Write your **student number** in the boxes above. **Letter**

Chemistry ¾ (Normal)

Question and Answer Book - SOLUTIONS

VCE Examination (Term 1 Mock) – April 2025

- Reading time is **15 minutes.**
- Writing time is **2 hours 30 minutes.**

Materials Supplied

- Question and Answer Book of 40 pages.
- Multiple-Choice Answer Sheet.

Instructions

- Follow the instructions on your Multiple-Choice Answer Sheet.
- At the end of the examination, place your Multiple-Choice Answer Sheet inside the front cover of this book.

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

Contents

Student's Full Name: ______________________________

Student's Email: ______________________________

Tutor's Name: ______________________________

Marks (Tutor Only): ____________________

Section A

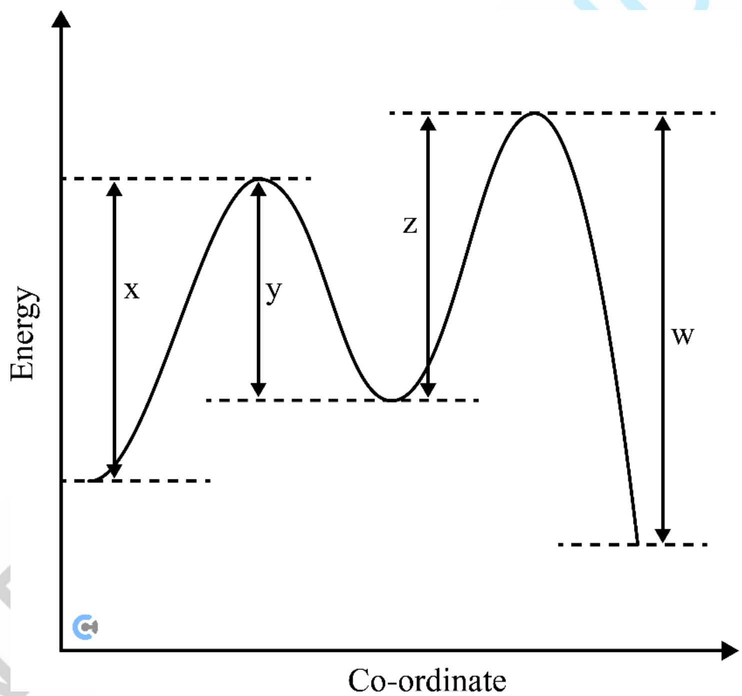
Instructions

- Answer **all** questions in pencil on the Multiple-Choice Answer Sheet.
- Choose the response that is **correct** or that **best answers** the question.
- A correct answer scores 1; an incorrect answer score 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.

Question 1 Learning Objective [1.1.1] Identify delta H & Ea in endothermic/exothermic energy profile diagrams.

The energy profile below represents the two steps in a reaction pathway from A to E.

D1



The overall energy change in the two-step process is:

A. Endothermic

B. $w - x$

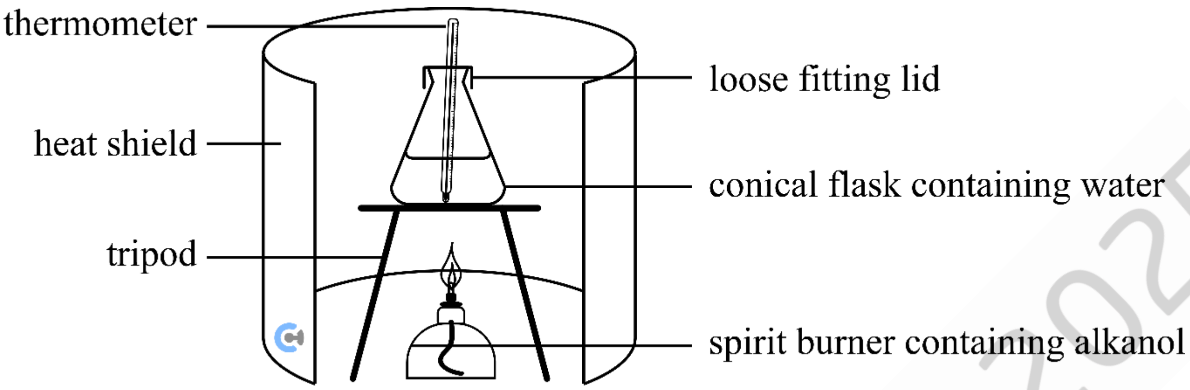
C. $x + z - w - y$

D. $z - y - w$

Question 2

Learning Objective [1.1.2] Identify differences between complete & incomplete combustion & write their thermochemical combustion equations.

The following equipment was set up to measure the heat of combustion of an alkanol.



Black deposits were observed on the bottom of the conical flask, and the heat of combustion measured was lower than the theoretical value. Which of the following equations could account for these observations?

A. $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$

B. $C_3H_8O(g) + 4O_2(g) \rightarrow CO_2(g) + CO(g) + 4H_2O(g)$

C. $2C_4H_{10}O(g) + 3O_2(g) \rightarrow 8C(s) + 2H_2(g) + 8H_2O(g)$

D. $2C_2H_6O(g) + 4O_2(g) \rightarrow 2CO_2(g) + 2C(s) + 6H_2O(g)$

D1

Question 3

Learning Objective [1.6.1] Apply oxidation numbers to find oxidant & reductant.

In which one of the following compounds is sulphur in its lowest oxidation state?

A. SO_3

B. HSO_4^-

C. SO_2

D. Al_2S_3

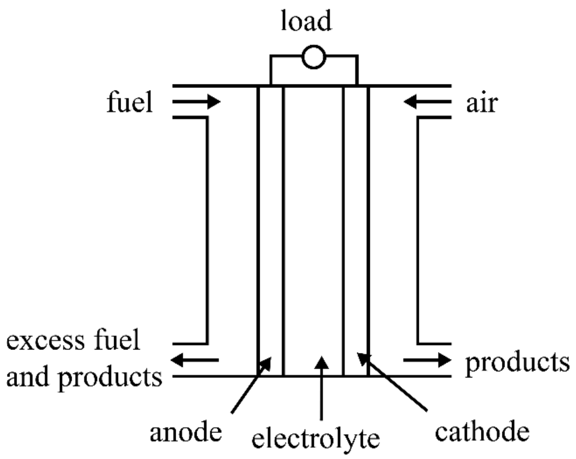
D1

Learning Objective [1.9.2] Identify key features of fuel cell including continuous supply, electrolyte movement and properties of electrodes (PICCY).

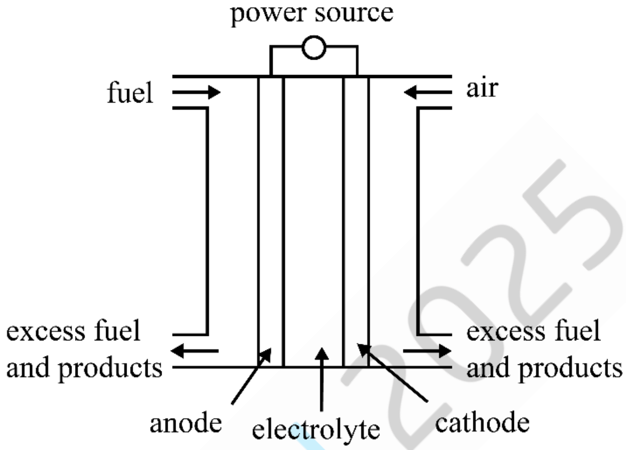
Question 4

Which of the following diagrams shows the common design features of a fuel cell?

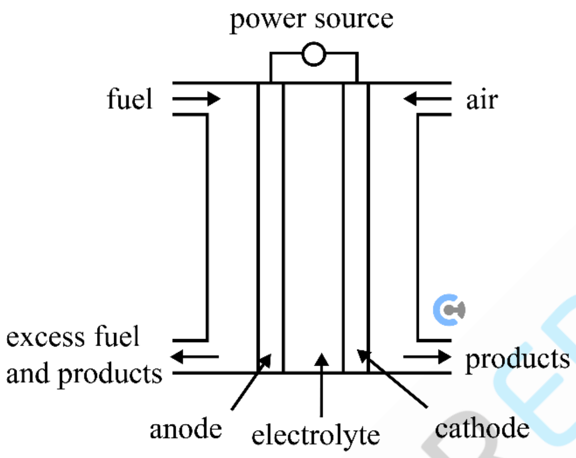
A.



B.

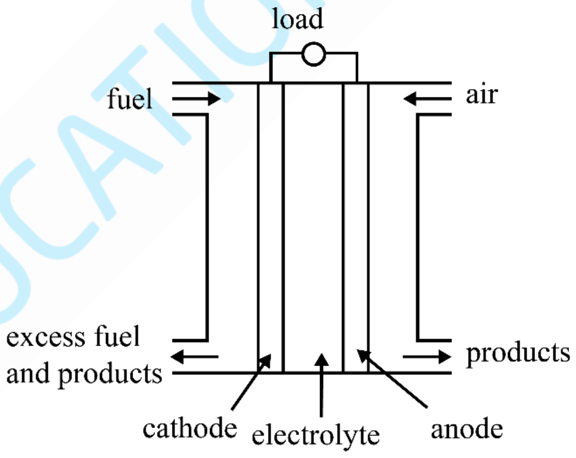


C.



D1

D.



Do not write in this area.

The following information applies to the two questions that follow.

The complete combustion of $0.500\ mol$ of a hydrocarbon produces $3.00\ mol$ of carbon dioxide during complete combustion. The carbon dioxide is stored at SLC.

D1

Question 5 Learning Objective [1.3.3] Apply m - m, m - v, v - v stoichiometry to calculation questions with equations.

The fuel could be:

A. Butane

B. Propane

C. Hexane

D. Methane

$C_6H_{14} + \frac{19}{2}O_2 \rightarrow 6CO_2 + 7H_2O$

Question 6 Learning Objective [1.3.3] Apply m - m, m - v, v - v stoichiometry to calculation questions with equations.

If the complete $0.500\ mol$ of this fuel was to be combusted, what would be the closest volume of water vapour which would be produced?

D1

A. $0.0\ L$

B. $15\ L$

C. $74\ L$

D. $87\ L$

Question 7 Learning Objective [1.3.4] Identify limiting reagents.

Carbon monoxide can be oxidised to carbon dioxide.

D1

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

$30\ mL$ of CO and $20\ mL$ of O_2 are mixed at SLC.

