

Answer key

CHEMISTRY Stage 3

Section One: Multiple-choice

25% (50 marks)

1	A	14	A
2	B	15	C
3	A	16	B
4	D	17	A
5	C	18	C
6	A	19	D
7	C	20	B
8	A	21	D
9	C	22	B
10	C	23	B
11	C	24	B
12	D	25	C
13	B		

Section Two: Short answer

35% (70 Marks)

This section has **eight (8)** questions. Answer **all** questions. Write your answers in the space provided.

When calculating numerical answers, show your working or reasoning clearly. Express numerical answers to three significant figures and include appropriate units where applicable.

Do not use abbreviations, such as 'nr' for 'no reaction', without first defining them.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

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Suggested working time: 60 minutes.

Question 26**(7 marks)**

For each of the following pairs of substances, provide details of a **chemical** test that would allow the two substances to be distinguished from one another. Equations are **not** required.

substances	chemical test	Observations 1 mark each
Ni(s) and Mg(s)	Add dilute acid (eg HCl(aq)) (1 mark)	Ni(s) Dissolves to give green solution
		Mg(s) Dissolves to give c/less solution
NaCH ₃ COO(s) and NaCl(s)	Dissolve solid in water (1 mark) then Add silver nitrate solution (1 mark) Simply adding AgNO ₃ (aq) gains only 1 mark	NaCH ₃ COO(s) Solid dissolves, but NVR on addition of silver nitrate
		NaCl(s) Solid dissolves, and white ppt formed on addition of silver nitrate

Accept other valid tests.

See next page

Question 27

(8 marks)

- (a) 2-methylpropanal, whose formula is $(\text{CH}_3)_2\text{CHCHO}$, has two structural isomers. In the spaces provided below, draw the full structure and give the IUPAC names of these two isomers. (4 marks)

structure	IUPAC name
$ \begin{array}{ccccccc} & \text{H} & \text{H} & \text{H} & & \text{O} & \\ & & & & & // & \\ \text{H} & - \text{C} & - \text{C} & - \text{C} & - & \text{C} & \\ & & & & & \backslash & \\ & \text{H} & \text{H} & \text{H} & & \text{H} & \end{array} $ <p>1 mark</p>	<p>Butanal 1 mark</p>
$ \begin{array}{c} \text{O} \\ \\ \text{CH}_2 - \text{CH}_2 - \text{C} - \text{CH}_3 \end{array} $ <p>1 mark</p>	<p>Butanone 1 mark</p>

2-methylpropanal can be converted into substance Y by heating it with a mixture of sodium dichromate and dilute sulfuric acid.

- (b) State an observation that can be made as this reaction proceeds. (1 mark)

Orange solution turns green 1 mark

- (c) Name the functional group present in substance Y that is **not** present in 2-methylpropanal. (1 mark)

Carboxylic acid 1 mark

- (d) Write a balanced half-equation showing the conversion of 2-methylpropanal into substance Y (2 marks)



correct formula of organic product

1 mark

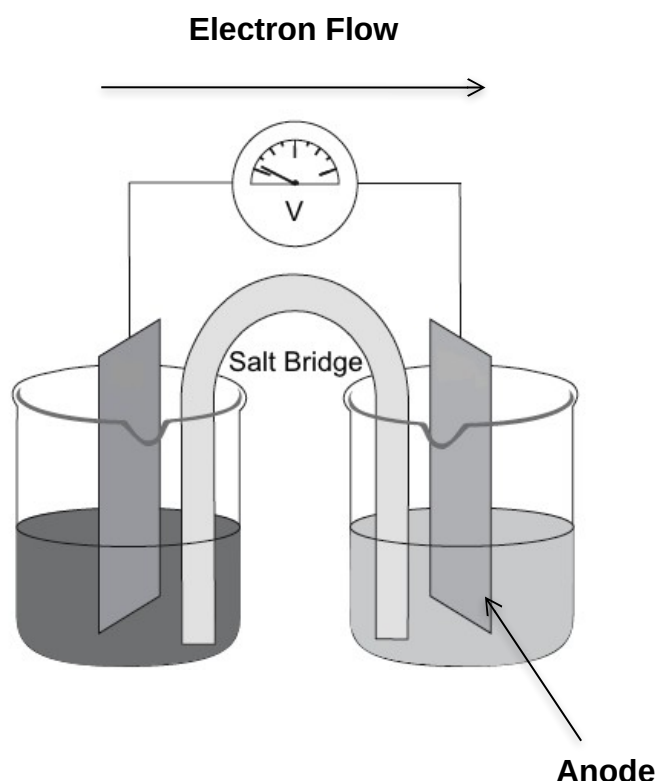
correctly balanced

1 mark

Question 28

(12 marks)

A student wishing to investigate the oxidising strength of various metals set up an electrochemical cell made up of a copper rod immersed in a solution of copper(II) sulfate and a magnesium rod immersed in a solution of magnesium nitrate. The apparatus used is shown in the diagram below, with the copper half cell on the left.



