

Victorian Certificate of Education
2022

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

STUDENT NUMBER

									Letter
--	--	--	--	--	--	--	--	--	--------

PHYSICS
Written examination

Wednesday 25 May 2022

Reading time: 10.00 am to 10.15 am (15 minutes)

Writing time: 10.15 am to 12.45 pm (2 hours 30 minutes)

QUESTION AND ANSWER BOOK

Structure of book

Section	Number of questions	Number of questions to be answered	Number of marks
A	20	20	20
B	20	20	110
			Total 130

- Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners, rulers, pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape) and one scientific calculator.
- Students are NOT permitted to bring into the examination room: blank sheets of paper and/or correction fluid/tape.

Materials supplied

- Question and answer book of 37 pages
- Formula sheet
- Answer sheet for multiple-choice questions

Instructions

- Write your student number in the space provided above on this page.
- Check that your **name** and **student number** as printed on your answer sheet for multiple-choice questions are correct, **and** sign your name in the space provided to verify this.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.
- All written responses must be in English.

At the end of the examination

- Place the answer sheet for multiple-choice questions inside the front cover of this book.
- You may keep the formula sheet.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

THIS PAGE IS BLANK

DO NOT WRITE IN THIS AREA

SECTION A – Multiple-choice questions

Instructions for Section A

Answer **all** questions in pencil on the answer sheet provided for multiple-choice questions.

Choose the response that is **correct** or that **best answers** the question.

A correct answer scores 1; an incorrect answer scores 0.

Marks will **not** be deducted for incorrect answers.

No marks will be given if more than one answer is completed for any question.

Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Take the value of g to be 9.8 m s^{-2} .

Question 1

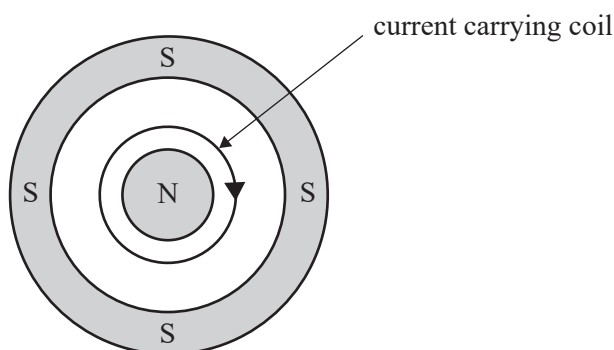
Two parallel plates that are 10 mm apart have a potential difference of 5.0 kV between them.

Which one of the following best gives the strength of the electric field between the plates?

- A. $5.0 \times 10^{-1} \text{ V m}^{-1}$
- B. $5.0 \times 10^1 \text{ V m}^{-1}$
- C. $5.0 \times 10^2 \text{ V m}^{-1}$
- D. $5.0 \times 10^5 \text{ V m}^{-1}$

Question 2

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 3

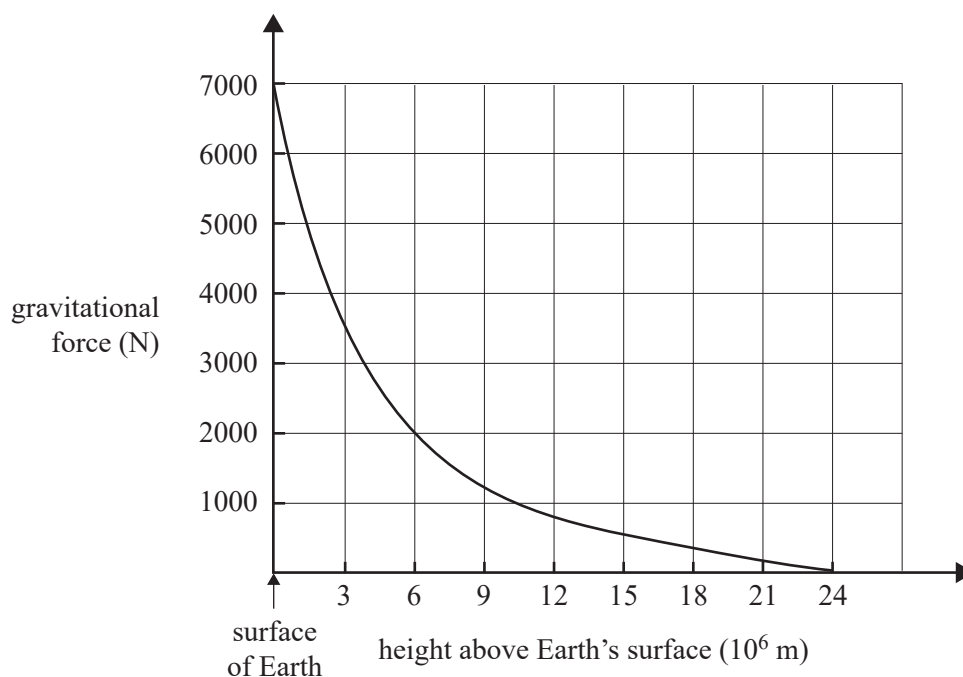
The gravitational field strength at the surface of a uniform spherical planet of radius R is $g \text{ N kg}^{-1}$.

At a distance of $3R$ above the planet's surface, the strength of gravity will be closest to

- A. 0
- B. $\frac{g}{3}$
- C. $\frac{g}{9}$
- D. $\frac{g}{16}$

Question 4

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. $4.0 \times 10^4 \text{ J}$
- B. $1.5 \times 10^5 \text{ J}$
- C. $4.0 \times 10^{10} \text{ J}$
- D. $1.5 \times 10^{11} \text{ J}$

Question 5

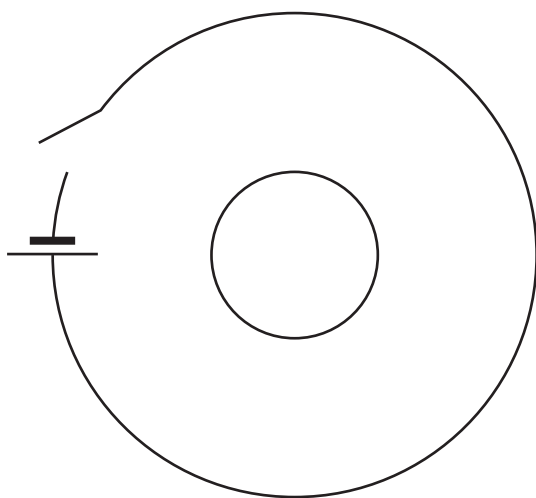
The ratio of the number of turns in an ideal step-up transformer is 350:1. An alternating RMS current of 30.0 mA is supplied to the primary coil.