A. $40\ mL$ of CO_2 produced.

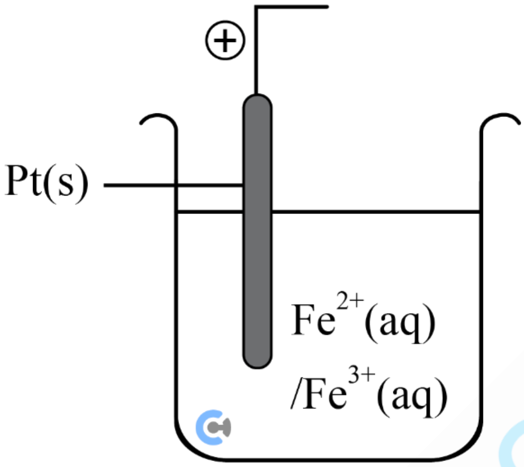
B. $20\ mL$ of CO_2 produced.

C. $10\ mL$ of CO unreacted.

D. $5\ mL$ of O_2 unreacted.

Question 8 Learning Objective [1.8.2] Write reactions in galvanic cells & calculate the maximum EMF produced.

Consider a galvanic cell that consists of $Fe^{3+}(aq)$ / $Fe^{2+}(aq)$ cell as shown below. What should the other cell be to maximise the cell's theoretical EMF? **D1**



A. $Ag^{+}(aq) + e^{-} \rightleftharpoons Ag(s)$

B. $Sn^{4+}(aq) + 2e^{-} \rightleftharpoons Sn^{2+}(aq)$

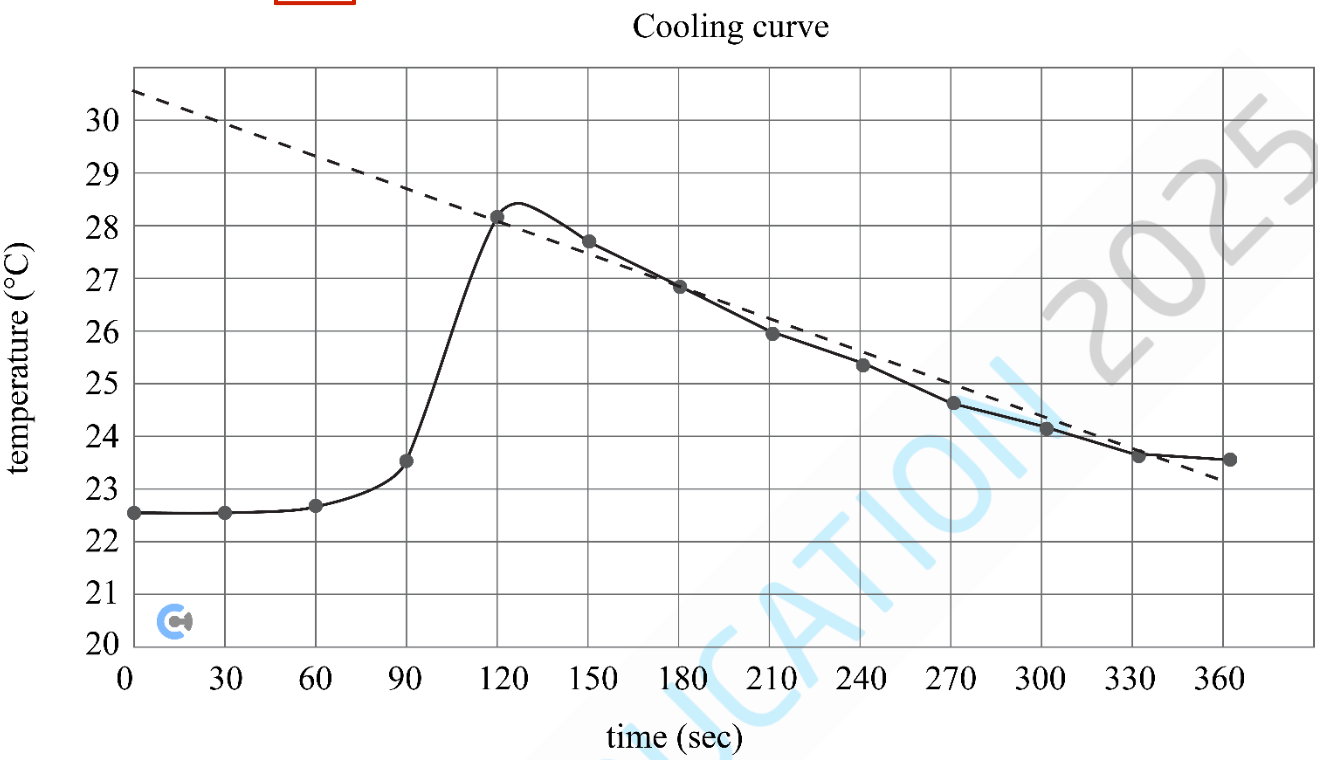
C. $F_2(g) + 2e^{-} \rightleftharpoons 2F^{-}(aq)$

D. $Cu^{2+}(aq) + 2e^{-} \rightleftharpoons Cu(s)$

Question 9 Learning Objective [1.4.3] Apply temperature - time graphs to calorimetry.

Consider the following temperature time graph of a calorimeter. Which of the following statements is incorrect?

D1



In a calorimeter, products stay inside the calorimeter to avoid heat loss.

A. Better insulation of the calorimeter would have resulted in a flatter dotted line.

B. At time 90 seconds, carbon dioxide is being released from the calorimeter.

C. After a long time, the graph will plateau at a constant value.

D. Better insulation would result in a higher maximum temperature.

Question 10 Learning Objective [1.4.1] Calculate calibration factor via electrical & chemical calibration (CF=E/delta T).

A calorimeter is calibrated by passing 5.0 *amps* at 10 volts through a calorimeter for 60 seconds. The calorimeter increased in temperature from 24 to 45 degrees Celsius.

What is the calibration factor?

D1

A. $143\ J\ °C^{-1}$

B. $143\ kJ\ °C^{-1}$

C. $14.3\ J\ °C^{-1}$

D. $14.2\ kJ\ °C^{-1}$

Question 11 Learning Objective [1.5.1] Explain the production of biofuels (biogas, bioethanol & biodiesel).

Which of the following statements is incorrect about biogas?

D1

A. They contain only methane.

B. They are produced via anaerobic respiration by bacteria.

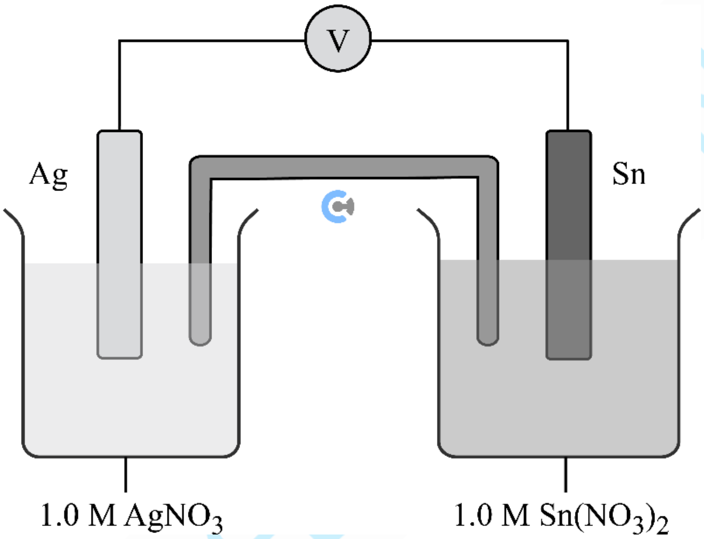
C. They have a lower energy density than pure methane.

D. They can be produced by most organic matter.

Question 12 Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

The diagram below shows a galvanic cell which is set up in a laboratory under standard conditions.

D1



Which one of the following statements about the cell is correct when electrical energy is being produced?

A. The mass loss of one electrode equals exactly the mass gain of the other electrode.

B. Electrons travel from the positive Ag electrode to the Sn electrode.

C. Positive ions travel towards the half-cell which contains the cathode.

D. As the electrolytes are aqueous, gas bubbles will appear at each electrode surface.

The following information applies to the two questions that follow.

Various reagents were mixed in separate flasks as shown in the table below.

Flask 1	Flask 2	Flask 3	Flask 4
$Cu(NO_3)_2(aq) + Sn$	$Ag^+(aq) + Sn$	$Fe^{3+}(aq) + NaCl(aq)$	I_2 solution + Cu

Question 13 Learning Objective [1.7.1] Apply the ECS to predict spontaneous reactions.

A reaction is likely to occur in: **D1**

A. Flasks 1 and 2 but not in flask 3.

B. Flasks 1 and 3 but not in flask 2.

C. Flask 2 but not in flasks 1 and 3.

A. Flask 3 but not in flasks 1 and 2.

Learning Objective [1.7.2] Identify differences between direct & indirect redox reactions, & features of ECS.

Question 14

Using the electrochemical series, a reaction is predicted to occur in flask 4. However, no reaction had occurred by the time any reactions took place in the other flasks. Which one of the following is the most likely reason to explain this? **D1**

A. The iodine was in a different state to that shown in the electrochemical series.

B. The enthalpy change for the reaction has a positive value.

C. An alloy of copper and zinc was used mistakenly in place of the pure copper metal.

D. The products are formed much more slowly than products in the other reactions.

Question 15 Learning Objective [1.6.1] Apply oxidation numbers to find oxidant & reductant.

The E^0 values for reduction reactions involving chromium are shown below.

D1

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O \quad +1.36\ V$$

$$Cr^{3+}(aq) + e^- \rightleftharpoons Cr^{2+}(aq) \quad -0.41\ V$$

$$Cr^{2+}(aq) + 2e^- \rightleftharpoons Cr\ (s) \quad -0.91\ V$$

The reaction begins with a solution of potassium dichromate. Which of the following could be used to reduce the potassium dichromate from an oxidation state of $+6$ to $+2$?

A. Cu

B. Al

C. Zn

D. F^- ions

Question 16 Learning Objective [1.4.1] Calculate calibration factor via electrical & chemical calibration (CF=E/delta T).

Consider the following situations:

I The volume of water surrounding the reaction chamber in the calorimeter was only 90% of the volume specified for the operation of the calorimeter.

II The outer layer of insulation on the calorimeter was removed.

During the calibration of the calorimeter using benzoic acid combustion, which of the above situations would result in a calculated calibration factor which is greater than the actual value?

