



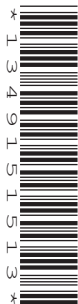
Oxford Cambridge and RSA

Monday 10 June 2024 – 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

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Candidate number

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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 pages 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.

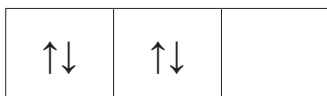
- 1** Oxygen has the electron configuration $1s^2 2s^2 2p^4$.

How are the electrons in an atom of oxygen arranged in the p-orbitals?

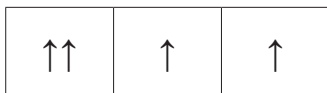
A



B



C



D



Your answer

D

[1]

- 2** Water has the anomalous properties below.

- Water has relatively high melting and boiling points.
- Ice is less dense than water.

Which statement explains these anomalous properties?

A The covalent bonding within water molecules.

B The hydrogen bonding between water molecules.

C The induced dipole–dipole interactions (London forces) between water molecules.

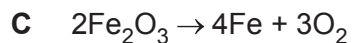
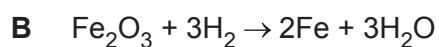
D The ionic bonding between water molecules.

Your answer

B

[1]

- 3 Which chemical process is the most sustainable in terms of the atom economy of the iron produced?



Your answer

C

[1]

- 4 Which compounds of magnesium can be used as 'antacids'?

A Chlorides

B Hydroxides

C Nitrates

D Sulfates

Your answer

B

[1]

- 5 Which statement explains the trend in boiling points down the halogens group?

A The bond enthalpy of the covalent bonds increases.

B The halogens become less electronegative.

C The induced dipole–dipole interactions (London forces) become stronger.

D The reactivity of the halogens decreases.

Your answer

C

[1]

6 Which equation does **not** represent a disproportionation reaction?

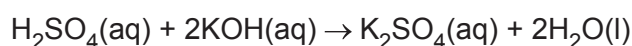
- A $\text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HClO} + \text{HCl}$
- B $\text{Cl}_2 + 2\text{NaOH} \rightarrow \text{NaClO} + \text{NaCl} + \text{H}_2\text{O}$
- C $4\text{KClO}_3 \rightarrow \text{KCl} + 3\text{KClO}_4$
- D $4\text{HCl} + \text{MnO}_2 \rightarrow \text{MnCl}_2 + \text{Cl}_2 + 2\text{H}_2\text{O}$

Your answer

D

[1]

7 The equation for the reaction of sulfuric acid with potassium hydroxide is shown below.



25 cm³ of 1.00 mol dm⁻³ H₂SO₄ is reacted with excess KOH.
The energy given out is 2.8 kJ.

What is the enthalpy change of neutralisation, in kJ mol⁻¹?

- A -56
- B -70
- C -112
- D -224

Your answer

A

[1]

8 Which row in the table explains how a catalyst affects the activation energy (E_a) and the proportion of molecules with energy $> E_a$?

	How the activation energy changes	Proportion of molecules with energy $> E_a$
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

Your answer

B

[1]

- 9 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?

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

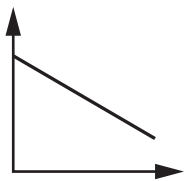
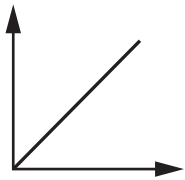
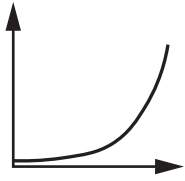
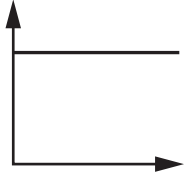
Your answer

B

[1]

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

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

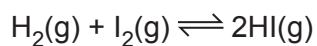
A	
B	
C	
D	

Your answer

D

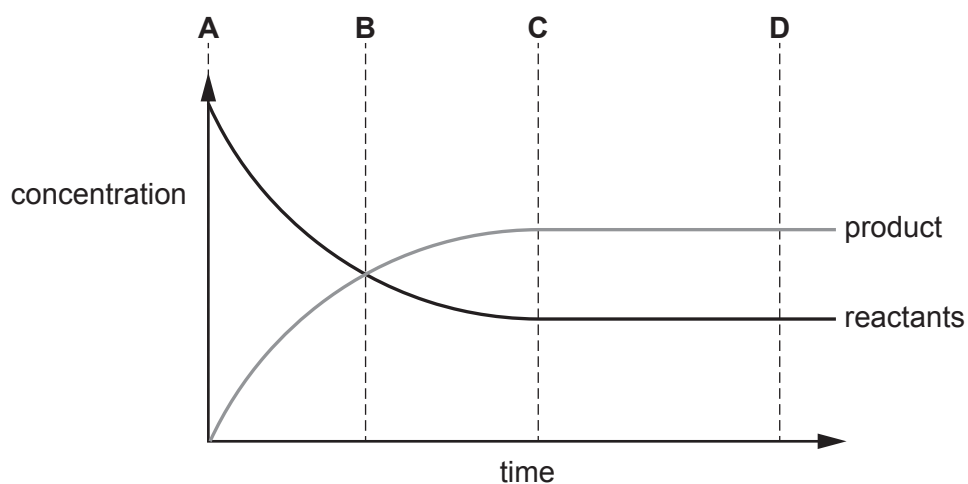
[1]

- 11 The reversible reaction between hydrogen and iodine to form hydrogen iodide is



The graph shows how the concentrations of the reactants and product change as the reaction reaches a dynamic equilibrium.

