

**Section A**Answer **all** questions.

**1** Choose from the following substances to answer the questions.

- A** aluminium oxide,  $\text{Al}_2\text{O}_3$
- B** carbon monoxide,  $\text{CO}$
- C** potassium dichromate(VI),  $\text{K}_2\text{Cr}_2\text{O}_7$
- D** ammonium nitrate,  $\text{NH}_4\text{NO}_3$
- E** potassium manganate(VII),  $\text{KMnO}_4$
- F** fluorine,  $\text{F}_2$
- G** nitrogen dioxide,  $\text{NO}_2$

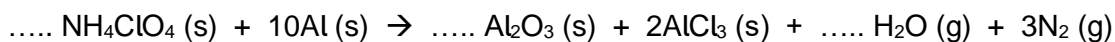
Use the letters **A, B, C, D, E, F** and **G** to answer the following questions.  
Each letter may be used once, more than once or not at all.

Write the symbol for the substance which

- (a) is a neutral oxide. .... [1]
- (b) is able to oxidise iodide ions to iodine. .... [1]
- (c) produces an alkaline gas when warmed with sodium hydroxide. .... [1]
- (d) contains a transition metal with an oxidation state of +6. .... [1]
- (e) is soluble in rainwater, forming acid rain. .... [1]

[Total: 5]

- 2 The reaction between ammonium perchlorate,  $\text{NH}_4\text{ClO}_4$ , and aluminium metal is used to propel space shuttles. The reaction produces many substances such as steam and nitrogen gas. The equation shown below represents the reaction.



(a) Balance and complete the equation by filling in the blanks. [1]

(b) Calculate the oxidation state of chlorine in perchlorate ion,  $\text{ClO}_4^-$ .

[2]

(c) The reaction between aluminium and ammonium perchlorate is a redox reaction.

State the role of aluminium in the redox reaction.

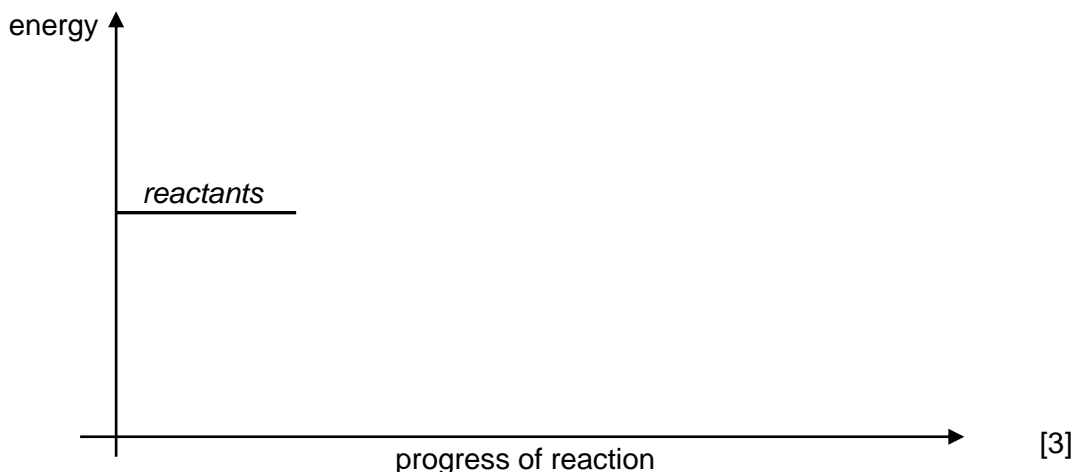
Explain your reasoning, using changes in oxidation states of aluminium and chlorine.

.....  
 .....  
 .....  
 ..... [3]

(d) Complete the energy profile diagram for this exothermic reaction.

Your diagram should show and label

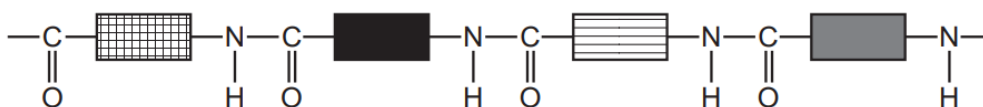
- 'products' of the reaction,
- the activation energy,  $E_a$ ,
- the enthalpy change,  $\Delta H$ , of reaction.