- a) Add a label to the diagram to show the anode. (1 mark)

Anode clearly shown as being electrode on the right

- b) By adding an arrow to the diagram, show the direction of electron flow in the external circuit. (1 mark)

Direction of electron flow clearly shown from left electrode to right

- c) Give the half equation for the reaction occurring at the positive electrode. (1 mark)



- d) Give the name or formula of a suitable substance that the salt bridge might contain. (1 mark)

Potassium nitrate

- e) Identify the reducing agent (reductant) in the cell. (1 mark)

See next page

Magnesium

- f) The initial voltage measured in the cell was higher than the 2.70 V that the student had expected to measure. Give **one** possible reason for this observation. (1 mark)

Not measured at 25°C/not 1 molL⁻¹ solutions

- g) Describe an observation that would be expected to be made in the copper half-cell whilst the experiment was taking place. (1 mark)

salmon-pink solid forms/blue solution fades

- h) The student weighed both electrodes before and after the experiment, and found that one had increased in mass by 0.253 g. Calculate the mass lost from the other electrode in g. (3 marks)

$$n(\text{Mg}) = n(\text{Cu}) \quad 1 \text{ mark}$$

$$n(\text{Cu}) = m(\text{Cu})/63.55 = 0.253/63.55 = 3.98 \times 10^{-3} \text{ mol (3sf)} \quad 1 \text{ mark}$$

$$m(\text{Mg}) = 3.98 \times 10^{-3} \times 24.31 = 9.68 \text{ g (3sf)} \quad 1 \text{ mark}$$

Max 2 marks if based on 0.253 g of Mg

Rusting can be described as the formation of iron(III) hydroxide from iron in the presence of water and oxygen. Rusting can be prevented by attaching magnesium to the object that is to be protected.

- i) With reference to the list of redox potentials found on your data sheet, explain why magnesium is a suitable material for this purpose. (2 marks)

Magnesium has a more negative potential than iron/is a better reducing agent than iron

1 mark

Magnesium will be oxidized instead of the iron

1 mark

Question 29

(9 marks)

For each species listed in the table below, draw the Lewis structure, representing all valence shell electron pairs either as : or as — **and** state or sketch the shape of the species.

(for example, water $\text{H}:\ddot{\text{O}}:\text{H}$ or $\text{H}-\ddot{\text{O}}-\text{H}$ or $\text{H}-\ddot{\text{O}}^--\text{H}$ bent, polar)

Species	Lewis structure (showing all valence electrons) 2 marks each	Shape (sketch or name) 1 mark
phosphorus trichloride PCl_3	$ \begin{array}{c} :\ddot{\text{Cl}}: \\ \\ :\ddot{\text{Cl}}-\text{P}-\ddot{\text{Cl}}: \\ \vdots \end{array} $	(trigonal) pyramidal
ethyne C_2H_2	$\text{H}-\text{C}\equiv\text{C}-\text{H}$	linear
nitrate ion NO_3^-	$ \left[\begin{array}{c} \ddot{\text{O}} \\ \\ :\ddot{\text{O}}-\text{N}-\ddot{\text{O}}: \\ \vdots \end{array} \right]^- $	(triangular/trigonal) planar

Question 30**(9 marks)**

By referring to the structure and/or bonding present, account for the following:

- (a) Carbon's electronegativity (2.55) is higher than that of phosphorus (2.19). (3 marks)

Carbon has fewer shells than phosphorus (or electrons are closer to nucleus) 1 mark

Phosphorus has more protons than carbon, but greater shielding (or phosphorus has a higher core charge) 1 mark

Bonding electrons experience greater pull from carbon's nucleus 1 mark

- (b) Aluminium is a better conductor of electricity than magnesium. (2 marks)

Aluminium forms 3+ ions, whereas magnesium forms 2+ 1 mark

More delocalized electrons (i.e. mobile charge carriers) in aluminium 1 mark

- (c) Silicon dioxide (SiO_2) is a solid with an extremely high melting point, whilst carbon dioxide (CO_2) sublimates at -78°C . (4 marks)

Silicon dioxide is a network covalent structure 1 mark

Melting involves breaking strong covalent bonds 1 mark

Carbon dioxide is covalent molecular 1 mark

Melting (subliming) involves breaking weak intermolecular (dispersion) forces 1 mark

Question 31

(7 marks)

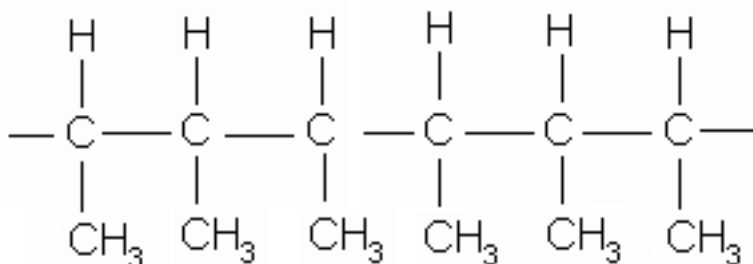
- (a) But-1-ene and but-2-ene are isomers of one another. What is the name given to this type of isomerism? (1 mark)

Structural isomerism

- (b) In addition to the type of isomerism displayed by the molecules in part (a), but-2-ene itself exhibits another type of isomerism. State the name given to this type of isomerism, and identify the features of but-2-ene that make this type of isomerism possible. (3 marks)

Geometric isomerism**1 mark****Presence of C=C double bond****1 mark****With two different groups attached to EACH end of C=C****1 mark**

- (c) In the space provided, draw a length of polymer chain that could be formed from but-2-ene, showing **three** repeating units. (2 marks)

**correct number of carbon atoms in main chain****1 mark****1 x CH₃ group on every carbon in chain****1 mark**

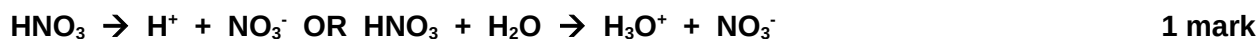
- (d) State the name given to the type of polymerisation described in part (c). (1 mark)

addition

Question 32

(8 marks)

- (a) Nitrous acid (HNO_2) is a weak acid. Use relevant equations to explain how you would expect the pH of a 0.1 mol L^{-1} solution of nitrous acid to compare with that of a 0.1 mol L^{-1} solution of nitric acid. (3 marks)



Since nitric acid dissociates completely, and nitrous acid does not, $[\text{H}^+]$ will be higher in solutions of nitric acid, hence pH is LOWER than for nitrous acid 1 mark

A titration is carried out using 25.0 mL of approximately 0.9 mol L^{-1} ammonia solution placed in a conical flask. A few drops of indicator are added, and 0.900 mol L^{-1} nitric acid is added from a burette.

