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 | | | | | | Candidate number | | | | |

First name(s) _____

Last name _____

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.

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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 ☐ **[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 ☐ **[1]**

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

A $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

B $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$

C $2Fe_2O_3 \rightarrow 4Fe + 3O_2$

D $2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$

Your answer ☐ **[1]**

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

A Chlorides

B Hydroxides

C Nitrates

D Sulfates

Your answer ☐ **[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 ☐ **[1]**

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

A $Cl_2 + H_2O \rightarrow HClO + HCl$

B $Cl_2 + 2NaOH \rightarrow NaClO + NaCl + H_2O$

C $4KClO_3 \rightarrow KCl + 3KClO_4$

D $4HCl + MnO_2 \rightarrow MnCl_2 + Cl_2 + 2H_2O$

Your answer ☐ **[1]**

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

$H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$

25 cm^3 of 1.00 mol dm^{-3} H_2SO_4 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 ☐ **[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 ☐ **[1]**

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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

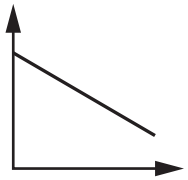
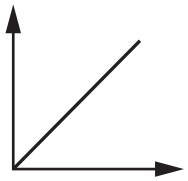
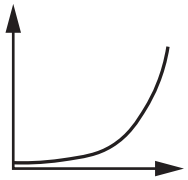
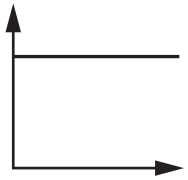
C +1920

D +133 000

Your answer ☐ **[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 ☐ **[1]**

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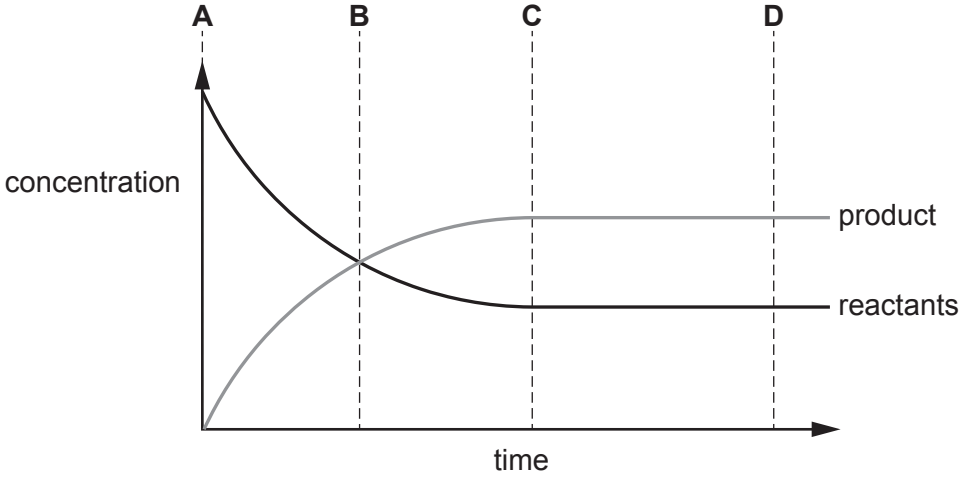
11 The reversible reaction between hydrogen and iodine to form hydrogen iodide is

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

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 ☐ **[1]**

12 Which solution can be added to $CH_3COOH(aq)$ to make a buffer solution?

A $CH_3COONa(aq)$

B $HCOOH(aq)$

C $HCl(aq)$

D $NaCl(aq)$

Your answer ☐ **[1]**

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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?

A $CuCl_2$

B $CuSO_4$

C $FeCl_2$

D $FeSO_4$

Your answer ☐ **[1]**

14 Chlorine has the electron configuration $[Ne]3s^2 3p^5$.

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 $3s^2$ electrons to form 2+ ions.

3 It can lose its $3p^5$ 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 ☐ **[1]**

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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 ☐ **[1]**

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Turn over for Section B

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SECTION B

16 This question is about energy changes.

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

$H_2O_2(l) \rightarrow H_2O(l) + \frac{1}{2}O_2(g)$ **Reaction 16.1**

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

	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
$H_2O_2(l)$	–188	110
$H_2O(l)$	–286	70.0
$O_2(g)$	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.

