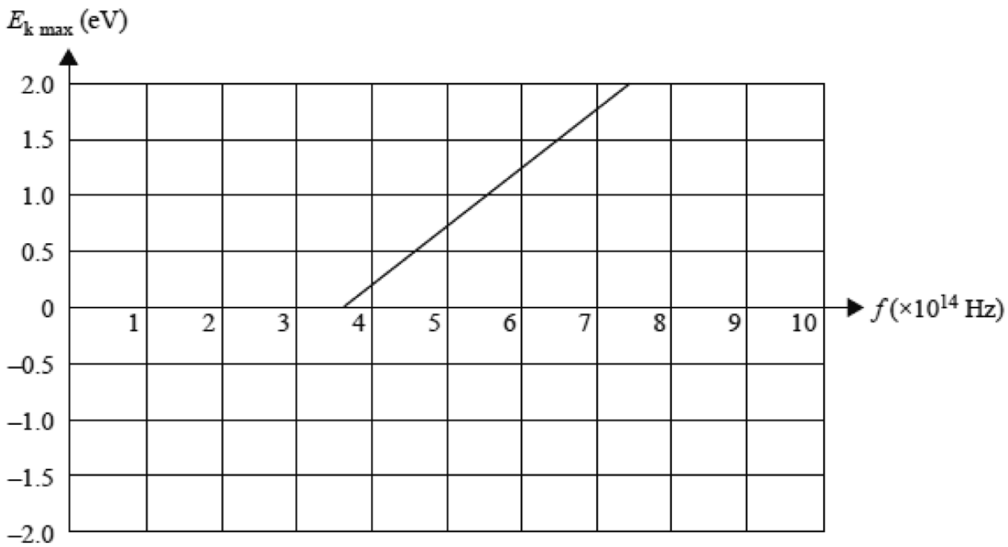
Question 18/ 49

[VCAA 2019 SB Q16]

Students are studying the photoelectric effect using the apparatus shown.



The graph below shows the results the students obtained for the maximum kinetic energy ($E_{k\ max}$) of the emitted photoelectrons versus the frequency of the incoming light.



a. Using only data from the graph, determine the values the students would have obtained for

i. Planck's constant, h. Include a unit in your answer

(2 marks)

ii. the maximum wavelength of light that would cause the emission of photoelectrons

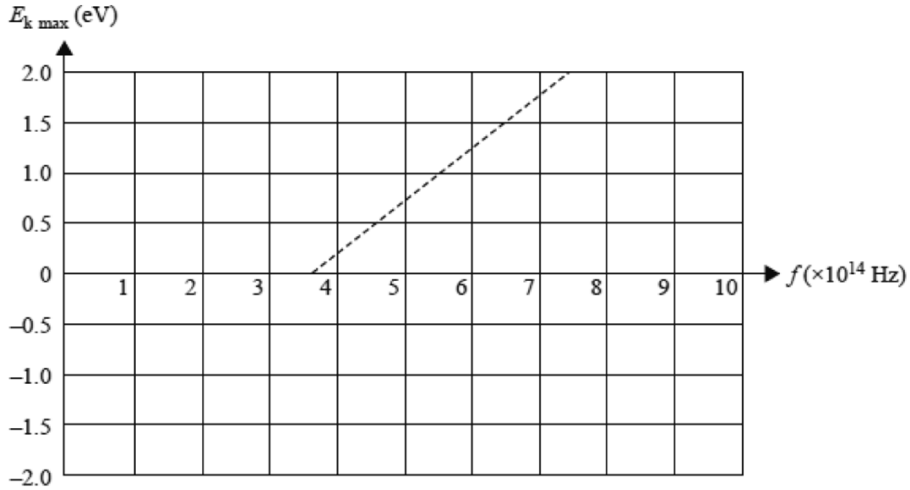
(1 mark)

iii. the work function of the metal of the photocell.

(1 mark)

b. The work function for the original metal used in the photocell is ϕ. On the graph below, draw the line that would be obtained if a different metal, with a work function of $\frac{1}{2}\phi$, were used in the photocell. The original graph is shown as a dashed line.

(2 marks)



Solution

ai 5.3×10^{-15}eV s

8.5×10^{-34}J s The gradient of the graph is equal to *h*. Answer can be quoted in either units, but eV s is easier here.

aii 810 nm Read threshold wavelength from graph and use $c = f\lambda$.

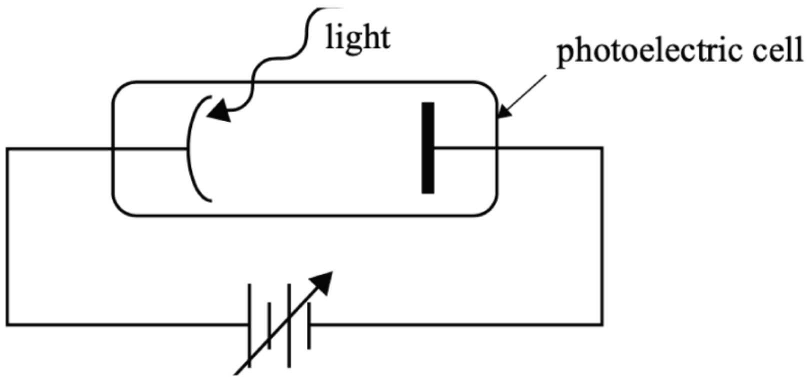
aiii 1.9 eV Extend line to *y*-axis and read intercept off graph.

b A straight line parallel to the dashed line, intercepting the *x*-axis at 1.85×10^{14}Hz (can be extended back to intercept *y*-axis at 0.95 eV).

Question 19/ 49

[VCAA 2020 SB Q15]

The metal surface in a photoelectric cell is exposed to light of a single frequency and intensity in the apparatus shown in the diagram below. The voltage of the battery can be varied in value and reversed in direction.



A graph of photocurrent versus voltage for one particular experiment is shown below.

Missing Image

a. On the diagram above, draw the trace that would result for another experiment using light of the same frequency but with triple the intensity.

(2 marks)

b. What is a name given to the point labelled A on the diagram above?

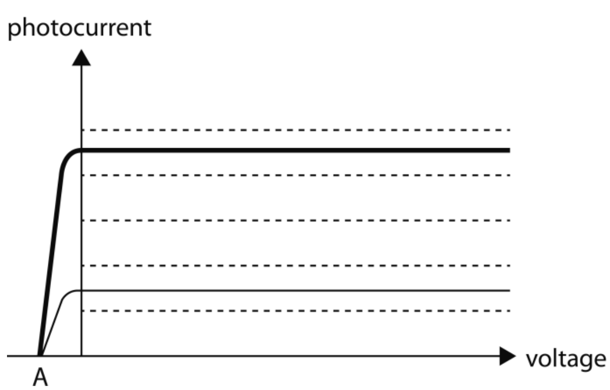
(1 mark)

c. Why does the photocurrent fall to zero at the point labelled A the diagram above?

(1 mark)

Solution

a



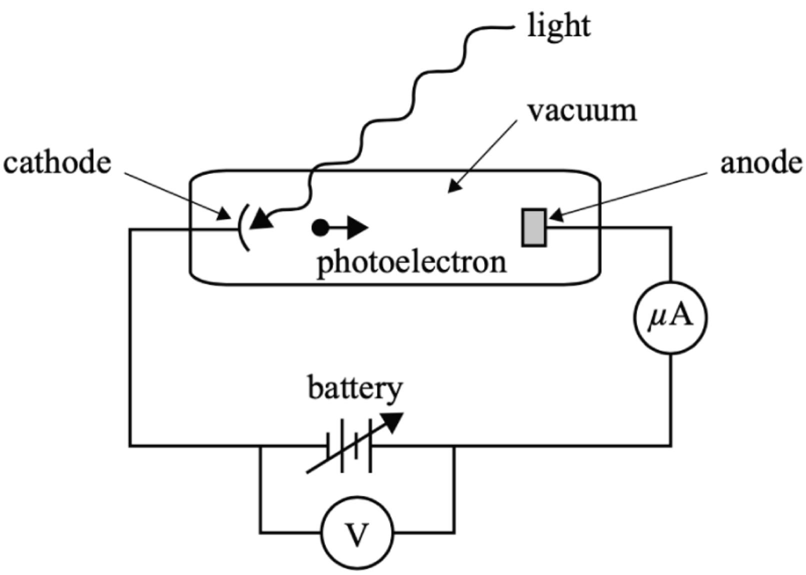
b Stopping voltage (or cut-off voltage)

c The stopping voltage is large enough so that even the most energetic photoelectrons cannot overcome the electrical PE to reach the cathode plate.

Question 20/ 49

[VCAA 2021 NHT SB Q15]

The apparatus shown below is used to investigate the photoelectric effect. Light of various wavelengths is shone onto a silver plate (the cathode). The work function of silver is 4.9 eV.



a. Explain what happens when light of wavelength 400 nm hits the silver plate. Use calculations to support your answer.

(2 marks)

b. Explain what happens when light with a photon energy of 5.4 eV hits the silver plate.

(2 marks)

c. Which model of light does this photoelectric investigation support? Specify the model and give two reasons to justify your answer.

(3 marks)

Solution

a No photoelectrons are emitted, because the energy of the 400 nm photons is only 3.1 eV (from $E = \frac{hc}{\lambda}$); this is less than the work function of silver (4.9 eV).

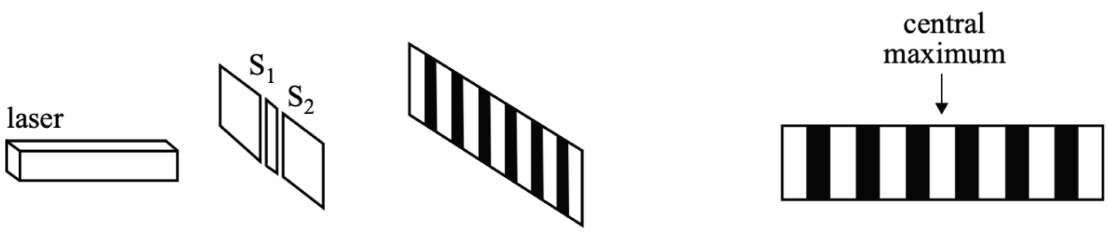
b 5.4 eV is greater than the work function so photelectrons will be emitted. Each photoelectron will have a maximum KE of $5.4 - 4.9 = 0.5$ eV.

c This investigation supports a particle (or photon) model of light. Reasons could include the existence of a threshold frequency, the independence of photoelectron KE on light intensity, the emission of photelectrons even at very low light intensity and the success of Einstein's equation $(E_{\text{k max}} = hf - W)$.

Question 21/ 49

[Adapted VCAA 2021 SB Q13]

In Young's double-slit experiment, the distance between two slits, S_1 and S_2, is 2.0 mm. The slits are 1.0 m from a screen on which an interference pattern is observed, as shown in the left-hand diagram. The right-hand diagram shows the position of the central maximum of the observed interference pattern.



Explain how this experiment supports the wave model of light.

(2 marks)

Solution

The interference pattern produce is a phenomenon typical of waves. When the light passes through each slit it diffracts and overlaps the light from the other slit. When the path difference between these two light sources is equal to zero or a whole number of wavelengths, constructive interference occurs, producing a bright band; when the path difference is equal to an odd number of half wavelengths, destructive interference occurs, producing a dark band.

Question 22/ 49

[VCAA 2021 SB Q15]

A photoelectric experiment is carried out by students. They measure the threshold frequency of light required for photoemission to be 6.5×10^{14} Hz and the work function to be 3.2×10^{-19} J. Using the students' measurements, what value would they calculate for Planck's constant? Outline your reasoning and show all your working. Give your answer in joule-seconds.

(3 marks)

Solution

4.9×10^{-34}J s Work function $(W) = hf_{\text{THRESHOLD}}$; so $h = \frac{3.2 \times 10^{-19}}{6.5 \times 10^{14}}$

Question 23/ 49

[VCAA 2021 SB Q16]

Light can be described by a wave model and also by a particle (or photon) model. The rapid emission of photoelectrons at very low light intensities supports one of these models but not the other. Identify the model that is supported, giving a reason for your answer.

(2 marks)

Solution

This supports the photon model of light. This predicts that single photons of energgy *hf* cause the emission of single photoelectrons; provided the photon energy is greater than the work function (the energy required to release electrons from the metal surface). Thus a single photon can release a photoelectron. This is light of very low intensity indeed. The wave model, on the other hand, assumes that energy from light wavefronts would gradually build up until there was enough energy to release an electron from the metal surface, so low intensity light would take some time to release a photoelectron.

Question 24/ 49

[Adapted VCAA 2021 SB Q17]

Show that the momentum of a 7.0×10^{15} Hz photon is equal to 1.55×10^{-26} kg m s^{-1}.

(1 mark)

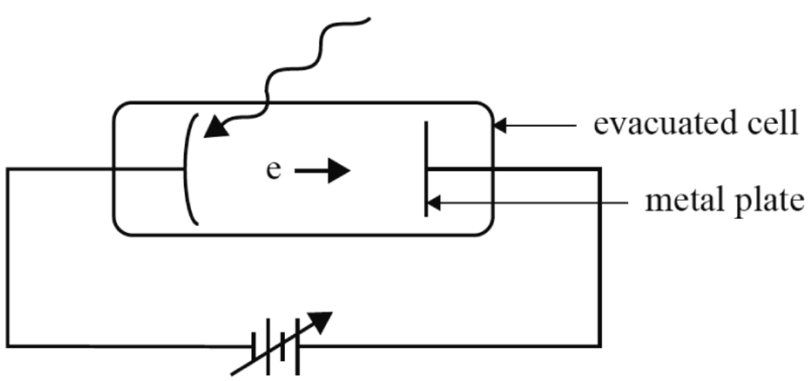
Solution

Use $p = \frac{h}{\lambda} = \frac{hf}{c} = \frac{6.63 \times 10^{-34} \times 7.0 \times 10^{15}}{3.0 \times 10^{8}}$.

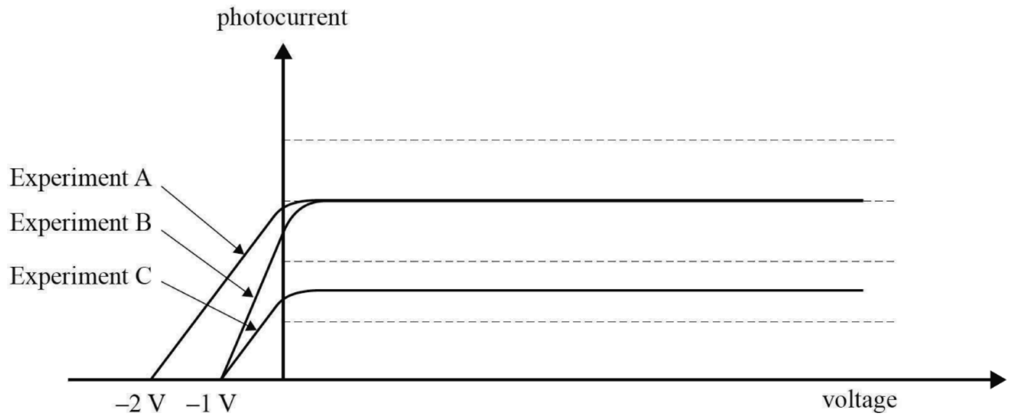
Question 25/ 49

[VCAA 2022 NHT SB Q15]

The diagram below shows an apparatus used to study the photoelectric effect. Light of various frequencies and intensities can be shone onto the metal plate inside an evacuated cell. This sometimes results in the release of photoelectrons. The voltage of the power supply can be varied and the direction can be reversed.



The graph in the diagram below shows the variation of photocurrent with voltage for three experiments, A, B and C, using light of different frequencies and intensities.



a. Using the terms ‘halved’, ‘no change’ or ‘doubled’, how would the intensity and frequency of the light used in Experiment B need to be changed so that Experiment B gives the same results as Experiment A in the diagram above?

(2 marks)

Intensity

Frequency

b. Using the terms ‘halved’, ‘no change’ or ‘doubled’, how would the intensity and frequency of the light used in Experiment B need to be changed so that Experiment B gives the same results as Experiment C in the diagram above?

(2 marks)

Intensity

Frequency

c. The metal plate is made of a metal that has a work function of 2.93 eV. Determine whether photoelectrons will be ejected from the metal plate when it is illuminated by light with a wavelength of 700 nm. Show your working.

(2 marks)

Solution

a The intensity would not be changed as the number of photons releasing photoelectrons would be the same. The frequency would need to double as the stopping voltage is double.

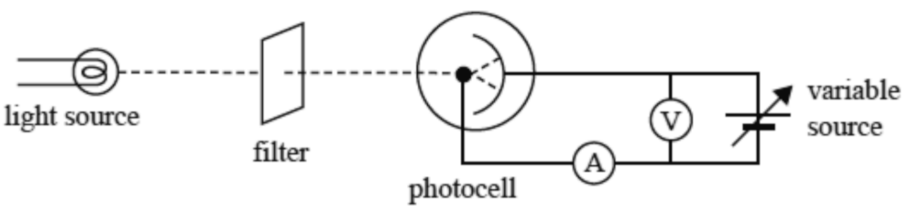
b The stopping voltage is unchanged so the frequency is also unchanged; but since the photocurrent is halved the number of photons would need to halve.

c They will not be ejected. The photons will have energy $\frac{hc}{\lambda} = 1.77 \text{ eV}$. This is less than the work function of 2.93 eV, so they carry insufficient energy to release any photoelectrons.

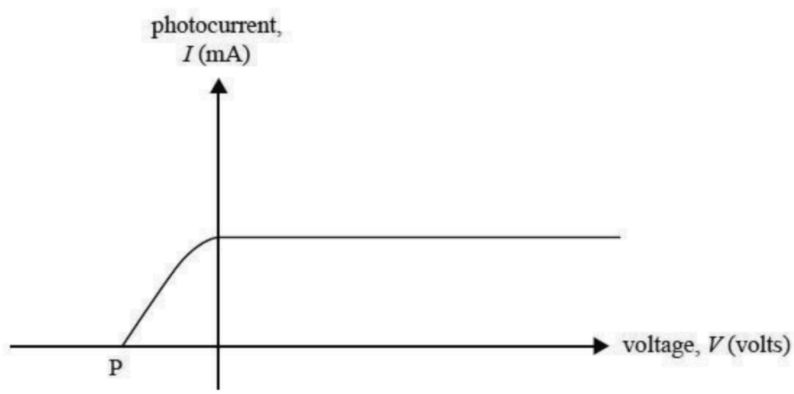
Question 26/ 49

[VCAA 2022 SB Q14]

Sam undertakes a photoelectric effect experiment using the apparatus shown. She uses a green filter.



Sam produces a graph of photocurrent, *I*, in milliamperes, versus voltage, *V*, in volts, as shown.



a. Identify what point P represents on the graph.

(1 mark)

b. Sam then significantly increases the intensity of the light. Sketch the resulting graph.

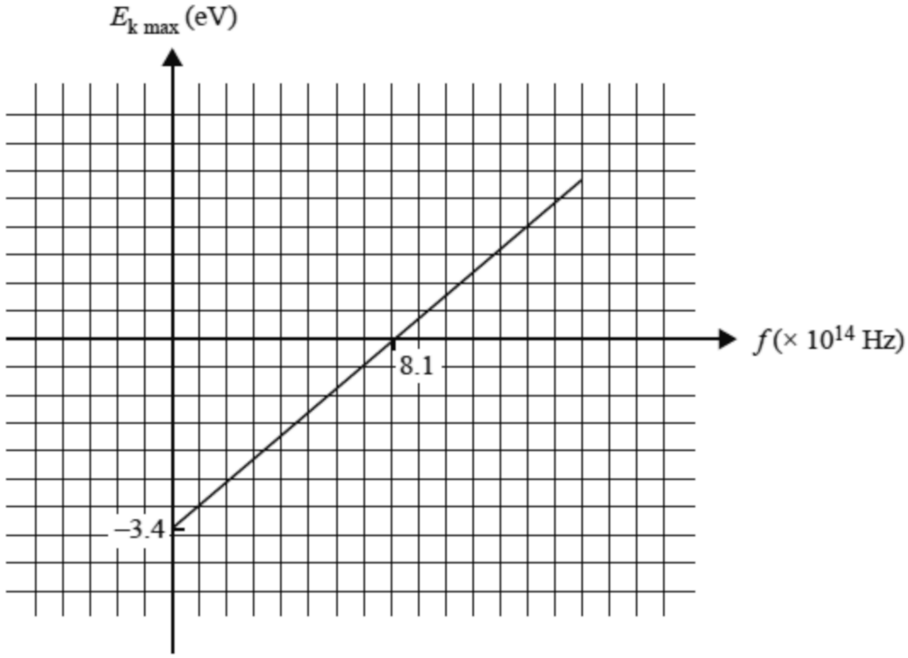
(2 marks)

c. Sam replaces the green filter with a violet filter, keeping the light source at the increased intensity. Sketch the resulting graph.

(2 marks)

d. Further experiments produce a graph of maximum kinetic energy, E_k max, of emitted photoelectrons versus frequency, *f*, of light. Determine the work function, in electron volts, of the metal surface used in the experiment that produced the data shown on the following page.

(1 mark)



e. From the graph shown above, calculate, in joule-seconds, the value of Planck's constant. Show your working.

(2 marks)

f. State one limitation of the wave model in explaining the results of the photoelectric effect.

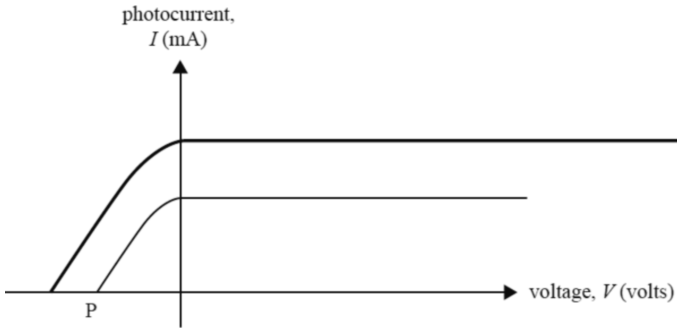
(1 mark)

Solution

a Stopping voltage, cut-off voltage or stopping potential.

b Missing Image

Same voltage intercept at P intercept and higher *I* intercept.



c

Voltage intercept to the left of P and higher *I* intercept.

d 3.4 eV Read from graph.

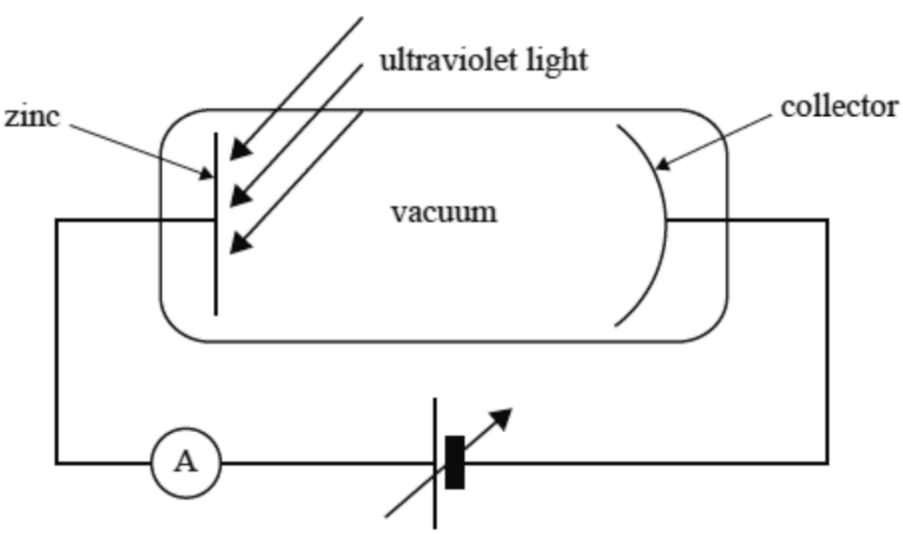
e $6.7 \times 10^{-34}\text{J s}\; h = \text{gradient} = \frac{3.4}{8.1 \times 10^{14}} = 4.2 \times 10^{-15}\text{eVs} = 6.7 \times 10^{-34}\text{J s}$

f Energy of the emitted electron is not dependent on light intensity; existence of a threshold frequency; no time delay in emission.

Question 27/ 49

[VCAA NHT 2023 SB Q19]

In an experiment on the photoelectric effect, Sam shines ultraviolet light onto a zinc plate and ejects photoelectrons, as shown below.



a. The work function of zinc is 4.30 eV.

Calculate the minimum frequency of the ultraviolet light that could eject a photoelectron.

(2 marks)

b. Sam wants to produce a greater photocurrent – that is, to emit more photoelectrons. He considers using a much brighter red light instead of the original ultraviolet light source used in part **a**.

Is Sam's idea likely to produce a greater photocurrent? Explain your answer.

(2 marks)

Solution

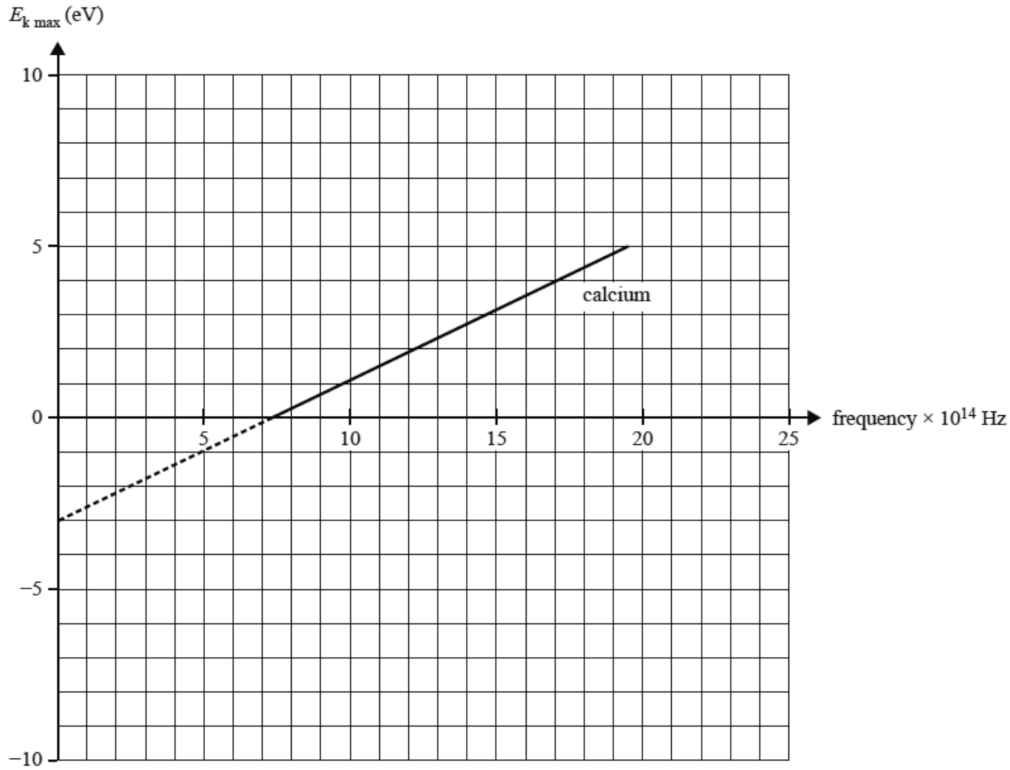
a $1.04 \times 10^{15}\text{Hz}$ $E = hf_0 - \Phi \Rightarrow f_0 = \frac{4.30}{4.14 \times 10^{-15}} = 1.04 \times 10^{15}\text{Hz}$

b Brighter light should (probably) produce more electrons but red light will have a frequency below the threshold so no photoelectrons will be produced, no matter how bright the red light.

Question 28/ 49

[VCAA 2023 SB Q13]

In a photoelectric effect experiment, a team of physics students investigated the relationship between the maximum kinetic energy of ejected electrons and the frequency of the light incident on calcium metal. Their results are shown in the diagram below.



a. Using data from the graph estimate the work function for calcium.

(1 mark)

b. Using data from the graph determine the maximum wavelength of the light

that can emit photoelectrons from the calcium surface.

(2 marks)

The calcium metal was replaced with copper metal with a work function of 4.70 eV.

c. On the grid in the diagram, draw the graph that would result when the calcium

metal was replaced with copper metal.

(2 marks)

d. The copper metal is illuminated by photons of wavelength 380 nm.

Will photoelectrons be ejected? Justify your answer using a calculation and any relevant data from the graph shown.

(3 marks)

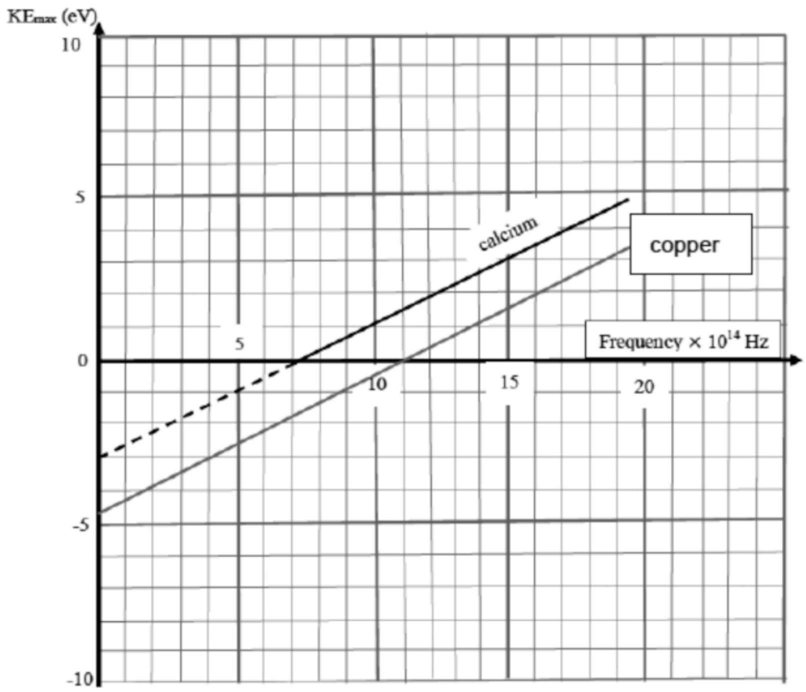
Solution

a 3 eV

b 4.1×10^{-7} m from intercept with x-axis $f = 7.2 \times 10^{14}$ Hz

$\lambda = c/f = 3.0 \times 10^8 / 7.2 \times 10^{14} = 4.17 \times 10^{-7}$ m

c Appropriate intercept - 4.7 eV. Parallel to original line with dotted line below x-axis.



d No The energy of the photon needs to be greater than the work function (4.7 eV) to release a photoelectron.

$$E = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3.0 \times 10^8}{380 \times 10^{-9}}$$

$$E = 3.27 \text{ eV} < 4.7 \text{ eV}$$

Chapter 16 Wave properties of matter

Question 1/ 14

The spacing between atoms in a certain metal crystal is 3×10^{-9} m. Which of the following would be most likely to show wave behaviour when fired at a thin layer of the crystal? Justify your choice.

A 60 eV electrons

B X-rays with a frequency of 10^{19} Hz

C 10^{-6} kg dust particles moving at 0.01 m s^{-1}

D Gamma rays of energy 2.5 MeV

Solution

A For A use: $\lambda = \frac{h}{\sqrt{2mE}} = 2 \times 10^{-10}$m;

For B use: $\lambda = \frac{c}{f} = 3 \times 10^{-12}$ m;

For C use: $\lambda = \frac{h}{mv} = 7 \times 10^{-26}$ m;

For D use: $\lambda = \frac{hc}{E} = 5 \times 10^{-13}$ m.

These are all to 1 sig. fig. Longest wavelength wins.

Question 2/ 14

In an experiment, electrons are sent at a pair of very closely spaced slits (just like the Young's experiment). The stream of electrons is very slow, and there is only one electron at a time in the apparatus, so at no stage can two electrons interfere destructively with each other. This means that

A no interference pattern will be able to be formed.

B a normal interference pattern will form, with the same spacing as would occur at higher electron numbers.

C an interference pattern will form, but only if the experiment runs for a very long time.

D interference with electrons only happens if the electrons are travelling near the speed of light.

Solution

B The wave nature of electrons ensures that interference occurs.

Question 3/ 14

Amy is interested in diffraction patterns of electrons and X-rays through small apertures. She knows that these patterns have their spacing controlled

A only by the size of the diffracting aperture.

B by the size of the aperture and the energy of the X-rays or electrons.

C only by the momentum of the X-rays or electrons.

D by the size of the aperture and the momentum of the X-rays or electrons.

Solution

D Both $\lambda(=\frac{h}{p})$ and the width of the aperture are involved.

Question 4/ 14

Amy reasoned that neutrons could also show diffraction patterns, if

A the diffracting aperture was comparable with the speed of the neutrons.

B the diffracting aperture was comparable with the ratio $\frac{h}{p}$ of the neutrons.

C the ratio $\frac{h}{p}$ of the neutrons was much smaller than the size of the diffracting aperture.