The RMS current in the output will be closest to

- A. 0 mA
- B. 0.086 mA
- C. 30.0 mA
- D. 1.1×10^4 mA

Question 6

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 once 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 7

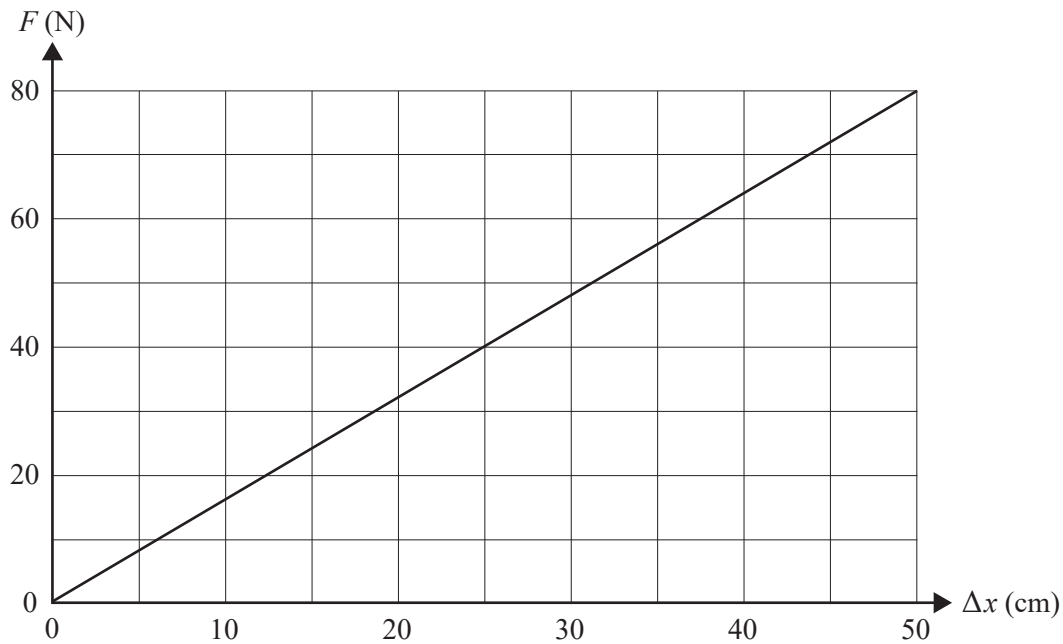
A car travelling at 60 km h^{-1} brakes to a complete stop over a distance of 18 m under a constant braking force.

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

Use the following information to answer Questions 8 and 9.

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.



Question 8

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

- A. 1.6 N m⁻¹
- B. 40 N m⁻¹
- C. 160 N m⁻¹
- D. 4000 N m⁻¹

Question 9

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 10

Ning travels at $0.67c$ 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 11

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.



The mass of one helium nucleus is 6.645×10^{-27} kg.

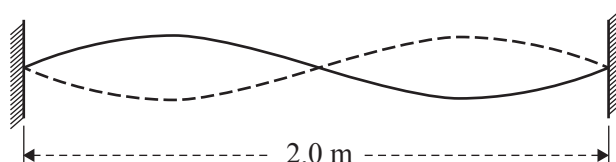
The mass of one carbon nucleus is 1.993×10^{-26} kg.

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} J

Question 12

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.



Which one of the following would be closest to the speed of a transverse wave travelling on the string?

- A. 0.40 m s^{-1}
- B. 2.5 m s^{-1}
- C. 5.0 m s^{-1}
- D. 10 m s^{-1}

Question 13

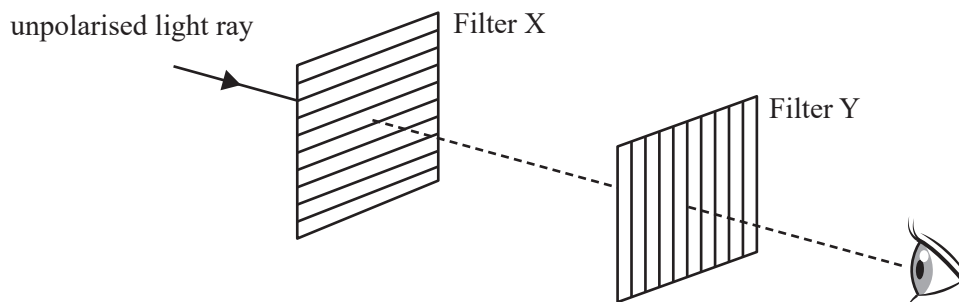
The refractive index of a diamond is 2.42 and the refractive index of water is 1.33

Which one of the following is closest to the critical angle for a diamond fully submerged in water?

- A. 2°
- B. 24°
- C. 33°
- D. 49°

Question 14

An unpolarised light ray is directed towards two polarising filters, X and Y, which are placed so that their planes of polarisation are at right angles to one another, as shown in the diagram below.



Which of the following correctly describes the direction of the electric field vibrations of the light emerging from the two filters?

	Electric field vibrations of light emerging from Filter X	Electric field vibrations of light emerging from Filter Y
A.	vibrate in every direction	vibrate in one direction
B.	vibrate in every direction	no vibration
C.	vibrate in one direction	vibrate in one direction
D.	vibrate in one direction	no vibration

Question 15

The Doppler effect can be observed

- A. only in sound waves.
- B. in all mechanical waves.
- C. only in electromagnetic waves.
- D. in water waves and sound waves but not in electromagnetic waves.