A. I only.

B. II only.

D1

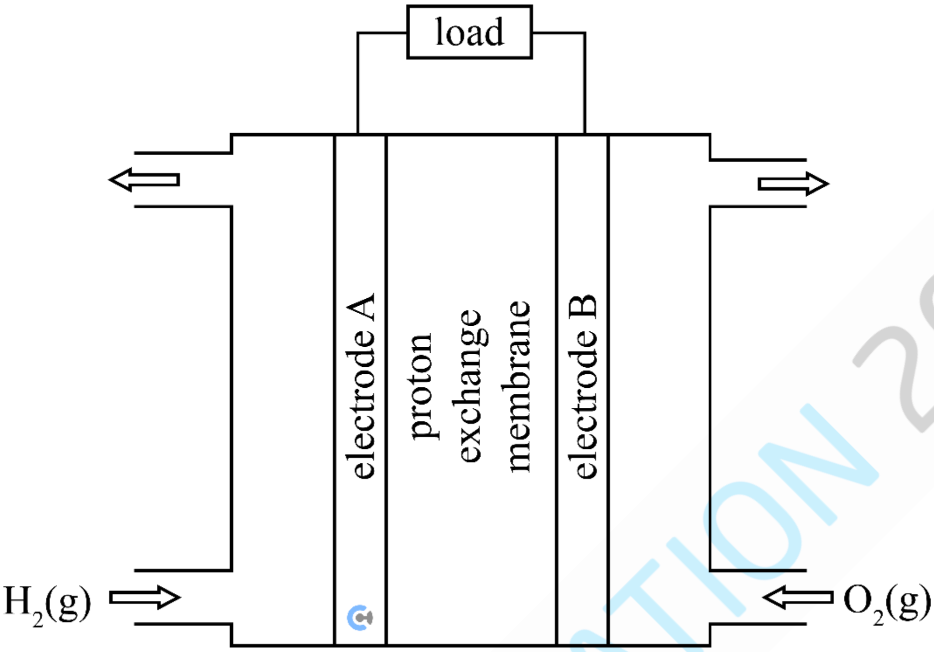
C. Both I and II.

D. Neither I and II.

Learning Objective [1.9.2] Identify key features of fuel cell including continuous supply, electrolyte movement and properties of electrodes (PICCY).

Question 17

The diagram below shows a typical proton exchange membrane fuel cell.



Which of the following would be correct when this fuel cell is releasing energy?

D1

	Electrode *A*	**Electrode *B***	**Ion movement in the membrane**
A.	Anode	Cathode	OH^- moving from the electrode B to electrode A.
B.	Cathode	Anode	H^+ moving from the electrode B to electrode A.
C.	Cathode	Anode	OH^- moving from the electrode A to electrode B.
D.	Anode	Cathode	H^+ moving from the electrode A to electrode B.

Learning Objective [1.10.3] Calculate the Charge of a Metal.

Question 18

In an experiment, the charge of vanadium ions is to be investigated. After 5000 C is passed through the cell, 0.88 g of vanadium is found to react.

The charge on the vanadium ions are:

A. +1

B. +2

C. +3

D. +4

D1

$n(e^-) = \frac{Q}{F} = \frac{5000}{96500} = 0.0518$

$n(V) = \frac{0.88}{50.9} = 0.0172$

$0.0172 : 0.0518$

$1 : 3$

Question 19

Learning Objective [1.2.3] Apply $q = mcAT$ to find energy absorbed.

A sample of a fuel is completely combusted, whereby $372\ J$ of energy is released, and is used to heat $1.50\ L$ of water at SLC. What is the final temperature reached by the water?

A. 0.059 ℃

B. 0.248 ℃

C. 59℃

D. 25.059℃

$q = mc\Delta T$ $372 = (1500) \cdot 4.18 \times \Delta T$

⇓

$\Delta T = 0.059°C$

$25 + 0.059°C = 25.059°C$

D1

Question 20

Learning Objective [2.4.3] Apply Faraday's laws to electroplating calculations.

Which one of the following factors would have the **least** impact on the amount of chlorine gas produced during the electrolysis of $150.0\ mL$ of an aqueous $2.0\ M$ sodium chloride solution?

D1

A. Length of time of electrolysis.

B. Current flowing.

C. Temperature of the electrolyte.

D. Volume of the electrolyte-containing vessel.

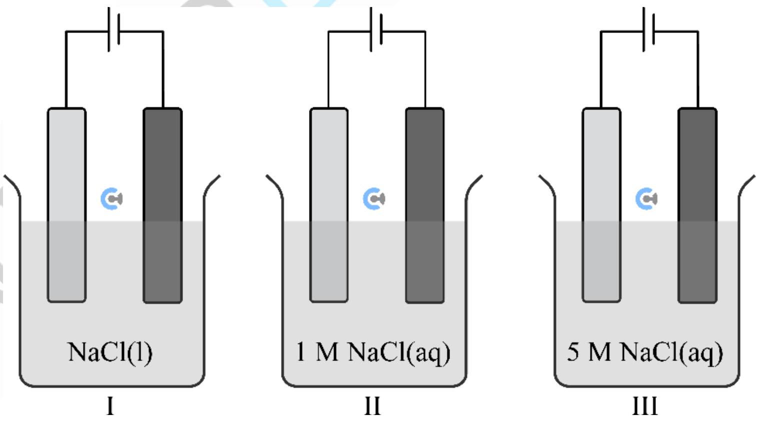
$n(e) = \frac{I \times t}{F}$ and $n(Cl_2) = \frac{1}{2} \times n(e)$

The amount of chlorine depends directly on the current and time, so neither A nor B is the correct response. Temperature may have some effect on the current flow and so may alter the amount of chlorine produced. C is incorrect. The volume and concentration of the sodium chloride solution are fixed, so the size of the vessel is unlikely to alter the amount of chlorine produced. D is the required response.

Question 21

Three electrolysis cells were constructed, each using a pair of graphite electrodes. Each cell contained sodium chloride as the electrolyte, but the state or concentration of the sodium chloride differed, as shown in the diagrams below.

Learning Objective [2.1.1] Identify differences between galvanic & electrolysis for electrodes, energy conversions, electron flow.



D1

For which cells would you expect to see the same chemical or chemicals initially produced at the anode when the electrolysis was performed?

A. I and II.

B. I and III.

C. II and III.

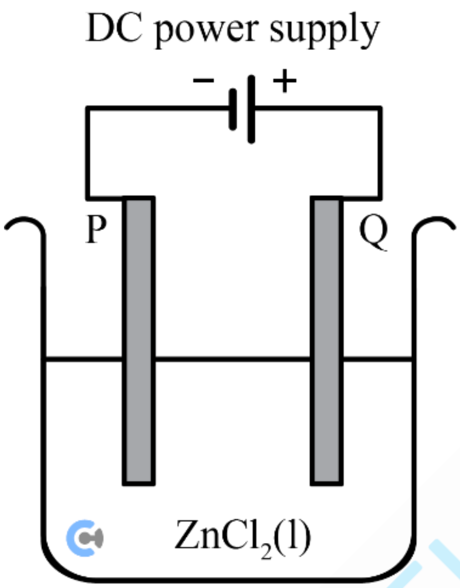
D. I, II and III.

Question 22

In the electrochemical cell represented below.

Learning Objective [2.2.1] Find electrolytic reactions in non-standard conditions (molten & high concentration).

D1



A. Oxygen gas forms at P.

B. Oxygen gas forms at Q.

C. Chloride gas forms at P.

D. Chloride gas forms at Q.

Question 23

Learning Objective [2.1.2] Write equations & calculate EMF required for electrolytic reactions.

An electrolytic cell is utilised with inert electrodes. Which of the following electrolytes will not result in the production of bubbles at either electrode?

D1

A. Iron (II) nitrate solution ($Fe(NO_3)_2(aq)$).

B. Sodium bromide solution ($NaBr(aq)$).

C. Molten sodium chloride ($NaCl(l)$).

D. Mixture of sodium hydroxide & cobalt iodide solutions ($NaOH$ and CoI_2).

Question 24

Learning Objective [2.1.1] Identify differences between galvanic & electrolysis for electrodes, energy conversions, electron flow.

In the electrolysis of a dilute solution of KNO_3, the nitrate ions are:

D1

A. Attracted to the positive electrode where they are oxidised.

B. Attracted to the positive electrode where they are reduced.

C. Attracted to the positive electrode where they are neither reduced nor oxidised.

D. Not attracted to either electrode as they are spectator ions only.

Question 25 Learning Objective [2.1.2] Write equations & calculate EMF required for electrolytic reactions.

A solution containing tin (II) nitrate is to be electrolysed, whereby the positive terminal of the battery is connected to a silver electrode, and the negative terminal of the battery is connected to a lead electrode. After the cell runs for 5.00 minutes, the overall reaction that occurs is observed to have changed once from the initial reaction.

D1

Which of the following is correct regarding the reactions which occur in the cell after 5.00 minutes?

A. The overall concentration of ions is decreasing.

B. Lead is deposited at the cathode.

C. The positive electrode decreases in mass.

D. There is no change in the mass of any electrode.

Question 26 Learning Objective [2.4.3] Apply Faraday's laws to electroplating calculations.

An electric charge of 8042 C is passed through a molten ionic solution. The product at the cathode could be: **D1**

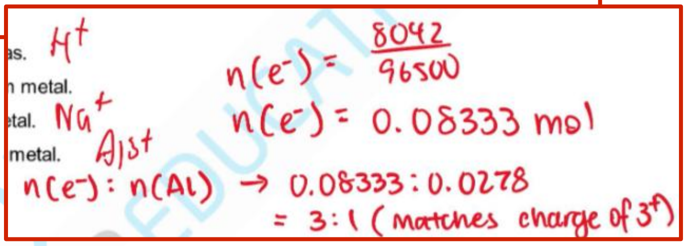
8042 coulomb is 1/12 of a mol (0.0833). The aluminium with a charge of 3+ will match this 0.0278 x 3 = 0.0833

A. 0.166 mol of hydrogen gas.

B. 0.0833 mol of magnesium metal.

C. 0.0417 mol of sodium metal.

D. 0.0278 mol of aluminium metal.



Question 27 Learning Objective [2.3.1] Write discharge & recharge reactions in secondary cells & redox flow batteries.

The rechargeable nickel-cadmium cell is used to power small appliances. The following reactions occur when chemical energy is converted to electrical energy:

D1

$$NiO_2(s) + 2H_2O(l) + 2e^- \rightarrow Ni(OH)_2(s) + 2OH^-(aq)$$

$$Cd(s) + 2OH^-(aq) \rightarrow Cd(OH)_2(s) + 2e^-$$

What is the half-reaction which occurs at the positive electrode when the cell is undergoing recharge?