ΔG = ...kJ mol^{-1} **[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.

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

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(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.

.....

..... **[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.

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

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(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**.

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

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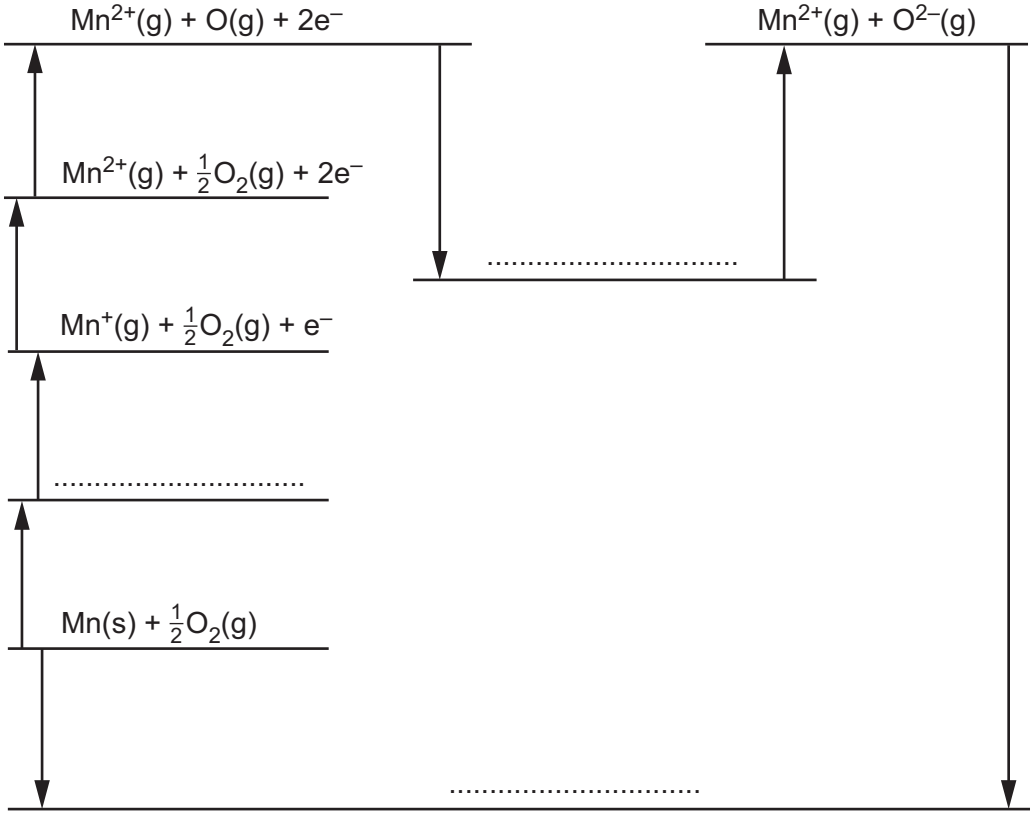
(ii) The diagram shows an incomplete Born-Haber cycle that can be used to determine the lattice enthalpy of MnO.



Complete the diagram by adding the species present on the dotted lines, include state symbols. **[3]**

(iii) Calculate the lattice enthalpy of MnO.