Question 16

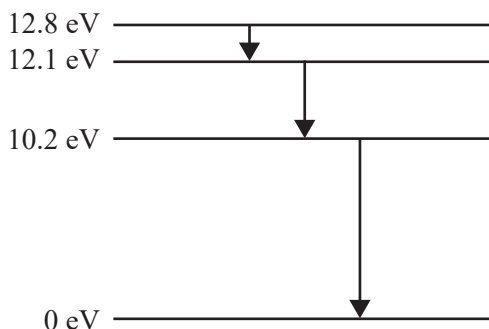
When light of a specific frequency strikes a metal surface, photoelectrons are emitted.

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
A.	increases	remains the same
B.	remains the same	increases
C.	increases	decreases
D.	remains the same	remains the same

Question 17

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 18

Which one of the following best describes how laser light is produced?

- A. by focusing solar radiation
- B. by stimulating the emission of radiation
- C. by accelerating positively charged particles
- D. by heating a tungsten filament in an evacuated glass tube

Question 19

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 20

The position and the momentum of an object cannot be measured precisely at exactly the same time, no matter how carefully the measurements are made.

This is explained by

- A. Newton's laws of motion.
- B. Young's double-slit experiment.
- C. de Broglie's matter-wave equation.
- D. Heisenberg's uncertainty principle.

SECTION B**Instructions for Section B**

Answer **all** questions in the spaces provided.

Where an answer box is provided, write your final answer in the box.

If an answer box has a unit printed in it, give your answer in that unit.

In questions where more than one mark is available, appropriate working **must** be shown.

Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Take the value of g to be 9.8 m s^{-2} .

Question 1 (4 marks)

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

m s^{-1}

Question 2 (7 marks)

The speed of a satellite in a circular orbit around a planet is given by $v = \sqrt{\frac{GM}{r}}$, where G is the universal gravitational constant, M is the mass of the planet and r is the orbital radius of the satellite.

Titan is the largest moon of Saturn and has an orbital radius of 1.2×10^9 m. The mass of Saturn is 5.7×10^{26} kg. Assume that Titan's orbit is circular.

- a. Calculate Titan's orbital speed.

2 marks

m s^{-1}

Another moon of Saturn is Rhea. Rhea is in a circular orbit of radius 5.3×10^8 m.

- b. Does Rhea travel faster than, at the same speed as or slower than Titan? Explain your answer.

2 marks

--

- c. Titan's period around Saturn is 16 days.

Calculate Rhea's period around Saturn. Show your working.

3 marks

days

Question 3 (4 marks)

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 Figure 1.

A positron has the same mass as an electron (9.1×10^{-31} kg) and has the same magnitude of electric charge as an electron (-1.6×10^{-19} C) but is positively charged ($+1.6 \times 10^{-19}$ C).

On Figure 1, sketch and label the respective paths that the positron and the electron will take while in the uniform magnetic field.

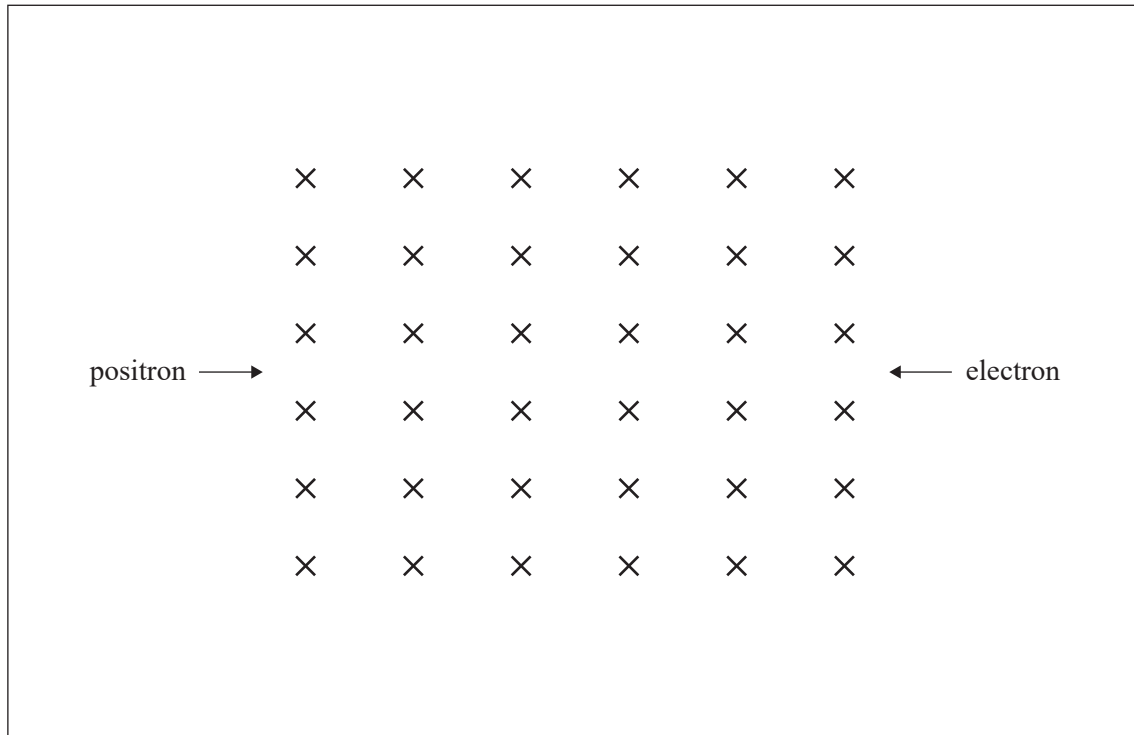


Figure 1

DO NOT WRITE IN THIS AREA

CONTINUES OVER PAGE

SECTION B – continued
TURN OVER

Question 4 (6 marks)

Figure 2 shows a schematic diagram of a simple DC generator with the output voltage 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 Figure 2. The average EMF generated in the coil for the first quarter turn is 35 mV. The coil is initially in the position shown in Figure 2.

