



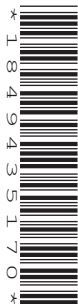
Oxford Cambridge and RSA

Tuesday 10 June 2025 – Morning

A Level Chemistry A

H432/01 Periodic table, elements and physical chemistry

Time allowed: 2 hours 15 minutes



You must have:

- the Data Sheet for Chemistry A

You can use:

- a scientific or graphical calculator
- an HB pencil



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

--	--	--	--	--

Candidate number

--	--	--	--

First name(s)

--

Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined page at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

- The total mark for this paper is **100**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **32** pages.

ADVICE

- Read each question carefully before you start your answer

2
Section A

You should spend a **maximum of 20 minutes** on this section.

Write your answer to each question in the box provided.

- 1** The table shows the number of protons and neutrons in four different atoms.

Atom	Number of protons	Number of neutrons
W	17	18
X	18	18
Y	19	18
Z	18	19

Which two atoms are isotopes of the same element?

- A** W and X
B X and Y
C X and Z
D Y and Z

Your answer C

[1]

- 2** 11.895 g of hydrated cobalt(II) chloride, $\text{CoCl}_2 \cdot x\text{H}_2\text{O}$, is heated to remove the water of crystallisation.

After heating to constant mass, the mass of the anhydrous salt was 6.495 g.

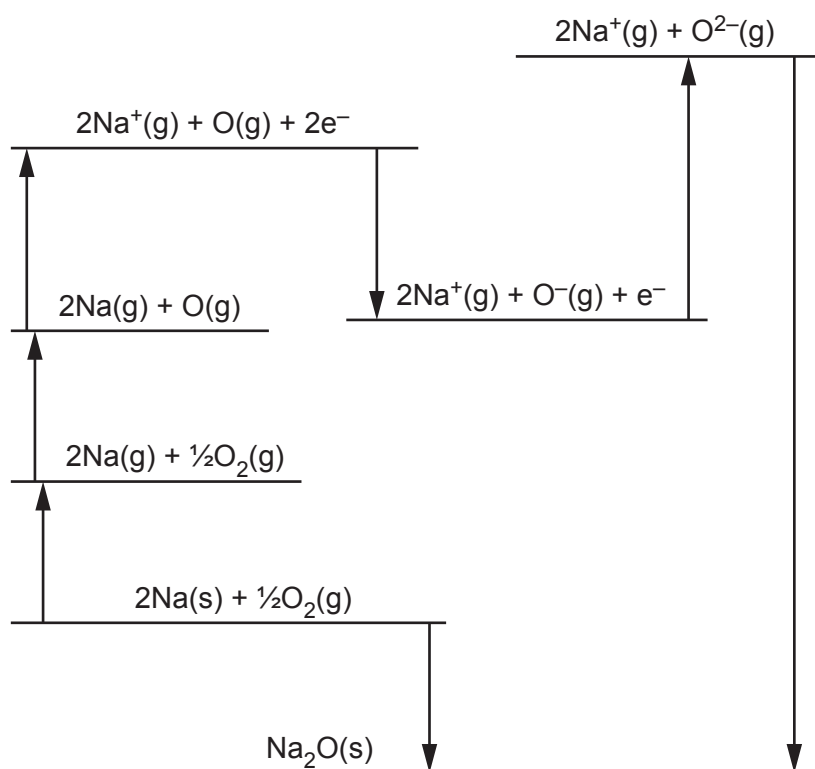
What is the value of **x**?

- A** 3
B 5
C 6
D 7

Your answer C

[1]

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



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

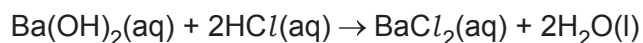
- A An electron is added to a high energy orbital.
- B An electron is added to a negative ion.
- C An electron is removed from a gaseous atom.
- D An electron is removed from a positive ion.

Your answer

B

[1]

- 4 What volume, in cm^3 , of $0.250 \text{ mol dm}^{-3}$ barium hydroxide solution is required to exactly neutralise 25.0 cm^3 of $0.115 \text{ mol dm}^{-3}$ hydrochloric acid?



