

OCR A-Level Chemistry A

Module 5: Physical chemistry and transition elements

Questions only

All 105 questions in Module 5: Physical chemistry and transition elements

Questions

105

Total marks

803

Name

Class or teacher

Date

Instructions

- Answer all questions in the spaces provided.
- Use black ink. Show your working for every calculation.
- You may use a scientific calculator and the OCR Data Sheet.
- Print the separate mark scheme when you are ready to mark your answers.

For marking

Total _____ / 803 Percentage _____ %

Questions from OCR past papers, 2017–2025, reproduced for revision. Practise these topics online, with instant marking:

whiteboardchemistry.com/revision/exam-questions/ocr-a-level-chemistry/?topics=acids-bases-and-buffers, equilibrium-constants, lattice-enthalpy-entropy-and-free-energy, rate-equations, redox-and-electrode-potentials, transition-elements&len=0

Questions

6 topics · 105 questions · 803 marks

Q1 · Acids, bases and buffers · June 2017 · Paper 1 (Periodic table, elements and physical chemistry) · Q21 · [12 marks]

This question also needs Amount of substance.

This question is about the properties and reactions of ethanoic acid, CH_3COOH .

Ethanoic acid is a weak acid with an acid dissociation constant, K_a , of $1.75 \times 10^{-5} \text{ mol dm}^{-3}$ at 25°C .

21(a) A student uses a pH meter to measure the pH of a solution of CH_3COOH at 25°C .

The measured pH is 2.440.

Calculate the concentration of ethanoic acid in the solution.

Give your answer to three significant figures.

concentration = mol dm^{-3}

[3 marks]

21(b) Ethanoic acid is added to another weak acid, fluoroethanoic acid, FCH_2COOH ($K_a = 2.19 \times 10^{-3} \text{ mol dm}^{-3}$). An equilibrium is set up containing two acid-base pairs.

Complete the equilibrium and label the conjugate acid-base pairs as A1, B1 and A2, B2.



[2 marks]

The student plans to prepare a buffer solution that has a pH of 4.50. The buffer solution will contain ethanoic acid, CH_3COOH , and sodium ethanoate, CH_3COONa .

The student plans to add 9.08 g CH_3COONa to 250 cm^3 of $0.800 \text{ mol dm}^{-3} \text{ CH}_3\text{COOH}$. The student assumes that the volume of the solution does not change.

21(c)(i) Show by calculation whether, or not, the student's experimental method would produce the required pH.

Show all your working.

[5 marks]

21(c)(ii) When the student prepares the buffer solution, the volume of solution increases slightly.

Suggest whether the pH of the buffer solution would be the same, greater than, or less than your calculated value in (c)(i).

Explain your reasoning.

[2 marks]

Q2 · Acids, bases and buffers · June 2018 · Paper 1 (Periodic table, elements and physical chemistry) · Q10 · [1 mark]

This question also needs Amount of substance.

A buffer solution is prepared by mixing 200 cm³ of 2.00 mol dm⁻³ propanoic acid, CH₃CH₂COOH, with 600 cm³ of 1.00 mol dm⁻³ sodium propanoate, CH₃CH₂COONa.

K_a for CH₃CH₂COOH = 1.32×10^{-5} mol dm⁻³

What is the pH of the buffer solution?

Tick (✓) one box.

☐ **A** 4.58

☐ **B** 4.70

☐ **C** 5.06

☐ **D** 5.18

Q3 · Acids, bases and buffers · June 2018 · Paper 1 (Periodic table, elements and physical chemistry) · Q19 · [11 marks]

This question also needs Acids and redox reactions, Amount of substance and Electrons, bonding and structure.

This question is about acids and bases found in the home.

Ethanoic acid, CH₃COOH, is the acid present in vinegar.

A student carries out an experiment to determine the pK_a value of CH₃COOH.

- The concentration of CH_3COOH in the vinegar is $0.870 \text{ mol dm}^{-3}$.
- The pH of the vinegar is 2.41.

19(a)(i) Write the expression for the acid dissociation constant, K_a , of CH_3COOH .

[1 mark]

19(a)(ii) Calculate the $\text{p}K_a$ value of CH_3COOH .

Give your answer to two decimal places.

$\text{p}K_a =$

[3 marks]

19(a)(iii) Determine the percentage dissociation of ethanoic acid in the vinegar.

Give your answer to three significant figures.

percentage dissociation = %

[1 mark]

19(b) Many solid drain cleaners are based on sodium hydroxide, NaOH.

- A student dissolves 1.26 g of a drain cleaner in water and makes up the solution to 100.0 cm³.
- The student measures the pH of this solution as 13.48.

Determine the percentage, by mass, of NaOH in the drain cleaner.

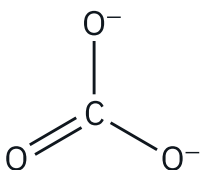
Give your answer to three significant figures.

percentage = %

[4 marks]

19(c) Sodium carbonate, Na_2CO_3 , is a base used in washing soda.

Na_2CO_3 contains the carbonate ion, CO_3^{2-} , shown below.



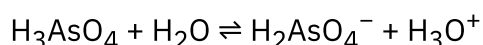
Draw the 'dot-and-cross' diagram for the carbonate ion.

Show outer electrons only and use different symbols for electrons from C and O, and any 'extra' electrons.

[2 marks]

Q4 · Acids, bases and buffers · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q12 · [1 mark]

The equation shows the dissociation of the acid H_3AsO_4 in water.



Which pair is a conjugate acid–base pair?

Tick (✓) one box.

- ☐ **A** H_3AsO_4 and H_2O
- ☐ **B** H_2AsO_4^- and H_3O^+
- ☐ **C** H_3AsO_4 and H_3O^+
- ☐ **D** H_3O^+ and H_2O

Q5 · Acids, bases and buffers · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q17 · [9

marks]

This question also needs Alkanes.

Healthy human blood needs to be maintained at a pH of 7.40 for the body to function normally.

17(a) Carbonic acid, H_2CO_3 , is a weak acid which, together with hydrogencarbonate ions, HCO_3^- , acts as a buffer to maintain the pH of blood.

The pK_a value for the dissociation of carbonic acid is 6.38.

Explain, in terms of equilibrium, how the carbonic acid–hydrogencarbonate mixture acts as a buffer in the control of blood pH, and calculate the $[\text{HCO}_3^-] : [\text{H}_2\text{CO}_3]$ ratio in healthy blood.

[6 marks]

17(b) Red blood cells contain haemoglobin.

Explain using ligand substitutions:

- how haemoglobin transports oxygen around the body
- why carbon monoxide is toxic.

[3 marks]

Q6 · Acids, bases and buffers · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q20 · [14

marks]

This question also needs Acids and redox reactions and Amount of substance.

This question is about weak acids.

The K_a values of three weak acids are shown in Table 20.1.

Weak acid	$K_a / \text{mol dm}^{-3}$
iodic(V) acid, $\text{HIO}_3(\text{aq})$	1.78×10^{-1}
propanoic acid, $\text{C}_2\text{H}_5\text{COOH}(\text{aq})$	1.35×10^{-5}
hydrocyanic acid, $\text{HCN}(\text{aq})$	6.17×10^{-10}

Table 20.1

20(a) Calculate the pH of $0.0800 \text{ mol dm}^{-3} \text{C}_2\text{H}_5\text{COOH}(\text{aq})$.

Give your answer to 2 decimal places.

pH =

[2 marks]

A student adds a total of 45.0 cm^3 of $0.100 \text{ mol dm}^{-3} \text{NaOH}(\text{aq})$ to 25.0 cm^3 of $0.0800 \text{ mol dm}^{-3} \text{C}_2\text{H}_5\text{COOH}(\text{aq})$ and monitors the pH throughout.

20(b)(i) Show by calculation that 20.0 cm^3 of $\text{NaOH}(\text{aq})$ is required to reach the end point.

[1 mark]

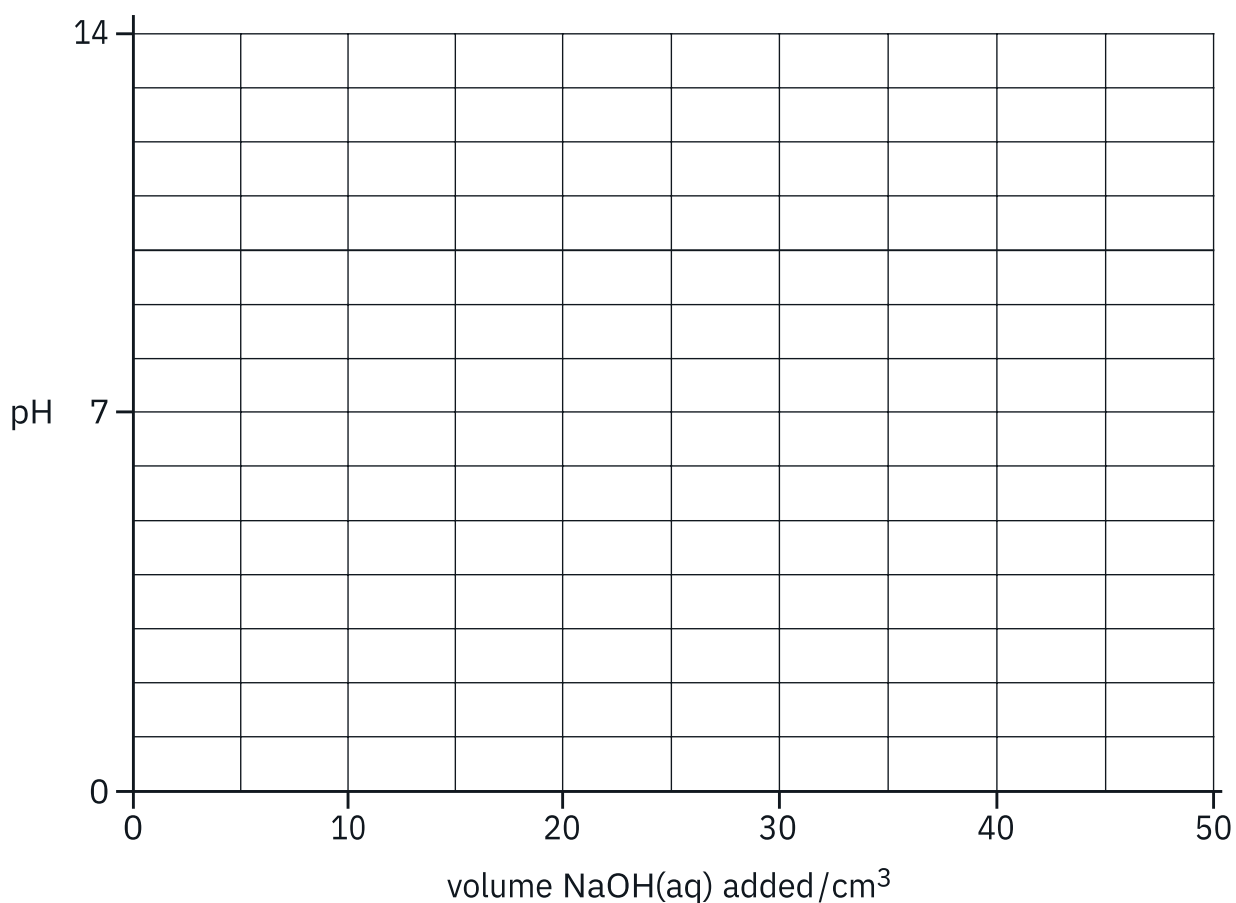
20(b)(ii) Calculate the pH of the final solution.

Give your answer to 2 decimal places.

pH =

[4 marks]

20(b)(iii) On the axes below, sketch a pH curve for the pH changes during the addition of 45.0 cm^3 of $0.100 \text{ mol dm}^{-3} \text{ NaOH(aq)}$ to 25.0 cm^3 of $0.0800 \text{ mol dm}^{-3} \text{ C}_2\text{H}_5\text{COOH(aq)}$.



[3 marks]

Draw your answer on the figure above.

20(b)(iv) The student considers using the four indicators in Table 20.2 for the titration.

Indicator	pH range
Cresol red	0.2 – 1.8
Bromophenol blue	3.0 – 4.6
Cresol purple	7.6 – 9.2
Indigo carmine	11.6 – 14.0

Table 20.2

Explain which indicator would be most suitable for the titration.

[1 mark]

20(b)(v) The student repeats the experiment starting with 25.0 cm^3 of $0.0800 \text{ mol dm}^{-3}$ HCN(aq) and adding a total of 45.0 cm^3 of $0.100 \text{ mol dm}^{-3}$ NaOH(aq) .

Predict one similarity and one difference between the pH curve with $\text{C}_2\text{H}_5\text{COOH(aq)}$

and the pH curve with HCN(aq) . Use the information in Table 20.1, and your answer to (b)(iii).

[2 marks]

Similarity

Difference

20(c) The student calculates the pH of $0.0800 \text{ mol dm}^{-3} \text{ HIO}_3(\text{aq})$. The student assumes that the equilibrium concentration of $\text{HIO}_3(\text{aq})$ is the same as the initial concentration of $\text{HIO}_3(\text{aq})$.

The student measures the pH, and finds that the measured pH value is different from the calculated pH value.

Explain why the measured pH is different from the calculated pH.

[1 mark]

Q7 · Acids, bases and buffers · June 2022 · Paper 1 (Periodic table, elements and physical chemistry) · Q11 · [1 mark]

The equilibrium equation for an indicator, HA, is shown below.

Equation:	$\text{HA}(\text{aq})$	$\rightleftharpoons$	$\text{A}^{-}(\text{aq})$	+	$\text{H}^{+}(\text{aq})$
Colour:	Blue		Yellow		

The indicator is added to a solution. The indicator turns a yellow colour.

An excess of aqueous sodium hydroxide is then added.

Which statement describes how the colour of this solution would be expected to change?

Tick (✓) one box.

- ☐ **A** Colour changes from yellow to blue.
- ☐ **B** Colour changes from yellow to green.
- ☐ **C** Colour changes from yellow to green and then to blue.
- ☐ **D** Colour stays yellow.

Q8 · Acids, bases and buffers · June 2022 · Paper 1 (Periodic table, elements and physical chemistry) · Q12 · [1 mark]

Ammonia and water react to set up an acid–base equilibrium.

What are the Brønsted–Lowry acids in the equilibrium mixture?

Tick (✓) one box.

☐ **A** H_2O and OH^-

☐ **B** OH^- and NH_3

☐ **C** NH_4^+ and H_2O

☐ **D** NH_4^+ and NH_3

Q9 · Acids, bases and buffers · June 2022 · Paper 1 (Periodic table, elements and physical chemistry) · Q19 · [14 marks]

This question also needs Amount of substance.

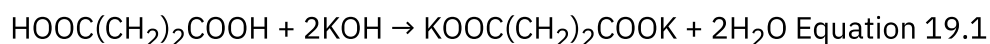
This question is about acids and buffer solutions.

Succinic acid, $\text{HOOC}(\text{CH}_2)_2\text{COOH}$, is a weak dibasic acid that is used in tablet form in health supplements.

A student plans to determine the mass of succinic acid in one tablet of a succinic acid health supplement.

The student carries out a titration with potassium hydroxide.

The end point occurs when both acidic protons in succinic acid have been replaced as shown in Equation 19.1.



The student uses the following method.

Stage 1 The student crushes four tablets of the health supplement and dissolves the powdered tablets in distilled water.

Stage 2 The student makes up the solution from Stage 1 to 250.0 cm^3 in a volumetric flask.

Stage 3 The student titrates 10.0 cm^3 portions of the solution obtained in Stage 2 with $0.0600 \text{ mol dm}^{-3}$ potassium hydroxide, using phenolphthalein as the indicator.

The student carries out a trial titration, followed by three further titrations.

The results are shown below.

Titration	Trial	1	2	3
Final burette reading / cm^3	25.25	23.75	25.35	25.75
Initial burette reading / cm^3	2.50	1.30	2.65	3.20
Titre / cm^3				

19(a)(i) Complete the table and calculate the mean titre that the student should use for analysing the results.

mean titre = cm^3

[2 marks]

19(a)(ii) Use the student's results and Equation 19.1 to calculate the mass, in mg, of succinic acid in **one** tablet of the health supplement.

Give your answer to **3** significant figures.

mass = mg

[5 marks]

Glycolic acid, HOCH_2COOH , ($\text{pK}_a = 3.83$) is a weak monobasic acid used in some skincare products.

A buffer solution is prepared by adding 60.0 cm^3 of $0.750 \text{ mol dm}^{-3}$ glycolic acid to 40.0 cm^3 of $0.625 \text{ mol dm}^{-3}$ potassium hydroxide, KOH .

19(b)(i) Explain why a buffer solution is formed.

[1 mark]

19(b)(ii) Calculate the pH of the buffer solution that has been prepared.

Give your answer to **2** decimal places.

pH =

[4 marks]

19(b)(iii) A small amount of aqueous ammonia, $\text{NH}_3(\text{aq})$, is added to the buffer solution.

Explain, in terms of equilibrium, how the buffer solution would respond to the added $\text{NH}_3(\text{aq})$.

[2 marks]

Q10 · Acids, bases and buffers · June 2023 · Paper 1 (Periodic table, elements and physical chemistry) · Q20 · [21 marks]

This question also needs Amount of substance.

This question is about acids and bases.

Table 20.1 shows the ionic product, K_w , of water at 25 °C and 40 °C.

Table 20.1

Temperature / °C	K_w / $\text{mol}^2 \text{ dm}^{-6}$
25	1.00×10^{-14}
40	2.92×10^{-14}

20(a)(i) Calculate the pH of water at 40 °C.

Give your answer to **2** decimal places.

pH =

[2 marks]

20(a)(ii) Table 20.1 shows different K_w values at 25 °C and at 40 °C. A student suggests that water is neutral at these temperatures.

Explain why this student is correct.

[1 mark]

20(b) A student reacts strontium metal with water to make a 250.0 cm^3 solution of aqueous strontium hydroxide, $\text{Sr}(\text{OH})_2$. The solution contains 0.145 g of strontium hydroxide.

- Write an equation for the reaction of strontium with water.
- Calculate the pH of this 250.0 cm^3 solution of strontium hydroxide at 40°C .

You should refer back to Table 20.1 at the start of (a).

Give your answer to **2** decimal places.

[5 marks]

Equation

Calculation

pH =

A student reacts 1.00 g of strontium carbonate, SrCO_3 , with an excess of dilute nitric acid, HNO_3 .
A gas is produced.

20(c)(i) Construct the equation for this reaction.

[1 mark]

20(c)(ii) The student then reacts 1.00 g of calcium carbonate, CaCO_3 , with an excess of dilute nitric acid, HNO_3 .

Explain why the student's two reactions produce different volumes of gas.

[2 marks]

A student reacts an excess of magnesium with 25.0 cm^3 of $0.500 \text{ mol dm}^{-3}$ hydrochloric acid, HCl .

The student also reacts an excess of magnesium with 25.0 cm^3 of $0.500 \text{ mol dm}^{-3}$ ethanoic acid, CH_3COOH .

20(d)(i) Construct an ionic equation for the reaction of magnesium with an acid.

[1 mark]

20(d)(ii) Explain why these two reactions of magnesium produce the same volume of gas but at different rates.

[3 marks]

Butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$, is a weak monobasic acid.

20(e)(i) Explain what is meant by the term **monobasic acid**.

[1 mark]

20(e)(ii) A buffer solution is prepared by dissolving 3.39 g of potassium hydroxide in 250 cm³ of 0.376 mol dm⁻³ butanoic acid.

This buffer solution has a pH of 5.07 at 25 °C.

Calculate the acid dissociation constant, K_a , of butanoic acid at 25 °C.

Assume that the volume of the solution remains constant at 250 cm³ when the potassium hydroxide is dissolved.

$K_a = \text{mol dm}^{-3}$

[4 marks]

20(f) A buffer solution has a pH of 4.50.

When a small volume of water is added to this buffer solution, the pH does **not** change.

Explain why the pH does **not** change.

[1 mark]

Q11 · Acids, bases and buffers · June 2024 · Paper 1 (Periodic table, elements and physical chemistry) · Q12 · [1

mark]

Which solution can be added to $\text{CH}_3\text{COOH}(\text{aq})$ to make a buffer solution?

Tick (✓) one box.

☐ **A** $\text{CH}_3\text{COONa}(\text{aq})$

☐ **B** $\text{HCOOH}(\text{aq})$

☐ **C** $\text{HCl}(\text{aq})$

☐ **D** $\text{NaCl}(\text{aq})$

Q12 · Acids, bases and buffers · June 2024 · Paper 1 (Periodic table, elements and physical chemistry) · Q19 · [11 marks]

This question is about acids and bases.

Chloroethanoic acid, ClCH_2COOH , is a weak monobasic acid.

19(a)(i) Write the expression for the acid dissociation constant, K_a , of ClCH_2COOH .

[1 mark]

19(a)(ii) The expression for the acid dissociation constant, K_a , of ClCH_2COOH can be simplified to:

$K_a = [\text{H}^+]^2 / [\text{ClCH}_2\text{COOH}]$ Expression 19.1

State one approximation that allows the expression from (a)(i) to be simplified to Expression 19.1.

[1 mark]

19(a)(iii) A student carries out an experiment to determine the pK_a value of a solution of $ClCH_2COOH$.

- The concentration of $ClCH_2COOH$ is $0.090 \text{ mol dm}^{-3}$.
- The pH of $ClCH_2COOH$ is 1.95.

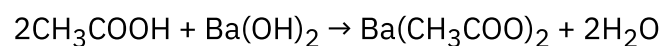
Use Expression 19.1 to calculate the pK_a value of $ClCH_2COOH$.

Give your answer to **2** decimal places.

$pK_a =$

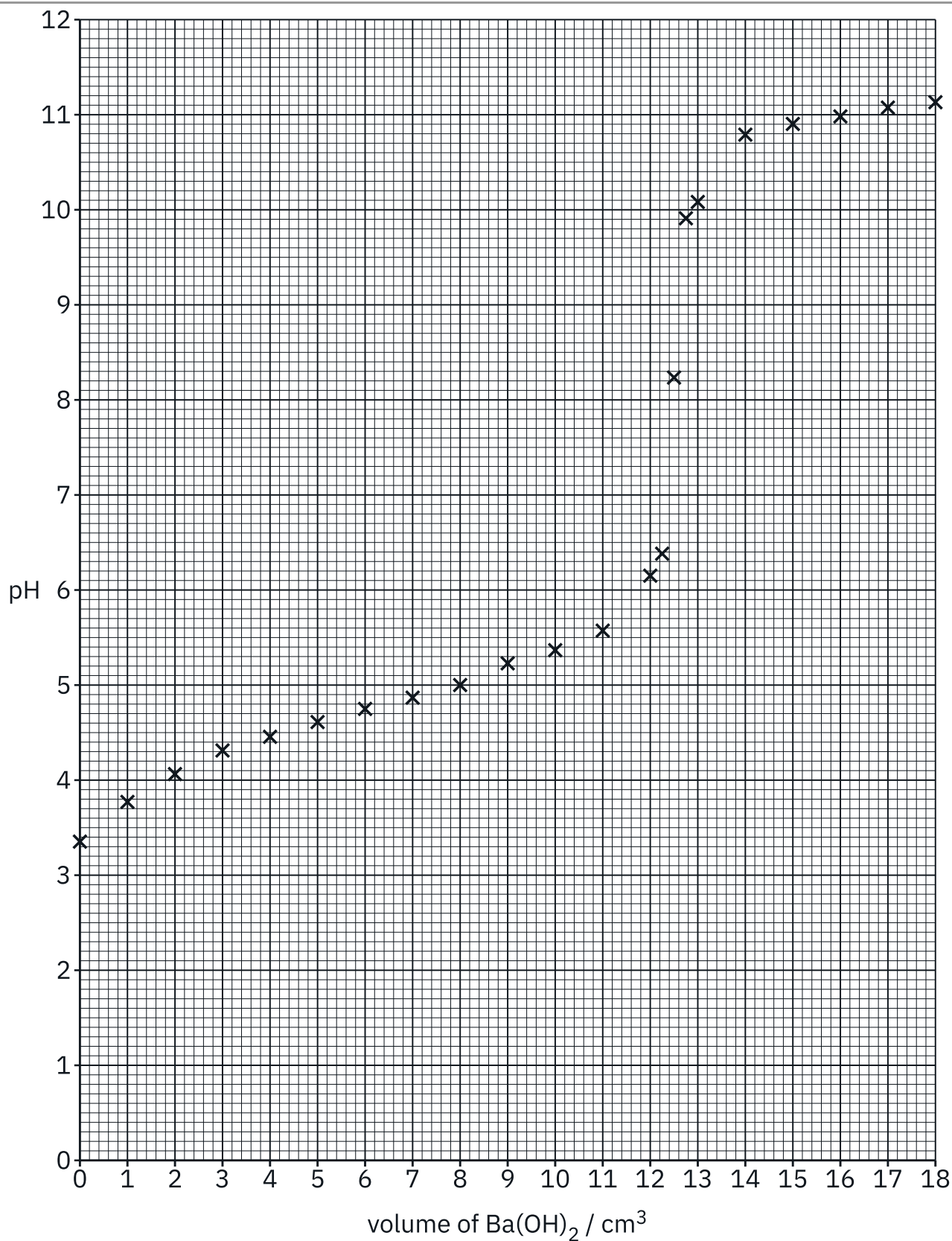
[3 marks]

A student titrates a 10.0 cm^3 sample of ethanoic acid, CH_3COOH , against an aqueous solution of $0.0560 \text{ mol dm}^{-3} \text{ Ba(OH)}_2$.



The student used a pH meter to measure the pH of the mixture after every addition of Ba(OH)_2 throughout the titration.

The student's results are shown below.



19(b)(i) Draw a best-fit curve on the graph and calculate the concentration of the CH_3COOH solution.

CH_3COOH concentration = mol dm^{-3}

[5 marks]

Draw your answer on the figure above.

19(b)(ii) The end point of the titration can also be found by observing the colour change of an indicator.

The pH ranges of some indicators are shown in the table.

Indicator	pH range
Malachite green	0.2 – 1.8
Bromophenol blue	2.8 – 4.6
Phenol red	6.8 – 8.4
Phenolphthalein	8.2 – 10.0

Identify the indicator in the table that would be suitable to observe the end point of the titration between CH_3COOH and $\text{Ba}(\text{OH})_2$.

[1 mark]

Q13 · Acids, bases and buffers · June 2024 · Paper 3 (Unified chemistry) · Q1 · [10 marks]

This question also needs Acids and redox reactions.

This question is about acids, bases and salts.

1(a) What is the pH of 1.00 dm^3 of $0.400 \text{ mol dm}^{-3}$ of $\text{NaOH}(\text{aq})$ at 298 K?

pH =

[2 marks]

1(b) Water is added to 10.0 cm^3 of $0.750 \text{ mol dm}^{-3}$ HCl(aq) to produce 100 cm^3 of diluted HCl(aq) .

What is the pH of the diluted HCl(aq) ?

Give your answer to **2** decimal places.

pH =

[1 mark]

1(c) A solution has concentrations of $0.300 \text{ mol dm}^{-3}$ $\text{CH}_3\text{COOH(aq)}$ and $0.100 \text{ mol dm}^{-3}$ $\text{CH}_3\text{COONa(aq)}$.

K_a for $\text{CH}_3\text{COOH} = 1.75 \times 10^{-5} \text{ mol dm}^{-3}$ at 298 K.

What is the pH of the solution at 298 K?

Give your answer to **2** decimal places.

pH =

[2 marks]

1(d) A student is provided with hydrated copper(II) nitrate, $\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$.

The student needs to prepare a standard solution of $\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$ with a concentration of $0.200 \text{ mol dm}^{-3}$. The student has access to usual laboratory apparatus and equipment.

Describe how the student would prepare 100.0 cm^3 of this solution, giving quantities, apparatus and method.

[5 marks]

Q14 · Acids, bases and buffers · June 2025 · Paper 1 (Periodic table, elements and physical chemistry) · Q13 · [1 mark]

A mixture of ethanoic acid and ethanol is left to reach equilibrium.

A student determines the amount of ethanoic acid remaining in the equilibrium mixture by titrating the mixture with a solution of sodium hydroxide.

Which row of the table shows a suitable indicator for the titration?

Tick (✓) one box.

- ☐ **A** pH range of the indicator: 1.2 – 2.8
- ☐ **B** pH range of the indicator: 4.8 – 6.0
- ☐ **C** pH range of the indicator: 9.4 – 10.6
- ☐ **D** pH range of the indicator: 12.0 – 13.4

Q15 · Acids, bases and buffers · June 2025 · Paper 1 (Periodic table, elements and physical chemistry) · Q19 · [12

marks]

This question also needs Acids and redox reactions.

This question is about monobasic acids and buffer solutions.

19(a) Nitric acid, HNO_3 , is a strong monobasic acid.

Calculate the pH of $0.150 \text{ mol dm}^{-3} \text{ HNO}_3$.

Give your answer to **2** decimal places.

pH =

[1 mark]

19(b)(i) Nitrous acid, HNO_2 , is a weak monobasic acid.

Predict whether the pH of $0.150 \text{ mol dm}^{-3} \text{ HNO}_2$ is higher, lower or the same as the pH of $0.150 \text{ mol dm}^{-3}$ nitric acid, HNO_3 .

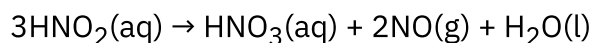
Explain your answer.

[2 marks]

Prediction

Explanation

19(b)(ii) When heated, aqueous HNO_2 disproportionates. The equation is shown below.



- What is meant by **disproportionation**?
- Use oxidation numbers to show that disproportionation has taken place.

[3 marks]

19(c) A student plans to prepare a buffer solution with a pH of 4.85 using propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, and sodium propanoate, $\text{CH}_3\text{CH}_2\text{COONa}$.

K_a for $\text{CH}_3\text{CH}_2\text{COOH} = 1.32 \times 10^{-5} \text{ mol dm}^{-3}$.

The student mixes 125 cm^3 of $0.180 \text{ mol dm}^{-3}$ $\text{CH}_3\text{CH}_2\text{COOH}(\text{aq})$ with a calculated mass of $\text{CH}_3\text{CH}_2\text{COONa}(\text{s})$. The student assumes that the volume of the solution does not change.

- Calculate the mass of $\text{CH}_3\text{CH}_2\text{COONa}$ needed to make 125 cm^3 of a buffer solution with a pH of 4.85.
- Explain why this solution resists changes in pH when a small amount of alkali is added.

[6 marks]

Q16 · Acids, bases and buffers · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q11 · [1 mark]

This question also needs Amount of substance.

20 cm³ of 0.10 mol dm⁻³ hydrochloric acid is added to 10 cm³ of 0.10 mol dm⁻³ sodium hydroxide.

What is the pH of the resulting mixture?

Tick (✓) one box.

- ☐ **A** 1.00
- ☐ **B** 1.18
- ☐ **C** 1.30
- ☐ **D** 1.48

Q17 · Acids, bases and buffers · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q18 · [11 marks]

This question also needs Acids and redox reactions and Amount of substance.

This question is about reactions and uses of the weak acids methanoic acid, HCOOH, and ethanoic

acid, CH_3COOH .

18(a) A student adds magnesium metal to an aqueous solution of ethanoic acid, CH_3COOH .

A redox reaction takes place.

Write the overall equation for this reaction and explain, in terms of oxidation numbers, which element has been oxidised and which element has been reduced.

[3 marks]

Equation

Oxidation

Reduction

18(b) The K_a values of HCOOH and CH_3COOH are shown in Table 18.1.

Weak acid	$K_a / \text{mol dm}^{-3}$
HCOOH	1.82×10^{-4}
CH_3COOH	1.78×10^{-5}

Table 18.1

A student adds methanoic acid to ethanoic acid.

An equilibrium is set up containing two acid-base pairs.

Complete the equilibrium and label the conjugate acid-base pairs as A1, B1 and A2, B2.

HCOOH	+	CH_3COOH	$\rightleftharpoons$		+	
.....						

[2 marks]

Use Table 18.1 to answer the following questions.

18(c)(i) The student measures the pH of $\text{CH}_3\text{COOH}(\text{aq})$ as 2.72.

Show that the concentration of the $\text{CH}_3\text{COOH}(\text{aq})$ is $0.204 \text{ mol dm}^{-3}$.

[2 marks]

18(c)(ii) The student plans to make a buffer solution of pH 4.00 from a mixture of $\text{CH}_3\text{COOH}(\text{aq})$ and sodium ethanoate, $\text{CH}_3\text{COONa}(\text{aq})$.

The student mixes 400 cm^3 of 0.204 mol dm^{-3} $\text{CH}_3\text{COOH}(\text{aq})$ with 600 cm^3 of $\text{CH}_3\text{COONa}(\text{aq})$.