At which point on the graph is the equilibrium reached?



Your answer

C

[1]

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

- A $\text{CH}_3\text{COONa}(\text{aq})$
- B $\text{HCOOH}(\text{aq})$
- C $\text{HCl}(\text{aq})$
- D $\text{NaCl}(\text{aq})$

Your answer

A

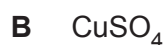
[1]

13 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?



Your answer

D

[1]

14 Chlorine has the electron configuration [Ne]3s²3p⁵.

Which statement(s) about chlorine is/are correct when it reacts in redox reactions?

1 It can gain one electron to form 1– ions.

2 It can lose its 3s² electrons to form 2+ ions.

3 It can lose its 3p⁵ electrons to form 5+ ions.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer

D

[1]

15 Which statement(s) about elements in the periodic table is/are correct?

- 1** The position of an element is determined by its relative atomic mass.
- 2** The elements in a group have similar chemical properties.
- 3** Transition elements are used as catalysts in the manufacture of chemicals.

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

Your answer

C

[1]

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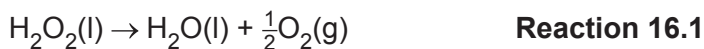
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Turn over for Section B

10
SECTION B

16 This question is about energy changes.

Hydrogen peroxide decomposes as shown in **Reaction 16.1**.



(a) The table shows enthalpy changes of formation and entropies.

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

(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.

$$\Delta H = -286 - (-188) = -98 \text{ kJ mol}^{-1}$$

$$\Delta S = 70.0 + \frac{1}{2}(205) - 110 = +62.5 \text{ J K}^{-1} \text{mol}^{-1}$$

$$= +0.0625 \text{ kJ K}^{-1} \text{mol}^{-1}$$

$$T = 25 + 273 = 298 \text{ K}$$

$$\Delta G = \Delta H - T\Delta S = -98 - (298 \times 0.0625)$$

$$\Delta G = -98 - 18.6 = -116.6 = -117 \text{ kJ mol}^{-1}$$

$$\Delta G = \dots\dots\dots -117 \dots\dots\dots \text{kJ mol}^{-1} \quad [4]$$

(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.

The activation energy is very high, so the rate of reaction is extremely slow at 25 °C. (ΔG takes no account of the rate of reaction).

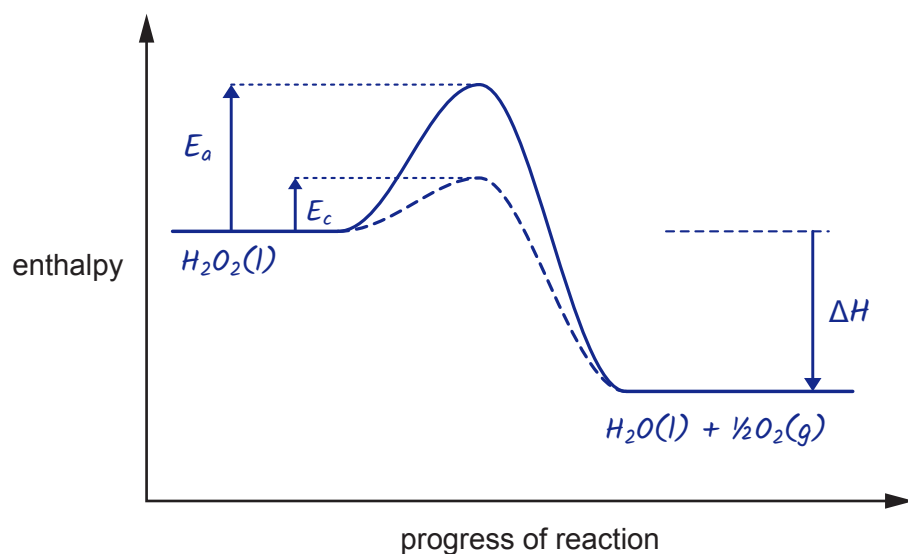
.....
..... [1]

- (b) 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.

- (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]

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

*..MnO₂ is in a different phase from the reactant; the catalyst is a solid and the
H₂O₂ is a liquid.*

[1]

- (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 .

..Mn is +2 and +3

[1]

- (c) 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 .