The table below shows some indicators, together with their pH ranges, and their colours.

indicator name	pH range	colour in acid	colour in base
methyl yellow	2.9 – 4.0	red	yellow
bromothymol blue	6.0 – 7.6	yellow	blue
nile blue	10.1 – 11.1	blue	red
nitramine	11.0 – 13.0	colourless	orange

- (b) From the indicators shown in the table, choose one that would be suitable for the titration, and state the colour change that would be expected to occur. (2 mark)

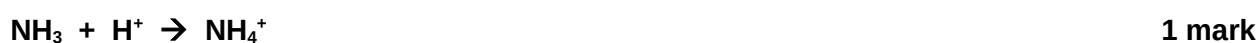
Indicator: methyl yellow or bromothymol blue

Colour change: yellow to red (MY) or blue to yellow (BB)

When approximately 12.5 mL of nitric acid have been added, the solution in the flask can be classified as a buffer solution.

- (c) With the aid of equations, explain how the solution is able to act as a buffer. (3 marks)

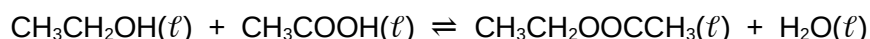
Ammonium ions are able to react with base, whilst ammonia molecules can react with acid 1 mark



Question 33

(10 marks)

When ethanol and ethanoic acid are mixed together in concentrated sulfuric acid, the following reversible reaction occurs:



- (a) Identify the type of reaction taking place in the forward direction, and give the IUPAC name of the organic product. (2 marks)

Type of reaction: **esterification/condensation**

Name of product: **ethyl ethanoate**

- (b) Write an expression for the equilibrium constant, K, for the reaction in the space provided. (1 mark)

$$K = \frac{[\text{CH}_3\text{CH}_2\text{OOCCH}_3][\text{H}_2\text{O}]}{[\text{CH}_3\text{CH}_2\text{OH}][\text{CH}_3\text{COOH}]}$$

- (c) The reaction is usually carried out at high temperatures in order to increase the yield. State and explain what this tells us about the enthalpy of the products compared to the enthalpy of the reactants. (3 marks)

Endothermic reactions are favoured by high T 1 mark

If yield increases at high T, then FORWARD reaction is endothermic 1 mark

Hence products have a higher enthalpy than the reactants 1 mark

A titration can be used to determine the proportions of reactants and products present at equilibrium. Sodium hydroxide solution is added quantitatively to the reaction mixture, reacting first with the sulfuric acid and then with any remaining ethanoic acid. The amount of ethanoic acid present at equilibrium can be easily determined since the sulfuric acid is present in the same quantity as at the start of the experiment.

Although the addition of sodium hydroxide does disturb the equilibrium, the inaccuracy introduced is small if the reaction mixture is cooled immediately prior to titration.

- (d) State the effect of addition of sodium hydroxide on the value of the **equilibrium constant**, K , by circling the correct answer below. (1 mark)

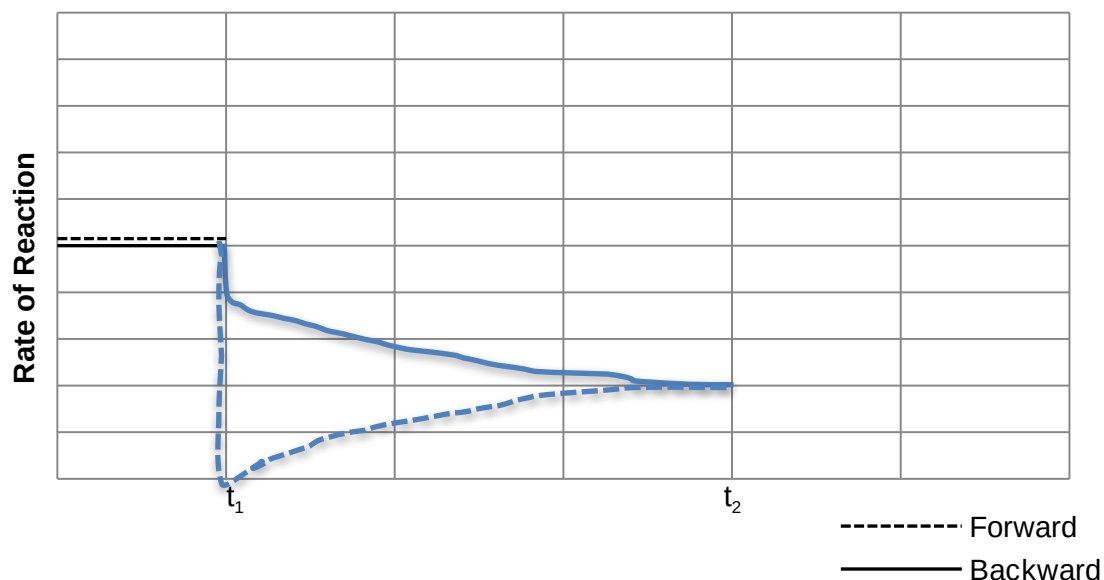
Effect on K (circle one)

INCREASE

DECREASE

NO CHANGE

- (e) On the axes shown below, sketch the effect of cooling the reaction mixture (t_1) on the rates of the forward and backward reactions until the system returns to a new equilibrium (t_2). (3 marks)



Both rates drop

1 mark

Forward rate drops more than backward

1 mark

Rates equal at t_2

1 mark

End of section two

See next page

Section Three: Extended answer

40% (85 marks)

This section contains **five (5)** questions. Answer **all** questions. Write your answers in the spaces provided.