D the neutrons were moving near the speed of light.

Solution

B Follows from $\lambda = \frac{h}{p}$.

Question 5/ 14

Which of the following expressions is correct for the (non-relativistic) energy of a proton, where E is the energy, m the mass, λ the de Bröglie wavelength, h Planck's constant, and c the speed of light?

A $E = \frac{h^2}{2m\lambda^2}$

B $E = \frac{h}{\lambda}$

C $E = pc$

D $E = hf$

Solution

A This is a form of $E = \frac{p^2}{m}$.

Question 6/ 14

Identify the one statement below about de Bröglie wavelengths that is true.

A Neutrons cannot have a de Bröglie wavelength because it is charged.

B Protons cannot have a de Bröglie wavelength because they never diffract.

C The de Bröglie wavelength of electrons increases with increasing speed.

D As neutrons approach the speed of light their de Bröglie wavelength reduces greatly.

Solution

D The others are all false.

Question 7/ 14

Which of the following formulas applies both to photons and electrons?

A $E\lambda = hc$

B $h = \lambda p$

C $E = pc$

D $E = hf$

Solution

B The others are all false.

Question 8/ 14

[VCAA 2019 SA Q14]

Electrons of mass 9.1×10^{-31} kg are accelerated in an electron gun to a speed of 1.0×10^{7} m s^{-1}. The best estimate of the de Broglie wavelength of these electrons is

A 4.5×10^{-6} m

B 7.3×10^{-8} m

C 7.3×10^{-11} m

D 4.5×10^{-12} m

Solution

C Use $\lambda = \frac{h}{mv}$.

Question 9/ 14

[VCAA 2019 SA Q15]

Electrons pass through a fine metal grid, forming a diffraction pattern. If the speed of the electrons was doubled using the same metal grid, what would be the effect on the fringe spacing?

A The fringe spacing would increase.

B The fringe spacing would decrease.

C The fringe spacing would not change.

D The fringe spacing cannot be determined from the information given.

Solution

D The de Bröglie wavelength of the electrons will increase, so there will be less diffraction (a narrower pattern).

Question 10/ 14

[VCAA 2020 SA Q18]

Quantised energy levels within atoms can best be explained by

A electrons behaving as individual particles with different energies.

B electrons behaving as waves, with each energy level representing a diffraction pattern.

C protons behaving as waves, with only standing waves at particular wavelengths allowed.

D electrons behaving as waves, with only standing waves at particular wavelengths allowed.

Solution

D Wave properties are needed to ensure stability of the energy levels; particles in orbits would radiate energy and the atomic orbits would collapse.

Question 11/ 14

[VCAA 2021 NHT SA Q17]

Protons of mass 1.67×10^{-27} kg are accelerated to a speed of 2.0×10^{3} m s^{-1}. The best estimate of the de Broglie wavelength of these protons is

A 1.2×10^{-10} m

B 2.0×10^{-10} m

C 1.2×10^{-7} m

D 2.0×10^{-7} m

Solution

B Use $\lambda = \frac{h}{mv}$.

Question 12/ 14

[VCAA 2021 SA Q17]

Which one of the following is closest to the de Broglie wavelength of a 663 kg motor car moving at 10 m s^{-1}?

A 10^{-37} m

B 10^{-36} m

C 10^{-35} m

D 10^{-34} m

Solution

A Use $p = \frac{h}{\lambda}$ in the form $\lambda = \frac{h}{mv}$.

Question 13/ 14

[VCAA NHT 2023 SA Q16]

A proton of mass 1.67×10^{-27} kg is accelerated until its de Broglie wavelength is 5.00×10^{-9} m. The speed of the proton is then closest to

A 1.33×10^{-18} m s^{-1}

B 1.26×10^{-2} m s^{-1}

C 79.4 m s^{-1}

D 5.04×10^{4} m s^{-1}

Solution

C Use $p = \frac{h}{\lambda}$ in the form $\lambda = \frac{h}{mv}$.

Question 14/ 14

[VCAA 2023 SA Q17]

Which one of the following statements best explains why it is possible to compare X-ray and electron diffraction patterns?

A X-rays can exhibit particle-like properties.

B Electrons can exhibit wave-like properties.

C Electrons are a form of high-energy X-rays.

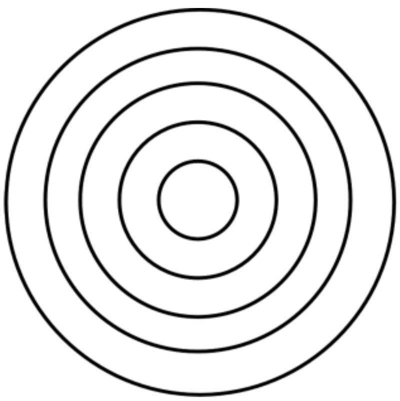
D Both electrons and X-rays can ionise matter.

Solution

B Diffraction is a property of waves. To compare X-ray and electron diffraction patterns requires electrons exhibiting wave like properties.

Question 1/ 35

X-rays are fired at metal foils. Those passing are *diffracted* to form rings centred on the axis. The pattern is sketched below.



When electrons are fired at the same foils, the same sorts of patterns, with identical dimensions, are formed. The X-ray photons had a wavelength of 8.35×10^{-10} m, and a momentum of 7.94×10^{-25} N s.

a. Calculate a value for Planck's constant from the data, in J s. Give your answer to three significant figures.

(2 marks)

b. The electron and X-ray diffraction patterns have the same spacing between rings. What did the electrons and X-ray photons used in these experiments have in common? Explain.

(3 marks)

Solution

a 6.63×10^{-34} J s Use $\lambda = \frac{h}{mv}$.

b • They have the same momentum.

- Diffraction pattern spacing depends on λ.
- λ depends on momentum (de Bröglie relationship).

Question 2/ 35

An electron is accelerated in a vacuum with a voltage of 900 V. It reaches a speed of $1.8 \times 10^{7}\ \mathrm{m\ s^{-1}}$.

a. Calculate its de Bröglie wavelength.

(2 marks)

b. The electron is aimed at a crystal, whose atomic spacing is close to 120 pm. Are interference effects likely to be observed with electrons of this speed? Support your answer with quantitative information.

(3 marks)

Solution

a $4.08 \times 10^{-11}\ \mathrm{m}$ Use $\lambda = \frac{h}{mv}$.

b Yes Within a factor of 10 of de Bröglie λ; 120 pm is $1.2 \times 10^{-10}\mathrm{m}$.

Question 3/ 35

Electrons in a diffraction experiment produce very similar patterns to X-rays with a wavelength of 56 pm. Estimate the momentum of the electrons.

(2 marks)

Solution

1.2×10^{-23} N s Since they produce same diffraction pattern spacing, they must have the same wavelength. Now use $p = \frac{h}{\lambda}$.

Question 4/ 35

Which of the following experiments is most likely to show diffraction effects? Support your choice with appropriate calculations.

A. 500 nm photons passing through a 0.05 mm slit.

B. 5×10^{6} m s^{-1} electrons passing through a 0.00015 mm slit.

(4 marks)

Solution

A Critical quantity: ratio $\frac{\lambda}{d}$, it's 10^{-2} for light and 10^{-2} for electrons.

Question 5/ 35

Calculate the de Bröglie wavelength of 1.9 eV electrons. Ignore relativistic effects. Take $m_e = 9.1 \times 10^{-31}$ kg and $h = 6.63 \times 10^{-34}$ J s.

(2 marks)

Solution

8.9×10^{-10} m First find $p = \sqrt(2mE)$, then $\lambda = \frac{h}{p}$.

Question 6/ 35

Physicists use the expression ‘wave-particle duality’ because light sometimes behaves like particles and electrons sometimes behave like waves. What evidence do we have that electrons can behave like waves? Explain how this evidence supports a wave model of electrons.

(2 marks)

Solution

Electrons are observed to diffract similarly to X-ray photons. When the electron de Bröglie wavelength is equal to the photon wavelength, spacings are the same.

Question 7/ 35

At very small scales, the ‘classical’ laws of physics used to describe motion do not work. Give an example of this.

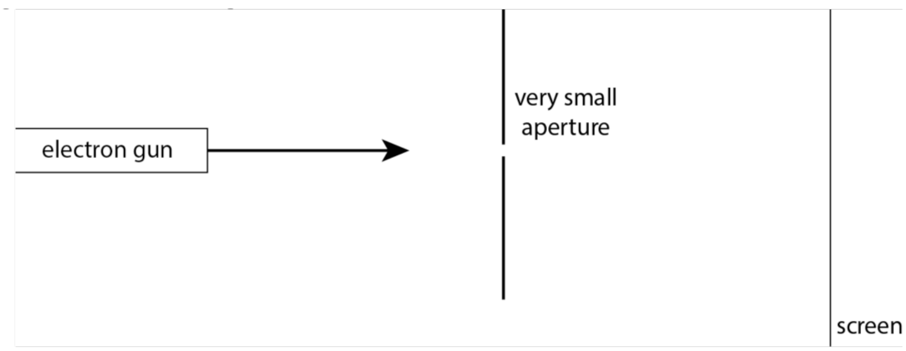
(3 marks)

Solution

Electrons are classically tiny particles with mass and should obey Newton’s laws of motion. However, they are found to possess the properties of waves. Classical Newtonian physics does not predict such behaviour. (The behaviour is found to extend to all tiny particles such as protons, neutrons, mesons etc.)

Question 8/ 35

Single-slit experiments can be performed with electron beams. In the experimental design below, a beam of 600 eV electrons is aimed at a very narrow slit in gold foil. The slit is vertical and viewed from above. Diffraction effects are clearly seen on the detecting screen on the right.



(not to scale)

For diffraction to be clearly seen with this apparatus, the electron wavelength must be no less than 1/500 of the slit width. What is the maximum slit width for the experiment to succeed? Show your working.

(4 marks)

Solution

2.5×10^{-8} m Use $w = 500 \times$ de Bröglie $\lambda = 500 \times \frac{h}{\sqrt{2mE}}$.

Question 9/ 35

When a beam of electrons is directed at a very narrow opening, diffraction effects are observed. Discuss how this phenomenon is *not* consistent with a classical mechanics view of the electron as a particle.

(4 marks)

Solution

The diffraction effects observed cannot be predicted at all from the classical view of the electron as a tiny particle of mass 9×10^{-31} kg. The behaviour is rather the behaviour of a wave, just like the diffraction of X-ray photons. The behaviour is well modelled by assigning the de Bröglie wavelength $\left(\lambda = \frac{h}{p}\right)$ to the electron.

Question 10/ 35

[VCAA 2016 SA Q20]

A beam of electrons is produced in an electron gun. The de Bröglie wavelength of each electron is 0.36 nm.

a. Calculate the speed of the electrons.

(2 marks)

An experiment is undertaken to compare the diffraction of these electrons and X-rays. With a similar gap spacing, the diffraction patterns are found to be nearly identical.

b. Calculate the energy of the X-rays. Show the steps of your working.

(3 marks)

c. Explain why similar patterns are observed.

(2 marks)

Solution

a 2.0×10^{6} m s^{-1} Use $\lambda = \frac{h}{mv}$.

b 3450 eV X-rays have same λ; now use $E = \frac{hc}{\lambda}$.

c The amount of diffraction is proportional to $\frac{\lambda}{w}$; since both λ and w are the same, patterns should be similar.

Question 11/ 35

[VCAA 2018 NHT SB Q13]

Electrons are accelerated through a potential difference of 4000 V and then pass through a metallic crystal. The resulting diffraction pattern is observed.

a. Calculate the de Bröglie wavelength of these electrons in nm.

(3 marks)

b. A student, Jane, says that X-rays of a suitable wavelength could produce the same diffraction pattern. Calculate the energy of the X-ray beam required to give a similarly spaced diffraction pattern to the electrons. Show your working and give your answer in eV.

(2 marks)

c. Explain how electrons and X-rays can exhibit similar diffraction patterns.

(2 marks)

Solution

a $1.9 \times 10^{-2}\text{nm}$ First find $p = \sqrt{(2mE)}$, then $\lambda = \frac{h}{p}$.

b $6.5 \times 10^{4}\text{eV}$. Same wavelength; then use $E = \frac{hc}{\lambda}$.

c Electrons and X-rays both have wave properties; electrons have a de Bröglie wavelength $(\text{given by} = \frac{hc}{\lambda}.)$ and electrons have a wavelength given by $\lambda = \frac{c}{f}$; if the wavelengths are the same, the wave properties will also be the same.

Question 12/ 35

[VCAA 2017 SB Q19]

Roger and Mary are discussing diffraction. Mary says electrons produce a diffraction pattern. Roger says this is impossible as diffraction is a wave phenomenon and electrons are particles; diffraction can only be observed with waves, as with electromagnetic waves, such as light and X-rays.

Evaluate Mary's and Roger's statements in light of the current understanding of light and matter. Describe *two* experiments that show the difference between Mary's and Roger's views.

(4 marks)

Solution

Mary is correct, as electrons have wave properties. Their wavelength can be found using the de Bröglie formula: $\lambda = \frac{h}{p}$

Experiments that could be referenced would include electron diffraction experiments through foils or crystals, electron single slit and double slit experiments, and versions of the G.I. Taylor experiment (single electrons passing through a single slit).

Question 13/ 35

[VCAA 2022 NHT SB Q18]

Provide an example of an instance in which classical laws of physics cannot describe motion at very small scales and explain why they cannot.

(3 marks)

Solution

Some examples follow.

- The structure of even the simplest atom (hydrogen) cannot be described by classical physics, which does not predict quantised energy states and also that the electrons should radiate energy and their orbits should collapse.

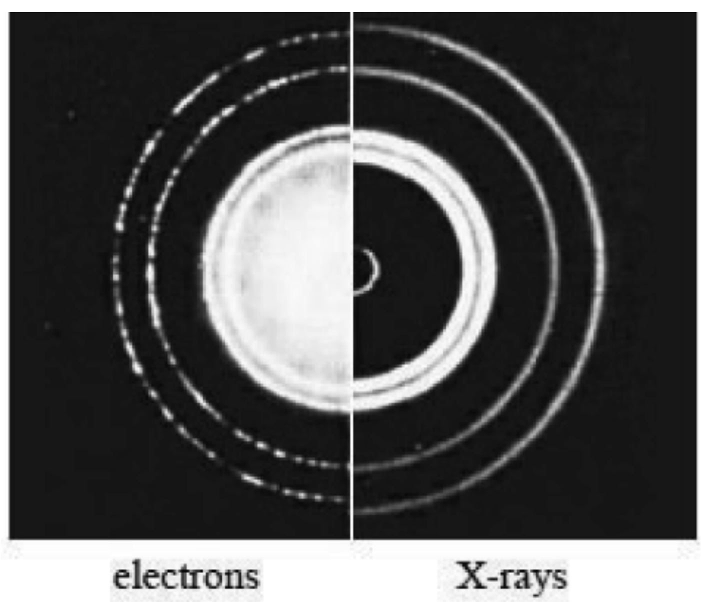
- Electron diffraction; classical physics would predict that electrons passing through small apertures like the lattice of a crystal would travel not spread out (diffract) as they do.

- In two slit electron diffraction where there is only one electron in the apparatus at a time, the electron appears to travel through both slits which is impossible classically.

Question 14/ 35

[VCAA 2018 SB Q18]

The diffraction patterns for X-rays and electrons through a thin polycrystalline aluminium foil have been combined in the diagram below, which shows an electron diffraction pattern on the left and an X-ray diffraction pattern on the right. The images are to the same scale. The X-rays have energy of 8000 eV.



a. Calculate the electron wavelength in nanometres. Show your working.

(2 marks)

b. Calculate the electron kinetic energy in joules. Show your working.

(3 marks)

Solution

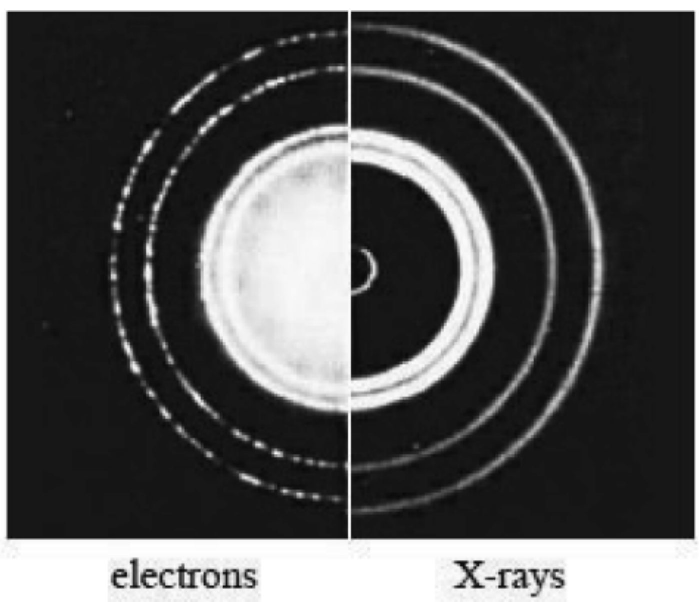
a 0.155 nm The electrons and the X-rays must have the same wavelengths; use $E = \frac{hc}{\lambda}$.

b 1.0×10^{-17} J Use $E = \frac{p^2}{2m_e} = \frac{\left(\frac{h}{\lambda}\right)^2}{2m_e} = \frac{h^2}{2m_e\lambda^2}$.

Question 15/ 35

[VCAA 2019 SB Q17]

Students are comparing the diffraction patterns produced by electrons and X rays, in which the same spacing of bands is observed in the patterns, as shown below. Note that both patterns shown are to the same scale.



The electron diffraction pattern is produced by 3.0×10^3 eV electrons.

a. Explain why electrons can produce the same spacing of bands in a diffraction pattern as X-rays.

(3 marks)

b. Calculate the frequency of X-rays that would produce the same band spacing in a diffraction pattern as for the electrons. Show your working.

(4 marks)

Solution

a Electrons have wave properties (wavelength is given by the de Bröglie wavelength); electrons and X-ray photons can have the same wavelength and if so, will produce identically spaced diffraction patterns.

b $1.34 \times 10^{19}\text{Hz}$ The wavelength of the electrons is given by $\frac{h}{\sqrt{2mEq}}$.

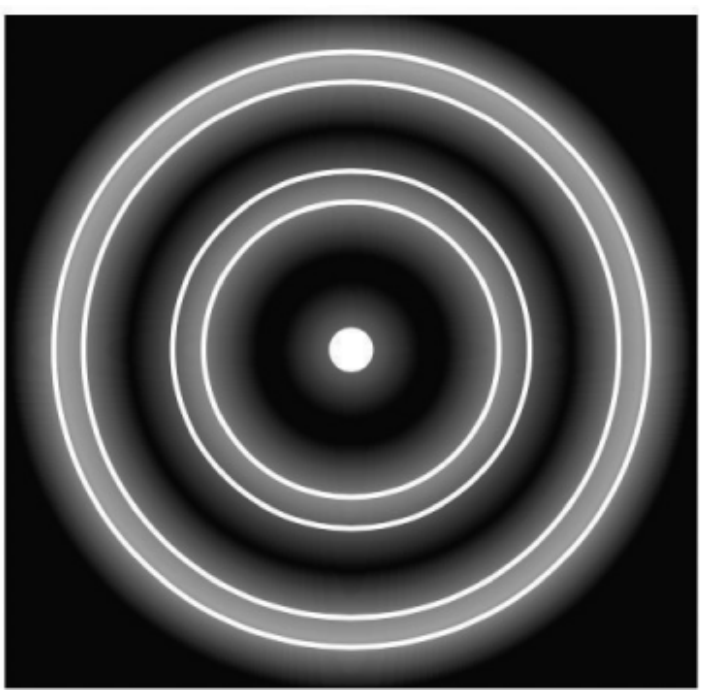
This gives $2.24 \times 10^{-11}\text{m}$ and is the photon wavelength.

Now use $c = f\lambda$.

Question 16/ 35

[VCAA 2020 SB Q16]

A beam of electrons travelling at $1.72 \times 10^5 \text{ m s}^{-1}$ illuminates a crystal, producing a diffraction pattern as shown in the diagram below. Take the mass of an electron to be $9.1 \times 10^{-31} \text{ kg}$. Ignore relativistic effects.



a. Calculate the kinetic energy of one of the electrons. Show your working.

(2 marks)

b. The electron beam is now replaced by an X-ray beam. The resulting diffraction pattern has the same spacing as that produced by the electron beam. Calculate the energy of one X-ray photon. Show your working.

(3 marks)

Solution

a 0.084 eV Find KE in joules $(0.5mv^2 = 1.35 \times 10^{-20}\ \mathrm{J})$. Divide by 1.6×10^{-19} to convert to eV.

b 293 eV Pattern spacing means $\lambda_{\text{X - ray}} = \lambda_{\text{electron}}$. Use $\lambda_{\text{electron}} = \frac{h}{mv}$; this equals $4.24 \times 10^{-9}\mathrm{m}$. Finally, use $E_{\text{X - ray}} = \frac{hc}{\lambda}$.

Question 17/ 35

[VCAA 2021 SB Q18]

Scientists are conducting experiments to compare the circular diffraction patterns formed by X-ray photons and electrons when they pass through small circular apertures. The X-ray photons have an energy of 100 eV and pass through an aperture of diameter 1.24 μm. The electrons are moving at $5.0 \times 10^5\ \mathrm{m\ s^{-1}}$.

a. Show that the de Broglie wavelength of the electrons is equal to $1.46 \times 10^{-9}\ \mathrm{m}$.

(1 mark)

b. The scientists want an aperture for the electrons that forms diffraction patterns with the same spacing as the diffraction patterns formed by the X-ray photons. Calculate the diameter of the aperture that the scientists should choose. Show your working.

(4 marks)

Solution

a Use $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63\times10^{-34}}{9.1\times10^{-31}\times5.00\times10^{5}}$.

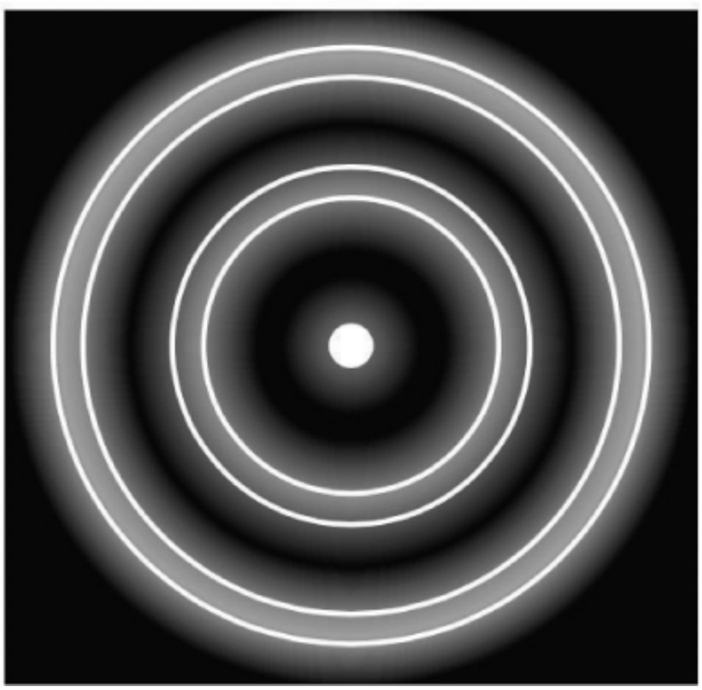
b $1.5 \times 10^{-7}\mathrm{m}$ Amount of diffraction is proportional to $\frac{\lambda}{w}$. So $\frac{\lambda_{\mathrm{x}}}{w_{\mathrm{x}}} = \frac{\lambda_{\mathrm{e}}}{w_{\mathrm{e}}}$

$\lambda_{\mathrm{x}} = \frac{hc}{E} = 1.24 \times 10^{-8}\mathrm{m}$. Now use $w_{\mathrm{e}} = \frac{w_{\mathrm{e}}\lambda_{\mathrm{e}}}{\lambda_{\mathrm{x}}} = 1.5 \times 10^{-7}$.

Question 18/ 35

[VCAA 2022 NHT SB Q16]

The diffraction pattern produced by an X-ray beam consisting of photons of energy 400 eV is shown below.



a. Show that the wavelength of an X-ray photon is approximately 3 nm.

(2 marks)

b. A stream of electrons produces a diffraction pattern with the same spacing as the X-ray diffraction pattern shown above. Calculate the speed of an electron in the stream. Take the mass of the electron to be 9.1×10^{-31} kg.

(3 marks)

Solution

a Use $E = \frac{hc}{f} = \frac{4.14\times10^{-15}\times3.0\times10^{8}}{400} = 3.11 \times 10^{-9}\text{m} = 3.1 \text{ nm}$.

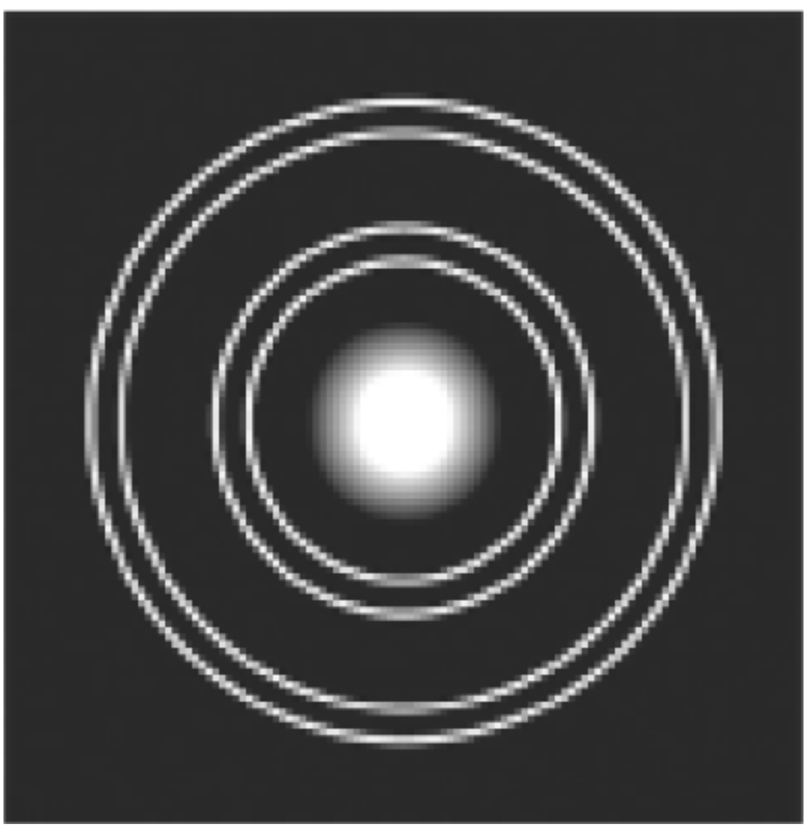
b $2.3 \times 10^{5}\ \text{m s}^{-1}$ Wavelengths are the same. $\lambda_\text{e} = \frac{h}{p_\text{e}} = \frac{h}{m_\text{e}v}$. Make *v* the subject; $v_\text{e} = \frac{h}{m_\text{e}\lambda_\text{e}} = \frac{6.63\times10^{-34}}{(9.1\times10^{-31})(3.11\times10^{-9})}$

$= 2.34 \times 10^{5}\ \text{m s}^{-1}$.

Question 19/ 35

[VCAA 2022 SB Q17]

A materials scientist is studying the diffraction of electrons through a thin metal foil. She uses electrons with an energy of 10.0 keV. The resulting diffraction pattern is shown below.



a. Calculate the de Bröglie wavelength of the electrons in nanometres.

(4 marks)

b. The materials scientist then increases the energy of the electrons by a small amount and hence their speed by a small amount. Explain what effect this would have on the de Bröglie wavelength of the electrons. Justify your answer.

(3 marks)

Solution

a 0.012 nm $\lambda_\mathrm{e} = \frac{h}{p} = \frac{h}{\sqrt{2mE_\mathrm{k}}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.00\times10^{4}\times1.6\times10^{-19}}}$

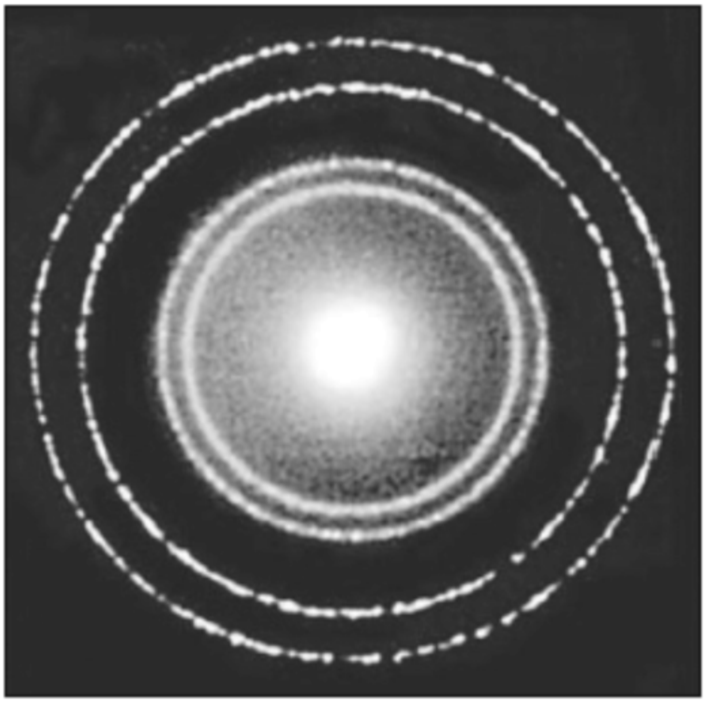
$= 1.23 \times 10^{-11}\mathrm{m} = 0.012\ \mathrm{nm}.$

b The de Bröglie wavelength will be smaller as $p = mv$ increases (as the speed increases) and $\lambda_\mathrm{e} = \frac{h}{p}$.

Question 20/ 35

[VCAA NHT 2023 SB Q20]

A beam of electrons, each with a momentum 4.60×10^{-24} kg m s^{-1}, is passed through a salt crystal to produce a diffraction pattern, as shown below.



a. Calculate the de Bröglie wavelength of the electrons.

(2 marks)

b. Explain why electron diffraction patterns from salt crystals provide evidence for the wavelike nature of matter.

(3 marks)

Solution

a $1.44 \times 10^{-10}\text{m}\ \lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{4.60\times10^{-24}} = 1.44 \times 10^{-10}$.

b Electrons have wave-like properties; diffraction is a property of waves; salt crystals have a spacing that produces diffraction patterns with a beam of electrons.

Question 21/ 35

[VCAA 2023 SB Q14]

Neutrons are subatomic particles and, like electrons, they can exhibit both particle-like and wave-like behaviour. Ignore any relativistic effects.

A beam of neutrons that can be used for scientific experiments is produced by a nuclear research reactor.

The mass of a neutron is 1.67×10^{-27} kg.

The de Broglie wavelength of the neutrons produced by the nuclear reactor is 3.02×10^{-10} m.

a. Calculate the speed of the neutrons.

(2 marks)

b. The neutron beam is then sent through a crystal that has an interatomic spacing of 3.62×10^{-10} m.

Would you expect to observe a diffraction pattern? Justify your answer.

(2 marks)

c. Consider an electron beam with the same de Broglie wavelength as the neutron beam, 3.02×10^{-10} m.

Which will have the greater speed: an electron in the electron beam or a neutron in the neutron beam? Justify your answer.

(2 marks)

Solution

a 1.3×10^3 m s^{-1} Use $\lambda = \frac{h}{mv}$

$v = (6.63 \times 10^{-34})/(1.67 \times 10^{-27})(3.02 \times 10^{-10})$

$= 1315$ m s^{-1}

b Yes Wavelength similar to interatomic spacing of crystal (ratio of $\frac{\lambda}{w} =\sim 0.8$), so diffraction will occur.

c Electron $\lambda = \frac{h}{mv}$ For the same λ the electron mass is smaller so velocity must be larger.

Chapter 17 Energy levels of atoms

Question 2/ 12

A molybdenum atom is excited to the 2.6 keV state. All of the following energy photons could be emitted from the atom, except one. Which one?

A 0.2 keV

B 0.4 keV

C 2.4 keV

D 2.8 keV

Solution

D All the others correspond to differences between levels.

Question 3/ 12

An atom of molybdenum in the 0.4 keV state absorbs a photon. Which one of the options below represents a possible energy for this absorbed photon?

A 20 keV

B 19.6 keV

C 0.4 keV

D 2.6 keV

Solution

B This is a transition up to the 20 keV level.

Question 4/ 12

An atom has only four possible energy levels available in an experiment. They are energies E_0, E_1, E_2, and E_3, in increasing energy. An atom is excited to E_3. Which of the following is a possible energy for an emitted photon?