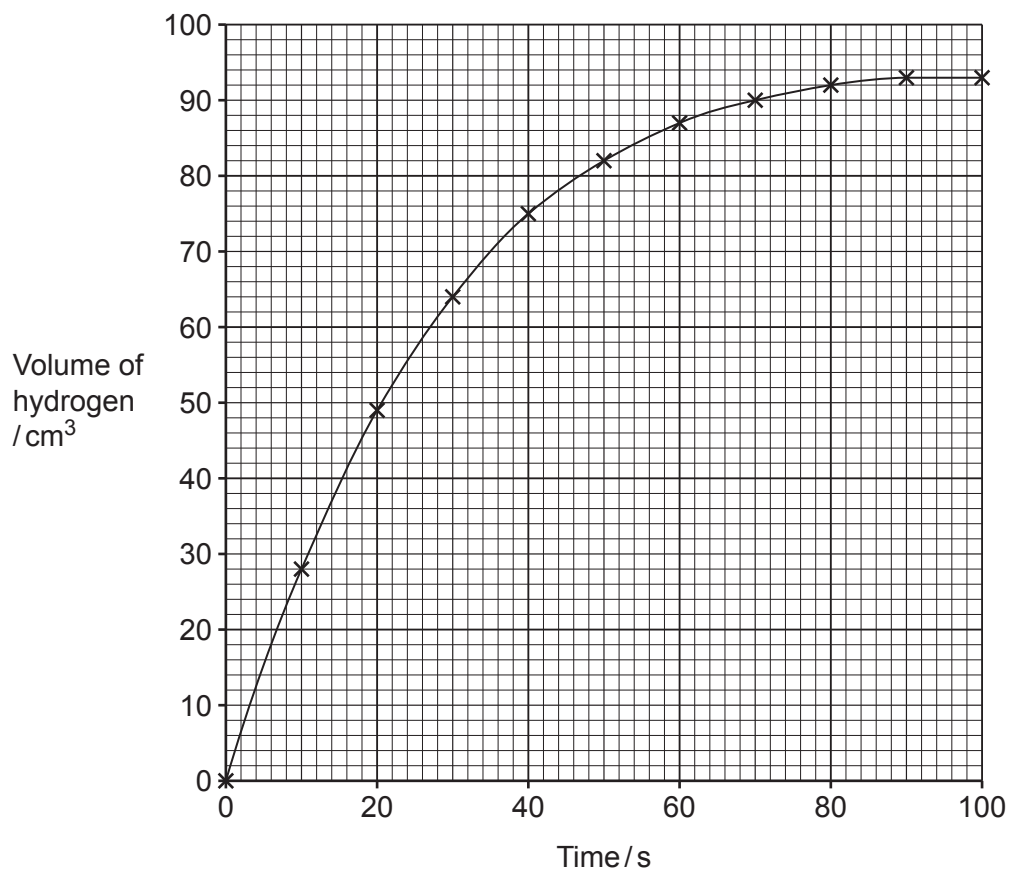
- A 5.75
- B 11.50
- C 23.00
- D 54.35

Your answer

A

[1]

- 5 The graph shows the volume of hydrogen released over time in a chemical reaction.



What is the rate of reaction, in cm^3s^{-1} , at 30 seconds?

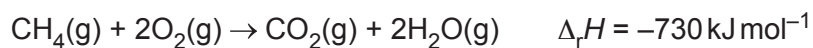
- A 0.8
- B 1.2
- C 2.1
- D 2.4

Your answer

B

[1]

- 6 Methane reacts with oxygen as shown in the equation:



The table shows some bond enthalpies.

Bond	O–H	O=O	C=O
Bond enthalpy / kJ mol^{-1}	+464	+498	+805

What is the bond enthalpy, in kJ mol^{-1} , of the C–H bond in methane?

- A +109
B +367
C +435
D +568

Your answer

C

[1]

- 7 The table below shows the boiling points of some hydrogen halides.

Hydrogen halide	Boiling point / K
HCl	188
HBr	206
HI	238

What is the best explanation for the trend in boiling points from HCl to HI?

- A The strength of the covalent bonds increases.
B The strength of the hydrogen bonds increases.
C The strength of the induced dipole–dipole interactions (London forces) increases.
D The strength of the permanent dipole–dipole interactions increases.

Your answer

C

[1]

- 8 The burette readings from an experiment are shown:

Final reading / cm ³	29.35
Initial reading / cm ³	2.60

The burette has an uncertainty of $\pm 0.05 \text{ cm}^3$.

What is the percentage uncertainty of the titre?

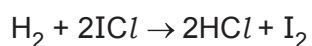
- A 0.17%
 B 0.19%
 C 0.34%
 D 0.37%

Your answer

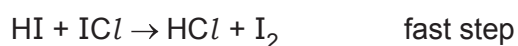
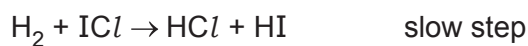
D

[1]

- 9 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 ?

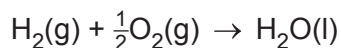
- A rate = $k[\text{HI}][\text{ICl}]$
 B rate = $k[\text{H}_2][\text{ICl}]$
 C rate = $k[\text{H}_2][\text{ICl}]^2$
 D rate = $k[\text{H}_2][\text{HI}][\text{ICl}]^2$

Your answer

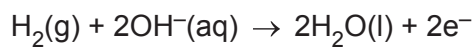
B

[1]

- 10 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?

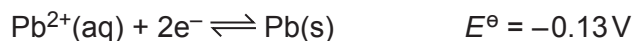
- A $\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + 2\text{e}^-$
 B $\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{OH}^-(\text{aq}) + 2\text{e}^-$
 C $\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow 2\text{OH}^-(\text{aq})$
 D $\text{O}_2(\text{g}) + 2\text{OH}^-(\text{aq}) + \text{H}_2(\text{g}) + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$

Your answer

C

[1]

- 11 Two redox systems are shown below.



Which species is the strongest reducing agent?

- A $\text{Mg}^{2+}(\text{aq})$
 B $\text{Mg}(\text{s})$
 C $\text{Pb}^{2+}(\text{aq})$
 D $\text{Pb}(\text{s})$

Your answer

B

[1]

- 12 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?

- A 4.29×10^{-3}
B 49
C 112
D 323

Your answer

C

[1]

- 13 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?

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

Your answer

C

[1]

14 Barium is in Group 2 of the periodic table.

Which statement(s) about barium is/are correct?

- 1** Its outer shell electrons are in an s-orbital.
- 2** It reacts more vigorously with water than magnesium.
- 3** It has a higher first ionisation energy than magnesium.

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

Your answer

B

[1]

15 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.