Where questions require an explanation and/or description, marks are awarded for the relevant chemical content and also for coherence and clarity of expression.

Final answers to calculations should be expressed to three (3) significant figures.

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Suggested working time: 70 minutes.

Question 34

(13 marks)

Chlorine is found in acids of various strengths. Chlorine can exist in different oxidation states. Some acids are shown in the table below.

Name and formula of acid	Strong/Weak
hydrochloric acid HCl	strong
hypochlorous acid HOCl	weak
chlorous acid HClO_2	weak
chloric acid HClO_3	strong
perchloric acid HClO_4	strong

- (a) What mass of perchloric acid would need to be dissolved in 250 mL of distilled water to produce a solution with a pH of 3.59? (3 marks)

$$[\text{HClO}_4] = [\text{H}^+] = 10^{-3.59} = 2.57 \times 10^{-4} \text{ mol L}^{-1} \quad \text{1 mark}$$

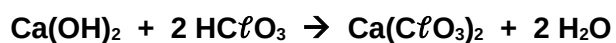
$$n = c \times v = 2.57 \times 10^{-4} \times 0.25 = 6.43 \times 10^{-5} \text{ mol} \quad \text{1 mark}$$

$$m = n \times M = 6.43 \times 10^{-5} \times (1.008 + 35.45 + 16 \times 4) = 6.46 \times 10^{-3} \text{ g} \quad \text{1 mark}$$

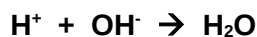
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1.20 g of solid calcium hydroxide was added to a beaker containing 200 mL of a 0.160 mol L⁻¹ aqueous solution of chloric acid, and the solution stirred until all the solid had dissolved.

(b) Write a balanced ionic equation to show the reaction taking place in the beaker. (2 marks)



1 mark



2 marks

(c) Determine the limiting reagent by calculation.

(4 marks)

$$n(\text{Ca(OH)}_2) = 1.20 / (40.06 + 2 \times 16 + 2 \times 1.008) = 1.62 \times 10^{-2} \text{ mol (3sf)}$$

1 mark

$$n(\text{HClO}_3) = c \times v = 0.160 \times 0.200 = 3.20 \times 10^{-2} \text{ mol}$$

1 mark

$$1.62 \times 10^{-2} \text{ mol of Ca(OH)}_2 \text{ requires } 2 \times 1.62 \times 10^{-2} \text{ mol HClO}_3 = 3.24 \times 10^{-2}$$

1 mark

so HClO₃ is LR

1 mark

(d) Calculate the pH of the resulting solution.

(4 marks)

$$n(\text{OH}^-) \text{ in XS} = 3.24 \times 10^{-2} - 3.20 \times 10^{-2} = 3.99 \times 10^{-4} \text{ mol}$$

1 mark

$$[\text{OH}^-] = n/v = 3.99 \times 10^{-4} / 0.200 = 2.00 \times 10^{-3} \text{ mol L}^{-1}$$

1 mark

$$[\text{H}^+] = 10^{-14} / 2.00 \times 10^{-3} = 5.01 \times 10^{-12}$$

1 mark

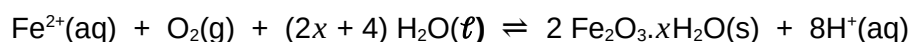
$$\text{pH} = -\log(5.01 \times 10^{-12}) = 11.3$$

1 mark

Question 35

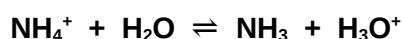
(17 marks)

Solutions of iron(II) salts are often used in redox titrations, but can be problematic as the Fe^{2+} ions can be oxidised by oxygen in the environment, forming various hydrated forms of iron(III) oxide, according to the following equation:



Ammonium iron(II) sulfate, or Mohr's salt, is often preferred over iron(II) sulfate for redox titration purposes since the unwanted oxidation of Fe^{2+} is prevented by the ammonium ions present, which reduce the pH of the solution. Mohr's salt is commonly found in hydrated form, as any of a number of salts with the formula $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$.

- (a) Write an equation to show how the ammonium ions are able to lower the pH of the solution. (2 marks)



- (b) Use the equation given above to explain why the oxidation of Fe^{2+} is prevented in solutions of low pH. (2 marks)

At low pH, we have increased $[\text{H}^+]$

1 mark

Rate of backward reaction will increase since there is an increased chance of collision

between $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$ and H^+ (i.e. preventing oxidation of Fe^{2+})

1 mark

10.0 g of hydrated ammonium iron(II) sulfate crystals were dissolved in distilled water and made up to 250 mL in a volumetric flask. 25.0 mL aliquots of this solution were titrated against 0.0240 mol L⁻¹ potassium permanganate solution until consistent results were obtained. The table below shows the results of the experiment.