A. $NiO_2(s) + 2H_2O(l) + 2e^- \rightarrow Ni(OH)_2(s) + 2OH^-(aq)$

B. $Ni(OH)_2(s) + 2OH^-(aq) \rightarrow NiO_2(s) + 2H_2O(l) + 2e^-$

C. $Cd(s) + 2OH^-(aq) \rightarrow Cd(OH)_2(s) + 2e^-$

D. $Cd(OH)_2(s) + 2e^- \rightarrow Cd(s) + 2OH^-(aq)$

Learning Objective [2.4.1] Identify the electroplating setup (location of object) & find the electroplating reactions.

Question 28

Iron metal is used to electroplate metal items to give them a lustrous coating. The item to be electroplated is placed into an electrolytic cell with an iron electrode and a solution of iron (II) ions, which are stirred constantly.

D1

In the course of the electrolytic process:

A. Electrons will travel from cathode to anode.

B. The mass of the anode will increase.

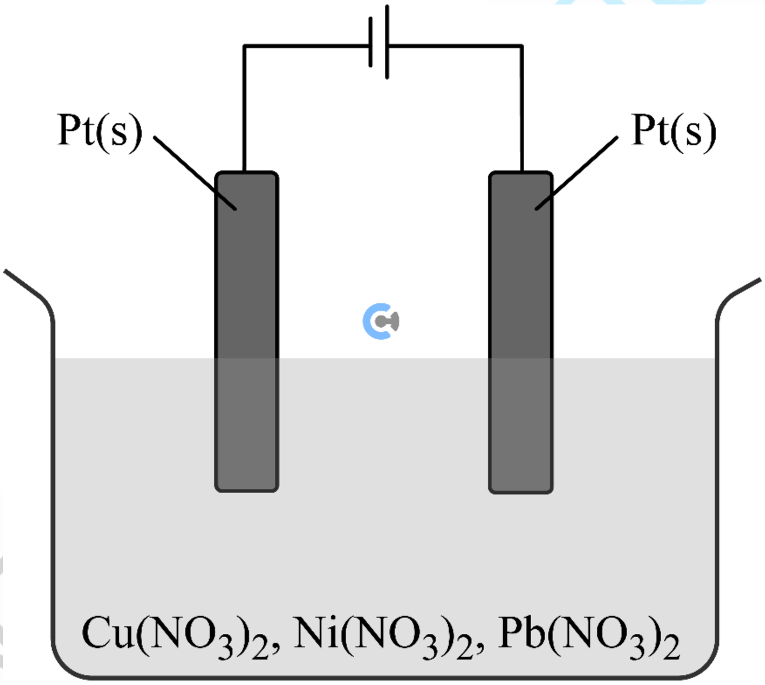
C. The concentration of iron ions in the electrolyte will decrease.

D. Iron ions will move towards the cathode.

Question 29 Learning Objective [2.4.2] Find next order reactions during electrolysis.

An electrolytic cell containing $0.20\ M$ of $Cu(NO_3)_2$, $Ni(NO_3)_2$ and $Pb(NO_3)_2$ is electrolysed, as shown.

D1



The reaction proceeds so that there are three layers of coating formed. The order of the coatings, from outside to inside are:

A. Ni, Pb, Cu

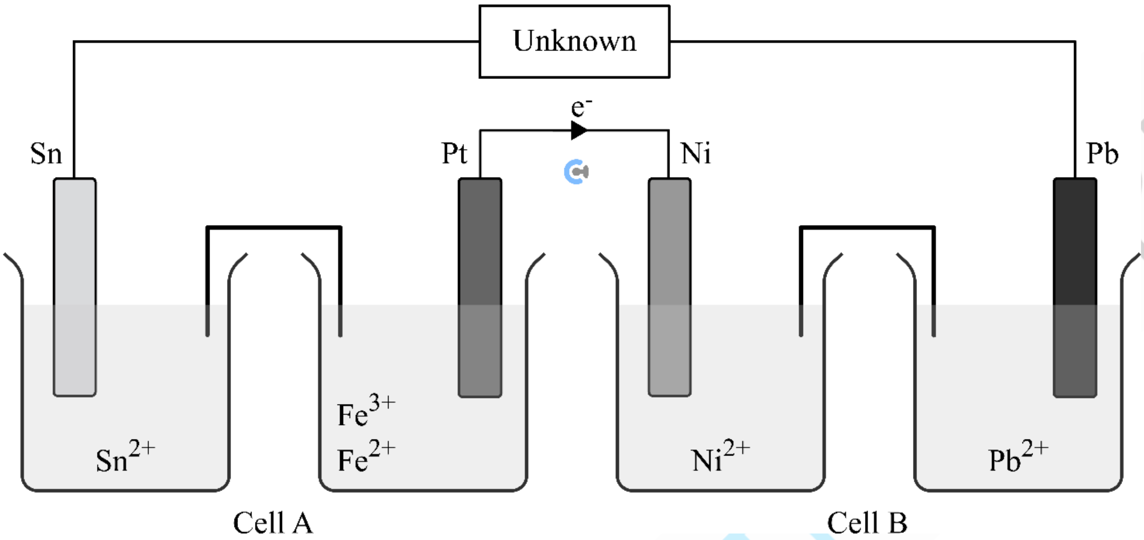
B. Cu, Pb, Ni

C. Cu, Ni, Pb

D. Pb, Ni, Cu

Question 30 Learning Objective [2.3.3] Find reactions occurring in connected cells.

A connected cell is shown below, where it is unknown if they are connected to a power source, load or just connected by wires. **D1**



The energy transformation which occurs in each electrode are:

	Cell *A*	**Cell *B***
A.	Chemical to electrical.	Chemical to electrical.
B.	Chemical to electrical.	Electrical to chemical.
C.	Electrical to chemical.	Chemical to electrical.
D.	Electrical to chemical.	Electrical to chemical.

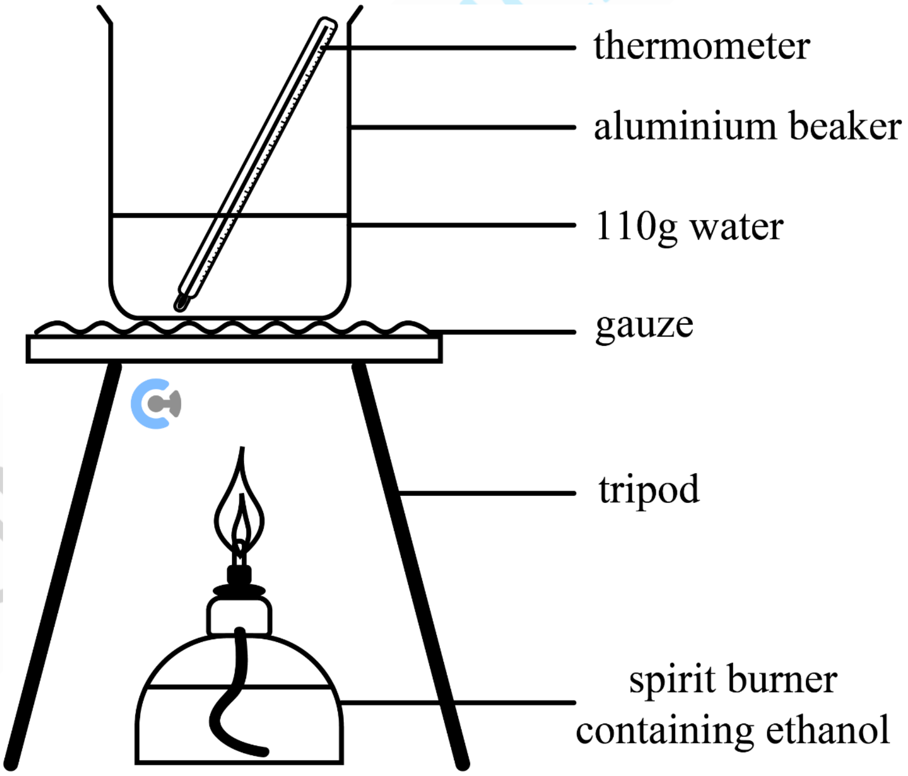
Section B

Instructions

- Answer all questions in the spaces provided.
- Write your responses in English.
- Give simplified answers to all numerical questions with an appropriate number of significant figures; unsimplified answers will not be given full marks.
- Show all working in your answers to numerical questions; no marks will be given for an incorrect answer unless it is accompanied by details of the working.
- Ensure chemical equations are balanced and that the formulas for individual substances include an indication of state, for example, $H_2(g), NaCI(s)$.
- Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1 (7 marks)

The following apparatus was used in an experiment to determine the molar enthalpy of the combustion of ethanol.



a. Calculate the experimental molar enthalpy of combustion (ΔH) of ethanol when $0.590\ g$ ethanol was used to raise the water temperature from $12.5°C$ to $40.0°C$. 4 marks

D2

Learning Objective [1.2.4] Calculate delta H experimentally.

$n(C_2H_5OH) = \frac{m}{Mr} = \frac{0.590}{46} = 0.012826 mol$ (1)

$q = mc\Delta T = 110 \times 4.18 \times (40 - 12.5) = 12644.5 J$ (1)

$\Delta H = \frac{q}{n} = \frac{12.645 kJ}{0.01283 mol} = 985.6 kJ$ (1)

$\Delta H = -986\ kJ/mol$ (1)

Learning Objective [1.3.1] Identify changes to minimise heat loss & calculate percentage efficiency.

b. Using your answer in **part a.**, find the % energy efficiency of the setup. 1 mark

D1

$\%\ efficiency = \frac{986}{1370} \times 100\% = 72.0\%$

c. Explain one change that could be made to the experiment that would improve the accuracy of the obtained value. 2 marks

D3

Learning Objective [1.3.1] Identify changes to minimise heat loss & calculate percentage efficiency.

(1) any change to reduce heat loss
- adding a lid

(2) explanation how it improves accuracy.

Lid reduces heat loss, thereby causing a theoretical value closer to the true value and increasing accuracy.

(1 Mark) Adding a heat shield

(1 Mark) A heat shield would prevent heat being lost to the surroundings and hence, reduced heat loss. Thereby, the theoretical value will be closer to the true value increasing accuracy

Question 2 (4 marks)

Hydrogen peroxide is a common cleaning agent used in substances such as bleach.

a. Hydrogen peroxide is then mixed with fluorine gas.

1M Learning Objective [1.7.1] Apply the ECS to predict spontaneous reactions.

i. Use the information from the electrochemical series in the Data Book to write a balanced overall equation for the reaction which occurs. 2 marks

D2

1M Learning Objective [1.6.3] Apply KOHES to write balanced half-equations and overall equations in acidic & basic conditions.