Calculate the concentration of $\text{CH}_3\text{COONa}(\text{aq})$ needed to prepare this buffer solution of pH 4.00.

concentration = mol dm^{-3}

[4 marks]

Q18 · Acids, bases and buffers · November 2020 · Paper 3 (Unified chemistry) · Q6 · [10 marks]

This question also needs Acids and redox reactions, Alcohols and haloalkanes, Amount of substance and 3 other topics.

This question is about two different types of acid found in organic compounds, carboxylic acids and sulfonic acids, as shown in Fig. 6.1.

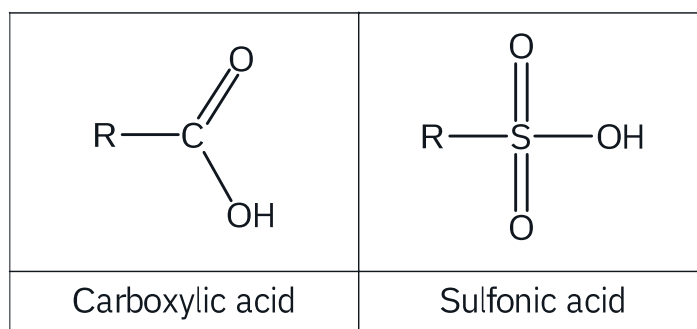


Fig. 6.1

6(a) Complete Table 6.1 to predict bond angles a and b and name the shapes which makes these bond angles in the functional groups of carboxylic acids and sulfonic acids.

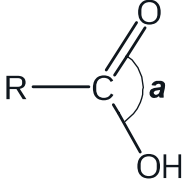
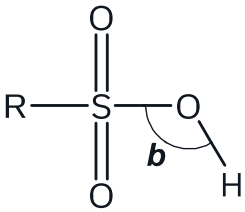
Type of acid	Acid	Bond angle	Name of shape
Carboxylic acid			
Sulfonic acid			

Table 6.1

[2 marks]

6(b) Ethanoic acid, CH_3COOH , and methanesulfonic acid, $\text{CH}_3\text{SO}_2\text{OH}$, are both monobasic acids.

The pK_a values are shown in the table.

Acid		pK_a
Ethanoic acid	CH_3COOH	4.76
Methanesulfonic acid	$\text{CH}_3\text{SO}_2\text{OH}$	-1.90

A student suggests that $1.0 \text{ mol dm}^{-3} \text{CH}_3\text{SO}_2\text{OH}$ should have a lower pH value than $1.0 \text{ mol dm}^{-3} \text{CH}_3\text{COOH}$.

Write an equation, showing conjugate acid–base pairs, for the equilibrium of $\text{CH}_3\text{SO}_2\text{OH}$ with water and explain, with reasons, whether the student is correct.

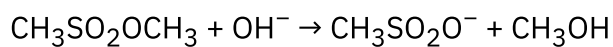
Label the conjugate acid–base pairs: A1, B1 and A2, B2.

[4 marks]

6(c) Carboxylic acids and sulfonic acids both form esters.

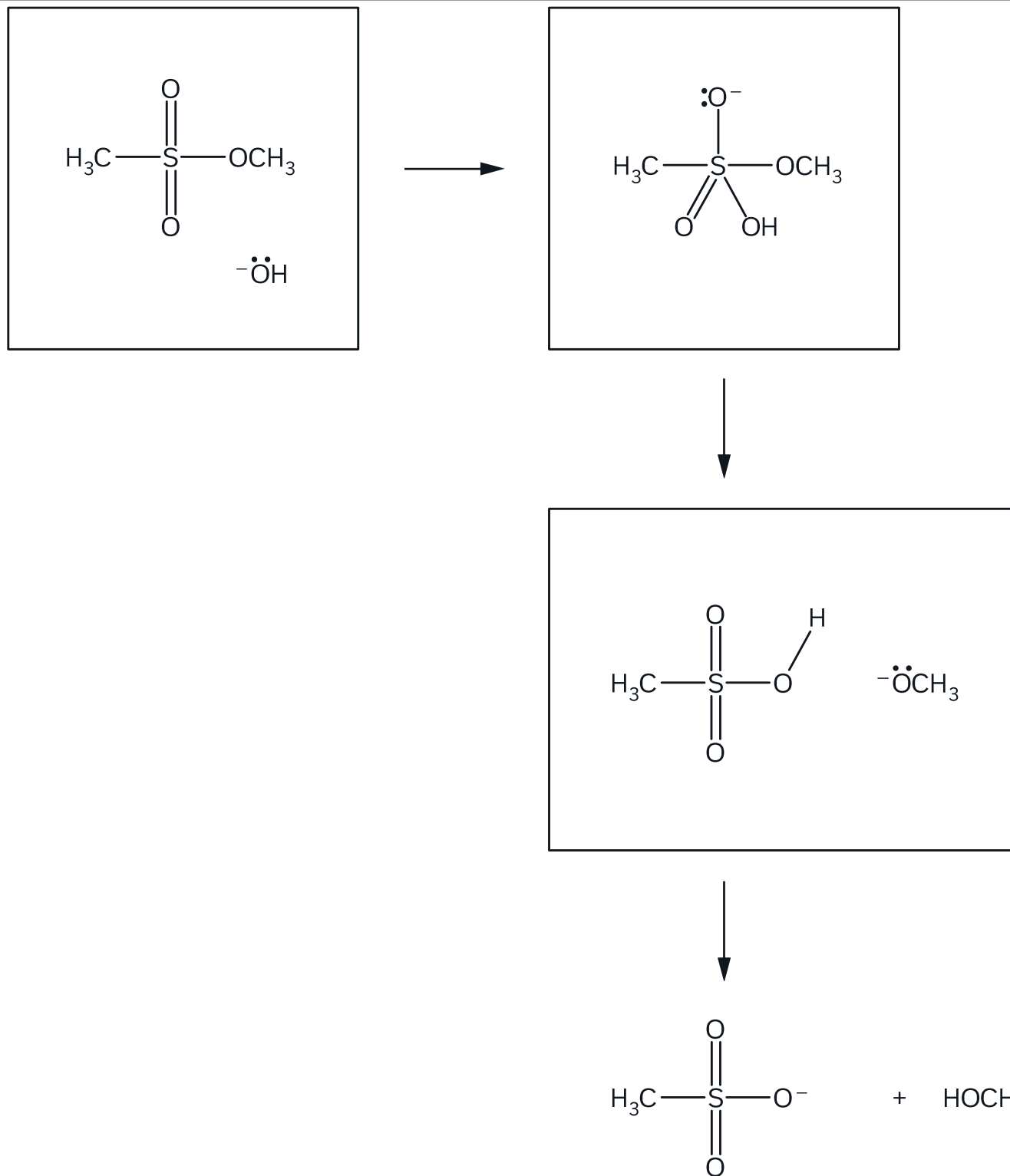
Sulfonic acid esters can be hydrolysed by aqueous alkali.

The equation shows the alkaline hydrolysis of a sulfonic acid ester.



In the 3 boxes below, add curly arrows to show the mechanism for this reaction.

In the first box, the hydroxide ion acts as a nucleophile.



[4 marks]

Draw your answer on the figure above.

Q22 · [16 marks]

This question also needs Acids and redox reactions, Amount of substance and Enthalpy changes.

This question is about acids, bases and buffers.

22(a) Sodium hydroxide, NaOH, is a strong base.

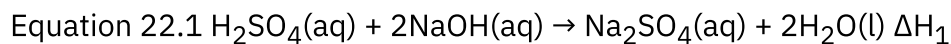
Calculate the pH of $0.140 \text{ mol dm}^{-3}$ NaOH(aq) at 298 K.

Give your answer to 2 decimal places.

pH =

[2 marks]

Sulfuric acid reacts with sodium hydroxide as shown in Equation 22.1.



This is a neutralisation reaction.

A student carries out an experiment to determine the enthalpy change ΔH_1 and uses this value to deduce the enthalpy change of neutralisation, $\Delta_{\text{neut}}H$.

The student measures out two solutions:

- 25.0 cm³ of 1.60 mol dm⁻³ H₂SO₄(aq)
- 55.0 cm³ of 1.50 mol dm⁻³ NaOH(aq) (an excess).

The temperature of each solution is the same.

The student mixes the two solutions. The temperature increases by 13.0 °C.

22(b)(i) Show that NaOH is in excess.

[2 marks]

22(b)(ii) Calculate the enthalpy change, ΔH_1 , for Equation 22.1, and deduce the value for the enthalpy change of neutralisation, $\Delta_{\text{neut}}H$, in kJ mol^{-1} .

Assume that the densities of all solutions and the specific heat capacity, c , of the reaction mixture are the same as for water.

enthalpy change, $\Delta H_1 = \text{kJ mol}^{-1}$

enthalpy change of neutralisation, $\Delta_{\text{neut}}H = \text{kJ mol}^{-1}$

[4 marks]

22(b)(iii) The student repeats the experiment using 50.0 cm^3 of $1.60 \text{ mol dm}^{-3} \text{ H}_2\text{SO}_4$ and 110.0 cm^3 of $1.50 \text{ mol dm}^{-3} \text{ NaOH}$.

Predict the increase in temperature.

Explain your reasoning.

[2 marks]

22(c) Nitrous acid, HNO_2 , is a weak Brønsted–Lowry acid with a pK_a value of 3.34 at room temperature.

HNO_2 can be prepared by reacting N_2O_3 with water.

HNO_2 is the only product.

A chemist makes up a buffer solution by the following method.

Step 1 The chemist weighs a sample of N_2O_3 .

Water is then added to form 100 cm^3 of 0.500 mol dm^{-3} $\text{HNO}_2(\text{aq})$.

Step 2 The chemist adds 100 cm^3 of 0.150 mol dm^{-3} $\text{NaOH}(\text{aq})$ to the 100 cm^3 solution of 0.500 mol dm^{-3} solution of $\text{HNO}_2(\text{aq})$.

The resulting solution is made up to 1.00 dm^3 .

Explain why a buffer solution forms in Step 2. Determine the pH of this buffer solution and the mass of N_2O_3 that was used in Step 1.

[6 marks]

Q20 • Equilibrium constants K_c and K_p • June 2017 • Paper 1 (Periodic table, elements and physical chemistry) •

Q13 · [1 mark]

This question also needs Amount of substance.

A mixture of N₂ and O₂ gases has a total pressure of 1.42 atm.

The mole fraction of N₂ is 0.700.

What is the partial pressure, in atm, of O₂ in the mixture?

Tick (✓) one box.

☐ **A** 0.211

☐ **B** 0.426

☐ **C** 0.493

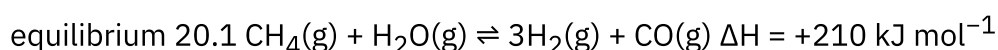
☐ **D** 0.994

Q21 · Equilibrium constants K_c and K_p · June 2017 · Paper 1 (Periodic table, elements and physical chemistry) · Q20 · [10 marks]

This question also needs Amount of substance, Enthalpy changes and Reaction rates and equilibrium.

This question is about equilibrium reactions.

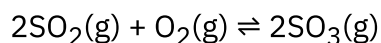
20(a) Hydrogen gas is manufactured by the chemical industry using the reaction of methane and steam. This is a reversible reaction, shown in equilibrium 20.1 below.



Explain, in terms of le Chatelier's principle, the conditions of pressure and temperature for a maximum yield of hydrogen from equilibrium 20.1, and explain why the operational conditions used by the chemical industry may be different.

[4 marks]

A chemist investigates the equilibrium reaction between sulfur dioxide, oxygen, and sulfur trioxide, shown below.



- The chemist mixes together SO_2 and O_2 with a catalyst.
- The chemist compresses the gas mixture to a volume of 400 cm^3 .
- The mixture is heated to a constant temperature and is allowed to reach equilibrium without changing the total gas volume.

The equilibrium mixture contains 0.0540 mol SO_2 and 0.0270 mol O_2 .

At the temperature used, the numerical value for K_c is $3.045 \times 10^4 \text{ dm}^3 \text{ mol}^{-1}$.

20(b)(i) Write the expression for K_c and the units of K_c for this equilibrium.

[2 marks]

20(b)(ii) Determine the amount, in mol, of SO_3 in the equilibrium mixture at this temperature.

Give your final answer to an appropriate number of significant figures.

Show all your working.

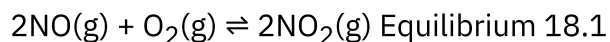
equilibrium amount of $\text{SO}_3 = \text{mol}$

[4 marks]

Q18 · [10 marks]

This question also needs Amount of substance and Enthalpy changes.

Nitrogen monoxide, NO, and oxygen, O₂, react to form nitrogen dioxide, NO₂, in the reversible reaction shown in equilibrium 18.1.



18(a) Write an expression for K_c for this equilibrium and state the units.

$K_c =$

Units =

[2 marks]

18(b) A chemist mixes together nitrogen and oxygen and pressurises the gases so that their total gas volume is 4.0 dm³.

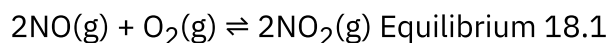
- The mixture is allowed to reach equilibrium at constant temperature and volume.
- The equilibrium mixture contains 0.40 mol NO and 0.80 mol O₂.
- Under these conditions, the numerical value of K_c is 45.

Calculate the amount, in mol, of NO₂ in the equilibrium mixture.

amount of NO₂ = mol

[4 marks]

The values of K_p for equilibrium 18.1 at 298 K and 1000 K are shown below.



Temperature / K	K_p / atm^{-1}
298	$K_p = 2.19 \times 10^{12}$
1000	$K_p = 2.03 \times 10^{-1}$

18(c)(i) Predict, with a reason, whether the forward reaction is exothermic or endothermic.

[1 mark]

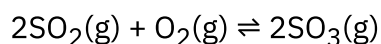
18(c)(ii) The chemist increases the pressure of the equilibrium mixture at the same temperature.

State, and explain in terms of K_p , how you would expect the equilibrium position to change.

[3 marks]

Q23 · Equilibrium constants Kc and Kp · June 2018 · Paper 1 (Periodic table, elements and physical chemistry) · Q9 · [1 mark]

The reversible reaction of sulfur dioxide and oxygen to form sulfur trioxide is shown below.



An equilibrium mixture contains 2.4 mol SO₂, 1.2 mol O₂ and 0.4 mol SO₃.

The total pressure is 250 atm.

What is the partial pressure of SO₃?

Tick (✓) one box.

- ☐ **A** 15 atm
- ☐ **B** 25 atm
- ☐ **C** 100 atm
- ☐ **D** 200 atm

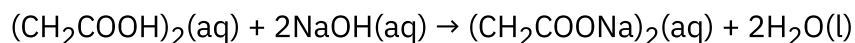
Q24 · Equilibrium constants Kc and Kp · June 2018 · Paper 3 (Unified chemistry) · Q5 · [11 marks]

This question also needs Acids and redox reactions, Alcohols and haloalkanes, Amount of substance and 4 other topics.

A student carries out two experiments in the laboratory based on succinic acid (butanedioic acid),



5(a) Aqueous succinic acid can be neutralised by aqueous sodium hydroxide, NaOH(aq):



This reaction can be used to determine a value for the enthalpy change of neutralisation, $\Delta_{\text{neut}}H$.

The student follows this method:

- Add 50.0 cm³ of 0.400 mol dm⁻³ succinic acid to a polystyrene cup.
- Measure out 50.0 cm³ of 1.00 mol dm⁻³ NaOH(aq), which is in excess.
- Measure the temperature of both solutions.
- Add the NaOH(aq) to the aqueous succinic acid in the polystyrene cup, stir the mixture, and record the maximum temperature.

Temperature readings

Maximum temperature of mixture/°C	26.5
Initial temperature of both solutions/°C	21.5

Calculate a value for the enthalpy change of neutralisation, $\Delta_{\text{neut}}H$, in kJ mol⁻¹.

Assume that the density of all solutions and the specific heat capacity, c , of the reaction mixture are the same as for water.

$\Delta_{\text{neut}}H = \text{kJ mol}^{-1}$

[4 marks]

Succinic acid is esterified by ethanol, $\text{C}_2\text{H}_5\text{OH}$, in the presence of an acid catalyst to form an equilibrium mixture.

The equilibrium constant, K_c , for this equilibrium can be calculated using the amounts, in moles, of the components in the equilibrium mixture, using expression 5.1.

$$K_c = \frac{n((\text{CH}_2\text{COOC}_2\text{H}_5)_2) \times n(\text{H}_2\text{O})^2}{n((\text{CH}_2\text{COOH})_2) \times n(\text{C}_2\text{H}_5\text{OH})^2} \text{ Expression 5.1}$$

A student carries out an experiment to determine the value of K_c for this equilibrium.

- The student mixes together 0.0500 mol of succinic acid and 0.150 mol of ethanol, with a small amount of an acid catalyst.
- The mixture is allowed to reach equilibrium.
- The student determines that 0.0200 mol of succinic acid are present in the equilibrium mixture.

5(b)(i) Which technique could be used to determine the equilibrium amount of succinic acid?

[1 mark]

5(b)(ii) Write the equation for the equilibrium reaction that takes place.

[1 mark]

5(b)(iii) Draw the skeletal formula of the ester present in the equilibrium mixture.

[1 mark]

5(b)(iv) K_c is the equilibrium constant in terms of equilibrium concentrations.

Why can expression 5.1 be used to calculate K_c for this equilibrium?

[1 mark]

5(b)(v) Calculate the value of K_c for this reaction.

Show your working.

$K_c =$

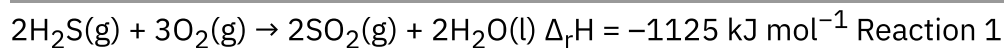
[3 marks]

Q25 · Equilibrium constants K_c and K_p · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q19 · [23 marks]

This question also needs Amount of substance, Enthalpy changes and Reaction rates and equilibrium.

Sulfuric acid is an important chemical used to make detergents, fertilisers and dyes. It is manufactured in a multi-step process.

In the first step of the manufacture of sulfuric acid, sulfur dioxide, SO_2 , can be made from the combustion of hydrogen sulfide, H_2S , shown in Reaction 1.



19(a)(i) Explain why the enthalpy change for Reaction 1 has a negative value.

Use ideas about enthalpy changes associated with bond breaking and bond making.

[1 mark]

19(a)(ii) Some standard entropy values are given below.

Substance	$\text{H}_2\text{S}(\text{g})$	$\text{O}_2(\text{g})$	$\text{SO}_2(\text{g})$	$\text{H}_2\text{O}(\text{l})$
$S^\ominus / \text{J K}^{-1} \text{ mol}^{-1}$	206	205	248	70

Using calculations, explain whether Reaction 1 is feasible at 20 °C.

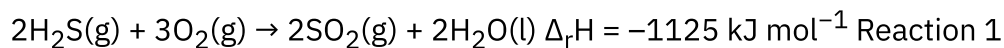
[4 marks]

Calculations

Explanation for feasible or non feasible

19(a)(iii) Calculate the standard enthalpy change of formation, $\Delta_f H^\ominus$, of hydrogen sulfide using the enthalpy change for Reaction 1, and the standard enthalpy changes of combustion below.

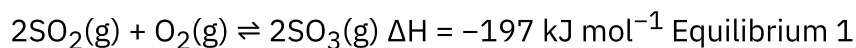
Substance	$\Delta_c H^\ominus / \text{kJ mol}^{-1}$
S(s)	-296.8
H ₂ (g)	-285.8



$\Delta_f H^\ominus$ of hydrogen sulfide = kJ mol^{-1}

[3 marks]

The second step in the manufacture of sulfuric acid is the conversion of SO_2 into sulfur trioxide, SO_3 , using Equilibrium 1.



An industrial chemist carries out some research into Equilibrium 1.

- The chemist fills a 10.2 dm^3 container with $\text{SO}_2(\text{g})$ at RTP, and then adds 12.0 g of $\text{O}_2(\text{g})$.
- The chemist adds the vanadium(V) oxide catalyst, and heats the mixture. The mixture is allowed to reach equilibrium at a pressure of 2.50 atm and a temperature of 1000 K .
- A sample of the equilibrium mixture is analysed, and found to contain 0.350 mol of SO_3 .

19(b)(i) Write an expression for K_p for Equilibrium 1.

Include the units.

units =

[2 marks]

19(b)(ii) Determine the value of K_p for Equilibrium 1 at 1000 K .

Show all your working.

Give your answer to 3 significant figures.

$K_p =$

[5 marks]

19(b)(iii) The chemist repeats the experiment in (b) at a different temperature.

The chemist finds that the value of K_p is greater than the answer to (b)(ii).

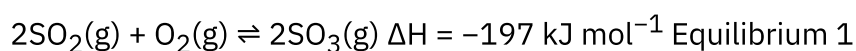
Explain whether the temperature in the second experiment is higher or lower than 1000 K.

[2 marks]

19(b)(iv) Explain the significance of the expression: $K_p \gg 1$.

[1 mark]

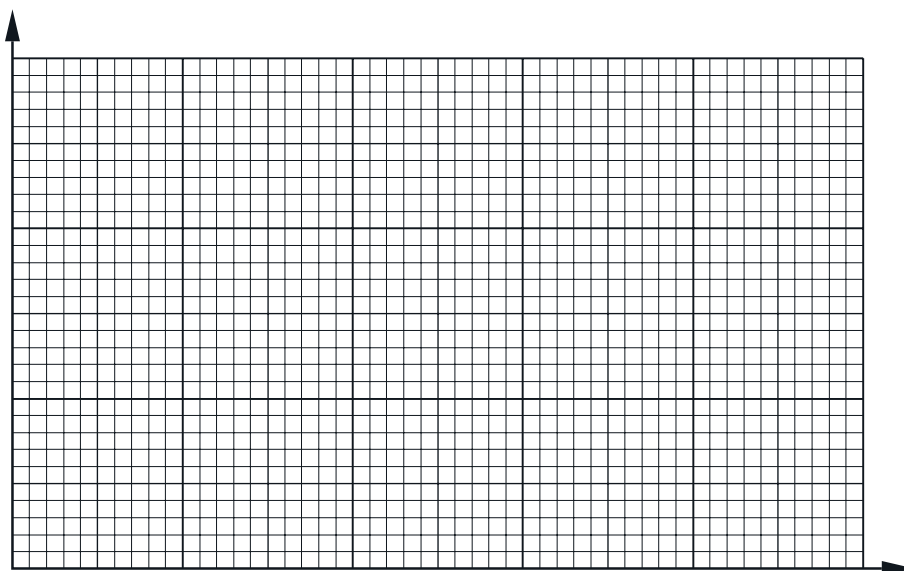
Vanadium(V) oxide, $V_2O_5(s)$, is used as a catalyst in equilibrium 1.



19(c)(i) Explain how the presence of $V_2O_5(s)$ increases the rate of reaction.

Include a labelled sketch of the Boltzmann distribution, on the grid below.

Label the axes.



[4 marks]

Draw your answer on the figure above.

19(c)(ii) Explain whether vanadium(V) oxide is acting as a homogeneous or heterogeneous catalyst.

[1 mark]

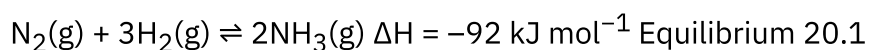
Q26 · Equilibrium constants Kc and Kp · June 2022 · Paper 1 (Periodic table, elements and physical chemistry) · Q20 · [8 marks]

This question also needs Reaction rates and equilibrium.

This question is about equilibria involving hydrogen.

20(a) Hydrogen is used industrially to manufacture ammonia.

The equilibrium is shown below.



1.20 mol $\text{N}_2(\text{g})$ is mixed with 3.60 mol $\text{H}_2(\text{g})$ in a 8.00 dm^3 container.

The mixture is heated to 550°C with an iron catalyst and allowed to reach equilibrium.

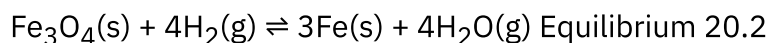
The equilibrium mixture contains 0.160 mol of NH_3 .

Determine the equilibrium constant K_c for Equilibrium 20.1, and explain why the operational conditions used by industry may be different from those required for a maximum equilibrium yield of ammonia.

[6 marks]

In industry, hydrogen is also used to reduce the iron oxide Fe_3O_4 as shown in Equilibrium 20.2.

The reaction is carried out at 500 °C.



20(b)(i) When the temperature is decreased, the value of K_p decreases.

Determine whether the forward reaction is exothermic or endothermic.

Explain your answer.

[1 mark]

20(b)(ii) Two students are discussing the effect of pressure on the equilibrium position of Equilibrium 20.2.

Student 1 says:

“There are more moles of products than reactants, so increasing the pressure will shift the equilibrium to the left hand side.”

Student 2 disagrees.

Determine which student is correct. Justify your answer.

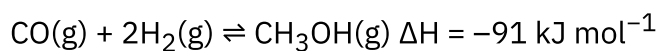
[1 mark]

Q27 · Equilibrium constants K_c and K_p · June 2025 · Paper 3 (Unified chemistry) · Q3 · [11 marks]

This question is about equilibrium and rates.

3(a) Methanol, CH₃OH, can be made industrially by the reaction of carbon monoxide, CO, with hydrogen, H₂, in the presence of a catalyst. This is a reversible reaction.

The equilibrium below is set up.



The concentrations of CO(g) and CH₃OH(g) in the equilibrium mixture are shown in the table below.

	CO(g)	CH ₃ OH(g)
equilibrium concentration / mol dm ⁻³	0.27	0.11

The value of the equilibrium constant, K_c, for this reaction is 1.8 dm⁶ mol⁻².

- Explain the conditions of pressure and temperature that would give the maximum equilibrium yield of CH₃OH(g).
- Calculate the concentration of H₂(g) in the equilibrium mixture to an **appropriate** number of significant figures.

[5 marks]

3(b) A reaction takes place when aqueous solutions of propanone, $\text{CH}_3\text{COCH}_3(\text{aq})$, and bromine, $\text{Br}_2(\text{aq})$, are mixed in the presence of dilute acid, $\text{H}^+(\text{aq})$.

The overall equation for this reaction is shown below.



- A student carries out three experiments to investigate the rate of this reaction.
- In each experiment, the student investigates the effect of changing the concentration of one of the three chemicals whilst keeping the concentrations of the other chemicals constant.

The student's results are shown below.

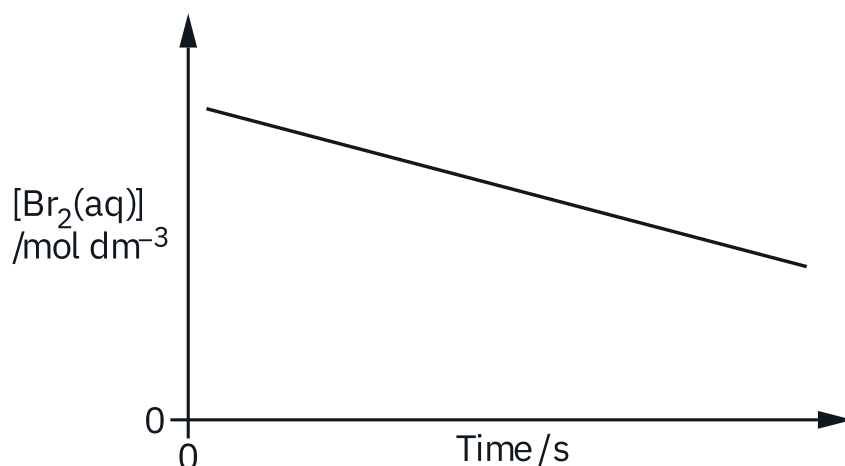
Experiment 1

Only $[\text{CH}_3\text{COCH}_3(\text{aq})]$ is varied.

Initial concentrations			
$\text{CH}_3\text{COCH}_3(\text{aq}) / \text{mol dm}^{-3}$	$\text{Br}_2(\text{aq}) / \text{mol dm}^{-3}$	$\text{H}^+(\text{aq}) / \text{mol dm}^{-3}$	Initial rate / $\text{mol dm}^{-3} \text{ s}^{-1}$
1.50×10^{-3}	2.00×10^{-1}	2.50×10^{-1}	1.70×10^{-7}
4.50×10^{-3}	2.00×10^{-1}	2.50×10^{-1}	5.10×10^{-7}

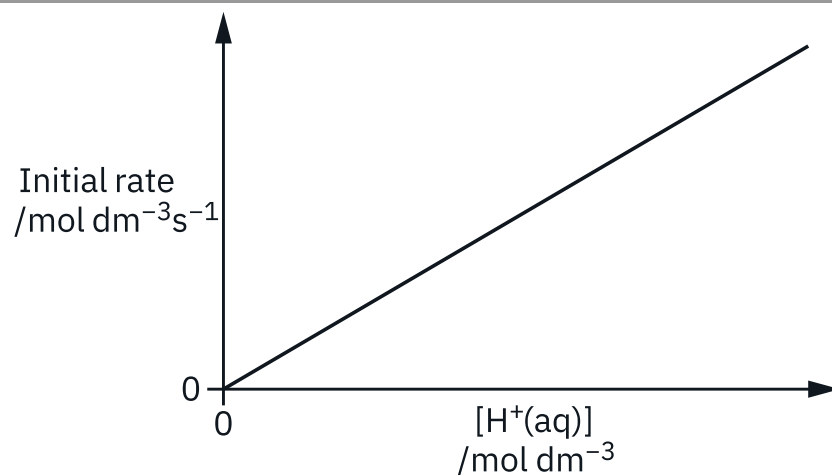
Experiment 2

Only $[\text{Br}_2(\text{aq})]$ is varied.



Experiment 3

Only $[\text{H}^+(\text{aq})]$ varied.



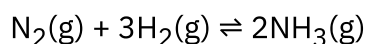
Use the student's results to determine the order with respect to each of the three chemicals, the rate equation and rate constant for Reaction 3.1. Explain your reasoning.

Explain how the student's results can be used to show that the mechanism of Reaction 3.1 has more than one step.

[6 marks]

Q28 · Equilibrium constants K_c and K_p · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q9 · [1 mark]

The reversible reaction of nitrogen and hydrogen to form ammonia is shown below.



In the equilibrium mixture, the partial pressure of N₂ is 18.75 MPa and the partial pressure of H₂ is 2.50 MPa.

The total pressure is 25 MPa.

What is the value of K_p, in MPa⁻²?

Tick (✓) one box.

☐ **A** 1.2×10^{-4}

☐ **B** 0.048

☐ **C** 0.075

☐ **D** 21

Q29 · Equilibrium constants K_c and K_p · November 2020 · Paper 3 (Unified chemistry) · Q5 · [9 marks]

This question also needs Enthalpy changes.

The equilibrium constant K_p and temperature T (in K) are linked by the mathematical relationship shown in equation 5.1 (R = Gas constant in J mol⁻¹ K⁻¹ and ΔH is enthalpy change in J mol⁻¹).

$$\ln K_p = -\Delta H / R \times 1 / T + \Delta S / R \text{ Equation 5.1}$$

5(a) The table shows the values of K_p at different temperatures for an equilibrium.

Complete the table by adding the missing values of $1/T$ and $\ln K_p$.