[Total: 9]

**3** Proteins and PET are polymers made by condensation polymerisation.

**(a)** The diagram in Fig. 3.1 shows the structure of a section of protein.



**Fig. 3.1**

**(i)** Draw a 'dot-and-cross' diagram of the molecule that is removed during the polymerisation of proteins. Show outer electrons only.

[2]

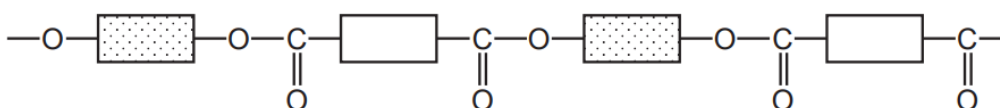
**(ii)** Proteins are polyamides.

Name one other example of a polyamide.

..... [1]

**(b)** PET is a polymer used to make plastic bottles.

The diagram in Fig. 3.2 shows the structure of PET.



**Fig. 3.2**

**(i)** Name the linkage present in PET.

..... [1]

**(ii)** Draw the structure of one of the monomers used to produce PET.

[1]

- (iii) Describe **one** environmental issue arising from excessive use of plastics and **one** method in which plastics can be recycled.

Issue: .....

.....

..... [1]

Method : .....

.....

..... [1]

- (c) Poly(ethene) is a polymer that is made by addition polymerisation.

Describe **two** differences between addition polymerisation and condensation polymerisation.

difference 1: .....

.....

..... [1]

difference 2: .....

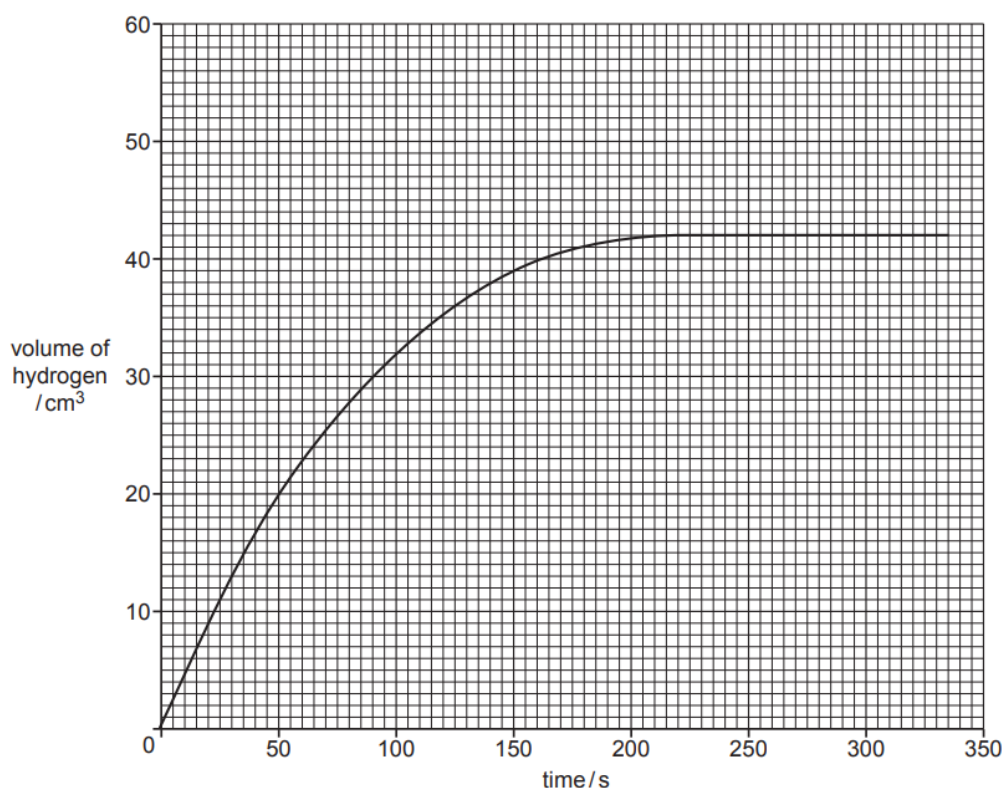
.....