lattice enthalpy = ... $kJ\,mol^{-1}$ **[2]**

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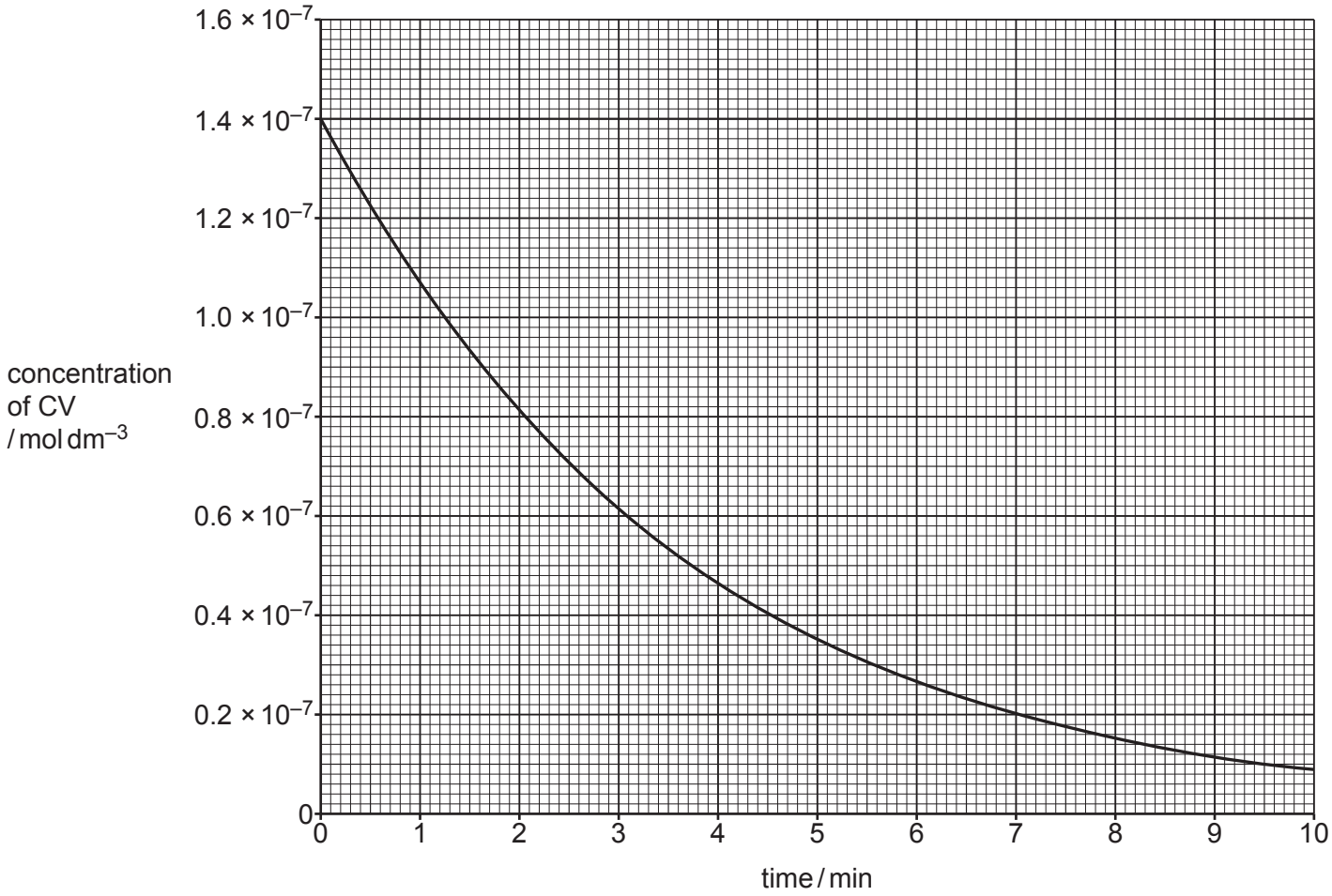
17 Crystal violet (CV) is a purple dye. In the presence of an alkali, CV reacts to form a colourless product.

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 2.8×10^{-7} mol dm^{-3} CV with 10.0 cm^3 of 0.016 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.

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

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(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]**

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Extra answer space if required.

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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**.

$SO_3(g) \rightleftharpoons SO_2(g) + \frac{1}{2}O_2(g)$ $\Delta H = +99\,kJ\,mol^{-1}$ **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.

K_p = ...

units ..... **[5]**

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(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.

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..... **[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°.

.....

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

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

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

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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 $ClCH_2COOH$.

[1]

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

$$K_a = \frac{[H^+]^2}{[ClCH_2COOH]}$$ **Expression 19.1**

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

.....