Temperature, T / K	400	500	600	700	800
K_p	3.00×10^{58}	5.86×10^{45}	1.83×10^{37}	1.46×10^{31}	1.14×10^{26}
$1/T / K^{-1}$	2.50×10^{-3}				
$\ln K_p$	135				

[2 marks]

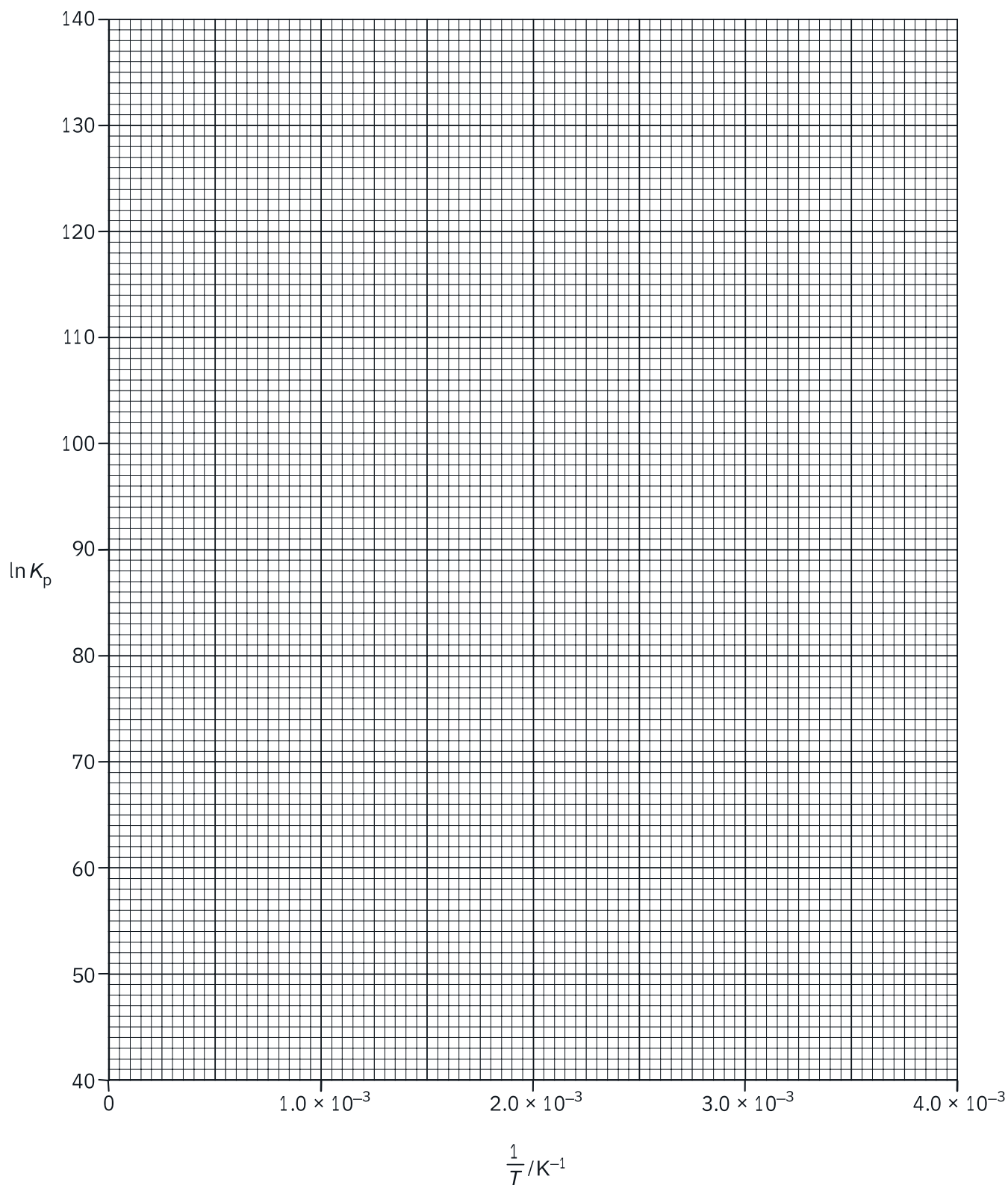
5(b) State and explain how increasing the temperature affects the position of this equilibrium and whether the forward reaction is exothermic or endothermic.

[1 mark]

5(c) Plot a graph of $\ln K_p$ against $1/T$ using the axes provided on the opposite page.

Use your graph and equation 5.1 to determine ΔH , in kJ mol^{-1} , for this equilibrium.

Give your answer to 3 significant figures.



$$\Delta H = \text{kJ mol}^{-1}$$

[4 marks]

Draw your answer on the figure above.

5(d) Explain how ΔS could be calculated from a graph of $\ln K_p$ against $1/T$.

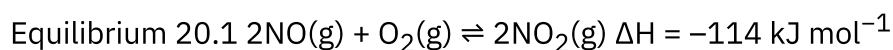
[2 marks]

Q30 • Equilibrium constants K_c and K_p • November 2021 • Paper 1 (Periodic table, elements and physical chemistry) • Q20 • [11 marks]

This question also needs Amount of substance and Reaction rates and equilibrium.

This question is about chemical equilibrium.

Nitrogen monoxide, NO, and oxygen, O₂, react to form nitrogen dioxide, NO₂, in the reversible reaction shown in Equilibrium 20.1.



$$\Delta S = -147 \text{ J mol}^{-1} \text{ K}^{-1}$$

20(a) A dynamic equilibrium exists in a closed system.

State one other feature of a dynamic equilibrium.

[1 mark]

20(b)(i) Show that the formation of NO_2 in Equilibrium 20.1 is feasible at 25°C .

[2 marks]

20(b)(ii) Determine the maximum temperature, in K, for feasibility.

Give your answer to an appropriate number of significant figures.

maximum temperature = K

[1 mark]

A chemist investigates the equilibrium shown in Equilibrium 20.1.

The chemist mixes together 1.60 mol of NO(g) and 1.50 mol of O₂(g) in a container and the mixture is allowed to reach equilibrium.

At equilibrium:

- 75% of the NO(g) has been converted to NO₂(g)
- the total pressure is 1.21 MPa.

20(c)(i) Calculate K_p , in MPa⁻¹, for Equilibrium 20.1.

Give your answer to 3 significant figures.

$K_p = \text{MPa}^{-1}$

[4 marks]

20(c)(ii) The chemist then repeats the experiment three times. In each experiment, the chemist makes one change but uses the same initial amounts of NO and O₂.

Complete the table to show the predicted effect of each change compared with the original experiment.

Only use the words greater, smaller or same.

Change	K_p	Equilibrium amount of NO ₂ (g)	Initial rate
Temperature increase			
Pressure increase			
Catalyst added			

[3 marks]

Q31 • Equilibrium constants K_c and K_p • November 2021 • Paper 3 (Unified chemistry) • Q1 • [18 marks]

This question also needs Acids and redox reactions, Alcohols and haloalkanes, Amount of substance and 4 other topics.

These short questions are from different areas of chemistry.

1(a) A flask contains 110 g CO₂ and 120 g O₂ at a pressure of 50.0 atm.

What is the partial pressure of the CO₂?

partial pressure of CO₂ = atm

[2 marks]

1(b) Pure PCl_5 is placed in a sealed container which is heated to 200°C .

An equilibrium is set up: $\text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$

Under these conditions:

- $K_c = 8.00 \times 10^{-3} \text{ mol dm}^{-3}$
- equilibrium concentration of $\text{PCl}_5 = 0.0500 \text{ mol dm}^{-3}$.

Calculate the concentrations of PCl_3 and Cl_2 at equilibrium.

concentration of $\text{PCl}_3 = \text{mol dm}^{-3}$

concentration of $\text{Cl}_2 = \text{mol dm}^{-3}$

[2 marks]

1(c) The electronegativities of H, C, N and F, and the boiling points of methane, ammonia and hydrogen fluoride are shown below.

Electronegativity	H: 2.1	C: 2.5	N: 3.0	F: 4.0
-------------------	--------	--------	--------	--------

Compound	CH_4	NH_3	HF
Boiling point / $^\circ\text{C}$	-161.5	-33.3	19.5

Explain the difference in the boiling points of CH_4 , NH_3 and HF .

[3 marks]

1(d) Compound A has the following percentage composition by mass:

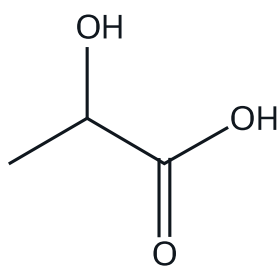
Ca, 81.10%; N, 18.90%.

A student reacts compound A with water to form alkaline gas B and alkali C.

Identify A, B and C and write the equation for the reaction of compound A with water.

[4 marks]

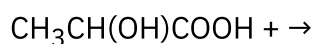
1(e) The structure of lactic acid is shown below.



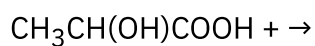
lactic acid

Complete and balance the equations for two reactions of lactic acid.

Reaction with sodium carbonate



Reaction with aluminium



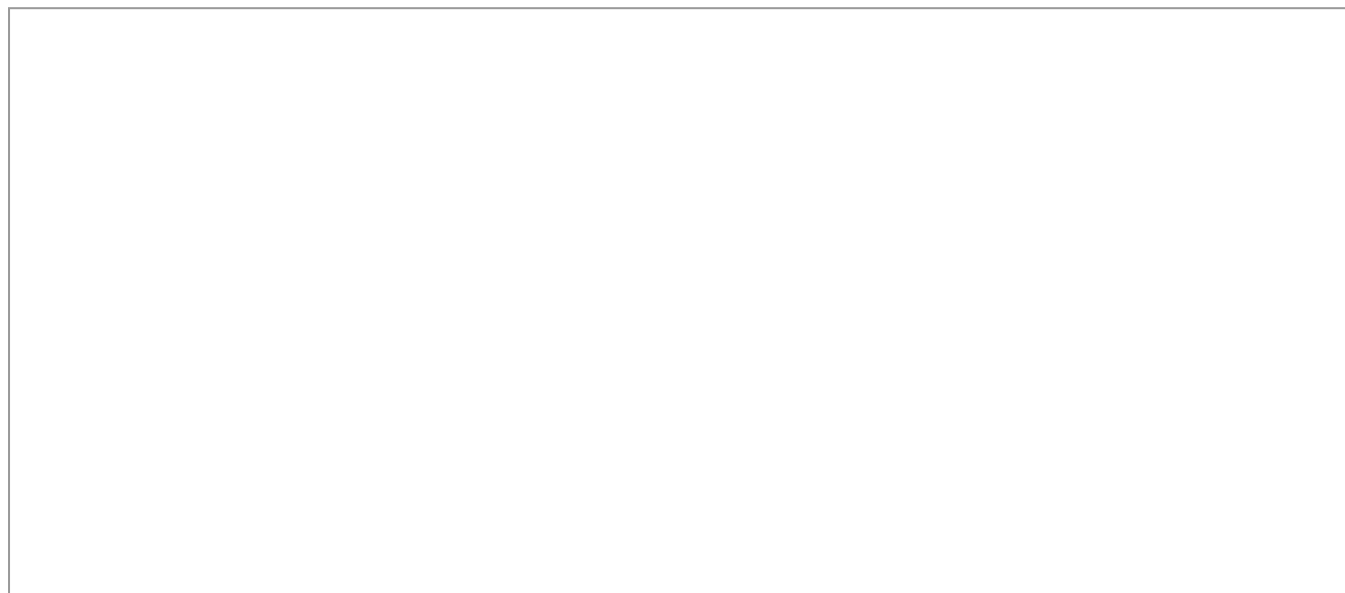
[4 marks]

1(f) The ester, methyl ethanoate, can be synthesised by reacting a haloalkane with a carboxylate ion.

The mechanism is nucleophilic substitution.

Outline the mechanism for this reaction.

[3 marks]



Q32 · Lattice enthalpy, entropy and free energy · June 2017 · Paper 1 (Periodic table, elements and physical

chemistry) · Q18 · [12 marks]

This question also needs Enthalpy changes.

This question is about free energy changes, ΔG , enthalpy changes, ΔH , and temperature, T .

18(a) The Gibbs' equation is shown below.

$$\Delta G = \Delta H - T\Delta S$$

A chemist investigates a reaction to determine how ΔG varies with T .

The results are shown in Fig. 18.1.

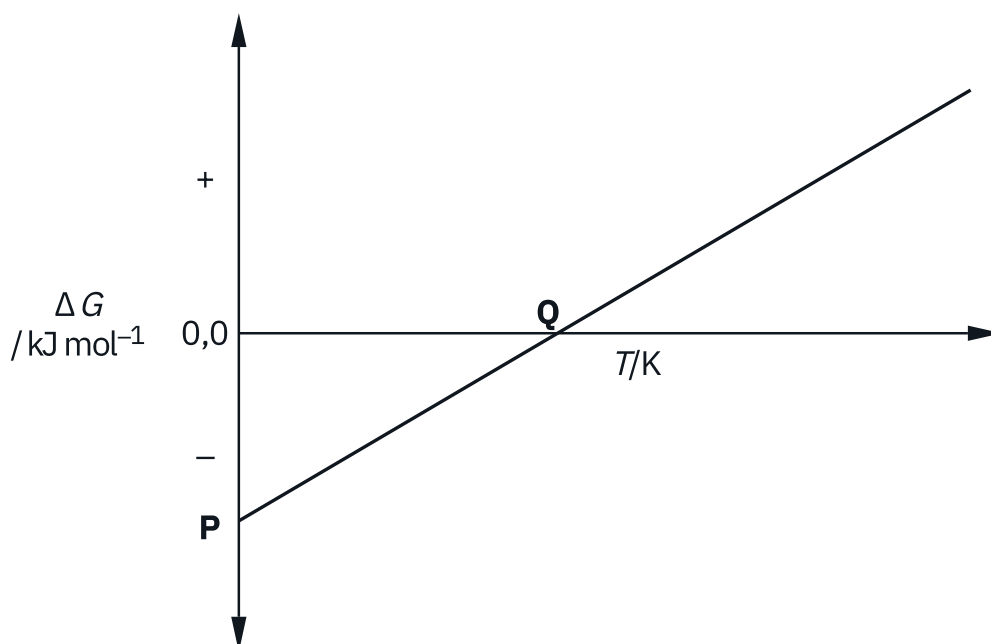


Fig. 18.1

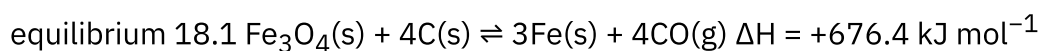
What is significant about the gradient of the line and the values P and Q shown in Fig. 18.1?

Explain your reasoning.

[4 marks]

Iron can be extracted from its ore Fe_3O_4 using carbon.

Several equilibria are involved including equilibrium 18.1, shown below.



$$\Delta S = +703.1 \text{ J K}^{-1} \text{ mol}^{-1}$$

18(b)(i) Why is equilibrium 18.1 a heterogeneous equilibrium?

[1 mark]

18(b)(ii) Write the expression for K_p for equilibrium 18.1.

[1 mark]

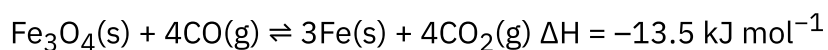
18(b)(iii) The forward reaction in equilibrium 18.1 is only feasible at high temperatures.

- Show that the forward reaction is not feasible at 25 °C.
- Calculate the minimum temperature, in K, for the forward reaction to be feasible.

minimum temperature = K

[3 marks]

18(b)(iv) Another equilibrium involved in the extraction of iron from Fe_3O_4 is shown below.



Enthalpy changes of formation, $\Delta_f H$, for $\text{Fe}_3\text{O}_4(\text{s})$ and $\text{CO}_2(\text{g})$ are shown in the table.

Compound	$\Delta_f H / \text{kJ mol}^{-1}$
$\text{Fe}_3\text{O}_4(\text{s})$	-1118.5
$\text{CO}_2(\text{g})$	-393.5

Calculate the enthalpy change of formation, $\Delta_f H$, for $\text{CO}(\text{g})$.

$\Delta_f H$, for $\text{CO}(\text{g}) = \text{kJ mol}^{-1}$

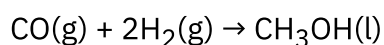
[3 marks]

Q33 · Lattice enthalpy, entropy and free energy · June 2018 · Paper 1 (Periodic table, elements and physical chemistry) · Q11 · [1 mark]

The table below shows standard entropies, $S^\ominus$.

Substance	CO(g)	H ₂ (g)	CH ₃ OH(l)
$S^\ominus / \text{J mol}^{-1} \text{K}^{-1}$	197.6	130.6	239.7

What is the entropy change, $\Delta S^\ominus$, in $\text{J mol}^{-1} \text{K}^{-1}$, for the following reaction?



Tick (✓) one box.

- ☐ **A** -219.1
- ☐ **B** -88.5
- ☐ **C** +88.5
- ☐ **D** +219.1

Q34 · Lattice enthalpy, entropy and free energy · June 2018 · Paper 1 (Periodic table, elements and physical chemistry) · Q16 · [15 marks]

This question also needs Amount of substance and Enthalpy changes.

This question is about enthalpy changes.

Table 16.1 shows enthalpy changes that can be used to determine the enthalpy change of hydration of fluoride ions, F^- .

Enthalpy change	Energy / kJ mol^{-1}
Hydration of Ca^{2+}	-1609
Solution of CaF_2	+13
Lattice enthalpy of CaF_2	-2630

Table 16.1

16(a)(i) Explain what is meant by the term enthalpy change of hydration.

[2 marks]

16(a)(ii) The enthalpy change of hydration of F^- can be determined using the enthalpy changes in Table 16.1 and the incomplete energy cycle below.

On the dotted lines, add the species present, including state symbols.



[4 marks]

16(a)(iii) Calculate the enthalpy change of hydration of fluoride ions, F^- .

enthalpy change of hydration = kJ mol^{-1}

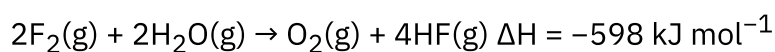
[2 marks]

16(a)(iv) Predict how the enthalpy changes of hydration of F^- and Cl^- would differ.

Explain your answer.

[2 marks]

Fluorine reacts with steam as shown in the equation below.



Average bond enthalpies are shown in the table.

Bond	Average bond enthalpy / kJ mol^{-1}
O-H	+464
O=O	+498
H-F	+568

16(b)(i) Explain what is meant by the term average bond enthalpy.

[2 marks]

16(b)(ii) Calculate the bond enthalpy of the F–F bond.

bond enthalpy = kJ mol^{-1}

[3 marks]

Q35 · Lattice enthalpy, entropy and free energy · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q16 · [15 marks]

This question also needs Amount of substance, Atomic structure and isotopes, Electrons, bonding and structure and 3 other topics.

Sir Humphry Davy discovered several elements including sodium, potassium, magnesium, calcium and strontium.

16(a) Explain which block in the Periodic Table sodium and magnesium belong to.

[1 mark]

16(b) A sample of magnesium, $A_r = 24.305$, is found to consist of three isotopes. The accurate relative isotopic masses and % abundances of two of the isotopes are shown in the table.

Isotope	Relative isotopic mass	% abundance
^{24}Mg	23.985	78.99%
^{25}Mg	24.986	10.00%

Determine the relative isotopic mass of the third isotope of magnesium in the sample.

Give your answer to 5 significant figures.

relative isotopic mass =

[2 marks]

A student adds an excess of calcium oxide to water in a test tube.

In a separate test tube, the student adds an excess of strontium oxide to water.

16(c)(i) Write the equation for the reaction of calcium oxide with water.

State symbols are not required.

[1 mark]

16(c)(ii) Suggest the approximate pH of the two solutions formed in the test tubes.

[1 mark]

pH with calcium oxide

pH with strontium oxide

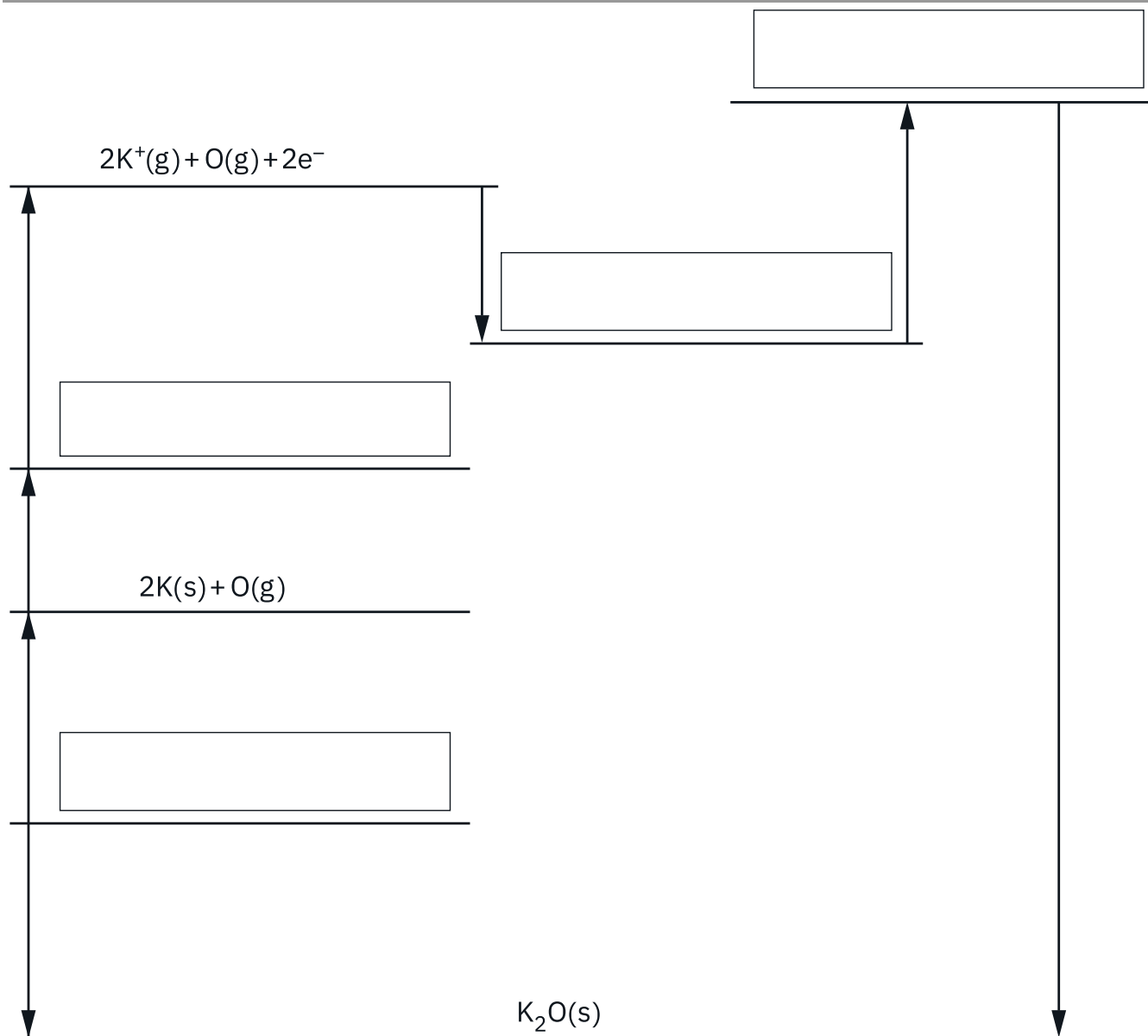
The table below shows enthalpy changes involving potassium, oxygen and potassium oxide, K_2O .

Enthalpy change / kJ mol^{-1}	
formation of potassium oxide	-363
1st electron affinity of oxygen	-141
2nd electron affinity of oxygen	+790
1st ionisation energy of potassium	+419
atomisation of oxygen	+249
atomisation of potassium	+89

16(d)(i) The incomplete Born–Haber cycle below can be used to determine the lattice enthalpy of potassium oxide.

In the boxes, complete the species present in the cycle.

Include state symbols for the species.



[4 marks]

Draw your answer on the figure above.

16(d)(ii) Calculate the lattice enthalpy of potassium oxide.

lattice enthalpy = kJ mol^{-1}

[2 marks]

A similar Born–Haber cycle to potassium oxide in (d) can be constructed for sodium oxide.

16(e)(i) The first ionisation energy of sodium is more endothermic than that of potassium.

Explain why.

[2 marks]

16(e)(ii) The lattice enthalpy of sodium oxide is more exothermic than that of potassium oxide.

Explain why.

[2 marks]

Q36 · Lattice enthalpy, entropy and free energy · June 2022 · Paper 1 (Periodic table, elements and physical chemistry) · Q10 · [1 mark]

For the condensation of ammonia gas, what are the signs of ΔH and ΔS ?

Tick (✓) one box.

☐ **A** ΔH –ve · ΔS –ve

☐ **B** ΔH –ve · ΔS +ve

☐ **C** ΔH +ve · ΔS +ve

☐ **D** ΔH +ve · ΔS –ve

Q37 · Lattice enthalpy, entropy and free energy · June 2022 · Paper 1 (Periodic table, elements and physical chemistry) · Q17 · [14 marks]

This question also needs Enthalpy changes.

This question is about energy changes.

Magnesium reacts with aqueous silver nitrate, $\text{AgNO}_3(\text{aq})$ as shown below.



A student adds an excess of magnesium to 100.0 cm^3 of $0.400 \text{ mol dm}^{-3} \text{ AgNO}_3(\text{aq})$.

The initial temperature is 20.0°C .

17(a)(i) Determine the maximum temperature reached in this reaction.

Give your answer to **3** significant figures.

Assume that the specific heat capacity and density of the solution are the same as for water, and that there are no heat losses.

maximum temperature reached = $^\circ\text{C}$

[4 marks]

17(a)(ii) The student wants to repeat the experiment, but there is not enough $\text{AgNO}_3(\text{aq})$ left to use another 100.0 cm^3 portion.

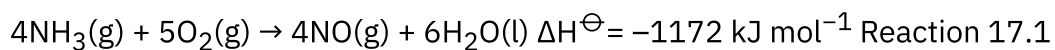
The student decides to modify the method by adding an excess of magnesium to 50.0 cm^3 of $0.400 \text{ mol dm}^{-3} \text{ AgNO}_3(\text{aq})$.

Predict, with reasons, how this modification would affect the maximum temperature reached. Assume that there are no heat losses.

[1 mark]

Nitric acid is manufactured from ammonia in a multi-stage process.

The equation for the first stage in this process is shown in Reaction 17.1.



Some standard enthalpy changes of formation are shown in the table.

Compound	$\Delta_f H^\ominus / \text{kJ mol}^{-1}$
$\text{NH}_3(\text{g})$	-46
$\text{H}_2\text{O}(\text{l})$	-286

17(b)(i) Explain the term **enthalpy change of formation**.

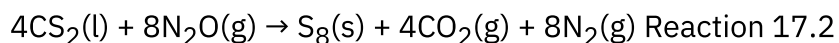
[1 mark]

17(b)(ii) Calculate the standard enthalpy change of formation, $\Delta_f H^\ominus$, of $\text{NO}(\text{g})$.

$$\Delta_f H^\ominus \text{ of } \text{NO}(\text{g}) = \text{kJ mol}^{-1}$$

[2 marks]

Carbon disulfide, CS_2 , reacts with dinitrogen oxide, N_2O , as shown in Reaction 17.2.



Standard entropies, $S^\ominus$, are shown in the table.

Substance	$\text{CS}_2(\text{l})$	$\text{N}_2\text{O}(\text{g})$	$\text{S}_8(\text{s})$	$\text{CO}_2(\text{g})$	$\text{N}_2(\text{g})$
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	151	220	256	214	192

17(c)(i) Explain the term **entropy**.

[1 mark]

17(c)(ii) The free energy change, ΔG , of Reaction 17.2 is $-2672 \text{ kJ mol}^{-1}$ at 25°C .

Calculate the enthalpy change, ΔH , of Reaction 17.2, in kJ mol^{-1} .

$\Delta H = \text{kJ mol}^{-1}$

[3 marks]

17(c)(iii) A student concludes that Reaction 17.2 is feasible at all temperatures.

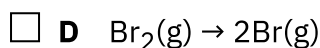
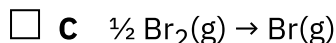
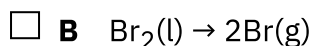
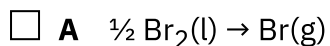
Explain whether the student is correct or not.

[2 marks]

Q38 · Lattice enthalpy, entropy and free energy · June 2022 · Paper 1 (Periodic table, elements and physical chemistry) · Q9 · [1 mark]

Which equation represents the change that accompanies the standard enthalpy change of atomisation of bromine?

Tick (✓) one box.

**Q39 · Lattice enthalpy, entropy and free energy · June 2023 · Paper 1 (Periodic table, elements and physical chemistry) · Q15 · [1 mark]**

Chlorine trifluoride can be decomposed into its elements forming the equilibrium mixture below.

$2\text{ClF}_3(\text{g})$	$\rightleftharpoons$	$\text{Cl}_2(\text{g})$	+	$3\text{F}_2(\text{g})$	$\Delta H = +318 \text{ kJ mol}^{-1}$
colourless gas		green gas		yellow gas	

Which statement(s) is/are correct?

1 The decomposition is a redox reaction.

2 When the equilibrium mixture is cooled, the colour fades.

3 The decomposition has a negative entropy change.

Tick (✓) one box.

☐ **A** 1, 2 and 3

☐ **B** Only 1 and 2

☐ **C** Only 2 and 3

☐ **D** Only 1

Q40 · Lattice enthalpy, entropy and free energy · June 2023 · Paper 1 (Periodic table, elements and physical chemistry) · Q16 · [10 marks]

This question also needs Periodicity.

This question is about energy changes.

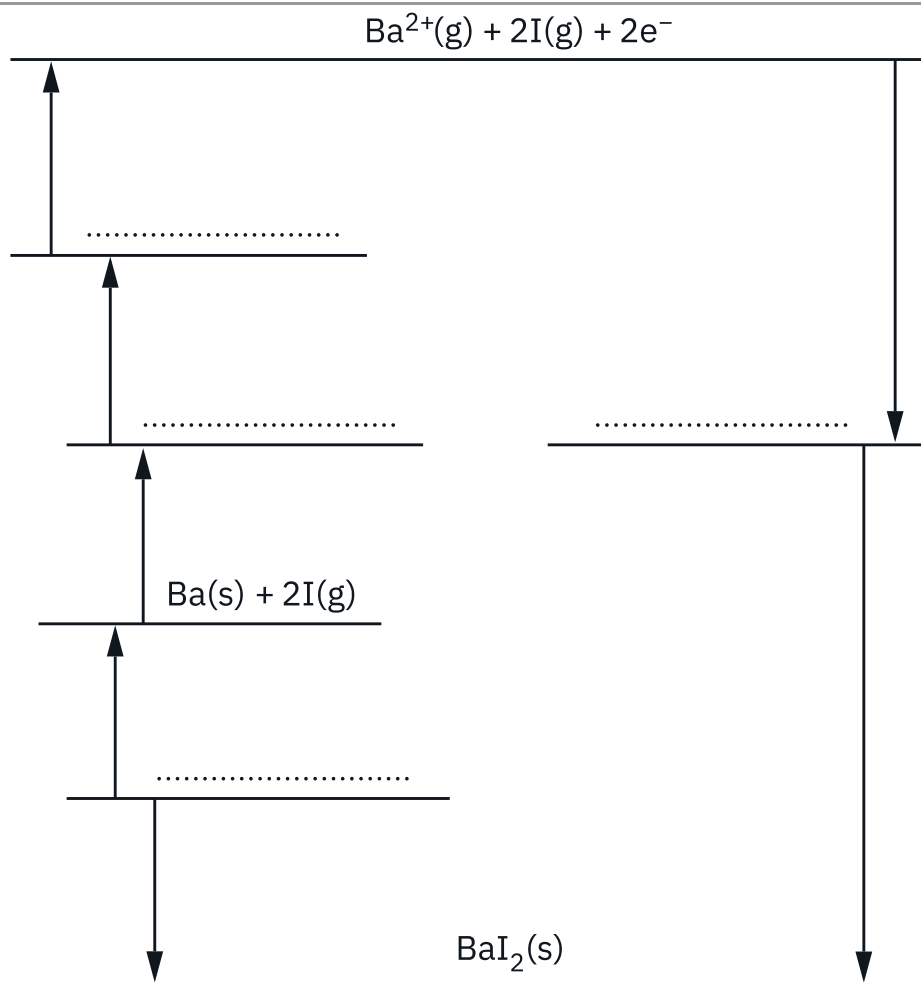
Lattice enthalpies can be determined indirectly using Born-Haber cycles.

The table below shows the energy changes that are needed to determine the lattice enthalpy of barium iodide, BaI_2 .

Energy term	Energy change / kJ mol^{-1}
formation of barium iodide	-602
1st electron affinity of iodine	-296
1st ionisation energy of barium	+503
2nd ionisation energy of barium	+965
atomisation of iodine	+107
atomisation of barium	+180

16(a)(i) The diagram below shows an incomplete Born-Haber cycle that can be used to calculate the lattice enthalpy of barium iodide.

On the dotted lines, add the species present, including state symbols.



[4 marks]

16(a)(ii) Calculate the lattice enthalpy of barium iodide.

lattice enthalpy = kJ mol^{-1}

[2 marks]

16(b) The first and second ionisation energies of magnesium, Mg, and strontium, Sr, in Group 2 are given in the table below.

Element	First ionisation energy / kJ mol^{-1}	Second ionisation energy / kJ mol^{-1}
Mg	+738	+1451
Sr	+550	+1064

- Explain why the first ionisation energy of Mg is greater than the **first** ionisation energy of Sr.
- Explain why the second ionisation energy of Sr is greater than the **first** ionisation energy of Sr.

[4 marks]

chemistry) · Q18 · [11 marks]

This question also needs Enthalpy changes.

This question is about enthalpy changes of reactions involving hydrocarbons.

18(a) A student determines the enthalpy change of combustion, $\Delta_c H$, of heptane, C_7H_{16} , using the method outlined below.

- Add 150 g of water to a beaker and measure its temperature.
- Weigh a spirit burner containing heptane and use it to heat the water.
- Extinguish the flame and record the maximum temperature reached by the water.
- Reweigh the spirit burner.

The temperature of the water increased by 10.5 °C.

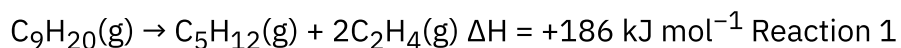
The spirit burner decreased in mass by 0.133 g.

Use the student's results to determine the enthalpy change of combustion of heptane, $\Delta_c H$ (C_7H_{16}), in kJ mol^{-1} .

$\Delta_c H (C_7H_{16}) = \text{kJ mol}^{-1}$

[3 marks]

18(b) Nonane, C_9H_{20} , can be broken down by heat to form pentane, C_5H_{12} , and ethene, C_2H_4 .