	Rough	1	2	3	4
Final volume (mL)	23.00	21.25	21.25	22.65	23.35
Initial volume (mL)	0.00	0.05	0.00	0.10	2.10
Titre (mL)	23.00	21.20	21.25	22.55	21.25

- (c) Complete the table and calculate the average titre volume.

(1 mark)

Average titre: **(21.20 + 21.25 + 21.25)/3 = 21.23 (2dp)**

(d) Write a balanced ionic equation for the reaction taking place.

(2 marks)



Correct species

1 mark

Balanced

1 mark

(e) Calculate the value of x in the formula $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$.

(10 marks)

$$n(\text{MnO}_4^-) = c \times v = 0.0240 \times 0.02123 = 5.10 \times 10^{-4} \text{ mol}$$

1 mark

$$n(\text{Fe}^{2+}) = n(\text{MnO}_4^-) \times 5$$

1 mark

$$n(\text{Fe}^{2+}) \text{ in } 25 \text{ mL} = 5.10 \times 10^{-4} \times 6 = 2.55 \times 10^{-3} \text{ mol}$$

1 mark

$$n(\text{Fe}^{2+}) \text{ in } 250 \text{ mL} = 2.55 \times 10^{-2} \text{ mol}$$

1 mark

$$n((\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2) = n(\text{Fe}^{2+}) = 2.55 \times 10^{-2} \text{ mol}$$

1 mark

$$M((\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2) = 2 \times 14.01 + 8 \times 1.008 + 55.85 + 2 \times 32.06 + 8 \times 16 = 284.054$$

1 mark

$$m((\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2) = n \times M = 2.55 \times 10^{-2} \times 284.054 = 7.24 \text{ g}$$

1 mark

$$m(\text{H}_2\text{O}) = 10.0 - 7.24 = 2.76 \text{ g}$$

1 mark

$$n(\text{H}_2\text{O}) = 2.76/18.016 = 0.153 \text{ mol}$$

1 mark

$$n((\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2) : n(\text{H}_2\text{O}) = 6.02 \text{ and } x = 6$$

1 mark

Question 36

(22 marks)

A sample of powdered magnesium sulfate is known to have been contaminated with sodium chloride. The percentage purity of the magnesium sulfate can be determined by the following method:

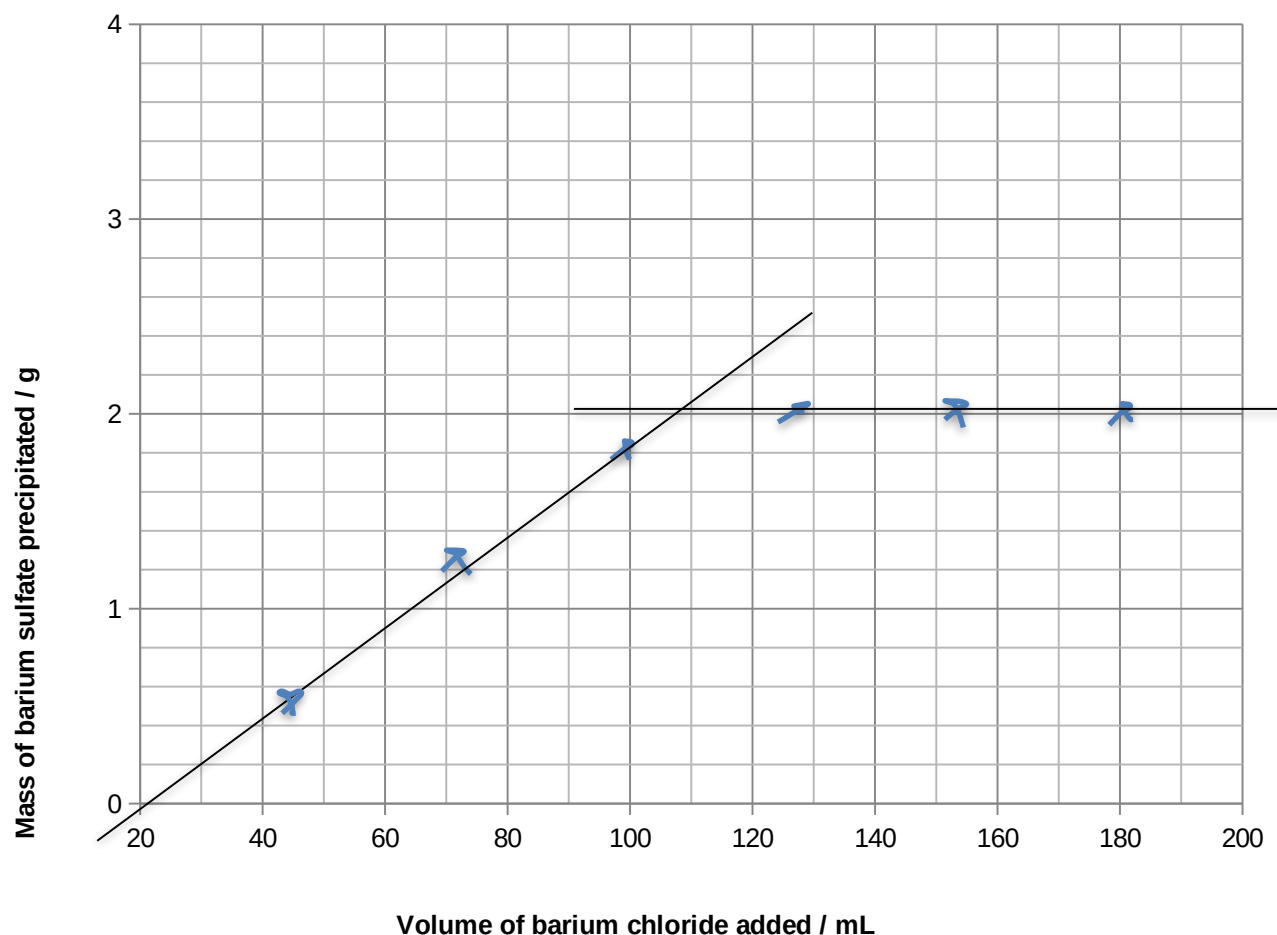
- 32.50 g of the impure magnesium sulfate is dissolved in water and the solution is made up to 500.0 mL in a volumetric flask.
- Six 20.0 mL aliquots of this solution are placed in separate conical flasks.
- Different volumes of $0.100 \text{ mol L}^{-1} \text{ BaCl}_2(\text{aq})$ are added to each flask, causing any sulfate ions present to precipitate out of the solution.
- The precipitate from each sample is filtered, rinsed with distilled water and then dried to constant mass.