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

Your answer

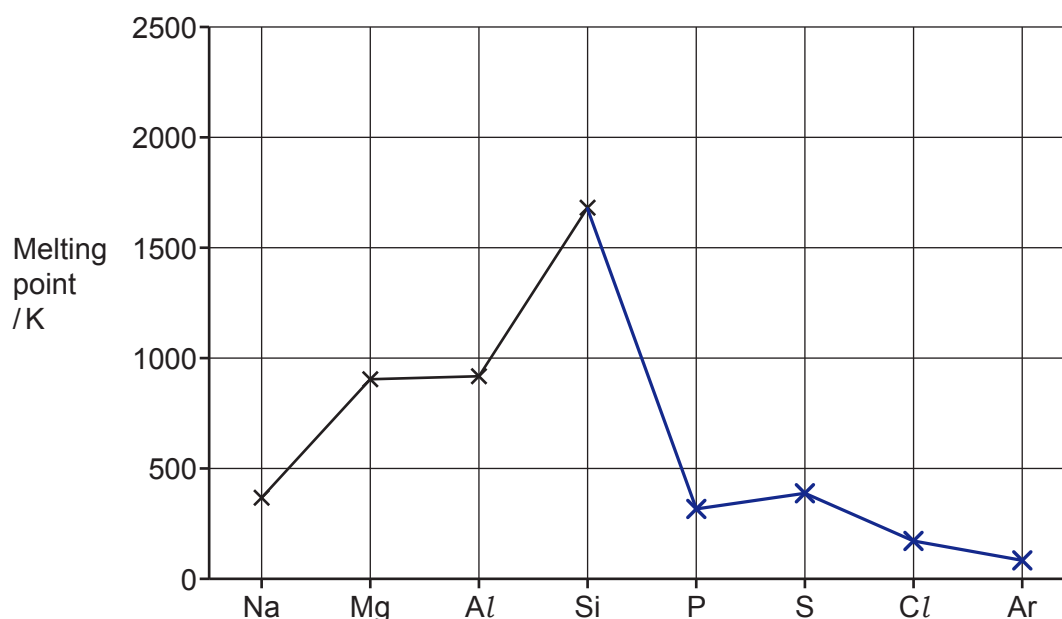
B

[1]

10
Section B

16 This question is about trends in the periodic table.

(a) The graph shows the melting points for Period 3 elements from sodium to silicon.



(i) Complete the graph to show approximate melting points for P, S, Cl and Ar. [2]

(ii) Explain why silicon has a higher melting point than aluminium.

Use ideas about structure and bonding in your answer.

Al has a giant metallic lattice: positive ions in a sea of delocalised electrons (metallic bonding). Si has a giant covalent (macromolecular) structure, each Si atom covalently bonded to 4 others. Covalent bonds in Si are stronger than metallic bonds in Al, so more energy is needed to break them.

[3]

(b) The table shows the first ionisation energies for the elements in Period 3.

Element	Na	Mg	Al	Si	P	S	Cl	Ar
First ionisation energy / kJ mol^{-1}	496	738	578	789	1012	1000	1251	1521

(i) Write an equation to represent the first ionisation energy of sulfur. Include state symbols.



(ii) The table shows that there is a general increase in first ionisation energies across Period 3, but that this trend is **not** followed by phosphorus to sulfur.

Explain why the first ionisation energy of sulfur is **lower** than the first ionisation energy of phosphorus.

In S ($3p^4$) two of the 3p electrons are paired in the same 3p orbital, but in P ($3p^3$) each 3p orbital has one unpaired electron.
The paired electrons in the 3p orbital repel each other, so less energy is needed to remove one of them.

..... [2]

(c) A student adds an aqueous solution of bromine, $\text{Br}_2(\text{aq})$, to two test tubes.

The student adds aqueous sodium iodide, $\text{NaI}(\text{aq})$, to the $\text{Br}_2(\text{aq})$ in one test tube, and aqueous sodium chloride, $\text{NaCl}(\text{aq})$, to the $\text{Br}_2(\text{aq})$ in the other test tube.

Complete the table to show the student's observations.

Write ionic equation(s) for any reaction(s) that take place.

Solutions	Observations
$\text{Br}_2(\text{aq}) + \text{NaI}(\text{aq})$	<i>orange solution turns brown</i> <i>(iodine, I_2, is formed)</i>
$\text{Br}_2(\text{aq}) + \text{NaCl}(\text{aq})$	<i>solution stays orange</i> <i>no colour change (no reaction)</i>

Ionic equation(s) *$\text{Br}_2 + 2\text{I}^- \rightarrow 2\text{Br}^- + \text{I}_2$*

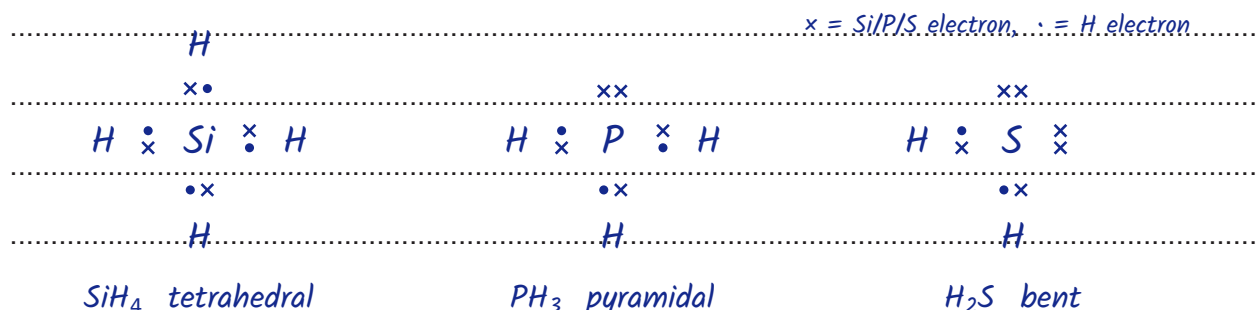
No reaction with Cl^- : Br_2 is a weaker oxidising agent than Cl_2 .

[3]

- (d)* The hydrides of silicon, phosphorus and sulfur have simple molecular structures, but their molecules have different shapes.

Explain why molecules of SiH_4 , PH_3 and H_2S have different shapes.

Your answer should include 'dot-and-cross' diagrams (outer shells only), the names of the shapes and an explanation of why the bond angles are different.



SiH_4 : 4 bonding pairs, no lone pairs. Electron pairs repel and get as far apart as possible, so SiH_4 is tetrahedral, 109.5° .

PH_3 : 3 bonding pairs and 1 lone pair, so (trigonal) pyramidal. Lone pairs repel more than bonding pairs, so the bond angle is smaller, about 107° .

H_2S : 2 bonding pairs and 2 lone pairs, so non-linear (bent / V-shaped). Two lone pairs repel even more, so the angle is smaller still, about 104.5° .

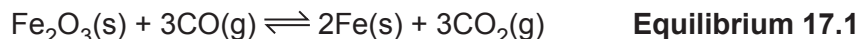
So bond angles decrease $\text{SiH}_4 > \text{PH}_3 > \text{H}_2\text{S}$: each extra lone pair repels more than a bonding pair, pushing the bonding pairs closer together, giving different shapes.