Reduction: $F_2(g) + 2e^- \rightarrow 2F^-(aq)$

Oxidation: $H_2O_2(aq) \rightarrow O_2(g) + 2H^+(aq) + 2e^-$ ①

Full equation: $F_2(g) + H_2O_2 \rightarrow O_2(g) + 2HF(aq)$ ①

ii. State the energy conversion which takes place as the reaction proceeds. 1 mark

Learning Objective [1.7.2] Identify differences between direct & indirect redox reactions, & features of ECS.

chemical to thermal

D1

b. Using data from the electrochemical series, a student suggests that a reaction will occur between acidified hydrogen peroxide and Ni(s). To test this prediction, a strip of nickel metal is dipped into a solution containing 1.0 *M* acidified hydrogen peroxide at 25℃. No reaction was observed after 2 minutes. 1 mark

Provide **one** possible chemical reason that explains why the predicted reaction was not observed.

D2

Learning Objective [1.7.2] Identify differences between direct & indirect redox reactions, & features of ECS.

the electrochemical series does not predict the rate of reaction, and the rate of reaction may have been too slow.

Do not write in this area.

Question 3 (7 marks)

In an extended electrochemical series, the following half-equations are investigated.

$$O_3(g) + H_2O(l) + 2e^- \rightleftharpoons O_2(g) + 2OH^-(aq) \qquad E^0 = +1.24\ V$$

$$Y^{3+}(aq) + 3e^- \rightleftharpoons Y(s) \qquad E^0 = -2.37\ V$$

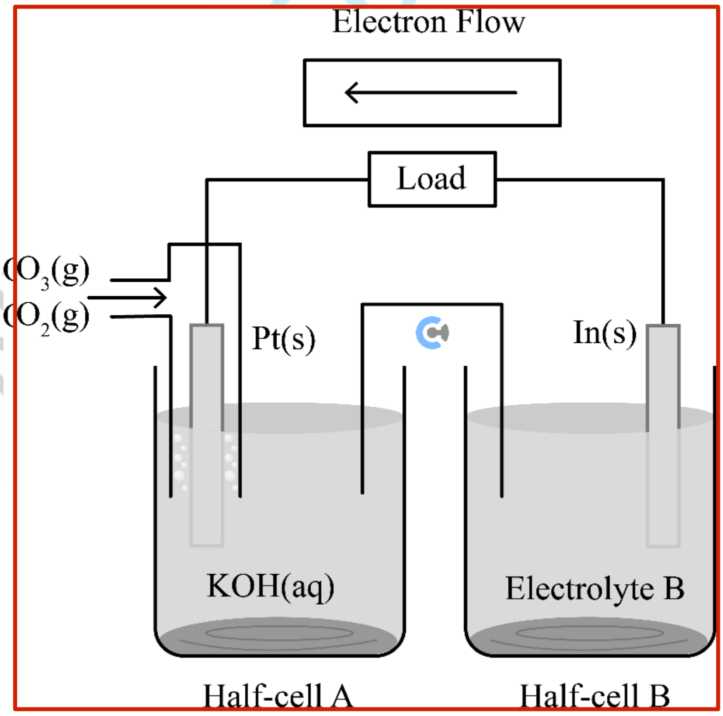
$$In^{3+}(aq) + 3e^- \rightleftharpoons In(s) \qquad E^0 = -0.34\ V$$

a. A strip of indium metal is dipped into 1.0 M of $Y(NO_3)_3(aq)$ solution. Predict if a reaction is expected to occur. Justify your answer. 1 mark

Learning Objective [1.7.1] Apply the ECS to predict spontaneous reactions. **D2**

(1 M) No reaction
(1 M) $Y^{3+}(aq)$ is a weak oxidant ($E^0 = -2.37\ V$) and Indium is a weak reductant ($-0.34\ V$) relative to each other.

b. A galvanic cell is constructed between the ozone / oxygen half-cell and $In^{3+}(aq)/In(s)$, as shown below. **D1**



i. In the box provided above, label the direction of electron flow. 1 mark

Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

Do not write in this area.

ii. Suggest a suitable substance for electrolyte B. **D2** 1 mark

Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

$In(NO_3)_3$ or any other electrolyte paired up with a soluble or inert anion.
$In^{3+}(aq)$ alone is not accepted.

iii. Write the balanced equation for the overall reaction which takes place. **D1** 1 mark

Learning Objective [1.8.2] Write reactions in galvanic cells & calculate the maximum EMF produced.

$3O_3(g) + 3H_2O(l) + 2In(s) \rightarrow 2In^{3+} + 3O_2(g) + 6OH^-(aq)$
or
$3O_3(g) + 3H_2O(l) + 2In(s) \rightarrow 2In(OH)_3(aq) + 3O_2(g)$

iv. A pH meter is inserted into the electrolyte of half-cell A. Explain what would happen to the pH as the reaction proceeds. **D1** 1 mark

Learning Objective [1.8.3] Identify & explain observations during operation of galvanic cells.

pH increases, as hydroxide ions are formed, making solution more basic.

c. In the salt bridge, potassium nitrate ions are present.

i. State **one** function of the salt bridge. **D1** 1 mark

Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

(1 M to one of) completes circuit / balances build-up of charge / maintains electric neutrality

ii. State **one** property of the potassium nitrate ions which helps with the operation of the cell. 1 mark

Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

D1

(1 M to one of) soluble / inert / doesn't form precipitates

Question 4 (3 marks)

Most batteries we use for household appliances are often categorised as alkaline batteries. Contour Industries is now trying to venture into the battery business and Jayden is the lead researcher on batteries. The battery contains zinc metal ($Zn(s)$) and manganese dioxide ($MnO_2(s)$) which can produce zinc oxide ($ZnO(s)$) and manganite ($MnOOH(s)$).

a. Jayden now must figure out where to place these reactions in the alkaline battery.

i. Write the reaction occurring at the anode. **D1** 1 mark

Learning Objective [1.6.2] Apply KOHES to write balanced half-equations in acidic & basic conditions.

$Zn(s) + 2OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^-$ (negative polarity)

ii. Write the reaction occurring at the cathode. **D1** 1 mark

Learning Objective [1.6.2] Apply KOHES to write balanced half-equations in acidic & basic conditions.

$MnO_{2(s)} + H_2O_{(l)} + e^- \longrightarrow MnOOH_{(s)} + OH^-_{(aq)}$.
(positive polarity)

b. A pacemaker is a small medical device placed in the chest to correct certain heart problems. While this type of battery is used in appliances, it is not suitable for use in a pacemaker. Explain this phenomenon. 1 mark **D1**

Learning Objective [1.10.1] Identify features of primary cells & how they operate.

This is not suitable for a pacemaker due to $ZnO(s)$ a product, being toxic towards humans to ingest. (Don't swallow batteries.)

Do not write in this area.

Question 5 (6 marks)

A solution calorimeter was used to experimentally determine the heat of the solution of potassium nitrate when it is dissolved in water. The calorimeter is found to have had a calibration factor of $2.5\ kJ\ ^{\circ}C^{-1}$.

It is found that the experimental heat of the solution of potassium nitrate is $+35.0\ kJ\ mol^{-1}$.

a. Write the balanced thermochemical equation for the dissolution reaction which occurs. 1 mark

Learning Objective [1.1.2] Identify differences between complete & incomplete combustion & write their thermochemical combustion equations.

D1

$KNO_3(s) \rightarrow KNO_3(aq) \quad \Delta H = +35.0\ kJ\ mol^{-1}$

b. A $30.0\ g$ sample of the potassium nitrate is dissolved in water at SLC.

i. Find the amount of energy in kilojoules which was absorbed by the reaction. 2 marks

D2

Learning Objective [1.2.1] Apply delta H = q x n to energy released.

$n(KNO_3) = \frac{m}{M} = \frac{30}{39.1+48+14}$

$= 0.297$ mol (1)

$q = \Delta H \times n$

$= 35 kJ/mol \times 0.297$ mol

$= 10.4 kJ$ (3 s.f) (1)

ii. Using the calibration factor given and your answer from **part b.i.**, find the final temperature reached after the $30.0\ g$ of potassium nitrate was completely dissolved into the water. 2 marks

Learning Objective [1.4.2] Apply calibration factor to find energy released (E = CF x delta T).

D2

$CF = \frac{E}{\Delta T}$

$\rightarrow \Delta T = \frac{E}{CF}$

$= \frac{10.4}{2.5 kJ/^{\circ}C}$

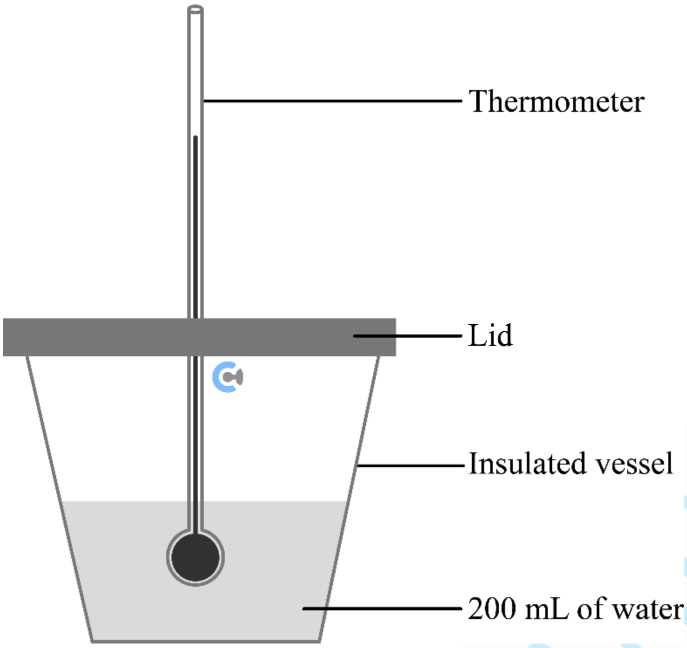
$\Delta T = 4.16$ (1)

$T_f = T_i - T_c$

$= 25^{\circ}C - 4.16^{\circ}C$

$= 20.84^{\circ}C$ (1)

The original calorimeter with a calibration factor of $2.5\ kJ\ ^\circ C^{-1}$ which contains $200\ mL$ of water is shown below.



The amount of water present in the calorimeter is increased to $250\ mL$, changing the calibration factor.

c. State whether this new calibration factor will be higher or lower than $2.5\ kJ\ ^\circ C^{-1}$. Justify your answer. 1 mark

Learning Objective [1.4.1] Calculate calibration factor via electrical & chemical calibration (CF=E/delta T).