..... [1]

[Total: 9]

- 4 Sue investigates the reaction of small pieces of zinc with dilute hydrochloric acid at 25°C. The dilute hydrochloric acid is in excess.

Fig. 4.1 shows the volume of hydrogen released as the reaction proceeds.



**Fig. 4.1**

- (a) Write a chemical equation, including state symbols, for the reaction.

..... [2]

- (b) Calculate the mass of zinc used in the reaction.

mass = ..... g [2]

- (c) From Fig. 4.1, how long did it take for half the mass of zinc to be used up?

..... [1]

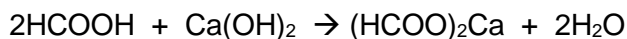
- (d) Sketch, on Fig. 4.1, the graph Sue will get if she repeats the experiment with hydrochloric acid in excess, but with half the mass of zinc used, in powdered form.

Label this graph as '*experiment 2*'.

[2]

[Total: 7]

- 5 Dilute methanoic acid reacts with aqueous calcium hydroxide.



- (a) Write an ionic equation for this neutralisation reaction between methanoic acid and calcium hydroxide.

..... [1]

- (b) Deduce the general equation for the reaction of methanoic acid with Group 2 metals. Use **M** as the symbol for a Group 2 metal.

..... [1]

- (c) Methanoic acid is a weak acid. It dissociates partially in water, producing methanoate ions and hydrogen ions, as shown.



- (i) How does the equation show that methanoic acid is a weak acid?

..... [1]

- (ii) Complete Fig. 5.1 to show the arrangement of the electrons, in the outer shells, for carbon and oxygen, in a methanoate ion.

Electrons of hydrogen (○) have been completed for you.

You should use the symbols provided for each element in the *key*.

[3]

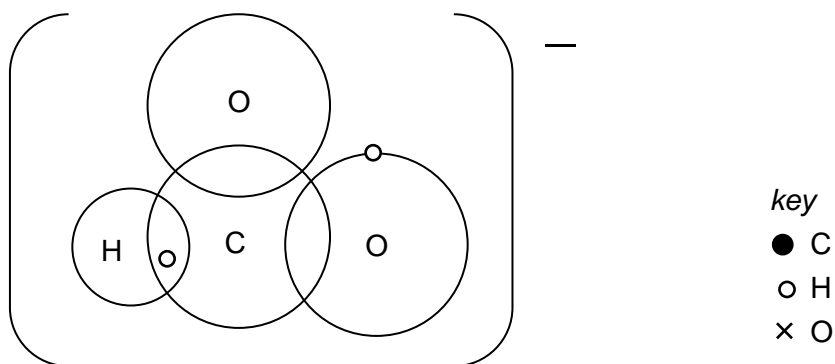


Fig. 5.1

[Total: 6]

- 6 Solvents made up of different mixtures of ethanol and water were used to separate the dyes in a sample of black ink. The black ink contains a mixture of blue, red and yellow dyes.

The coloured dyes have different  $R_f$  values in solvents with different compositions of ethanol as shown in Fig. 6.1 below.