The enthalpy changes of combustion of $C_9H_{20}(g)$ and $C_2H_4(g)$ are shown in the table below.

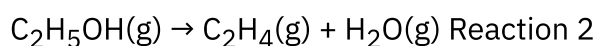
Hydrocarbon	$\Delta_c H / \text{kJ mol}^{-1}$
$C_9H_{20}(g)$	-6171
$C_2H_4(g)$	-1411

Use ΔH in Reaction 1 and the enthalpy changes of combustion in the table to determine the enthalpy change of combustion of $C_5H_{12}(g)$.

$$\Delta_c H (C_5H_{12}(g)) = \text{kJ mol}^{-1}$$

[2 marks]

Ethene can be produced from ethanol, as shown in Reaction 2 below.

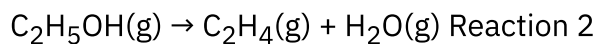


18(c)(i) Predict the sign of the entropy change, ΔS , for Reaction 2.

Explain your reasoning.

[1 mark]

18(c)(ii) Reaction 2 is repeated:



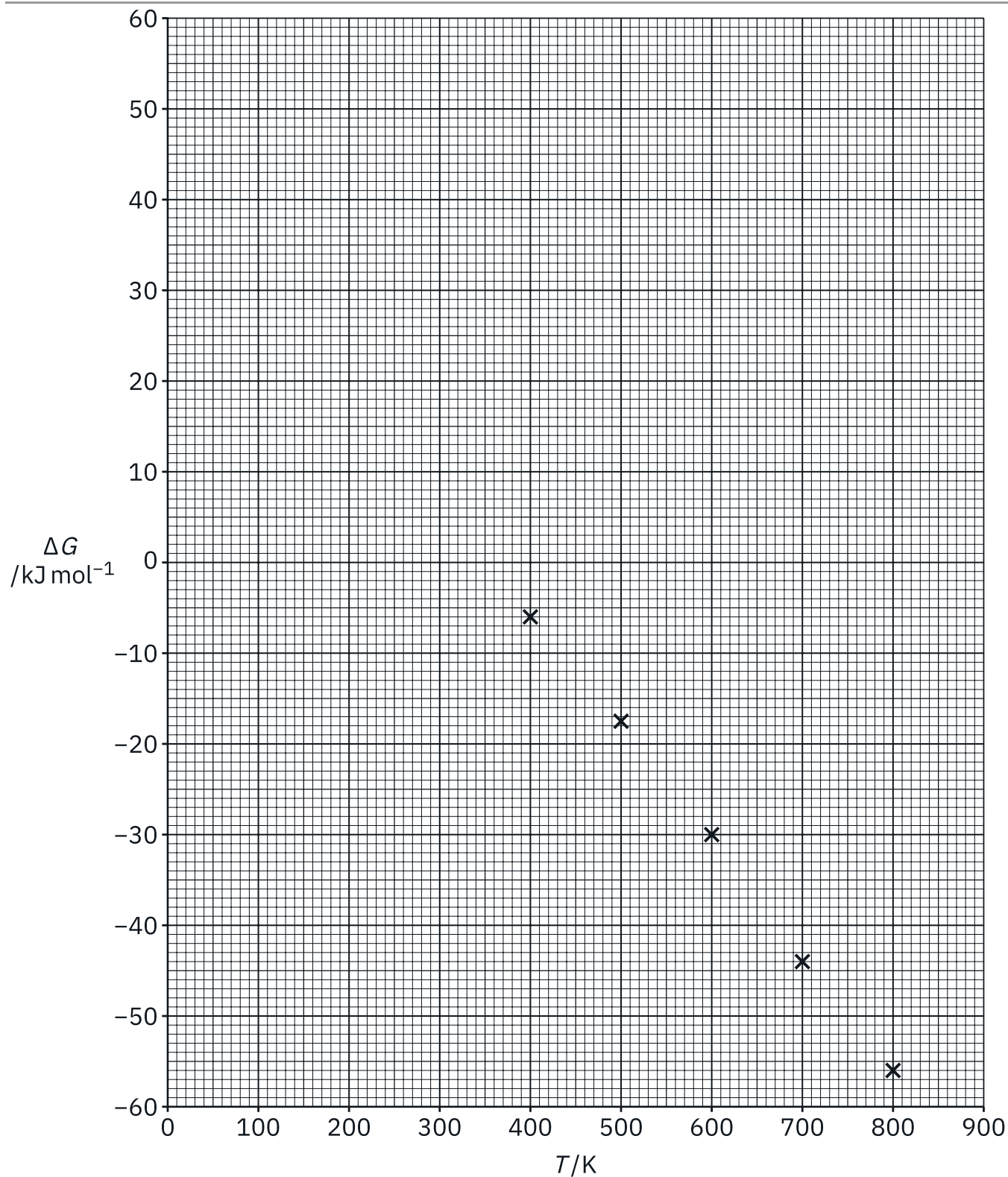
The Gibbs equation is shown below.

$$\Delta G = \Delta H - T\Delta S$$

The enthalpy change, ΔH , and the entropy change, ΔS , can be assumed to be constant at different temperatures.

Fig. 18.1 shows values of the free energy change, ΔG , in kJ mol^{-1} , at different temperatures, T , in K, for Reaction 2.

Fig. 18.1



Use the graph in Fig. 18.1 to answer the following:

- Draw the best-fit line on the graph in Fig. 18.1.
- Determine ΔS , in J K⁻¹ mol⁻¹, for Reaction 2.
- Determine the minimum temperature, T , at which the reaction is feasible.
- Determine ΔH for Reaction 2.

$$\Delta S = \text{J K}^{-1} \text{ mol}^{-1}$$

minimum $T = \text{K}$

$$\Delta H = \text{kJ mol}^{-1}$$

[5 marks]

Draw your answer on the figure above.

Q42 · Lattice enthalpy, entropy and free energy · June 2023 · Paper 1 (Periodic table, elements and physical chemistry) · Q9 · [1 mark]

The table below shows standard entropies, $S^\ominus$.

Substance	$\text{SO}_2(\text{g})$	$\text{O}_2(\text{g})$	$\text{SO}_3(\text{l})$
$S^\ominus / \text{J K}^{-1} \text{ mol}^{-1}$	248	204	96

What is the standard entropy change, $\Delta S^\ominus$, in J K mol^{-1} , for the formation of 1 mol of $\text{SO}_3(\text{l})$ from $\text{SO}_2(\text{g})$ and $\text{O}_2(\text{g})$?

Tick (✓) one box.

☐ **A** -508

☐ **B** -254

☐ **C** +254

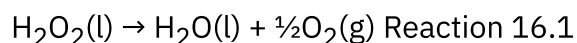
☐ **D** +508

Q43 · Lattice enthalpy, entropy and free energy · June 2024 · Paper 1 (Periodic table, elements and physical chemistry) · Q16 · [17 marks]

This question also needs Enthalpy changes and Reaction rates and equilibrium.

This question is about energy changes.

Hydrogen peroxide decomposes as shown in Reaction 16.1.



The table shows enthalpy changes of formation and entropies.

	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
$\text{H}_2\text{O}_2(\text{l})$	-188	110
$\text{H}_2\text{O}(\text{l})$	-286	70.0
$\text{O}_2(\text{g})$	0	205

16(a)(i) Calculate the free-energy change, ΔG , in kJ mol^{-1} , of Reaction 16.1 at 25 °C.

Give your answer to **3** significant figures.

$\Delta G = \text{kJ mol}^{-1}$

[4 marks]

16(a)(ii) The decomposition of hydrogen peroxide shown in Reaction 16.1 is feasible.

Suggest why Reaction 16.1 does **not** take place at 25 °C despite being feasible.

[1 mark]

The rate of decomposition of hydrogen peroxide shown in Reaction 16.1 can be increased by adding a small amount of powdered manganese(IV) oxide, MnO_2 .

The MnO_2 acts as a catalyst.

16(b)(i) Complete the enthalpy profile diagram for Reaction 16.1 using formulae for the reactants and products.

- Use E_a to label the activation energy **without** MnO_2 .
- Use E_c to label the activation energy **with** MnO_2 .
- Use ΔH to label the enthalpy change of reaction.



[3 marks]

Draw your answer on the figure above.

16(b)(ii) Explain why MnO_2 is described as a **heterogeneous** catalyst for this reaction.

[1 mark]

16(b)(iii) Mn_3O_4 is a compound in which Mn has two different oxidation states. The two oxidation states are different from the Mn in MnO_2 .

Suggest the two oxidation states of manganese in Mn_3O_4 .

[1 mark]

Manganese(II) oxide, MnO , has a giant ionic lattice structure.

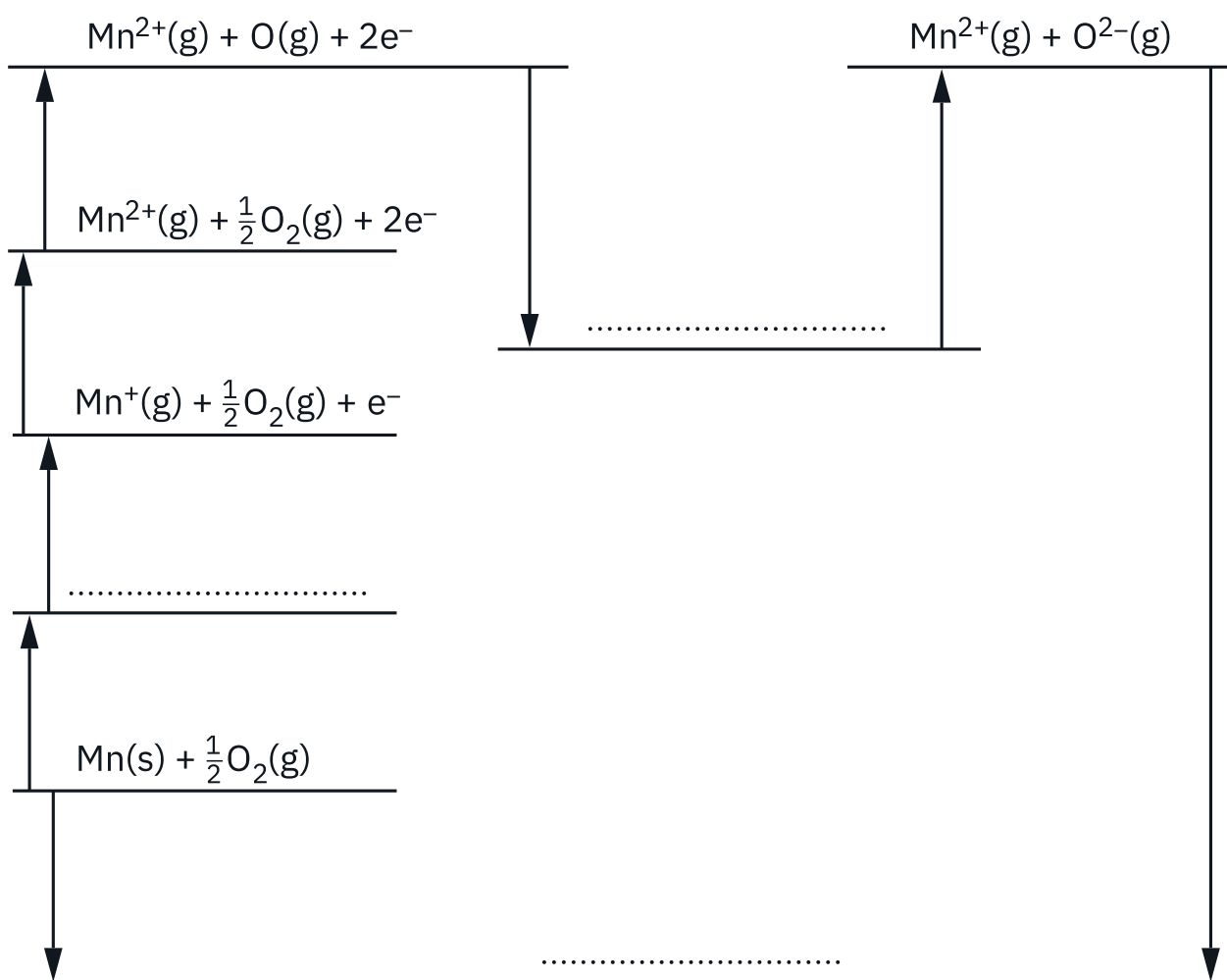
The table shows the enthalpy changes that are needed to determine the lattice enthalpy of MnO .

	enthalpy change / kJ mol^{-1}
atomisation of manganese	+281
atomisation of oxygen	+249
first ionisation energy of manganese	+717
second ionisation energy of manganese	+1509
first electron affinity of oxygen	-141
second electron affinity of oxygen	+798
formation of manganese(II) oxide	-385

16(c)(i) Define the term **lattice enthalpy**.

[2 marks]

16(c)(ii) The diagram shows an incomplete Born-Haber cycle that can be used to determine the lattice enthalpy of MnO.



Complete the diagram by adding the species present on the dotted lines, include state symbols.

[3 marks]

Draw your answer on the figure above.

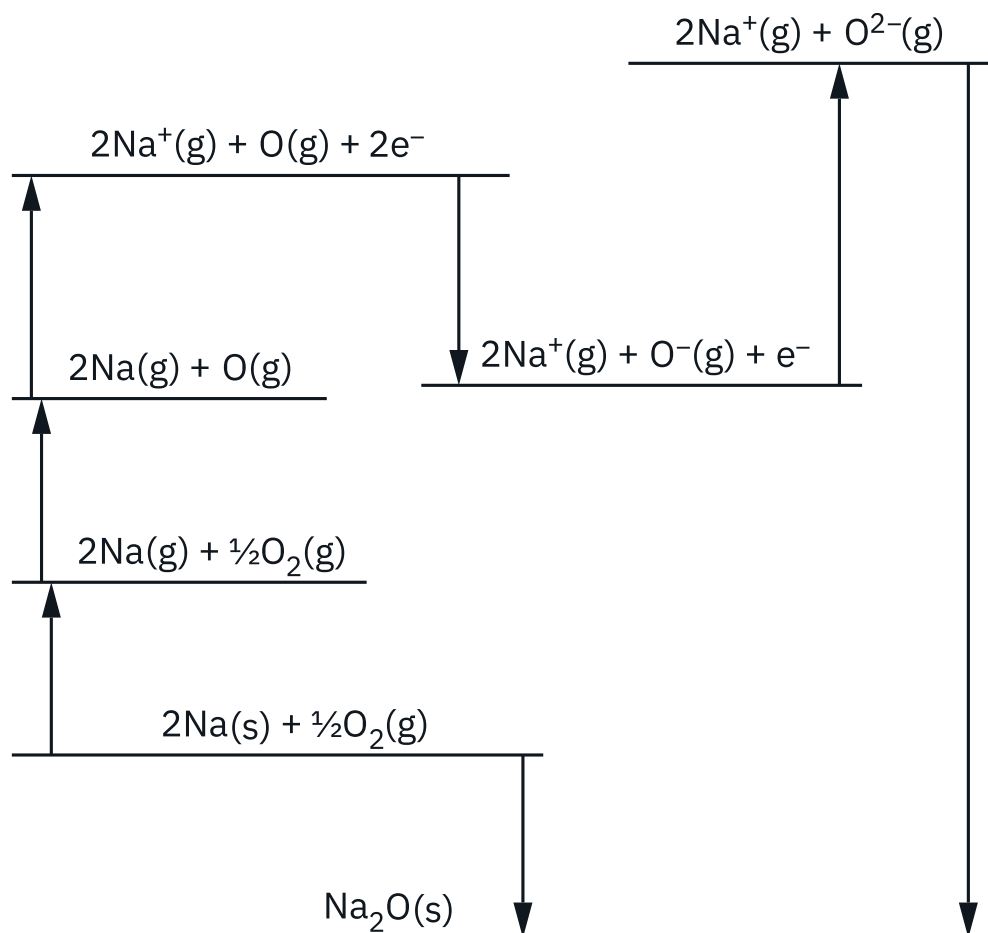
16(c)(iii) Calculate the lattice enthalpy of MnO.

lattice enthalpy = kJ mol^{-1}

[2 marks]

Q44 · Lattice enthalpy, entropy and free energy · June 2025 · Paper 1 (Periodic table, elements and physical chemistry) · Q3 · [1 mark]

The diagram shows the Born-Haber cycle for sodium oxide, Na_2O .



Why is the value for the second electron affinity of oxygen positive?

Tick (✓) one box.

- ☐ **A** An electron is added to a high energy orbital.
- ☐ **B** An electron is added to a negative ion.
- ☐ **C** An electron is removed from a gaseous atom.
- ☐ **D** An electron is removed from a positive ion.

Q45 · Lattice enthalpy, entropy and free energy · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q17 · [13 marks]

This question also needs Alkanes, Amount of substance, Enthalpy changes and Reaction rates and equilibrium.

Methanol, CH_3OH , can be made industrially by the reaction of carbon monoxide with hydrogen, as shown in equilibrium 1.



17(a) Predict the conditions of pressure and temperature that would give the maximum equilibrium yield of CH_3OH in equilibrium 1.

Explain your answer.

[3 marks]

17(b) A catalyst is used in the production of methanol in equilibrium 1.

State two ways that the use of catalysts helps chemical companies to make their processes more sustainable and less harmful to the environment.

[2 marks]

1

2

17(c) Standard entropy values are given below.

Substance	CO(g)	H ₂ (g)	CH ₃ OH(g)
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	198	131	238

A chemist proposed producing methanol at 525 K using equilibrium 1.

Explain, with a calculation, whether the production of methanol is feasible at 525 K.

[5 marks]

17(d) At 298 K, the free energy change, ΔG , for the production of methanol in equilibrium 1 is $-2.48 \times 10^4 \text{ J mol}^{-1}$.

ΔG is linked to K_p by the relationship: $\Delta G = -RT \ln K_p$.

R = gas constant

T = temperature in K.

Calculate K_p for equilibrium 1 at 298 K.

Give your answer to 3 significant figures.

K_p = units

[3 marks]

Q46 • Lattice enthalpy, entropy and free energy • November 2021 • Paper 1 (Periodic table, elements and physical chemistry) • Q11 • [1 mark]

The feasibility of a chemical reaction depends on the temperature and the signs of ΔH and ΔS .

Which row has signs for ΔH and ΔS for a reaction that is feasible at high temperatures but is not feasible at low temperatures?

Tick (✓) one box.

☐ **A** ΔH : + ΔS : +

☐ **B** ΔH : + ΔS : -

☐ **C** ΔH : - ΔS : +

☐ **D** ΔH : - ΔS : -

Q47 • Lattice enthalpy, entropy and free energy • November 2021 • Paper 1 (Periodic table, elements and physical

chemistry) · Q16 · [14 marks]

This question also needs Amount of substance, Enthalpy changes, Group 2 and the halogens and Periodicity.

This question is about magnesium and magnesium halides.

16(a) Magnesium has metallic bonding and is a good conductor of electricity.

Describe, with the aid of a labelled diagram, the metallic bonding in magnesium and explain why magnesium conducts electricity.

Include the correct charges on the particles in your diagram.

[3 marks]

The 12 successive ionisation energies of magnesium are shown in Table 16.1.

Ionisation number	Ionisation energy / kJ mol^{-1}
1	738
2	1451
3	7733
4	10 541
5	13 629
6	17 995
7	21 704
8	25 657
9	31 644
10	35 463
11	169 996
12	189 371

Table 16.1

16(b)(i) Write an equation to represent the fourth ionisation energy of magnesium.

Include state symbols.

[1 mark]

16(b)(ii) Explain how the successive ionisation energies provide evidence that magnesium is in Group 2 of the periodic table.

[1 mark]

16(b)(iii) Electrons occupy orbitals.

In Table 16.2 below, add a tick (✓) below the ionisation numbers that are responsible for removing an electron from a full orbital in a magnesium atom.

Ionisation number	1	2	3	4	5	6	7	8	9	10	11	12
-------------------	---	---	---	---	---	---	---	---	---	----	----	----

Table 16.2

[1 mark]

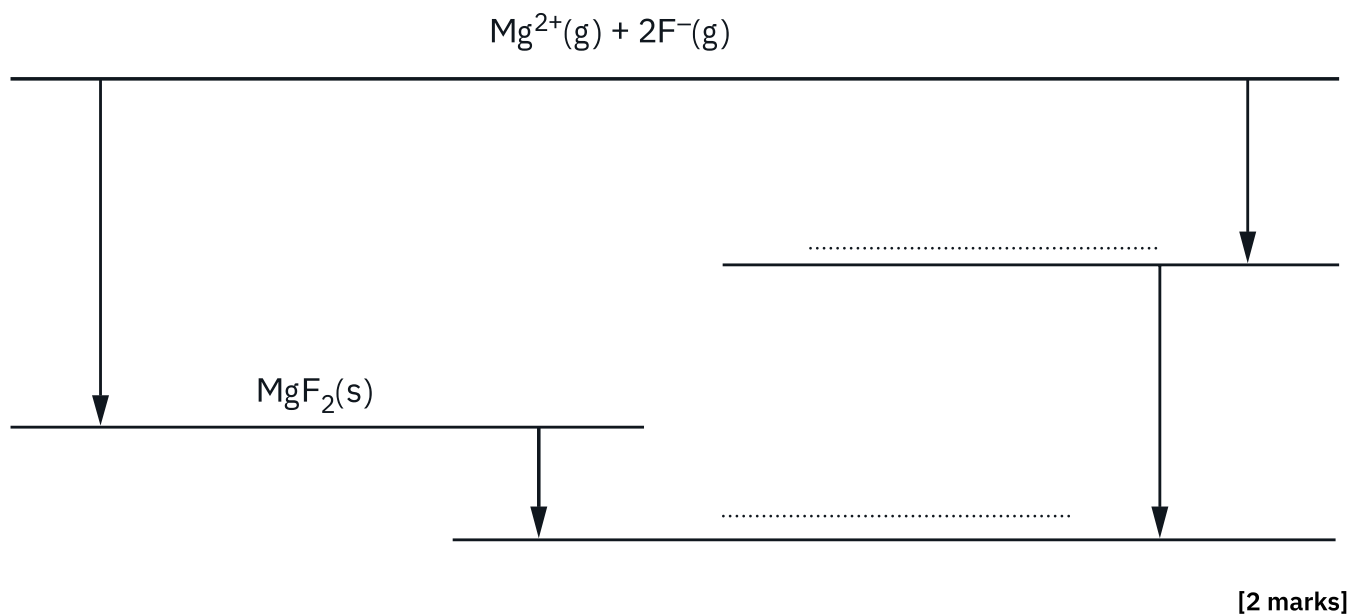
The enthalpy change of solution for magnesium fluoride, MgF_2 , can be determined indirectly using an energy cycle based on the enthalpy changes below.

Enthalpy change	Energy / kJ mol^{-1}
Lattice enthalpy of magnesium fluoride	-2926
Hydration of magnesium ions	-1920
Hydration of fluoride ions	-506

16(c)(i) Explain what is meant by enthalpy change of solution.

[1 mark]

16(c)(ii) On the dotted lines, add the species present, including state symbols.



16(c)(iii) Calculate the enthalpy change of solution of MgF_2 .

enthalpy change of solution = kJ mol^{-1}

[1 mark]

16(c)(iv) The enthalpy changes of solution of the magnesium halides show a trend from MgF_2 to MgI_2 .

Explain why it is difficult to predict whether the enthalpy change of solution becomes more exothermic or less exothermic down the group from MgF_2 to MgI_2 .

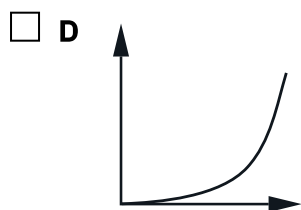
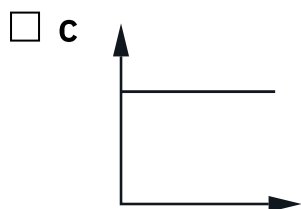
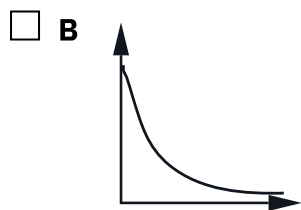
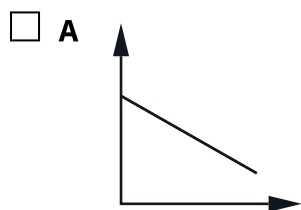
[4 marks]

Q48 · Rate equations · June 2017 · Paper 1 (Periodic table, elements and physical chemistry) · Q10 · [1 mark]

A reaction is zero order with respect to a reactant A.

Which concentration–time graph for reactant A is the correct shape?

Tick (✓) one box.

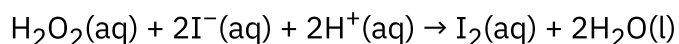


Q49 · Rate equations · June 2017 · Paper 3 (Unified chemistry) · Q3 · [14 marks]

This question also needs Amount of substance, Basic concepts of organic chemistry and Reaction rates and equilibrium.

This question is about reactions of hydrogen peroxide, H_2O_2 .

Hydrogen peroxide, H_2O_2 , iodide ions, I^- , and acid, H^+ , react as shown in the equation below.



A student carries out several experiments at the same temperature, using the initial rates method, to determine the rate constant, k , for this reaction.

The results are shown below.

Initial concentrations				
Experiment	$[\text{H}_2\text{O}_2(\text{aq})] / \text{mol dm}^{-3}$	$[\text{I}^-(\text{aq})] / \text{mol dm}^{-3}$	$[\text{H}^+(\text{aq})] / \text{mol dm}^{-3}$	Rate / $10^{-6} \text{ mol dm}^{-3} \text{ s}^{-1}$
1	0.0100	0.0100	0.100	2.00
2	0.0100	0.0200	0.100	4.00
3	0.0200	0.0100	0.100	4.00
4	0.0200	0.0100	0.200	4.00

3(a)(i) Determine the rate equation and calculate the rate constant, k , including units.

k = units

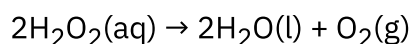
[3 marks]

3(a)(ii) The rate constant, k , for this reaction is determined at different temperatures, T .

Explain how the student could determine the activation energy, E_a , for the reaction graphically using values of k and T .

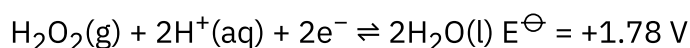
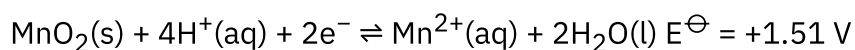
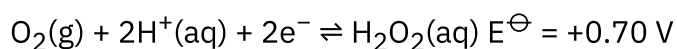
[3 marks]

3(b) Solutions of hydrogen peroxide decompose slowly into water and oxygen:



This reaction is catalysed by manganese dioxide, $\text{MnO}_2(\text{s})$.

Standard electrode potentials are shown below.



Using the electrode potentials, explain how MnO_2 is able to act as a catalyst for the decomposition of hydrogen peroxide.

Your answer should include relevant equations.

[4 marks]

Peroxycarboxylic acids are organic compounds with the COOOH functional group.

Peroxyethanoic acid, CH₃COOOH, is used as a disinfectant.

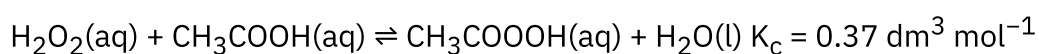
3(c)(i) Suggest the structure for CH₃COOOH.

The COOOH functional group must be clearly displayed.

[1 mark]

3(c)(ii) Peroxyethanoic acid can be prepared by reacting hydrogen peroxide with ethanoic acid.

This is a heterogeneous equilibrium.



A 250 cm³ equilibrium mixture contains concentrations of 0.500 mol dm⁻³ H₂O₂(aq) and 0.500 mol dm⁻³ CH₃COOH(aq).

Calculate the amount, in mol, of peroxyethanoic acid in the equilibrium mixture.

amount = mol

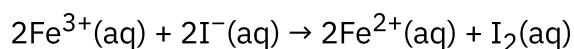
[3 marks]

Q50 · Rate equations · June 2018 · Paper 1 (Periodic table, elements and physical chemistry) · Q17 · [11 marks]

This question also needs Reaction rates and equilibrium.

This question is about reaction rates.

Aqueous iron(III) ions, $\text{Fe}^{3+}(\text{aq})$, react with aqueous iodide ions, $\text{I}^{-}(\text{aq})$, as shown below.



A student carries out three experiments to investigate how different concentrations of $\text{Fe}^{3+}(\text{aq})$ and $\text{I}^{-}(\text{aq})$ affect the initial rate of this reaction. The results are shown below.

Experiment	$[\text{Fe}^{3+}(\text{aq})] / \text{mol dm}^{-3}$	$[\text{I}^{-}(\text{aq})] / \text{mol dm}^{-3}$	Initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	4.00×10^{-2}	3.00×10^{-2}	8.10×10^{-4}
2	8.00×10^{-2}	3.00×10^{-2}	1.62×10^{-3}
3	4.00×10^{-2}	6.00×10^{-2}	3.24×10^{-3}

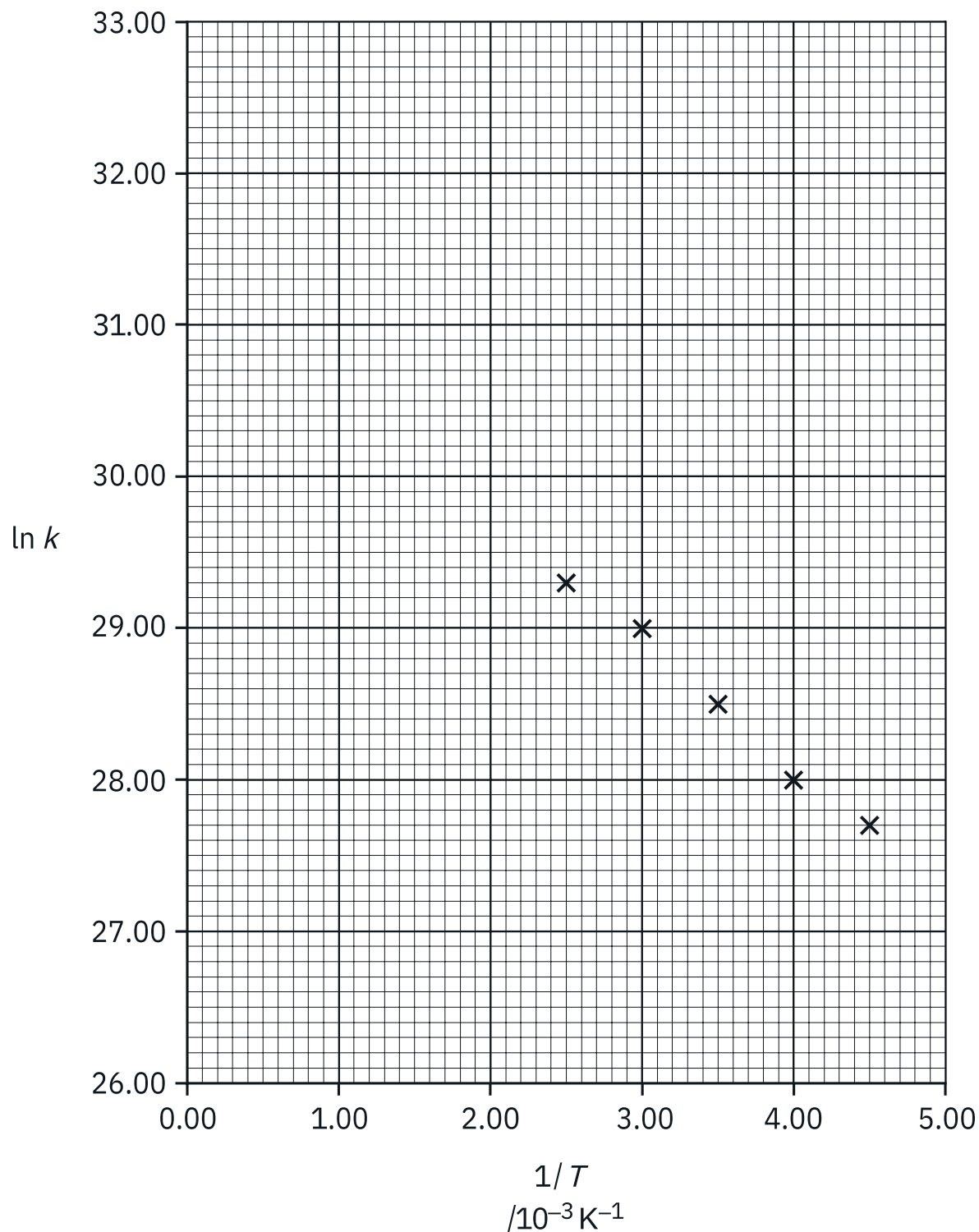
17(a) Determine the rate constant and a possible two-step mechanism for this reaction that are consistent with these results.

[6 marks]

A student carries out an investigation to find the activation energy, E_a , and the pre-exponential factor, A , of a reaction.

The student determines the rate constant, k , at different temperatures, T .