A E_3

B $E_3 - E_0$

C $E_2 + E_1$

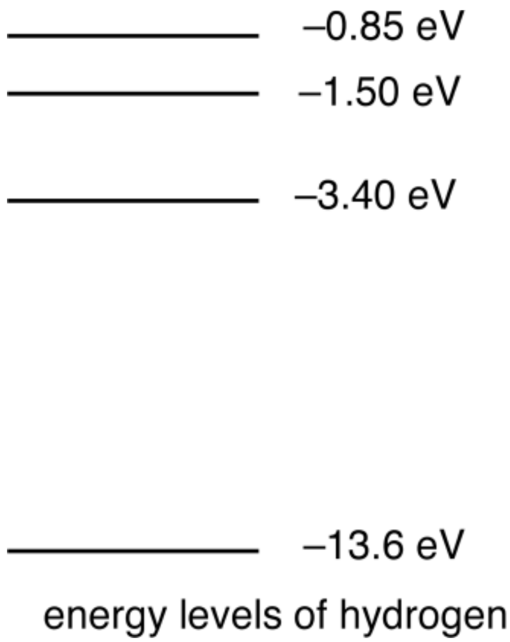
D E_0

Solution

B This is the gap between E_3 and E_o.

Question 5/ 12

The energy levels of hydrogen atoms are shown in the diagram below. The *lowest* level, the ground state, is at $-13.6\ \mathrm{eV}$. For a large number of hydrogen atoms excited to the $-1.50\ \mathrm{eV}$ level, how many different energy photons could be emitted?



A 4

B 3

C 2

D 1

Solution

B -1.50 to -13.6; -1.50 to -3.40, and -3.40 to $-13.6\ \mathrm{eV}$.

Question 6/ 12

An individual atom is excited to the $-0.85\ \mathrm{eV}$ level. Which of the following statements is *false?*

A A 2.55 eV photon would be followed by a 10.2 eV photon.

B A 0.65 eV photon could be followed by a 1.9 eV photon.

C A 0.65 eV photon could be followed by a 12.1 eV photon.

D A 12.75 eV photon could be followed by a 0.65 eV photon.

Solution

D The 12.75 eV photon would leave the atom in the ground state.

Question 7/ 12

Which of the following energy photons could an atom of hydrogen in the ground state absorb?

A 10.2 eV

B 1.9 eV

C 2.55 eV

D 0.65 eV

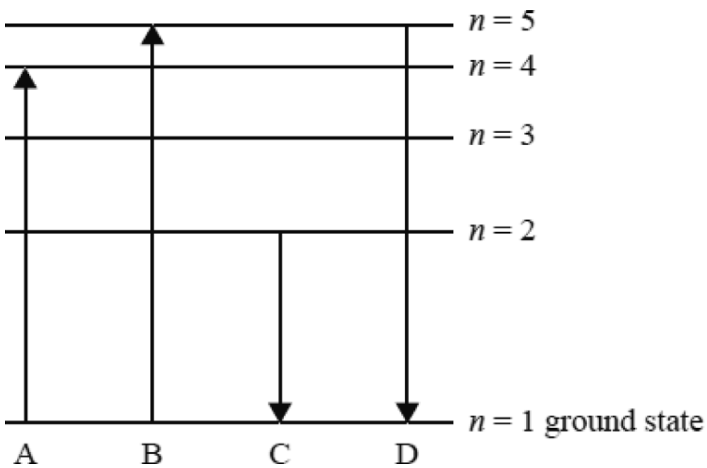
Solution

A This would take it to the $-3.40\ \mathrm{eV}$ level.

Question 8/ 12

[VCAA 2019 NHT SA Q19]

Part of the energy-level diagram for an unknown atom is shown below.



Which one of the arrows shows a change of energy level corresponding to the absorption of a photon of highest frequency?

A A

B B

C C

D D

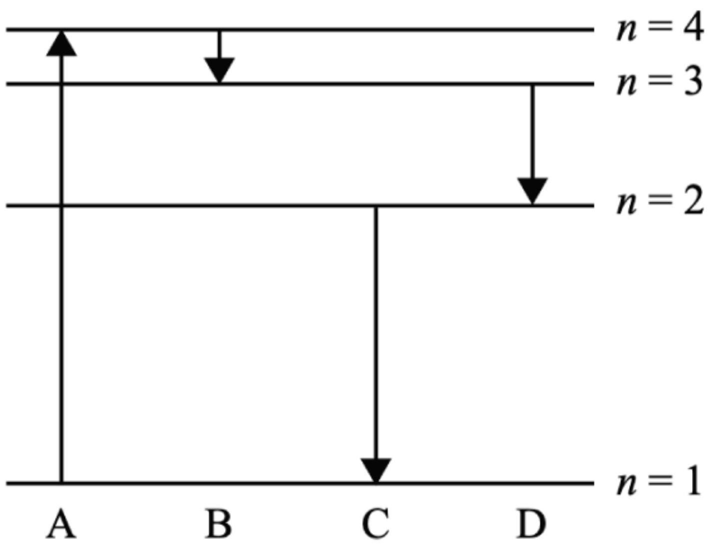
Solution

B Absorption means arrow going up; largest frequency corresponds to largest energy change $(E = hf)$.

Question 9/ 12

[VCAA 2020 SA Q17]

The diagram below shows some of the energy levels for the electrons within an atom. The arrows labelled A, B, C and D indicate transitions between the energy levels and their lengths indicate the relative size of the energy change.



Which transition results in the emission of a photon with the most energy?

A A

B B

C C

D D

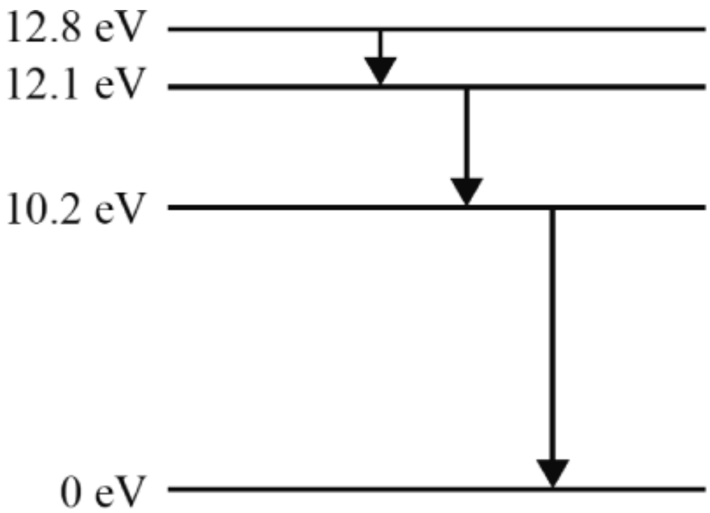
Solution

C The energy gap is the greatest of the emission lines. Transition A corresponds to an absorption line.

Question 10/ 12

[VCAA 2022 NHT SA Q17]

Some of the energy levels of the hydrogen atom are shown in the diagram below. A hydrogen atom has been excited to the 12.8 eV energy level. It returns to the ground state via the three transitions shown.



Which of the following indicates the energies of the emitted photons?

A 0.7 eV, 2.6 eV, 10.2 eV

B 0.7 eV, 1.9 eV, 10.2 eV

C 1.9 eV, 2.6 eV, 10.2 eV

D 10.2 eV, 12.1 eV, 12.8 eV

Solution

B The options in B match the energy gaps indicated by the arrows.

Question 11/ 12

[VCAA 2022 SA Q17]

Gamma radiation is often used to treat cancerous tumours. The energy of a gamma photon emitted by radioactive cobalt-60 is 1.33 MeV.

Which one of the following is closest to the frequency of the gamma radiation?

A 1.33×10^{6} Hz

B 3.21×10^{20} Hz

C 3.21×10^{21} Hz

D 2.01×10^{39} Hz

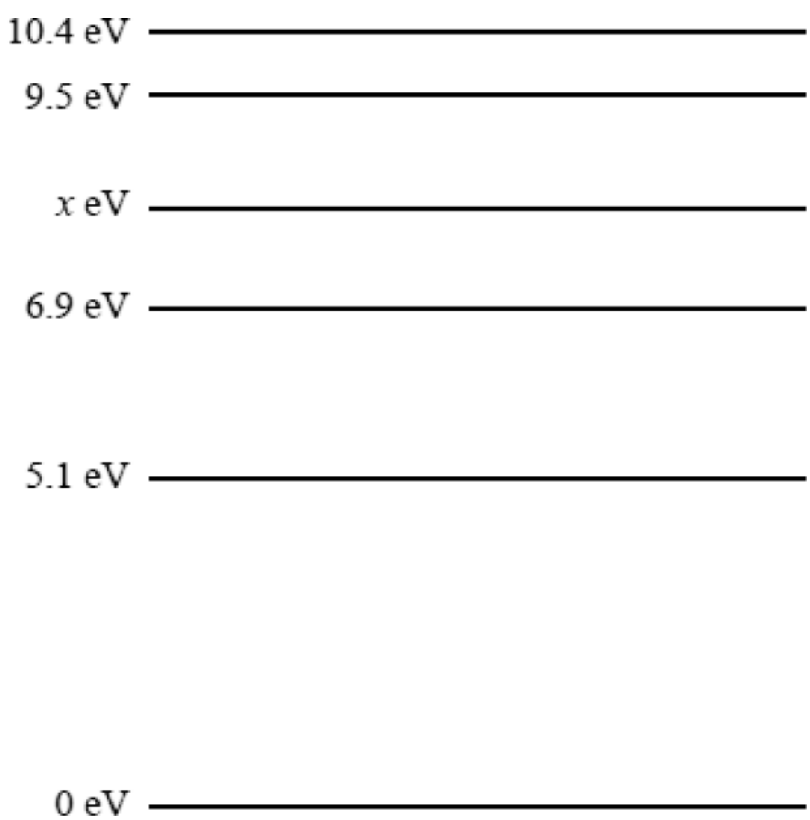
Solution

C $F = \frac{E}{h} = \frac{1.33 \times 10^6}{4.14 \times 10^{-15}} = 3.21 \times 10^{20}$

Question 12/ 12

[VCAA NHT 2023 SA Q19]

Some of the energy levels for an unknown atom are shown in the diagram below, with one of the lines labelled *x* eV. These energy levels are not drawn to scale.



A part of the emission spectrum of the atom shows lines at 1.0 eV, 1.6 eV and 1.9 eV.

The value of *x* is closest to

A 7.7

B 7.9

C 8.0

D 8.5

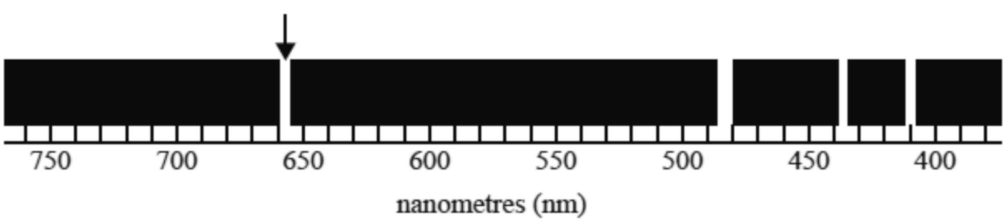
Solution

D   Only value that gives all three emission spectral lines.

Question 13/ 12

[VCAA 2023 SA Q19]

The diagram below shows the spectrum of light emitted by a hydrogen vapour lamp. The spectral line indicated by the arrow on the diagram is in the visible region of the spectrum.



Which one of the following is closest to the frequency of the light corresponding to the spectral line indicated by the arrow?

A 6.5×10^{2} Hz

B 4.6×10^{14} Hz

C 6.5×10^{14} Hz

D 4.6×10^{16} Hz

Solution

B Use $c = f\lambda$

Question 1/ 29

An electron makes a 5.9 eV transition between two energy levels. What wavelength photon is likely to be observed as a result?

(2 marks)

Solution

$2.1 \times 10^{-7}\mathrm{m}$ Use $E = \frac{hc}{\lambda}$.

Question 2/ 29

An atom has only four possible energy levels. They have energies E_0, E_1, E_2, and E_3, in increasing energy order. An atom is excited to level E_1. Write down the possible photon energies it could absorb.

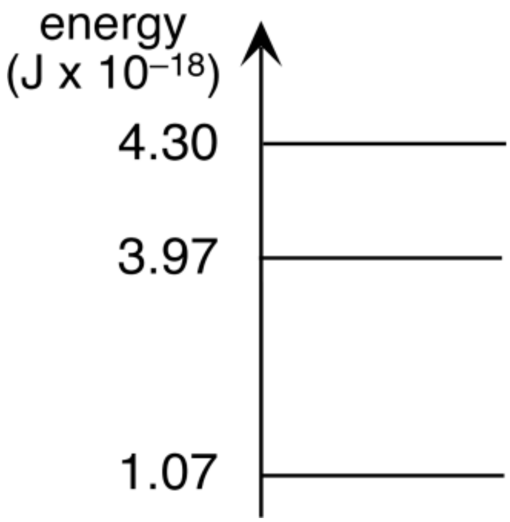
(3 marks)

Solution

$(E_2 - E_1)$ and $(E_3 - E_1)$.

Question 3/ 29

The diagram below shows some energy levels in the neon atom.



Use the data in the diagram to calculate two photon frequencies that could be absorbed by neon atoms in the lowest state shown in the diagram.

(3 marks)

Solution

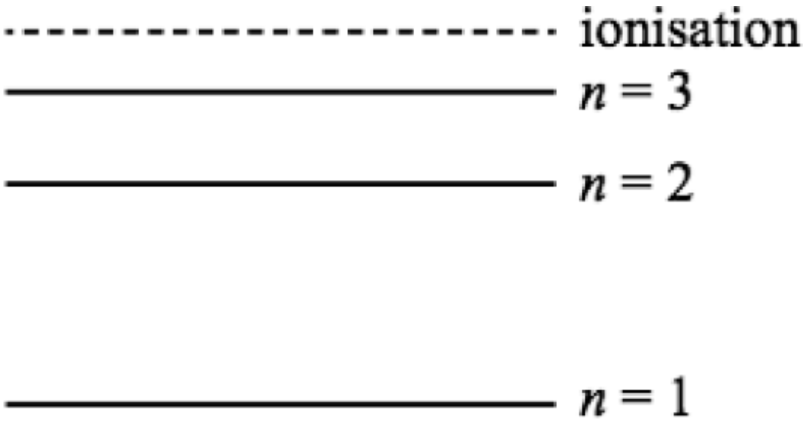
$4.37 \times 10^{15} \mathrm{Hz}$

$4.87 \times 10^{15} \mathrm{Hz}$ Use $E = hf$.

Question 4/ 29

[Adapted VCAA 2015 SA Q19]

An atom has a single electron in the second $(n = 3)$ excited state. When it returns to the ground $(n = 1)$ state, the emission spectrum has lines of 2.63×10^{16} Hz, 2.22×10^{16} Hz and 0.41×10^{16} Hz. The energy level diagram is shown below.



Use this information to calculate the energy of the $n = 2$ and $n = 3$ states.

(4 marks)

Solution

92 eV and 109 eV The energies of the emitted photons are 17 eV, 92 eV and 109 eV (from $E = \frac{hc}{\lambda}$). The largest energy must be the transition from $n = 3$ to $n = 1$. The transition from $n = 3$ to $n = 2$ is *probably* 17 eV, fixing $n = 2$ as 92 eV. (However, logically an alternative could be 17 eV, but the examiners' report does not mention this possibility.)

Question 5/ 29

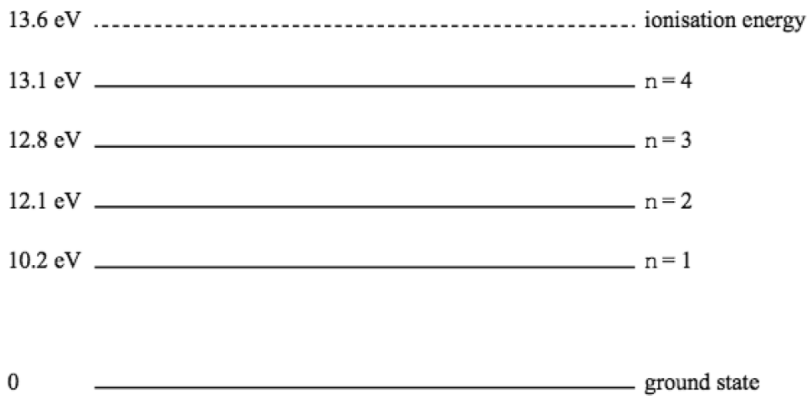
[VCAA 2016 SA 21]

The visible spectrum of the hydrogen atom is observed to emit photons of energy 2.6 eV.

a. Calculate the wavelength of this emission spectral line.

(2 marks)

The energy levels for the hydrogen atom are shown below.



b. Draw an arrow on the diagram above to indicate the transition that could cause the spectral line calculated in part **a.**

(2 marks)

c. A hydrogen atom is excited to the 12.8 eV energy level.

List the possible photon energies that could be emitted as it returns to the ground state.

(3 marks)

Solution

a 478 nm Use $\Delta E = \frac{hc}{\lambda}$.

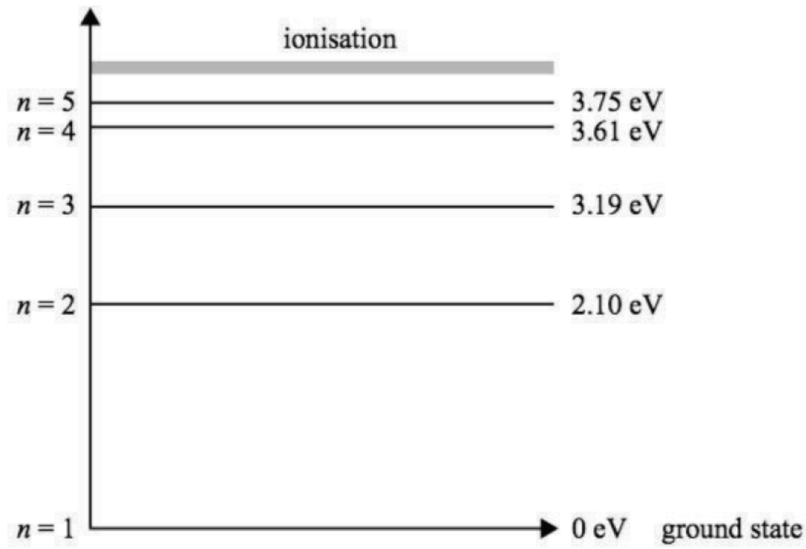
b Arrow starting at $n = 3$ level (12.8 eV) down to $n = 1$ level (10.2 eV).

c 0.7 eV, 1.9 eV, 2.6 eV, 10.2 eV, 12.1 eV and 12.8 eV.

Question 6/ 29

[VCAA 2017 SB Q18]

The energy-level diagram for sodium is shown below. Part of the emission spectrum of sodium vapour includes a photon of energy 1.65 eV.



a. Draw an arrow on the energy-level diagram above to demonstrate the atomic energy level transition resulting in the emission of a 1.65 eV photon.

(1 mark)

b. What is the shortest possible wavelength of a photon that can be emitted when the atom decays from the $n = 5$ level to the ground state?

(2 marks)

c. A student measures a spectral line with energy 2.5 eV. In terms of the quantised states of the atom, explain why this is not possible.

(2 marks)

Solution

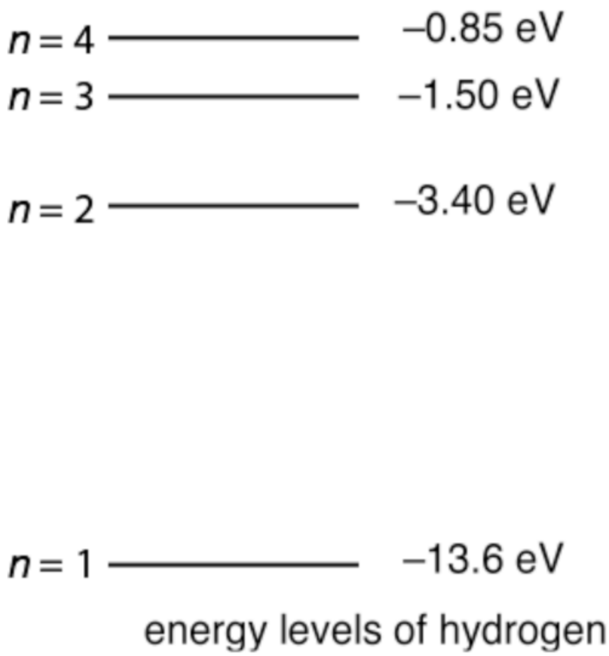
a An arrow downwards from the $n = 5$ state to the $n = 2$ state.

b 331 nm Shortest wavelength corresponds to highest energy transition, i.e. 3.75 eV. Now use $\Delta E = \frac{hc}{\lambda}$.

c Only possible transitions are between allowed energy levels. There is no gap between levels equal to 2.5 eV.

Question 7/ 29

Some of the energy levels of the hydrogen atom are shown below.



a. A photon of wavelength $4.87 \times 10^{-7} \mathrm{m}$ is *emitted* by an excited hydrogen atom within the Sun. Identify the transition occurring within hydrogen by naming the initial and final states.

(2 marks)

b. A photon of wavelength $1.03 \times 10^{-7} \mathrm{m}$ is *absorbed* by a hydrogen atom within the Sun. Identify the transition occurring within hydrogen by naming the initial and final states.

(2 marks)

Solution

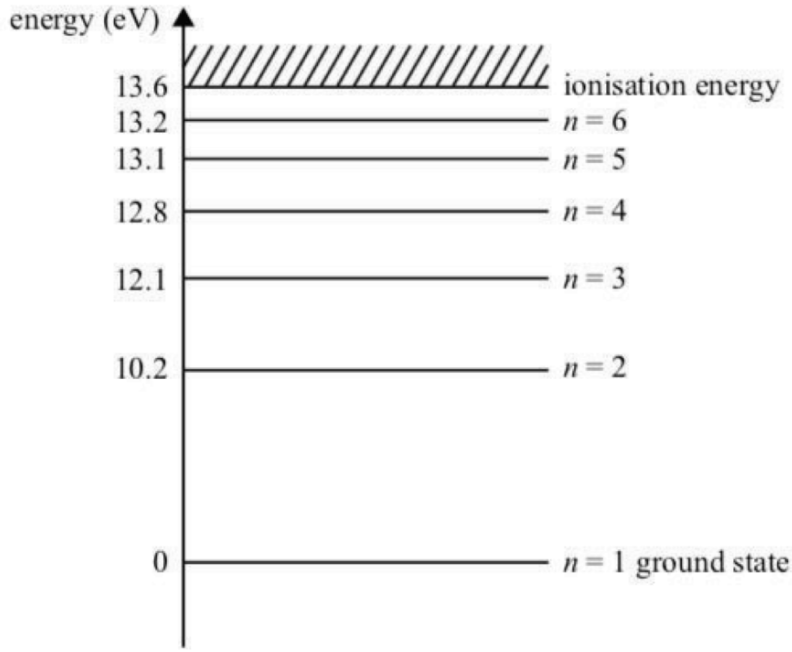
a The energy is 2.55 eV (from $\frac{hc}{\lambda}$), hence the transition is from $n = 4$ to $n = 2$.

b The energy is 12.1 eV, hence the transition is from $n = 1$ up to $n = 3$.

Question 8/ 29

[Adapted VCAA 2018 Sample SB Q9]

The diagram shows the energy level diagram for the hydrogen atom.



List the possible photon energies following emissions from the $n = 4$ state.

(3 marks)

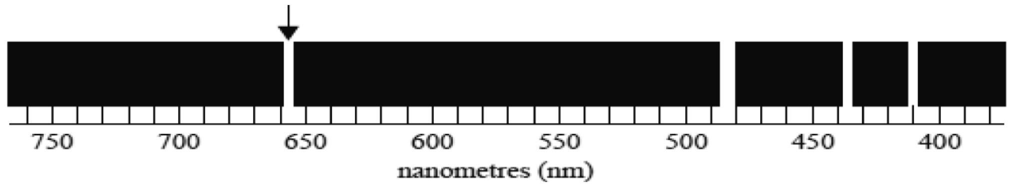
Solution

Use simple subtraction to yield 0.7, 1.9, 2.6, 10.2, 12.1 and 12.8 eV.

Question 9/ 29

[VCAA 2018 SB Q19]

The diagram shows the spectrum of light emitted from a hydrogen vapour lamp. The spectral line, indicated by the arrow on the diagram, is in the visible region of the spectrum.



a. The following list gives the four visible colours that are emitted by the hydrogen atom. Circle the colour that corresponds to the spectral line.

violet blue-violet blue-green red

(1 mark)

b. Explain why the visible spectrum of light emitted from a hydrogen vapour lamp gives discrete spectral lines, as shown in the diagram above.

(3 marks)

Solution

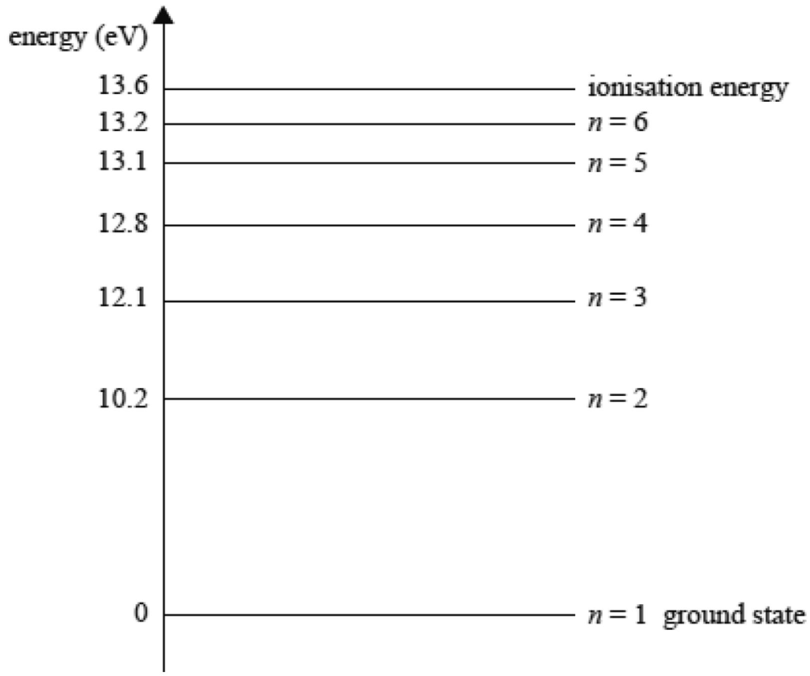
a Red. This is the longest wavelength in the list.

b The electrons in the hydrogen atom are arranged in discrete energy levels; when there is a transition between two of these levels, a photon of well-defined energy corresponding to the difference in the energy levels is emitted.

Question 10/ 29

[VCAA 2019 SB Q18]

The energy level diagram for a hydrogen atom is shown below.



a. A hydrogen atom in the ground state is excited to the $n = 4$ state. Explain how the hydrogen atom could be excited to the $n = 4$ state in one step.

(2 marks)

b. List the possible photon energies that could be emitted as the atom goes from the $n = 4$ state to the $n = 2$ state.

(3 marks)

Solution

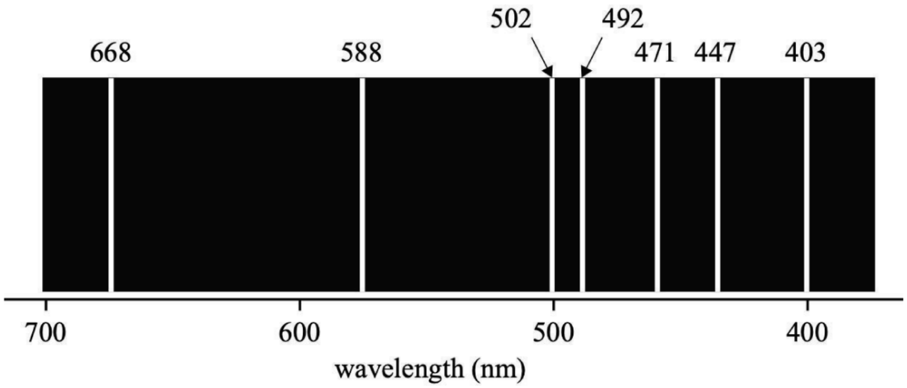
a If 12.8 eV of energy is transferred to the atom, for example, from a photon of that energy, it can transition to the $n = 4$ state.

b 0.7 eV, 1.9 eV, 2.6 eV.

Question 11/ 29

[VCAA 2020 SB Q17]

The diagram below shows the emission spectrum for helium gas.



a. Which spectral line indicates the photon with the lowest energy?

(1 mark)

b. Calculate the frequency of the photon emitted at the 588 nm line. Show your working.

(2 marks)

c. Explain why only certain wavelengths and, therefore, certain energies are present in the helium spectrum.

(2 marks)

Solution

a 668 nm The longest wavelength will have the lowest energy.

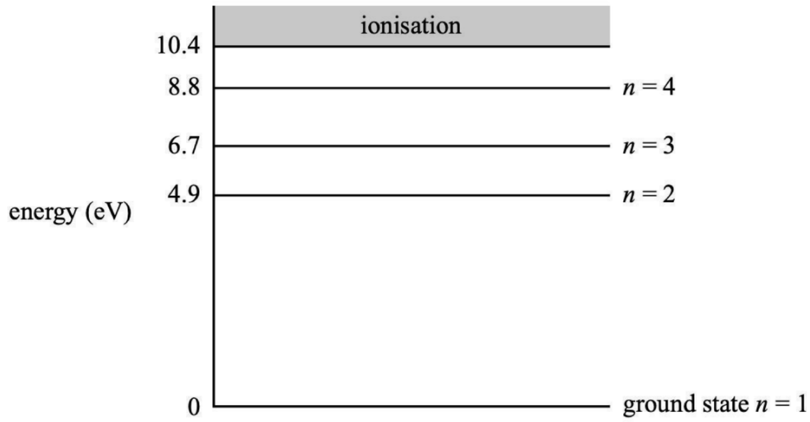
b $5.1 \times 10^{14}\text{Hz}$ Use $f = \frac{c}{\lambda}$.

c Only certain energies are allowed (and hence visible) as the electrons exist only in definite quantised energy levels. When electrons move between energy levels, they emit only discrete amounts of energy.

Question 12/ 29

[VCAA 2021 NHT SB Q17]

Light from a mercury vapour lamp shows a line spectrum related to discrete energy levels. Some of the energy levels for the mercury atom are shown below.



a. Draw an arrow on the diagram above to indicate the transition between the listed energy states that would produce the lowest frequency of an emitted photon.

(1 mark)

b. Calculate the energy of the light emitted when the mercury atom makes a transition from the third energy level $(n=3)$ to its ground state $(n=1)$. Show your working.

(2 marks)

c. Explain what happens to a mercury atom in its ground state if a photon of energy 2.1 eV is incident on it.

(2 marks)

Solution

a A downwards arrow from the 6.7 eV level to the 4.9 eV level is required.

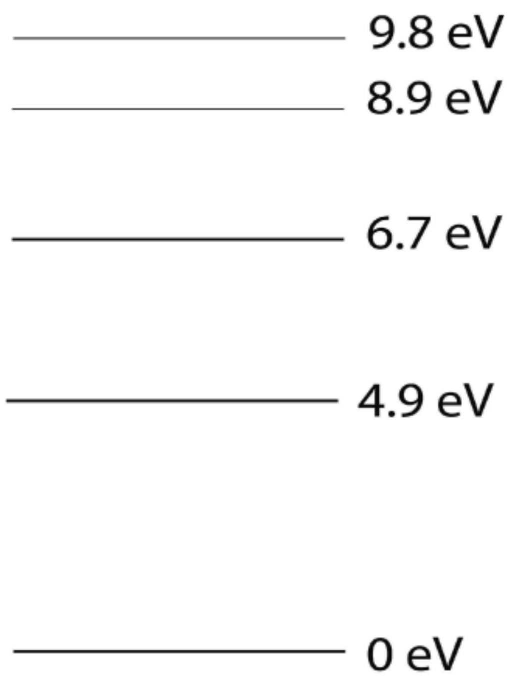
b 1.1×10^{-18} J $\text{Energy change} = 6.7\ \text{eV}$; convert to J; multiply by 1.6×10^{-19}.

c A minimum energy of 4.9 eV is required for a transition to the $n=2$ state; the photon will not transfer energy to the mercury atom but collide elastically with it.

Question 13/ 29

[VCAA 2021 SB Q19]

A simplified diagram of some of the energy levels of an atom is shown below.



a. Identify the transition on the energy level diagram that would result in the emission of a 565 nm photon. Show your working.

(2 marks)

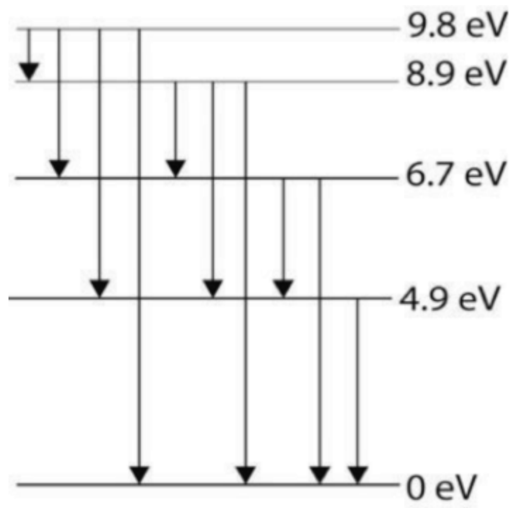
b. A sample of the atoms is excited into the 9.8 eV state and a line spectrum is observed as the states decay. Assume that all possible transitions occur. What is the total number of lines in the spectrum? Explain your answer. You may use the diagram above to support your answer.