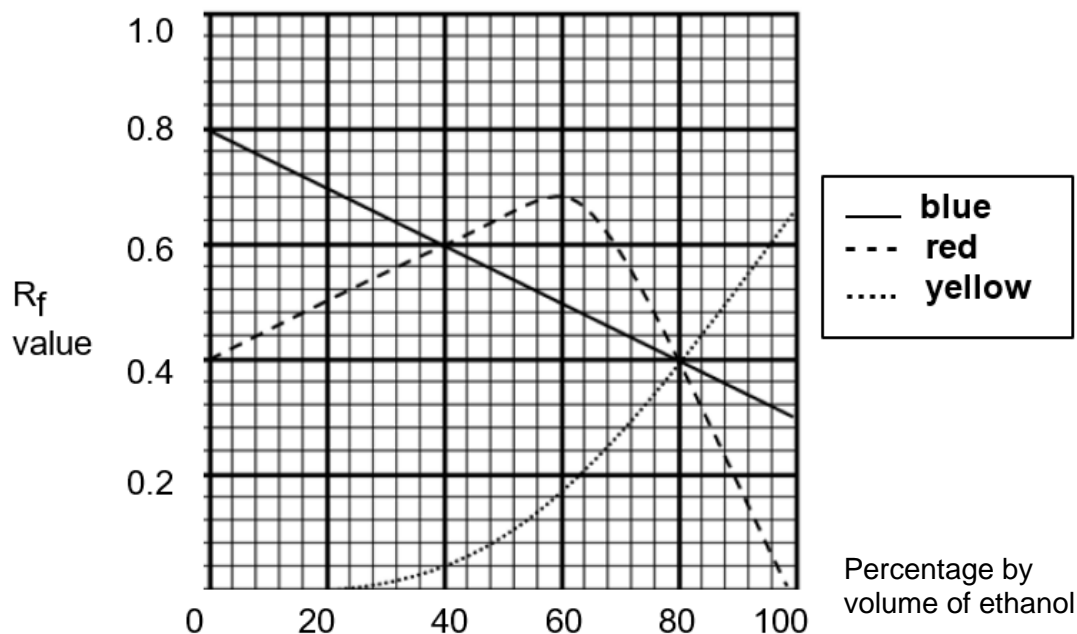


Fig. 6.1

- (a) Which coloured dye in black ink is insoluble in a solvent containing 100% ethanol?

..... [1]

- (b) From Fig. 6.1, which percentage by volume of ethanol cannot be used to separate all the dyes in black ink?

..... % [1]

Explain your answer.

..... [1]

- (c) What is the  $R_f$  value of the blue dye, when the solvent is made up of 96 cm<sup>3</sup> ethanol and 104 cm<sup>3</sup> water?

Show your working clearly.

[2]

[Total: 5]

- 7 The reactivity series of metals can be compared by their reactions with water, steam and displacement reactions. Some data of these experiments are recorded in Table 7.1 below.

Table 7.1

Metals	Reaction with water	Reaction with steam	Displacement reactions
Mercury	No visible change.	No visible change. Silvery metal remains unchanged.	No visible change.
Magnesium	Slow reaction	Metal burns in steam. Grey solid turns white.	Displaces zinc from $\text{Zn}(\text{NO}_3)_2$ (aq)
Iron	No visible change.	Reacts slowly with steam. Silvery solid turns black.	Displaces mercury from aqueous $\text{Hg}(\text{NO}_3)_2$ (aq)
Zinc	No visible change.	Reacts slowly with steam. Grey solid turns yellow when hot.	Displaces iron from $\text{Fe}(\text{NO}_3)_2$ (aq)

- (a) Arrange the metals in Table 7.1, from least reactive to most reactive.

..... [1]

- (b) Write an ionic equation, with state symbols, for the displacement reaction between zinc powder and aqueous iron(II) nitrate.

..... [2]

- (c) Solutions containing chromium(II) ions are usually blue and the reactivity of chromium is between iron and zinc.

Give one observation you would see if a piece of zinc metal is added to aqueous chromium(II) nitrate.

.....  
 .....  
 ..... [1]



- (d) The apparatus in Fig. 7.2 were set-up. Steam was passed into the first tube containing zinc powder. The zinc powder and iron(II) oxide were then heated.

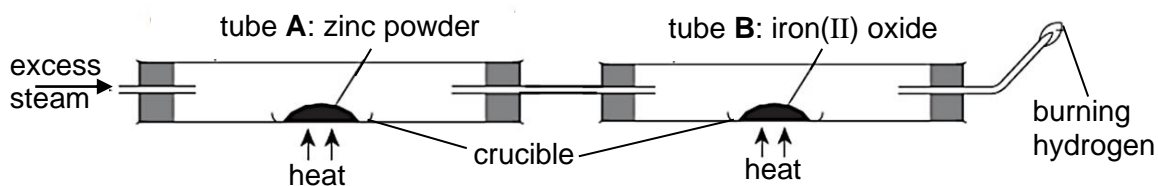


Fig. 7.2

- (i) Write a chemical equation for the reaction that occurs in tube A.

..... [1]

- (ii) Describe the redox reaction iron(II) oxide undergoes in tube B.

.....  
 ..... [1]

- (e) The following data were obtained from the experiment in Fig. 7.2.

	Mass / g
empty crucible used in tube B	10.03
empty crucible + solid residue after heating in tube B	18.03

Determine the mass of zinc used in tube A.