The student then plots a graph of $\ln k$ against $1/T$ as shown below.



17(b)(i) Draw a best-fit straight line and calculate the activation energy, in J mol^{-1} .

Give your answer to three significant figures.

Show your working.

activation energy, $E_a = + \text{J mol}^{-1}$

[3 marks]

Draw your answer on the figure above.

17(b)(ii) Use the graph to calculate the value of the pre-exponential factor, A.

Show your working.

pre-exponential factor, A =

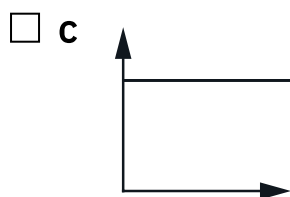
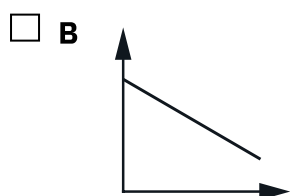
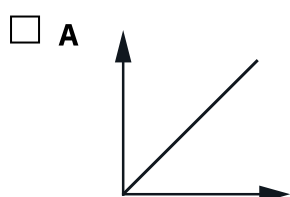
[2 marks]

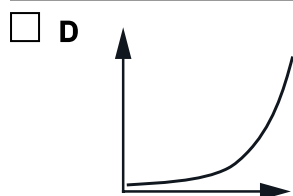
Q51 • Rate equations • June 2018 • Paper 1 (Periodic table, elements and physical chemistry) • Q8 • [1 mark]

A reaction is first order with respect to a reactant X.

Which rate–concentration graph for reactant X is the correct shape?

Tick (✓) one box.



**Q52 · Rate equations · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q11 · [1 mark]**

This question also needs Reaction rates and equilibrium.

A graph of $\ln k$ against $1/T$ (T in K) for a reaction has a gradient with the numerical value of -4420 .

What is the activation energy, in kJ mol^{-1} , for this reaction?

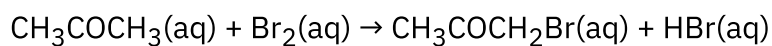
Tick (✓) one box.

- ☐ **A** -532
- ☐ **B** -36.7
- ☐ **C** $+36.7$
- ☐ **D** $+5.32 \times 10^5$

Q53 · Rate equations · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q21 · [6 marks]

This question also needs Amount of substance.

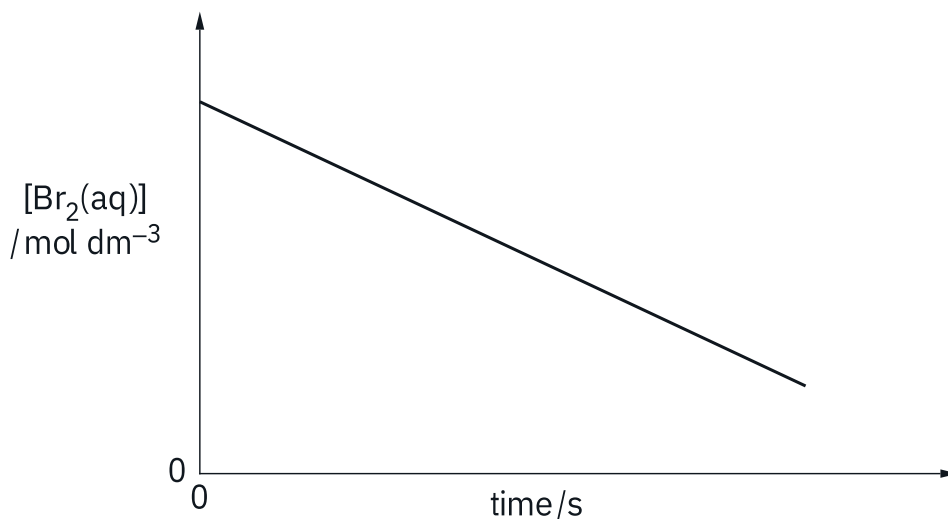
21 Three students carry out a rates investigation on the reaction between bromine and propanone in the presence of hydrochloric acid.



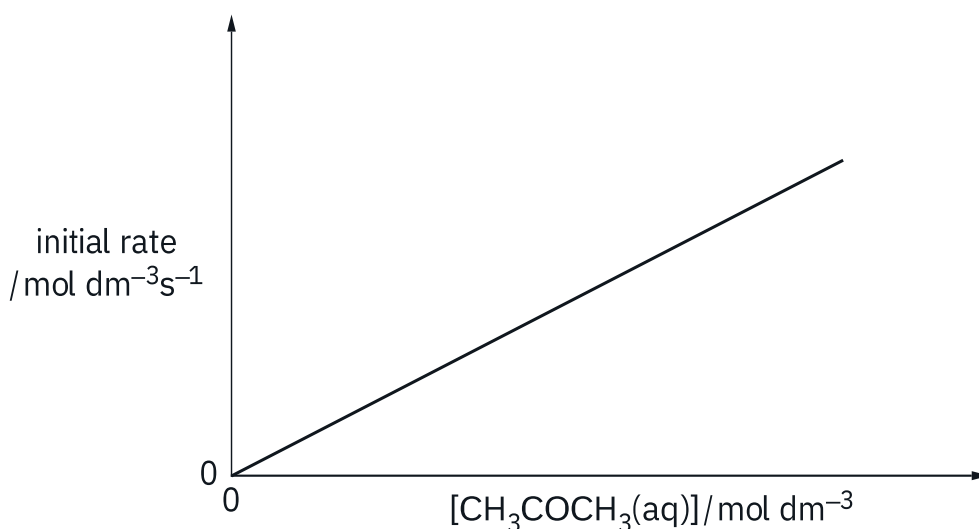
Each student investigates the effect of changing the concentration of one of the reactants whilst keeping the other concentrations constant.

Their results are shown below.

Results of student 1



Results of student 2



Results of student 3

Experiment	$[\text{Br}_2(\text{aq})] / \text{mol dm}^{-3}$	$[\text{CH}_3\text{COCH}_3(\text{aq})] / \text{mol dm}^{-3}$	$[\text{H}^+(\text{aq})] / \text{mol dm}^{-3}$	Initial rate / $10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1}$
1	0.004	1.60	0.20	1.25
2	0.004	1.60	0.40	2.50

Explain how the reaction orders can be determined from the students' results, and determine the rate equation and rate constant.

[6 marks]

Q54 • Rate equations • June 2022 • Paper 1 (Periodic table, elements and physical chemistry) • Q8 • [1 mark]

The half-life for a first order reaction is 80 s.

What is the rate constant k , in s^{-1} , for this reaction?

Tick (✓) one box.

☐ **A** 8.66×10^{-3}

☐ **B** 0.0125

☐ **C** 55.5

☐ **D** 115

Q55 • Rate equations • June 2022 • Paper 3 (Unified chemistry) • Q4 • [8 marks]

This question also needs Reaction rates and equilibrium.

Two students plan to investigate Equilibrium 4.1, shown below.

$\text{CoCl}_4^{2-}(\text{aq})$	+	$6\text{H}_2\text{O}(\text{l})$	$\rightleftharpoons$	$[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$	+	$4\text{Cl}^{-}(\text{aq})$	Equilibrium 4.1
blue				pink			

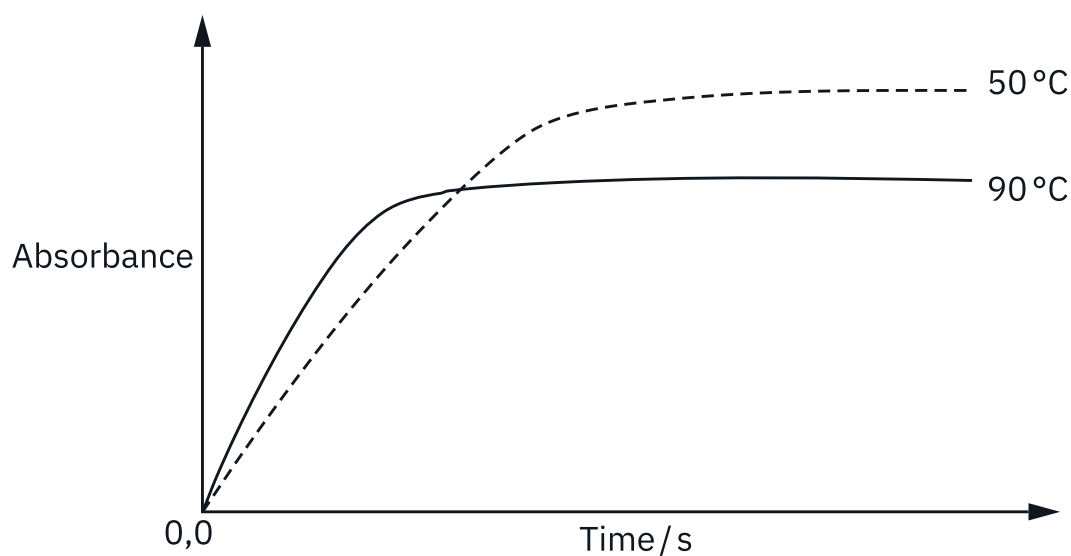
4(a) The students are supplied with the equilibrium mixture in Equilibrium 4.1 at room temperature.

- One student heats 20 cm^3 of the mixture to $50\text{ }^{\circ}\text{C}$.
- The other student heats 20 cm^3 of the mixture to $90\text{ }^{\circ}\text{C}$.

The students use colorimetry to observe how the colour of the equilibrium mixture changes over time.

- The colorimeter is set up so that the greater the absorbance, the greater the concentration of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.
- The initial absorbance is set to zero.
- The absorbance is recorded every 30 seconds.

The students plot the graph below from the results of the experiment.



Use the graph and relevant chemical theory to answer the following. Include all reasoning:

- Explain the different initial rates at $50\text{ }^{\circ}\text{C}$ and $90\text{ }^{\circ}\text{C}$.

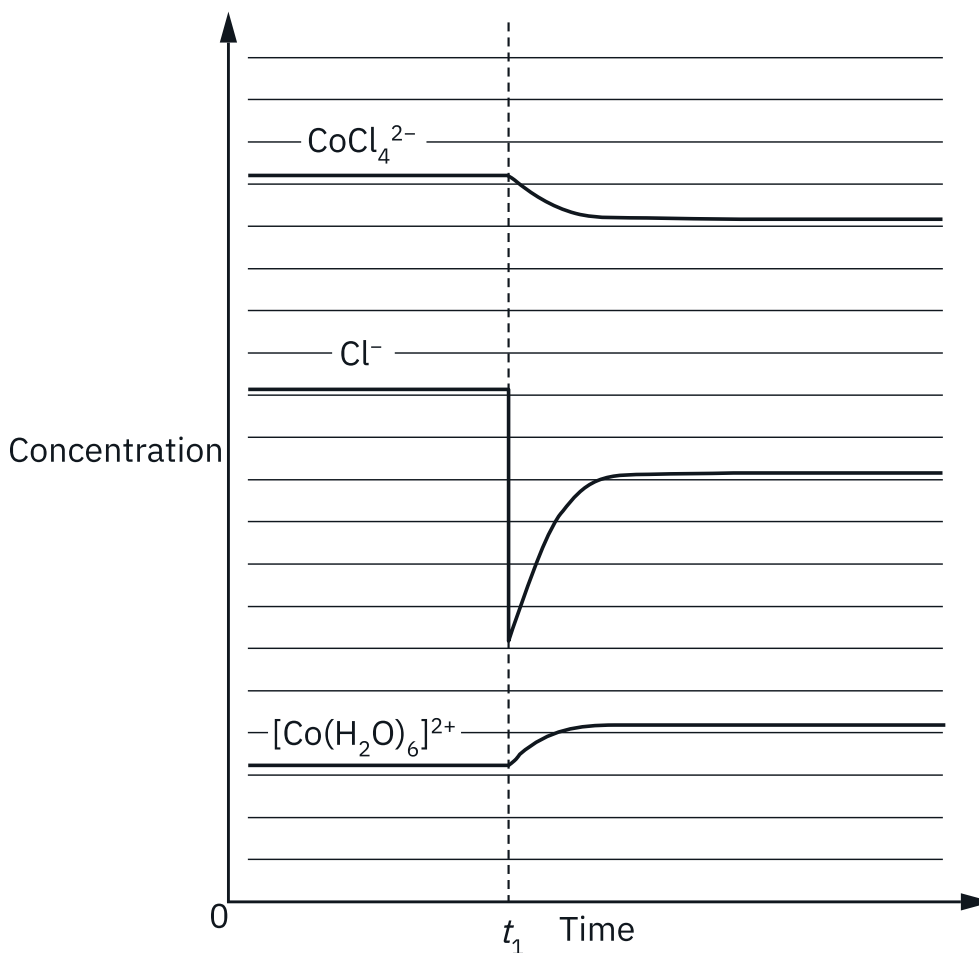
- Predict the sign of ΔH for the forward reaction in Equilibrium 4.1.

[4 marks]

The students investigate how addition of aqueous silver nitrate, $\text{AgNO}_3(\text{aq})$, affects the equilibrium position in Equilibrium 4.1.

The graph shows the changes in the equilibrium concentrations of CoCl_4^{2-} , Cl^- and $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ after addition of the $\text{AgNO}_3(\text{aq})$.

The $\text{AgNO}_3(\text{aq})$ is added at time = t_1 .



4(b)(i) Explain why the Cl^- concentration drops sharply at time = t_1 .

[1 mark]

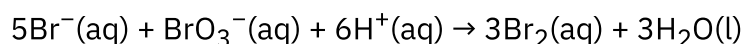
4(b)(ii) Explain the changes in concentration of CoCl_4^{2-} , Cl^- and $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ after time = t_1 .

Refer to Equilibrium 4.1 in your answer.

[3 marks]

Q56 · Rate equations · June 2023 · Paper 1 (Periodic table, elements and physical chemistry) · Q17 · [6 marks]

17 Bromine, Br₂, can be produced by the reaction:



A student investigates the rate of this reaction by carrying out four experiments at the same temperature. The student's results are shown below.

Experiment	[Br ⁻] / mol dm ⁻³	[BrO ₃ ⁻] / mol dm ⁻³	[H ⁺] / mol dm ⁻³	Initial rate / mol dm ⁻³ s ⁻¹
1	2.00 × 10 ⁻²	1.20 × 10 ⁻¹	8.00 × 10 ⁻²	2.52 × 10 ⁻⁴
2	6.00 × 10 ⁻²	1.20 × 10 ⁻¹	8.00 × 10 ⁻²	7.56 × 10 ⁻⁴
3	4.00 × 10 ⁻²	6.00 × 10 ⁻²	8.00 × 10 ⁻²	2.52 × 10 ⁻⁴
4	2.00 × 10 ⁻²	6.00 × 10 ⁻²	4.00 × 10 ⁻¹	3.15 × 10 ⁻³

Explain how the reaction orders can be determined from the student's results, and determine the rate equation and rate constant for this reaction.

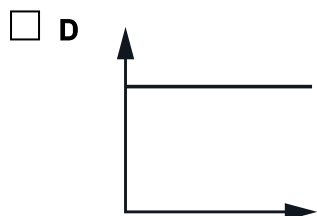
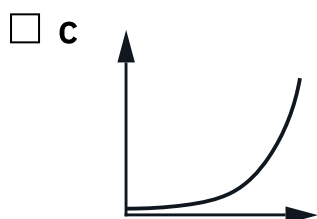
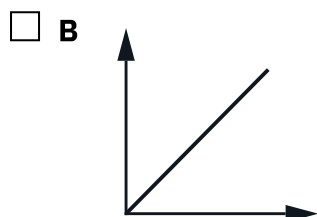
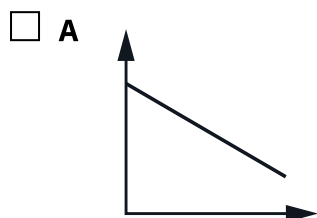
[6 marks]

Q57 · Rate equations · June 2024 · Paper 1 (Periodic table, elements and physical chemistry) · Q10 · [1 mark]

A reaction is zero order with respect to a reactant.

Which rate–concentration graph for the reactant is the correct shape?

Tick (✓) one box.

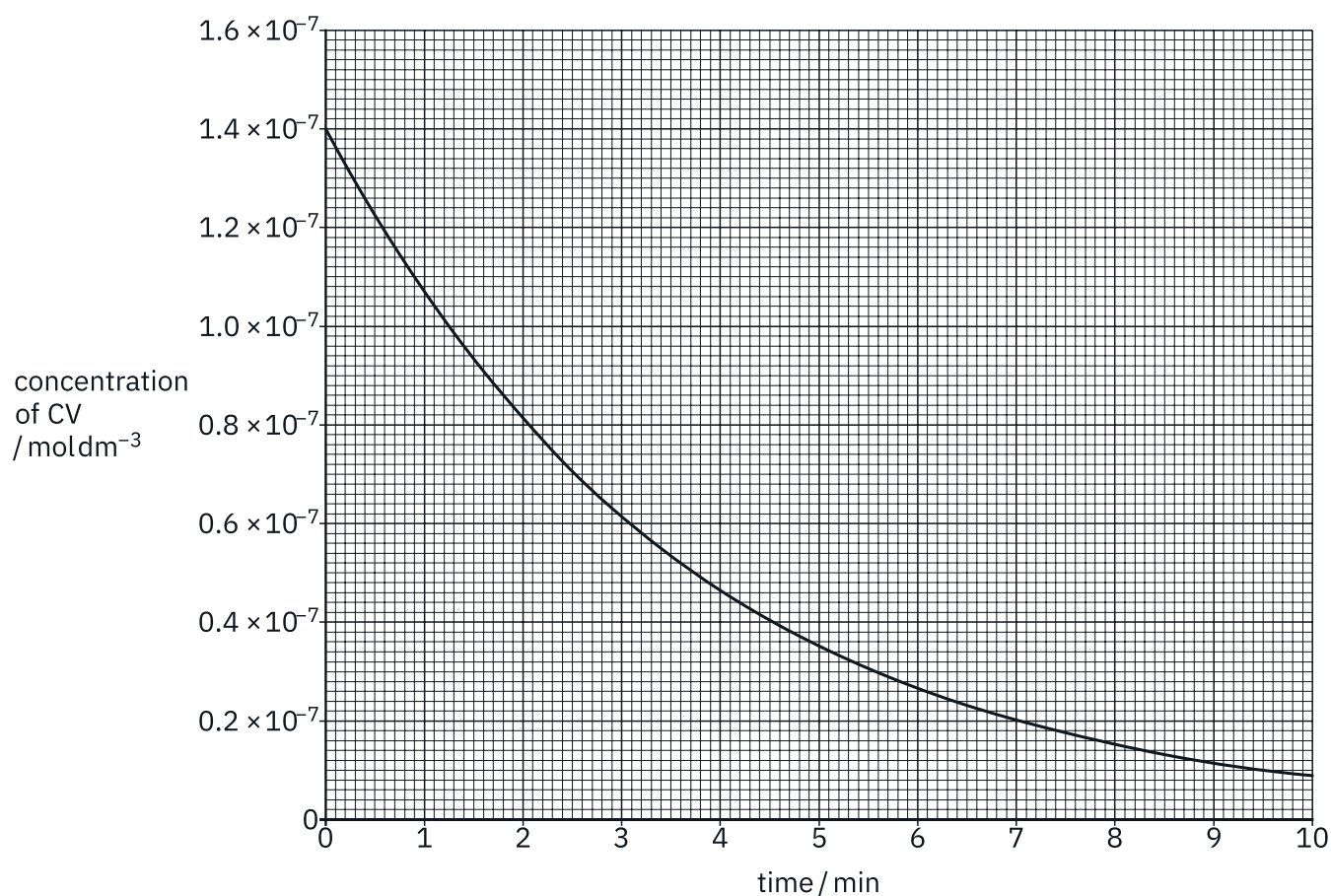
**Q58 · Rate equations · June 2024 · Paper 1 (Periodic table, elements and physical chemistry) · Q17 · [7 marks]**

Crystal violet (CV) is a purple dye. In the presence of an alkali, CV reacts to form a colourless product.

A student uses a colorimeter to investigate the rate of the reaction between CV and sodium hydroxide, NaOH.

- The student mixes 10.0 cm^3 of $2.8 \times 10^{-7} \text{ mol dm}^{-3}$ CV with 10.0 cm^3 of $0.016 \text{ mol dm}^{-3}$ NaOH.
- A large excess of NaOH is used, so that the reaction is effectively zero-order with respect to OH^- ions.
- The student places a sample of the reaction mixture in a colorimeter and measures the absorbance over time.

The student uses the absorbance readings to calculate the concentration of CV and plots a graph of concentration of CV against time, as shown below.



17(a) Using collision theory, explain why the gradient decreases over time.

[1 mark]

17(b) Use the graph to determine the order of reaction with respect to CV, the rate of the reaction at three minutes and the rate constant, k.

Your answer must show full working on the graph and on the lines below.

[6 marks]

Q59 • Rate equations • June 2024 • Paper 1 (Periodic table, elements and physical chemistry) • Q9 • [1 mark]

A graph of $\ln(k)$ is plotted against $1/T$ for a reaction.

(k = rate constant, T = temperature in K.)

The gradient has the numerical value of $-16\,000$.

What is the activation energy, in kJ mol^{-1} , for this reaction?

Tick (✓) one box.

- ☐ **A** +1.92
- ☐ **B** +133
- ☐ **C** +1920
- ☐ **D** +133 000

Q60 · Rate equations · June 2025 · Paper 1 (Periodic table, elements and physical chemistry) · Q12 · [1 mark]

The rate constant, k , for a first order reaction is $6.19 \times 10^{-3} \text{ s}^{-1}$.

What is the half-life, in s, for the reaction?

Tick (✓) one box.

☐ **A** 4.29×10^{-3}

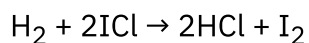
☐ **B** 49

☐ **C** 112

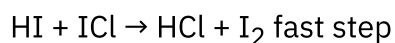
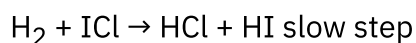
☐ **D** 323

Q61 · Rate equations · June 2025 · Paper 1 (Periodic table, elements and physical chemistry) · Q9 · [1 mark]

Hydrogen reacts with iodine monochloride, ICl, as shown in the equation:



The mechanism for the reaction is:



What is the rate equation for the reaction between H_2 and ICl?

Tick (✓) one box.

☐ **A** $\text{rate} = k[\text{HI}][\text{ICl}]$

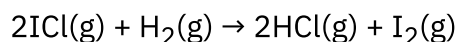
☐ **B** $\text{rate} = k[\text{H}_2][\text{ICl}]$

☐ **C** $\text{rate} = k[\text{H}_2][\text{ICl}]^2$

☐ **D** $\text{rate} = k[\text{H}_2][\text{HI}][\text{ICl}]^2$

Q62 · Rate equations · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q10 · [1 mark]

The equation for the reaction of ICl and H₂ is shown below.



The rate constant k for this reaction is $1.63 \times 10^{-6} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$.

What is the overall order of the reaction?

Tick (✓) one box.

☐ **A** 0

☐ **B** 1

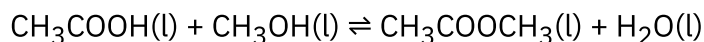
☐ **C** 2

☐ **D** 3

Q63 · Rate equations · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q20 · [9 marks]

This question also needs Amount of substance and Reaction rates and equilibrium.

A student investigates the reaction between ethanoic acid, CH₃COOH(l) and methanol, CH₃OH(l), in the presence of an acid catalyst. The equation is shown below.

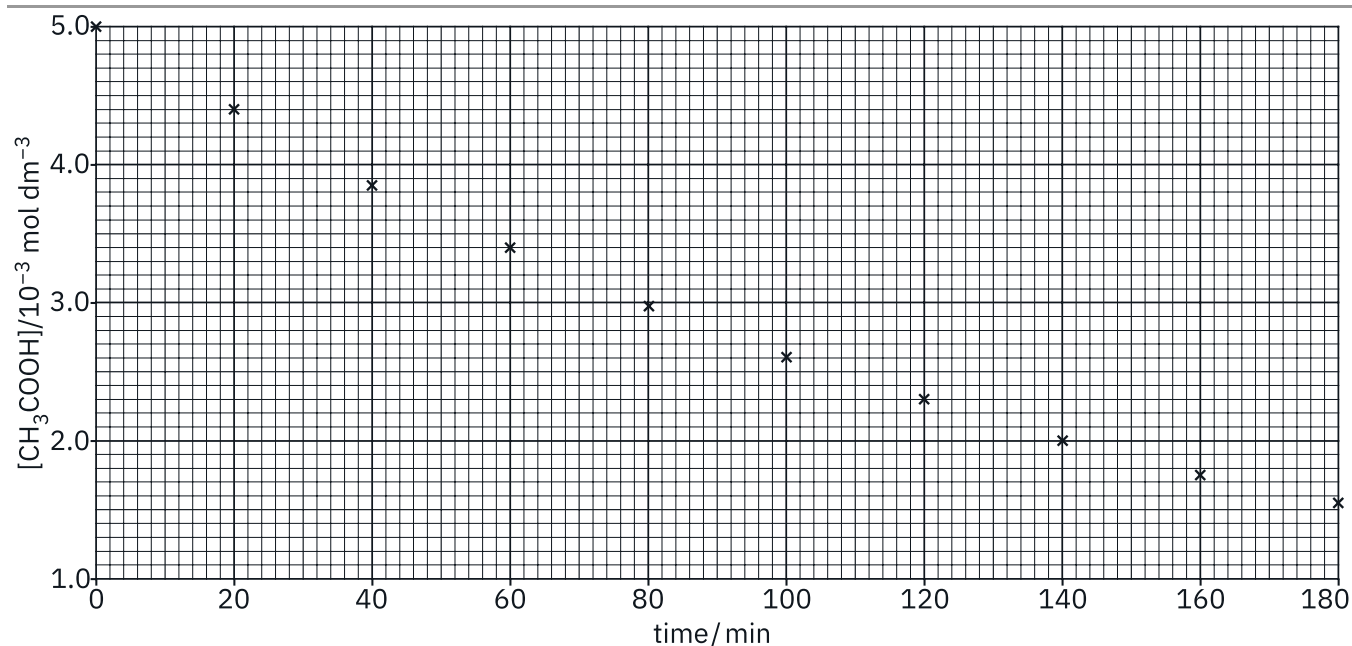


The student carries out an experiment to determine the order of reaction with respect to CH₃COOH.

The student uses a large excess of CH₃OH. The temperature is kept constant throughout the experiment.

The student takes a sample from the mixture every 20 minutes, and then determines the concentration of the ethanoic acid in each sample.

From the experimental results, the student plots the graph below.



20(a)(i) Explain why the student uses a large excess of methanol in this experiment.

[1 mark]

20(a)(ii) Use the half-life of this reaction to show that the reaction is first order with respect to CH_3COOH .

Show your working on the graph and below.

[2 marks]

20(a)(iii) Determine the initial rate of reaction.

initial rate = $\text{mol dm}^{-3} \text{ min}^{-1}$

[2 marks]

20(b) The student carries out a second experiment to determine the value of K_c for this reaction.

The student mixes 9.6 g of CH_3OH with 12.0 g of CH_3COOH and adds the acid catalyst.

When the mixture reaches equilibrium, 0.030 mol of CH_3COOH remains.

Calculate K_c for this equilibrium.

$K_c =$

[4 marks]

Q64 · Rate equations · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q8 · [1 mark]

This question also needs Reaction rates and equilibrium.

A graph is plotted of $\ln(k)$ against $1/T$.

(k = rate constant, T = temperature in K)

The gradient has the numerical value of $-55\,000$.

What is the activation energy, in kJ mol^{-1} ?

Tick (✓) one box.

☐ **A** $+1.5 \times 10^{-7}$

☐ **B** $+2.22 \times 10^{-6}$

☐ **C** $+6.62$

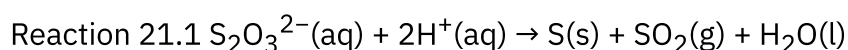
☐ **D** $+457$

Q65 · Rate equations · November 2021 · Paper 1 (Periodic table, elements and physical chemistry) · Q21 · [10 marks]

This question also needs Reaction rates and equilibrium.

This question is about how the rate of reaction is affected by changes in conditions.

A student carries out two investigations using the reaction between aqueous thiosulfate ions, $\text{S}_2\text{O}_3^{2-}(\text{aq})$, and aqueous hydrogen ions, $\text{H}^+(\text{aq})$.



In Investigation 1, the student determines how the rate of Reaction 21.1 is affected by changes in concentration.

The results are shown in the table.

Experiment	$[\text{S}_2\text{O}_3^{2-}(\text{aq})] / \text{mol dm}^{-3}$	$[\text{H}^+(\text{aq})] / \text{mol dm}^{-3}$	initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.16	1.00	0.0120
2	0.08	1.00	0.0060
3	0.02	0.50	0.0015

From the results, the student concludes that the rate equation is

$$\text{rate} = k [\text{S}_2\text{O}_3^{2-}(\text{aq})]$$

21(a)(i) Explain how the student's results support this rate equation.

[2 marks]

21(a)(ii) Predict a possible two-step mechanism for Reaction 21.1.

The first step is the rate-determining step.

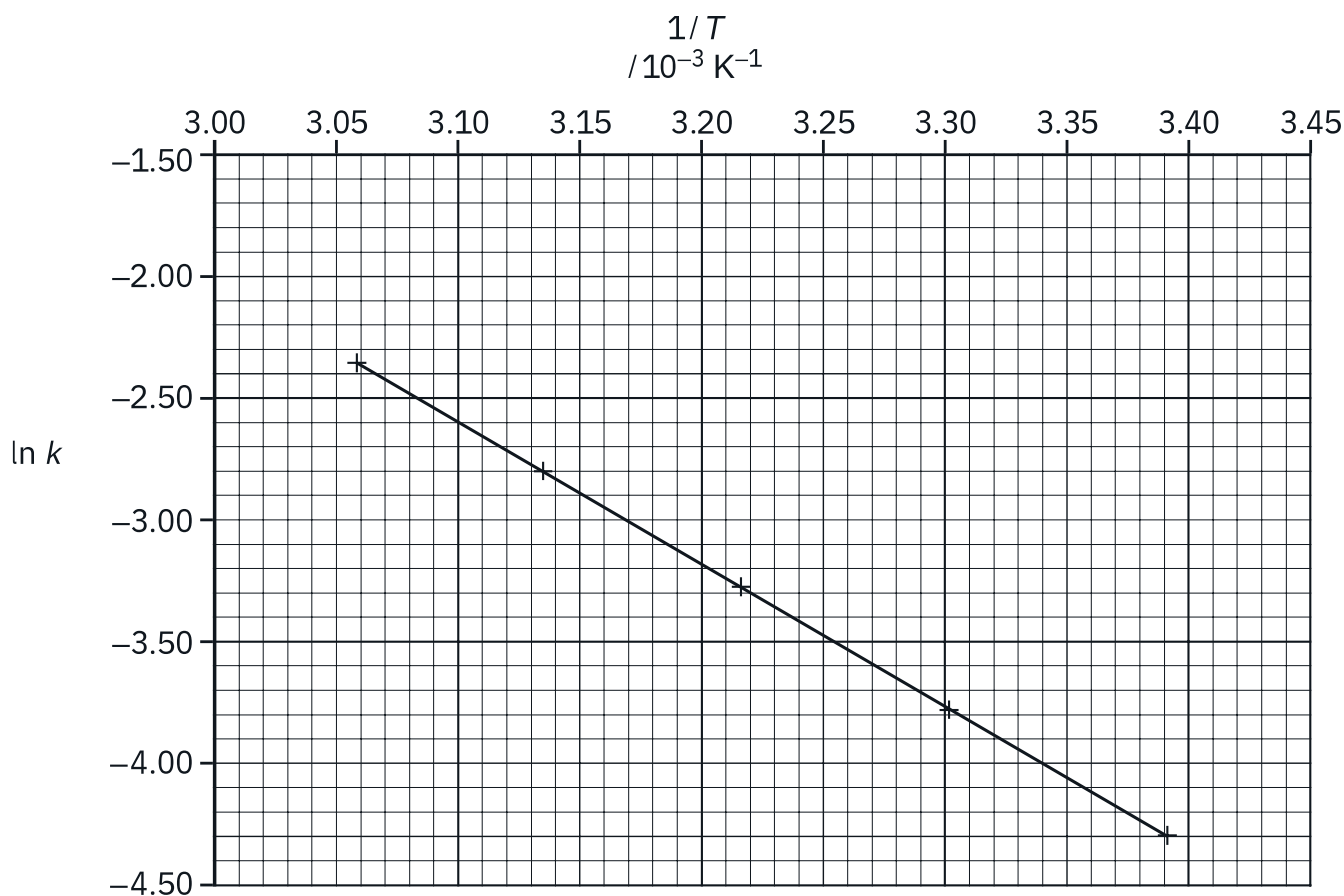
[2 marks]

Step 1

Step 2

In Investigation 2 the student determines the rate constant k of Reaction 21.1 at different temperatures, T .