[6]

Additional answer space if required.

17 This question is about carbon monoxide and carbon as reducing agents in industry.

(a) Iron(III) oxide, Fe_2O_3 , can be reduced by carbon monoxide to form iron.



Some standard enthalpy change of formation, $\Delta_f H^\ominus$, and standard entropy, $S^\ominus$, values are shown in the table.

Substance	$\text{Fe}_2\text{O}_3(\text{s})$	$\text{CO}(\text{g})$	$\text{Fe}(\text{s})$	$\text{CO}_2(\text{g})$
$\Delta_f H^\ominus / \text{kJ mol}^{-1}$	-824	-111	0	-394
$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$	87	198	To calculate in part (a)(iv)	214

(i) Explain why the standard enthalpy change of formation of Fe has a value of 0 kJ mol^{-1} .

Fe is an element in its standard state, so no energy change: an element is formed from the same element. [1]

(ii) Calculate the enthalpy change, $\Delta_r H$, for the forward reaction in **Equilibrium 17.1**.

$$\begin{aligned} \Delta_r H &= \Sigma \Delta_f H(\text{products}) - \Sigma \Delta_f H(\text{reactants}) \\ &= [2(0) + 3(-394)] - [(-824) + 3(-111)] \\ &= (-1182) - (-1157) \end{aligned}$$

$$\Delta H = \dots\dots\dots -25 \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

(iii) Explain why the standard entropy of CO_2 is greater than the standard entropy of Fe_2O_3 .

Fe_2O_3 is a solid, whereas CO_2 is a gas.
Gas particles are far more disordered (move randomly), so there are more ways of arranging the particles and their energy in CO_2 , so its entropy is greater. [2]

- (iv) The standard entropy change, ΔS° , for the forward reaction in **Equilibrium 17.1** has a value of $+15 \text{ J K}^{-1} \text{ mol}^{-1}$.

Use data from the table to calculate the standard entropy, S° , of Fe.

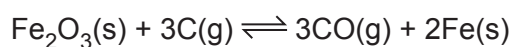
$$\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$$

$$15 = [2S(\text{Fe}) + 3(214)] - [87 + 3(198)]$$

$$15 = 2S(\text{Fe}) + 642 - 681, \text{ so } 2S(\text{Fe}) = 54$$

$$S^\circ = \dots\dots\dots 27 \dots\dots\dots \text{ J K}^{-1} \text{ mol}^{-1} \quad [2]$$

- (b) Carbon can also reduce $\text{Fe}_2\text{O}_3(\text{s})$ to iron as shown in **Equilibrium 17.2**.



Equilibrium 17.2

$$\Delta H = +491 \text{ kJ mol}^{-1}$$

$$\Delta S = +543 \text{ J K}^{-1} \text{ mol}^{-1}$$

The forward reaction is only feasible at high temperatures.

- Show that the forward reaction is **not** feasible at 100°C .
- Calculate the minimum temperature, in K, for the forward reaction to be feasible.

Give the minimum temperature to the nearest whole number.

$$\text{At } 100^\circ\text{C}, T = 373 \text{ K}; \quad \Delta S = +543 \text{ J K}^{-1} \text{ mol}^{-1} = +0.543 \text{ kJ K}^{-1} \text{ mol}^{-1}$$

$$\Delta G = \Delta H - T\Delta S = 491 - (373 \times 0.543)$$

$$\Delta G = 491 - 202.5 = +288 \text{ kJ mol}^{-1}$$

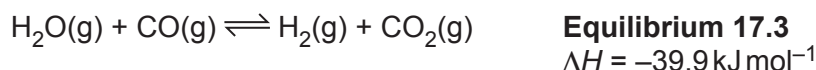
$\Delta G > 0$, so the forward reaction is not feasible at 100°C .

Feasible when $\Delta G \leq 0$, so the minimum T is when $\Delta G = 0$:

$$T = \Delta H \div \Delta S = 491 \div 0.543 = 904.2 \text{ K}$$

$$T = \dots\dots\dots 904 \dots\dots\dots \text{ K} \quad [3]$$

- (c) Steam can be reduced by carbon monoxide in a reversible reaction.



At 700 K the value of K_p is 8.13.

- (i) Explain why K_p for **Equilibrium 17.3** has no units.

There are equal numbers of moles of gas on each side, so the pressure units cancel: $K_p = p(\text{H}_2) p(\text{CO}_2) \div p(\text{H}_2\text{O}) p(\text{CO})$, $\text{kPa}^2 \div \text{kPa}^2$.

[1]

- (ii) An equal number of moles of steam and carbon monoxide are left at 700 K in a sealed container until equilibrium is reached.

At equilibrium, both H_2 and CO_2 have a partial pressure of 211 kPa.

Calculate the partial pressures of H_2O and CO at equilibrium.

$$K_p = p(\text{H}_2) \times p(\text{CO}_2) \div (p(\text{H}_2\text{O}) \times p(\text{CO}))$$

Equal moles of H_2O and CO react 1 : 1, so $p(\text{H}_2\text{O}) = p(\text{CO}) = x$

$$x^2 = (211 \times 211) \div 8.13 = 5476.1$$

$$x = \sqrt{5476.1} = 74.0 \text{ kPa}$$

Partial pressure of H_2O = ... 74.0 kPa

Partial pressure of CO = ... 74.0 kPa
[3]

- (iii) At a second temperature the value of K_p for **Equilibrium 17.3** is 129.

Explain whether the second temperature is higher or lower than 700 K.

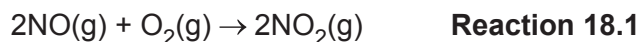
Lower than 700 K. The forward reaction is exothermic, so lowering the temperature shifts the equilibrium position to the right, so K_p increases (8.13 to 129).

[2]

DO NOT WRITE ON THIS PAGE

Turn over for the next question

18 Nitrogen monoxide, NO, reacts with oxygen to form nitrogen dioxide, NO₂.



(a) The rate of reaction increases in the presence of a heterogeneous platinum catalyst.