(2 marks)

Solution

a The transition from the 8.9 eV level to the level at 6.7 eV. First identify the energy of a 565 nm photon. Use $E = \frac{hc}{\lambda}$. this gives $\Delta E = 2.2 \text{ eV}$. Then scan the energy gaps in the diagram.

b



There are 10 possible transitions (count the arrows). However, there are only 9 distinct lines in the spectrum because the transition from the 9.8 eV level to the 4.9 eV level has the same energy and wavelength as the transition from the 4.9 eV level to the ground state.

Question 14/ 29

[VCAA 2022 NHT SB Q17]

Describe how absorption line spectra are produced and describe their relationship to electron transitions within atoms.

(3 marks)

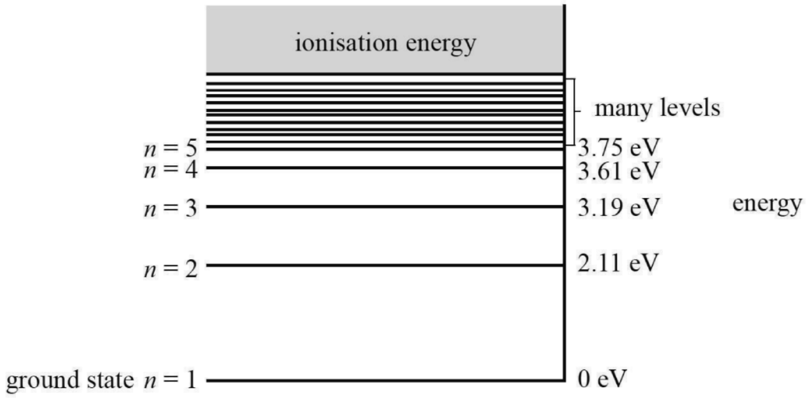
Solution

Photons with energies matching ΔE transitions are absorbed from broad continuous spectrum. This results in electrons excited to higher energy states; they rapidly decay in many directions leaving a gap in the spectrum. It appears as a dark line and the wavelengths appear to be missing.

Question 15/ 29

[VCAA 2022 NHT SB Q19]

The diagram below shows the energy levels of a sodium atom.



A sodium atom is initially in the $n = 4$ excited state.

Calculate the highest frequency of light that the sodium atom in this excited state could emit.

(2 marks)

Solution

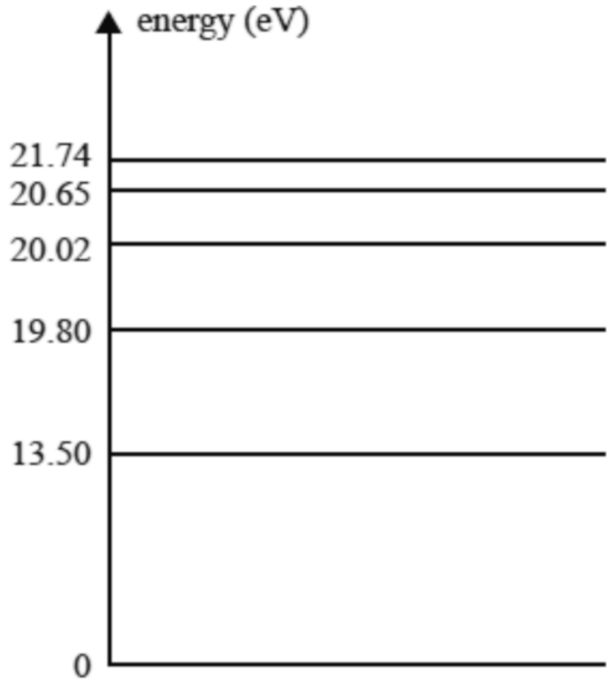
$8.7 \times 10^{14} \mathrm{Hz}$ Highest frequency corresponds to the largest value of ΔE, which is a transition from $n = 4$ to the ground state $(n = 1)$.

Now use $\Delta E = 3.61 = hf = 4.14 \times 10^{-15} \times f$.

Question 16/ 29

[VCAA 2022 SB Q15]

The diagram below shows some of the energy levels of excited neon atoms. These energy levels are not drawn to scale.



a. Show that the energy transition required for an emitted photon of wavelength 640 nm is 1.94 eV.

(1 mark)

b. Draw an arrow to show the transition that would emit this photon.

(1 mark)

Solution

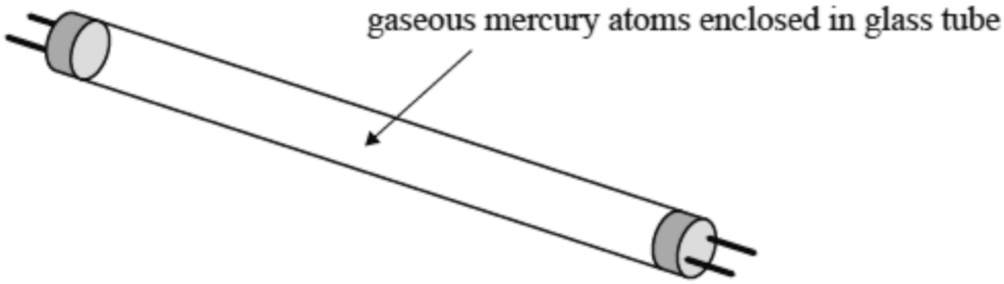
a $E = hf = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{640 \times 10^{-9}}$

b Down arrow from 21.74 to 19.80 eV.

Question 17/ 29

[VCAA 2023 SB Q16]

Fluorescent lights, when operating, contain gaseous mercury atoms, as shown below.

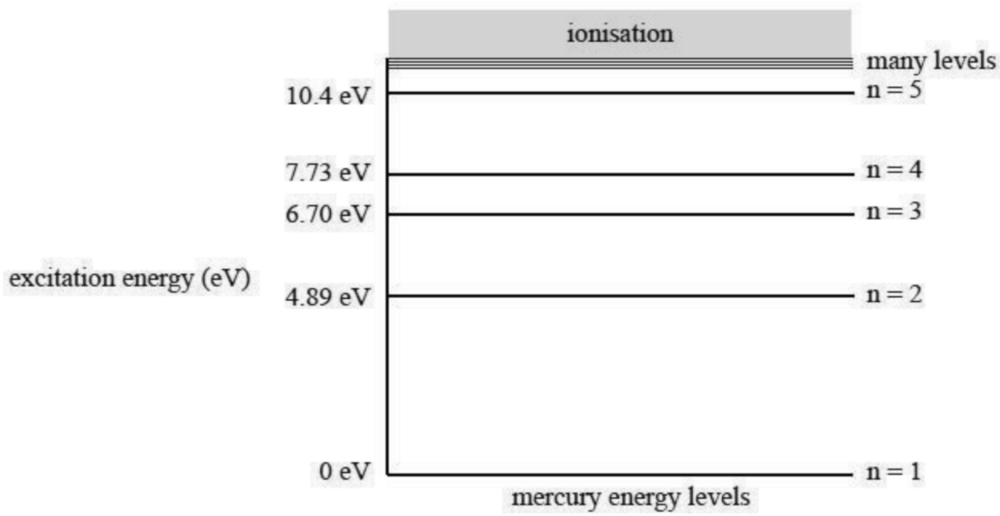


Analysis of the light produced by fluorescent lights shows a number of emission spectral lines, including a prominent line representing a wavelength of 436.6 nm.

a. Calculate the energy of the photons represented by the emission spectral line representing a wavelength of 436.6 nm.

(2 marks)

The diagram on the next page shows the lowest five energy levels for mercury.



b. On the energy level diagram shown above draw an arrow showing the energy level transition that corresponds to the production of the spectral line representing a wavelength of 436.6 nm.

(1 mark)

c. A 6.7 eV photon is absorbed by a mercury atom in the ground state and then the atom transitions back to the ground state.

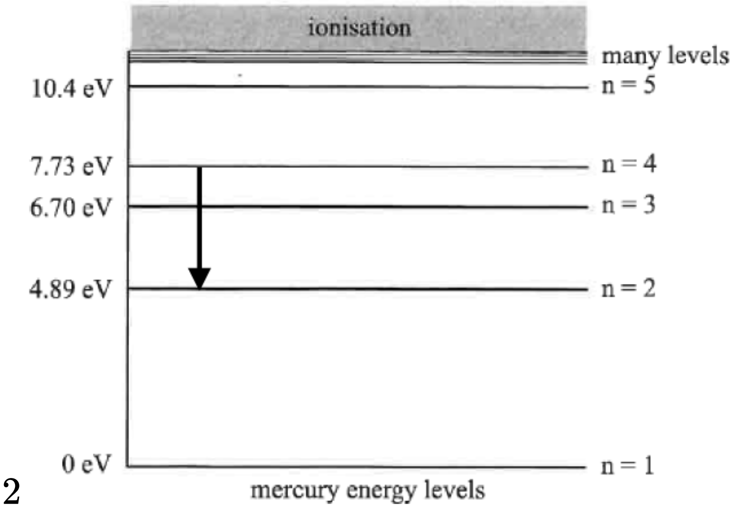
Identify the energies, in eV, of all the possible photons that could be produced.

(3 marks)

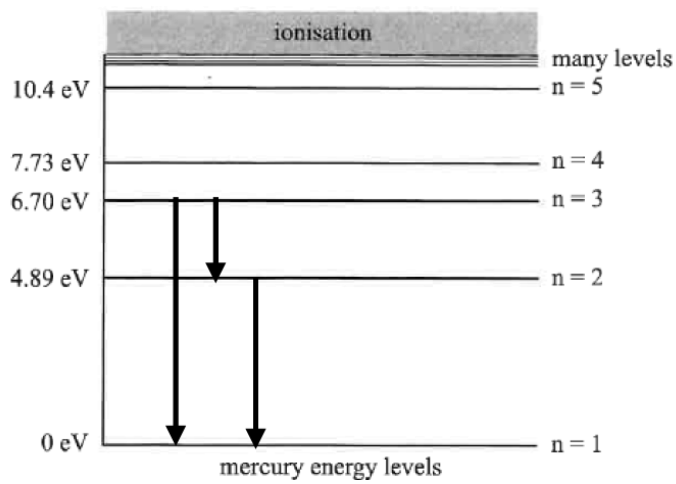
Solution

a 2.8 eV $E = hc/\lambda = (4.14 \times 10^{-15})(3.0 \times 10^{8})/(436.6 \times 10^{-9})$.

b Downward arrow from $n = 4$ to $n = 2$



c 6.70 eV, 4.89 eV, 1.81 eV



Chapter 18 Relativity

Question 1/ 36

Unstable subatomic particles have different lifetimes, depending on whether they are moving relative to the observer measuring the lifetime. One particle has a lifetime, measured at rest, of 5.1 ps. However, when these particles are moving very fast, they have a lifetime of 510 ps. Which of the following is closest to the speed that these particles are travelling at?

A 99.994% of *c*

B 99.995% of c

C 99.996% of c

D 99.998% of c

Solution

B This means $\gamma = 10$; use $v = c\sqrt{(1-\gamma^{-2})}$.

Question 2/ 36

A spaceship is observed moving by an observer; its length is measured to be exactly one-quarter of its proper length. Which of the following is closest to the speed of the spaceship relative to the observer making this measurement?

A $2.3 \times 10^8 \text{ m s}^{-1}$

B $2.6 \times 10^8 \text{ m s}^{-1}$

C $2.9 \times 10^8 \text{ m s}^{-1}$

D $3.2 \times 10^8 \text{ m s}^{-1}$

Solution

C This means $\gamma = 4$; use $v = c\sqrt{(1-\gamma^{-2})}$.

Question 3/ 36

Which of the following is closest to the work that must be done on an electron to increase its speed from zero to $0.3c$?

A 4.0×10^{-23} J

B 8.1×10^{-23} J

C 1.6×10^{-22} J

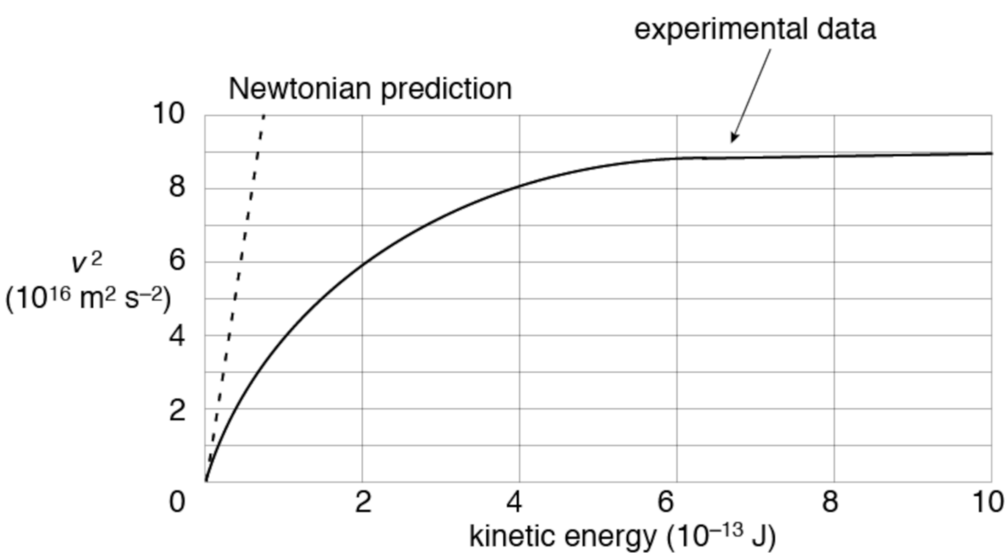
D 3.9×10^{-15} J

Solution

D Use $\mathrm{KE} = (\gamma - 1)mc^2$.

Question 4/ 36

The variation of kinetic energy of electrons with speed is shown in the graph below. The data originates from MIT. The square of the speed is plotted against the kinetic energy of the electrons.



Which of the following equations best explains the shape of the graph above?

A $E_{\mathrm{K}} = m_0 c^2$

B $E_{\mathrm{K}} = \gamma \, m_0 c^2$

C $E_{\mathrm{K}} = (\gamma + 1) \, m_0 c^2$

D $E_{\mathrm{K}} = (\gamma - 1) \, m_0 c^2$

Solution

D The only correct expression.

Question 5/ 36

Which of the following is *not* a version of the postulates of Einstein's theory of special relativity?

A The laws of physics are the same in all inertial reference frames.

B The speed of light is the same in all media.

C The speed of light is independent of the motion of the source.

D The speed of light is independent of the motion of the observer.

Solution

B A, C and D are all versions of the postulates.

Question 6/ 36

Two anti-particles, a *tau* particle and an *anti-tau* particle, both at rest, annihilate each other producing two photons, each of energy 1.773 GeV. Which of the following is closest to the rest mass of a single tau particle?

A 3.2×10^{-27} kg

B 3.2×10^{-33} kg

C 3.4×10^{-10} kg

D 3.2×10^{-30} kg

Solution

A Put $1.773 \text{ GeV} = mc^2$; make *m* the subject.

Question 7/ 36

Samantha is on a train moving past a station at $v = 0.85c$; Jim is standing still on the station. Which one of the following measurements is not a *proper* measurement (i.e. it is not a proper time or a proper length)?

A The measurement Samantha makes of the time taken for her to pass the station

B Jim's measurement of the length of the station platform

C Samantha's measurement of the length of the train

D Jim's measurement of the length of the train

Solution

D The others are all proper measurements.

Question 8/ 36

Which of the following is closest to the speed of a particle produced in an accelerator with a Lorentz factor (γ) equal to 11.5?

A $2.989 \times 10^8 \text{ m s}^{-1}$

B $2.867 \times 10^8 \text{ m s}^{-1}$

C $2.997 \times 10^8 \text{ m s}^{-1}$

D $2.739 \times 10^8 \text{ m s}^{-1}$

Solution

A Use $v = c\sqrt{(1 - \gamma^{-2})}$.

Question 9/ 36

As the speed of a mass tends towards the speed of light, the kinetic energy

A increases proportionally to the square of the speed.

B increases more than proportionally to the square of the speed.

C increases less than proportionally to the square of the speed.

D tends towards an upper limit.

Solution

B Formula is $(\gamma - 1)mc^2$; γ increases at an increasing rate near c.

Question 11/ 36

[Adapted VCAA 2016 SB Q1]

Which one of the following statements correctly describes the behaviour of these two clocks?

A The period of vibration in Anna's clock (observed by Anna) will be shorter than the period of vibration in Barry's clock (observed by Barry).

B The period of vibration in Anna's clock (observed by Anna) will be longer than the period of vibration in Barry's clock (observed by Barry).

C The period of vibration in Anna's clock (observed by Anna) will be the same as the period of vibration in Barry's clock (observed by Barry).

D Only the time on Barry's clock is reliable because it is at rest.

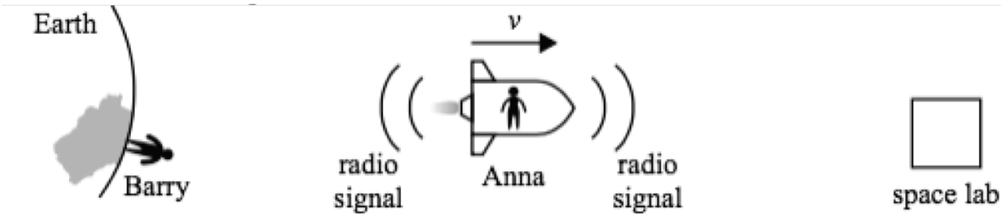
Solution

C Both Anna and Barry observe undilated time intervals.

Question 12/ 36

[VCAA 2016 SB Q2]

When Anna is halfway between Earth and the space lab, she sends a radio pulse towards Earth and towards the space lab, as shown.



As observed by Anna, which one of the following statements correctly gives the order in which this signal is received by Barry and by the space lab?

A Barry receives the signal first.

B The space lab receives the signal first.

C The signal is received by Barry and the space lab at the same time.

D It is not possible to predict since special relativity applies to light but not to radio signals.

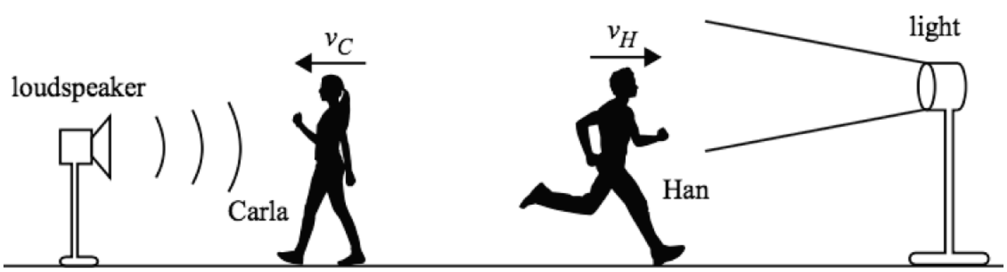
Solution

B In Anna’s reference frame, the lab is moving towards her and Earth is moving away, so the signal has less distance to travel to reach the lab.

Question 13/ 36

[VCAA 2016 SB Q3]

The diagram shows Carla moving towards a loudspeaker at a speed of v_C and Han running towards a light source at speed v_H.



Which of the following correctly shows the speed of sound relative to Carla and the speed of light relative to Han? (The speed of sound in air is v_s.)

Speed of sound relative to Carla	Speed of light relative to Han
v_S	c
$v_S + v_C$	$c + v_H$
$v_S + v_C$	c
$v_S - v_C$	$c - v_H$

Solution

C Carla will reach successive wavefronts more quickly; but for Han the speed of light must be *c*.

Question 14/ 36

[VCAA 2016 SB Q5]

Pions are particles that are present in cosmic rays striking Earth. Pions have a half-life of 26 ns (the time for half of a large number of pions to decay). In which frame of reference will the undilated value of the half-life be observed?

A in the frame of the high-energy source of each pion

B in each pion's own frame

C in any inertial frame

D in Earth's frame

Solution

B Definition of proper time (which is undilated).

Question 15/ 36

[Adapted VCAA 2016 SB Q8]

A linear accelerator increases the speed of a charged particle from rest. The particle is accelerated in a time of 40 ns and reaches a speed where $\gamma = 1.6$.

What is the time taken for this acceleration in the particle's own frame of reference?

A 40 ns

B 40 ns divided by the average γ during the trip between the electrodes

C 64 ns

D cannot be determined using special relativity

Solution

D Implicit in the presence of acceleration.

Question 16/ 36

[VCAA 2017 SA Q10]

A student sits inside a windowless box placed on a smooth-riding train carriage. He conducts a series of motion experiments to investigate frames of reference. Which one of the following observations is correct?

A The results when the train accelerates are identical to the results when the train is at rest.

B The results when the train accelerates differ from the results when the train is in uniform motion in a straight line.

C The results when the train is at rest differ from the results when the train is in uniform motion in a straight line.

D The results when the train accelerates are identical to the results when the train is in uniform motion in a straight line.

Solution

B Results in a *non-inertial* (accelerating) frame will differ from those in an *inertial* frame (non-accelerating).

Question 17/ 36

[VCAA 2017 SA Q11]

On average, the sun emits $3.8 \times 10^{26} \mathrm{J}$ of energy each second in the form of electromagnetic radiation, which originates from the nuclear fusion reactions taking place in the sun's core. The corresponding loss in the sun's mass each second would be closest to

A 2.1×10^{9} kg

B 4.2×10^{9} kg

C 8.4×10^{9} kg

D 2.1×10^{12} kg

Solution

B Use $E = \Delta m c^2$.

Question 18/ 36

[VCAA 2018 NHT SA Q10]

A linear accelerator (linac) accelerates electrons to an energy of 100 MeV over a distance of about 10 m. After the first metre of acceleration in the linac, the electrons are travelling at approximately 99.9% of the speed of light. The Lorentz factor, γ, for an electron travelling at this speed would be closest to

A 22.4

B 44.8

C 500

D 1000

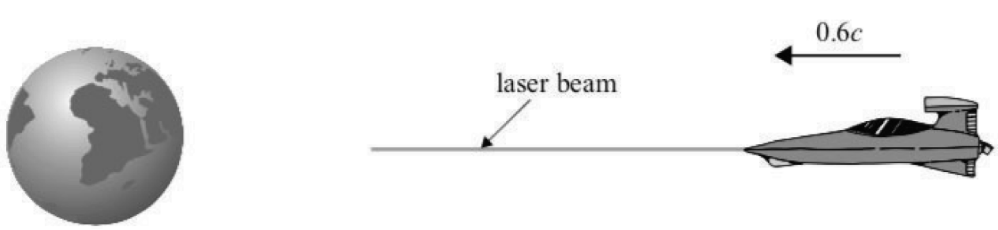
Solution

A Use $\gamma = (1 - \frac{v^2}{c^2})^{-\frac{1}{2}}$.

Question 19/ 36

[VCAA 2018 NHT SA Q11]

An alien spaceship has entered our solar system and is heading directly towards Earth at a speed of 0.6c, as shown in the diagram below. When it reaches a distance of $3.0 \times 10^{11} \mathrm{m}$ from Earth (in Earth's frame of reference), the aliens transmit a 'be there soon' signal via a laser beam.



How long will the signal take to reach Earth according to an Earth observer?

A 1.0 s

B 1.7 s

C 625 s

D 1000 s

Solution

D Use $t = \frac{x}{v}$ with $v = 3 \times 10^8 \text{ m s}^{-1}$.

Question 20/ 36

Which of the following is *not* a version of the postulates of Einstein's theory of special relativity?

A The laws of physics are the same in all inertial reference frames.

B The speed of light is the same in all media.

C The speed of light is independent of the motion of the source.

D The speed of light is independent of the motion of the observer.

Solution

B The speed of light depends on the electrical and magnetic properties of the medium.

Question 21/ 36

When a relativistic particle increases its speed from $v = 0.95c$ to $0.975c$, its value for γ increases by

A 1.4

B 3.2

C 4.3

D 10

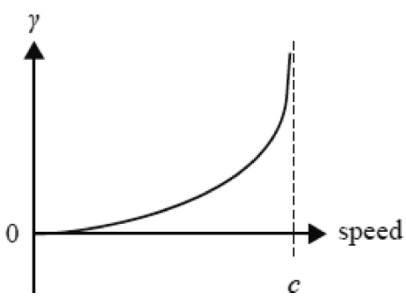
Solution

A Use $\gamma = (1 - \beta^2)^{-\frac{1}{2}}$, where $\beta = \frac{v}{c}$.

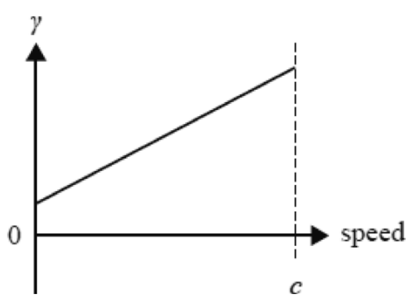
Question 22/ 36

[VCAA 2018 SA Q13]

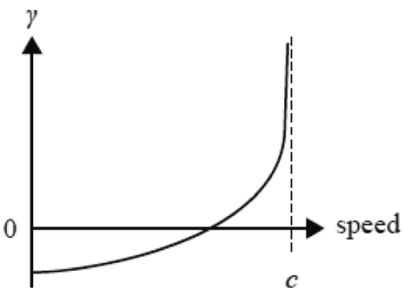
Which one of the following diagrams best represents the graph of γ (the Lorentz factor) versus speed for an electron that is accelerated from rest to near the speed of light, c?

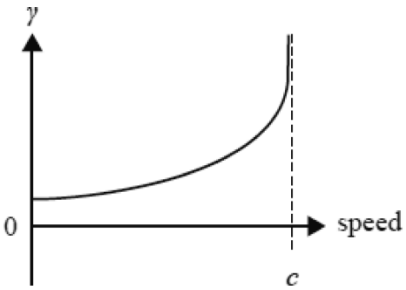


A



B

C 

D 

Solution

D Varies from a value of 1 to asymptote to infinity.

Question 23/ 36

[VCAA 2018 SA Q14]

Which one of the following statements about the kinetic energy, E_{k}, of a proton travelling at relativistic speed is the most accurate?

A The difference between the proton's relativistic E_{k} and its classical E_{k} cannot be determined.

B The proton's relativistic E_{k} is greater than its classical E_{k}.

C The proton's relativistic E_{k} is the same as its classical E_{k}.

D The proton's relativistic E_{k} is less than its classical E_{k}.

Solution

B Follows from the relationship $\mathrm{KE} = (\gamma - 1)mc^2$.

Question 24/ 36

[VCAA 2019 NHT SA Q16]

In a particle accelerator, magnesium ions are accelerated to 20.0% of the speed of light. Which one of the following is closest to the Lorentz factor, γ, for the magnesium ions at this speed?

A 1.02

B 1.12

C 1.20

D 2.24

Solution

A Use $\gamma = (1 - \frac{v^2}{c^2})^{-\frac{1}{2}}$.

Question 25/ 36

[VCAA 2019 NHT SA Q17]

The lifetime of stationary muons is measured in a laboratory to be 2.2 μs. The lifetime of relativistic muons produced in Earth's upper atmosphere, as measured by ground-based scientists, is 16 μs. The resulting time dilation observed by the scientists gives a Lorentz factor, γ, of

A 0.14

B 1.4

C 3.5

D 7.3

Solution

D The ratio of the dilated time to the proper time ($\frac{16}{2.2}$) gives γ.

Question 26/ 36

[VCAA 2019 NHT SA Q18]

If a particle's kinetic energy is 10 times its rest energy, E_{rest}, then the Lorentz factor, γ, would be closest to

A 9

B 10

C 11

D 12

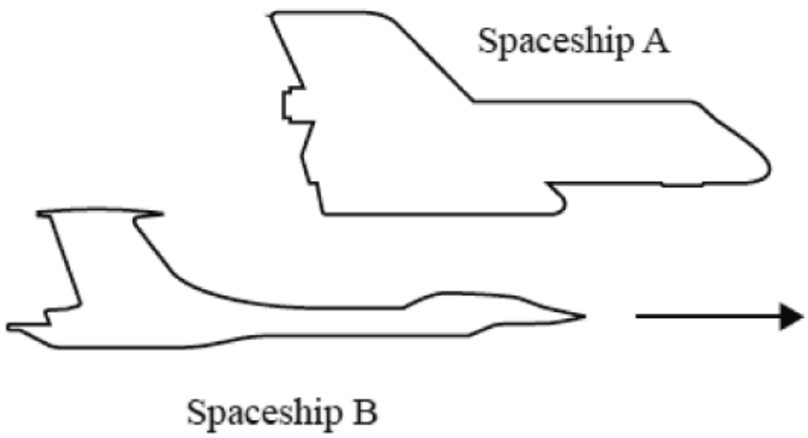
Solution

C Follows from $\text{KE} = (\gamma - 1)mc^2$ and $\text{KE} = 10mc^2$.

Question 27/ 36

[VCAA 2019 SQ Q13]

Joanna is an observer in Spaceship A, watching Spaceship B fly past at a relative speed of $0.943c$ ($\gamma = 3.00$). She measures the length of Spaceship B from her frame of reference to be 150 m. Which one of the following is closest to the proper length of Spaceship B?



A 50 m

B 150 m

C 450 m

D 900 m

Solution

C 150 m is a contracted length and the Lorentz factor $\gamma = 3.00$. Proper length is the uncontracted length of $150 \times 3 = 450$ m.

Question 28/ 36

[VCAA 2020 SA Q12]

A high-energy proton is travelling through space at a constant velocity of $2.50 \times 10^8 \text{ m s}^{-1}$. The Lorentz factor, γ, for this proton would be closest to

A 1.81

B 2.44

C 3.27

D 3.39

Solution

A Use $\gamma = (1 - \frac{v^2}{c^2})^{-\frac{1}{2}}$.

Question 29/ 36

[VCAA 2020 SA Q13]

Matter is converted to energy by nuclear fusion in stars. If the star Alpha Centauri converts mass to energy at the rate of $6.6 \times 10^9 \text{ kg s}^{-1}$, then the power generated is closest to

A $2.0 \times 10^{18} \text{ W}$

B $2.0 \times 10^{18} \text{ J}$

C $6.0 \times 10^{26} \text{ W}$

D $6.0 \times 10^{26} \text{ J}$

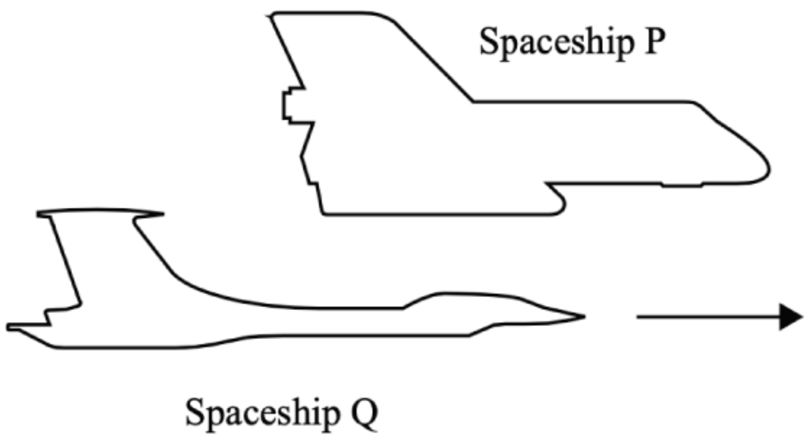
Solution

C Use $E = \Delta m \times c^2$

Question 30/ 36

[VCAA 2021 NHT SA Q13]

Joanna is an observer in Spaceship P and is watching Spaceship Q fly past at a relative speed of $0.943c$ $(\gamma = 3.00)$. She observes a stationary clock measuring a time interval of 75.0 s between two events in Spaceship Q. This is a proper time interval.



Which one of the following is closest to the time interval observed between the two events in Spaceship P's frame of reference?

A 15.0 s

B 25.0 s

C 125 s

D 225 s

Solution

D The time interval between the two events observed from Spaceship P will be a dilated time by a factor of 3.00.

Question 31/ 36

[VCAA 2021 NHT SA Q20]

A nucleus in an excited energy state emits a gamma ray of energy $3.6 \times 10^{-13}\mathrm{J}$ as it decays to its ground state. The initial mass of the excited nucleus is $\mathrm{M_i}$.

The final mass of the nucleus after decay is closest to

A $\mathrm{M_i} - 4 \times 10^{-30}$ kg

B $\mathrm{M_i} - 8 \times 10^{-30}$ kg

C $\mathrm{M_i}$ kg

D $\mathrm{Mi} + 4 \times 10^{-30}$ kg

Solution

A The mass equivalent of 3.6×10^{-13} J is 4.0×10^{-30} kg.