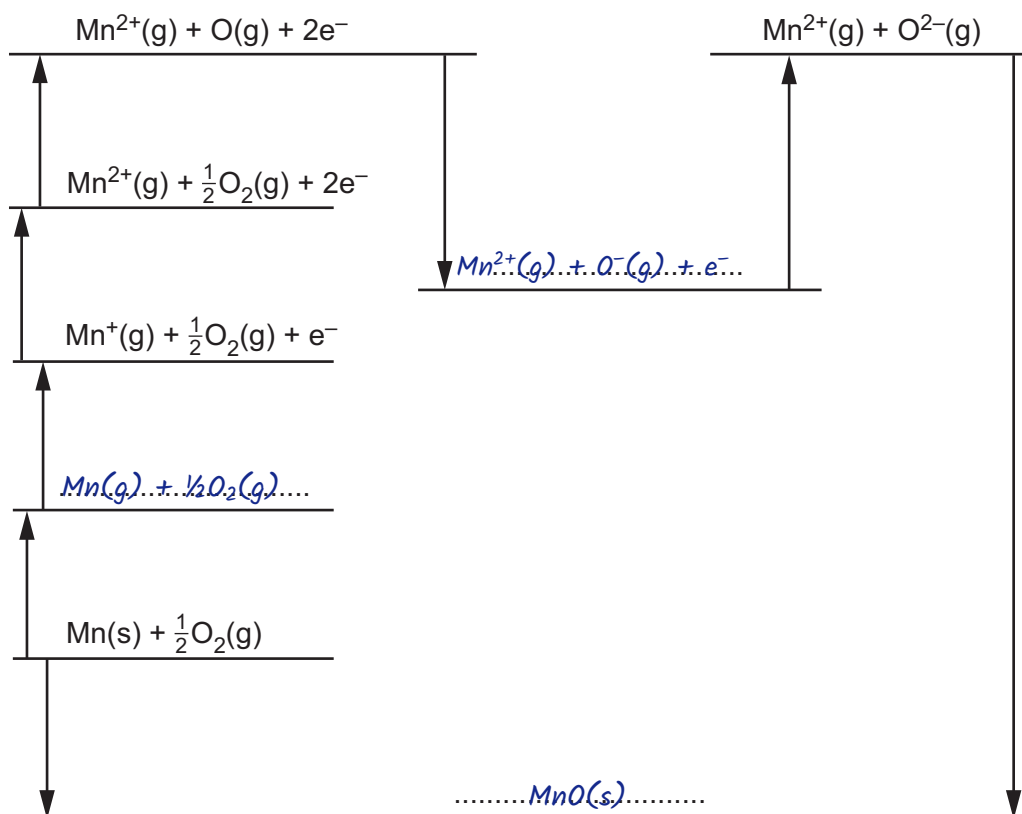
	enthalpy change / kJ mol^{-1}
atomisation of manganese	+281
atomisation of oxygen	+249
first ionisation energy of manganese	+717
second ionisation energy of manganese	+1509
first electron affinity of oxygen	-141
second electron affinity of oxygen	+798
formation of manganese(II) oxide	-385

- (i) Define the term **lattice enthalpy**.

*The enthalpy change when 1 mole of an ionic compound is formed from its
gaseous ions (under standard conditions)*

[2]

- (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]

- (iii) Calculate the lattice enthalpy of MnO.

$$\Delta H_f = \text{sum of other steps} + \text{lattice enthalpy}$$

$$\text{lattice enthalpy} = -385 - (281 + 249 + 717 + 1509 - 141 + 798)$$

$$= -385 - 3413$$

$$= -3798 \text{ kJ mol}^{-1}$$

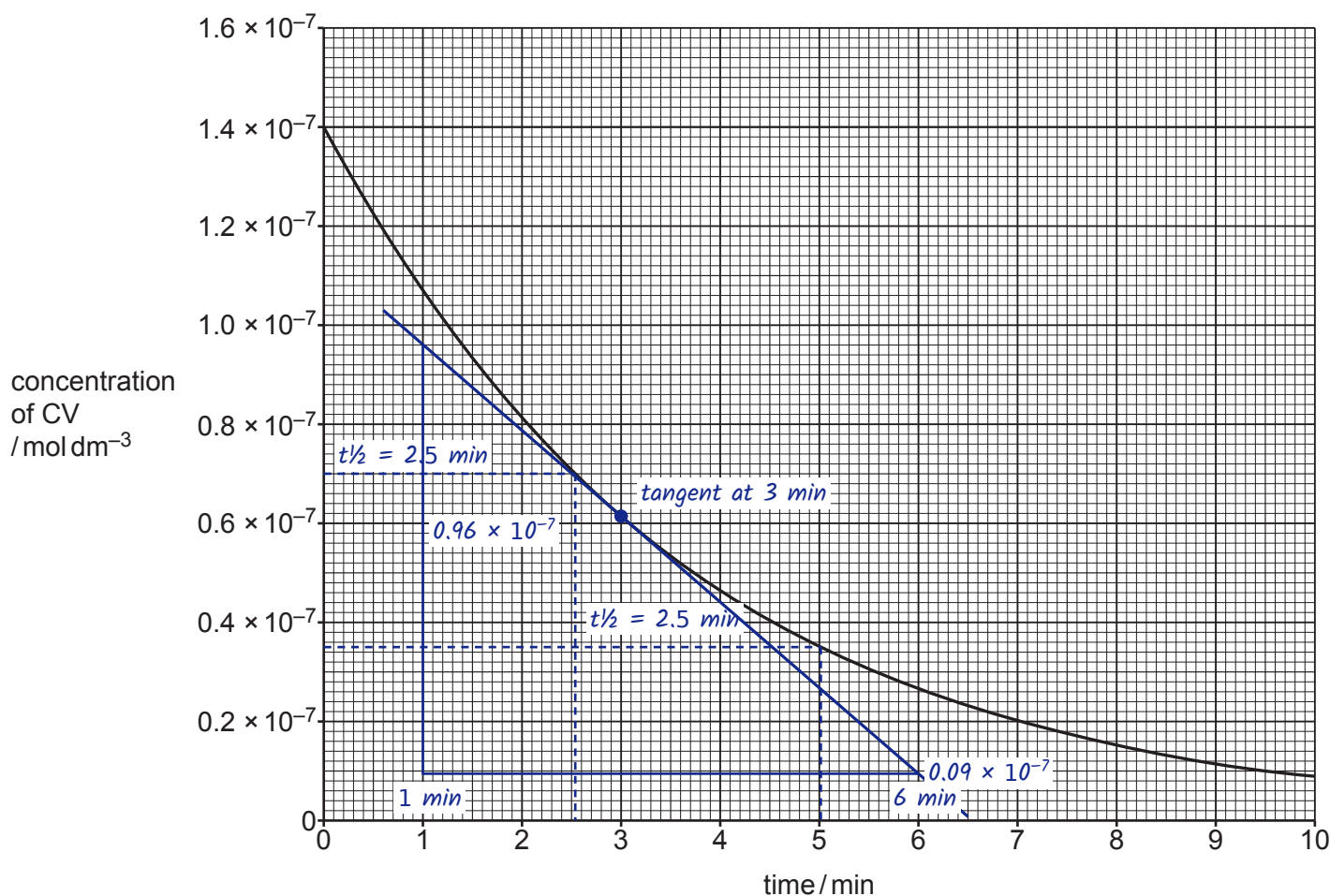
$$\text{lattice enthalpy} = \dots\dots\dots -3798 \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