The results of this analysis are shown in the table below.

Sample	1	2	3	4	5	6
Volume of $\text{BaCl}_2(\text{aq})$ added (mL)	30.0	60.0	90.0	120.0	150.0	180.0
Mass of $\text{BaSO}_4(\text{s})$ precipitated (g)	0.61	1.23	1.83	2.04	2.04	2.04

(a) Display the results in a suitable format using the axes provided.

(2 marks)



Points plotted correctly
2 best fit straight lines

1 mark
1 mark

See next page

(b) Write a balanced ionic equation for the reaction taking place. (1 mark)



(c) Explain why the mass of precipitate remained constant for the last three samples, in spite of the fact that more barium chloride was being added. (1 mark)

Sulfate ions are limiting reagent/no more sulfate ions left in solution **1 mark**

(d) Use the mass of precipitate to calculate the percentage purity of the magnesium sulfate. (5 marks)

$n(\text{BaSO}_4) = 2.04 / (137.3 + 32.06 + 4 \times 16) = 8.74 \times 10^{-3} \text{ mol}$ **1 mark**

$n(\text{MgSO}_4) \text{ in } 20.0 \text{ mL} = n(\text{SO}_4) = 8.74 \times 10^{-3} \text{ mol}$ **1 mark**

$n(\text{MgSO}_4) \text{ in } 500.0 \text{ mL} = 8.74 \times 10^{-3} \text{ mol} \times 25 = 0.219 \text{ mol}$ **1 mark**

$m(\text{MgSO}_4) = 0.219 \times (24.3 + 32.06 + 4 \times 16) = 26.3 \text{ g}$ **1 mark**

$\% \text{ by mass} = 26.3 / 32.50 \times 100\% = 80.9\%$ **1 mark**

(e) Use the graph you have drawn in part (a) to estimate the minimum volume of barium chloride needed to precipitate all the sulfate ions from solution. (1 mark)

97 – 102 mL

Question 36 (continued)

- (f) Calculate the final concentration (in mol L⁻¹) of chloride ions in the filtrate collected from **sample four**. You may assume that sodium chloride was the only impurity present in the impure magnesium sulfate. (7 marks)

(using 102 mL from previous q)

$$n(\text{Cl}^-) \text{ from BaCl}_2 = 2 \times c \times v = 0.100 \times 0.120 = 0.0120 \text{ mol} \quad 1 \text{ mark}$$

$$m(\text{NaCl}) \text{ in } 500 \text{ mL} = 19.1\% \times 32.5 \text{ g} = 6.20 \text{ g} \quad 1 \text{ mark}$$

$$m(\text{NaCl}) \text{ in } 20 \text{ mL} = 6.20/25 = 0.248 \text{ g} \quad 1 \text{ mark}$$

$$n(\text{Cl}^-) \text{ in } 20 \text{ mL} = n(\text{NaCl}) = 0.248/(22.99 + 35.45) = 4.24 \times 10^{-3} \text{ mol} \quad 1 \text{ mark}$$

$$\text{total } n(\text{Cl}^-) = 4.24 \times 10^{-3} + 0.0120 = 0.0162 \text{ mol} \quad 1 \text{ mark}$$

$$\text{total volume} = 0.120 + 0.020 = 0.140 \text{ L} \quad 1 \text{ mark}$$

$$c = n/v = 0.0162/0.140 = 0.116 \text{ mol L}^{-1} \quad 1 \text{ mark}$$

- (g) Another student carried out a similar analysis, but neglected to rinse the precipitates before drying them. Explain what effect this would have on the student's calculated value of the percentage purity. (3 marks)