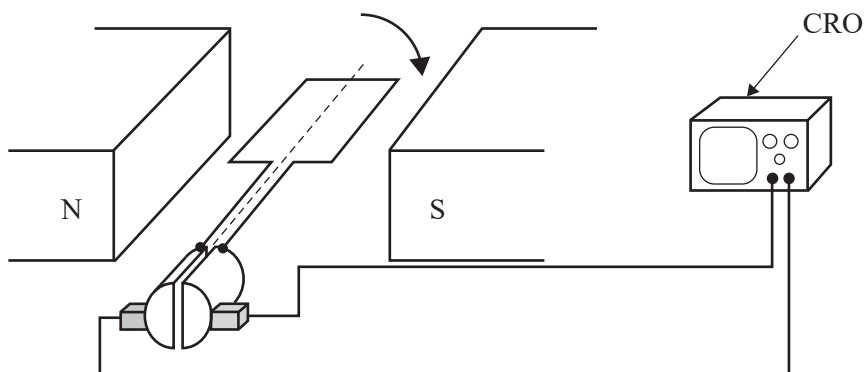


Figure 2

- 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.

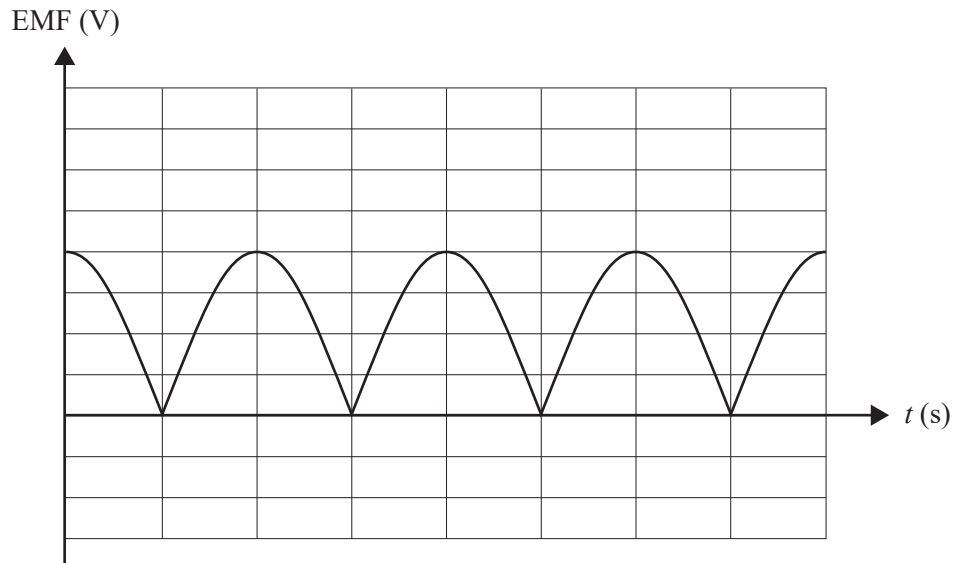
3 marks

 m²

- c. The graph below 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 5 (2 marks)

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 Figure 3. The loop is stationary.

**Figure 3**

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.

Question 6 (4 marks)

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.

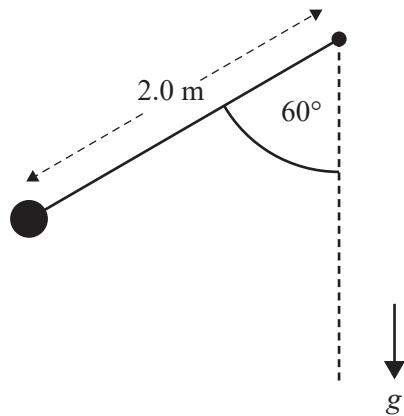
- a. Calculate the ratio of the number of turns $\frac{N_p}{N_s}$. Show your working. 2 marks

- b. Calculate the RMS current delivered by the power point while the battery is charging. 2 marks

A

Question 7 (7 marks)

A spherical mass of 2.0 kg is attached to a piece of string with a length of 2.0 m. The spherical mass is pulled back until it makes an angle of 60° with the vertical, as shown in Figure 4. The spherical mass is then released. Ignore the mass of the string.

**Figure 4**

- a. Show that the maximum speed of the spherical mass is 4.4 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

- c. Calculate the maximum tension in the string.

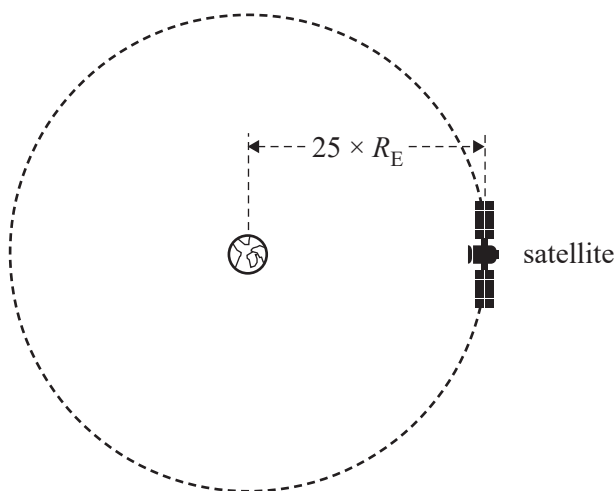
3 marks

	N
--	---

DO NOT WRITE IN THIS AREA

Question 8 (6 marks)

A satellite is moving in a stable circular orbit 25 Earth radii from the centre of Earth, as shown in Figure 5. The period of the satellite is T .

**Figure 5**

- a. Calculate the magnitude of the acceleration of the satellite. Show your working. 2 marks