From the results, the student plots a graph of $\ln k$ against $1/T$ as shown below.



Graph 21.2

21(b)(i) Calculate the activation energy, E_a , for Reaction 21.1, in kJ mol^{-1} .

Give your answer to 3 significant figures.

$E_a = \text{kJ mol}^{-1}$

[3 marks]

21(b)(ii) From the graph the student estimates the value of $\ln A$ as -2.00 .

(A is the pre-exponential factor.)

Explain what mistake the student has made.

[1 mark]

21(b)(iii) The student calculates the value of k in Investigation 1 as 0.075 s^{-1} .

Using Graph 21.2, determine the temperature, in $^{\circ}\text{C}$, at which Investigation 1 was carried out.

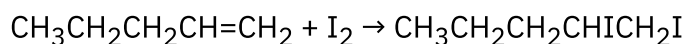
temperature = $^{\circ}\text{C}$

[2 marks]

Q66 • Rate equations • November 2021 • Paper 3 (Unified chemistry) • Q4 • [11 marks]

This question also needs Amount of substance and Reaction rates and equilibrium.

Pent-1-ene and iodine react as shown in the equation below.



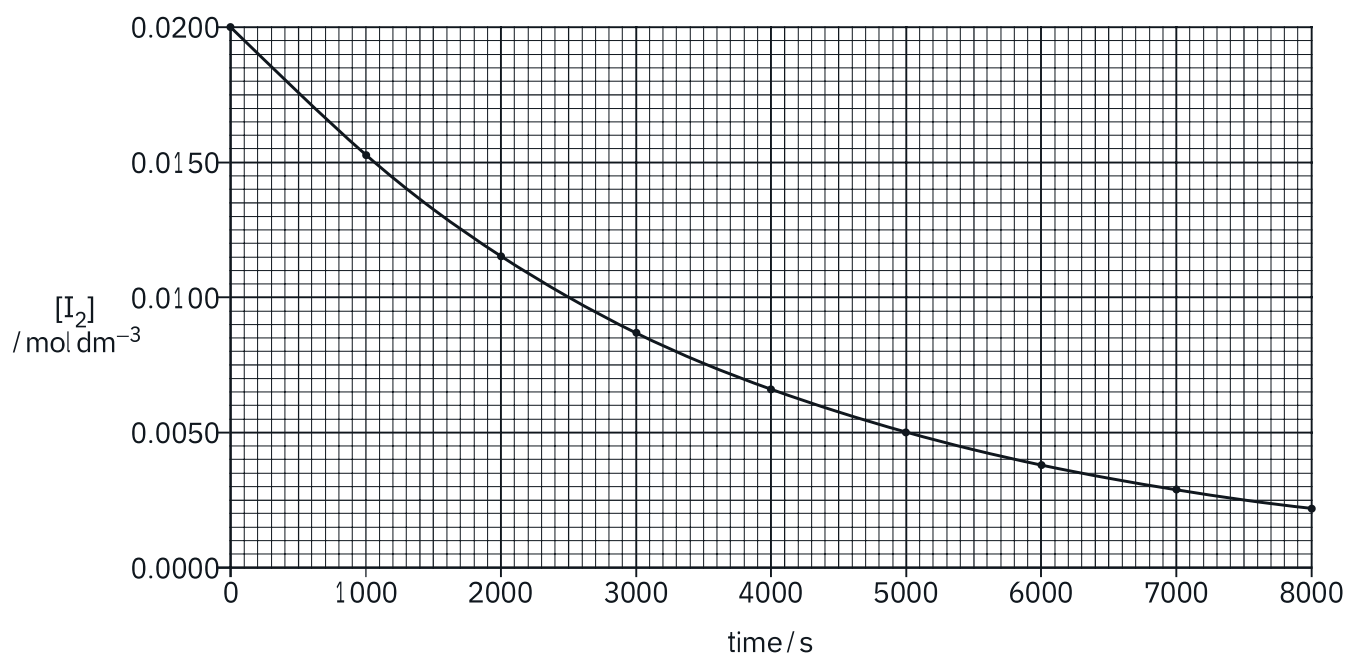
A student investigates the rate of this reaction by monitoring the concentration of iodine over time.

The initial concentrations are shown in the table.

Concentration / mol dm^{-3}	
I_2	0.0200
$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}=\text{CH}_2$	2.0000

In this investigation, the order with respect to pent-1-ene can be assumed to be zero.

The student plots the graph below from the experimental results.



4(a) Why can the order with respect to pent-1-ene be assumed to be zero in this investigation?

[1 mark]

4(b) The student's experimental procedure shows that the reaction is first order with respect to iodine.

Show that this statement is true and determine the initial rate of reaction and rate constant.

Assume that the reaction is zero order with respect to pent-1-ene. Show your working on the graph on page 10 and the lines below as appropriate.

[6 marks]

Further experiments provide evidence that the reaction is first order with respect to both $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}=\text{CH}_2$ AND I_2 .

4(c)(i) Write equations to suggest a two-step mechanism for the reaction.

[2 marks]

Slow

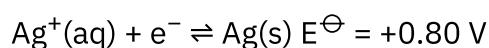
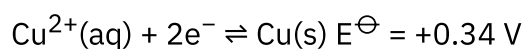
Fast

4(c)(ii) Suggest how the investigation could be modified to show that the reaction is first order with respect to pent-1-ene.

[2 marks]

Q67 • Redox and electrode potentials • June 2017 • Paper 1 (Periodic table, elements and physical chemistry) • Q14 • [1 mark]

A cell is constructed from the two redox systems below.



Which statement(s) is/are correct for the cell?

- 1 The cell potential is 1.14 V.
- 2 The reaction at the copper electrode is $\text{Cu}(\text{s}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^{-}$.
- 3 The silver electrode increases in mass.

Tick (✓) one box.

- ☐ **A** 1, 2 and 3
- ☐ **B** Only 1 and 2
- ☐ **C** Only 2 and 3
- ☐ **D** Only 1

Q68 • Redox and electrode potentials • June 2017 • Paper 1 (Periodic table, elements and physical chemistry) • Q22 • [9 marks]

This question also needs Amount of substance and Enthalpy changes.

This question is about redox, electrode potentials and feasibility.

Table 22.1 shows standard electrode potentials for four redox systems.

You need to use this information to answer the questions below.

Redox system	Equation	$E^\ominus / \text{V}$
1	$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
2	$\text{SO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{SO}_3^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.17
3	$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
4	$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51

Table 22.1

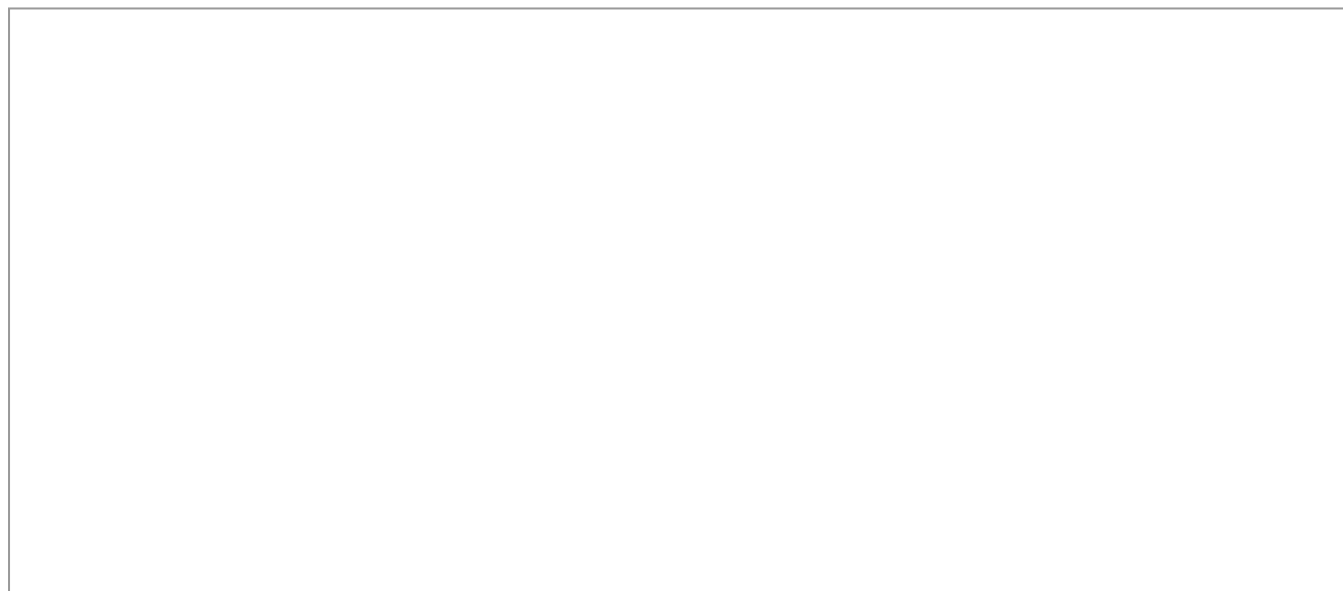
A standard cell is set up in the laboratory based on redox systems 1 and 3 and the standard cell potential is measured.

22(a)(i) Draw a labelled diagram to show how this cell could be set up to measure its standard cell potential.

Include details of the apparatus, solutions and the standard conditions required to measure this standard cell potential.

Standard conditions

[4 marks]



22(a)(ii) Predict the standard cell potential of this cell.

standard cell potential = V

[1 mark]

22(b) In Table 22.1, what is the strongest reducing agent and the strongest oxidising agent?

[2 marks]

Strongest reducing agent

Strongest oxidising agent

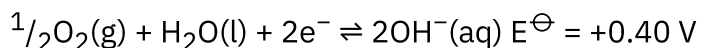
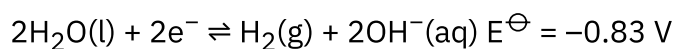
22(c) Electrode potentials can be used to predict the feasibility of reactions.

Construct an overall equation for the predicted reaction between the species in redox systems 2 and 4.

[2 marks]

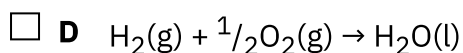
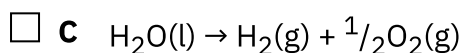
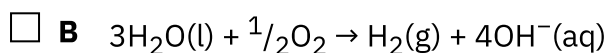
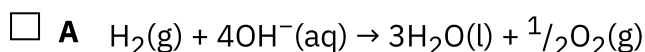
Q69 · Redox and electrode potentials · June 2018 · Paper 1 (Periodic table, elements and physical chemistry) · Q12 · [1 mark]

The redox equilibria for a hydrogen–oxygen fuel cell in alkaline solution are shown below.



What is the equation for the overall cell reaction?

Tick (✓) one box.



Q70 · Redox and electrode potentials · June 2018 · Paper 1 (Periodic table, elements and physical chemistry) · Q20 · [20 marks]

This question also needs Acids and redox reactions, Amount of substance, Electrons, bonding and structure and

3 other topics.

This question is about the halogen group of elements and some of their compounds.

20(a) The halogens show trends in their properties down the group.

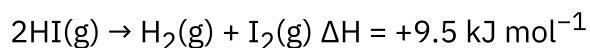
The boiling points of three halogens are shown below.

Halogen	Boiling point / °C
Chlorine	−35
Bromine	59
Iodine	184

Explain why the halogens show this trend in boiling points.

[3 marks]

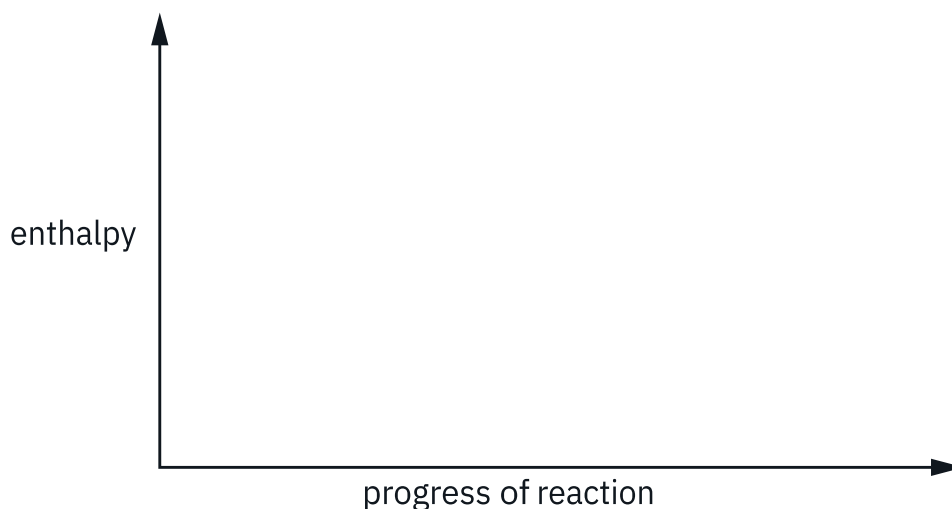
20(b) Hydrogen iodide, HI, is decomposed by heat into its elements:



The decomposition is much faster in the presence of a platinum catalyst.

Complete the enthalpy profile diagram for this reaction using formulae for the reactants and products.

- Use E_a to label the activation energy without a catalyst.
- Use E_c to label the activation energy with a catalyst.
- Use ΔH to label the enthalpy change of reaction.



[3 marks]

Draw your answer on the figure above.

20(c) Compound A is an oxide of chlorine that is a liquid at room temperature and pressure and has a boiling point of 83 °C.

When 0.4485 g of A is heated to 100 °C at 1.00×10^5 Pa, 76.0 cm³ of gas is produced.

Determine the molecular formula of compound A.

Show all your working.

molecular formula of A =

[4 marks]

Compound B is an iodate(V) salt of a Group 1 metal.

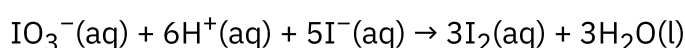
The iodate(V) ion has the formula IO_3^- .

A student carries out a titration to find the formula of compound B.

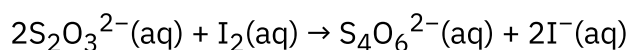
Step 1: The student dissolves 1.55 g of B in water and makes up the solution to 250.0 cm^3 in a volumetric flask.

Step 2: The student pipettes 25.00 cm^3 of the solution of B into a conical flask, followed by 10 cm^3 of dilute sulfuric acid and an excess of $\text{KI}(\text{aq})$.

The iodate(V) ions are reduced to iodine, as shown below.



Step 3: The resulting mixture is titrated with $0.150 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$.



The student repeats step 2 and step 3 until concordant titres are obtained.

Titration readings

Titration	Trial	1	2	3
Final burette reading / cm^3	24.00	47.40	23.75	47.05
Initial burette reading / cm^3	0.00	24.00	0.00	23.20
Titre / cm^3				

Table 20.1

20(d)(i) Complete Table 20.1 and calculate the mean titre that the student should use for analysing the results.

mean titre = cm³

[2 marks]

20(d)(ii) The uncertainty in each burette reading is $\pm 0.05 \text{ cm}^3$.

Calculate the percentage uncertainty in the titre obtained from titration 1.

Give your answer to two decimal places.

percentage uncertainty = %

[1 mark]

20(d)(iii) Describe and explain how the student should determine the end point of this titration accurately.

[2 marks]

20(d)(iv) Determine the relative formula mass and formula of the Group 1 iodate(V), B.

Show your working.

relative formula mass of B =

formula of B =

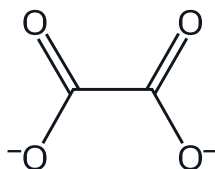
[5 marks]

Q71 · Redox and electrode potentials · June 2018 · Paper 3 (Unified chemistry) · Q3 · [10 marks]

This question also needs Acids and redox reactions and Amount of substance.

This question is about ethanedioic acid, $(\text{COOH})_2$, and ethanedioate ions, $(\text{COO}^-)_2$.

3(a) The ethanedioate ion, shown below, can act as a bidentate ligand.



Fe^{3+} forms a complex ion with three ethanedioate ions.

The complex ion has two optical isomers.

Draw the 3D shapes of the optical isomers.

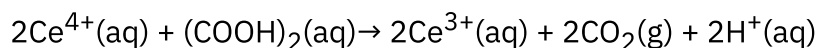
In your diagrams, show the structure of the ethanedioate ligands and any overall charge.

[3 marks]

Ethanedioic acid, $(\text{COOH})_2$, is present in rhubarb leaves.

A student carries out a redox titration using aqueous cerium(IV) sulfate, $\text{Ce}(\text{SO}_4)_2(\text{aq})$, to determine the percentage, by mass, of ethanedioic acid in rhubarb leaves.

In the titration, $\text{Ce}^{4+}(\text{aq})$ ions oxidise ethanedioic acid in hot acid conditions:



$\text{Ce}^{4+}(\text{aq})$ ions have a yellow colour. $\text{Ce}^{3+}(\text{aq})$ ions are colourless.

The student weighs 82.68 g of rhubarb leaves and extracts ethanedioic acid from the leaves.

The ethanedioic acid is added to dilute sulfuric acid to form a colourless solution which is made up to 250.0 cm^3 with distilled water.

The student heats 25.00 cm^3 of this solution to 70°C and titrates this volume with $0.0500 \text{ mol dm}^{-3}$ $\text{Ce}(\text{SO}_4)_2$ from the burette.

The student repeats the titration to obtain concordant (consistent) titres.

Titration results

The trial titre has been omitted.

	1	2	3
Final reading/ cm^3	24.30	47.80	23.65
Initial reading/ cm^3	1.05	24.30	0.50

3(b)(i) This titration is self-indicating and the student does not need to add an indicator.

What colour change would the student observe at the end point?

Colour change from to

[1 mark]

3(b)(ii) Calculate the percentage, by mass, of ethanedioic acid in the rhubarb leaves.

Give your answer to an appropriate number of significant figures.

percentage of ethanedioic acid = %

[6 marks]

Q72 · Redox and electrode potentials · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q15 · [1 mark]

Four redox systems relevant to hydrogen–oxygen fuel cells are shown below.

		$E^\ominus/\text{V}$
$\text{H}_2\text{O}(\text{l}) + \text{e}^- \rightleftharpoons$	$\text{OH}^-(\text{aq}) + \frac{1}{2}\text{H}_2(\text{g})$	-0.83
$\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons$	$\frac{1}{2}\text{H}_2(\text{g})$	0.00
$\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightleftharpoons$	$2\text{OH}^-(\text{aq})$	+0.40
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons$	$\text{H}_2\text{O}(\text{l})$	+1.23

Which statement(s) is/are correct for an alkaline hydrogen–oxygen fuel cell?

1 The reaction at the positive electrode is: $\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2\text{O}(\text{l})$.

2 The overall cell reaction is: $\text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$.

3 The cell potential is 1.23 V.

Tick (✓) one box.

- ☐ **A** 1, 2 and 3
- ☐ **B** Only 1 and 2
- ☐ **C** Only 2 and 3
- ☐ **D** Only 1

Q73 · Redox and electrode potentials · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q18 · [18 marks]

This question also needs Acids and redox reactions, Amount of substance and Electrons, bonding and structure.

This question is about reactions of ions and compounds of transition elements.

A student carries out two experiments on a solution containing $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$.

Experiment 1

The student adds an excess of aqueous ammonia to a solution containing $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$

until a purple solution is formed.

Experiment 2

The student carries out the following reaction sequence.

Step 1 NaOH(aq) is added slowly to a solution containing $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ in a boiling tube.

A grey–green precipitate forms.

Step 2 An excess of NaOH(aq) is added to the boiling tube.

The precipitate dissolves and a green solution forms containing a 6 coordinate complex ion.

Step 3 H_2O_2 is added to the mixture and the boiling tube is heated.

A yellow solution forms.

Step 4 The solution in the boiling tube is acidified.

The solution now contains $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$.

18(a)(i) What is the formula of the complex ion in the purple solution that forms in Experiment 1?

[1 mark]

18(a)(ii) Suggest an equation for the reaction in Experiment 2, Step 1.

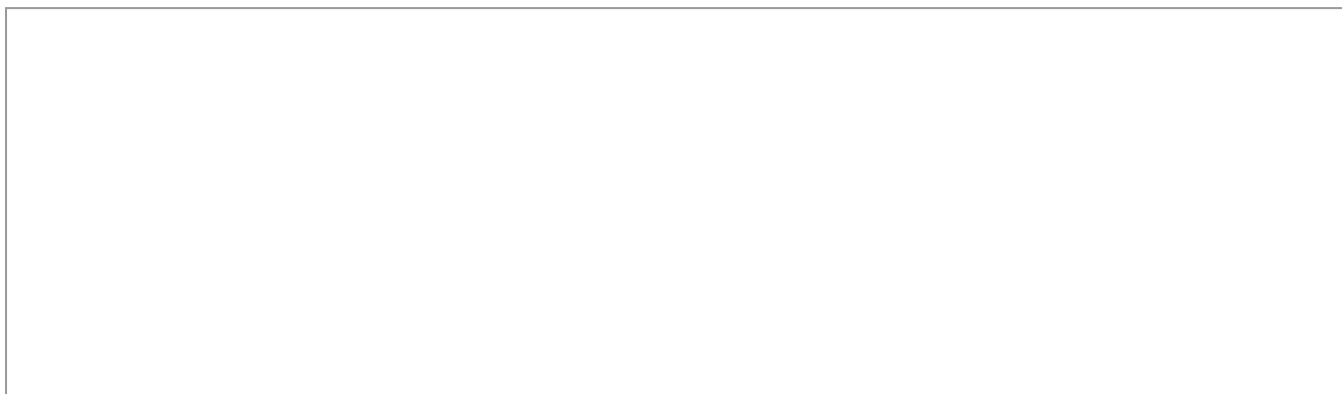
Include state symbols.

[1 mark]

18(a)(iii) Draw a 3-D diagram for the shape of the complex ion that forms in Experiment 2, Step 2.

Include the charge of the ion.

[2 marks]



18(a)(iv) What is the formula of the ion that causes the yellow colour in Experiment 2, Step 3?

[1 mark]

18(a)(v) State the colour of the solution that forms in Experiment 2, Step 4.

[1 mark]

Vanadium ions have four common oxidation states. Table 18.1 shows the colours of the ions in aqueous solution.

Oxidation state of vanadium	Vanadium ion	Colour
+5	$\text{VO}_2^+(\text{aq})$	yellow
+4	$\text{VO}^{2+}(\text{aq})$	blue
+3	$\text{V}^{3+}(\text{aq})$	green
+2	$\text{V}^{2+}(\text{aq})$	violet

Table 18.1

18(b)(i) Complete the electron configuration of a V^{3+} ion.

$1s^2$

[1 mark]

18(b)(ii) The student adds excess iron to a solution containing $\text{VO}^{2+}(\text{aq})$ ions, and observes that the colour of the solution changes from blue to green and then to violet.

Use the relevant standard electrode potentials shown in Table 18.2 to explain these observations.

	Redox system	$E^\ominus/\text{V}$
1	$\text{V}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{V}(\text{s})$	-1.18
2	$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
3	$\text{V}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{2+}(\text{aq})$	-0.26
4	$\text{VO}^{2+}(\text{aq}) + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{V}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.34
5	$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
6	$\text{VO}_2^+(\text{aq}) + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{VO}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+1.00

Table 18.2

[3 marks]

18(b)(iii) Construct an equation for the first colour change from blue to green.

[1 mark]

Iron(II) gluconate, $\text{C}_{12}\text{H}_{22}\text{FeO}_{14}$, is the active ingredient in some brands of iron supplements.

A student carries out an experiment to determine the mass of iron(II) gluconate in one tablet of an iron supplement, using the method below.

Stage 1 The student crushes two tablets and dissolves the powdered tablets in dilute sulfuric acid.

Stage 2 The student makes up the solution from Stage 1 to 250.0 cm^3 in a volumetric flask.

Stage 3 The student then titrates 25.0 cm^3 portions of the solution obtained in Stage 2 with $0.00200\text{ mol dm}^{-3}$ potassium manganate(VII).

The student obtains a mean titre of 13.50 cm^3 .

In this titration, 1 mol of manganate(VII) ions reacts with 5 mol of iron(II) ions.

18(c)(i) Explain why the student used $0.00200\text{ mol dm}^{-3}$ potassium manganate(VII) solution for this titration, rather than the more usual concentration of $0.0200\text{ mol dm}^{-3}$ used in manganate(VII) titrations.

[1 mark]

18(c)(ii) Use the student's results to determine the mass, in mg, of iron(II) gluconate in one tablet.

Give your answer to 3 significant figures.

mass of iron(II) gluconate in one tablet = mg

[5 marks]

18(c)(iii) Some iron supplements contain iron(II) sulfate or iron(II) fumarate.

The information in Table 18.3 is taken from the labels of two iron supplements, A and B.

Iron supplement	Iron compound	Mass of iron compound in one tablet / mg
A	iron(II) sulfate, FeSO_4	180
B	iron(II) fumarate, $\text{C}_4\text{H}_2\text{FeO}_4$	210

Table 18.3

Choose which iron supplement, A or B, would provide the greater mass of iron per tablet.

iron supplement:

[1 mark]

Q74 • Redox and electrode potentials • June 2022 • Paper 3 (Unified chemistry) • Q2 • [13 marks]

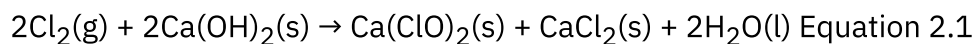
This question also needs Amount of substance.

This question is about redox reactions.

'Calcium hypochlorite', $\text{Ca}(\text{ClO})_2$, is an ionic compound used in 'bleaching powder'.

The ClO^- ion in $\text{Ca}(\text{ClO})_2$ is the active ingredient that kills bacteria.

Calcium hypochlorite is prepared by reacting chlorine gas with calcium hydroxide.



2(a)(i) 420 dm^3 of chlorine, measured at RTP, is reacted with an excess of $\text{Ca}(\text{OH})_2$.

The solid products are dissolved in water to form 4.00 m^3 of solution.

Calculate the concentration of $\text{Ca}(\text{ClO})_2(\text{aq})$ in this solution, in mol dm^{-3} .

Give your answer to an **appropriate** number of significant figures and in standard form.

concentration = mol dm^{-3}

[3 marks]

2(a)(ii) Calcium hypochlorite, $\text{Ca}(\text{ClO})_2$, is heated. The $\text{Ca}(\text{ClO})_2$ decomposes to form CaCl_2 and $\text{Ca}(\text{ClO}_3)_2$. This is a disproportionation reaction.

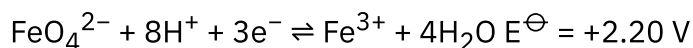
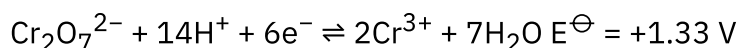
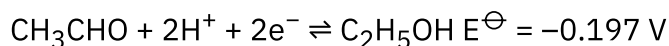
Write an equation for this decomposition and explain, using oxidation numbers, why this is a disproportionation reaction.

[3 marks]

equation

explanation

2(b) A student analyses the redox reactions shown below. State symbols have been omitted.



The student concludes that different ions containing chromium can act as oxidising or reducing agents.

Using the terms oxidising agent and reducing agent, and ideas about electrode potentials and equilibrium, explain how the student is correct.

Include overall equations.

[5 marks]

2(c) A student bubbles hydrogen sulfide gas, $\text{H}_2\text{S}(\text{g})$, through an acidified solution containing manganate(VII) ions, $\text{MnO}_4^-(\text{aq})$.

A redox reaction takes place, forming aqueous manganese(II) ions, a yellow precipitate and one other product.

Construct the equation for this reaction. State symbols are not required.

[2 marks]

Q75 • Redox and electrode potentials • June 2023 • Paper 1 (Periodic table, elements and physical chemistry) •

Q12 · [1 mark]

The equations show the electrode potentials of the half-cells used in a lithium-ion cell.

	$E^{\ominus}/\text{V}$
$\text{Li}^+ + \text{e}^- \rightleftharpoons \text{Li}$	-3.04
$\text{Li}^+ + \text{CoO}_2 + \text{e}^- \rightleftharpoons \text{LiCoO}_2$	+1.16

Which statement is correct in a lithium-ion cell?

Tick (✓) one box.

- ☐ **A** The cell potential is 2.88 V.
- ☐ **B** The reaction at the positive electrode is: $\text{LiCoO}_2 \rightarrow \text{Li}^+ + \text{CoO}_2 + \text{e}^-$
- ☐ **C** The overall cell reaction is: $\text{Li} + \text{CoO}_2 \rightarrow \text{LiCoO}_2$
- ☐ **D** The oxidation number of Co changes from +2 to +1.

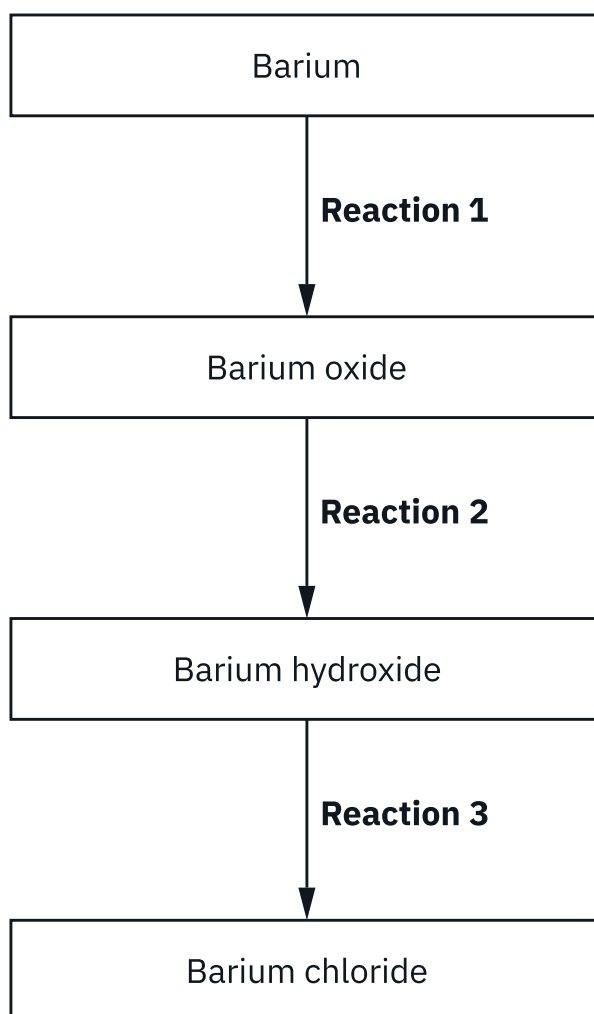
Q76 · Redox and electrode potentials · June 2024 · Paper 1 (Periodic table, elements and physical chemistry) ·

Q21 · [15 marks]

This question also needs Amount of substance and Group 2 and the halogens.

This question is about redox reactions and electrode potentials.

21(a) The flowchart shows some reactions of barium and its compounds.



- Write balanced equations for Reaction 1 and Reaction 2.
- Identify the type of reaction in Reaction 3.

[3 marks]

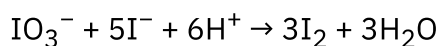
Reaction 1: equation

Reaction 2: equation

Reaction 3: type of reaction

21(b) Potassium iodate tablets prevent the uptake of radioactive iodine in the human body following a nuclear accident.

The mass of potassium iodate(V), KIO_3 , in a tablet can be determined by reaction with an aqueous solution of potassium iodide, KI , in the presence of acid.



A chemist finds that two KIO_3 tablets react with exactly 26.2 cm^3 $0.150 \text{ mol dm}^{-3}$ KI .

Calculate the mass, in mg, of KIO_3 in **one** tablet.

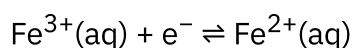
Give your answer to the nearest whole number.

mass $\text{KIO}_3 = \text{mg}$

[4 marks]

21(c) Standard electrode potentials are measured by comparison with a reference half-cell.

Draw a labelled diagram to show how the standard electrode potential could be measured for the redox system below.



Include details of the apparatus, solutions and the standard conditions needed when measuring this standard electrode potential.

Standard conditions

[4 marks]

Many electric vehicles are powered by lithium-ion cells.

Hydrogen-oxygen fuel cells can also be used to power vehicles.

Six redox systems are shown in the table. State symbols have been omitted.

Redox system	Half-equation	$E^\ominus / \text{V}$
1	$\text{Li}^+ + \text{e}^- \rightleftharpoons \text{Li}$	-3.04
2	$2\text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{H}_2 + 2\text{OH}^-$	-0.83
3	$2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2$	0.00
4	$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightleftharpoons 4\text{OH}^-$	+0.40
5	$\text{Li}^+ + \text{CoO}_2 + \text{e}^- \rightleftharpoons \text{LiCoO}_2$	+1.16
6	$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}$	+1.23

21(d)(i) A lithium-ion cell involves redox systems 1 and 5.

Construct the overall cell equation for a lithium-ion cell.