Question 32/ 36

[VCAA 2021 SA Q20]

One of Einstein's postulates for special relativity is that the laws of physics are the same in all inertial frames of reference. Which one of the following best describes a property of an inertial frame of reference?

A It is travelling at a constant speed.

B It is travelling at a speed much slower than *c*.

C Its movement is consistent with the expansion of the universe.

D No observer in the frame can detect any acceleration of the frame.

Solution

D   Non-accelerating reference frames are inertial.

Question 33/ 36

[VCAA 2022 NHT SA Q10]

Ning travels at 0.67*c* from Earth to the star Proxima Centauri, which is a distance of 4.25 light-years away, as measured by an observer on Earth.

Which one of the following statements is correct?

A In Ning's frame of reference, the distance to Proxima Centauri is less than 4.25 light-years.

B In Ning's frame of reference, the distance to Proxima Centauri is more than 4.25 light-years.

C According to Ning's clock, the trip takes longer than the time measured by Earth-based clocks.

D In Ning's frame of reference, the distance to Proxima Centauri is exactly equal to 4.25 light-years.

Solution

A   Ning measures a dilated length between Earth and Proxima Centauri.

Question 34/ 36

[VCAA 2022 NHT SA Q11]

The star Betelgeuse is classified as a red supergiant. At the core of this star, three stationary helium nuclei fuse to form one carbon nucleus and two gamma-ray photons, as represented by the equation below.

$$^4\text{He}+^4\text{He}+^4\text{He}\rightarrow ^{12}C+\gamma+\gamma$$

The mass of one helium nucleus is 6.645×10^{-27} kg.

The mass of one carbon nucleus is 1.993×10^{-26} kg.

The energy released from the fusion of three helium nuclei is closest to

A 5.0×10^{-30} J

B 1.5×10^{-21} J

C 4.5×10^{-13} J

D 1.2×10^{-9}

Solution

C Use $\Delta E = \Delta m \times c^2$.

Question 35/ 36

[VCAA 2022 SA Q18]

Which one of the following is an example of an inertial frame of reference?

A a bus travelling at constant velocity

B an express train that is accelerating

C a car turning a corner at a constant speed

D a roller-coaster speeding up while heading down a slope

Solution

A The bus is an inertial frame because it is not accelerating.

Question 36/ 36

[VCAA 2022 SA Q19]

A particle produced in a linear particle accelerator is travelling at a speed of $2.99 \times 10^{8}\ \mathrm{m\ s^{-1}}$. Take the speed of light to be $3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$. Which one of the following is closest to the Lorentz factor (γ) of the particle?

A 5.51

B 7.86

C 12.3

D 15.1

Solution

C Use $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$.

Question 37/ 36

[VCAA NHT 2023 SA Q20]

A pion and its antiparticle, each at rest, annihilate and produce only two photons with a total energy of $4.5 \times 10^{-11}\mathrm{J}$. The masses of the pion and its antiparticle are the same.

The rest mass of the pion is closest to

A 1.3×10^{-28} kg

B 2.5×10^{-28} kg

C 5.0×10^{-28} kg

D 7.5×10^{-20} kg

Solution

B Use $\Delta E = \Delta mc^2$

Question 1/ 69

A spaceship moving past an observer has its length measured as exactly one-quarter of its proper length. Calculate the speed of the spaceship relative to the observer making this measurement.

(2 marks)

Solution

0.968c Use $v = c\sqrt{(1 - \gamma^{-2})}$.

Question 2/ 69

Calculate the work that must be done on an electron to increase its speed from rest to $0.3c$.

(2 marks)

Solution

3.9×10^{-15} J Use $\mathrm{KE} = (\gamma - 1)mc^2; \gamma = 1.048$.

Question 3/ 69

Unstable subatomic particles have different lifetimes, depending on whether they are moving relative to the observer measuring the lifetime. One particle has a lifetime, measured at rest, of 5.1 ps. However, when they are moving close to the speed of light, they have a lifetime of 510 ps. Calculate the speed that these particles are travelling at, as a percentage of c.

(2 marks)

Solution

99.995% of c Clearly $\gamma = 100$; now use $v = c\sqrt{(1 - \gamma^{-2})}$.

Question 4/ 69

[Adapted VCAA 2016 SB Q6]

Consider one pion approaching Earth at a speed of $0.98c$. In its own frame of reference it decays after 26 ns after it is formed. How long did the pion exist as observed in Earth's frame of reference?

(2 marks)

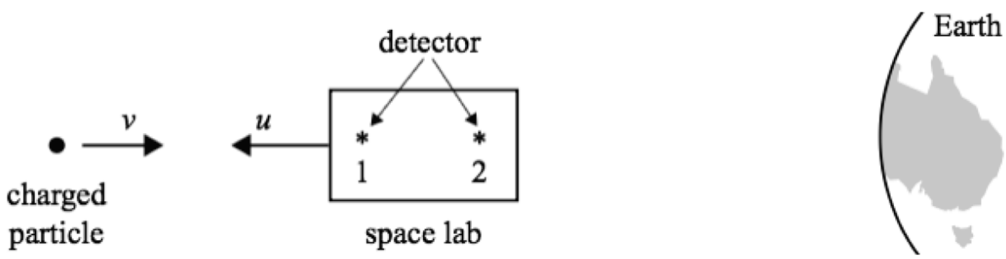
Solution

131 ns $v = 0.98c$ implies $\gamma = 5.03$, hence dilated $\text{time} = 26 \times 5.03 \text{ ns}$.

Question 5/ 69

[Adapted VCAA 2016 SB Q7]

A space lab travelling at $u = 0.8c\,(\gamma = 1.67)$ away from Earth can record high-energy charged particles passing through its detectors.



One particle is travelling towards Earth at $v = 0.91c\ (= 2.4)$ relative to the space lab. Two detectors, numbered 1 and 2 in the diagram above, are 2.0 m apart in the space lab's frame. How far apart are the two detectors in the particle's frame?

(2 marks)

Solution

83 cm $\text{Contracted length} = 2.0/2.4 \text{ m}$.

Question 6/ 69

One of the postulates of special relativity can be written as:

'The speed of light has a constant value for all observers regardless of their motion or the motion of the source.'

Give a specific example of an application of this postulate.

(2 marks)

Solution

A spaceship travelling at 0.9*c* sends out a light beam towards an approaching spaceship, also travelling at 0.9*c*. Both ships measure the speed of light as *c*.

Question 7/ 69

Sally is in a spaceship moving at a fast but constant velocity. Sam is stationary on the ground. Both have identical atomic clocks. Sam observes Sally's clock 'ticking' at half the rate that his clock ticks at.

a. At what speed is Sally's spaceship moving relative to Sam?

(2 marks)

b. At what rate does Sally observe Sam's clock to be ticking (compared to hers)? Give reasons for your answer.

(2 marks)

c. Sam measures Sally's ship to be 500 m long. Calculate the proper length of Sally's spaceship.

(2 marks)

Solution

a 0.866*c* $\gamma = 2$ hence $v = 0.866c$.

b Half the rate of Sally's clock.

c 1000 m Since $\gamma = 2$, length contraction is a factor of 2.

Question 8/ 69

A very fast train $(v = 0.85c)$ of proper length 700 m enters a tunnel of length 600 m. A trainspotter is watching from a nearby hill and can see both ends of the tunnel. Outline what the trainspotter will observe from the time just before she sees the front of the train entering the tunnel to the time just after the back of the train leaves the tunnel. Explain your reasoning.

(3 marks)

Solution

$\gamma = 1.898$, so she will measure the train to be $\frac{700}{1.898} = 369\ \mathrm{m}$ long. She will see the train enter the tunnel, vanish, and then emerge from the other end, still 369 m long.

Question 9/ 69

Calculate the value of γ for a spaceship travelling at 0.7711c. Give your answer to four significant figures.

(2 marks)

Solution

1.571 Use $\gamma = (1 - \frac{v^2}{c^2})^{-\frac{1}{2}}$.

Question 10/ 69

A proton $(\text{mass} = 1.67 \times 10^{-27}\ \text{kg})$ in an accelerator beamline $(\text{proper length} = 4.2\ \text{km})$ has a γ value of 2.35.

a. Calculate the speed of the proton relative to the beamline in units of c. Give your answer to three significant figures.

(2 marks)

b. Calculate the length of the beamline in the reference frame of the proton.

(2 marks)

c. Calculate the time of flight of the protons down the full length of the beamline in the reference frame of the scientists standing beside the beamline.

(2 marks)

d. Calculate the kinetic energy of the proton, in units of MeV. Show your working.

(3 marks)

Solution

a 0.905c Use $v = c\sqrt{(1 - \gamma^{-2})}$.

b 1.79 km Length contraction; divide by γ.

c 15 µs Use $t = \frac{x}{v}$ in scientists' reference frame.

d 1270 MeV Use $(\gamma - 1)mc^2$.

Question 11/ 69

Scientists accelerate a proton from rest to a final speed where $\gamma = 4.5$. The mass of a proton is 1.67×10^{-27} kg. How much work was done on the proton?

(2 marks)

Solution

5.3×10^{-10} J Use $(\gamma - 1)mc^2$.

Question 12/ 69

The Sun's power output is currently about 385 yottawatt $(3.85 \times 10^{26}\ \mathrm{W})$.

a. Calculate the rate at which the Sun's mass is reducing (in $\mathrm{kg\ s^{-1}}$). Show your working.

(3 marks)

b. The Sun's current mass is about 2×10^{30} kg. Estimate the reduction in its mass in one billion years (10^9 y) time. Assume its power output remains the same during that time. Give your answer as a percentage of its current mass, to one significant figure. Show your working.

(3 marks)

Solution

a $4.3 \times 10^9\ \mathrm{kg\ s^{-1}}$ Put $3.85 \times 10^{26} = \Delta m \times c^2$.

b 0.007% $\text{Energy loss} = 1.2 \times 10^{43}\ \text{kg}$; this is a mass loss of $1.3 \times 10^{26}\ \text{kg}$; this is 0.007% of the Sun’s current mass.

Question 13/ 69

[Adapted VCAA 2016 SB Q9]

A proton is accelerated from rest, gaining a kinetic energy of $1.20 \times 10^{-10}\ \text{J}$. What value of γ is reached? (The mass of a proton is $1.67 \times 10^{-27}\ \text{kg}$.)

(2 marks)

Solution

1.8 Use $\text{KE} = (\gamma - 1)mc^2$.

Question 14/ 69

[Adapted VCAA 2016 SB Q10]

A high-energy proton with $\gamma = 3$ collides with a stationary nucleus and rebounds in the opposite direction to its original motion. The kinetic energy of the proton after the collision is mc^2, where *m* is the proton mass. The nucleus gains kinetic energy and the collision is elastic. Determine, in terms of *m* and *c*, the kinetic energy of the nucleus after the collision.

(2 marks)

Solution

mc^2 Energy before $= 2mc^2$ (from $\text{KE} = (\gamma - 1)mc^2$); energy after $=$ energy of proton (mc^2) + energy of nucleus.

Question 15/ 69

[VCAA 2017 SB Q10]

The length of a spaceship is measured to be exactly one-third of its proper length as it passes by an observing station. What is the speed of this spaceship, as determined by the observing station, as a multiple of *c*?

(2 marks)

Solution

0.94*c* From contracted length, $\gamma = 3$; use formula between *v* and *γ*.

Question 16/ 69

[VCAA 2017 SB Q11]

Tests of relativistic time dilation have been made by observing the decay of short-lived particles. A muon, travelling from the edge of the atmosphere to the surface of Earth, is an example of such a particle.

To model this in the laboratory, another elementary particle with a shorter half-life is produced in a particle accelerator. It is travelling at $0.99875c\,(\gamma = 20)$. Scientists observe that this particle travels 9.14×10^{-5} m in a straight line from the point where it is made to the point where it decays into other particles. It is not accelerating.

a. Calculate the lifetime of the particle in the scientists' frame of reference.

(2 marks)

b. Calculate the distance that the particle travels in the laboratory, as measured in the particle's frame of reference.

(2 marks)

c. Explain why the scientists would observe more particles at the end of the laboratory measuring range than classical physics would expect.

(3 marks)

Solution

a $3.05 \times 10^{-13}\text{s}$ Simply use $t = \frac{x}{v}$.

b $4.6 \times 10^{-6}\text{m}$ Use $L = \frac{L_0}{\gamma}$, where $L = 9.14 \times 10^{-5}\text{m}$.

c In the frame of the scientists, the half-life of the particles is dilated, so more particles reach the end of the measuring distance than a non-dilated (classical) half-life would predict.

Question 17/ 69

[VCAA 2018 NHT SB Q15]

An unstable subatomic particle, known as a π_0 meson, decays completely into electromagnetic radiation. The mass of this π_0 meson is 2.5×10^{-28} kg. How much energy would be released by this π_0 meson if it decays at rest?

(2 marks)

Solution

$2.25\,(2.3) \times 10^{-11}$ J Use $E = \Delta mc^2$.

Question 18/ 69

[VCAA 2018 NHT SB Q14]

An Earth-like planet has been discovered orbiting a distant star. A mission to this planet is suggested. The planet is 1.0×10^{18} m from Earth. The spaceship suggested for the mission can travel at an average speed of $0.99c\,(\gamma = 7.1)$.

Scientists are concerned about the length of time the passengers would have to spend on the spaceship to travel to this planet. Use special relativity to estimate this time, in years, as measured on the spaceship.

(3 marks)

Solution

15 y In the spaceship's frame, the journey length will be contracted $\left(L = \frac{L_0}{\gamma} = 1.4 \times 10^{17}\text{m}\right)$; the time will be $\text{proper} = \frac{L}{0.99c}$.

Question 19/ 69

[VCAA 2018 SB Q14]

Jani is stationary in a spaceship travelling at constant speed. Does this mean that the spaceship must be in an inertial frame of reference? Justify your answer.

(2 marks)

Solution

No. The spaceship could be accelerating by travelling in a circular path at constant speed.

Question 20/ 69

[VCAA 2018 SB Q15]

A stationary scientist in an inertial frame of reference observes a spaceship moving past her at a constant velocity. She notes that the clocks on the spaceship, which are operating normally, run eight times slower than her clocks, which are also operating normally. The spaceship has a mass of 10 000 kg. Calculate the kinetic energy of the spaceship in the scientist's frame of reference. Show your working.

(3 marks)

Solution

6.3×10^{21} J Use $\mathrm{KE} = (\gamma - 1)mc^2; \gamma = 8$ from time dilation.

Question 21/ 69

[VCAA 2018 SB Q16]

Quasars are among the most distant and brightest objects in the universe. One quasar (3C446) has a brightness that changes rapidly with time. Scientists observe the quasar's brightness over a 20-hour time interval in Earth's frame of reference. The quasar is moving away from Earth at a speed of $0.704c$ $(\gamma = 1.41)$. Calculate the time interval that would be observed in the quasar's frame of reference. Show your working.

(2 marks)

Solution

14 hours Time dilation factor of 1.41; proper time measured in quasar reference frame.

Question 22/ 69

[VCAA 2019 SB Q17]

A spaceship is travelling from Earth to the star system Epsilon Eridani, which is located 10.5 light-years from Earth as measured by Earth-based instruments. If the spaceship travels at $0.85c$ $(\gamma = 1.90)$, determine the duration of the flight as measured by the astronauts on the spaceship travelling to Epsilon Eridani. Take one light-year to be 9.46×10^{15} m. Show your working.

(3 marks)

Solution

6.5 years Distance measured by scientists on $\mathrm{Earth} = 9.93 \times 10^{16}\mathrm{m}$.

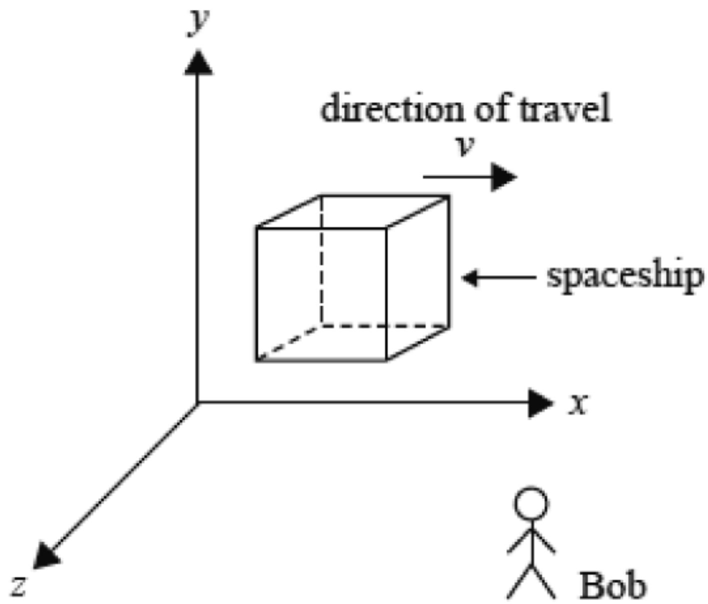
Time measured by scientists on $\mathrm{Earth} = \frac{x}{v} = 3.89 \times 10^{8}\mathrm{s}$.

This is a dilated time, so the astronauts measure proper $\mathrm{time} = 2.04 \times 10^{8}\mathrm{s} = 6.49\ \mathrm{years}$.

Question 23/ 69

[VCAA 2019 NHT SB Q18]

Alien astronauts are travelling between star systems aboard a cube-shaped spaceship, as shown below. The sides of the cube along the *x*-axis, *y*-axis and *z*-axis are 3200 m in the spaceship's reference frame. The spaceship passes Bob, who is on a space station at speed $v = 0.990c\,(\gamma = 7.09)$.



Determine the dimensions of the cube-shaped spaceship as measured from Bob's frame of reference and explain your reasoning. Give the length of the side along the *x*-axis, the length of the side along the *y*-axis and the length of the side along the *z*-axis.

(3 marks)

Solution

Length along $x\text{-axis} = 451\ \mathrm{m}$ (length contraction); lengths along *y* and *z* axes are 3200 m (no length contraction).

Question 24/ 69

[VCAA 2019 NHT SB Q19]

In a nuclear fusion reaction in the Sun's core, two deuterium nuclei, each with a mass of $3.3436 \times 10^{-27}\ \mathrm{kg}$, fuse to produce one helium-4 nucleus with a mass of $6.6465 \times 10^{-27}\ \mathrm{kg}$. Ignore the kinetic energy of the nuclei before the reaction. Calculate the energy released. Show your working.

(2 marks)

Solution

3.663×10^{-12} J Use the formula $\Delta E = \Delta mc^2$.

Question 25/ 69

[VCAA 2019 SB Q11]

What is the second postulate of Einstein's theory of special relativity regarding the speed of light? Explain how the second postulate differs from the concept of the speed of light in classical physics.

(3 marks)

Solution

The postulate is that the speed of light in free space is the same for all observers in inertial frames. An example would be the speed of light of the headlights of a fast train (imagine it moving at $0.5c$) on a straight track would be the same for an observer on the train and a stationary observer on the train tracks; the speed of the train would not affect the speed of the light from the headlights. In classical physics, the speed observed by the person on the train tracks would be $1.5c$.

Question 26/ 69

[VCAA 2020 SB Q11]

An astronaut has left Earth and is travelling on a spaceship at $0.800c$ $(\gamma = 1.67)$ directly towards the star known as Sirius, which is located 8.61 light-years away from Earth, as measured by observers on Earth.

a. How long will the trip take according to a clock that the astronaut is carrying on his spaceship? Show your working.

(2 marks)

b. Is the trip time measured by the astronaut in part a. a proper time? Explain your reasoning.

(2 marks)

Solution

a 6.44 years The Earth observers use $x = 8.61$ light-years (a proper distance) measure the time using $t = \frac{x}{v} = \frac{8.6}{0.8}$ years. (This uses distance units of light-years, time as years and speed as the speed of light fraction. It can also be done with SI units). This is a dilated time; the astronaut measures the proper time; this is given by $t_0 = \frac{t}{\gamma} = 6.44$ years.

b The astronaut will measure the proper time because in his reference frame his clock is stationary.

Question 27/ 69

[VCAA 2021 NHT SB Q10]

Jacinta is standing still while observing a spaceship passing Earth at a speed of 0.984*c*.

a. Calculate γ for this speed, correct to three significant figures. Show your working.

(2 marks)

b. The spaceship is travelling to the Alpha Centauri star system in a straight line at this speed. In Jacinta's frame of reference, this distance is measured to be 4.37 light-years (that is, it would take light 4.37 years to travel this distance). Calculate the time that would be measured by Jacinta for the spaceship's journey, correct to three significant figures. Show your working.

(2 marks)

Solution

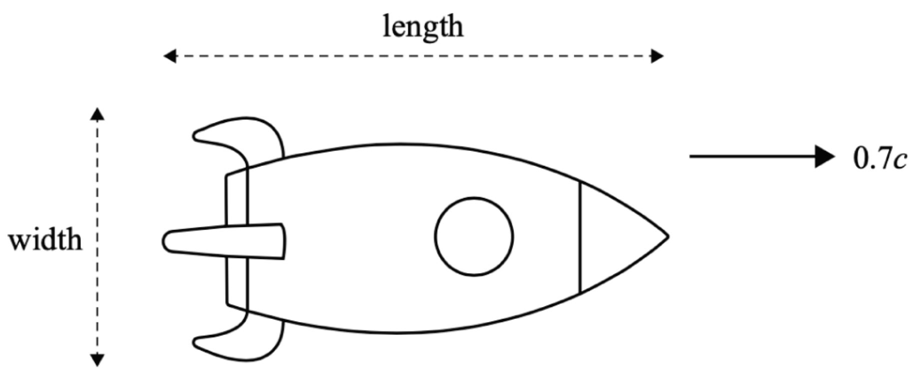
a 5.61 Use $\gamma = (1 - \frac{v^2}{c^2})^{-\frac{1}{2}}$.

b 4.44 years Use $t = \frac{x}{v} = \frac{4.37}{0.984}$ years. (This uses distance units of light-years, time as years and speed as the speed of light fraction. It can also be done with SI units.) This is a dilated time; the astronaut measures the proper time which will be shorter.

Question 28/ 69

[VCAA 2021 SB Q10]

A new spaceship that can travel at 0.7*c* has been constructed on Earth. A technician is observing the spaceship travelling past in space at 0.7*c*, as shown. The technician notices that the length of the spaceship does not match the measurement taken when the spaceship was stationary in a laboratory, but its width matches the measurement taken in the laboratory.



a. Explain, in terms of special relativity, why the technician notices there is a different measurement for the length of the spaceship, but not for the width of the spaceship.

(2 marks)

b. If the technician measures the spaceship to be 135 m long while travelling at a constant 0.7*c*, what was the length of the spaceship when it was stationary on Earth? Show your working.

(2 marks)

Solution

a Relativistic length contraction only occurs parallel to the velocity direction.

b 189 m Use $L = \frac{L_0}{\gamma}$, where $L = 135$ and $\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}} = 1.4$.

Question 29/ 69

[VCAA 2022 NHT SB Q11]

An experiment is set up at a linear accelerator research facility to study muons. The muons created at the research facility are measured to have a speed of $0.950c \ (\gamma = 3.20)$.

a. One muon has a lifetime of 2.3 μs, as measured in the muon's frame of reference. Calculate this muon's lifetime, as measured by the researchers. Show your working.

(2 marks)

b. In one observation, a 0.950*c* muon travels 1.5 km, as measured by the researchers. If measured in the muon's frame of reference, would this length be the same, shorter or longer? Use a calculation to justify your answer.

(2 marks)

Solution

a 7.4 μs The muon will 'measure' the proper time; the researchers will measure a dilated time. Hence $\tau = 2.3\ (\tau_0) \times 3.2 = 7.4\ \mu$s.

b Shorter The muon will measure a contracted length; the researchers will measure the proper length. Hence $L = \frac{L_0}{3.2} = 0.47\ \text{km}$. The length is shorter.

Question 30/ 69

[VCAA 2022 SB Q9]

A star is transforming energy at a rate of 2.90×10^{25} W. Explain the type of transformation involved and what effect, if any, the transformation would have on the mass of the star. No calculations are required.

(2 marks)

Solution

The mass of the star would decrease. Some of the mass is being transformed into energy $(E = \Delta mc^2)$.

Question 31/ 69

[VCAA 2022 SB Q11]

Explain why muons formed in the outer atmosphere can reach the surface of Earth even though their half-lives indicate that they should decay well before reaching Earth's surface.

(2 marks)

Solution

There are two possible approaches. The first is to note that in the reference frame of the muon, Earth is moving, so the thickness of the atmosphere is length contracted. The second approach is to note that in the reference frame of Earth, the muon is moving, so the time in its frame is time dilated.

Question 32/ 69

[VCAA NHT 2023 SB Q14]

A spaceship of length 71 m, measured when stationary on Earth, is travelling horizontally past an observer on Earth at a speed of $0.80c$.

a. The spaceship emits a beam of light towards the observer.

State the speed of the light as measured by the observer on Earth.

Justify your answer.

(2 marks)

b. Calculate the length of the spaceship as measured by the observer on Earth.

(2 marks)

Solution

a $3 \times 10^8 \text{ m s}^{-1}$ or c The measured speed of light is the same for the spaceship and Earth observer.

b 43 m $L = \frac{L_0}{\gamma} \rightarrow L = \frac{71}{\gamma}$ (correct gamma $= 1.67$). $L = 43$ m.

Question 33/ 69

[VCAA 2023 SB Q10]

A proton in an accelerator beamline of proper length 4.80 km has a Lorentz factor, γ, of 2.00.

a. Calculate the speed of the proton relative to the beamline in terms of c, the speed of light in a vacuum. Give your answer to three significant figures.

(3 marks)

b. Calculate the length of the beamline in the reference frame of the proton.

(1 mark)

c. Calculate the kinetic energy of the proton in joules. Show your working.

$\text{Mass of proton} = 1.67 \times 10^{-27}$ kg.

(2 marks)

Solution

a 0.866c Use $\gamma = \frac{1}{\sqrt{1-\beta^2}}$ where $\beta = \frac{v}{c}$ Note answer to three significant figures

b 2.4 km Use $L = L_0/\gamma$.

c 1.50×10^{-10} J Use $E_k = (\gamma - 1)\ mc^2$

$= (2.00 - 1)(1.67 \times 10^{-27})(3.00 \times 10^8)^2$

Chapter 19 Principles of practical physics

Question 1/ 25

In experimental investigations, *independent* variables are best described as

A ones that the investigator selects values for.

B the key variables to be measured.

C independent of the investigator’s control.

D fixed throughout the experiment.

Solution

A Standard knowledge.

Question 2/ 25

In experimental investigations, *dependent* variables are those that

A the investigator selects values for.

B are the least important variables to be measured.

C are dependent on the selected values of other variable(s).

D are fixed throughout the experiment.

Solution

C Standard knowledge.

Question 3/ 25

In experimental investigations, *controlled* variables are those that, generally

A the investigator varies the values for.

B are the least important variables to be measured.

C are dependent on the selected values of other variables.

D are fixed throughout the experiment.

Solution

D Standard knowledge.

Question 4/ 25

An *accurate* value for a measurement is one that

A is the result of many careful investigations.

B is made by a highly skilled scientific investigator.

C when repeated many times changes very little.

D is close to the true value of the quantity being measured.

Solution

D Standard knowledge.

Question 5/ 25

Data is said to be *precise* when

A it is the result of a careful investigation.

B repeated many times, the results change very little.

C the same experimental method is used by different investigators.

D it is close to the true value of the quantity being measured.

Solution

B Standard knowledge.

Question 6/ 25

Data cannot be said to be *valid* when

A systematic errors are very large.

B repeated measurements give a wide range of values.

C the experimental method used is too straightforward.

D the measurement is repeated too many times.

Solution

A When systematic errors are large, measurements cannot be relied on to measure the target variable.

Question 7/ 25

The *error* in a measurement is best understood as

A the difference between the measured value and the true value.

B a mistake in the recording of a measurement.

C a mistake in the experimental method.

D the expected variation in subsequent measurement values.

Solution

A   Standard knowledge.

Question 8/ 25

The experimental *uncertainty* of a measurement is best understood as

A an estimate of the validity of the data.

B the confidence of an experimenter in their experimental technique.

C the repeatability of the measurement.

D an estimate of how far the measurement is from the true value.

Solution

D   Standard knowledge.

Question 9/ 25

A *hypothesis* is best understood as

A a program of investigative research.

B a testable scientific explanation of a phenomenon.

C a well-established scientific belief system.

D a scientific explanation of a phenomenon from a qualified scientist.

Solution

B Standard knowledge.

Question 10/ 25

A scientific *theory* is best understood as

A a program of investigative research.

B a testable scientific explanation of a phenomenon.

C a well-tested and verified scientific explanation of a phenomenon.

D a scientific explanation of a phenomenon from a qualified scientist.

Solution

C Standard knowledge.

Question 11/ 25

[Adapted VCAA 2017 SA Q18]

Two students, Rob and Jan, measure the current in a circuit under the same conditions and with the same equipment on separate occasions.

Rob obtains the following readings: 9.50 mA, 9.21 mA, 9.10 mA and 9.60 mA (average 9.35 mA).

Jan obtains the following readings: 9.27 mA, 9.26 mA, 9.30 mA and 9.32 mA (average 9.29 mA).

The value of the current using a very accurate meter is found to be 9.34 mA.

Which one of the following best describes these two sets of measurements?

A Rob’s results are more accurate than Jan’s results.

B Both sets of results are equally accurate.

C Rob’s results are more precise than Jan’s results.

D Both sets of results are equally precise.

Solution

A From the definition of accuracy.

Question 12/ 25

[VCAA 2017 SA Q19]

Which one of the following best describes a *hypothesis*?

A A possible explanation that needs to be tested against experimental evidence

B An explanation that has been supported by rigorous experimental evidence

C A statement that is widely accepted by scientists

D An explanation that is mathematically correct

Solution

A Standard knowledge.

Question 13/ 25

[VCAA 2017 SA Q20]

Which one of the following statements about systematic and random error is correct?

A Random error can be reduced by repeated readings.

B Both random and systematic errors can be reduced by repeated readings.

C Systematic errors can be reduced by repeated readings.

D Neither systematic nor random errors can be reduced by repeated readings.

Solution

A Standard knowledge.

Question 14/ 25

[VCAA 2017 Sample SA Q9]

Some students are measuring the acceleration due to gravity in a region of Earth's surface where the value is well established as $9.81 \pm 0.01 \text{ m s}^{-2}$.

They take five measurements, as follows:

9.83 m s^{-2}; 9.81 m s^{-2}; 9.79 m s^{-2}; 9.78 m s^{-2}; 9.84 m s^{-2}.

Systematic errors are negligible.

The students could reasonably describe the measurement uncertainty of their results as about

A 0.03 m s^{-2}

B 0.10 m s^{-2}

C 0.005 m s^{-2}

D 9.81 m s^{-2}

Solution

A Simplest estimates is half the range of the measured values.

Question 15/ 25

[VCAA 2018 SA Q18]

The experimental uncertainty in a measurement of any particular quantity is *best* described as

A a quantitative estimate of the doubt associated with the measurement.

B the degree of confidence a scientist has in their experimental technique.

C the difference between the measurement and the true value of the quantity.

D the result of one measurement; repeated measurements can eliminate uncertainty.

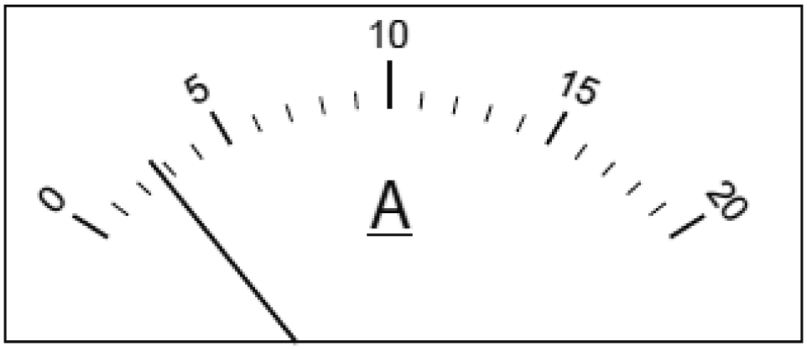
Solution

A Standard knowledge.

Question 16/ 25

[VCAA 2018 SA Q19]

The diagram below shows a properly calibrated ammeter with its pointer registering a current of close to 3 A.



Which one of the following is an appropriate measure of the uncertainty of this single reading of the pointer?

A 0.05 A

B 0.5 A

C 0.8 A

D 1 A

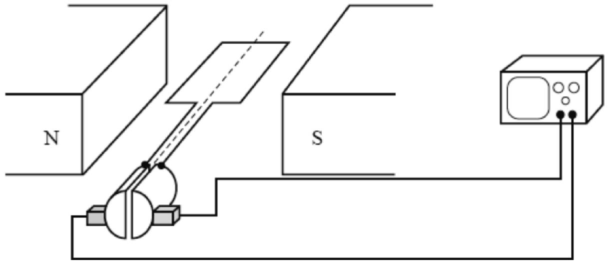
Solution

B Equal to half of the smallest division.