m s^{-2}

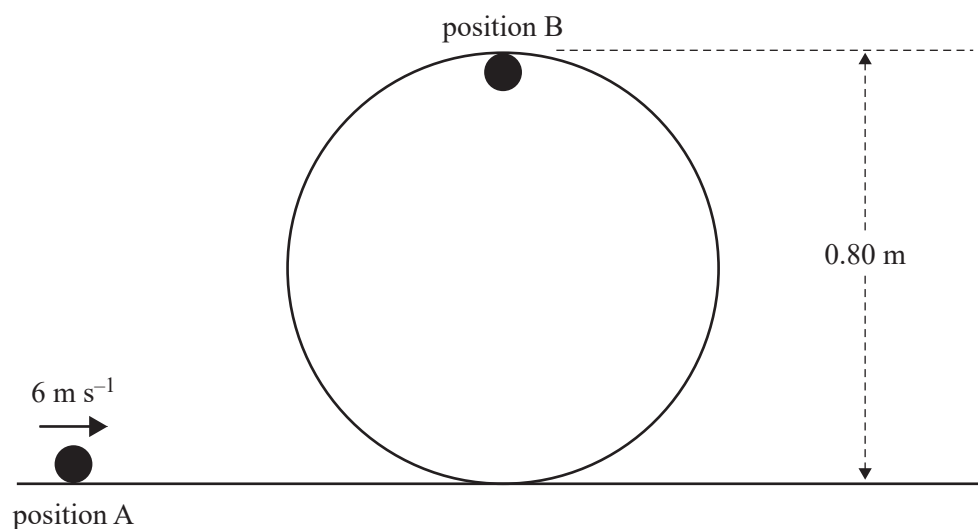
- b. Indicate the direction of the acceleration of the satellite by drawing an arrow on the satellite shown in Figure 5. 1 mark
- c. Another identical satellite is placed in a stable circular orbit 30 Earth radii from the centre of Earth.

Using the terms ‘less than’, ‘same as’ or ‘more than’, complete the table below to describe the magnitude of the acceleration, the kinetic energy and the period of this satellite compared to those of the satellite that is orbiting at 25 Earth radii. 3 marks

Magnitude of acceleration	
Kinetic energy	
Period	

Question 9 (5 marks)

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 in Figure 6. Assume that the radius of the ball and that the frictional forces are negligible.

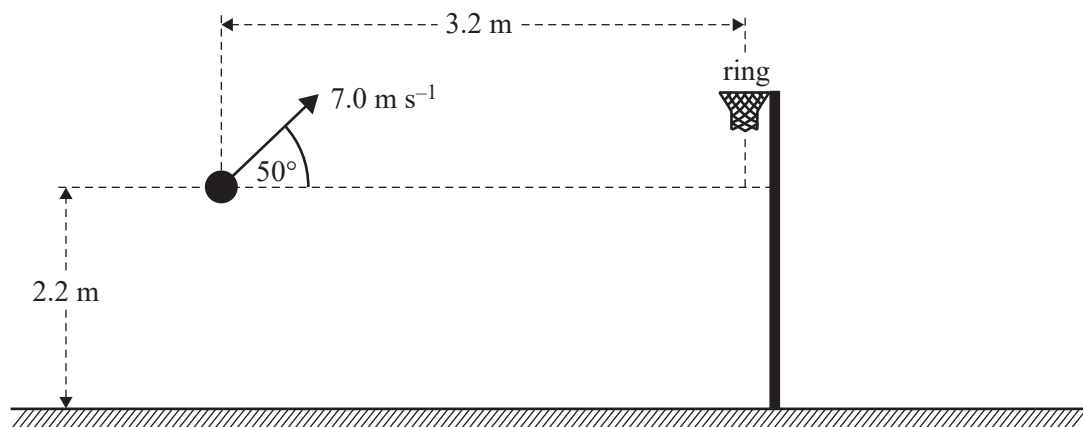
**Figure 6**

- a. Show that the kinetic energy of the ball at position A in Figure 6 is 5.4 J . 1 mark

- b. Will the ball remain on the track at the top of the loop (position B in Figure 6)? Give your reasoning. 4 marks

Question 10 (6 marks)

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 in Figure 7. 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.

**Figure 7**

- 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

m

Question 11 (4 marks)

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 $2.3 \mu\text{s}$, as measured in the muon's frame of reference.

Calculate this muon's lifetime, as measured by the researchers. Show your working.

2 marks

	μs
--	---------------

- b. In one observation, a $0.950c$ muon travels 1.5 km, as measured by the researchers.

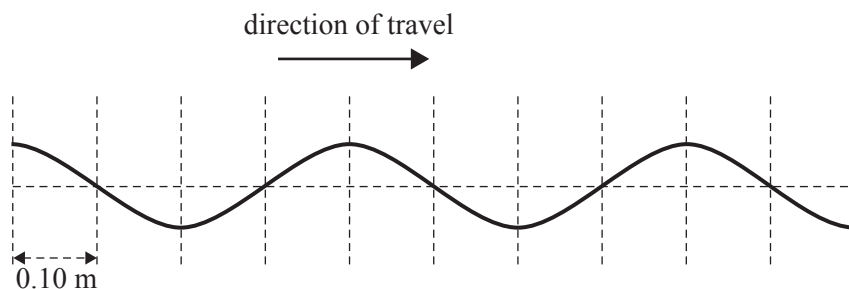
If measured in the muon's frame of reference, would this length be the same, shorter or longer? Use a calculation to justify your answer.

2 marks

Length

Question 12 (6 marks)

A transverse wave travels to the right along a length of string at a speed of 8.0 m s^{-1} . Figure 8 shows the wave at one instant in time.

**Figure 8**

- a. Calculate the frequency of the wave shown in Figure 8.

2 marks

Hz

- b. On Figure 8, draw the wave as it would appear 25 ms after the instant shown. Show any calculations and state any assumptions that you have made.

2 marks

- c. The wave source (not shown in Figure 8) is now adjusted to increase the frequency.

Explain the effect that this will have on the wavelength, stating any assumptions that you have made.