- 17 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.



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

Over time the concentration of CV decreases (fewer particles per unit volume),
so collisions become less frequent and the rate decreases.

[1]

- (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]

Order: [CV] falls from 1.40×10^{-7} to $0.70 \times 10^{-7} \text{ mol dm}^{-3}$ in 2.5 min, then from 0.70×10^{-7} to $0.35 \times 10^{-7} \text{ mol dm}^{-3}$ in a further 2.5 min (shown on the graph).

The half-life is constant (2.5 min), so the reaction is first order with respect to CV.

Rate at 3 min: a tangent is drawn to the curve at $t = 3 \text{ min}$, where $[\text{CV}] = 0.61 \times 10^{-7} \text{ mol dm}^{-3}$.

gradient = $(0.96 \times 10^{-7} - 0.09 \times 10^{-7}) \div (6 - 1) = 1.74 \times 10^{-8}$

rate at 3 min = $1.7 \times 10^{-8} \text{ mol dm}^{-3} \text{ min}^{-1}$

Rate constant: rate = $k[\text{CV}]$, so $k = \text{rate} \div [\text{CV}]$

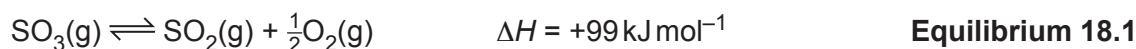
$k = 1.74 \times 10^{-8} \div 0.61 \times 10^{-7} = 0.28 \text{ min}^{-1}$

Check using the half-life: $k = \ln 2 \div t_{1/2} = 0.693 \div 2.5 = 0.28 \text{ min}^{-1}$ ($= 4.6 \times 10^{-3} \text{ s}^{-1}$), which agrees.

Extra answer space if required.

18 This question is about two oxides of sulfur: sulfur dioxide, SO_2 , and sulfur trioxide, SO_3 .

(a) SO_3 decomposes to form SO_2 and O_2 , as shown in **Equilibrium 18.1**.



(i) 2.25 moles of SO_3 is heated to 550°C in the presence of a catalyst and the resulting mixture allowed to reach equilibrium.

The equilibrium mixture contains 0.900 mol of SO_2 and the total pressure is 2.80 atm.

Calculate the numerical value for K_p for **Equilibrium 18.1** under these conditions and state the units of K_p .

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

$$n(\text{SO}_2) = 0.900 \text{ mol}, \quad n(\text{O}_2) = 0.900 \div 2 = 0.450 \text{ mol}$$

$$n(\text{SO}_3) = 2.25 - 0.900 = 1.35 \text{ mol}$$

$$n(\text{total}) = 1.35 + 0.900 + 0.450 = 2.70 \text{ mol}$$

$$p(\text{SO}_3) = (1.35 \div 2.70) \times 2.80 = 1.40 \text{ atm}$$

$$p(\text{SO}_2) = (0.900 \div 2.70) \times 2.80 = 0.933 \text{ atm}$$

$$p(\text{O}_2) = (0.450 \div 2.70) \times 2.80 = 0.467 \text{ atm}$$

$$K_p = \frac{p(\text{SO}_2) \times p(\text{O}_2)^{1/2}}{p(\text{SO}_3)}$$

$$K_p = \frac{0.933 \times (0.467)^{1/2}}{1.40} = 0.4555 = 0.455 \text{ (3 s.f.)}$$

$$\text{units: } \frac{\text{atm} \times \text{atm}^{1/2}}{\text{atm}} = \text{atm}^{1/2}$$

$$K_p = \dots\dots\dots 0.455 \dots\dots\dots$$

$$\text{units } \dots\dots\dots \text{atm}^{1/2} \dots\dots\dots \text{[5]}$$

- (ii) The numerical values of K_p for **Equilibrium 18.1** at temperatures T_1 and T_2 are shown below.