Question 17/ 25

[VCAA 2018 SA Q20]

A group of Physics students conducts a controlled experiment to investigate the phenomenon of electromagnetic induction. The students place a coil within a uniform magnetic field, as shown in the diagram below.



The coil is spun at 50 revolutions per minute, 100 revolutions per minute and then 150 revolutions per minute, and the peak EMF is measured each time on an oscilloscope. Which of the following *best* identifies the independent and dependent variables, and a possible controlled variable in this experiment?

Independent variable	**Dependent variable**	**Controlled variable**
speed of rotation	strength of magnetic field	peak EMF
speed of rotation	peak EMF	strength of magnetic field
peak EMF	speed of rotation	strength of magnetic field
peak EMF	strength of magnetic field	speed of rotation

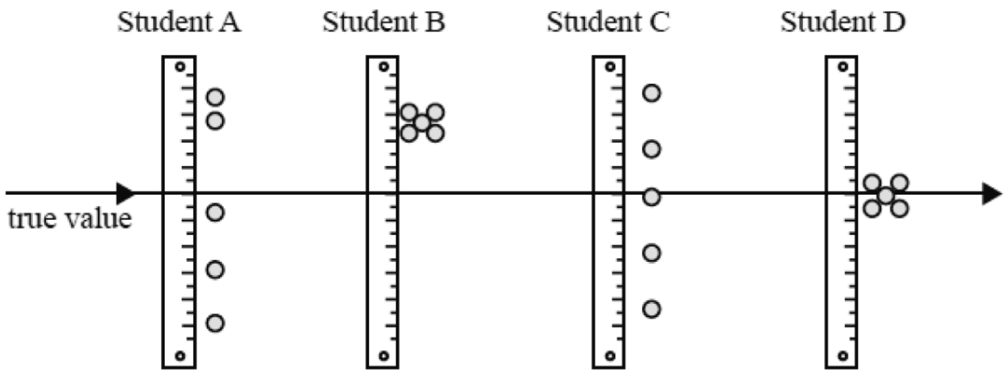
Solution

B The independent variable is varied by the students; the dependent variable varies as a result and the controlled variable is kept constant throughout.

Question 18/ 25

[VCAA 2019 NHT SA Q20]

Four students measure the length of a piece of string. Each student takes five measurements and displays the results as five dots, as shown in the diagram below. A ‘calibrated value’ using a very accurate method is also shown.



Which student produced a set of precise but inaccurate results?

A Student A

B Student B

C Student C

D Student D

Solution

B Tightly clustered therefore precise; not close to true value therefore not accurate.

Question 20/ 25

[VCAA 2019 SA Q18]

Which of the following best identifies the independent, dependent and controlled variables in the students' experimental investigation?

Independent	Dependent	Controlled
length	time	mass, amplitude
time	length	mass, amplitude
mass	time	length, amplitude

amplitude length time, mass

Solution

A The experimenter varies the length and observes the effect on the period. The mass and amplitude are kept constant.

Question 21/ 25

[VCAA 2019 SA Q19]

Which one of the following best explains why the students measured the time for five oscillations rather than the time for one oscillation?

A One oscillation is too quick to see.

B Five oscillations reduce the effect of air friction.

C Five oscillations reduce the uncertainty of the measured period.

D Five oscillations reduce the uncertainty of the measured length.

Solution

C If the uncertainty in measuring a time interval is, for example, ± 0.5 s, then the uncertainty for one period when 5 periods are measured is ± 0.1 s (one fifth of ± 0.5 s).

Question 22/ 25

[VCAA 2020 SA Q19]

Which one of the following best describes a hypothesis?

A a testable scientific explanation

B a well-tested scientific explanation

C a scientific explanation by a famous scientist

D a widely believed and highly plausible explanation

Solution

A This is its definition.

Question 23/ 25

[VCAA 2021 NHT SA Q19]

In an experimental investigation, an independent variable is one that is

A independent of the investigator's control.

B a value selected by the investigator.

C fixed throughout the experiment.

D the key variable to be measured.

Solution

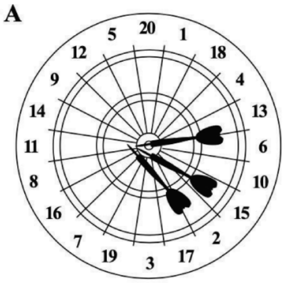
B This is a key characteristic of the independent variable. The dependent is described by option D; controlled variables are described by C and possibly A.

Question 24/ 25

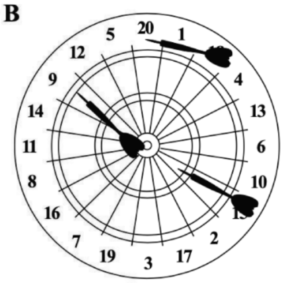
[VCAA 2021 SA Q1]

The aim of darts is to hit the bullseye at the centre of a dartboard. Four darts players (A, B, C and D) each threw three darts. The results of their throws are shown below.

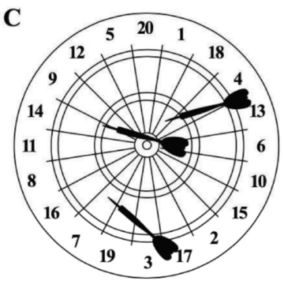
Player A



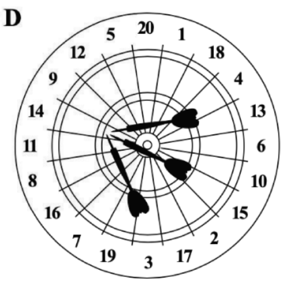
Player B



Player C



Player D



Which one of the players produced a set of attempts that could be described as being precise but inaccurate?

A Player A

B Player B

C Player C

D Player D

Solution

D The results are closely spaced (therefore precise) but not close to the bullseye (therefore inaccurate).

Question 25/ 25

[VCAA 2022 SA Q20]

The experimental uncertainty of a measurement is best understood as

A an estimate of the validity of the data.

B a mistake in the experimental method used.

C a mistake in the recording of a measurement.

D an estimate of the maximum likely difference between the measurement and the true value.

Solution

D Standard knowledge.

Question 26/ 25

[VCAA NHT 2023 SA Q11]

Which one of the following best describes a hypothesis?

A an explanation that is correct

B a statement that is widely accepted by physicists

C an explanation that has been supported by experimental evidence

D a possible explanation that needs to be tested by experimental evidence

Solution

D Standard knowledge.

Question 1/ 45

Express the following quantities to three significant figures.

a. 0.0003455 N

b. 34 500 A

c. 8.7964×10^3 C

(3 marks)

Solution

a 0.000346 N

b 3.45×10^4 A

c 8.80×10^3 C

Question 2/ 45

Identify the units in the following list that are not SI *base units*:

• kilogram

• milliamp

• grams

• ampere

• seconds

• millikelvin

(2 marks)

Solution

milliamp, grams, millikelvin

Question 3/ 45

Write out the name of the following abbreviations in full:

kA, mV, MPa, mJ, μT, mW

(2 marks)

Solution

kiloampere, millivolt, megapascal, millijoule, microtesla, milliwatt

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Question 4/ 45

Students are investigating how the resistance of an incandescent globe changes with the power supplied to the globe. They have access to the globe, a suitable ammeter and voltmeter, connecting wires and a variable voltage power supply.

a. Draw a circuit that they could use to measure the globe resistance at different power inputs. Label the components of the circuit clearly.

(3 marks)

b. Identify dependent, independent and controlled variables in this investigation.

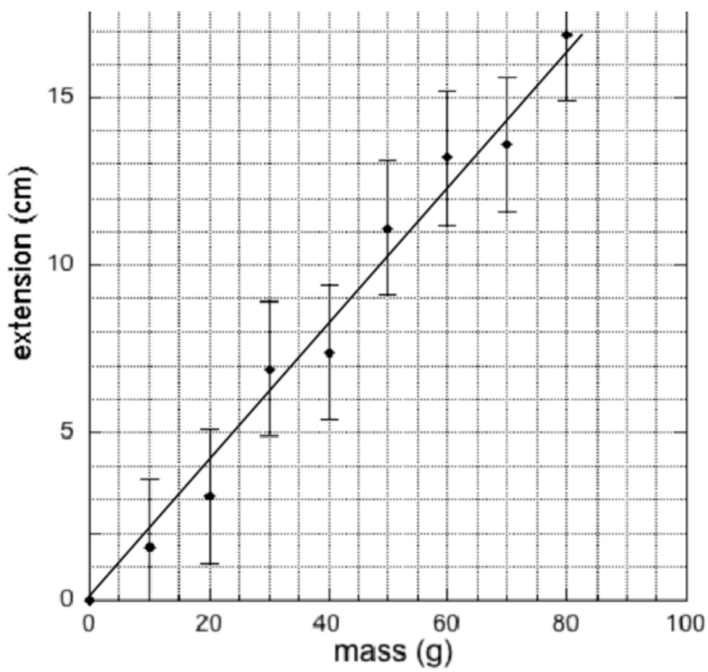
(3 marks)

c. Outline a procedure that they could follow to gather data for their investigation.

(4 marks)

Solution

a



Note: trend line going through origin.

Trend line must take equal account of other points as they have same uncertainties.

b Independent: probably the power supply voltage, but would be possible to choose the current.

Dependent: probably the current, though (see above) could be the voltage.

Controlled: temperature of the components, as the resistance of the globe would change with environmental changes.

c 1. Test all components.

2. Ensure the two meters read 0 when disconnected.

3. Change the output of the power supply into a suitable number of steps. The exact number will depend on the power supply and the voltage rating of the globe (if V too high, the globe will break and the circuit will be broken). Allow the globe to come to an equilibrium temperature for each reading.

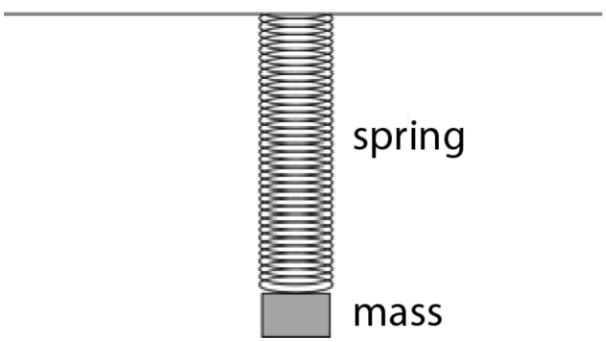
4. For each voltage recorded, simultaneously record the current.

5. Repeat all the measurements at least 3 times (as time permits).

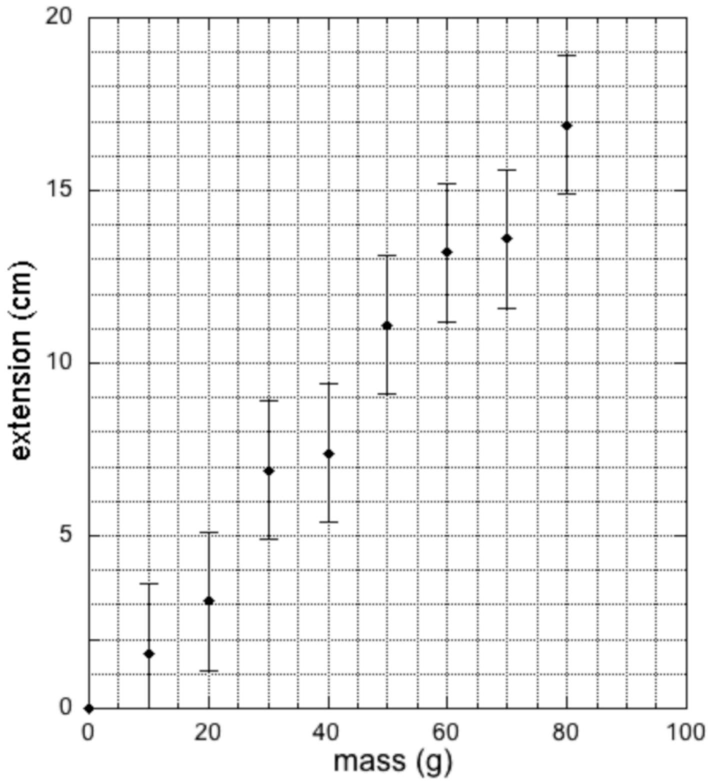
6. Find the corresponding power for each set of V and I $(P = VI)$.

Question 5/ 45

Students gather data to measure the force constant of a spring attached to the ceiling. Masses are added gently to the lower end of the spring.



They measure the spring extension against the mass size, and draw the graph shown on the next page. The vertical uncertainty bars show the confidence that the students have in the accuracy of their measurements. There are no horizontal bars, as the masses are known very accurately.



a. Draw a trend line through the points. Explain how you decided on the shape and position of the line you draw.

(3 marks)

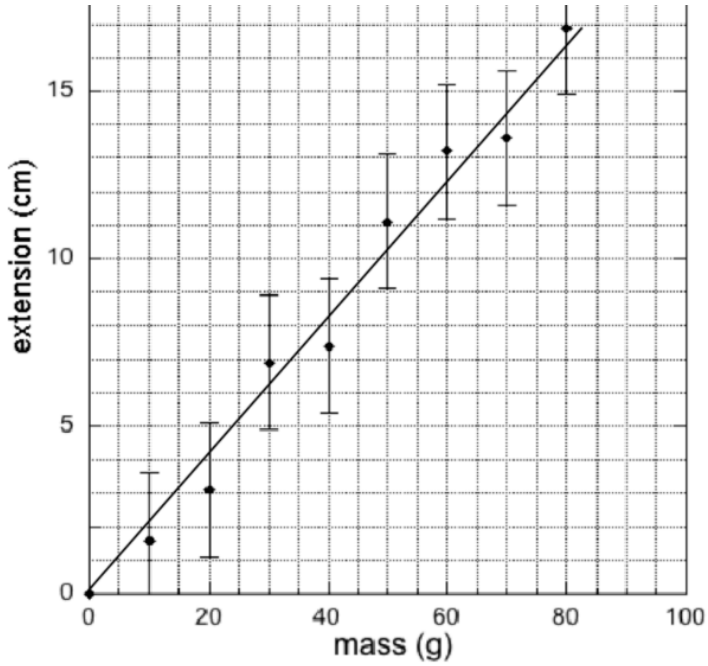
b. Use your trend line to determine the force constant of the spring, in Nm^{-1}. Show all your working.

(4 marks)

c. Estimate the uncertainty in your value for the force constant. (You may find it helpful to draw more lines on the graph.) Show your reasoning.

(4 marks)

Solution



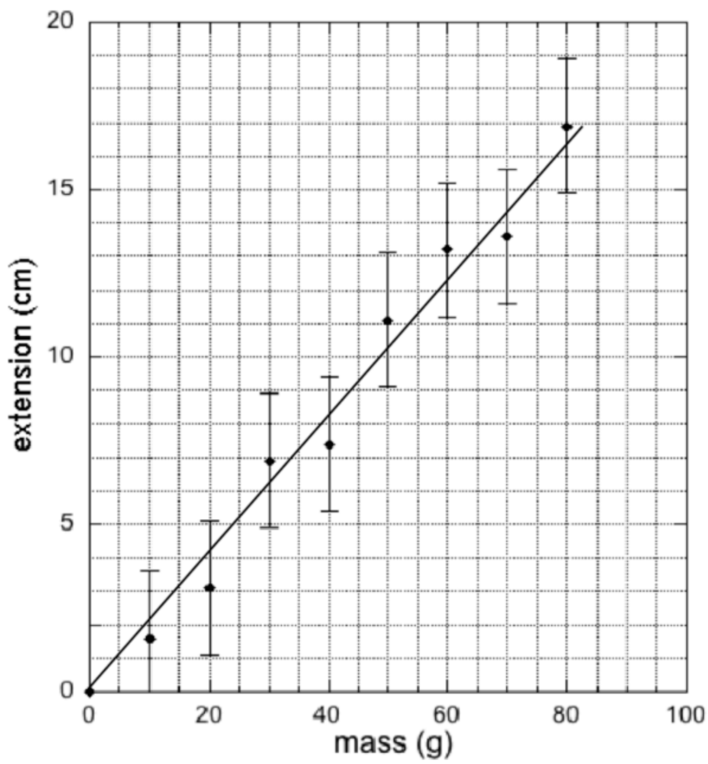
a

Note: trend line must go through zero, as this point is accurate.

Trend line must take equal account of other points as they have same uncertainties.

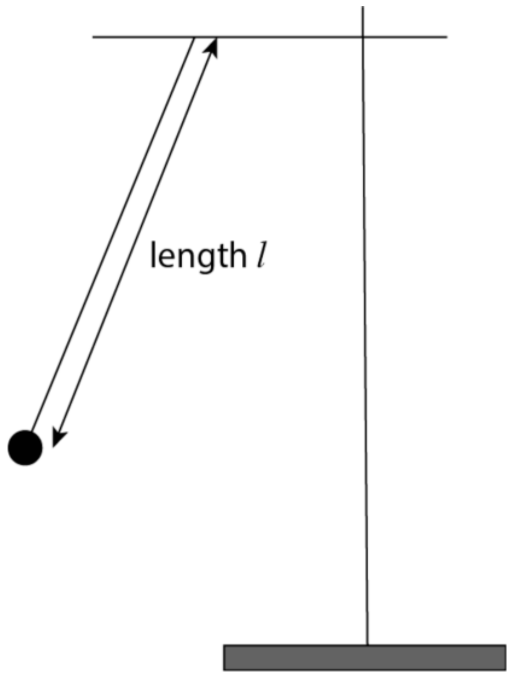
b $5.0\ \mathrm{N\ m^{-1}}$ Gradient of graph; should be $\pm$ within $0.1\ \mathrm{N\ m^{-1}}$.

c The hypothesis is not supported, as the changes in the period are smaller than the uncertainty of the measurements and there is no discernible trend.



Question 6/ 45

Students are using a simple pendulum to measure the local gravitational field (*g*). A fishing line supports a small mass from a sturdy stand.



The length of the fishing line supporting the mass $95\text{ cm} \pm 2\text{ cm}$. The 2 cm figure represents the measurement uncertainty of the length of the fishing line. The students measure the *period* of the pendulum as it swings through a small angle. They measure the time for 20 complete swings, and they repeat the measurement five times.

a. Explain why they repeat the measurement.

(2 marks)

They then repeat the experiment for five different small masses, and the results with measurement uncertainties are shown in the table below.

Mass (g)	Angle of swing (°)	Period (average of 5 swings)
50	4 ± 1	1.99 ± 0.06
75	4 ± 1	2.02 ± 0.06
100	4 ± 1	1.96 ± 0.06
125	4 ± 1	2.03 ± 0.06
150	4 ± 1	1.97 ± 0.06

b. Identify the controlled, independent and dependent variable in this experiment.

(3 marks)

c. One of the students had made the hypothesis that larger masses would result in a longer period. Evaluate the results of the experiment with this hypothesis.

(2 marks)

Their research (using reliable internet sites) shows that, provided the swing amplitude is small, the connection between the period (*T*), length (*l*) and gravitational field (*g*) should be:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

d. They use the formula above to determine a value for the local gravitational field. What value will they obtain? Show your working.

(4 marks)

e. Their teacher tells them that their result should have an experimental uncertainty of close to 8%. Evaluate their result, given that the local value of *g* has been very accurately measured to be $9.81\ \mathrm{N\ kg}^{-1}$.

(2 marks)

Solution

a The average of repeated measurements will be more reliable than a single reading and should have a lower value of measurement uncertainty.

b Controlled: the angle of swing; independent: the mass; dependent: the period.

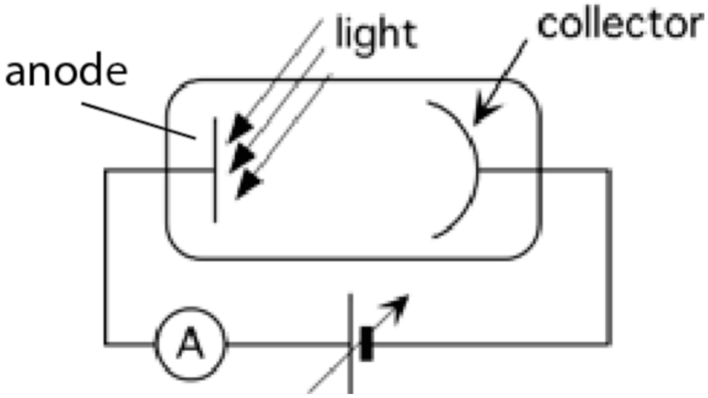
c The hypothesis is not supported, as the changes in the period are smaller than the uncertainty of the measurements.

d $9.47\ \mathrm{N\ kg}^{-1}$ Rearrange the formula to read $g = \frac{4\pi^2 l}{T^2}$; insert average value of *T* and measured length of *l*.

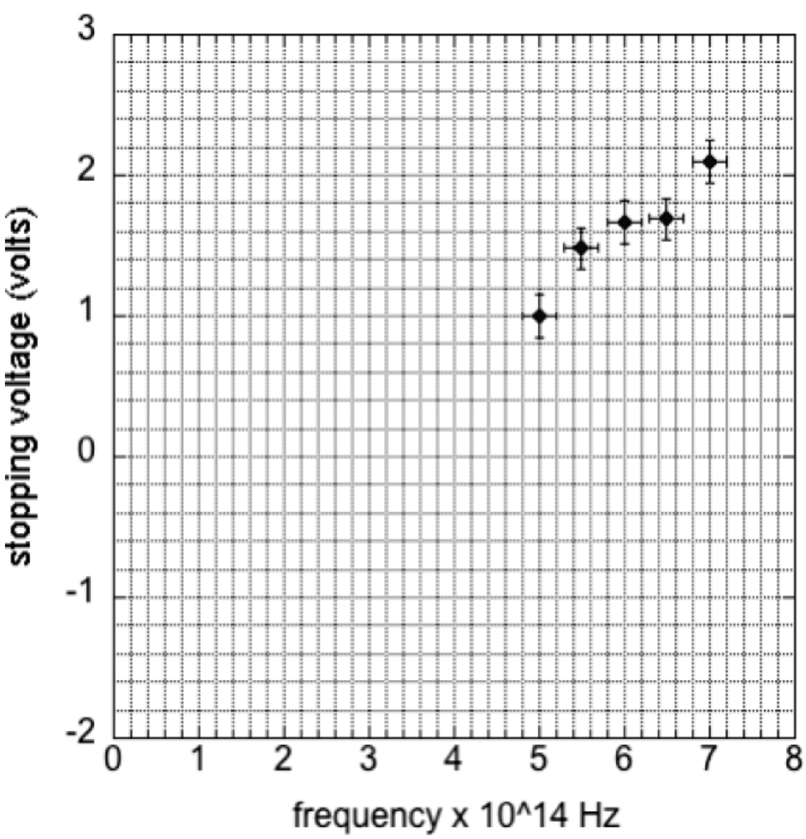
e Their value differs from the ‘true’ value by close to 4%; this is smaller than the 8% experimental uncertainty.

Question 7/ 45

Students are experimenting with a photocell. When light of a high enough frequency strikes the anode (a metal plate), photoelectrons are emitted.



Students record the power supply voltage that just reduces the current in the ammeter to zero against the frequency of the light (they use a range of filters). The results that they obtain are graphed on the next page. The horizontal and vertical bars attached the graph points show their measurement uncertainties.



a. Draw a line of best fit to the data in the graph.

(2 marks)

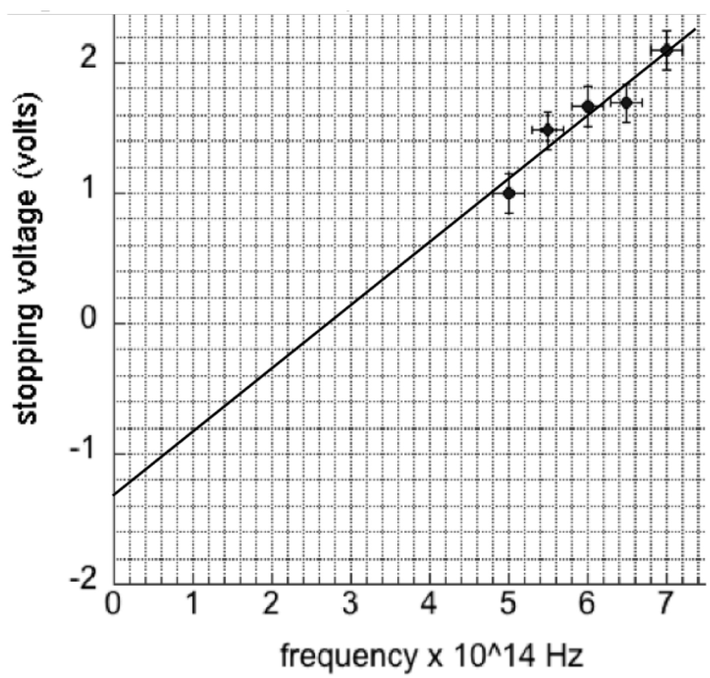
b. From your line, calculate the work function of the photocell, in eV.

(2 marks)

c. From your line, calculate the value of Planck's constant, in eV s.

(2 marks)

Solution



a

Note that the line of best fit should pass through the uncertainty limits of the data.

b 1.3 eV The negative of the value of the *y*-intercept.

c 4.8×10^{-15}eV s Carefully measure the gradient (rise over run).

Question 8/ 45

Students use a resonance tube to measure the wavelength of sound at various frequencies. They change the frequency and measure the resulting wavelength. They aim measure accurately the speed of sound. Results are shown below. They keep the temperature steady at 20°C throughout.

Frequency f (Hz)	Wavelength λ (cm)	$1/\lambda\ (\mathbf{m^{-1}})$
100	345	
150	202	
200	179	
250	126	
300	122	

a. Identify the dependent, independent and controlled variables.

(2 marks)

b. Complete the table values in the last column. Use the units indicated.

(3 marks)

c. Plot a graph of frequency (*x*-axis) against (1/*λ*) (*y*-axis). Take the uncertainties as $\pm 15\ \mathrm{Hz}$ (for *f*) and $\pm 9\%$ (for 1/*λ*).

(4 marks)

d. Draw a trendline (line of best fit).

(2 marks)

e. Evaluate whether the linear fit is justified by the uncertainties involved.

(2 marks)

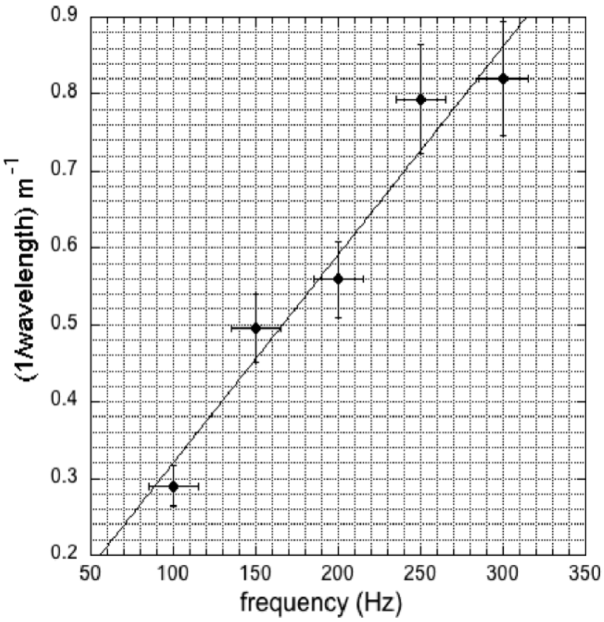
f. Use the trendline gradient to calculate the speed of sound. Show your working.

(3 marks)

Solution

a Independent: frequency; dependent: wavelength; controlled: temperature.

b Values descending: 0.290, 0.495, 0.559, 0.794, 0.820 (all in m^{-1}).



c, d

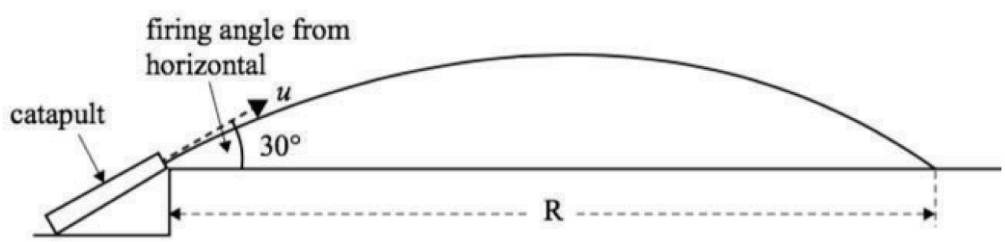
e The line passes through all the uncertainty limits, so the fit is satisfactory. There is no case for a more complex fit.

f $368\ \mathrm{m\ s^{-1}}$ The gradient of the line is the inverse of the speed of sound (from $\frac{1}{\lambda} = \left(\frac{1}{v}\right) f$).

Question 9/ 45

[Adapted VCAA 2017 SB Q9]

Students investigate the relationship between various initial variables of projectiles and their range, *R* (on level ground) as in the diagram below. In their investigation they use a 0.10 kg ball and keep the launching catapult at a fixed angle of 30°. The ball lands at the same height that it was launched from.



a. The variables in the experiment can be classified as controlled, dependent or independent. Complete the table below by providing one variable from the experiment described for each classification.

Classification	*Variable*
Controlled	

Dependent

Independent

(3 marks)

b. The students gather the following data from a series of experiments similar to the experiment described in part **a**.

$u = initial\ speed\ \left(m\ s^{-1}\right)$	$R = range\ (m)$
1.0	0.10
2.0	0.35
3.0	0.78
4.0	1.40
5.0	2.15

The students use a tape measure that is marked with intervals of 10 cm to measure the range that the ball travels at different initial speeds.

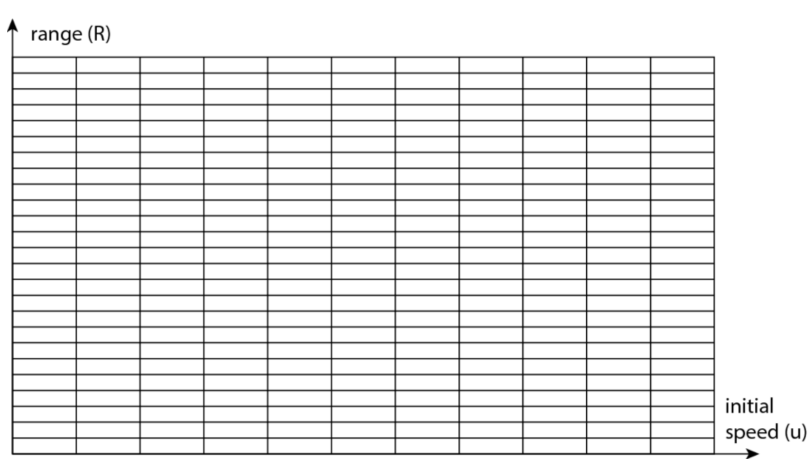
On the grid provided below:

• graph the data gathered by the students (from the table above)

• include scales and units on each axis

• insert appropriate uncertainty bars for the range (distance) on the graph

• draw a smooth curve of best fit.



(8 marks)

Solution

a Controlled: firing angle, mass of ball; dependent: range; independent: initial speed.

b Missing Image

Question 10/ 45

Two students attempt to measure the local acceleration of gravity by timing the drop of a golf ball. They measure the fall distance with a tape measure (marked in 1 cm intervals) and the time of fall with a stopwatch. They do not have access to more sophisticated equipment. They can choose to drop the ball over distances between 1 and 5 m. The stopwatch measurement uncertainty of time intervals is ± 0.1 s. They aim to use the measured drop time and distance to calculate *g*.

a. Identify the dependent and independent variables.

(1 mark)

b. Suggest a procedure for conducting the experiment (use dot points) that will maximise the accuracy of the drop time measurements.

(3 marks)

c. Outline the calculation steps that they should take with the drop time measurements to determine a value for *g*.

(2 marks)

d. Which of the measurements that they take has an experimental uncertainty with the greatest effect on the accuracy of their results? Explain your reasoning.

(3 marks)

Solution

a Dependent variable: drop time; independent variable: length of drop.

b Major problem with the investigation is inaccuracy in measuring the drop time. A 1 m fall will take $\sim 0.44\ \text{s}$, making the measurement uncertainty around $\pm 25\%$, a large value. Best solution is to use longest fall available (5 m); this should reduce uncertainty to $\pm 10\%$. Any effect of air resistance is likely to be far smaller than this with a dense object like a golf ball. Hence the following is suggested:

- Select the 5 m drop distance; measure it at least 5 times and average the results.
- Drop the ball repeatedly with a sharp audio indication of the start of the fall.
- The sound of the ball striking the floor would be a good signal of the end of the fall.
- Repeat this measurement as many times as possible – say at least 20 times.

(there is no point in using the other fall distances.)

- Advanced error analysis (well beyond Year 12) would allow quantifying the reduction in measurement uncertainty by the repeated measurements.

c • Use the formula $x = \frac{1}{2}gt^2$ in the form $g = \frac{2x}{t^2}$.

- Use the average values for *x* and for *t* in the formula.

d Most significant are uncertainties in measurement of *x* (estimate: $\sim \pm 0.2\%$) and in *t* (estimate: $\sim \pm 5\%$, assuming repeats can halve the uncertainty from 10%). However, this reduction is complex to quantify and beyond Year 12 work.