D2

Higher – more energy is required to increase temperature of calorimeter by $1^\circ C$ as there is more water to heat up.

Question 6 (14 marks)

Contour Industries is an up-and-oncoming company looking to expand its outreach to the energy industry. They look for sources of methane.

a. Write the thermochemical equation for the complete combustion of methane. 2 marks

D2

Learning Objective [1.1.2] Identify differences between complete & incomplete combustion & write their thermochemical combustion equations.

$CH_4 (g) + 2O_2 (g) \rightarrow CO_2 (g) + 2H_2O (l)$ $\Delta H = -890$ kJ mol^{-1}

1 M: balanced equation with correct states
1 M: for the delta H value

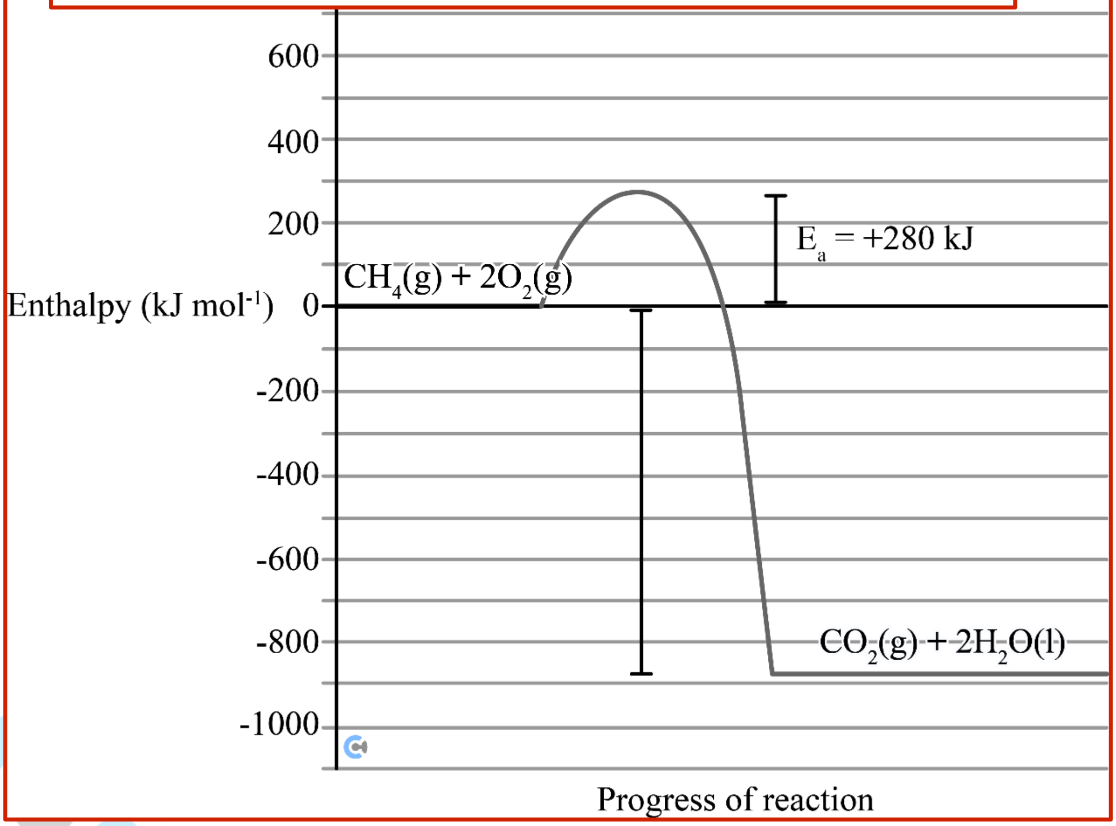
b. The activation energy for the combustion of methane is 280 $kJ\ mol^{-1}$.

Learning Objective [1.1.1] Identify delta H & Ea in endothermic/exothermic energy profile diagrams.

i. Complete the energy profile diagram on the axes provided below. 2 marks

1 M: shape of energy profile diagram & labelled reactants and products
1 M: labelled delta H and E_a, with their values

D3



ii. State the activation energy for the reverse reaction. 1 mark

Learning Objective [1.1.3] Apply changing equations to thermochemical equations & energy profile diagrams.

D1

890 + 280 = 1170 kJ

c. A surveyor decides whether to drill for natural gas or to obtain methane from biogas.

D2

i. Explain how biogas is produced. 1 mark

Learning Objective [1.5.1] Explain the production of biofuels (biogas, bioethanol & biodiesel).

Anaerobic respiration of organic matter by bacteria / microorganisms.

ii. Noah says that 'natural gas is considered to be fossil fuels as it produces greenhouse gases which are harmful to the environment.' 2 marks

D3

Evaluate Noah's statement, justifying your response.

Learning Objective [1.5.2] Identify & explain differences between fossil fuels & biofuels with reference to renewability.

(1) Noah is correct in saying natural gas is a fossil fuel.

(2) However, it is not due to producing GHG. Rather as it is a non-renewable source of energy which cannot be produced in a relatively short time by natural processes.

d. Methane is used as a fuel over alternatives such as methanol. Methanol has a lower heat of combustion in kJ/mol. Explain the differences in the heat of combustion. 2 marks

D2

Learning Objective [1.5.2] Identify & explain differences between fossil fuels & biofuels with reference to renewability.

(1) Methanol is partially oxidised as it contains an oxygen whereas methane does not and is not oxidised.

(2) Therefore, since combustion is oxidation, methanol is unable to oxidise as much as methane and thus releases less energy.

e. Contour Industries is planning to expand into the domestic stove market with its own natural gas stove, the Burnout Mark IV. Methane is used at high pressure and low temperature, whereby it is compressed and turned into liquified petroleum gas, LPG.

i. Given that this LPG is only made of methane, which has a density of $0.580\ g\ mL^{-1}$, find the theoretical volume of LPG, in mL, which is required to obtain $2.00\ MJ$ of energy. 3 marks

Learning Objective [1.2.2] Apply delta H in kJ/mol, kJ/g & kJ/mL to energy calculations.

D2

energy. $\Delta H\ (CH_4) = 890\ kJ/mol$ → 2000 kJ

$n(CH_4) = \frac{q}{\Delta H} = \frac{2000}{890} = 2.24719\ mol$ ①

$m(CH_4) = 2.24719 \times (12+4) = 35.955...\ g$ ①

$V(CH_4) = 35.955\ g \div 0.580\ g/mL = 61.99...\ mL$

$= 62.0\ mL$ of LPG ①

ii. In practice, the efficiency of the gas stove is 70%, find the amount of energy the experimental volume of LPG required to achieve the same amount of energy as **part e.i.** 1 mark

Learning Objective [1.3.1] Identify changes to minimise heat loss & calculate percentage efficiency.

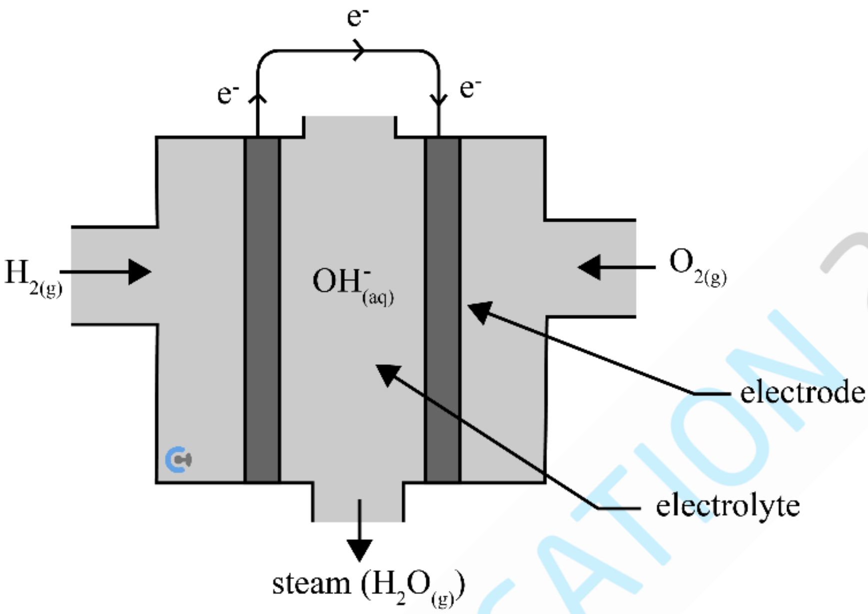
D1

$2000 \div 0.7 = 2857.142857\ kJ$ ①

$\approx 2.9 \times 10^3\ kJ$

Question 7 (11 marks)

With society moving to net zero carbon emissions by 2050, cars have started to be developed to be run on hydrogen gas as the main fuel rather than petrol. Some cars have begun development on a hydrogen/oxygen fuel cell, whereby a simplified version is shown below.



The fuel cell consists of two hydrogen gas that is inserted through the left pipe and oxygen gas through another. The two pipes are joined, and the alkaline electrolyte, KOH, passes through the centre of the cell.

a. Write balanced ionic half-equations for the reactions occurring at the anode and cathode. 2 marks

D1 Learning Objective [1.9.1] Write fuel cell half & overall reactions in acidic conditions.

Anode: $H_{2(g)} + 2OH^-_{(aq)} \rightarrow 2H_2O_{(g)} + 2e^-$

Cathode: $O_{2(g)} + 3H^+ + 3e^- \rightarrow H_2O_{(g)} + OH^-_{(aq)}$

b. The electrodes consist of a porous nickel alloy mesh. 2 marks

State **two** roles that the nickel electrodes play in the operation of the fuel cell.

D1 Learning Objective [1.9.2] Identify key features of fuel cell including continuous supply, electrolyte movement and properties of electrodes (PICCY).

Any two of:
- Act as catalyst.
- Allow the gases to come in contact with electrode.
- Allow oxidation and reduction to occur.

c. Explain one major advantage of using hydrogen fuel cells to power cars over combustion engines fuelled by hydrogen, referring to one 'Green Chemistry Principle'. Use item **26. ii.** of the Data Book. 3 marks

Learning Objective [1.9.3] Explain advantages & disadvantages of fuel cells with reference to green chemistry principles.

D2

(1 M) Design for energy efficiency.
(1 M) Fuel cells have direct conversion from chemical to electrical energy, whereas combustion engines fueled by hydrogen have multiple energy conversions which leads to more energy loss. This results in greater energy efficiency for fuel cells.
(1 M) With greater efficiency, less fuel is required to produce the same amount of energy, resulting in less $H_2O(g)$ formed, and thus less greenhouse gas emissions, minimising environmental impact.

d. This fuel cell creates a current of $5.60\ A$. Calculate the volume of hydrogen gas consumed at SLC, if the cell runs for $30.0\ min$. 4 marks

3M Learning Objective [1.10.2] Apply Faraday's First & Second Law and Q=It & Q=n(e)F to calculations.