Temperature	K_p
T_1	3.3×10^{-5}
T_2	7.7×10^{-2}

Explain why T_2 is a higher temperature than T_1 .

*The forward reaction is endothermic ($\Delta H = +99 \text{ kJ mol}^{-1}$).
 Increasing the temperature shifts the equilibrium to the right (towards the products), so K_p increases.
 K_p at T_2 (7.7×10^{-2}) is greater than at T_1 (3.3×10^{-5}), so T_2 is the higher temperature.* [2]

- (iii) Suggest how the value of K_p would change if the reaction was repeated with no catalyst added and the pressure of the system increased.

Tick (✓) one box in each row.

Change	Decrease	No change	Increase
No catalyst		✓	
Increased pressure		✓	

[2]

- (b) SO_2 and SO_3 both have molecules with sulfur in the centre and bond angles of approximately 120° .

- (i) Explain why the bond angles in SO_3 are 120° .

There are 3 regions of electron density (3 double bonds) around S and no lone pairs; these repel equally, as far apart as possible (trigonal planar). [1]

- (ii) Explain why both SO_2 and SO_3 have polar bonds, but only SO_2 has polar molecules.

*Oxygen is more electronegative than sulfur, so the S-O bonds are polar ($\text{S}^{\delta+}-\text{O}^{\delta-}$).
 SO_2 has a lone pair on S, so it is bent (non-linear) and asymmetrical; the dipoles do not cancel.
 SO_3 is trigonal planar and symmetrical, so its dipoles cancel.* [2]

18
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19 This question is about acids and bases.

(a) Chloroethanoic acid, ClCH_2COOH , is a weak monobasic acid.

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

$$K_a = \frac{[\text{H}^+][\text{ClCH}_2\text{COO}^-]}{[\text{ClCH}_2\text{COOH}]}$$

[1]

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

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

Expression 19.1

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

$[\text{H}^+] = [\text{ClCH}_2\text{COO}^-]$ (the dissociation of water is negligible)..... [1]

(iii) A student carries out an experiment to determine the $\text{p}K_a$ 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 $\text{p}K_a$ value of ClCH_2COOH .

Give your answer to 2 decimal places.

$$[\text{H}^+] = 10^{-1.95} = 1.122 \times 10^{-2} \text{ mol dm}^{-3}$$

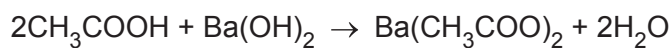
$$K_a = \frac{[\text{H}^+]^2}{[\text{ClCH}_2\text{COOH}]} = \frac{(1.122 \times 10^{-2})^2}{0.090}$$

$$K_a = 1.40 \times 10^{-3} \text{ mol dm}^{-3}$$

$$\text{p}K_a = -\log(1.40 \times 10^{-3}) = 2.85$$

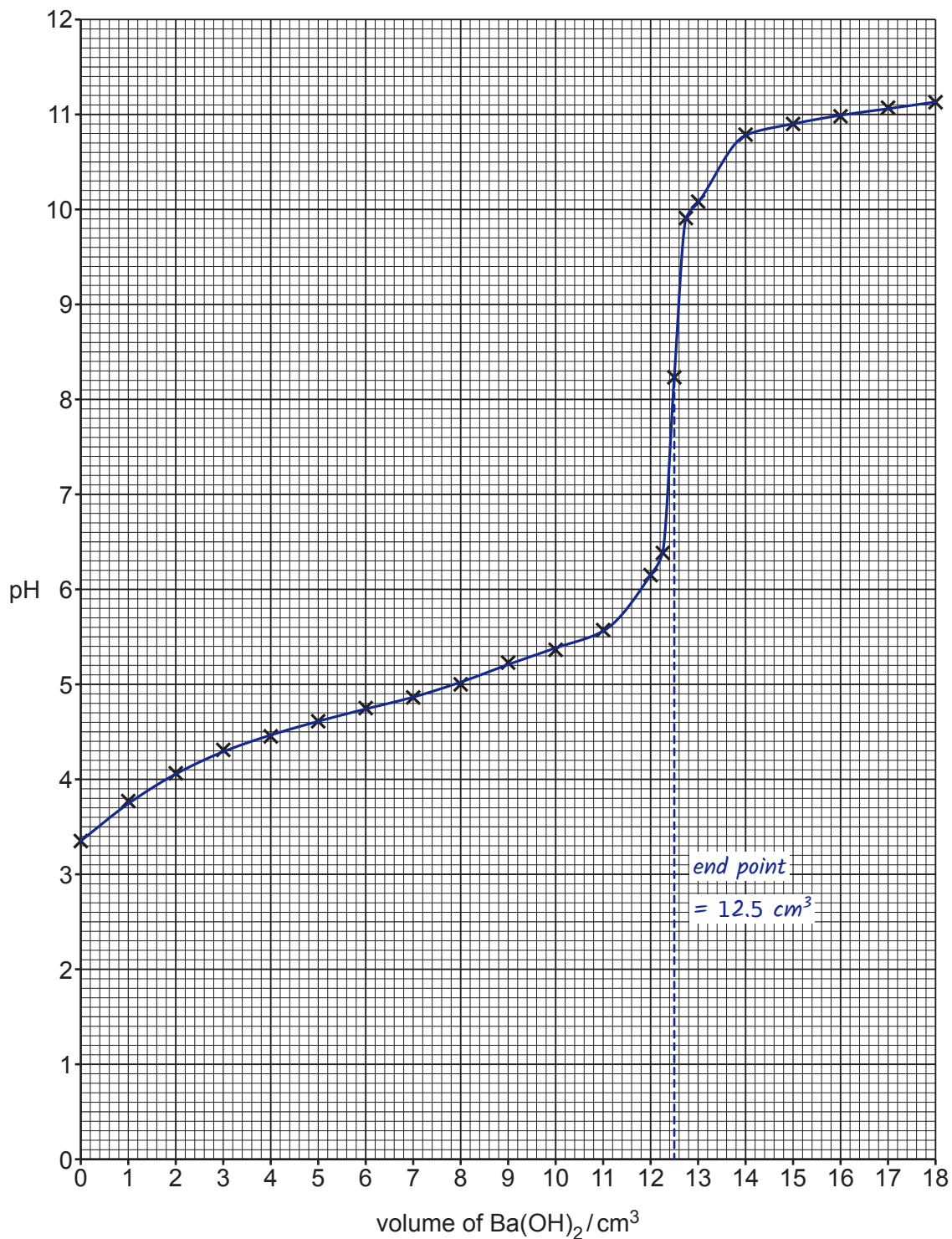
$$\text{p}K_a = \dots\dots\dots 2.85 \dots\dots\dots [3]$$