Question 11/ 45

[VCAA 2018 SB Q20]

Some students have collected data on the orbital period, *T*, and orbital radius, *R*, of five of Saturn's moons. The results are shown in the table below. Assume that the moons are in circular orbits.

Moon	Orbital period (s)	Orbital radius (m)	$T^2\ (10^{10}\text{s}^2)$	$R^3\ (10^{24}\text{m}^3)$
Mimas	8.14×10^4	1.86×10^8	0.66	6.40
Enceladus	1.18×10^5	2.38×10^8	1.39	13.5
Tethys	1.63×10^5	2.95×10^8	2.66	25.7

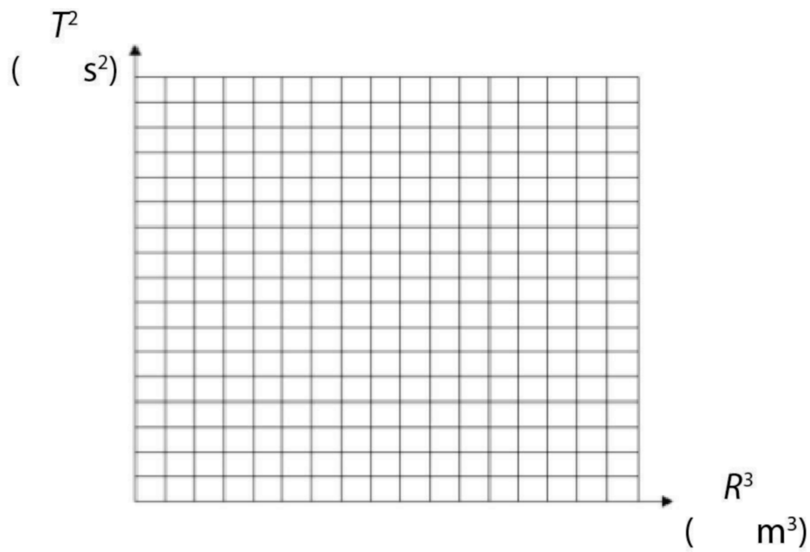
Moon	Orbital period (s)	Orbital radius (m)	$T^2\ (10^{10}\mathrm{s}^2)$	$R^3\ (10^{24}\mathrm{m}^3)$
Dione	2.36×10^5	3.77×10^8	5.57	53.6
Rhea	3.90×10^5	5.27×10^8	15.2	146

a. On the axes provided below:

• plot a graph of the observational data T^2 versus R^3

• include a scale on each axis

• draw a line of best fit.



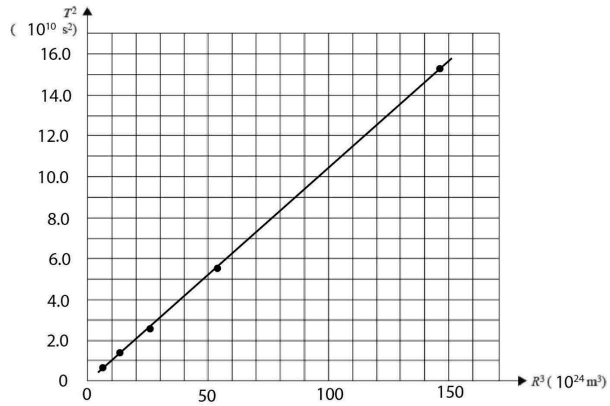
b. Calculate the gradient of the line of best fit drawn in part **a**. Show your working.

(2 marks)

c. Use the value of the gradient calculated in part **b.** to determine the mass of Saturn. Show your working.

(3 marks)

Solution

a 

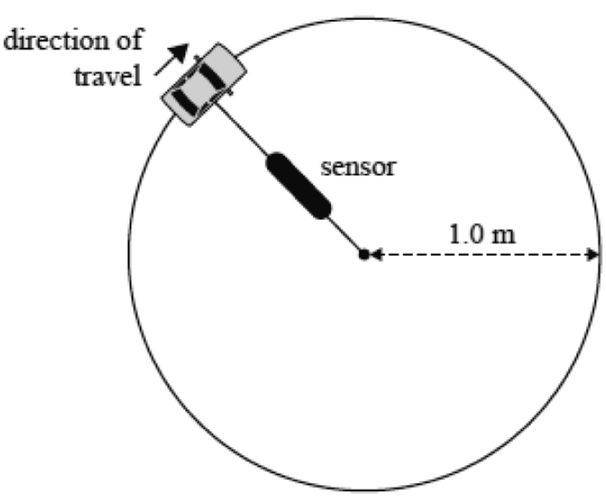
b $(1.05 \pm 0.05) \times 10^{-15} \mathrm{s}^2 \mathrm{m}^{-3}$ $\text{Gradient} = \frac{\text{rise}}{\text{run}}$.

c 5.7×10^{26} kg $\text{Gradient} = \left(\frac{4\pi^2}{GM_{\text{SATURN}}}\right)$; make M_{SATURN} the subject.

Question 12/ 45

[VCAA 2019 NHT SB Q8]

Students are investigating the forces involved in horizontal circular motion. Their apparatus consists of a model car that travels in a circle at constant speed. The speed of the model car can be set at different values. The car is connected by a string of length 1.0 m to the centre of the circle. Incorporated in the string is a sensor that measures the tension (force) of the string. There is no radial friction force between the car's tyres and the surface that the car moves on. The diagram below shows the experimental arrangement viewed from above.



The students obtain a number of measurements by varying the setting for the period of rotation T and recording the force, F_{T}, in the string. They know T with great accuracy but the sensor has an experimental uncertainty of $\pm$ 0.4 N.

a. What is experimental uncertainty and how can it be reduced?

[2 marks}

b. Identify the independent variable, the dependent variable and two controlled variables involved in this experiment.

(3 marks)

c. i. The students have recorded the data for the period of rotation, *T*, and the force, F_{T}, in the table below. The radius of the circle is 1.0 m. Calculate the values of $\frac{1}{T^2}$ and write them in the table below.

(1 mark)

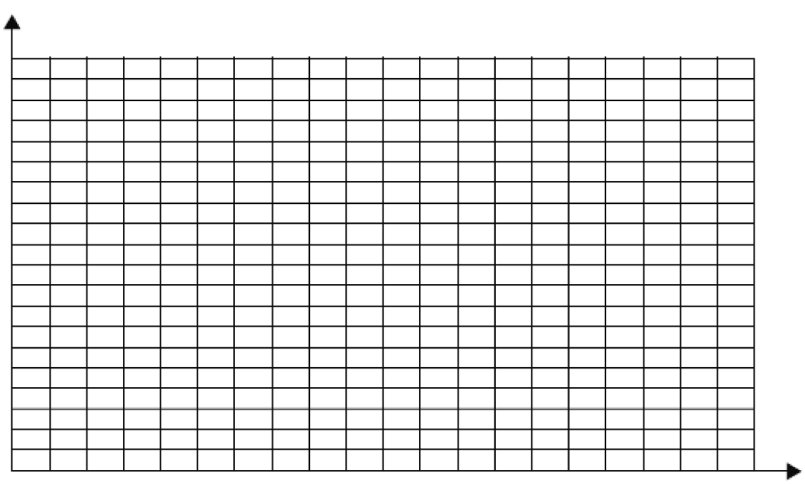
Period (s)	$\frac{1}{T^2}\left(\mathrm{s}^{-2}\right)$	Force F_{T} (N)
5.00		8
10.0		2
15.0		0.9
20.0		0.5

The relationship between F_{T} and *T* is given by the formula

$$F_T = \frac{4\pi^2 mr}{T^2}$$

ii. On the axes provided on the next page, plot a graph of F_{T} versus $\frac{1}{T^2}$ using the data in the table above. Include the correct uncertainty bars for the F_{T} values. Label each of the axes correctly and draw a line of best fit.

(6 marks)



d. Using the line of best fit and the formula given in part **c ii.**, determine the value of *m*, the mass of the car. Show your working.

(3 marks)

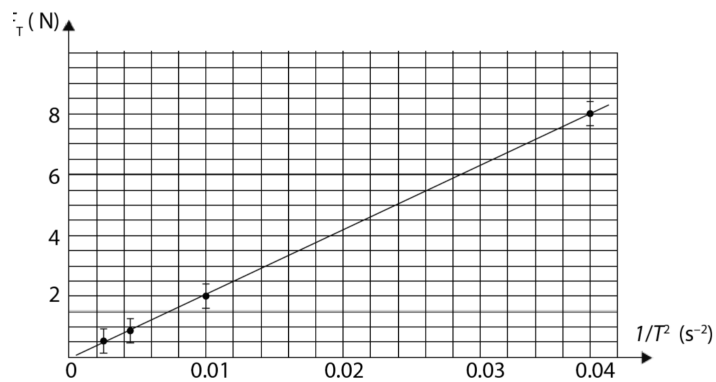
Solution

a The experimental uncertainty of measurement is an estimated measrurement of how close the measurement is to the true value. It can be reduced by using more accurate measuring techniques or equipment. The random effects of the uncertainty can also be reduced by averaging repeated readings. However, if there are systematic effects involved, repeated readings will not reduce these.

b IV: period of rotation *T*; DV: tension in the string F_T; CVs: length of string, lack of radial friction between tyres and surface, type of model car, mass of model car.

ci Values in the $\frac{1}{T^2}$ column (downwards): 0.0400, 0.0100, 0.00444, 0.00250

cii



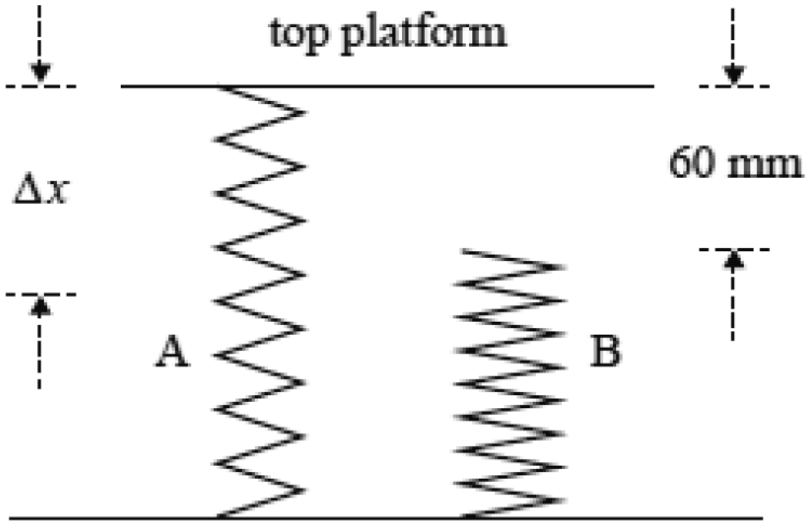
NOTE: the graph could reasonably be 'forced' through the origin on physics grounds.

d 5.1 kg From the graph, $\text{gradient} = 200 \text{ N s}^2$ or kg m. The gradient is also equal to $4\pi^2 mr$; equate these and make *m* the subject.

Question 13/ 45

[VCAA 2019 SB Q19]

As part of their practical investigation, some students investigate a spring system consisting of two springs, A and B, and a top platform, as shown below. The students place various masses on the top platform. Assume that the top platform has negligible mass.



With no masses on the top platform of the spring system, the distance between the uncompressed Spring A and the top of Spring B is 60 mm. The students place various masses on the top platform of the spring system and note the vertical compression, Δx, of the spring system. They use a ruler with millimetre gradations to take readings of the compression of the spring(s), Δx, with an uncertainty of $\pm 2\ \mathrm{mm}$.

The results of their investigation are shown in the table below.

Mass (g)	**Compression, Δx (mm)**
0	0
300	21
600	40
900	60
1300	68
1700	75
1900	80

The students plot a force (F) versus compression (Δx) graph for the spring system and use $g = 10\ \mathrm{N\ kg}^{-1}$ for the value of the magnitude of the gravitational field strength.

a. On the axes provided below:

• plot a graph of force (F) versus compression (Δx) for the spring system

• include scales and units on each axis

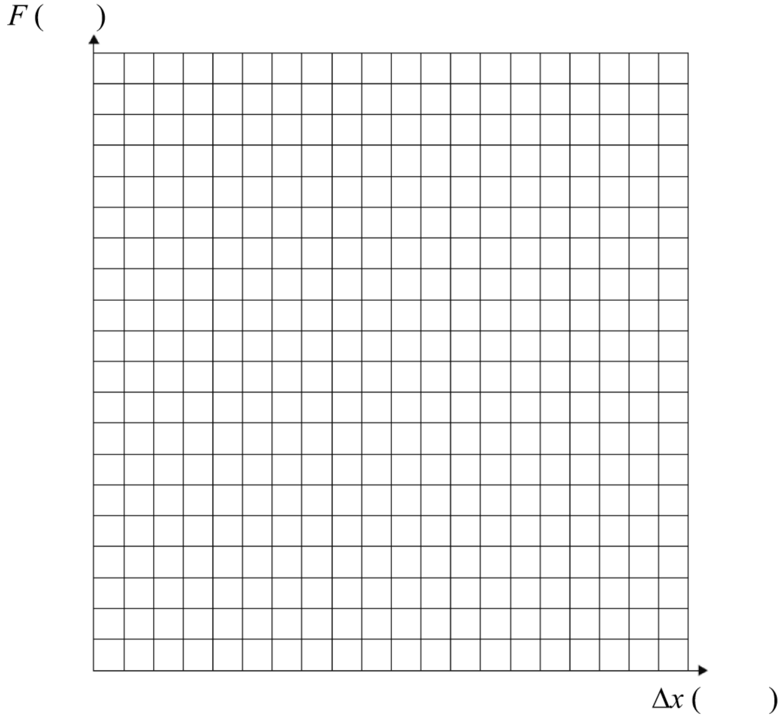
• insert appropriate uncertainty bars for the compression values on the graph

• draw lines that best fit the data for:

– the effect of Spring A alone

– the effect of Spring A and Spring B.

(6 marks)



b. i. Determine the spring constant for Spring A, k_{A}. Show your working.

(2 marks)

ii. Determine the spring constant for Spring B, k_{B}. Show your working.

(2 marks)

c. Using the area under the force (F) versus compression (Δx) graph, or otherwise, determine

i. the potential energy (PE_{A}) stored in Spring A when the spring system is compressed by 80 mm. Show your working.

(2 marks)

ii. the potential energy $(PE_{\mathrm{A+B}})$ stored in the spring system when the spring system is compressed by 80 mm. Show your working.

(2 marks)

iii. the work done to compress Spring B when the spring system is compressed by 80 mm. Show your working.

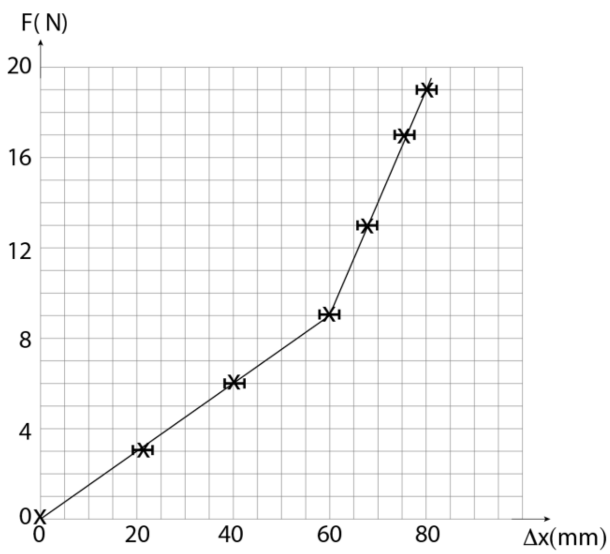
(2 marks)

d. Explain how this type of spring system could be used in car spring suspension systems to enable the car to negotiate small bumps and more severe bumps in the road.

(2 marks)

Solution

a



bi 150 N m^{-1} Measure gradient of line between 0 and 60 mm.

bii 350 N m^{-1} Either use $F_\text{B} = k_\text{B}\Delta x$ (use extra force from $\text{B} = 7$ and $\Delta x = 0.02$) or, better, measure $k_{\text{A + B}}$ from steep section and subtract k_A (for springs in parallel k-values add). Take care with units.

ci 0.48 J Area under graph (may need to extend A section of graph) Watch units.

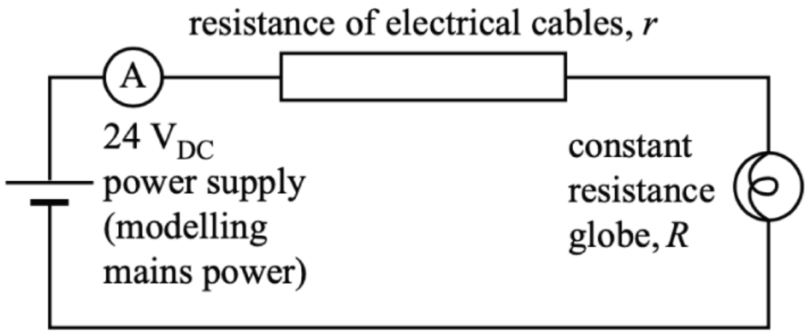
cii 0.55 J Total area under $\text{A} + \text{B}$ graph. Watch units.

ciii 0.070 J Subtract 0.48 from $0.55 = 0.070 \text{ J}$.

d The first, softer, spring can absorb PE for small bumps in the road; the second, stiffer, spring can absorb more PE from more severe bumps.

[VCAA 2020 SB Q18]

Students are modelling the effect of the resistance of electrical cables, *r*, on the transmission of electrical power. They model the cables using the circuit shown below.



a. The $24\ \mathrm{V_{DC}}$ power supply models the mains power. Describe the effect of increasing the resistance of the electrical cables, *r*, on the brightness of the constant resistance globe, *R*.

(2 marks)

The students investigate the effect of changing *r* by measuring the current in the electrical cables for a range of values. Their results are shown in the table below.

Resistance of cables, $r\ (\Omega)$	**Current in cables** ***I*** **(A)**	$1/i\ (\mathrm{A}^{-1})$
2.4	2.4	
3.6	2.0	
6.4	1.7	
7.6	1.5	
10.4	1.3	

b. Identify the dependent and the independent variables in this experiment. Give your reasoning.

(2 marks)

c. To analyse the data, the students use the following equation to calculate the resistance of the cables for the circuit.

$r = \frac{24}{i} - R$

Show that this equation is true for the circuit shown above. Show your working.

(2 marks)

d. Calculate the values of $\frac{1}{i}$ and write them in the spaces provided in 1the last column of the table above.

(2 marks)

e. Plot a graph of *r* on the *y*-axis against $\frac{1}{i}$ on the *x*-axis on the grid provided on the next page. On your graph:

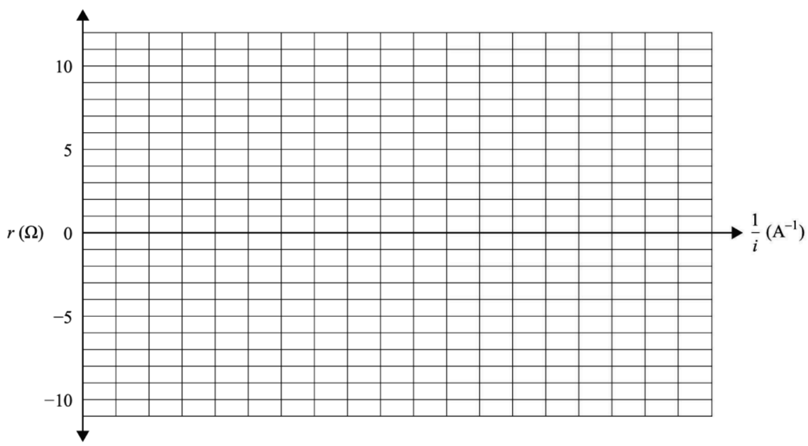
• choose an appropriate scale and numbers for the *x*-axis

• draw a straight line of best fit through the plotted points

• include uncertainty bars ($\pm x$ -direction only) of $\pm 0.02\ \mathrm{A}^{-1}$.

(Uncertainty bars in the *y*-direction are not required.)

(6 marks)



f. Use the straight line of best fit to find the value of the constant resistance globe, *R*. Give your reasoning.

(2 marks)

Solution

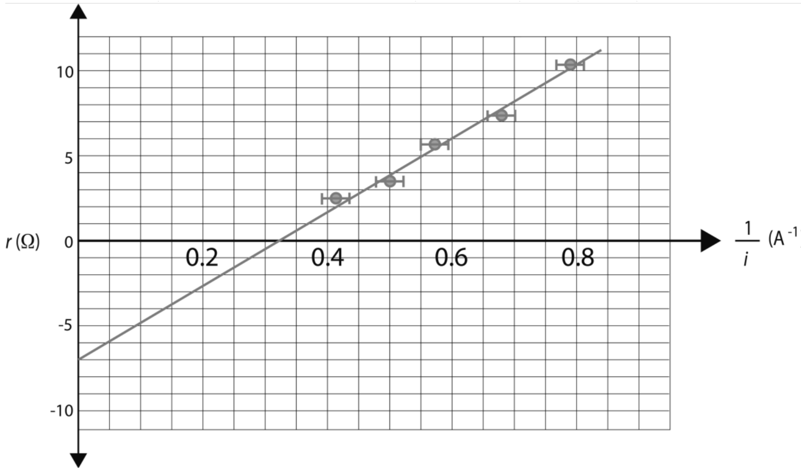
a The brightness of the globe will be decreased because the total resistance of the circuit will increase, causing a drop in the current through the globe. Alternatively, describe the changes in the voltages across the cables (increase) and the globe (decrease). Both explanations are satisfactory.

b independent variable: resistance of cables; dependent variable: current in cables.

c Ohm's law applied to whole circuit is $24 = ir + iR$. Make *r* the subject: $r = \frac{24}{i} - R$.

d Correct values, from $r = 2.4$ to $r = 10.4$, are: 0.42, 0.50, 0.59, 0.67 and 0.77.

e



f 7 Ω

Question 15/ 45

[Adapted VCAA 2021 NHT SB Q18]

During their practical investigation, some Physics students investigate the bounce of a small rubber ball. The ball falls from a height of 1.00 m and rebounds to a height of 0.78 m. The students record the ball's vertical position versus time by using a smartphone's video feature and a metre ruler.

The uncertainty in the ball's vertical position is $\pm 0.03\ \mathrm{m}$. The results from the students' recorded data are plotted on the graph below.

Missing Image

a. On the graph:

• label each axis and include units on each axis

• insert appropriate uncertainty bars for the height values on the graph, for the readings for the first four data points after the ball is released

• draw smooth curves of best fit.

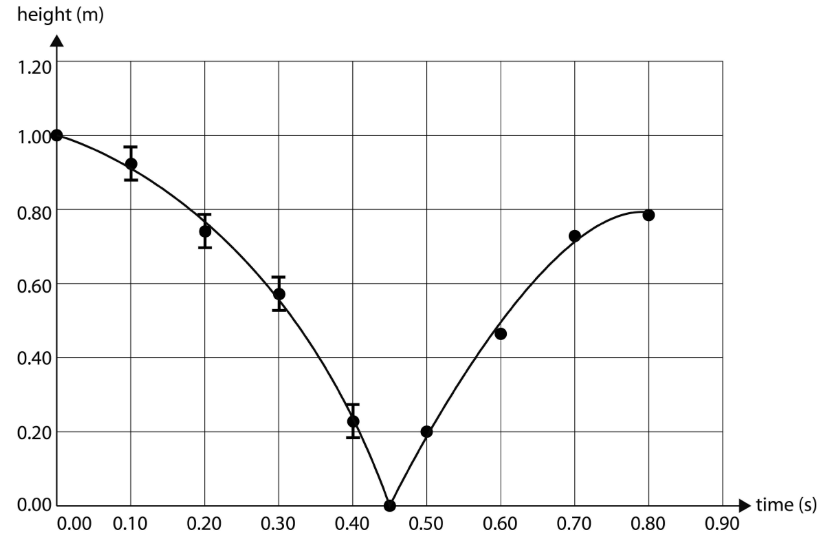
(5 marks)

b. Estimate the speed of the ball at the instant of impact using an appropriate gradient of the graph. Use calculations to support your answer.

(3 marks)

Solution

a

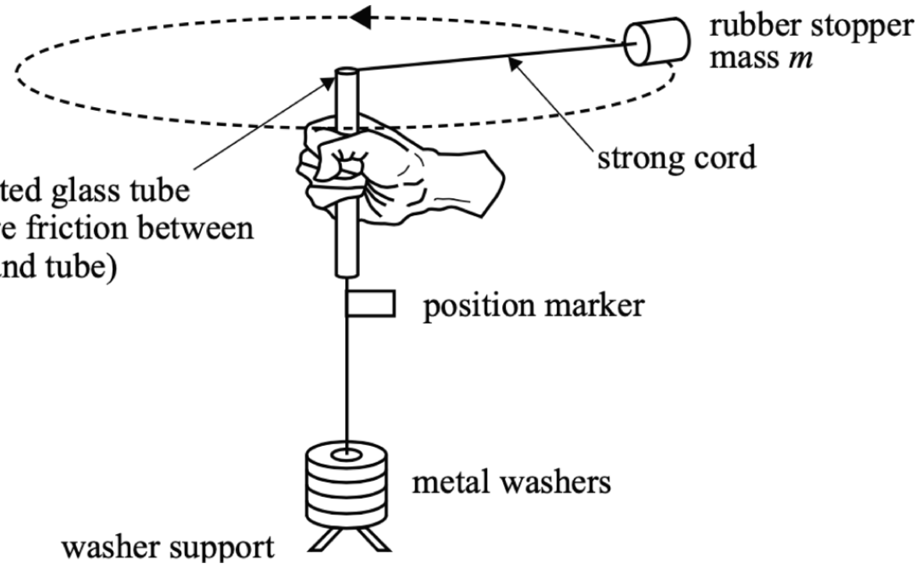


b 4.6 m s^{-1} The speed at impact is given by the gradient at $t = 4.5$ s. Draw a tangent at this point and calculate the size of the gradient. Using values at $t = 0.4$ and $t = 0.45$ also gives a similar answer. Suggest values between 4.2 m s^{-1} and 5.0 m s^{-1} would have been allowed.

Question 16/ 45

[VCAA 2021 SB Q20]

Two Physics students, Jerome and Priya, set out to investigate centripetal force. The diagram below shows the experimental set-up and the apparatus that the students use. In reality, the students find that the cord is not quite horizontal but dips downward slightly due to the gravitational force acting on the rubber stopper. Their teacher explains that they can safely ignore this effect when collecting their experimental results.



Jerome and Priya note the following data in their logbook.

radius of circle	0.75 m
mass of each metal washer	30 g
initial number of washers	10

Priya holds the glass tube and sets the rubber stopper rotating in a horizontal circle. She maintains a constant radius of the circle by keeping the position marker at a fixed position just below the bottom of the glass tube. Jerome uses a stopwatch to measure the time for 20 rotations of the rubber stopper, repeating this measurement three times. He notes all the data collected in their logbook. The experiment is then repeated four more times with two extra metal washers added before each new trial is undertaken.

a. Why did the students take repeated time measurements during the experiment?

(1 mark)

b. The tension in the cord supplies the centripetal force that the rubber stopper needs to rotate in a circle. What is the cause of this tension?

(1 mark)

c. The gravitational force acting on the metal washers is given by Mg, where M is the total mass of the washers and g is the gravitational field.

Symbol	Symbol represents
π	a constant
m	mass of rubber stopper
R	radius of rotation

Symbol	Symbol represents
T	period of rotation

Develop an equation between Mg and the quantities listed in the table above.

(3 marks)

Jerome and Priya record some of their results in the table below. The students are told by their teacher that they can use $g = 10\ \mathrm{N\ kg^{-1}}$ for their calculations.

d. Fill in the blank columns in the table below.

(4 marks)

Line number	**Total mass of washers, *M*(kg)**	**Gravitational force acting on washers, *Mg*(N)**	**Average time for 20 rotations (s)**	**Period, *T*(s)**	$\frac{1}{T^2}\left(\mathrm{s}^{-2}\right)$
1	0.30		14.0		
2	0.36		12.8		
3	0.42		11.8		
4	0.48		11.0		
5	0.54		10.4		

(4 marks)

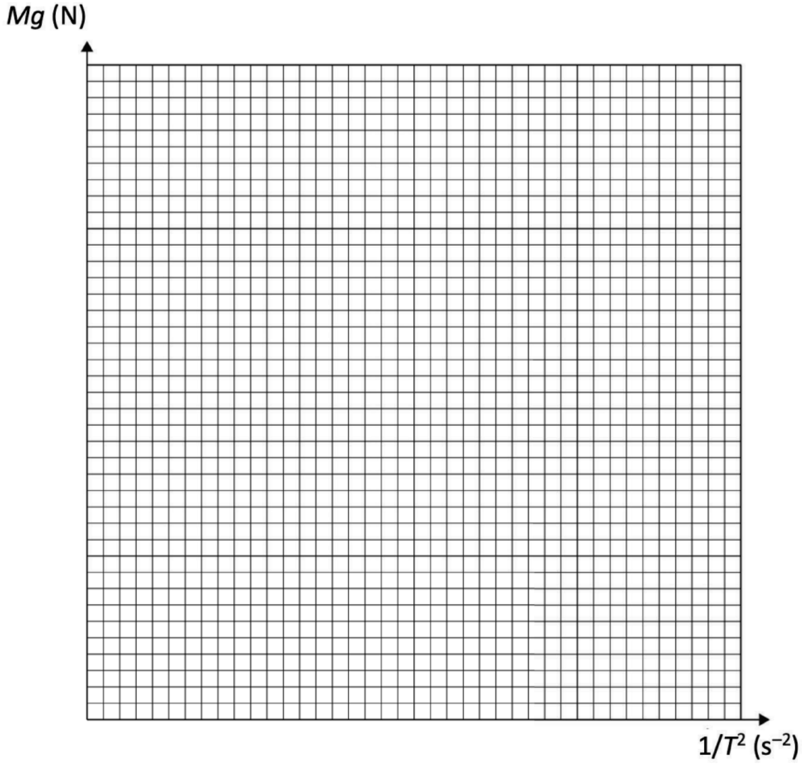
e. Using your values in the table above, plot a graph of *Mg* on the *y*-axis against on the *x*-axis on the grid provided on the next page.

On your graph:

• draw a straight line of best fit through the plotted points

• include uncertainty bars ($\pm x$ -direction only) of $\pm\ 0.1\ \mathrm{s}^{-2}$.

(Uncertainty bars in the *y*-direction are not required.)



f. Calculate the gradient of the graph plotted in part **e**.

(2 marks)

g. Using the gradient calculated in part **f**, show that *m*, the mass of the rubber stopper, is approximately 50 g.