[3]

[Total: 9]

- 8 Methanol and propan-1-ol are alcohols.

The structural formula of methanol and propan-1-ol are shown in Fig. 8.1

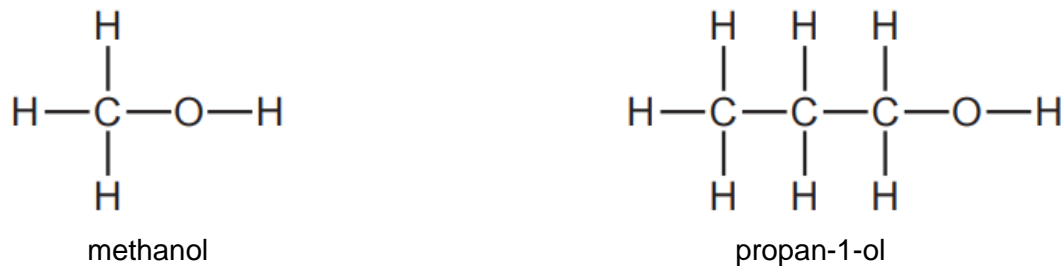


Fig. 8.1

- (a) Draw the structural formula of an isomer of propan-1-ol.

[1]

- (b) Purple acidified potassium manganate(VII) decolourises when added to a beaker of propan-1-ol.

Explain the observation and draw the structural formula of the product formed by propan-1-ol.

.....  
 .....  
 .....

[2]

- (c) Methanol reacts with ethanoic acid to form a sweet smelling product.

Draw the structural formula of this product.

[1]

- (d) (i) **X** is an organic acid containing the following composition by mass:

57.1% carbon

4.8% hydrogen

38.1% oxygen

Calculate the empirical formula of **X**.

[2]

- (ii) A 0.194 g sample of **X** is neutralised by 0.00462 mol of KOH.  
Given that one mole of **X** reacts with three moles of KOH, calculate the relative molecular mass of **X**, and hence deduce its molecular formula.

[2]

[Total: 8]

- 9 A news article reported how increasingly frequent hot weather had grounded commercial planes and affected air travel.

### How hot weather – and climate change – affect airline flights<sup>[1]</sup>

High air temperatures affect the physics of how aircraft fly, meaning aircraft takeoff performance can be impaired on hot days. The amount of lift that an airplane wing generates is affected by the density of the air. Air density in turn depends mostly on air temperature and elevation; higher temperatures and higher elevations both reduce density.

Hot air is less dense than cooler air. That affects the amount of lift an airplane can generate. The lower the air density, the faster an airplane must travel to produce enough lift to take off.