[1 mark]

21(d)(ii) Hydrogen-oxygen fuel cells can operate in acidic or in alkaline conditions.

Show that for acidic and alkaline hydrogen–oxygen fuel cells, the standard cell potentials, and the overall cell equations, are the same.

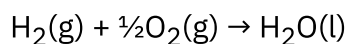
[3 marks]

Acidic

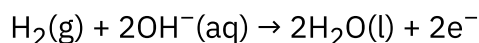
Alkaline

Q77 · Redox and electrode potentials · June 2025 · Paper 1 (Periodic table, elements and physical chemistry) · Q10 · [1 mark]

The overall equation for a hydrogen–oxygen fuel cell is:



The half-equation at the negative electrode is:



What is the half-equation at the positive electrode?

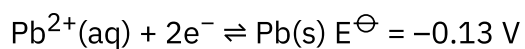
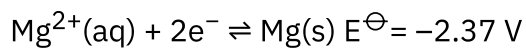
Tick (✓) one box.

- ☐ **A** $\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + 2\text{e}^-$
- ☐ **B** $\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{OH}^-(\text{aq}) + 2\text{e}^-$
- ☐ **C** $\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow 2\text{OH}^-(\text{aq})$
- ☐ **D** $\text{O}_2(\text{g}) + 2\text{OH}^-(\text{aq}) + \text{H}_2(\text{g}) + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$

Q78 · Redox and electrode potentials · June 2025 · Paper 1 (Periodic table, elements and physical chemistry) ·

Q11 · [1 mark]

Two redox systems are shown below.



Which species is the strongest reducing agent?

Tick (✓) one box.

☐ **A** $\text{Mg}^{2+}(\text{aq})$

☐ **B** $\text{Mg}(\text{s})$

☐ **C** $\text{Pb}^{2+}(\text{aq})$

☐ **D** $\text{Pb}(\text{s})$

Q79 · Redox and electrode potentials · June 2025 · Paper 1 (Periodic table, elements and physical chemistry) · Q20 · [9 marks]

Standard electrode potentials for seven redox systems are shown in the table below.

Redox system	Half-equation	$E^\ominus / \text{V}$
1	$\text{V}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{V}(\text{s})$	-1.18
2	$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
3	$\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Co}(\text{s})$	-0.28
4	$\text{V}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{2+}(\text{aq})$	-0.26
5	$2\text{H}^+(\text{aq}) + \text{VO}^{2+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.34
6	$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
7	$2\text{H}^+(\text{aq}) + \text{VO}_2^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{VO}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+1.00

20(a)(i) A student sets up a standard cell based on redox systems **2** and **4**.

Draw a labelled diagram to show how this cell could be set up to measure its standard cell potential.

Include the conditions required to measure the standard cell potential.

standard conditions

[4 marks]

20(a)(ii) Calculate the standard cell potential of this cell.

standard cell potential = V

[1 mark]

20(b) A student predicts that cobalt metal will reduce acidified VO^{2+} ions to form V^{2+} ions in two stages.

Explain why this two-stage reduction should happen in terms of electrode potentials and equilibria shifts.

Include overall equations for the predicted reactions.

[4 marks]

Q80 • Redox and electrode potentials • June 2025 • Paper 3 (Unified chemistry) • Q5 • [16 marks]

This question also needs Amount of substance and Carbonyls, carboxylic acids and esters.

This question is about two metal hydrides, lithium aluminium hydride, LiAlH_4 , and sodium borohydride, NaBH_4 . Both hydrides are used as reducing agents in organic chemistry.

LiAlH_4 , is a stronger reducing agent than NaBH_4 , and can reduce esters to alcohols.

A student plans to use LiAlH_4 to reduce the liquid ester, ethyl phenylmethanoate, $\text{C}_6\text{H}_5\text{COOC}_2\text{H}_5$ (density = 1.05 g cm^{-3}) to the alcohol, $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$ ($M_r = 108$).

The student uses $\text{C}_6\text{H}_5\text{COOC}_2\text{H}_5$ and LiAlH_4 (an excess) in a 1.0 : 2.5 molar ratio.

The student's method is outlined below.

Step 1	7.50 cm ³ of C ₆ H ₅ COOC ₂ H ₅ is dissolved in an organic solvent.
Step 2	LiAlH ₄ is added to the solution from Step 1. The reduction takes place.
Step 3	The mixture from Step 2 is heated with dilute aqueous acid.
Step 4	The impure C ₆ H ₅ CH ₂ OH is purified.

The student carries out this preparation and obtains 4.40 g of pure C₆H₅CH₂OH.

5(a)(i) What is the systematic name of the alcohol C₆H₅CH₂OH?

[1 mark]

5(a)(ii) Calculate the mass of LiAlH₄ that the student should use in Step 2 and the percentage yield of pure C₆H₅CH₂OH obtained in Step 4.

Give the mass of LiAlH₄ and the percentage yield of pure C₆H₅CH₂OH to **3** significant figures.

Mass of LiAlH₄ = g

Percentage yield of pure C₆H₅CH₂OH = %

[4 marks]

5(a)(iii) In the preparation, LiAlH_4 behaves as a nucleophile.

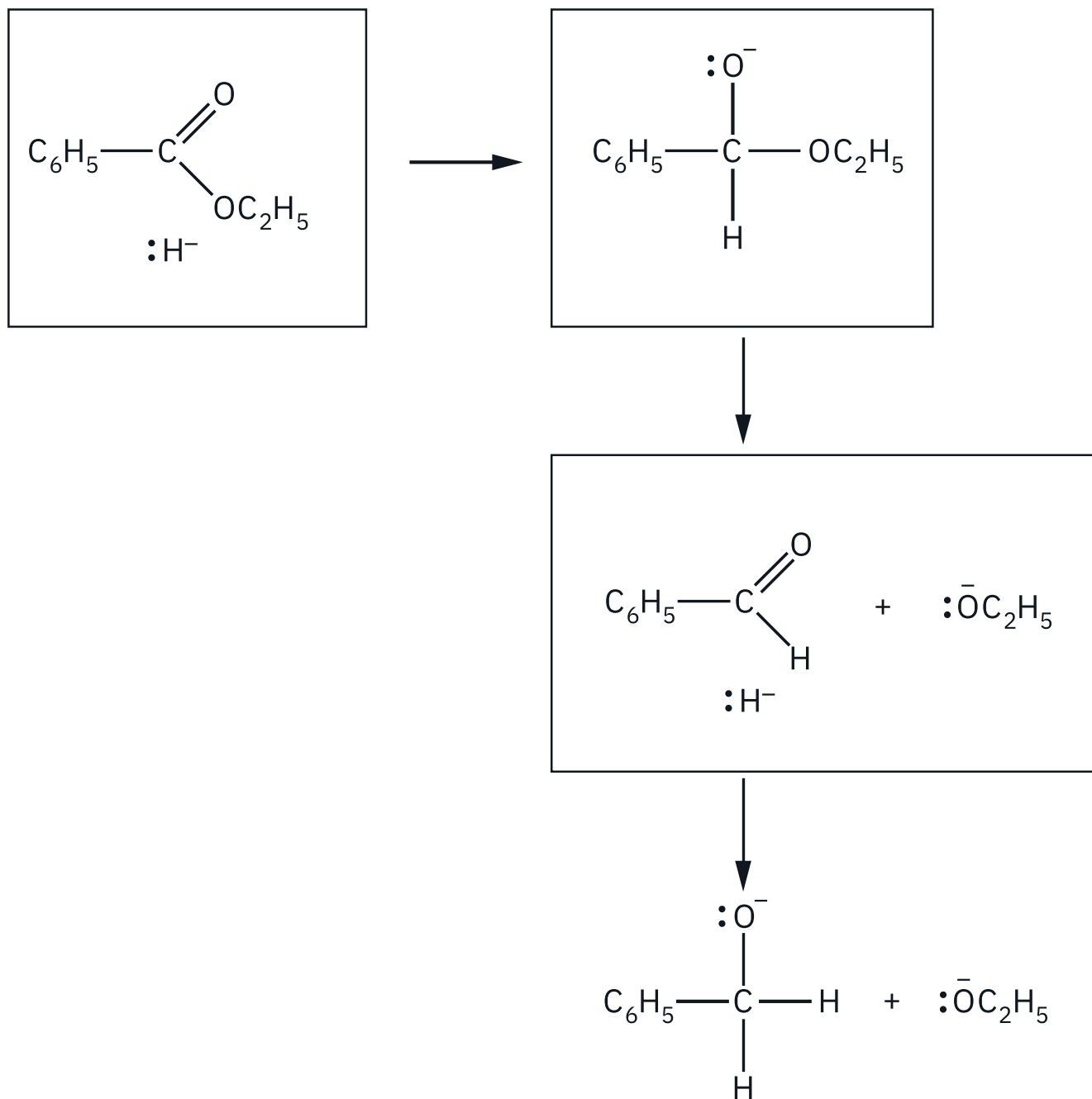
What is meant by the term **nucleophile**?

[1 mark]

5(a)(iv) The mechanism for Step 2 in the reduction of $\text{C}_6\text{H}_5\text{COOC}_2\text{H}_5$ is shown below.

In the mechanism, LiAlH_4 can be represented as H^- .

Complete the mechanism by adding curly arrows to the three boxes.



[4 marks]

Draw your answer on the figure above.

5(a)(v) Suggest why the student heated the mixture from Step 2 with dilute aqueous acid in Step 3.

[1 mark]

5(b) NaBH_4 contains Na^+ and BH_4^- ions.

Draw a 'dot-and-cross' diagram for NaBH_4 .

Use a different symbol for the electrons from each element.

Show outer electrons only.

[2 marks]

$\text{NaBH}_4 / \text{O}_2$ cells are being investigated as potential fuel cells.

- The positive electrode contains O_2 .
- The negative electrode contains NaBH_4 .

The reaction at the positive electrode and the overall cell reaction for a $\text{NaBH}_4 / \text{O}_2$ fuel cell are shown below.

Reaction at positive electrode: $\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$ $E^\ominus = +0.40 \text{ V}$

Overall cell reaction: $\text{NaBH}_4 + 2\text{O}_2 \rightarrow \text{NaBO}_2 + 2\text{H}_2\text{O}$ $E^\ominus_{\text{cell}} = 1.64 \text{ V}$

5(c)(i) What is the standard electrode potential of the negative electrode in this cell?

Standard electrode potential = V

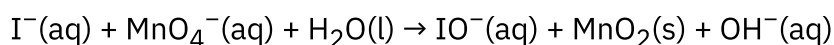
[1 mark]

5(c)(ii) Construct the equation for the reaction at the negative electrode of this cell.

[2 marks]

Q81 · Redox and electrode potentials · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q12 · [1 mark]

Iodide ions, $\text{I}^-(\text{aq})$, react with $\text{MnO}_4^-(\text{aq})$. The unbalanced equation is shown below.



What is the ratio of $\text{MnO}_2(\text{s})$ to $\text{OH}^-(\text{aq})$ in the balanced equation?

Tick (✓) one box.

☐ **A** 1 : 3

☐ **B** 1 : 2

☐ **C** 1 : 1

☐ **D** 3 : 2

Q82 · Redox and electrode potentials · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q19 · [9 marks]

This question also needs Amount of substance.

Standard electrode potentials for four redox systems are shown in Table 19.1.

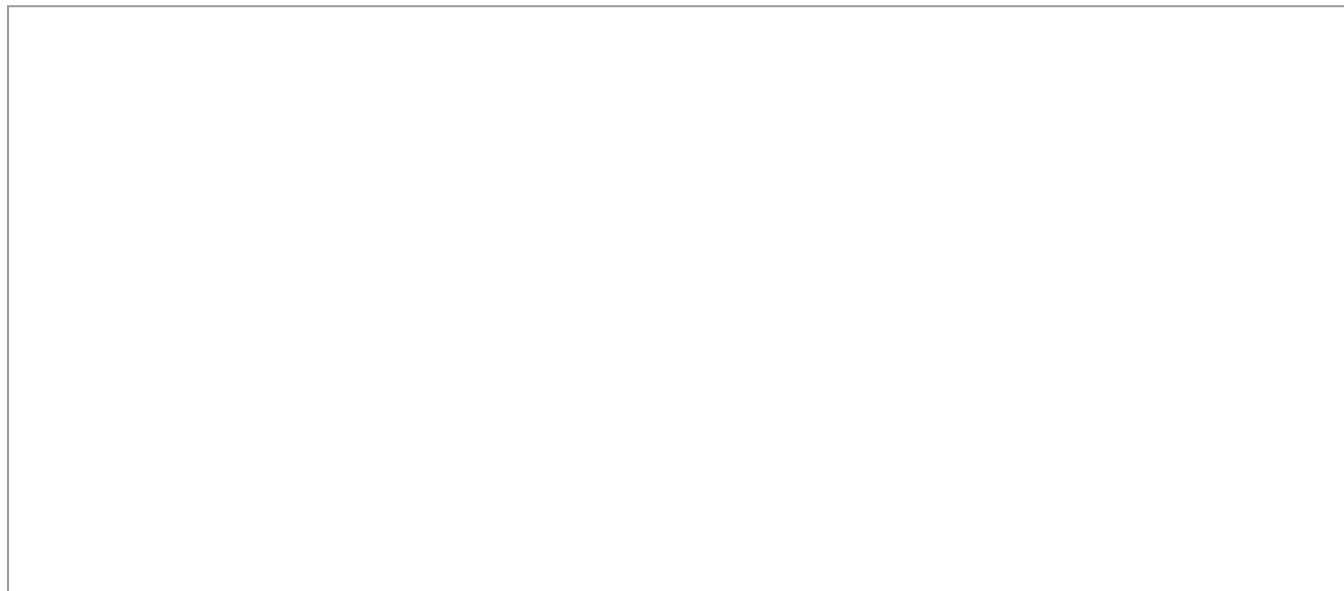
Redox system	Half-equation	$E^\ominus / \text{V}$
1	$\text{CO}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{HCOOH}(\text{aq})$	-0.11
2	$\text{HCOOH}(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{HCHO}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	-0.03
3	$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
4	$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51

Table 19.1

19(a) A student sets up a standard cell in the laboratory based on redox systems 3 and 4.

Draw a labelled diagram to show how this cell could be set up to measure its standard cell potential at 298 K.

[3 marks]



19(b) A student warms a mixture of methanal, HCHO , and acidified potassium manganate(VII).

The student observes gas bubbles.

Explain this observation in terms of electrode potentials and equilibria.

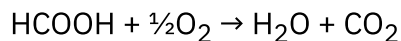
Include overall equations in your answer.

[4 marks]

19(c) Methanoic acid, HCOOH , can be used in a fuel cell. As with all fuel cells, the fuel (HCOOH) is supplied at one electrode and the oxidant (oxygen) at the other electrode.

The standard cell potential for this fuel cell is 1.34 V.

The overall reaction is shown below.



Using the information in Table 19.1, deduce the half-equation for the reaction at the oxygen electrode, and calculate the standard electrode potential for the oxygen half-cell.

half-equation

standard electrode potential = V

[2 marks]

Q83 • Redox and electrode potentials • November 2021 • Paper 1 (Periodic table, elements and physical chemistry) • Q12 • [1 mark]

Two redox systems are shown below.



Which species in the two redox systems is the strongest oxidising agent?

Tick (✓) one box.

☐ **A** $\text{Fe}^{2+}(\text{aq})$

☐ **B** $\text{Fe}(\text{s})$

☐ **C** $\text{Cu}^{2+}(\text{aq})$

☐ **D** $\text{Cu}(\text{s})$

Q84 • Redox and electrode potentials • November 2021 • Paper 1 (Periodic table, elements and physical

chemistry) · Q19 · [11 marks]

This question also needs Acids and redox reactions and Group 2 and the halogens.

Storage cells and fuels cells are types of electrochemical cell.

The electrode potentials for five redox systems are shown in Table 19.1.

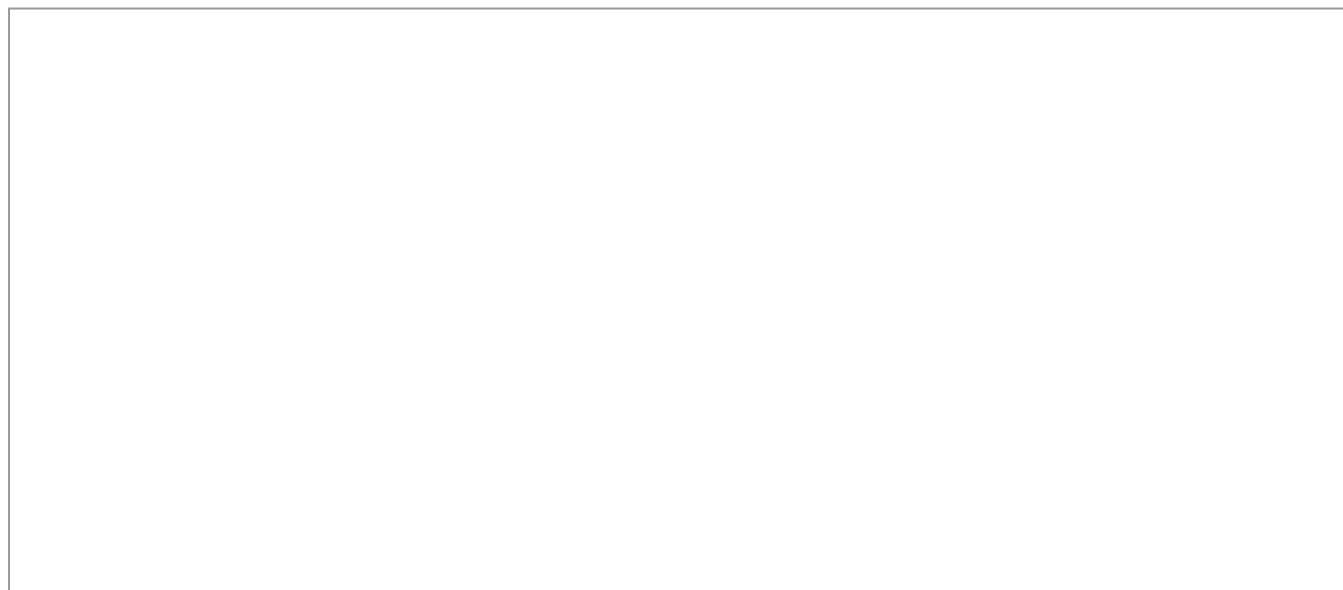
Redox system	Half-equation	$E^\ominus / \text{V}$
1	$\text{Cr}^{3+}(\text{aq}) + 3\text{e}^- \rightleftharpoons \text{Cr}(\text{s})$	-0.74
2	$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightleftharpoons 4\text{OH}^-(\text{aq})$	+0.40
3	$\text{MnO}_4^-(\text{aq}) + \text{e}^- \rightleftharpoons \text{MnO}_4^{2-}(\text{aq})$	+0.56
4	$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51
5	$\text{MnO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{MnO}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l})$	+1.70

Table 19.1

A student sets up an electrochemical cell based on redox systems 1 and 4 in Table 19.1.

19(a)(i) Draw a labelled diagram to show how this cell could be set up in the laboratory.

[3 marks]



19(a)(ii) Construct the equation for the overall cell reaction.

[1 mark]

In acid conditions, $\text{MnO}_4^{2-}(\text{aq})$ disproportionates to form $\text{MnO}_2(\text{s})$ and $\text{MnO}_4^{-}(\text{aq})$.

19(b)(i) Explain, in terms of oxidation numbers, why disproportionation has taken place.

[2 marks]

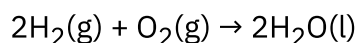
19(b)(ii) Explain, in terms of electrode potentials and equilibrium shifts why $\text{MnO}_4^{2-}(\text{aq})$

disproportionates in acid conditions. Use the information in Table 19.1.

[2 marks]

An alkaline hydrogen-oxygen fuel cell is set up.

The overall equation for the cell reaction is shown below.



Redox system 2 in Table 19.1 is the positive electrode of this cell.

19(c)(i) Write the half-equation at the negative electrode.

[1 mark]

19(c)(ii) The cell potential is 1.23 V.

Calculate the electrode potential of the negative electrode.

electrode potential = V

[1 mark]

19(c)(iii) State one important feature of a fuel cell that is different from a conventional storage cell.

[1 mark]

Q85 • Transition elements • June 2017 • Paper 1 (Periodic table, elements and physical chemistry) • Q11 • [1 mark]

Aqueous Cr^{3+} ions are reacted with an excess of aqueous sodium hydroxide.

Which product is formed?

Tick (✓) one box.

☐ **A** $\text{Cr}(\text{OH})_6^{3-}$

☐ **B** $\text{Cr}(\text{OH})_3$

☐ **C** $[\text{Cr}(\text{OH})_4(\text{H}_2\text{O})_2]^-$

☐ **D** $[\text{Cr}(\text{OH})_4]^{3-}$

Q86 · Transition elements · June 2017 · Paper 1 (Periodic table, elements and physical chemistry) · Q2 · [1 mark]

This question also needs Electrons, bonding and structure.

What is the bonding between the ligands and the metal ion in $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$?

Tick (✓) one box.

- ☐ **A** Metallic
- ☐ **B** Ionic
- ☐ **C** Hydrogen
- ☐ **D** Dative covalent

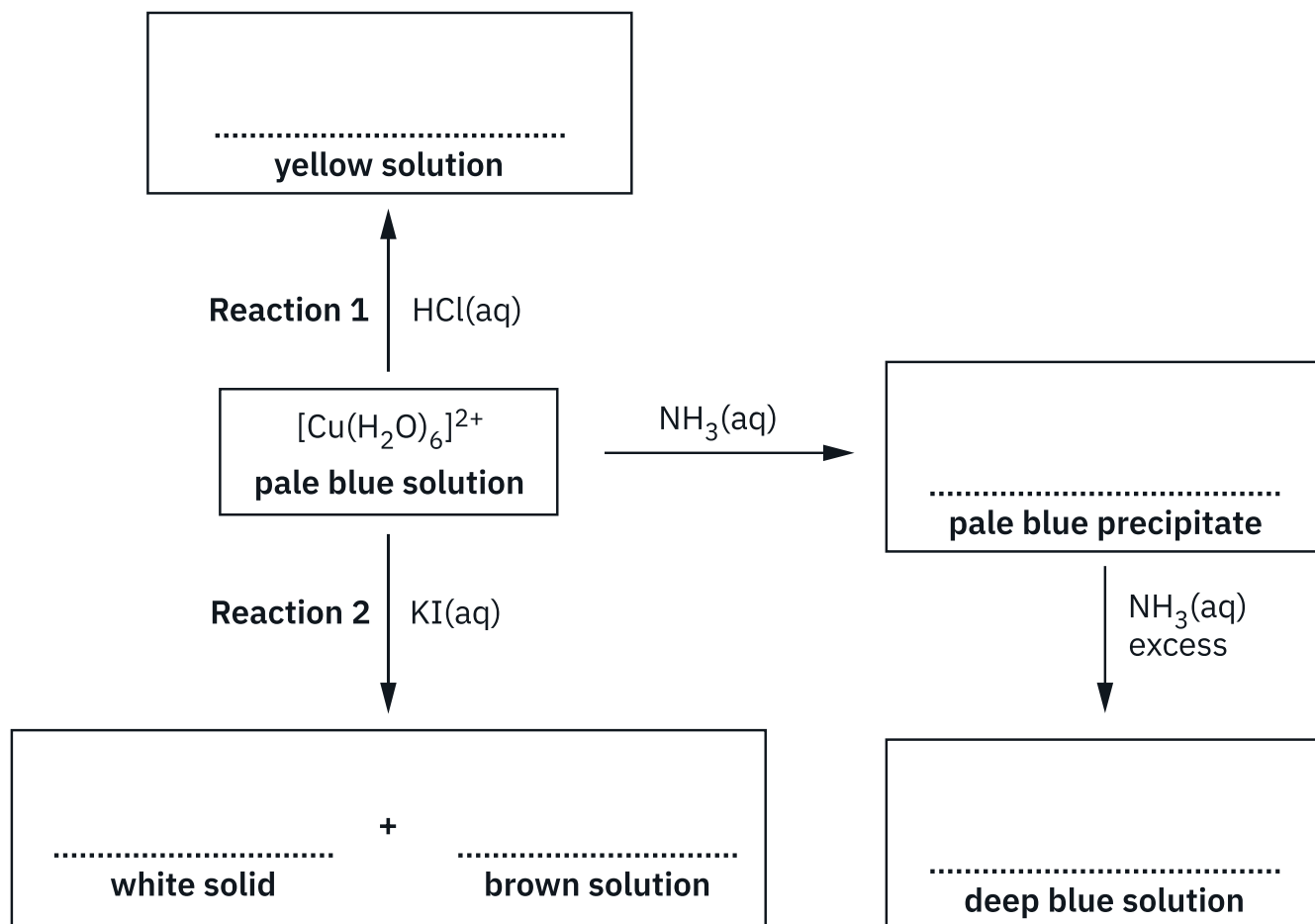
Q87 · Transition elements · June 2017 · Paper 1 (Periodic table, elements and physical chemistry) · Q23 · [13 marks]

This question also needs Amount of substance.

This question is about reactions of ions and compounds of transition elements.

The flowchart shows reactions of the complex ion $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$.

23(a)(i) In the boxes, write down the formulae of the species responsible for the observations.



[5 marks]

23(a)(ii) Name the type of reaction for Reaction 1 and Reaction 2.

[2 marks]

Reaction 1

Reaction 2

23(b) A hydrated nickel(II) complex, A, is heated in a crucible to remove the water of crystallisation.

The anhydrous complex B is formed. The results are shown below.

Mass of crucible + hydrated complex A = 59.554 g

Mass of crucible + anhydrous complex B = 58.690 g

Mass of crucible = 51.257 g

The anhydrous complex B is analysed and found to have a molar mass of 309.7 g mol^{-1} and to contain the following percentage composition by mass:

Ni, 18.95%; C, 23.25%; N, 27.12%; H, 7.75%; Cl, 22.93%.

The anhydrous complex B contains a cation C comprising Ni, C, N and H only.

Cation C is six-coordinate, contains three molecules of the bidentate ligand D, and exists as optical isomers.

Determine the formula of A, B, C and D and show the 3D structures for the optical isomers of C.

Show all your working.

[6 marks]

mark]

This question also needs Alkenes and addition polymers and Electrons, bonding and structure.

Which statement(s) is/are correct for the complex $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$?

1 One of its stereoisomers is used as an anti-cancer drug.

2 It has bond angles of 109.5° .

3 It has optical isomers.

Tick (✓) one box.

☐ **A** 1, 2 and 3

☐ **B** Only 1 and 2

☐ **C** Only 2 and 3

☐ **D** Only 1

Q89 · Transition elements · June 2018 · Paper 1 (Periodic table, elements and physical chemistry) · Q21 · [18 marks]

This question also needs Acids and redox reactions, Amount of substance, Electrons, bonding and structure and 2 other topics.

This question is about some reactions of d block elements and their ions.

Table 21.1 shows standard electrode potentials which will be needed within this question.

$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Zn}(\text{s})$	$E^\ominus = -0.76 \text{ V}$
$\text{Cr}^{3+}(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\text{Cr}^{2+}(\text{aq})$	$E^\ominus = -0.42 \text{ V}$
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Ni}(\text{s})$	$E^\ominus = -0.25 \text{ V}$
$\text{I}_2(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$2\text{I}^-(\text{aq})$	$E^\ominus = +0.54 \text{ V}$
$\text{Fe}^{3+}(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\text{Fe}^{2+}(\text{aq})$	$E^\ominus = +0.77 \text{ V}$
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^-$	$\rightleftharpoons$	$2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	$E^\ominus = +1.33 \text{ V}$
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$2\text{H}_2\text{O}(\text{l})$	$E^\ominus = +1.78 \text{ V}$

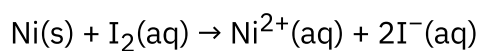
Table 21.1

21(a) Complete the electron configuration of a Ni atom: $1s^2$

a Ni^{2+} ion: $1s^2$

[2 marks]

A standard cell is set up in the laboratory with the cell reaction shown below.

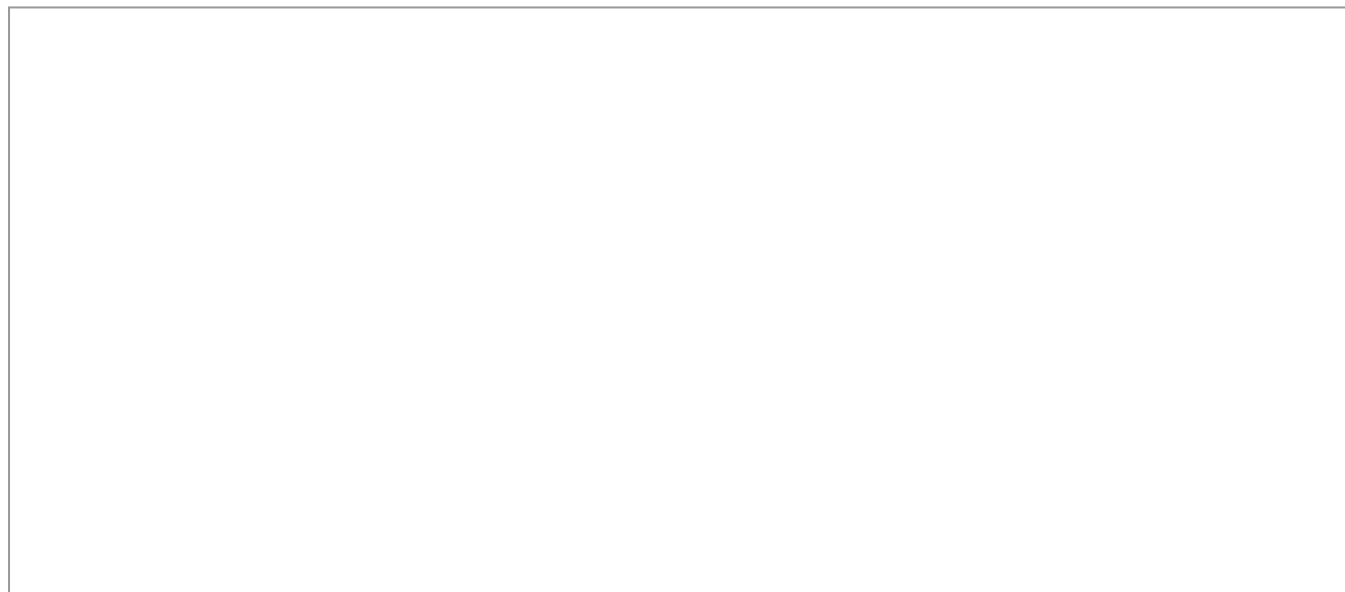


21(b)(i) Draw a labelled diagram to show how this cell could be set up to measure its standard cell potential.

Include details of apparatus, solutions and the standard conditions required.

Standard conditions

[4 marks]



21(b)(ii) Predict the standard cell potential of this cell.

standard cell potential = V

[1 mark]

Use the information in Table 21.1 to help you answer both parts of this question.

21(c)(i) Write the overall equation for the oxidation of Fe^{2+} by acidified H_2O_2 .

[1 mark]

21(c)(ii) Zinc reacts with acidified $\text{Cr}_2\text{O}_7^{2-}$ ions to form Cr^{2+} ions in two stages.

Explain why this happens in terms of electrode potentials and equilibria.

Include overall equations for the reactions which occur.

[4 marks]

21(d) Three different reactions of copper compounds are described below.

Reaction 1: Aqueous copper(II) sulfate reacts with excess aqueous ammonia in a ligand substitution reaction. A deep-blue solution is formed, containing an octahedral complex ion, C, which is a trans isomer.

Reaction 2: Copper(I) oxide reacts with hot dilute sulfuric acid in a disproportionation reaction. A blue solution, D, and a brown solid, E are formed.

Reaction 3: Copper(II) oxide reacts with warm dilute nitric acid in a neutralisation reaction, to form a blue solution. Unreacted copper(II) oxide is filtered off, and the solution is left overnight in an evaporating basin.

A hydrated salt, F, crystallises, with the percentage composition by mass:

Cu, 26.29%; H, 2.48%; N, 11.59%; O, 59.63%.

Identify C–F by formulae or structures, as appropriate.

Include equations, any changes in oxidation number, and working.

[6 marks]

Q90 · Transition elements · June 2019 · Paper 1 (Periodic table, elements and physical chemistry) · Q14 · [1 mark]

This question also needs Electrons, bonding and structure.

Which property/properties is/are correct for a transition element?

- 1 The element has atoms with a partially filled d sub-shell.
- 2 The existence of more than one oxidation state in its compounds.
- 3 The formation of coloured ions.

Tick (✓) one box.

- ☐ **A** 1, 2 and 3
- ☐ **B** Only 1 and 2
- ☐ **C** Only 2 and 3
- ☐ **D** Only 1

Q91 · Transition elements · June 2022 · Paper 1 (Periodic table, elements and physical chemistry) · Q15 · [1 mark]

Which ion(s) contain(s) one or more unpaired electrons?