2 marks

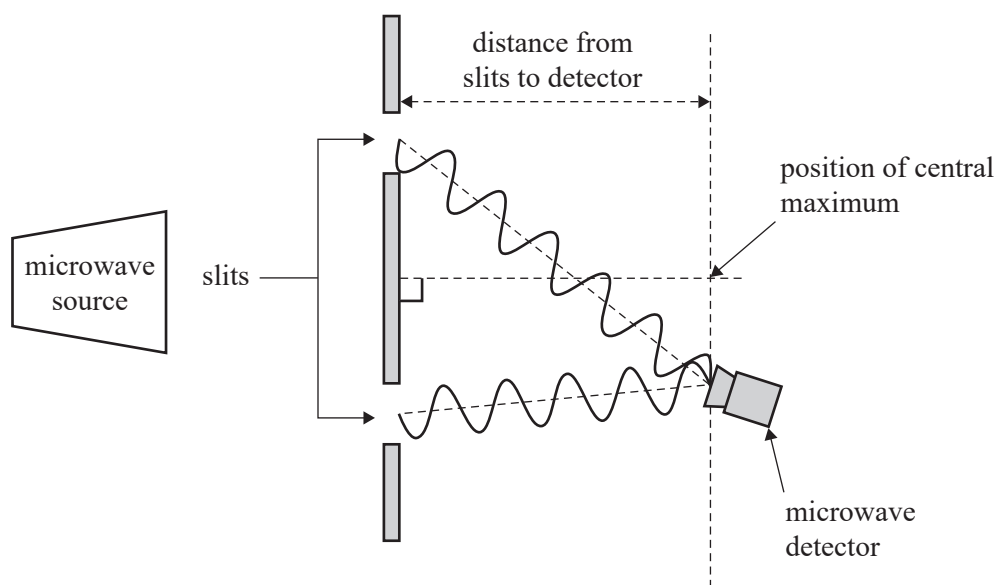
DO NOT WRITE IN THIS AREA

CONTINUES OVER PAGE

SECTION B – continued
TURN OVER

Question 13 (9 marks)

Students are investigating the interference of waves using a source of coherent microwaves, two narrow slits and a microwave detector. Figure 9 shows the microwaves travelling from the slits to the detector.

**Figure 9**

- a. The frequency of the microwaves is 12.0 GHz.

Calculate the wavelength of the microwaves. Show your working.

2 marks

m

- b. Using the information in Figure 9 and your answer to **part a.**, calculate the path difference between the two waves arriving at the detector. Give your reasoning.

2 marks

m

- c. Will the intensity of the microwaves at the detector's position, as shown in Figure 9, be a maximum or a minimum? Justify your answer.

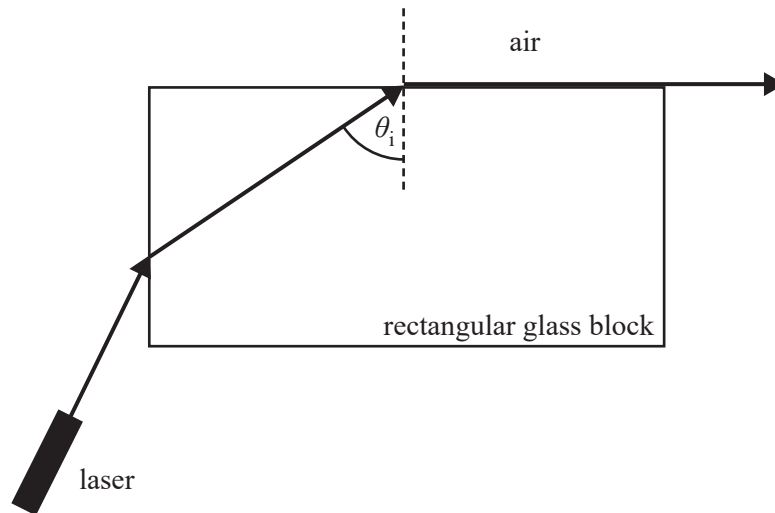
2 marks

- 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 14 (4 marks)

Students are conducting an experiment to investigate how the path of a light ray from a laser changes when the ray passes from one medium to another. They direct a light ray from air into a rectangular glass block and change the angle of the ray until it emerges back into the air, parallel to the surface of the block, as shown in Figure 10.

**Figure 10**

- a. Describe how the speed of the light ray changes as it enters the glass block. 1 mark

- b. The students measure the angle θ_i , shown in Figure 10, to be 41° .

Use this information to determine if the glass is most likely to be crown glass (refractive index 1.52), normal flint glass (refractive index 1.59) or heavy flint glass (refractive index 1.66).

Show your working.

3 marks

Type of glass

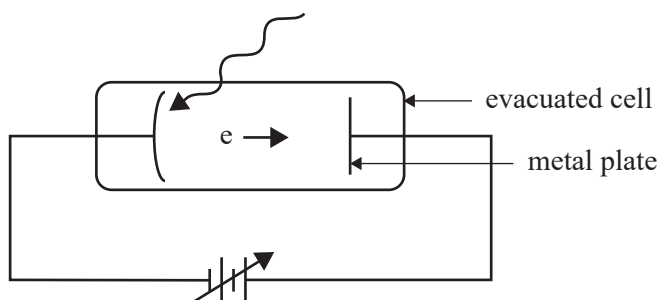
DO NOT WRITE IN THIS AREA

CONTINUES OVER PAGE

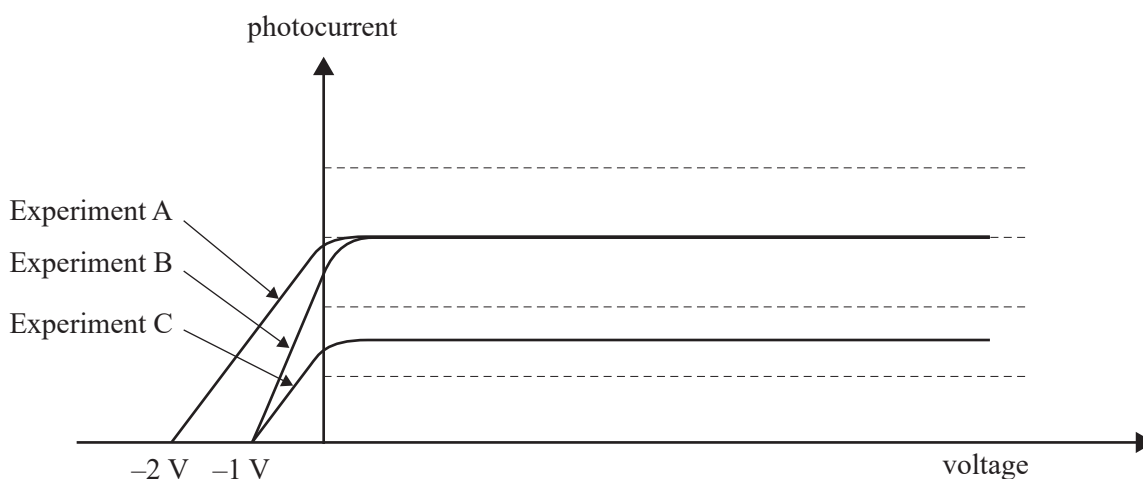
SECTION B – continued
TURN OVER

Question 15 (6 marks)

Figure 11 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.