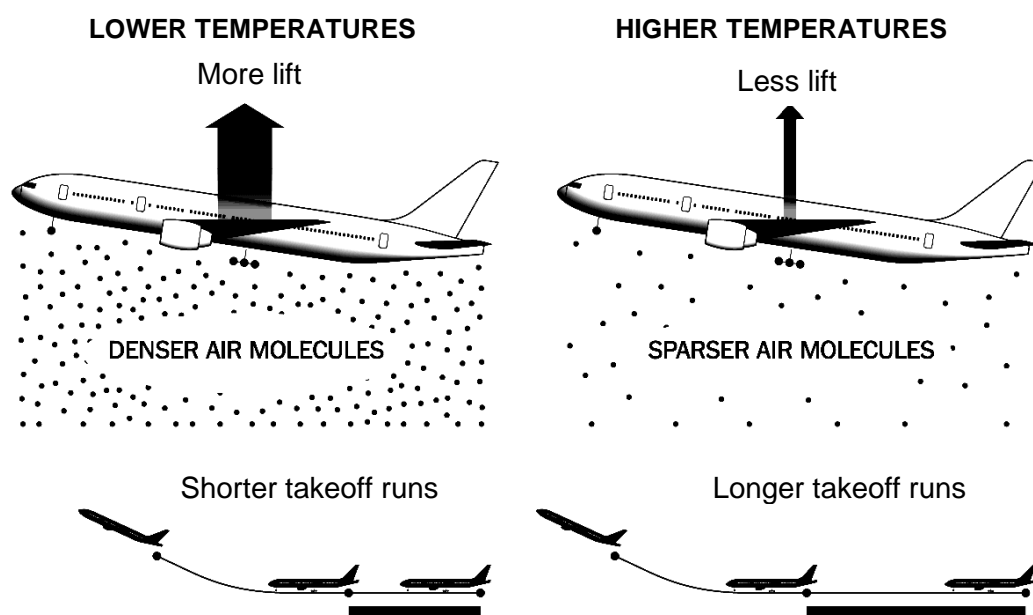


Fig. 9.1<sup>[2]</sup>

The takeoff distance (in feet) required for a 2550-pound airplane, at different temperatures, is given in Table 9.2. As a safety precaution, pilots typically will add an additional 15% to the required takeoff distance when planning their take offs.

Table 9.2<sup>[3]</sup>

Takeoff distance (in feet) at different temperatures					
Altitude (feet)	0°C	10°C	20°C	30°C	40°C
sea level	1465	1575	1690	1810	1945
1000	1600	1720	1850	1990	2135
2000	1755	1890	2035	2190	2355
3000	1925	2080	2240	2420	2605
4000	2120	2295	2480	2685	2880
5000	2345	2545	2755	2975	3205

With the increase in global temperature, at the same altitude, the takeoff distance also increases. This means a longer runway will have to be built for future airports, and more fuel, usually hydrocarbons, will have to be burnt to power the plane. However, environmentalists had put up a study to show that greater fuel usage may further contribute to global warming.

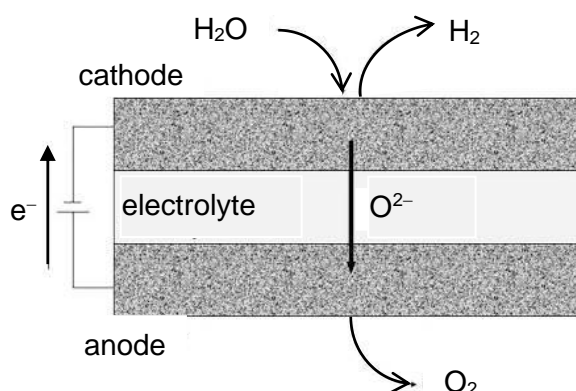
One of the current practices to reduce carbon dioxide emissions is to consider the use of green fuels. Green fuels, also termed synthetic or electrofuels (e-fuels), are liquid, or gaseous fuels produced with electricity from renewable sources. Examples for such e-fuels are synthetic natural gas (SNG), green methanol or ammonia. They are carbon-neutral when burned, emitting only the amount of  $\text{CO}_2$  absorbed during its production.<sup>[4]</sup>

Global ammonia production accounts for 1.3% of energy-related  $\text{CO}_2$  emissions, and uses hydrogen obtained from natural gas. The ammonia produced is used to manufacture fertilisers in the Haber Process.

Green ammonia is produced without fossil fuels and could help cut the high emissions associated with synthetic fertiliser production. Hydrogen is first produced via electrolysis of steam using solid oxide electrolyser (SOEs). A typical SOE consists of a cathode, a dense oxide-ion conducting electrolyte material and an anode. A SOE uses electricity to produce hydrogen.

The operating principle of a SOE steam electrolyser is shown in Fig. 9.3.

Steam enters on the cathode side of the cell where it accepts electrons provided by an external power source and is split into hydrogen gas and oxide ions. These oxide ions then migrate through dense electrolyte layer to the anode side of the cell where they are oxidised to form oxygen gas, which exits via the anode outlet.<sup>[5]</sup>



**Fig. 9.3**

- (a) Air density is measured by number of air molecules per unit volume. Using the Kinetic Particle Theory, explain why there are fewer air molecules per unit volume on a hotter day.

.....

.....

.....

[2]

- (b) With reference to Table 9.2, describe the relationship between takeoff distance and altitude.

.....  
 .....  
 ..... [2]

- (c) What is the takeoff distance (in metres) required for a 2550 pounds airplane to take off from Kallang Airport (take altitude to be at sea level) at 30°C?  
 [1 metre  $\approx$  3.28 feet]

takeoff distance  $\approx$  ..... m [1]

- (d) Suggest why greater fuel usage of planes contributes to global warming.