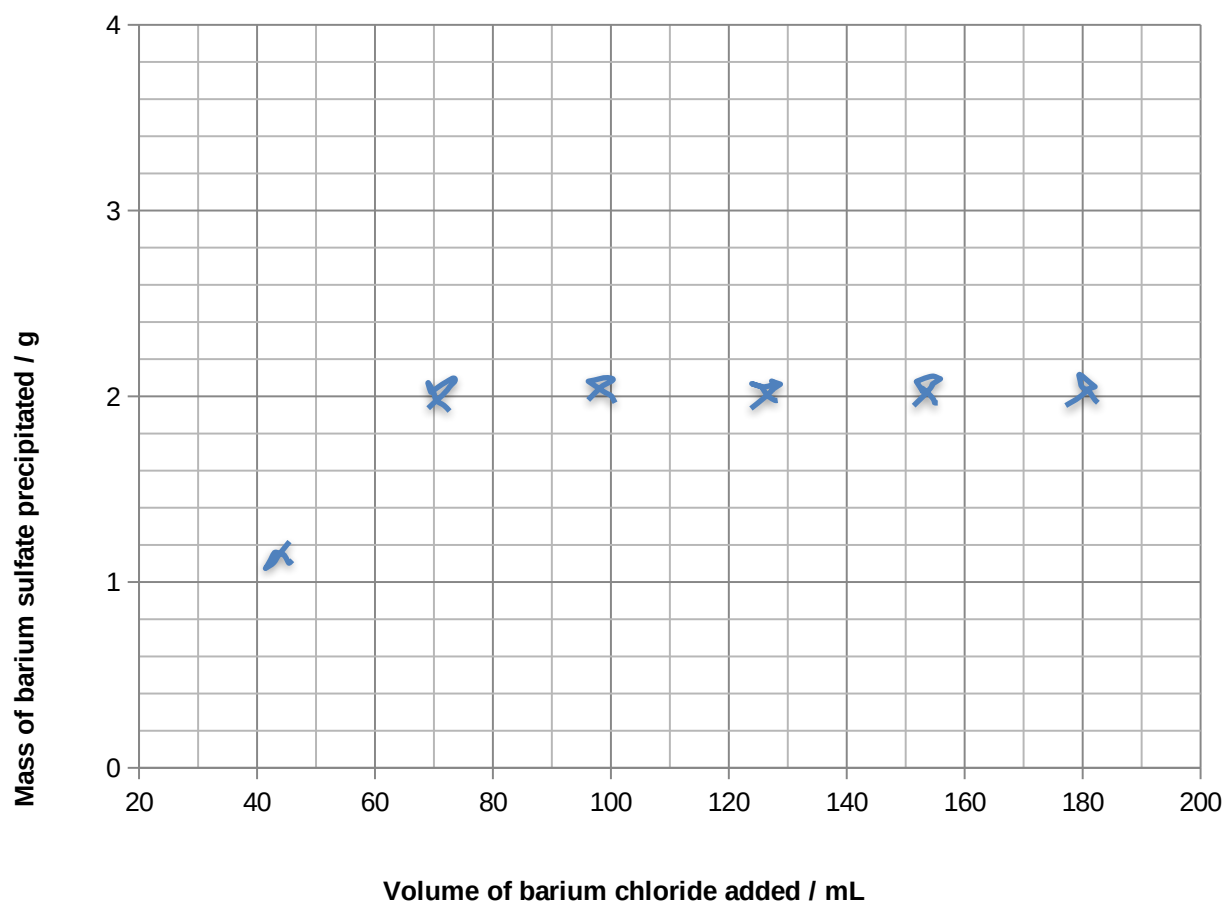
Precipitates would have artificially large masses 1 mark

Gives higher $n(\text{SO}_4^{2-})$ 1 mark

And artificially high % purity (i.e. % MgSO_4 too high) 1 mark

The analysis was repeated using six further 20 mL aliquots of the impure magnesium sulfate solution and the same volumes of barium chloride. However, the concentration of the barium chloride solution used was 0.200 mol L^{-1} .

- (h) Using the axes below, draw the graph of the expected results when plotting the mass of barium sulfate precipitated against volume of barium chloride added. (2 marks)



1st point at 30 mL showing 1.22 g of barium sulfate

1 mark

All other points at 2.04 g

1 mark

Question 37

(11 marks)

The functional groups present in organic molecules can, by definition, have a strong influence on the chemical properties of those molecules, but they can also play a role in determining the physical properties of substances.

The table below outlines some of the physical properties of four organic substances; pentane, 2,2-dimethylpropane, 2-pentene, and propanoic acid.

	boiling point (°C)	solubility in water	solubility in ethanol
pentane	36.1	low	high
2,2-dimethylpropane	9.5	low	high
pent-2-ene	37.0	low	high
propanoic acid	144.1	high	high

With clear reference to the structure and bonding present, compare and contrast the **chemical and physical properties** of the four substances. You should focus on the physical data provided in the table, and use your knowledge of the functional group chemistry of the compounds.

Your answer should include equations where appropriate.

Marks are awarded for clarity of communication. Answers may be written as a series of dot points and diagrams may be used, but care should be taken to ensure that there is a logical sequence of ideas and that any abbreviations or diagrams are explained clearly.

Intermolecular Forces

- Pentane, 2,2-dimethylpropane and pent-2-ene are all non-polar molecules, so dispersion forces are the only intermolecular force
- All the molecules have similar molecular mass, so should be expected to have similar strength dispersion forces
- 2,2-dimethylpropane has a lower boiling point than pentane and pent-2-ene since its branches prevent molecules from packing as closely together
- Propanoic acid is able to form hydrogen bonds
- Hydrogen bonds are the strongest intermolecular force, hence highest boiling point for propanoic acid
- The dispersion forces that pentane, 2,2-dimethylpropane and pent-2-ene are able to form with water are weak compared to the H-bonds between water molecules, hence they are insoluble in water
- However, ethanol can form stronger dispersion forces with pentane, 2,2-dimethylpropane and pent-2-ene than can water, hence all dissolve well in ethanol
- Propanoic acid can form strong H-bonds with water and ethanol, making it soluble in both solvents