**Figure 11**

The graph in Figure 12 shows the variation of photocurrent with voltage for three experiments, A, B and C, using light of different frequency and intensity.

**Figure 12**

- 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 Figure 12?

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 Figure 12?

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 16 (5 marks)

Figure 13 shows the diffraction pattern produced by an X-ray beam consisting of photons of energy 400 eV.

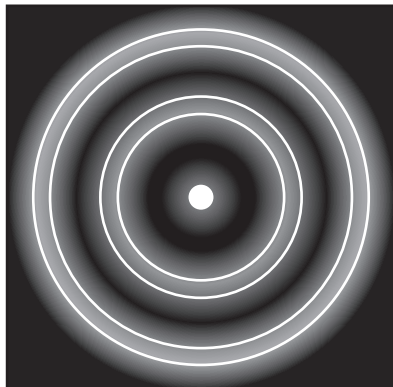


Figure 13

- 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 in Figure 13.

Calculate the speed of an electron in the stream. Take the mass of the electron to be 9.1×10^{-31} kg.

3 marks

m s⁻¹

Question 17 (3 marks)

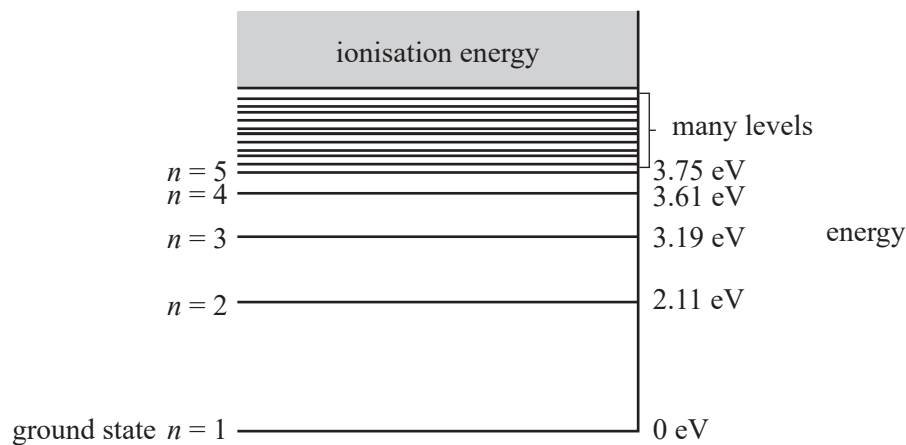
Describe how absorption line spectra are produced and describe their relationship to electron transitions within atoms.

Question 18 (3 marks)

Provide an example of an instance in which classical laws of physics cannot describe motion at very small scales and explain why they cannot.

Question 19 (4 marks)

Figure 14 shows the energy levels of a sodium atom.

**Figure 14**

A sodium atom is initially in the $n = 4$ excited state.

- a. Calculate the highest frequency of light that the sodium atom in this excited state could emit. 2 marks

Hz

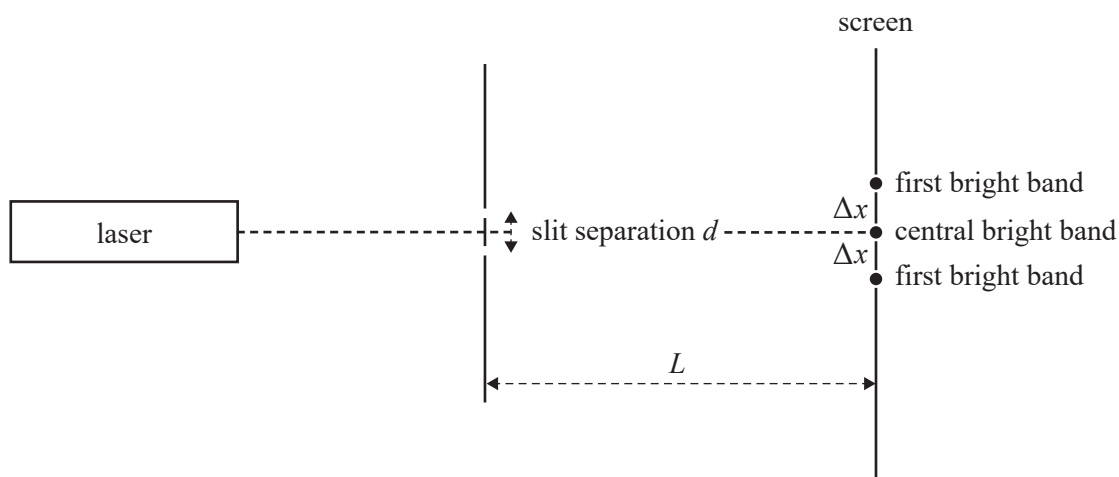
- b. Figure 14 shows some specific energy levels that electrons in a sodium atom can occupy.

Describe how the wave nature of electrons explains the existence of the energy levels shown in Figure 14.

2 marks

Question 20 (15 marks)

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 Figure 15.