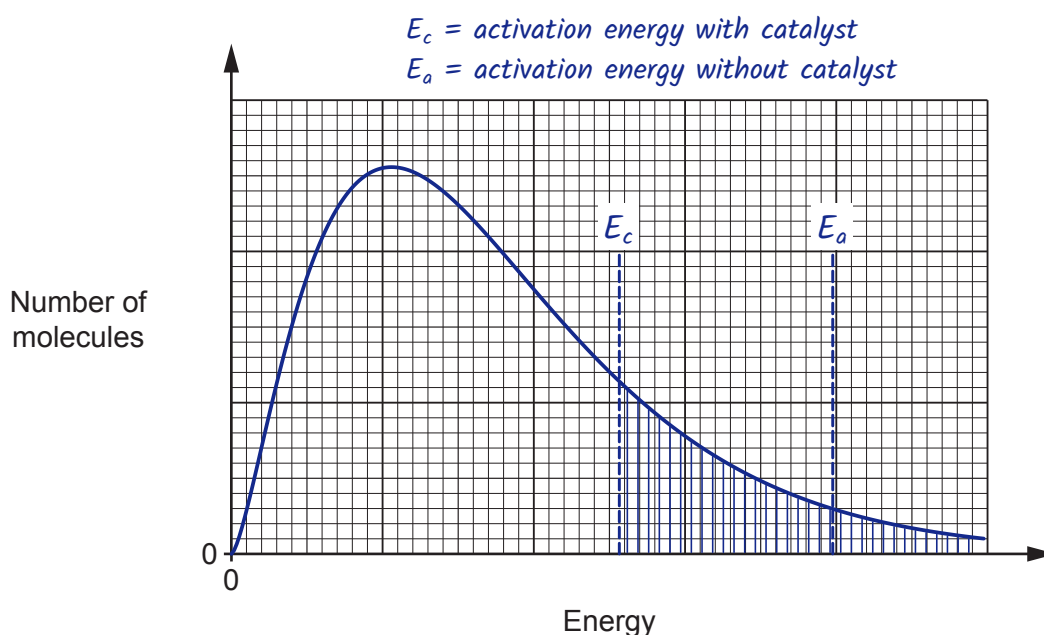
(i) Explain why platinum is an example of a *heterogeneous* catalyst for **Reaction 18.1**.

Pt is in a different phase (solid) from the reactants, which are gases.

[1]

(ii) Explain how the platinum catalyst increases the rate of reaction.

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



The catalyst provides an alternative reaction pathway with a lower activation energy (E_c instead of E_a).

So a greater proportion of molecules have energy greater than or equal to the activation energy (shaded area), so more collisions are successful.

[2]

(iii) In industry, catalysts have great economic importance and benefits for increased sustainability.

Explain how the use of catalysts is beneficial to the environment.

Reactions can be run at lower temperatures, so less energy is needed and less fossil fuel is burnt, reducing CO₂ emissions.

[1]

- (b) The following data was obtained in a series of experiments on the rate of the reaction for **Reaction 18.1** at a constant temperature.

Experiment	[NO]/mol dm ⁻³	[O ₂]/mol dm ⁻³	rate/mol dm ⁻³ s ⁻¹
1	0.040	0.035	7.45×10^{-4}
2	0.040	0.070	1.49×10^{-3}
3	0.060	0.035	1.68×10^{-3}

Determine the orders with respect to NO and O₂. Explain your reasoning.

Determine the rate equation and calculate the rate constant, k , including units.

Experiments 1 and 2: [NO] stays the same and [O₂] doubles ($\times 2$); the rate also doubles (7.45×10^{-4} to 1.49×10^{-3} , $\times 2$), so the reaction is 1st order with respect to O₂.

Experiments 1 and 3: [O₂] stays the same and [NO] increases $\times 1.5$; the rate increases $\times 2.25$ ($1.68 \times 10^{-3} \div 7.45 \times 10^{-4}$). As $1.5^2 = 2.25$, the reaction is 2nd order with respect to NO.

Rate equation: $\text{rate} = k[\text{NO}]^2[\text{O}_2]$

$k = \text{rate} \div ([\text{NO}]^2[\text{O}_2]) = 7.45 \times 10^{-4} \div (0.040^2 \times 0.035)$

$k = 7.45 \times 10^{-4} \div 5.6 \times 10^{-5} = 13.3$

units = $\text{mol dm}^{-3} \text{ s}^{-1} \div (\text{mol dm}^{-3})^3 = \text{dm}^6 \text{ mol}^{-2} \text{ s}^{-1}$

$k = 13.3$ units $\text{dm}^6 \text{ mol}^{-2} \text{ s}^{-1}$

[5]

- (c) The rate constant varies with temperature, according to the Arrhenius equation.

A technician determines the activation energy for **Reaction 18.1** by determining the rate constant, k , at different temperatures.

The table shows the technician's results.

Temperature /K	$\frac{1}{T}/\text{K}^{-1}$	k	$\ln k$
1500	6.7×10^{-4}	1.81×10^3	7.50
1750	5.7×10^{-4}	8.51×10^4	11.4.....
2000	5.0×10^{-4}	2.79×10^5	12.5
2250	4.4×10^{-4}	1.47×10^6	14.2
2500	4.0×10^{-4}	5.70×10^6	15.6

- (i) Complete the table by adding the missing value of $\ln k$.

[1]

- (ii) Plot a graph of $\ln k$ against $\frac{1}{T}$ on the grid opposite.

Use your graph to calculate the value of the activation energy, E_a , in kJ mol^{-1} .