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



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

The student's results are shown below.



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

End point (middle of the vertical section) = 12.5 cm^3 of $\text{Ba}(\text{OH})_2$

$$n(\text{Ba}(\text{OH})_2) = 0.0560 \times 12.5 \div 1000 = 7.00 \times 10^{-4} \text{ mol}$$

$$n(\text{CH}_3\text{COOH}) = 2 \times 7.00 \times 10^{-4} = 1.40 \times 10^{-3} \text{ mol}$$

$$[\text{CH}_3\text{COOH}] = 1.40 \times 10^{-3} \div (10.0 \div 1000)$$

$$= 0.140 \text{ mol dm}^{-3}$$

CH_3COOH concentration = ...0.140..... mol dm^{-3} [5]

- (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 $\text{Ba}(\text{OH})_2$.

..phenolphthalein..... [1]

20 This question is about elements in the periodic table.

(a) Chlorine has many uses.

(i) Chlorine is used to treat water in large-scale water treatment plants.

Suggest why chlorine is added to water in large-scale water treatment plants.

To kill bacteria (microorganisms) so that the water is safe to drink.
..... [1]

(ii) Sea water contains aqueous bromide ions.

Chlorine is used to extract bromine from sea water.

Construct the ionic equation for this reaction and explain why chlorine is suitable for this extraction of bromine but iodine is **not**.

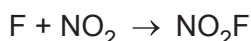
Equation *$\text{Cl}_2 + 2\text{Br}^- \rightarrow \text{Br}_2 + 2\text{Cl}^-$*
.....
Explanation *Chlorine is a stronger oxidising agent (more reactive) than bromine, so it oxidises Br^- to Br_2 ; iodine is a weaker oxidising agent (less reactive) than bromine, so it cannot.*
..... [2]

(b) Fluorine, F_2 , reacts with nitrogen dioxide, NO_2 , to form nitryl fluoride, NO_2F , as shown in **Reaction 20.1** below.



The mechanism for this reaction involves two steps. **Step 1** is the 'slow' step and **Step 2** is the 'fast' step.

The equation for **Step 2** is shown below:



Suggest the equation for **Step 1** and the rate equation for **Reaction 20.1**.

Equation for **Step 1**: *$\text{F}_2 + \text{NO}_2 \rightarrow \text{F} + \text{NO}_2\text{F}$*
.....
Rate equation for **Reaction 20.1**: *$\text{rate} = k[\text{F}_2][\text{NO}_2]$*
..... [2]

(c)* The table shows the melting points of some of the elements in Period 3 of the periodic table.

Element	Al	Si	P ₄	S ₈
Melting point/°C	660	1410	44	119

Explain the melting points in terms of bonding and structure.

[6]

Al has a giant metallic lattice: strong electrostatic attraction between positive Al^{3+} ions and delocalised electrons. A lot of energy is needed to overcome this metallic bonding, so the melting point is high (660 °C).

Si has a giant covalent lattice: each Si atom is covalently bonded to 4 other Si atoms. The covalent bonds are strong (attraction between the shared pair of electrons and the nuclei) and many must be broken, so the most energy is needed and Si has the highest melting point (1410 °C).