.....  
 .....  
 ..... [2]

- (e) Write half equations for the processes taking place at the electrodes in the SOE steam electrolyser (Fig. 9.3).

	half equation
cathode	
anode	

[2]

- (f) (i) Construct the overall equation in the operation of the SOE steam electrolyser.

..... [1]

- (ii) Using your equation or otherwise, calculate the maximum mass of hydrogen that can be made from 1 tonne of steam.  
 (1 tonne = 1000 kg)

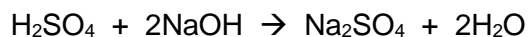
[2]

[Total: 12]

**Section B**

Answer **one** question from this section.

- 10** Sulfuric acid,  $\text{H}_2\text{SO}_4$ , is neutralised when it is added to aqueous sodium hydroxide,  $\text{NaOH}$ .



The reaction is exothermic.

**P** is  $1.25 \text{ mol/dm}^3$  aqueous sodium hydroxide.

**Q** is dilute sulfuric acid.

To determine the concentration of the sulfuric acid in **Q**, a student conducted six experiments and the results are tabulated in Table 10.1.

**Table 10.1**

experiment number	volume of <b>P</b> / $\text{cm}^3$	volume of water / $\text{cm}^3$	volume of <b>Q</b> / $\text{cm}^3$	initial temperature / $^\circ\text{C}$	highest temperature reached / $^\circ\text{C}$	temperature rise / $^\circ\text{C}$
1	25.0	20	5.0	23.0	25.5	
2	25.0	15	10.0	24.5	29.5	5.0
3	25.0	10		25.0	32.5	7.5
4	25.0	7	18.0	25.0	33.0	8.0
5	25.0	5	20.0	25.5	33.5	8.0
6	25.0		25.0	24.5	32.5	8.0

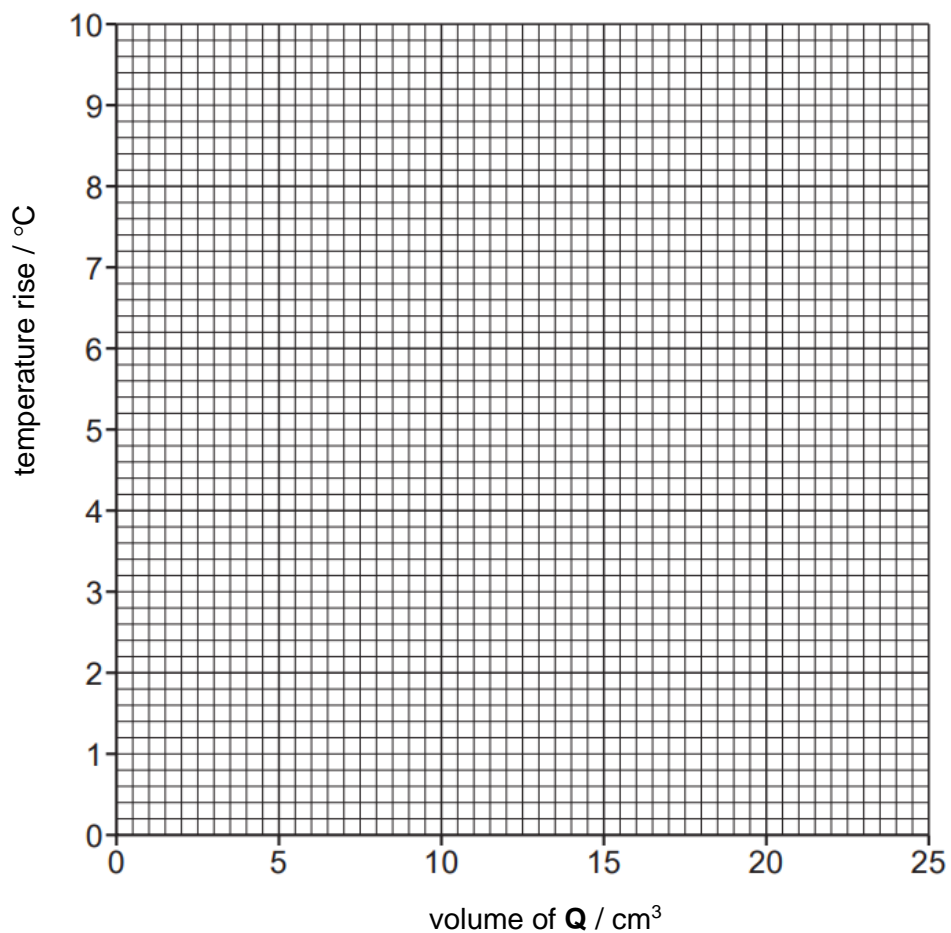
- (a)** Complete Table 10.1 by filling in the three missing values.