1M Learning Objective [1.3.2] Apply n=V/Vm to calculate volumes of gases at SLC.

D2

$Q = It = 5.60\ A \times 30\ min \times 60\ s/min = 10080\ C$ (1)

$n(e^-) = \frac{Q}{F} = \frac{10080\ C}{96500\ C/mol} = 0.1045\ mol$ (1)

$n(H_2) = \frac{1}{2} n(e^-) = 0.0522\ mol$ (1)

$V(H_2) = n \times V_m = 0.0522\ mol \times 24.8\ L/mol$
$= 1.295\ L = \boxed{1.30\ L}$ (1)

Question 8 (8 marks)

Scientists help investigate how ethanol can be produced renewably. They decide to use spinach to produce ethanol.

a. Write the equation for the reaction which takes place within the spinach plant to produce glucose. 1 mark

Learning Objective [1.5.3] Write cellular respiration & photosynthesis equations.

D1

$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$ – include UV light on top of the arrow.

b. They then use the glucose to produce ethanol via fermentation with the presence of yeast as a catalyst.

i. Write the balanced equation for the reaction which takes place. 1 mark

Learning Objective [1.5.1] Explain the production of biofuels (biogas, bioethanol & biodiesel).

D1

$$C_6H_{12}O_6(aq) \xrightarrow{yeast} 2C_2H_5OH(aq) + 2CO_2(g)$$

ii. The ethanol produced is dissolved in water. Propose a method to separate the ethanol and water. 1 mark

Learning Objective [1.5.1] Explain the production of biofuels (biogas, bioethanol & biodiesel).

D1

Simple distillation

c. Is the ethanol produced in this manner renewable? Justify your answer. 1 mark

D1

Learning Objective [1.5.2] Identify & explain differences between fossil fuels & biofuels with reference to renewability.

Renewable – it is produced by natural processes (photosynthesis) within a relatively short time

d. Suggest **one** sustainability challenge presented by the use of spinach plants to produce bioethanol in terms of the United Nations Sustainable Development Goal 2. Referning to answer UN Sustainability goal, suggest and explain another sustainability challenge. 2 marks

D3

Learning Objective [1.5.2] Identify & explain differences between fossil fuels & biofuels with reference to renewability.

(1 M) Goal 2 – zero hunger – farmland is used to produce bioethanol instead of spinach for consumption as food, which may result in food shortages/insecurity, detracting away from zero hunger.

(1 M) Land is cleared for farmland for production of bioethanol, which can lead to habitat destruction, which is a challenge for goal 15: life on land.

They then repivot their focus and use the spinach for consumption instead. Spinach has the following composition:

Composition	**Mass per 100 g of spinach (g)**
Water	91.40
Cellulose	2.20
Other Carbohydrates	0.42
Protein	2.86
Lipid	0.39
Other Minerals	2.73

Source: U.S. Department of Agriculture. (2019). FoodData Central. Usda.gov. https://fdc.nal.usda.gov/fdc-app.html#/food-details/168462/nutrients

e. Assuming the body does not obtain energy from the other minerals, calculate the energy present in 100 g of the spinach. 2 marks

Learning Objective [1.5.4] Calculate energy obtained from foods.

D2

$0.42\,g \times 16\,kJ/g + 2.86\,g \times 17\,kJ/g + 0.39\,g \times 37\,kJ/g$ (1)

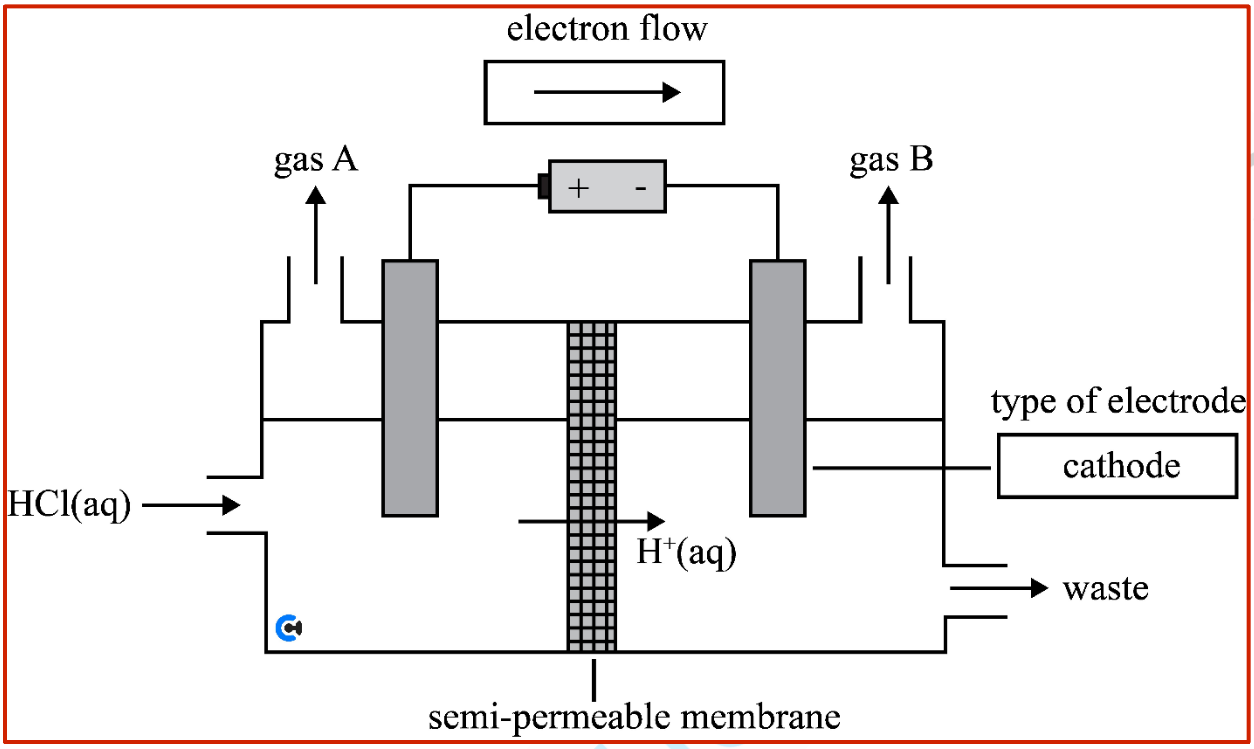
$= 69.77\,kJ$

$= 70\,kJ$ (1)

Do not write in this area.

Question 9 (8 marks)

To allow 1.0 M hydrochloric acid to react, the following cell is used, which is powered by a battery, whereby two gases, gas A and gas B, are observed to be produced.



Do not write in this area.

a. Inert electrodes are used.

Learning Objective [2.1.1] Identify differences between galvanic & electrolysis for electrodes, energy conversions, electron flow.

i. Indicate whether the right electrode acts as the cathode or the anode in the box provided above. 1 mark

D1

Learning Objective [2.1.1] Identify differences between galvanic & electrolysis for electrodes, energy conversions, electron flow.

ii. Place an arrow to indicate the direction of electron flow in the box provided above. 1 mark

D1

iii. Write the balanced half-equation which occurs at the electrode connected to the negative terminal of the battery. 1 mark

D1

Learning Objective [2.1.2] Write equations & calculate EMF required for electrolytic reactions.

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

iv. Identify gas A which is produced. 1 mark

D1 Learning Objective [2.1.2] Write equations & calculate EMF required for electrolytic reactions.

$O_2(g)$ / oxygen gas

b. The cell is then altered, whereby high concentrations of hydrochloric acid of 5.0 *M* are inserted into the cell instead. The equations at one of the electrodes are observed to change. 1 mark

Write the balanced half-equation for the reaction which occurs at this electrode.

D1

Learning Objective [2.2.1] Find electrolytic reactions in non-standard conditions (molten & high concentration).

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$

c. In the cell, a semi-permeable membrane is selected to only allow hydrogen ions to pass through. State **one** other function of the semi-permeable membrane. Justify your answer. 1 mark

D1

separates products so that they do not spontaneously react and cause an explosion.

d. The production of hydrogen in a 'green manner is to be investigated.

i. Propose **one** cell which can be used to produce 'green hydrogen.' 1 mark

D1

Polymer electrolyte membrane electrolysis powered by photovoltaic (solar) or wind energy
Or
Artifical photosynthesis using water oxidation and proton reduction catalyst system.

ii. Suggest **one** manner in which the proposed cell in **part d.i.** can aid with the United Nations Sustainable Development Goal 13. 1 mark

D2

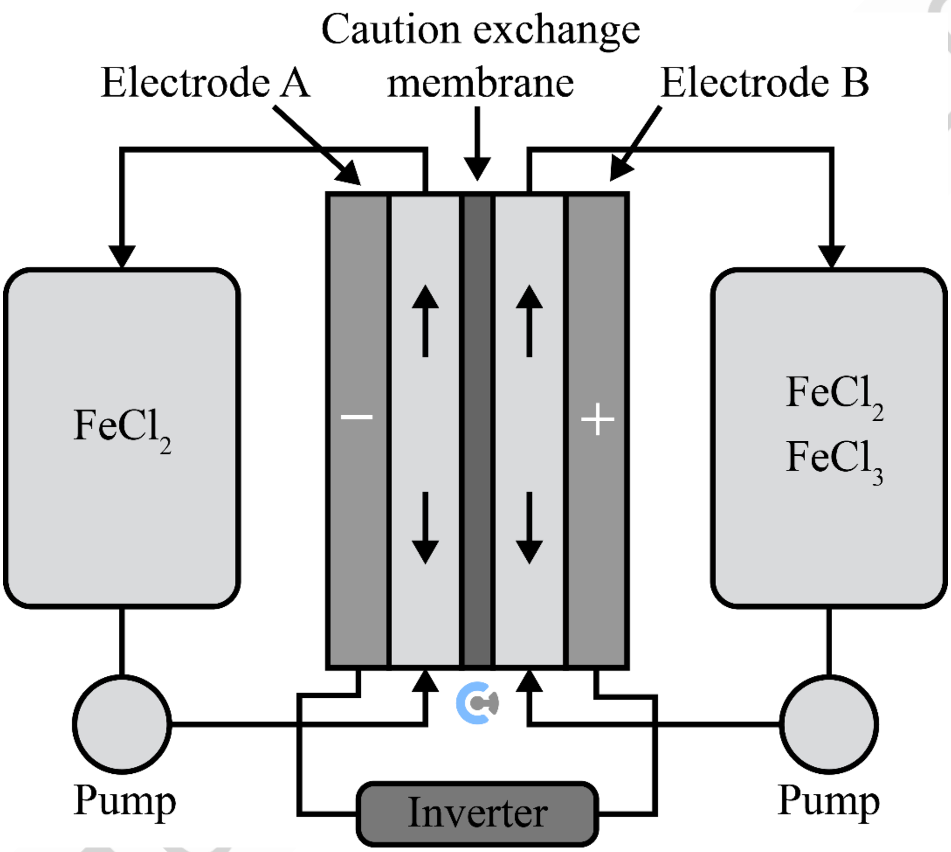
They use renewable energy (e.g. solar or wind) which does not produce CO_2 which would otherwise contribute to greenhouse gas emissions.