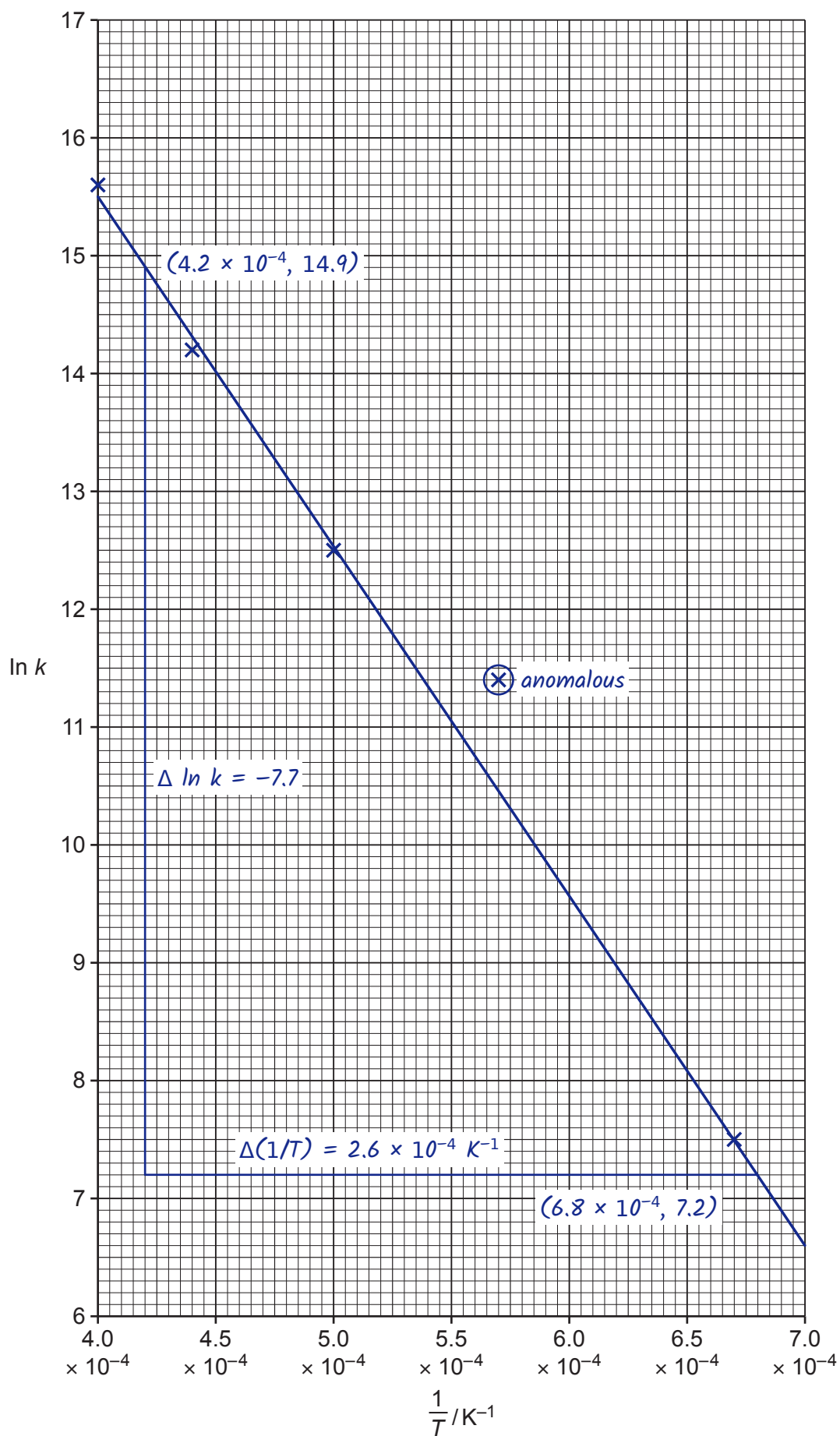
Give your answer to **2** significant figures.

$$\ln k = \ln A - E_a/RT, \text{ so gradient} = -E_a/R$$

$$\text{gradient} = (7.2 - 14.9) \div ((6.8 - 4.2) \times 10^{-4}) = -2.96 \times 10^4 \text{ K}$$

$$E_a = 2.96 \times 10^4 \times 8.314 = 2.46 \times 10^5 \text{ J mol}^{-1} = 246 \text{ kJ mol}^{-1}$$

$$E_a = \dots\dots\dots 250 \dots\dots\dots \text{ kJ mol}^{-1} \text{ [4]}$$



19 This question is about monobasic acids and buffer solutions.

(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.

$$\text{pH} = -\log[\text{H}^+] = -\log(0.150)$$

$$\text{pH} = \dots\dots\dots 0.82 \dots\dots\dots [1]$$

(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 .

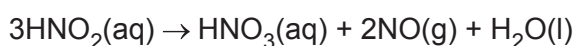
Explain your answer.

Prediction *higher*

Explanation *HNO_3 fully dissociates but HNO_2 only partially dissociates (ionises),
so HNO_2 has a lower concentration of H^+ ions, so its pH is higher.*

..... [2]

(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.

Disproportionation is the simultaneous oxidation and reduction of the same element in one reaction.

Oxidation numbers of N: +3 in HNO_2 , +5 in HNO_3 , +2 in NO

N is oxidised from +3 (in HNO_2) to +5 (in HNO_3).

N is reduced from +3 (in HNO_2) to +2 (in NO).

So nitrogen is both oxidised and reduced: disproportionation.

..... [3]

- (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 $0.180 \text{ mol dm}^{-3}$ $\text{CH}_3\text{CH}_2\text{COOH(aq)}$ with a calculated mass of $\text{CH}_3\text{CH}_2\text{COONa(s)}$. 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.

$$[\text{H}^+] = 10^{-\text{pH}} = 10^{-4.85} = 1.41 \times 10^{-5} \text{ mol dm}^{-3}$$

$$K_a = [\text{H}^+][\text{CH}_3\text{CH}_2\text{COO}^-] \div [\text{CH}_3\text{CH}_2\text{COOH}]$$

$$[\text{CH}_3\text{CH}_2\text{COO}^-] = K_a \times [\text{CH}_3\text{CH}_2\text{COOH}] \div [\text{H}^+] = (1.32 \times 10^{-5} \times 0.180) \div$$

$$1.41 \times 10^{-5} = 0.168 \text{ mol dm}^{-3}$$

$$n(\text{CH}_3\text{CH}_2\text{COONa}) = n(\text{CH}_3\text{CH}_2\text{COO}^-) = 0.168 \times 125 \div 1000 = 0.0210 \text{ mol}$$

$$M(\text{CH}_3\text{CH}_2\text{COONa}) = 3(12.0) + 5(1.0) + 2(16.0) + 23.0 = 96.0 \text{ g mol}^{-1}$$

$$\text{mass} = 0.0210 \times 96.0 = 2.02 \text{ g}$$

In the buffer: $\text{CH}_3\text{CH}_2\text{COOH} \rightleftharpoons \text{H}^+ + \text{CH}_3\text{CH}_2\text{COO}^-$, with large reservoirs of the weak acid and its conjugate base.