- 1 Mn^{3+}
- 2 V^{3+}
- 3 Cu^{+}

Tick (✓) one box.

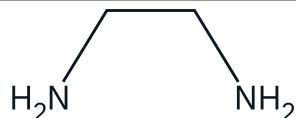
- ☐ **A** 1, 2 and 3
- ☐ **B** Only 1 and 2
- ☐ **C** Only 2 and 3
- ☐ **D** Only 1

Q92 · Transition elements · June 2022 · Paper 1 (Periodic table, elements and physical chemistry) · Q22 · [16 marks]

This question is about reactions of transition metal compounds.

Ethane-1,2-diamine, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, is a bidentate ligand.

The structure of ethane-1,2-diamine is shown below.



22(a)(i) Explain why ethane-1,2-diamine can act as a bidentate ligand.

[1 mark]

22(a)(ii) The iron(III) ion, Fe^{3+} , forms a complex ion A with two ethane-1,2-diamine ligands and two chloride ligands.

Complex ion A has cis and trans stereoisomers.

One of these stereoisomers exists as optical isomers.

Determine the empirical formula, with charge, of complex ion A and draw the 3-D structures of the three stereoisomers.

[4 marks]

Empirical formula with charge

Structures

Aqueous sodium hydroxide is added to an aqueous solution of iron(II) sulfate.

A pale green precipitate forms which turns brown when left to stand in air.

22(b)(i) Write an ionic equation for the formation of the pale green precipitate.

[1 mark]

22(b)(ii) Use the information below to explain why the pale green precipitate turns brown when left to stand in air and construct an equation for the reaction which occurs.

Redox System	Equation	$E^\ominus / \text{V}$
1	$\text{Fe}(\text{OH})_3(\text{s}) + \text{e}^- \rightleftharpoons \text{Fe}(\text{OH})_2(\text{s}) + \text{OH}^-(\text{aq})$	-0.56 V
2	$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightleftharpoons 4\text{OH}^-(\text{aq})$	+0.40 V

[4 marks]

22(c) This question is about copper and copper compounds.

Experiment 1

Hydrochloric acid, HCl(aq) , is added to an aqueous solution containing $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

A yellow-green solution forms containing complex ion B.

Experiment 2

A piece of copper metal is heated with concentrated sulfuric acid.

A reaction takes place forming a pale blue solution C and 45 cm^3 of a gas D, measured at RTP. The mass of gas D is 0.12 g.

Experiment 3

An excess of copper(II) oxide is heated with dilute nitric acid. The resulting mixture is filtered. The filtrate is a blue solution E.

Aqueous potassium iodide, KI(aq) , is added to the blue solution E.

A white precipitate F and a brown solution G form.

Determine the formulae of B–G.

Construct equations for the reactions taking place, include any changes in oxidation number, and show your working where appropriate.

[6 marks]

mark]

Which statement(s) is/are correct for the anti-cancer complex $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$?

- 1 It has bond angles of 90° .
- 2 The oxidation number of Pt is +4.
- 3 It forms both optical and cis-trans isomers.

Tick (✓) one box.

- ☐ **A** 1, 2 and 3
- ☐ **B** Only 1 and 2
- ☐ **C** Only 2 and 3
- ☐ **D** Only 1

Q94 · Transition elements · June 2023 · Paper 1 (Periodic table, elements and physical chemistry) · Q22 · [14 marks]

This question is about the d-block elements in Period 4 of the periodic table (Sc to Zn).

22(a) Explain, with examples from Period 4, what is meant by the terms **d-block element** and **transition element**.

Explain why some d-block elements are **not** transition elements.

Use electron configurations to support your explanations.

[6 marks]

22(b)(i) Describe precipitation reactions using **either** copper **or** chromium ions as examples.

Include equations.

[2 marks]

22(b)(ii) Describe ligand substitution reactions using **either** copper **or** chromium ions as examples.

Include equations.

[2 marks]

22(c) The ethanedioate ion, $\text{C}_2\text{O}_4^{2-}$, is a bidentate ligand.

A complex ion of cobalt(III) contains two ethanedioate ligands and two water ligands.

Determine the charge of this complex ion **and** the coordination number of cobalt in the complex ion.

[2 marks]

Charge of complex ion

Coordination number of cobalt

22(d) An acidified solution containing $\text{Cr}_2\text{O}_7^{2-}$ ions reacts with vanadium(III) ions in a redox reaction to form a solution containing Cr^{3+} ions and VO_2^+ ions.

Construct the overall equation for this reaction.

[2 marks]

Q95 • Transition elements • June 2023 • Paper 3 (Unified chemistry) • Q4 • [10 marks]

This question also needs Amount of substance.

Tutton's salts are 'double salts' with the formula $\text{X}_2\text{Y}(\text{Z}\text{O}_4)_2 \cdot 6\text{H}_2\text{O}$.

A Tutton's salt contains two cations: X^+ and Y^{2+} .

- X^+ can be an ion of the Group 1 elements K, Rb, Cs or Fr, or an ammonium ion.
- Y^{2+} can be a 2+ ion of magnesium or an ion of most of the transition elements in Period 4.
- Z can be S or Cr.

$(\text{NH}_4)_2\text{Cu}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ is an example of a Tutton's salt.

4(a) Predict the formula of a Tutton's salt containing different ions from $(\text{NH}_4)_2\text{Cu}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

[1 mark]

A student prepares a sample of the Tutton's salt, $(\text{NH}_4)_2\text{Cu}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ using the method shown below.

Step 1 Dissolve 0.025 mol of ammonium sulfate and 0.025 mol of hydrated copper(II) sulfate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, in water and make up to 50 cm^3 .

Step 2 Boil the resulting mixture for 2 minutes and allow to cool.

Step 3 Allow the solvent to evaporate slowly. Pale blue crystals of the Tutton's salt form.

4(b)(i) What masses are needed of ammonium sulfate and $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$?

[2 marks]

mass of ammonium sulfate g

mass of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ g

4(b)(ii) In Step 3, why does the student allow the solvent to evaporate and **not** boil off all the solvent in Step 2?

[1 mark]

The student dissolves their Tutton's salt in water. A pale blue solution forms.

The student carries out two tests on this aqueous solution.

4(c)(i) The student adds an excess of aqueous ammonia to their aqueous solution of Tutton's salt. A deep blue solution forms.

The complex ion responsible for the deep blue solution has a molar mass of 167.5 g mol^{-1} .

Suggest the formula of this complex ion.

[1 mark]

4(c)(ii) The student adds NaOH(aq) to the aqueous solution of Tutton's salt and warms the mixture.

A precipitate and a gas are formed.

Write the formulae of the precipitate and gas and suggest a test that could confirm the identity of the gas.

[3 marks]

Formula of precipitate

Formula of gas

Test to confirm the identity of the gas

4(c)(iii) How could the student carry out a test-tube test to confirm the anion in the Tutton's salt?

[2 marks]

Q96 • Transition elements • June 2024 • Paper 1 (Periodic table, elements and physical chemistry) • Q13 • [1

mark]

A student analyses a solution of a salt.

The results are shown below.

Test	Observation
Reaction with NaOH(aq)	Green precipitate
Reaction with Ba(NO ₃) ₂ (aq)	White precipitate

What is the formula of the salt?

Tick (✓) one box.

☐ **A** CuCl₂

☐ **B** CuSO₄

☐ **C** FeCl₂

☐ **D** FeSO₄

Q97 • Transition elements • June 2024 • Paper 1 (Periodic table, elements and physical chemistry) • Q22 • [12

marks]

This question is about transition elements.

22(a) Iron is in the d block of the periodic table and contains s, p and d orbitals.

- Draw diagrams to show the shapes of an s orbital and a p orbital.
- Complete the electron configurations of an iron atom and an iron(II) ion.

Shapes

s orbital	p orbital
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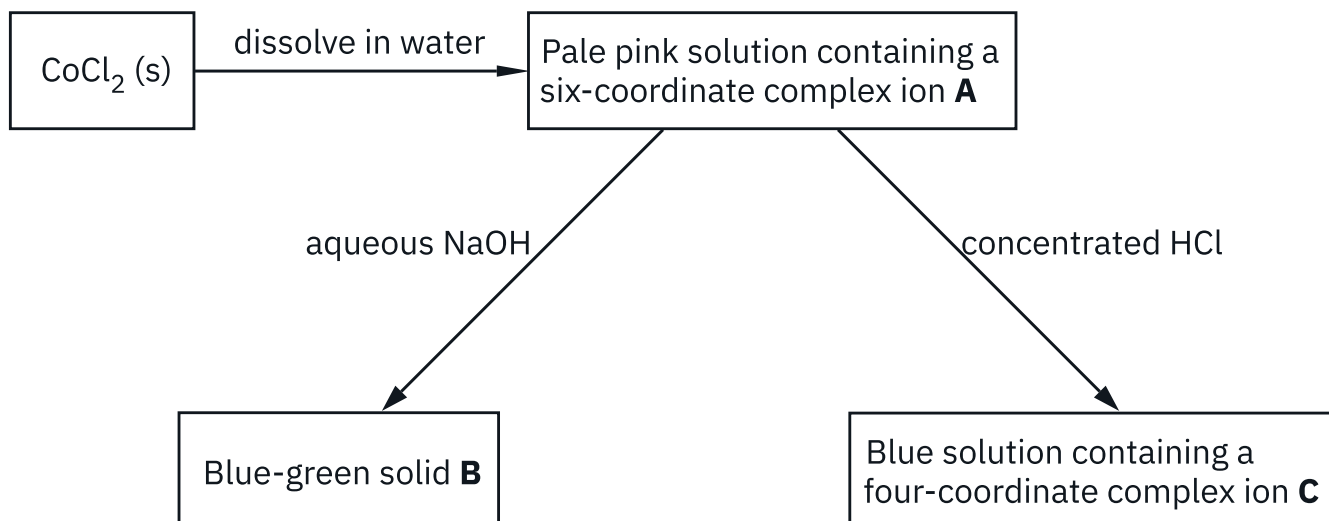
[2 marks]

Electron configurations

Iron atom: $1s^2$

Iron(II) ion $1s^2$

The flowchart shows some reactions of cobalt(II) chloride, CoCl_2 .



In A, B and C, cobalt has an oxidation number of +2.

22(b)(i) Suggest the formulae of A, B and C.

Complex ion A:

Solid B:

Complex ion C:

[3 marks]

22(b)(ii) Cobalt (III) forms an octahedral complex ion D, which contains both ammonia and chloride ligands.

Complex ion D has a molar mass of 197.9 g mol^{-1} .

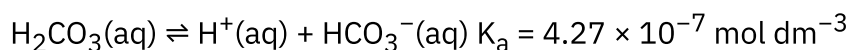
Determine the formula **and** charge of complex ion D.

[2 marks]

22(c) Red blood cells contain haemoglobin which transports oxygen around the body.

For efficient transportation of oxygen, healthy human blood must be maintained at a pH value between 7.35 and 7.45.

Human blood acts as a buffer due to the presence of carbonic acid, H_2CO_3 , and hydrogencarbonate, HCO_3^- , ions as shown below.



- Explain, using ligand substitution, how haemoglobin transports oxygen around the body.
- Determine whether a sample of blood with a $[\text{HCO}_3^-] : [\text{H}_2\text{CO}_3]$ ratio of 8.5:1 is healthy.

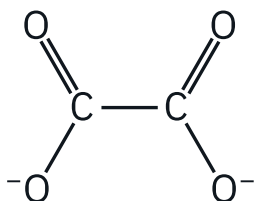
[5 marks]

Q98 · Transition elements · June 2024 · Paper 3 (Unified chemistry) · Q3 · [17 marks]

This question also needs Amount of substance.

This question is about compounds and ions of iron(II) and iron(III) that contain ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$.

The $\text{C}_2\text{O}_4^{2-}$ ion, shown below, is an example of a bidentate ligand.



3(a)(i) Explain what is meant by the term **bidentate ligand**.

[2 marks]

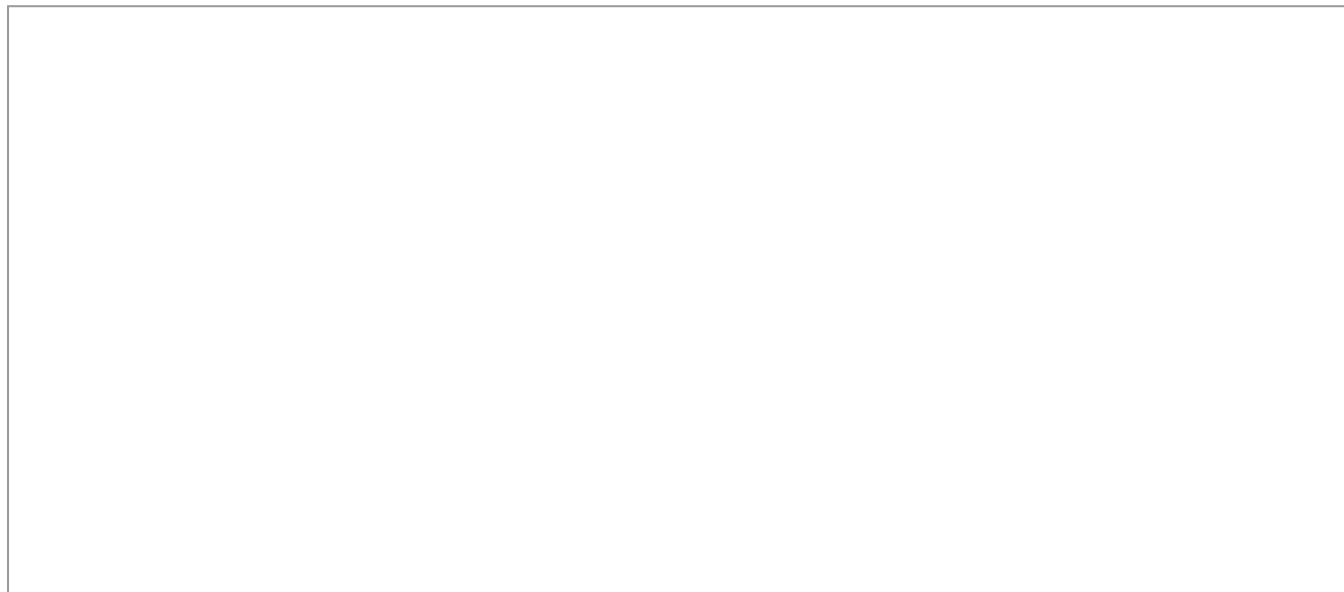
3(a)(ii) A complex ion E contains three $\text{C}_2\text{O}_4^{2-}$ ions bonded to an iron(III) ion in an octahedral shape.

Complex ion E exists as a mixture of two optical isomers.

Draw 3D diagrams to show the structures of the optical isomers of E.

Include any overall charge.

[3 marks]



A student plans an investigation to find the number of waters of crystallisation, x , in a sample of hydrated iron(II) ethanedioate, $\text{FeC}_2\text{O}_4 \cdot x\text{H}_2\text{O}$.

The student decides to carry out a redox titration between solutions of iron(II) ethanedioate and potassium manganate(VII) in acidic conditions.

3(b)(i) In the titration, both iron(II) ions and ethanedioate, $\text{C}_2\text{O}_4^{2-}$, ions are oxidised.

Construct half-equations for the oxidation of iron(II) and ethanedioate ions.

[2 marks]

Oxidation of iron(II) ions

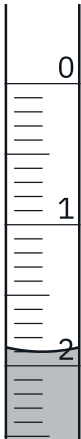
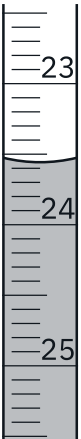
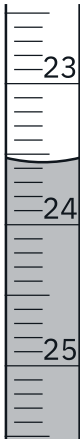
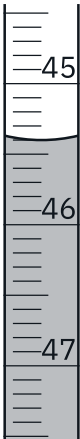
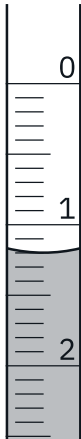
Oxidation of ethanedioate ions

3(b)(ii) The student prepares a 250.0 cm^3 solution of iron(II) ethanedioate by dissolving 1.295 g of $\text{FeC}_2\text{O}_4 \cdot x\text{H}_2\text{O}$, in dilute sulfuric acid.

The student titrates 25.0 cm^3 samples of this solution with $0.0200 \text{ mol dm}^{-3} \text{ KMnO}_4$ in the burette.

The student carries out a trial, followed by three further titrations.

The diagrams show the initial burette readings and the final burette readings for the student's three further titrations.

Titration 1		Titration 2		Titration 3	
Initial reading	Final reading	Initial reading	Final reading	Initial reading	Final reading
					

All burette readings are measured to the nearest 0.05 cm^3 .

Complete the titration table.

	1	2	3
Final reading / cm^3			
Initial reading / cm^3			

Titre / cm³

[3 marks]

3(b)(iii) The uncertainty in each burette reading is $\pm 0.05 \text{ cm}^3$.

Calculate the percentage uncertainty for the titre in Titration 1.

percentage uncertainty = %

[1 mark]

3(b)(iv) In the titration, 5 mol of iron(II) ethanedioate reacts with 3 mol of manganate(VII) ions.

Analyse the student's results to find the number of waters of crystallisation, x , in the hydrated iron(II) ethanedioate, $\text{FeC}_2\text{O}_4 \cdot x\text{H}_2\text{O}$.

[6 marks]

mark]

Chromium forms the complex ions $[\text{Cr}(\text{NH}_3)_6]^{3+}$ and $[\text{Cr}(\text{OH})_6]^{3-}$.

Which statement(s) about the complexes is / are correct?

1 Chromium is in the same oxidation state in each complex ion.

2 The complex ions are different colours.

3 The complex ions have different coordination numbers.

Tick (✓) one box.

☐ **A** 1, 2 and 3

☐ **B** Only 1 and 2

☐ **C** Only 2 and 3

☐ **D** Only 1

Q100 · Transition elements · June 2025 · Paper 1 (Periodic table, elements and physical chemistry) · Q21 · [17 marks]

This question also needs Amount of substance.

This question is about reactions of compounds of iron and copper.

21(a)(i) Complete the electron configuration of an Fe atom: $1s^2$

a Cu^{2+} ion: $1s^2$

[2 marks]

21(a)(ii) Solutions of iron(II) sulfate, FeSO_4 , and copper(II) sulfate, CuSO_4 , can be distinguished by adding aqueous sodium hydroxide.

Describe what would be observed when NaOH(aq) is added to each solution.

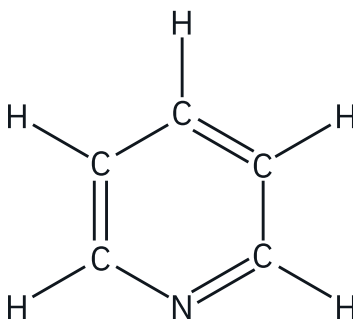
[2 marks]

Observation with $\text{FeSO}_4\text{(aq)}$

Observation with $\text{CuSO}_4\text{(aq)}$

The cyclic organic compound pyridine, $\text{C}_5\text{H}_5\text{N}$, can act as a monodentate ligand.

The structure of pyridine is shown below.



21(b)(i) What is meant by a **monodentate ligand**?

[1 mark]

21(b)(ii) An iron(II) complex contains two different ligands: $\text{C}_5\text{H}_5\text{N}$, and Cl^- .

The complex has a molar mass of 442.8 g mol^{-1} and the following percentage composition by mass:

Fe, 12.6%; C, 54.3%; H, 4.5%; N, 12.6%; Cl, 16.0%

Determine the empirical formula of the iron(II) complex.

Deduce the number of $\text{C}_5\text{H}_5\text{N}$ ligands in the complex and the coordination number of the iron(II) ion.

[4 marks]

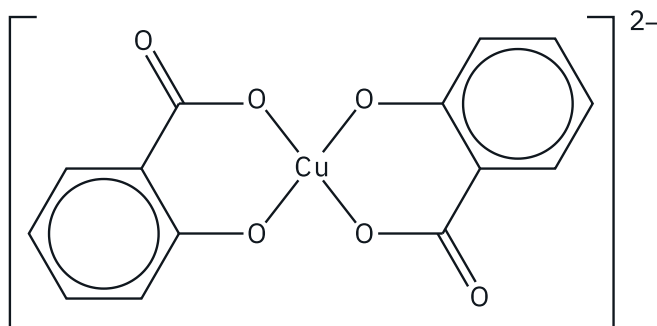
Empirical formula of iron(II) complex

Number of $\text{C}_5\text{H}_5\text{N}$ ligands

Coordination number of iron(II) ion

21(c) Aqueous copper(II) sulfate reacts with salicylic acid to form a complex ion which has two stereoisomers.

One isomer of the complex ion is shown:



Draw the other stereoisomer of the complex.

Identify the type of stereoisomerism shown by the complexes.

Type of stereoisomerism

[2 marks]

Mixture A is a mixture of copper(II) sulfate crystals, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and iron(II) sulfate crystals, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$.

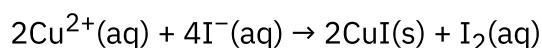
A student carries out a titration to determine the percentage by mass of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in Mixture A.

The student uses the following method.

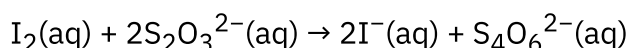
Step 1 Dissolve 9.51 g of Mixture A in water and make up the solution to 250.0 cm^3 in a volumetric flask.

Step 2 Pipette 25.0 cm^3 of the solution from Step 1 into a conical flask and add an excess of aqueous potassium iodide, $\text{KI}(\text{aq})$.

The copper(II) ions react with iodide ions to form a precipitate of copper(I) iodide and a solution of iodine.



Step 3 Titrate the contents of the conical flask from Step 2 with $0.0800 \text{ mol dm}^{-3}$ sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3$, using starch as the indicator.



Step 4 Repeat Step 2 and Step 3 to obtain concordant titres and calculate the mean titre.

Results

Mean titre = 31.15 cm^3

21(d)(i) Calculate the percentage by mass of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in Mixture A.

Give your answer to **3** significant figures.

Percentage of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in Mixture A = %

[5 marks]

21(d)(ii) The student repeats their method, but after carrying out Step 1 they leave the solution exposed to the air for a few days.

Some of the iron(II) sulfate is oxidised to iron(III) sulfate.

The student then continues with Step 2, Step 3 and Step 4 of the method.

This mean titre is greater than 31.15 cm^3 .

Suggest why this mean titre is greater than 31.15 cm^3 .

[1 mark]

Q101 · Transition elements · June 2025 · Paper 3 (Unified chemistry) · Q4 · [15 marks]

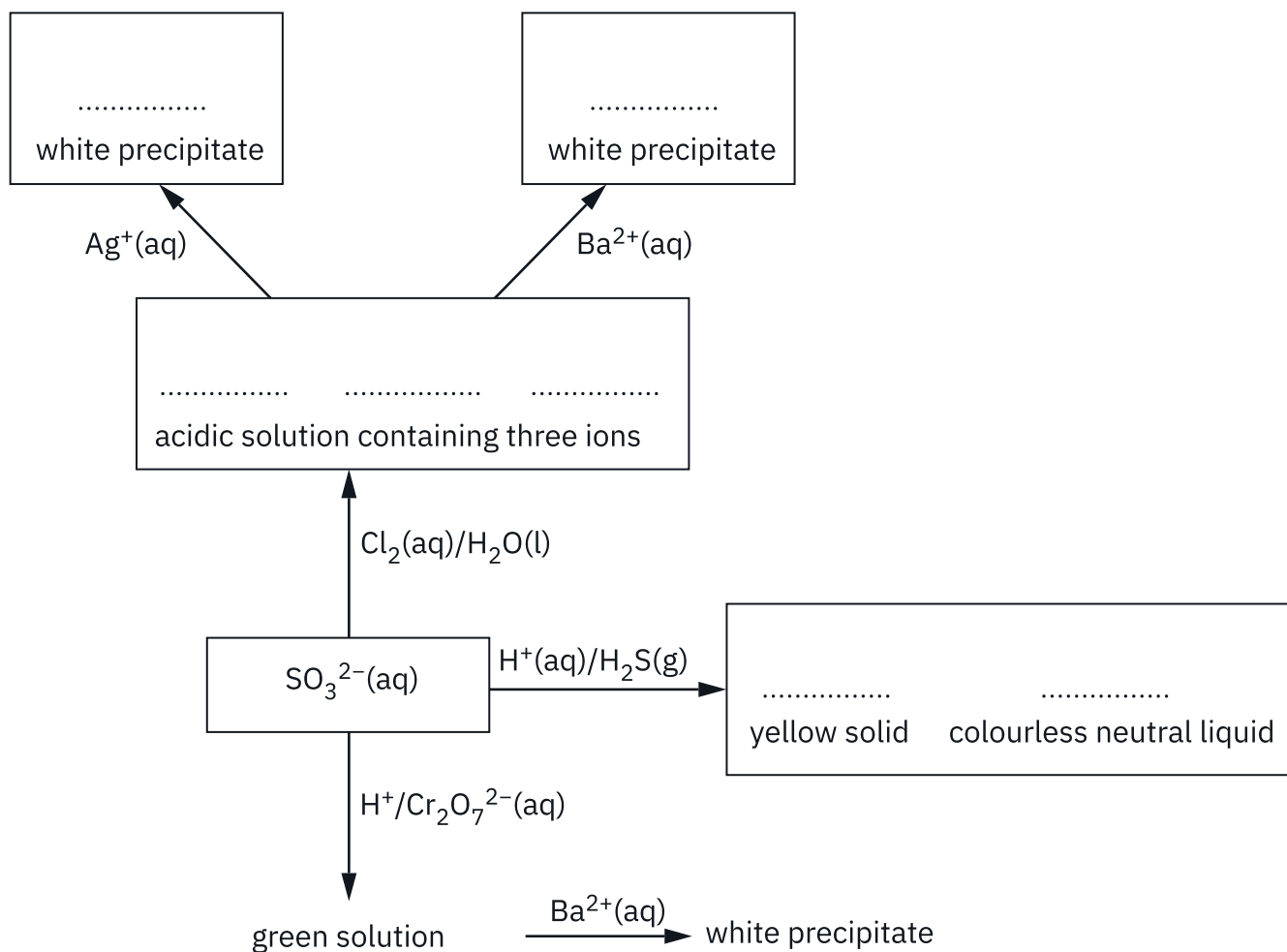
This question is about inorganic chemistry.

The flowchart shows reactions involving $\text{SO}_3^{2-}(\text{aq})$ ions.

4(a)(i) What is the systematic name of a SO_3^{2-} ion?

[1 mark]

4(a)(ii) Complete the flowchart by adding formulae in the boxes.

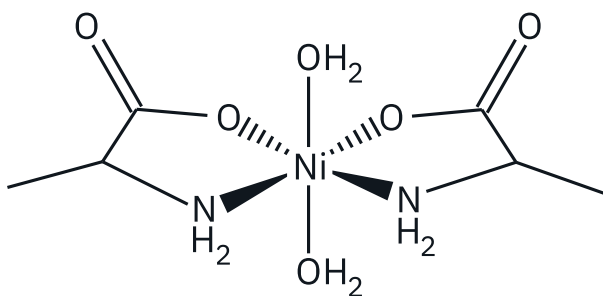


[7 marks]

4(a)(iii) Construct an ionic equation for the reaction of SO_3^{2-} with $\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$.

[2 marks]

The structure of a neutral nickel(II) complex, A, is shown below.



Complex A

4(b)(i) What is the empirical formula of complex A?

[1 mark]

4(b)(ii) Complex A can be prepared by reacting an aqueous solution of nickel(II) sulfate with amino acid B and potassium hydroxide.

Aqueous nickel(II) sulfate contains the octahedral hexaaquo complex ion C.

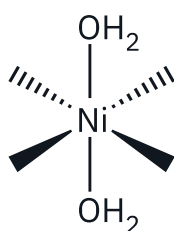
Draw the structure of amino acid B and the 3D structure, including the overall charge, of complex ion C.

Amino acid B

Complex ion C

[3 marks]

4(b)(iii) Complete the 3D diagram below to show a stereoisomer of complex A.



[1 mark]

Draw your answer on the figure above.

[1 mark]

Which statement(s) for the complex ion $[\text{Co}(\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2)_3]^{2+}$ is/are correct?

1 It has cis and trans isomers.

2 It has optical isomers.

3 It is six-fold coordination.

Tick (✓) one box.

☐ **A** 1, 2 and 3

☐ **B** Only 1 and 2

☐ **C** Only 2 and 3

☐ **D** Only 1

Q103 · Transition elements · November 2020 · Paper 1 (Periodic table, elements and physical chemistry) · Q22 ·

[15 marks]

This question also needs Acids and redox reactions and Amount of substance.

22(a) B and C are compounds of two different transition elements.

A student carries out test tube reactions on aqueous solutions of B and C.

The observations of the student's tests are shown below.

	Test	B(aq)	C(aq)
1	NH ₃ (aq) added dropwise	green precipitate D	grey-green precipitate E
	excess NH ₃ (aq) added	no further change	purple solution F
2	HNO ₃ (aq)	no change	no change
	followed by Ba(NO ₃) ₂ (aq)	white precipitate G	no change
3	HNO ₃ (aq)	no change	no change
	followed by AgNO ₃ (aq)	no change	white precipitate H

Analyse the results to identify B to H, and construct ionic equations for the formation of products D to H.

[6 marks]

A compound of nickel, J, has the formula $(\text{NH}_4)_2[\text{Ni}(\text{SCN})_x(\text{NH}_3)_y]$ and contains SCN^- and NH_3 ligands.

The percentage by mass of three of the elements in compound J is shown below:

Ni, 16.26%; S, 35.56%; N, 31.00%.

22(b)(i) Calculate the values of x and y in the formula of compound J.

x =

y =

[3 marks]

22(b)(ii) Determine the oxidation number of nickel in compound J.

oxidation number:

[1 mark]

22(c) Sodium sulfite(IV), Na_2SO_3 , is used as a preservative in some foods.

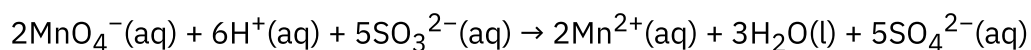
Food safety legislation allows a maximum of 850 mg Na_2SO_3 per kg of burger meat.

A chemist determines the amount of Na_2SO_3 in a sample of burger meat using a manganate(VII) titration.

Step 1 The Na_2SO_3 from 525 g of burger meat is extracted to form a solution containing $\text{SO}_3^{2-}(\text{aq})$ ions.

Step 2 The solution from step 1 is made up to 250.0 cm^3 in a volumetric flask with water. 25.0 cm^3 of this diluted solution is pipetted into a conical flask.

Step 3 The pipetted solution from step 2 is acidified with dilute sulfuric acid and then titrated with $0.0100 \text{ mol dm}^{-3}$ potassium manganate(VII), KMnO_4 .



12.60 cm^3 of $\text{KMnO}_4(\text{aq})$ is required to reach the endpoint.

Analyse the results to determine whether the burger meat complies with food safety legislation.

[5 marks]

Q104 · Transition elements · November 2020 · Paper 3 (Unified chemistry) · Q2 · [6 marks]

2 Transition metal ions can bond to ligands to form complex ions with different shapes.

Explain what is meant by the terms ligand, coordination number and ligand substitution, using suitable examples of complex ions with different shapes, limited to monodentate ligands.

Your answer should include diagrams and equations where appropriate.

[6 marks]

Q105 · Transition elements · November 2021 · Paper 1 (Periodic table, elements and physical chemistry) · Q17 · [11 marks]

This question also needs Alkenes and addition polymers, Amount of substance and Electrons, bonding and structure.

This question is about d-block elements.

17(a) Most d-block elements are also classified as transition elements.

Explain why scandium and zinc are classified as d-block elements but are not also transition elements.

Your explanations should include full electron configurations.

[4 marks]

Compound A is a hydrated chromium(III) salt with a molar mass of 608.3 g mol^{-1} and the following percentage composition by mass:

Cr, 17.10%; H, 3.94%; O, 63.13%; S, 15.83%.

A student dissolves compound A in water.

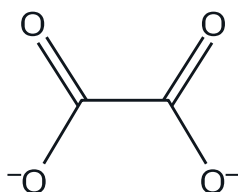
The resulting solution contains the complex ion $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$.

The student mixes this solution with aqueous sodium ethanedioate, $\text{Na}_2\text{C}_2\text{O}_4$.

A ligand substitution reaction takes place forming a solution containing three stereoisomers of a complex ion B of chromium(III).

Complex ion B is six-coordinate and contains two ethanedioate ligands and two water ligands.

The ethanedioate ion is the bidentate ligand shown below.



Ethanedioate ligand

17(b)(i) What is meant by a bidentate ligand?

[1 mark]

17(b)(ii) Determine the formulae of A and B. Write the ionic equation for the ligand substitution and show 3D structures for the three stereoisomers of B.

[6 marks]

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