Chemical Properties

- All substances will burn in oxygen to form carbon dioxide and water
- e.g. $\text{C}_5\text{H}_{12} + 8 \text{O}_2 \rightarrow 5 \text{CO}_2 + 6 \text{H}_2\text{O}$
- Pentane and 2,2-dimethylpropane will react with halogens in the presence of UV light in substitution reactions
- e.g. $\text{C}_5\text{H}_{12} + \text{Br}_2 \rightarrow \text{C}_5\text{H}_{11}\text{Br} + \text{HBr}$
- Pent-2-ene will react with halogens in the dark in addition reactions
- $\text{C}_5\text{H}_{10} + \text{Br}_2 \rightarrow \text{C}_5\text{H}_{10}\text{Br}_2$

See next page

- Propanoic acid will react with metals to form a salt and hydrogen (or other typical acid reactions)
- e.g. $2 \text{CH}_3\text{CH}_2\text{COOH} + \text{Mg} \rightarrow 2 \text{CH}_3\text{CH}_2\text{COO}^- + \text{Mg}^{2+} + \text{H}_2$
- Propanoic acid will react with alcohols to produce esters
- e.g. $\text{CH}_3\text{CH}_2\text{COOH} + \text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_3\text{CH}_2\text{COOCH}_2\text{CH}_3 + \text{H}_2\text{O}$
- Pent-2-ene will form addition polymers

Students can score marks for a maximum of 10 points

A mark should be awarded for an answer that is clearly written with points made in a logical order

Question 38

(17 marks)

The European Aviation Safety Agency (EASA) have recently sponsored studies into ultra-low sulfur jet (ULSJ) fuel standard. It is estimated that, by reducing the amount of sulfur in jet fuel, between 1000 and 4000 pollution-related deaths could be prevented globally each year.

However, the cost to the aviation industry would be between \$1 billion and \$4 billion per year, which equates to an increase in the cost of jet fuel of around 2%. It is also believed that reducing the amount of sulfates in the atmosphere (produced by the burning of jet fuel), would actually cause warming of the planet to increase.

Sulfur is present in fossil fuels in the form of sulfur-containing organic compounds, such as dibenzothiophenes. Analysis of one such compound showed that it was made up only of the elements carbon, hydrogen and sulfur. Upon combustion in excess oxygen, a 22.60 g sample of the compound was found to produce 8.85 g of water vapour and 77.9 L of carbon dioxide, measured at 1000°C and 200 kPa.

(a) Find the empirical formula of the compound. (8 marks)

$$n(\text{C}) = n(\text{CO}_2) = PV/RT = (200 \times 77.9) / (8.314 \times 1273.15) = 1.47 \text{ mol} \quad 1 \text{ mark}$$

$$m(\text{C}) = 1.47 \times 12.01 = 17.7 \text{ g} \quad 1 \text{ mark}$$

$$n(\text{H}) = 2 n(\text{H}_2\text{O}) = 2 \times 8.85/18.016 = 0.982 \text{ mol} \quad 1 \text{ mark}$$

$$m(\text{H}) = 0.99 \text{ g} \quad 1 \text{ mark}$$

$$m(\text{S}) = 22.60 - 17.7 - 0.99 = 3.91 \text{ g} \quad 1 \text{ mark}$$

$$n(\text{S}) = 3.91/32.06 = 0.122 \text{ mol} \quad 1 \text{ mark}$$

$$\text{C} : \text{H} : \text{S} = 1.47 : 0.982 : 0.122 = 12 : 8 : 1 \quad 1 \text{ mark}$$

$$\text{EF} = \text{C}_{12}\text{H}_8\text{S} \quad 1 \text{ mark}$$

Another sample of the compound, weighing 10.71 g, was vapourised in the absence of oxygen. The vapours occupied 1.265 L at 200 kPa and 250°C.

- (b) Use this information and your answer to part (a) to find the molecular formula of the compound. (3 marks)

$$n = PV/RT = 1.265 \times 200 / (8.314 \times 523.15) = 0.0582 \text{ mol} \quad 1 \text{ mark}$$

$$M = m/n = 10.71 / 0.0582 = 184.1 \quad 1 \text{ mark}$$

$$M(\text{EF}) = 12 \times 12.01 + 8 \times 1.008 + 32.06 = 184.244$$

$$\text{EF} = \text{MF} = \text{C}_{12}\text{H}_8\text{S} \quad 1 \text{ mark}$$

Question 38 (continued)

The ULSJ fuel standard is equivalent to a concentration of sulfur 15 ppm (parts per million).

- (c) Calculate the concentration of sulfur in ULSJ fuel in mol L⁻¹ if 1L of the fuel weighs 800 g.
(3 marks)

15 mg S in 1 kg of fuel: 1 kg of fuel = 1/0.800 L = 1.25 L **1 mark**

c(S) = 15 mg/1.25 L = 12 mgL⁻¹ **1 mark**

n(S) = m/M = 12 x 10⁻³/32.06 = 3.74 x 10⁻⁴ molL⁻¹ **1 mark**

One of the problems associated with the presence of sulfur in fuels is that as rain falls through oxides of sulfur in the atmosphere, they react with the rain. The effect is that the rain becomes acidic.

- (d) With the help of equations, explain how these oxides can cause rainwater to become acidic.
(3 marks)

Gases dissolve in rainwater according to EITHER:



OR:



(both) lead to an increase in [H⁺], and hence acidic rainwater **1 mark**

End of questions

Question number: _____

Spare answer page

Question number: _____

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Spare answer page

Question number: _____

[illegible]

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Question number: _____

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