**Figure 15**

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

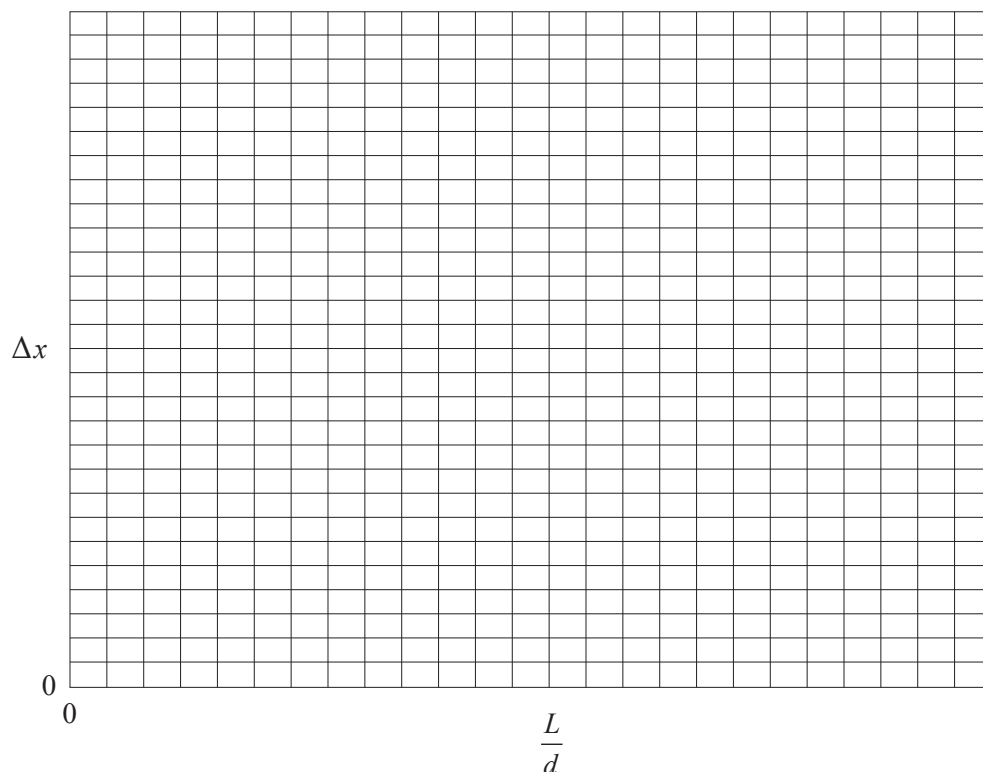
The experimental measurements taken are shown in Table 1.

Table 1

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 $\lambda = \frac{\Delta x d}{L}$ 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 Table 1. 2 marks
- c.** Plot the values from Table 1 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 ± 0.5 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

mm

- e. Use the gradient from **part d.** to determine the wavelength of the laser light. Give all the steps of your reasoning.

2 marks

m

Victorian Certificate of Education
2022

PHYSICS

Written examination

FORMULA SHEET

Instructions

This formula sheet is provided for your reference.
A question and answer book is provided with this formula sheet.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

Physics formulas

Motion and related energy transformations

velocity; acceleration	$v = \frac{\Delta s}{\Delta t}; \quad a = \frac{\Delta v}{\Delta t}$
equations for constant acceleration	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $s = vt - \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{1}{2}(v + u)t$
Newton's second law	$\Sigma F = ma$
circular motion	$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$
Hooke's law	$F = -k\Delta x$
elastic potential energy	$\frac{1}{2}k(\Delta x)^2$
gravitational potential energy near the surface of Earth	$mg\Delta h$
kinetic energy	$\frac{1}{2}mv^2$
Newton's law of universal gravitation	$F = G \frac{m_1 m_2}{r^2}$
gravitational field	$g = G \frac{M}{r^2}$
impulse	$F\Delta t$
momentum	mv
Lorentz factor	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
time dilation	$t = t_0 \gamma$
length contraction	$L = \frac{L_0}{\gamma}$
rest energy	$E_{\text{rest}} = mc^2$
relativistic total energy	$E_{\text{total}} = \gamma mc^2$
relativistic kinetic energy	$E_k = (\gamma - 1)mc^2$

Fields and application of field concepts

electric field between charged plates	$E = \frac{V}{d}$
energy transformations of charges in an electric field	$\frac{1}{2}mv^2 = qV$
field of a point charge	$E = \frac{kq}{r^2}$
force on an electric charge	$F = qE$
Coulomb's law	$F = \frac{kq_1q_2}{r^2}$
magnetic force on a moving charge	$F = qvB$
magnetic force on a current carrying conductor	$F = nIlB$
radius of a charged particle in a magnetic field	$r = \frac{mv}{qB}$

Generation and transmission of electricity

voltage; power	$V = RI; \quad P = VI = I^2R$
resistors in series	$R_T = R_1 + R_2$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$
ideal transformer action	$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$
AC voltage and current	$V_{\text{RMS}} = \frac{1}{\sqrt{2}}V_{\text{peak}} \quad I_{\text{RMS}} = \frac{1}{\sqrt{2}}I_{\text{peak}}$
electromagnetic induction	EMF: $\mathcal{E} = -N \frac{\Delta\Phi_B}{\Delta t}$ flux: $\Phi_B = B_{\perp}A$
transmission losses	$V_{\text{drop}} = I_{\text{line}} R_{\text{line}} \quad P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$

Wave concepts

wave equation	$v = f\lambda$
constructive interference	path difference = $n\lambda$
destructive interference	path difference = $\left(n - \frac{1}{2}\right)\lambda$
fringe spacing	$\Delta x = \frac{\lambda L}{d}$
Snell's law	$n_1 \sin\theta_1 = n_2 \sin\theta_2$
refractive index and wave speed	$n_1 v_1 = n_2 v_2$

The nature of light and matter

photoelectric effect	$E_{k\max} = hf - \phi$
photon energy	$E = hf$
photon momentum	$p = \frac{h}{\lambda}$
de Broglie wavelength	$\lambda = \frac{h}{p}$

Data

acceleration due to gravity at Earth's surface	$g = 9.8 \text{ m s}^{-2}$
mass of the electron	$m_e = 9.1 \times 10^{-31} \text{ kg}$
magnitude of the charge of the electron	$e = 1.6 \times 10^{-19} \text{ C}$
Planck's constant	$h = 6.63 \times 10^{-34} \text{ J s}$ $h = 4.14 \times 10^{-15} \text{ eV s}$
speed of light in a vacuum	$c = 3.0 \times 10^8 \text{ m s}^{-1}$
universal gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
mass of Earth	$M_E = 5.98 \times 10^{24} \text{ kg}$
radius of Earth	$R_E = 6.37 \times 10^6 \text{ m}$
Coulomb constant	$k = 8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$

Prefixes/Units

p = pico = 10^{-12}	n = nano = 10^{-9}	μ = micro = 10^{-6}	m = milli = 10^{-3}
k = kilo = 10^3	M = mega = 10^6	G = giga = 10^9	t = tonne = 10^3 kg