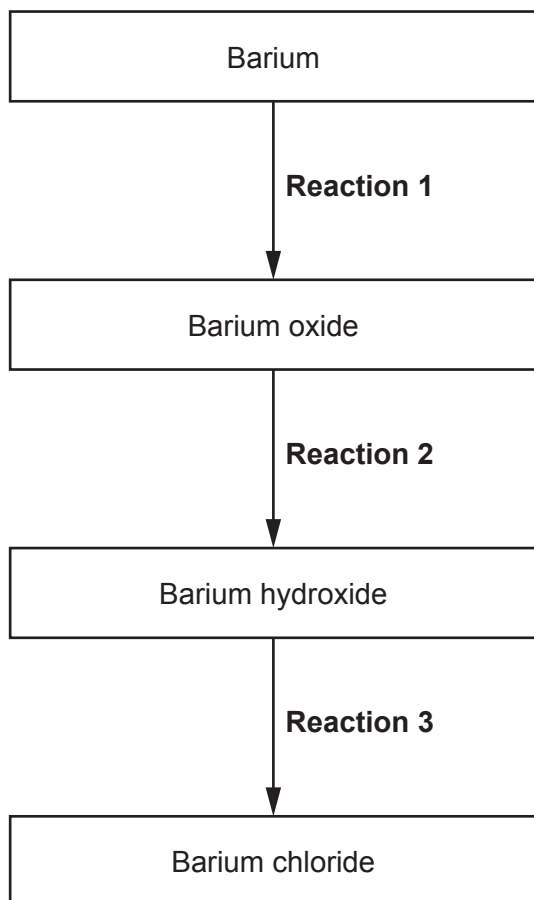
P₄ and S₈ have simple molecular (simple covalent) lattices. The covalent bonds within the molecules are strong, but on melting only the weak induced dipole-dipole interactions (London forces) between the molecules are overcome, so little energy is needed and their melting points are low.

S₈ has a higher melting point than P₄ because an S₈ molecule has more electrons (128) than P₄ (60), so there are stronger London forces between the molecules, which need more energy to overcome.

Extra answer space if required.

21 This question is about redox reactions and electrode potentials.

(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**.

Reaction 1: equation $2\text{Ba} + \text{O}_2 \rightarrow 2\text{BaO}$

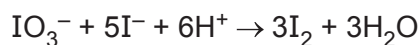
Reaction 2: equation $\text{BaO} + \text{H}_2\text{O} \rightarrow \text{Ba}(\text{OH})_2$

Reaction 3: type of reaction *neutralisation (acid-base)*

[3]

- (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.

$$n(\text{I}^-) = 0.150 \times 26.2 \div 1000 = 3.93 \times 10^{-3} \text{ mol}$$

$$n(\text{IO}_3^-) \text{ in 2 tablets} = 3.93 \times 10^{-3} \div 5 = 7.86 \times 10^{-4} \text{ mol}$$

$$n(\text{KIO}_3) \text{ in 1 tablet} = 7.86 \times 10^{-4} \div 2 = 3.93 \times 10^{-4} \text{ mol}$$

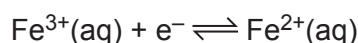
$$M(\text{KIO}_3) = 39.1 + 126.9 + 3(16.0) = 214.0 \text{ g mol}^{-1}$$

$$\text{mass} = 3.93 \times 10^{-4} \times 214.0 = 0.0841 \text{ g} = 84 \text{ mg}$$

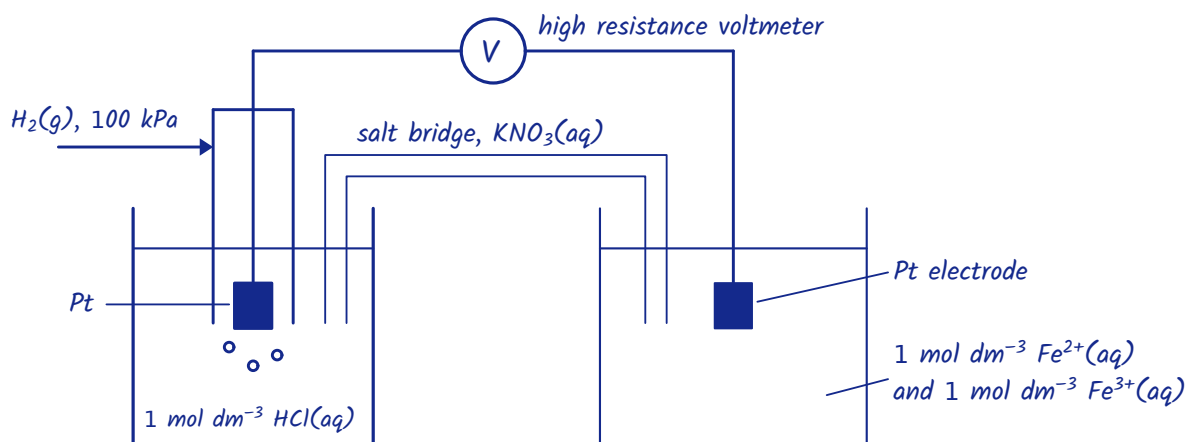
$$\text{mass KIO}_3 = \dots\dots\dots 84 \dots\dots\dots \text{ mg [4]}$$

- (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 $298 \text{ K (} 25^\circ \text{C) and } 100 \text{ kPa (} 1 \text{ atm) pressure;}$

$\dots\dots\dots \text{all solutions } 1 \text{ mol dm}^{-3} \text{ (equal } 1 \text{ mol dm}^{-3} \text{ Fe}^{2+} \text{ and Fe}^{3+}\text{)}$

- (d) 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°/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

- (i) A lithium-ion cell involves **redox systems 1 and 5**.