Question 10 (6 marks)

An iron redox flow battery (IRFB) involves a reaction between the following relevant half-equations:

$$Fe^{3+}(aq) + e^{-} \rightleftharpoons Fe^{2+}(aq) \qquad E^{0} = +0.77\ V$$
$$Fe^{2+}(aq) + 2e^{-} \rightleftharpoons Fe(s) \qquad E^{0} = -0.44\ V$$

The cell is shown below, whereby the electrode A is made of iron metal, and electrode B is made of platinum metal.



a. Write the balanced overall reaction which occurs during the **discharge** cycle. 1 mark

D1 Learning Objective [2.3.1] Write discharge & recharge reactions in secondary cells & redox flow batteries.

$2Fe^{3+}(aq) + Fe(s) \rightarrow 3Fe^{2+}(aq)$

b. When the cell is **recharged**, write the balanced half-equation for the reaction occurring at the anode. 1 mark

Learning Objective [2.3.1] Write discharge & recharge reactions in secondary cells & redox flow batteries.

D1

$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^{-}$

c. The IRFB is compared to a typical secondary cell. Compare IRFB to a typical secondary cell by stating **one** similarity and **one** difference. 2 marks

D2

Learning Objective [2.3.2] Identify factors which affect rechargeability & compare similarities/differences between secondary cells and other cells.

similarity – can both be discharged and recharged
difference – IRFB has continuous flow of reactants, but typical secondary cell does not.

d. During discharge, electrode *A* acts as the negative electrode. Compare whether electrode *A* acts as cathode or anode, and whether it is the positive or negative electrode during the discharge and recharge reactions. Explain your answer. 2 marks

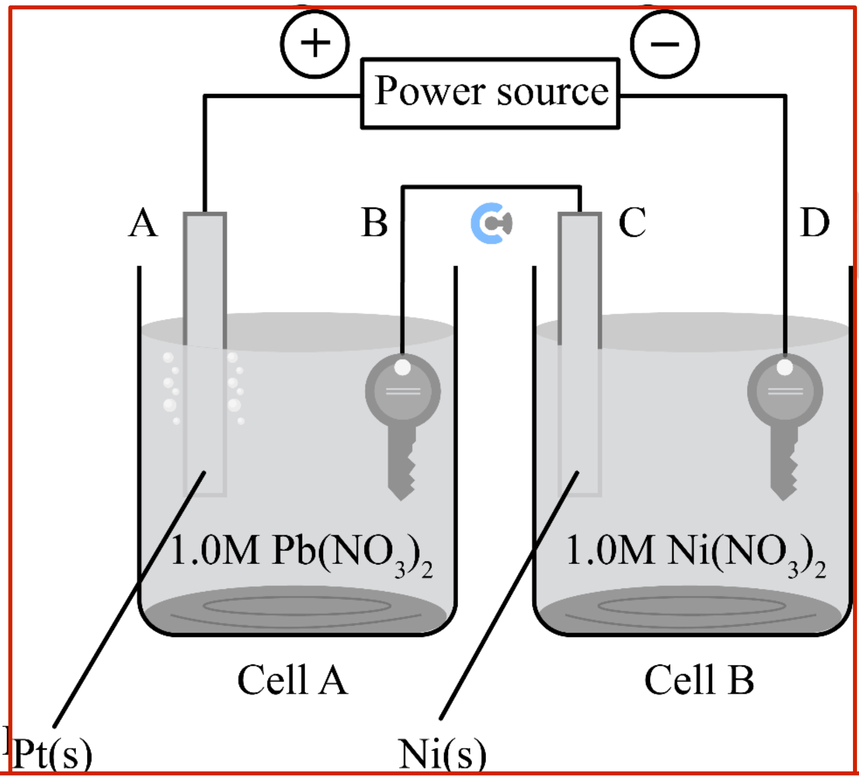
D2

Learning Objective [2.3.2] Identify factors which affect rechargeability & compare similarities/differences between secondary cells and other cells.

(1 M for both discharge and recharge)
during discharge, electrode A acts as the anode and is negative
during recharge, electrode A acts as the cathode and is negative.
(1 M) Overall, the type of electrode (cathode/anode) swap, but the polarity stays negative.

Question 11 (9 marks)

Two identical copper keys with identical mass are to be electroplated according to the connected cell below, whereby the electrode A is made of platinum metal, and electrode C is made of nickel metal. The electrolyte of Cell A contains $100\ mL$ of $1.0\ M$ $Pb(NO_3)_2$, whereas the electrolyte of Cell B contains $100\ mL$ of $1.0\ M$ $Ni(NO_3)_2$.



Learning Objective [2.4.1] Identify the electroplating setup (location of object) & find the electroplating reactions.

a. Label the polarities of the power source for the metals to be electroplated onto the respective keys in the circles provided above. 1 mark

b. Write the balanced half-equations for the reaction which occurs within cell B at the: 2 marks

Positive electrode: $Ni(s) \rightarrow Ni^{2+}(aq) + 2e^-$ **D1**

Negative electrode: $Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$ **D1**

1M Learning Objective [2.4.1] Identify the electroplating setup (location of object) & find the electroplating reactions.

1M Learning Objective [2.3.3] Find reactions occurring in connected cells.

c. After some time has elapsed, the concentration of $Pb^{2+}(aq)$ ions in Cell A is seen to decrease, but the volume still remains at $100\ mL$.

i. State how the concentration of $Ni^{2+}(aq)$ ions in Cell B will change. Explain your answer. 1 mark

D2

Learning Objective [2.4.1] Identify the electroplating setup (location of object) & find the electroplating reactions.

stays same - $Ni^{2+}(aq)$ ions are produced at the anode, and used at the cathode at the same rate.

ii. Find the initial amount of $Pb^{2+}(aq)$ ions present in the solution before electrolysis occurred in moles. 1 mark

Learning Objective [2.4.3] Apply Faraday's laws to electroplating calculations.

D1

$$n(\text{Pb})_{initial} = cV = 1.0\ M \times 0.1\ L = 0.1\ mol$$

iii. Given that the power source provides a current of $2.20\ A$ for $20.0\ min$, find the final concentration of $Pb^{2+}(aq)$ ions present. 4 marks

D2

Learning Objective [2.4.3] Apply Faraday's laws to electroplating calculations.

$$Q = It = 2.20\ A \times 20 \times 60s = 2640\ C\ (1\ M)$$

$$n(e^-) = \frac{Q}{F} = \frac{2640}{96500} = 0.0274\ mol\ (1\ M)$$

$$n(Pb)_{reacted} = \frac{1}{2}n(e^-) = 0.0137\ mol\ (1\ M)$$

$$n(Pb)_{final} = n_{initial} - n_{reacted} = 0.1 - 0.0137\ mol = 0.0863\ mol$$

$$c(Pb)_{final} = \frac{n}{V} = \frac{0.0863\ mol}{0.100\ L} = 0.863\ M\ (1\ M)$$

Do not write in this area.

Question 12 (7 marks)

In electrochemistry, the standard hydrogen electrode (abbreviated SHE), is a redox electrode that forms the basis of the thermodynamic scale of oxidation-reduction potentials.

Its absolute electrode potential is estimated to be $4.44 \pm 0.02\ V$ at $25°C$, but to form a basis for comparison with all other electrochemical reactions, hydrogen's standard electrode potential $(E°)$ is declared to be zero volts at any temperature. The potentials of all other electrodes are compared with that of the standard hydrogen electrode at the same temperature.

Source: IUPAC, *Compendium of Chemical Terminology*, 2nd ed. (the "Gold Book") (1997). Online corrected version: (2006–) "standard hydrogen electrode". doi:10.1351/goldbook.S05917

An organic molecule '$X^+(aq)$' is to be placed in the electrochemical series in the following reaction:

$$X^+(aq) + e^- \rightleftharpoons X(s)$$

The organic molecule '$X^+(aq)$' is then placed in a set of **three** reactions, as detailed below.

- **Reaction 1:** When placed directly in a beaker and $Zn(s)$ is placed inside, the zinc begins to corrode.
- **Reaction 2:** When placed in a $2.0\ M$ KOH solution, bubbles are produced.
- **Reaction 3:** When placed in a solution with $1.0\ M$ NaBr, no reaction takes place.

Do not write in this area.

4M Learning Objective [1.7.3] Find strongest oxidants/reductants by constructing your own ECS.

Explain the significance of each of the above reactions and observations to provide the range of possible E^0 values of the compound $X^+(aq)$.

In your response, for each of the three reactions, include:

D3

- Any relevant half-equations.
- Deduction for the E^0 value.

3M Learning Objective [1.7.1] Apply the ECS to predict spontaneous reactions.

- Any relevant half-equations.
- Deduction for the E^0 value.

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

(1) • $X^+(aq)$ reacts w/ $Zn(s)$ spontaneously.
$X^+(aq)$: strong oxidant, $Zn(s)$: strong reductant
∴ $E^0 > -0.76V$ (1)

(1) • X^+ reacts spontaneously w/ $K^+(aq)$ & $OH^-(aq)$
$X^+(aq)$: strong oxidant, $OH^-(aq)$: strong reductant
$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$
∴ $E^0 > +0.40V$ (1)

(1) • $X^+(aq)$ doesn't react spontaneously w/ $Na^+(aq)$ & $Br^-(aq)$
$X^+(aq)$: weak oxidant, $Br^-(aq)$: weak reductant
∴ $E^0 < +1.09V$ (1)

∴ $E^0 > -0.76V$ and $E^0 > +0.4V$ and $E^0 < +1.09V$

∴ For $X^+(aq)$, $+0.40V < E^0 < +1.09V$

(1) for conclusion