When a small amount of alkali is added, OH^- reacts with H^+ : $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$

(or $\text{CH}_3\text{CH}_2\text{COOH} + \text{OH}^- \rightarrow \text{CH}_3\text{CH}_2\text{COO}^- + \text{H}_2\text{O}$).

The equilibrium shifts to the right as more $\text{CH}_3\text{CH}_2\text{COOH}$ dissociates, restoring

$[\text{H}^+]$. The ratio $[\text{CH}_3\text{CH}_2\text{COOH}] \div [\text{CH}_3\text{CH}_2\text{COO}^-]$ changes very little, so the pH

hardly changes.

[6]

Additional answer space if required.

20 Standard electrode potentials for seven redox systems are shown in the table below.

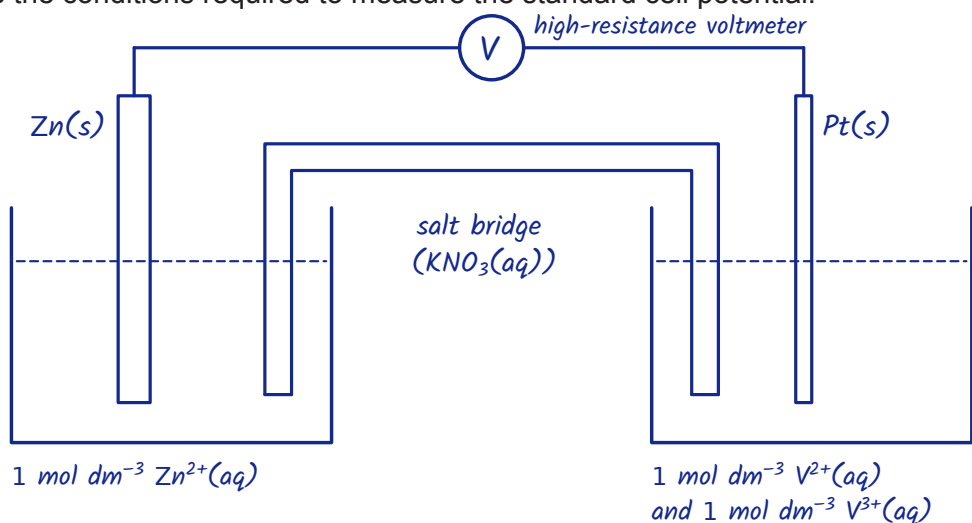
Redox system	Half-equation	$E^\ominus/\text{V}$
1	$\text{V}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{V}(\text{s})$	-1.18
2	$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
3	$\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Co}(\text{s})$	-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

(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 298 K (25 °C); 1 mol dm⁻³ Zn²⁺(aq),
and V²⁺(aq) and V³⁺(aq) both 1 mol dm⁻³ (equal concentrations); 100 kPa.

[4]

(ii) Calculate the standard cell potential of this cell.

$$E^\ominus_{\text{cell}} = (-0.26) - (-0.76)$$

standard cell potential = +0.50 V [1]

- (b) A student predicts that cobalt metal will reduce acidified VO^{2+} ions to form V^{2+} ions in two stages.

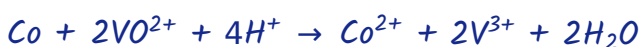
Explain why this two-stage reduction should happen in terms of electrode potentials and equilibria shifts.

Include overall equations for the predicted reactions.

$E^\ominus$ of Co^{2+}/Co (system 3, -0.28 V) is more negative than $E^\ominus$ of $\text{VO}^{2+}/\text{V}^{3+}$

(system 5, $+0.34 \text{ V}$) and also more negative than $E^\ominus$ of $\text{V}^{3+}/\text{V}^{2+}$ (system 4, -0.26 V).

Stage 1: system 3 shifts to the left ($\text{Co} \rightarrow \text{Co}^{2+} + 2\text{e}^-$) and system 5 shifts to the right, reducing VO^{2+} to V^{3+} ($E_{\text{cell}} = +0.62 \text{ V}$):



Stage 2: system 3 is still more negative than system 4, so system 3 shifts left and system 4 shifts right, reducing V^{3+} to V^{2+} ($E_{\text{cell}} = +0.02 \text{ V}$):



V^{2+} is not reduced to V , as $E^\ominus(\text{V}^{2+}/\text{V}) = -1.18 \text{ V}$ is more negative than -0.28 V .

[4]

21 This question is about reactions of compounds of iron and copper.

(a)

(i) Complete the electron configuration of

an Fe atom: $1s^2$ $2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$

a Cu^{2+} ion: $1s^2$ $2s^2 2p^6 3s^2 3p^6 3d^9$

[2]

(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.

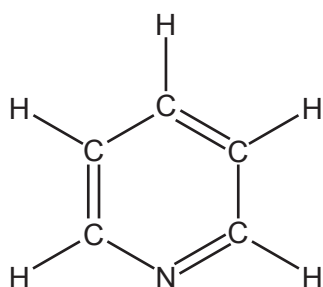
Observation with $\text{FeSO}_4\text{(aq)}$ green precipitate

Observation with $\text{CuSO}_4\text{(aq)}$ pale blue precipitate

[2]

(b) 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.



(i) What is meant by a **monodentate ligand**?