(2 marks)

Solution

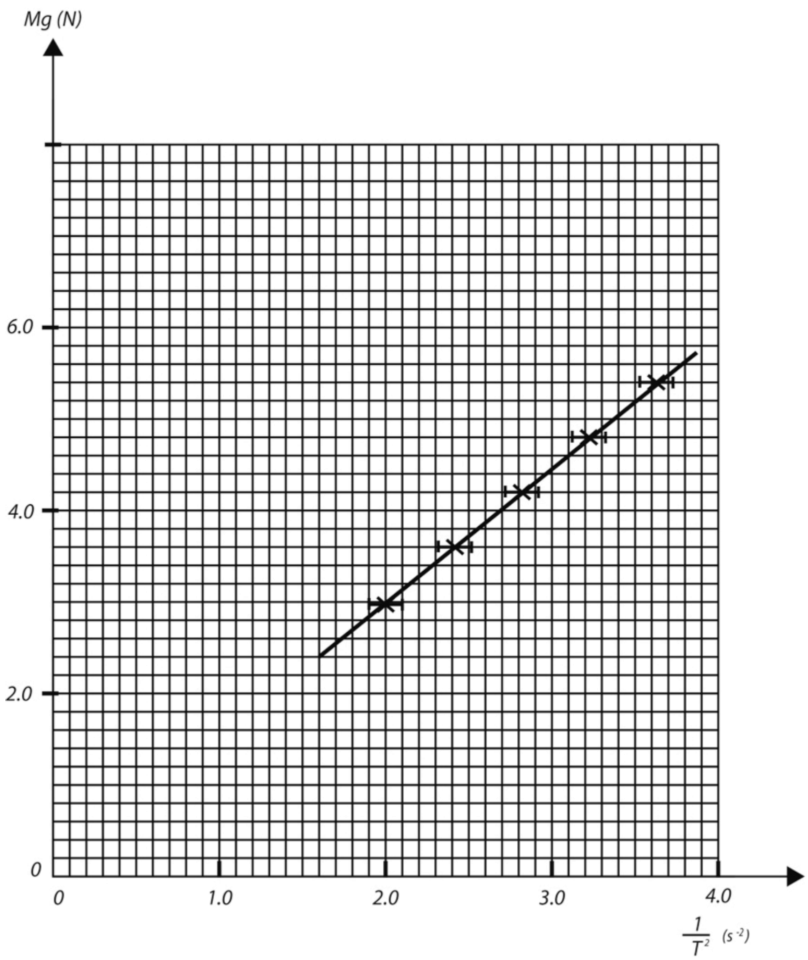
a The average of repeated readings is likely to more accurate than a single measurement.

b The gravitational force acting on the metal washers.

c The gravitational force *Mg* is equal to the tension providing the centripetal force acting on the rubber stopper. Hence, $Mg = \frac{4p^2 mR}{T^2}$.

d

Line number	Total mass of washers, M (kg)	Gravitational force acting on washers, Mg (N)	Average time for 20 rotations (s)	Period, T (s)	$\frac{1}{T^2}$ (s^{-2})
1	0.30	3.0	14.0	0.70	2.04
2	0.36	3.6	12.8	0.64	2.44
3	0.42	4.2	11.8	0.59	2.87
4	0.48	4.8	11.0	0.55	3.30
5	0.54	5.4	10.4	0.52	3.70



e

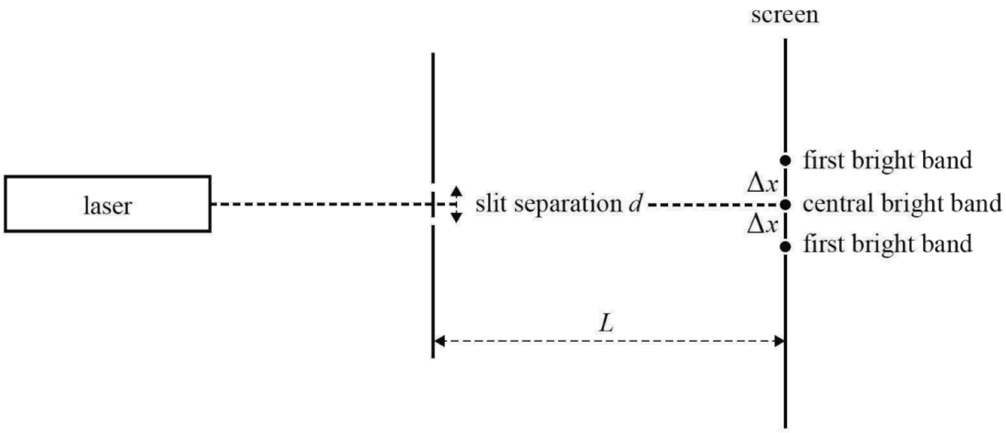
f 1.4 N s^2

g 0.052 kg

Question 17/ 45

[VCAA 2022 NHT SB Q20]

A group of Physics students used a double-slit interference experiment to measure the wavelength of the light from a laser. The laser was directed, at right angles, towards a double slit in a darkened room and an interference pattern was observed on a screen. The arrangement is shown schematically in the diagram below.



The students had access to two double-slit slides, one with a slit spacing of 0.16 mm and the other with a slit spacing of 0.26 mm. They placed the screen at distances of $L = 1.5$ m, 2.5 m and 3.5 m and measured the average distance, Δx, from the central bright band to the first bright band on either side.

a. Identify the dependent variable, the independent variables and one controlled variable in this experiment.

(3 marks)

The experimental measurements taken are shown in the table.

***L* (mm)**	***d* (mm)**	$\frac{L}{d}$ (no unit) ($\times 1000$)	**Δx (mm)**
1500	0.26		3.3
2500	0.26		5.5
3500	0.26		7.7
1500	0.16		4.9
2500	0.16		8.2
3500	0.16		12.3

The students used the approximate equation $l = \frac{\Delta x d}{L}$ and a graph of Δx plotted against $\frac{L}{d}$ to find a value for the wavelength λ.

b. Calculate the values of $\frac{L}{d}$ to two significant figures and write them in the table above.

(2 marks)

c. Plot the values from the table on the grid provided below.

• Include an appropriate scale, numbers and a unit on the *y*-axis.

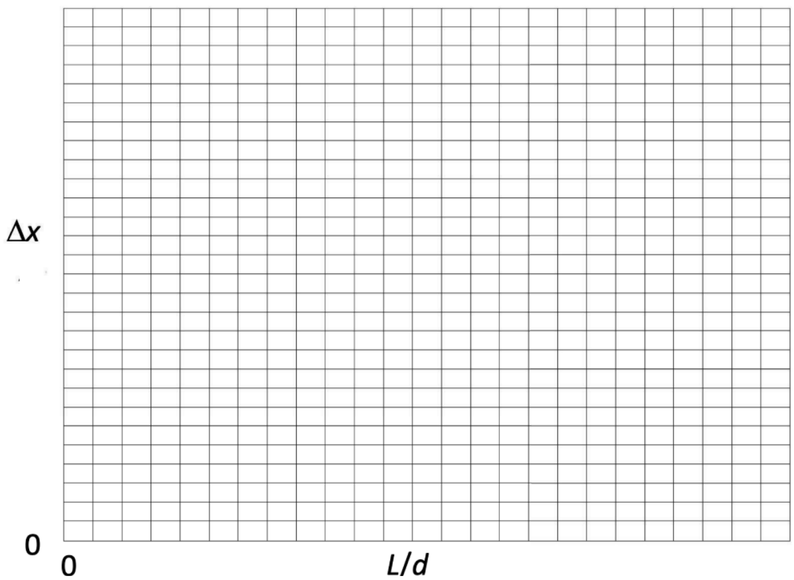
• Include an appropriate scale and numbers on the *x*-axis.

• Include uncertainty bars in the *y*-direction of $\pm\ 0.5\ \mathrm{mm}$.

(No uncertainty bars are required in the *x*-direction.)

• Draw a linear trend line through the plotted points.

(6 marks)



d. Calculate the gradient of the trend line. Show all the steps of your working.

(2 marks)

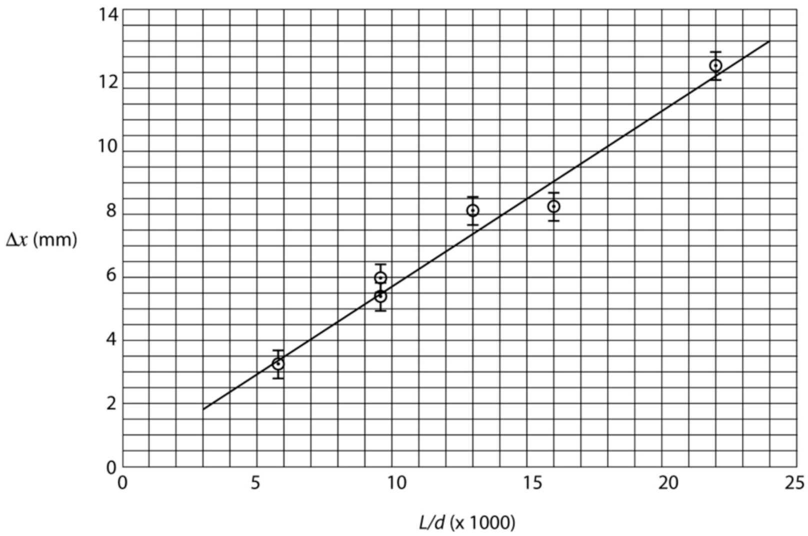
e. Use the gradient from part **d** to determine the wavelength of the laser light. Give all the steps of your reasoning.

(2 marks)

Solution

a Dependent variable: Δx; independent variables: L and d; controlled variables: laser frequency; width of slits; medium of propagation.

b 5.8, 9.6, 13, 9.4, 16, 22 (no units).



c

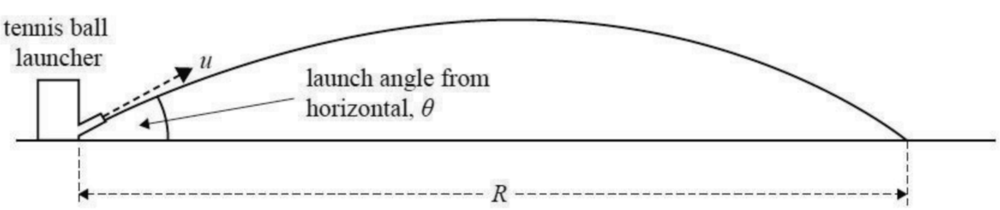
d 5.4×10^{-4}mm

e 540 nm

Question 18/ 45

[VCAA 2022 SB Q10]

Physics students use a tennis ball launcher on a level, outdoor oval on a windless day to investigate projectile motion as shown below. Assume that the tennis balls are launched from ground level.



The tennis ball launcher can be set to project tennis balls at various speeds, u, between values of $8 \mathrm{~m} \mathrm{~s}^{-1}$ and $30 \mathrm{~m} \mathrm{~s}^{-1}$ and at angles, θ, between 10° and 80°. Standard tennis balls of mass 56 g are used.

The students measure the range, *R*, of the projected tennis ball at a fixed speed for various angles.

a. Classify the controlled, dependent or independent variables in this experiment.

(3 marks)

b. The students set the tennis ball launcher to project tennis balls at a speed of $25 \mathrm{~m} \mathrm{~s}^{-1}$. They vary the angle between 10° and 80° and measure the range, *R*.

The students repeat each experiment at each angle three times and determine the average range. The results are shown in the table below.

Angle (°)	10	20	30	40	50	60	70	80
Average range (m)	17	30	37	40	40	36	29	15

The students determine that the uncertainty in the measurement of the range is $\pm 1\ \mathrm{m}$.

On the grid provided on the next page:

• plot the data

• add a scale to each axis

• insert appropriate uncertainty bars for the range for at least three data points

• draw a smooth curve of best fit.

(6 marks)

Missing Image

c. From the graph in part **b**, estimate the maximum range and the angle that gives the maximum range.

(2 marks)

d. The students think that air resistance on the tennis ball may affect the maximum range. They decide to compare their data to the theoretical range achieved when air resistance is ignored.

i. Using the range formula, calculate the theoretical range of a projectile launched at an initial speed of $25\ \mathrm{m\ s^{-1}}$ and at an angle of 30°. Use $g = 9.8\ \mathrm{m\ s^{-2}}$.

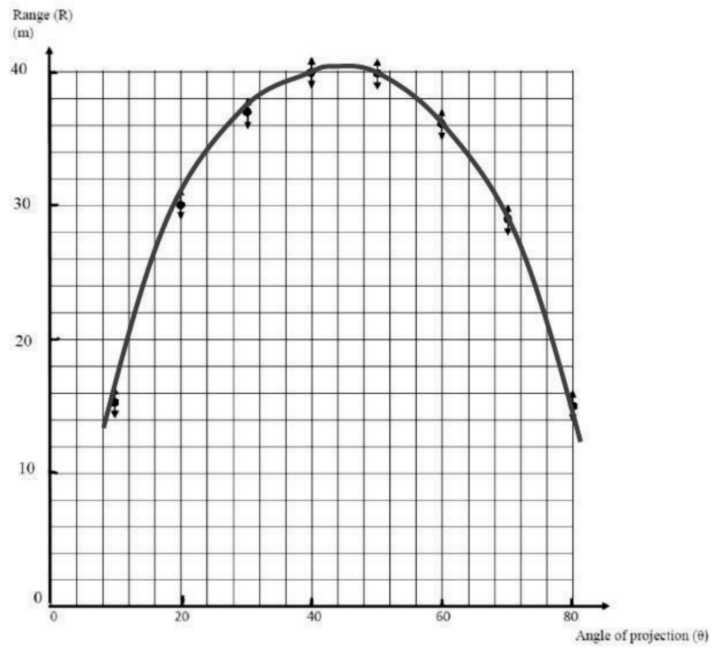
(2 marks)

ii. Evaluate whether the effect of air resistance can be ignored by the students when analysing their data. Justify your answer.

(3 marks)

Solution

a Controlled: mass; dependent: range; independent: angle.



b

c 41 m; 45° Accept values that can be reasonably inferred from the plotted graph.

di 55 m $R = \frac{u^2 \sin 2\theta}{g} = \frac{25^2 \sin 60^\circ}{9.8} = 55.2 \text{ m}.$

dii Air resistance cannot be ignored as the theoretical range is considerably larger than the measured range and the discrepancy is larger than the uncertainty.

Question 19/ 45

[VCAA NHT 2023 SB Q13]

As part of their practical investigations, two Physics students, Chris and Arya, investigate changes in gravitational potential energy and elastic potential energy for a 2.0 kg mass initially hanging on a spring, as shown on the next page.

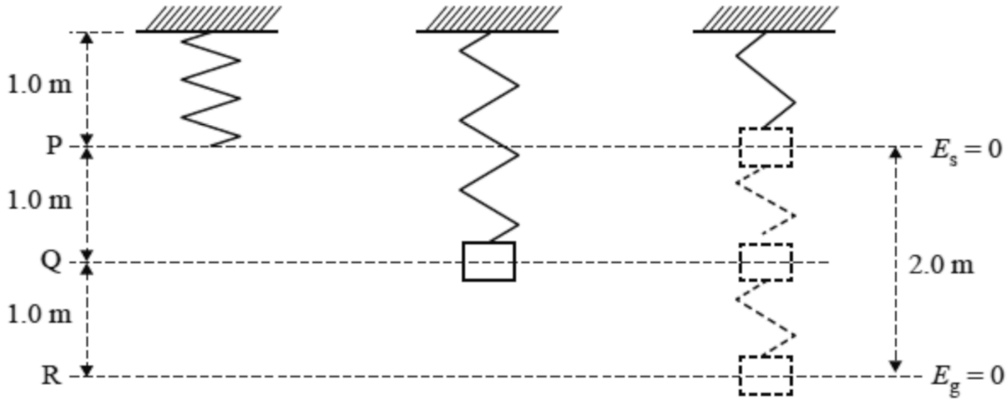
The spring has an unstretched length of 1.0 m, as shown at position P below.

The 2.0 kg mass is placed by Arya on the unstretched spring and it hangs stationary at position Q below.

Their Physics teacher tells them that they can use $g = 10 \text{ m s}^{-2}$ for their calculations.

a. Show that the spring constant of the spring, *k*, is 20 N m^{-1}.

(1 mark)



Chris then pulls the mass down a further 1.0 m below position Q, to position R, and releases it so that it oscillates between positions R and P, as shown below.

The students decide that the gravitational potential energy, E_g, is zero at position R, and that they can use the formula for gravitational potential energy, $E_g = mg\Delta h$, where Δh is the height above position R.

The students also decide that the elastic potential energy is zero at the top position P, and that they can use the elastic potential energy formula $E_s = \frac{1}{2}k(\Delta x)^2$, where Δx is the extension of the spring beyond its unstretched length.

Arya enters the following information into a table.

Position	***h*(m)**	**E_g(J)**	**Δx (m)**	**E_s (J)**
P	2.0	40.0	0	0
	1.5	30.0	0.5	2.5
Q	1.0		1.0	10.0
	0.5	10.0	1.5	
R	0	0	2.0	40.0

b. Using the formulas for E_g and E_s, verify that Arya's $E_s = 10$ J at position Q is correct and fill in the missing data points in the table. Show your working for each calculation.

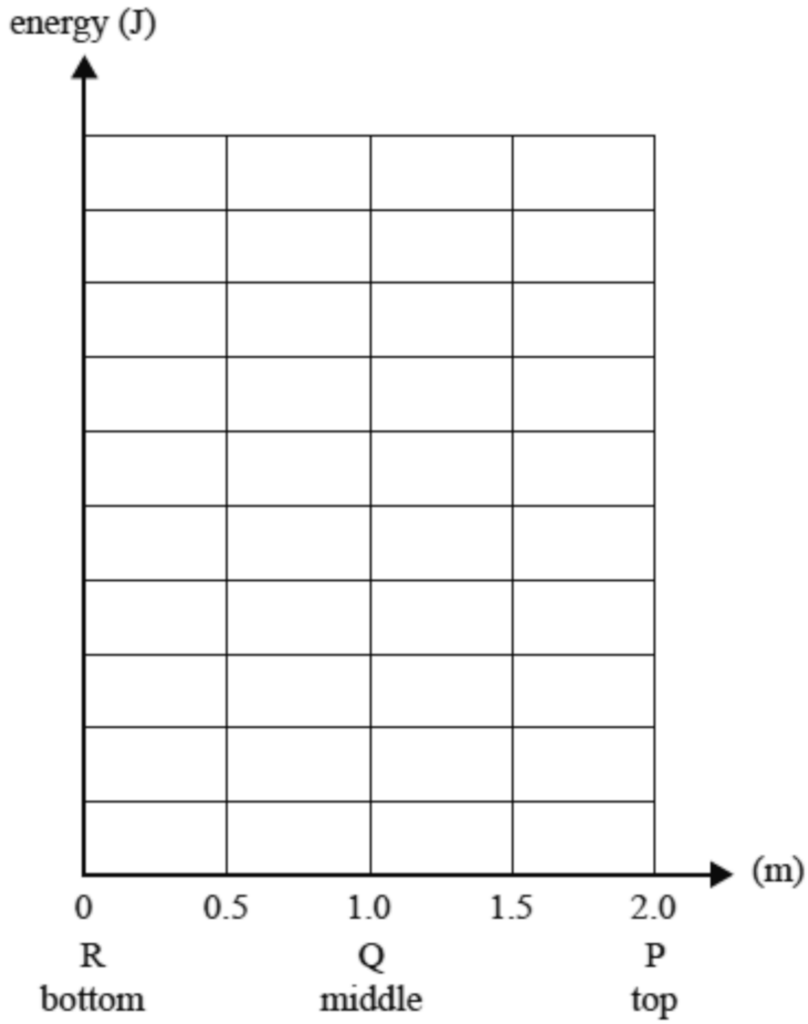
(3 marks)

c. On the axes below, plot the E_g and E_s versus position data for the oscillating mass. On your graph:

- choose an appropriate scale and numbers for the *y*-axis
- use small circles for the E_g data and small triangles for the E_s data
- draw a line/curve of best fit through the plotted points for the E_g data

• draw a line/curve of best fit through the plotted points for the E_s data.

(4 marks)



d. Determine the speed of the mass as it goes through position Q.

(3 marks)

e. Arya and Chris discuss the graphs that they have drawn. Chris says that their calculation must be wrong because the graphs should add up to a constant amount – the total energy of the system. However, Arya says that the graphs are correct.

Explain why Chris is incorrect.

(3 marks)

Solution

a $F = kx$

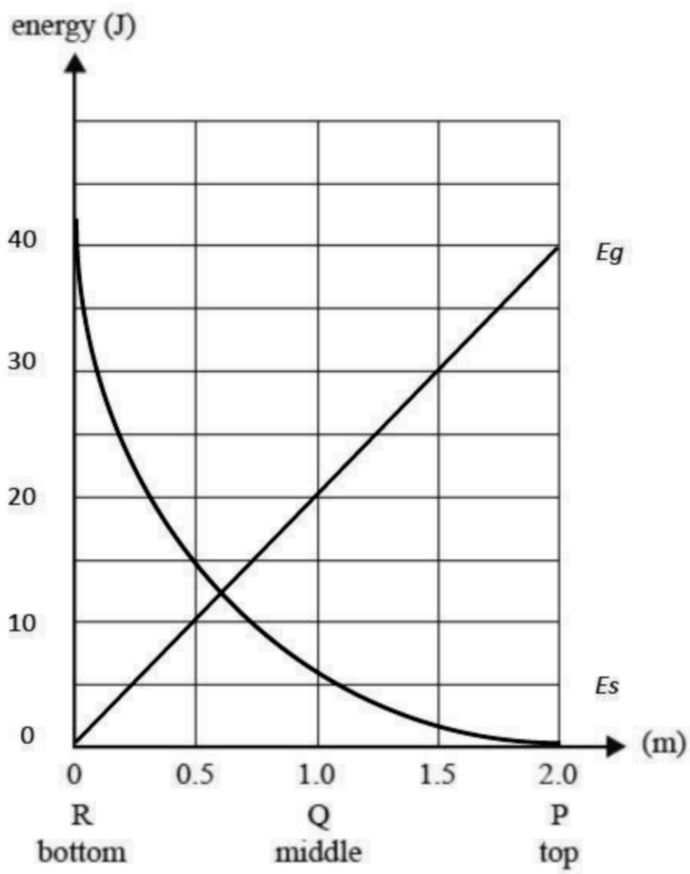
$k = \frac{10 \times 2.0}{1.0} = 20 \text{ N m}^{-1}$.

b $E_s = \frac{1}{2}k\Delta x^2 = \frac{1}{2}(20)(1)^2 = 10.0 \text{ J}$.

For position Q: $E_g = mgh = 2 \times 10 \times 1 = 20 \text{ J}$.

For position midway between Q and R: $E_s = \frac{1}{2}k\Delta x^2 = \frac{1}{2}(20)(1.5)^2 = 22.5$.

Position	***h*** **(m)**	***E_g*** **(J)**	**Δx (m)**	***E_s*** **(J)**
P	2.0	40.0	0	0
	1.5	30.0	0.5	2.5
Q	1.0	**20.0**	1.0	10.0
	0.5	10.0	1.5	**22.5**
R	0	0	2.0	40.0



c

d 3.2 m s^{-1} Kinetic energy at middle point is 10 J.

$\frac{1}{2}mv^2 = 10$ where $m = 2.0 \text{ kg}$.

$v = \sqrt{10} = 3.16 \text{ m s}^{-1}$.

e The graphs plotted do not include the kinetic energy of the oscillating mass.

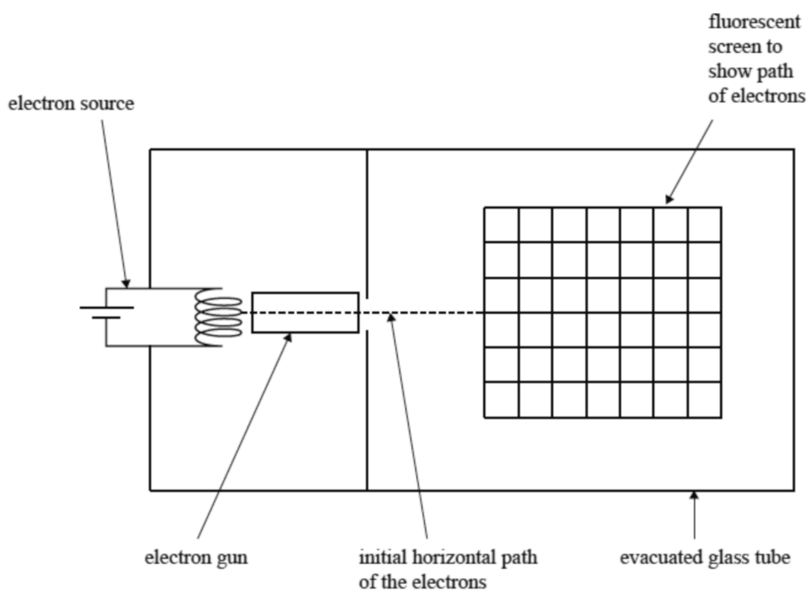
If the kinetic energy (E_k) of the oscillating mass had been included, then the total $\text{energy} = E_s + E_g + E_k$ would have added up to a constant value.

Question 20/ 45

[VCAA 2023 SB Q17]

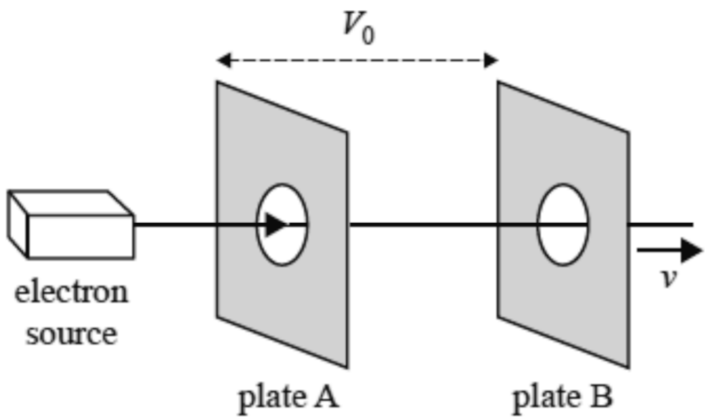
JJ Thomson discovered electrons in 1897. He used evacuated cathode ray tubes to determine the ratio of electric charge to mass of these rays, which we now know were electrons.

Modern-day physics students plan an experiment to measure the ratio of the charge, *e*, to the mass, *m*, of electrons. This can be written as *e/m*. The apparatus they use is shown schematically below.



An electron gun ejects a beam of electrons horizontally from the left side of the apparatus through the evacuated glass tube. A fluorescent screen displays the path the electrons take.

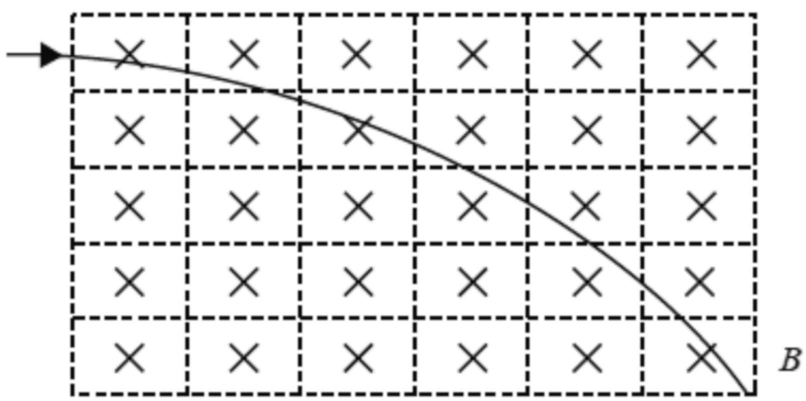
The electron gun can be modelled as shown below. Electrons are produced at the electron source and accelerated between plate A and plate B.



Electrons reach plate A with negligible speed and are accelerated by the potential difference between the plates, V_0, emerging from plate B with speed, *v*.

a. Write an equation that gives the speed, *v*, in terms of potential difference, V_0, the electron mass, *m*, and the electron charge, *e*. Assume that *v* is much less than the speed of light, *c*. (1 mark)

b. A uniform magnetic field, *B*, directed into the page, is applied to the region of the fluorescent screen and the electrons follow a circular arc of radius, *r*, as shown below.



Explain why the path followed by the electrons is a circular arc. (2 marks)

c. Write an equation that represents the relationship between the electron mass, *m*, the electron charge, *e*, the electron speed, *v*, the magnetic field, *B*, and the radius, *r*, of the circular arc. (1 mark)

The equations in **part a**. and **part c**. can be combined to show that

$$V_0 = \frac{eB^2}{2m}r^2$$

(Do not attempt to derive this equation.)

The physics students planning the experiment keep the uniform magnetic field, *B*, constant at 2.0 mT. They vary the voltage, V_0, and measure the resulting radius, *r*, of the circular path of the electrons.

d. Identify the independent variable, the dependent variable and one controlled variable.

(2 marks)

e. The table on the next page shows the values of V_0 and r measured by the students. Complete the missing values. (2 marks)

V_0 **(volts)**	r**(m)**	$r^2(\mathrm{~m}^2)$
500	0.036	0.0013
1000	0.052	
1500	0.059	
2000	0.072	

f. On the grid below:

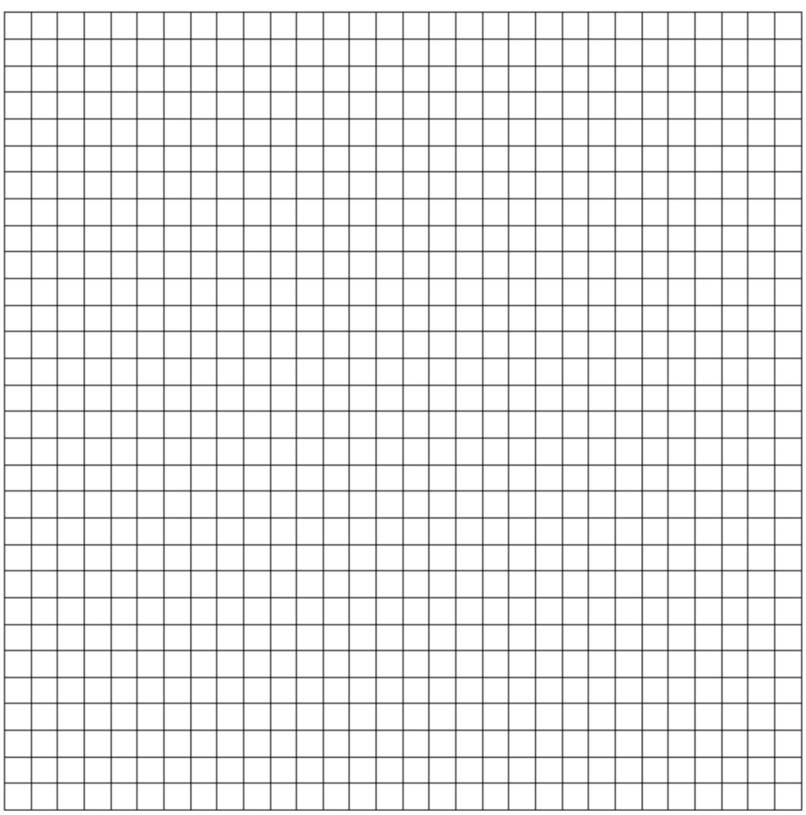
• Plot the values of V_0 on the y-axis and the corresponding value of r^2 on the x-axis. Include a point for $V_0=0$.

• Label the axes correctly.

• Add an uncertainty of $+/-\ 0.0002$ to the r^2 values.

• Draw a straight line of best fit through the plotted points.

(7 marks)



g. Using the graph produced in **part f.**, calculate the gradient of the line of best fit. Show your working.

(2 marks)

h. Use the value of the gradient found in **part g.** to find a value for *e/m*. Show your working.

(3 marks)

Solution

a $eV_o = \frac{1}{2}mv^2$ Work done on the electron (eV_o) is the change in kinetic energy ($\frac{1}{2}mv^2$).

b Constant magnitude of force where the force is radially inwards/perpendicular to the velocity/path.

c $evB = mv^2/r$ The centripetal force (mv^2/r) is supplied by the magnetic force (*evB*).

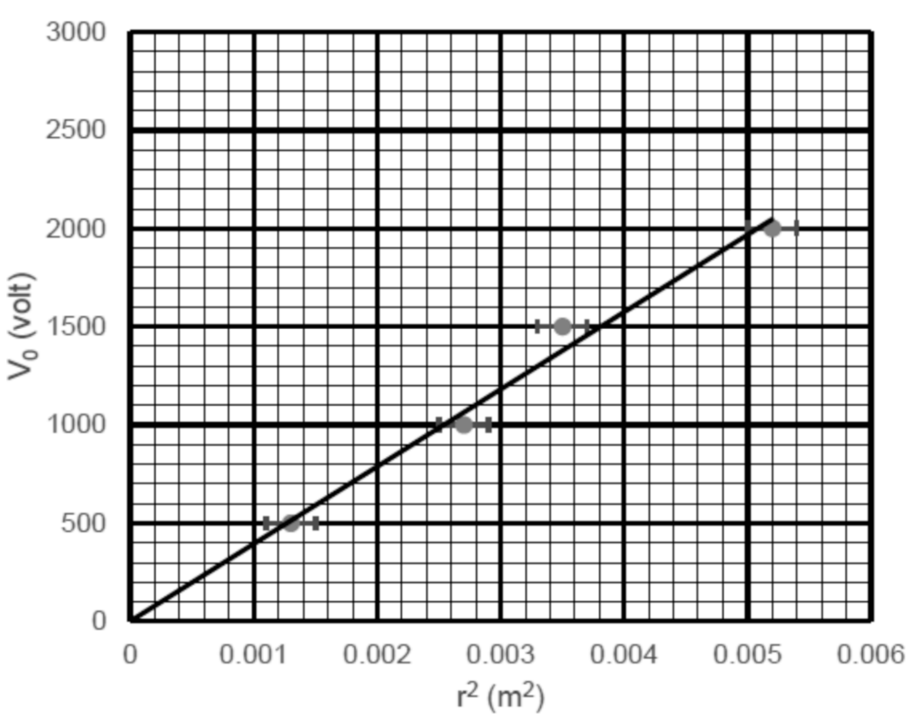
d Independent voltage V_0

Dependent radius *r*

Controlled magnetic field *B*

e

V_0 (volts)	*r* (m)	r^2 (m^2)
500	0.036	.0013
1000	0.052	**.0027**
1500	0.059	**.0035**
2000	0.072	**.0052**



f

- both axes labelled with units

- scales/size appropriate, using half or more on each axis

- points plotted correctly

- uncertainty bars correct

- correct straight line of best fit

g $4.0 \times 10^5 \text{ V m}^{-2}$ Rise/run of the line of best fit.

h $2.0 \times 10^{11} \text{ C kg}^{-1}$ $V_0 = \frac{(eB^2r^2)}{2m}$

$\frac{e}{m} = \frac{(2V_0)}{(B^2r^2)} = \frac{(2 \times 4.0 \times 10^5)}{(2.0 \times 10^{-3})^2}$

$= 2.0 \times 10^{11} \text{ C kg}^{-1}$