[1]

**(b)** Draw a graph of temperature rise against volume of **Q** on the grid below.

You should:

- plot the point (0,0) as there is no temperature rise when no **Q** is added;
- plot the temperature rises and volumes of **Q** from Table 10.1;
- draw a straight line of best fit for the first four points;
- draw a straight line of best fit for the last three points;
- extend the lines so that they intersect.



[3]

**(c)** The point where the two lines intersect indicates the volume of **Q** that exactly neutralises 25.0 cm<sup>3</sup> of **P**.

Determine the volume of **Q** where the two lines on the graph intersect.

volume of **Q** ..... cm<sup>3</sup> [1]



- (d)** Use your answer to **(c)** to calculate the concentration of the sulfuric acid in **Q**.

concentration of **Q** ..... mol/dm<sup>3</sup> [2]

- (e)** Calculate the mass of sodium sulfate produced in Experiment 5.

[3]

[Total: 10]

- 11 An ionic salt **W** has the chemical formula  $X_2Y_3$ .

**W** is a white solid at room temperature. It is soluble in water to form a colourless solution. The relative formula mass of **W** is 342.

Electrolysis of a solution of **W**, using inert electrodes, gives the observations as shown in Table 11.1.

**Table 11.1**

	At the anode	At the cathode
Observation	Colourless gas <b>Q</b> produced.	Colourless gas <b>R</b> produced.

To a sample of solution **W**, the following tests in Table 11.2 are conducted, and the observations are shown in the same table.

**Table 11.2**

test	Observation
1) Add NaOH (aq) until no further change	White ppt, soluble in excess NaOH (aq), giving a colourless solution
2) Add $NH_3$ (aq) until no further change	White ppt, insoluble in excess $NH_3$ (aq)
3) Add acidified barium nitrate solution	White ppt <b>S</b>
4) Add acidified silver nitrate solution	No visible change

- (a) State the identity of colourless gas **Q** and **R**.

colourless gas **Q** .....

colourless gas **R** .....

cation **X** .....

anion **Y** .....

[4]

- (b) Write the ionic equation for the formation of white precipitate **S**.

.....

[1]

- (c) (i) Write the half equation for the production of colourless gas **Q** at the anode.

.....

[1]

- (ii) Describe a chemical test for colourless gas **Q**.

.....  
 ..... [1]

- (d) Electrolysis of molten **W** can be done to extract metal **X**. In the extraction, **W** decomposes to produce metal **X**, oxygen and waste gases that contains an acidic gas that dissolves readily in rain water to form *acid rain*.

- (i) Describe one harmful effect of *acid rain*.

.....  
 ..... [1]

- (ii) Suggest a chemical reagent you can use to remove the acidic gas from the waste gases.

.....  
 ..... [1]

- (iii) Give the overall chemical equation for the decomposition of molten **W**.

..... [1]

[Total: 10]

### End of Paper

#### Sources:

[1] <https://theconversation.com/how-hot-weather-and-climate-change-affect-airline-flights-80795>

[2] Infographic from National Oceanic and Atmospheric Administration by The New York Times

[3] <https://bruceair.wordpress.com/2022/04/20/takeoff-and-landing-performance/>

[4] [https://www.engieimpact.com/insights/green-](https://www.engieimpact.com/insights/green-fuels#:~:text=There%20are%20three%20types%20of,and%20e%2Dmethanol%20(green%20hydrogen)

[fuels#:~:text=There%20are%20three%20types%20of,and%20e%2Dmethanol%20\(green%20hydrogen](https://www.engieimpact.com/insights/green-fuels#:~:text=There%20are%20three%20types%20of,and%20e%2Dmethanol%20(green%20hydrogen)

[5] <https://www.sciencedirect.com/science/article/pii/S0196890423001620>