Construct the overall cell equation for a lithium-ion cell.

$\text{Li} + \text{CoO}_2 \rightarrow \text{LiCoO}_2$ [1]

- (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.

Acidic $E_{\text{cell}} = 1.23 - 0.00 = 1.23 \text{ V}$ (system 6 - system 3)

reduction (6): $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$

oxidation (3): $2\text{H}_2 \rightarrow 4\text{H}^+ + 4\text{e}^-$

overall: $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$

Alkaline $E_{\text{cell}} = 0.40 - (-0.83) = 1.23 \text{ V}$ (system 4 - system 2)

reduction (4): $\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$

oxidation (2): $2\text{H}_2 + 4\text{OH}^- \rightarrow 4\text{H}_2\text{O} + 4\text{e}^-$

overall: $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$, so both are the same

[3]

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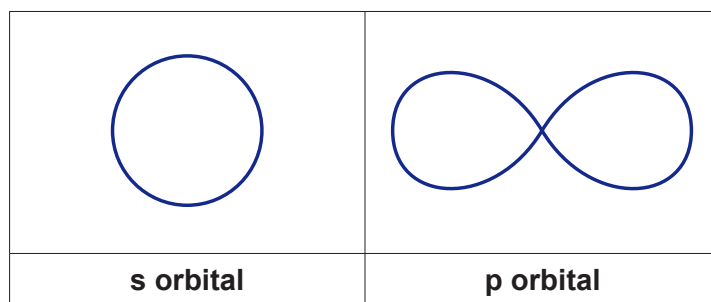
Turn over for the next question

22 This question is about transition elements.

(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



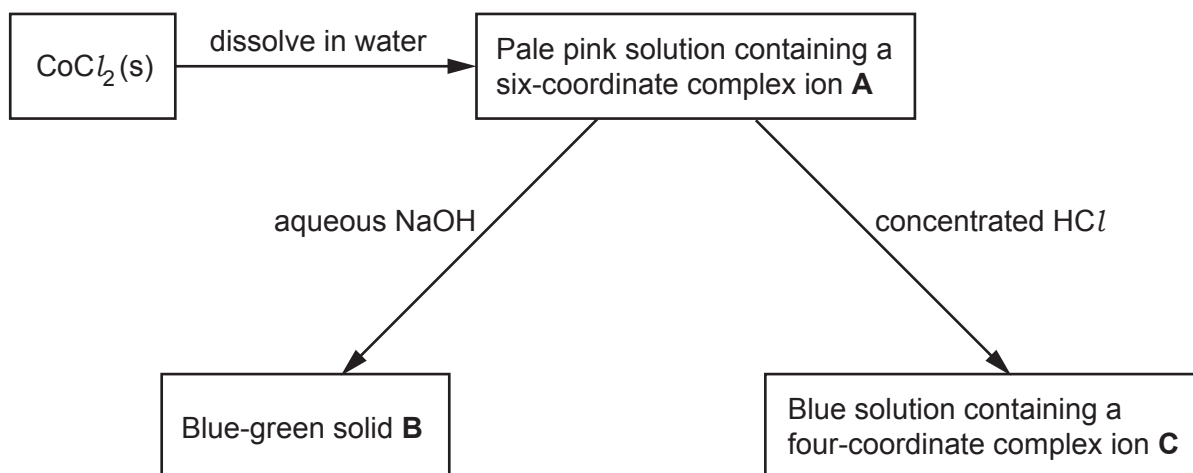
Electron configurations

Iron atom: $1s^2 \dots 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$

Iron(II) ion $1s^2 \dots 2s^2 2p^6 3s^2 3p^6 3d^6$

[2]

(b) The flowchart shows some reactions of cobalt(II) chloride, CoCl_2 .



In **A**, **B** and **C**, cobalt has an oxidation number of +2.

(i) Suggest the formulae of **A**, **B** and **C**.

Complex ion **A**: $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$

Solid **B**: $\text{Co}(\text{OH})_2$

Complex ion **C**: $[\text{CoCl}_4]^{2-}$

[3]

- (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**.

$58.9 + 4(17.0) + 2(35.5) = 197.9$; **D** is $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]^+$
 charge = $+3 + 2(-1) = +1$ [2]

- (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.

Haemoglobin contains Fe^{2+} . In the lungs, O_2 uses a lone pair on oxygen to form a coordinate (dative) bond to the Fe^{2+} ion, replacing a water ligand (ligand substitution).

The O_2 bonds reversibly, so in respiring tissues it is replaced by H_2O (or CO_2) and the O_2 is released.

$$[\text{H}^+] = K_a \times [\text{H}_2\text{CO}_3] \div [\text{HCO}_3^-] = 4.27 \times 10^{-7} \times 1 \div 8.5$$

$$[\text{H}^+] = 5.02 \times 10^{-8} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log(5.02 \times 10^{-8}) = 7.30$$

7.30 is below 7.35, so this blood sample is not healthy (it is too acidic).

[5]

END OF QUESTION PAPER

[illegible]

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