A ligand that donates one lone pair of electrons to the metal ion, forming one coordinate (dative covalent) bond.

[1]

- (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.

$$\text{Fe} : \text{C} : \text{H} : \text{N} : \text{Cl} = 12.6/55.8 : 54.3/12.0 : 4.5/1.0 : 12.6/14.0 : 16.0/35.5$$

$$= 0.226 : 4.525 : 4.5 : 0.900 : 0.451$$

$$\div 0.226: \quad 1 : 20 : 20 : 4 : 2$$

$$\text{Empirical formula mass} = 55.8 + 240.0 + 20.0 + 56.0 + 71.0 = 442.8$$

$$= \text{molar mass, so molecular formula} = \text{FeC}_{20}\text{H}_{20}\text{N}_4\text{Cl}_2$$

1 N per $\text{C}_5\text{H}_5\text{N}$, so 4 N means 4 pyridine ligands

4 $\text{C}_5\text{H}_5\text{N}$ + 2 Cl^- = 6 monodentate ligands, so 6 coordinate bonds

Empirical formula of iron(II) complex $\text{FeC}_{20}\text{H}_{20}\text{N}_4\text{Cl}_2$

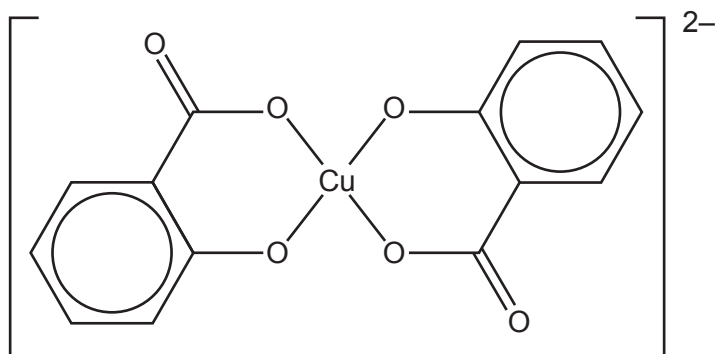
Number of $\text{C}_5\text{H}_5\text{N}$ ligands 4

Coordination number of iron(II) ion 6

[4]

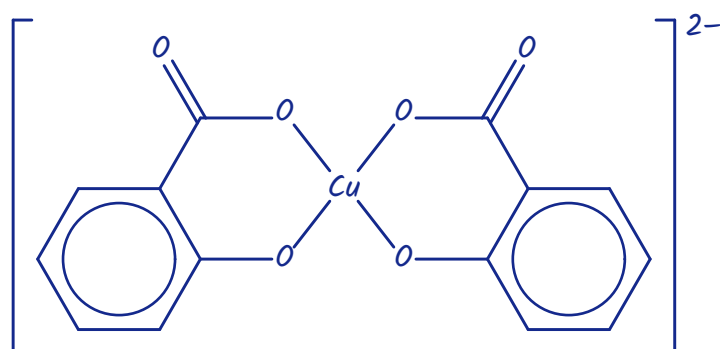
- (c) Aqueous copper(II) sulfate reacts with salicylic acid to form a complex ion which has two stereoisomers.

One isomer of the complex ion is shown:



Draw the other stereoisomer of the complex.

Identify the type of stereoisomerism shown by the complexes.



cis isomer

Type of stereoisomerism *cis-trans (geometric) isomerism*..... [2]

29
BLANK PAGE

DO NOT WRITE ON THIS PAGE

Question 21(d) starts on Page 30

- (d) **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, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$.

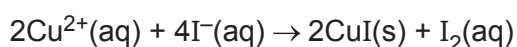
A student carries out a titration to determine the percentage by mass of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in **Mixture A**.

The student uses the following method.

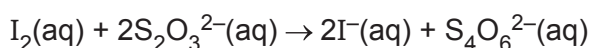
Step 1 Dissolve 9.51 g of **Mixture A** in water and make up the solution to 250.0 cm^3 in a volumetric flask.

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

- (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.

$$n(\text{S}_2\text{O}_3^{2-}) = 0.0800 \times 31.15 \div 1000 = 2.492 \times 10^{-3} \text{ mol}$$

$$n(\text{I}_2) = 2.492 \times 10^{-3} \div 2 = 1.246 \times 10^{-3} \text{ mol}$$

$$n(\text{Cu}^{2+}) \text{ in } 25.0 \text{ cm}^3 = 2 \times 1.246 \times 10^{-3} = 2.492 \times 10^{-3} \text{ mol}$$

$$n(\text{Cu}^{2+}) \text{ in } 250.0 \text{ cm}^3 = 2.492 \times 10^{-3} \times 10 = 2.492 \times 10^{-2} \text{ mol}$$

$$M(\text{CuSO}_4 \cdot 5\text{H}_2\text{O}) = 63.5 + 32.1 + 4(16.0) + 5(18.0) = 249.6 \text{ g mol}^{-1}$$

$$\text{mass of } \text{CuSO}_4 \cdot 5\text{H}_2\text{O} = 2.492 \times 10^{-2} \times 249.6 = 6.220 \text{ g}$$

$$\% = 6.220 \div 9.51 \times 100 = 65.4\%$$

Percentage of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in **Mixture A** = ... **65.4** % [5]

- (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 .

Fe^{3+} ions oxidise iodide ions to iodine ($2\text{Fe}^{3+} + 2\text{I}^- \rightarrow 2\text{Fe}^{2+} + \text{I}_2$), so more I_2 is formed and more thiosulfate is needed to react with it.

[1]

END OF QUESTION PAPER

[illegible]

Oxford Cambridge and RSA

OCR is committed to seeking permission to reproduce all third-party content that it uses in its assessment materials. OCR has attempted to identify and contact all copyright holders whose work is used in this paper. To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced in the OCR Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download from our public website (www.ocr.org.uk) after the live examination series.

For queries or further information please contact The OCR Copyright Team, The Triangle Building, Shaftesbury Road, Cambridge CB2 8EA.

© OCR 2025