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

(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 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]**

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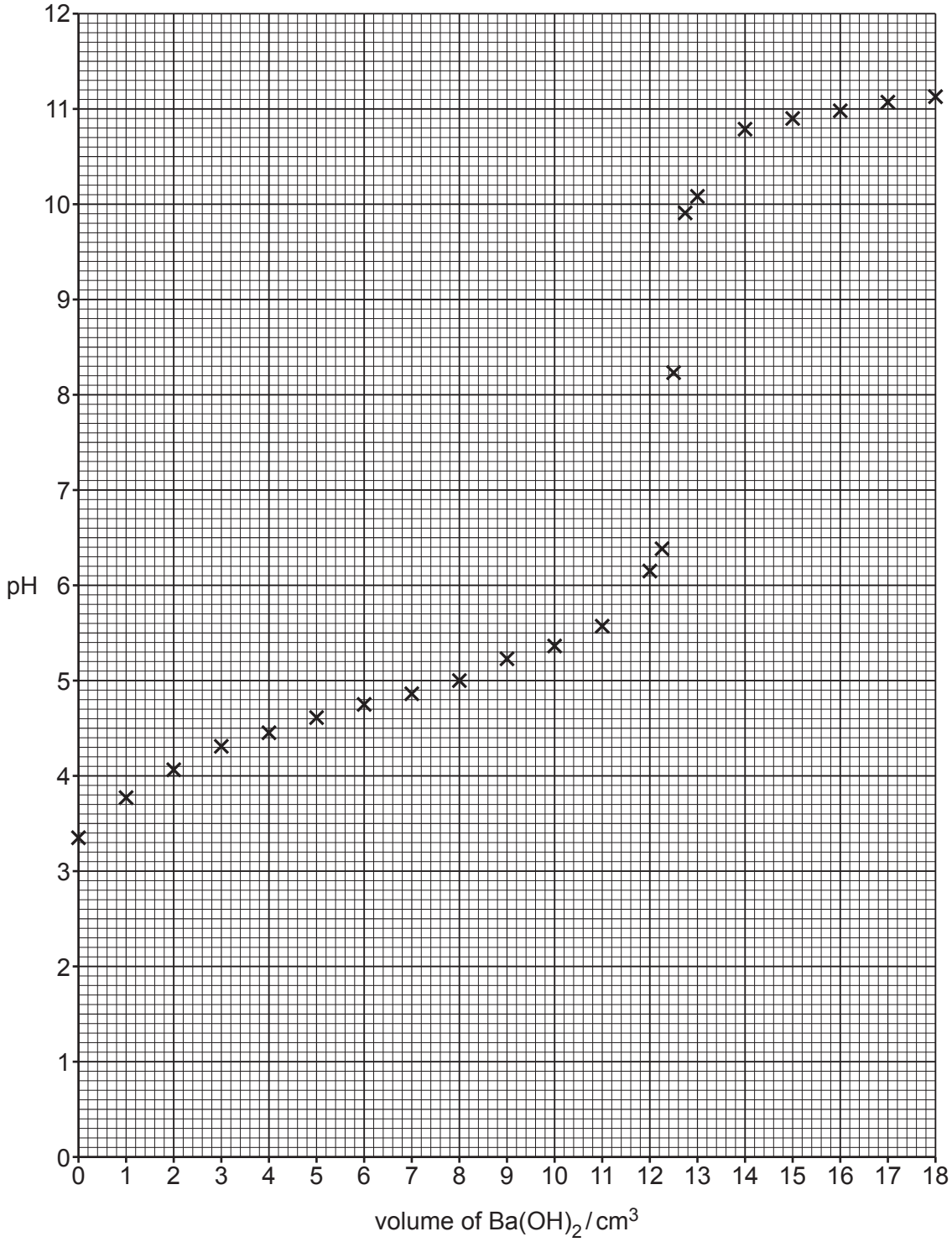
(b) A student titrates a 10.0 cm^3 sample of ethanoic acid, CH_3COOH, against an aqueous solution of 0.0560 mol dm^{-3} $Ba(OH)_2$.

$$2CH_3COOH + Ba(OH)_2 \rightarrow Ba(CH_3COO)_2 + 2H_2O$$

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.



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(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]**

(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 $Ba(OH)_2$.

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

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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.

.....

..... **[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 .....

Explanation .....

.....

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

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

$F_2 + 2NO_2 \rightarrow 2NO_2F$ **Reaction 20.1**

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:

$F + NO_2 \rightarrow NO_2F$

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

Equation for **Step 1**: .....

Rate equation for **Reaction 20.1**: .....

[2]

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(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]**

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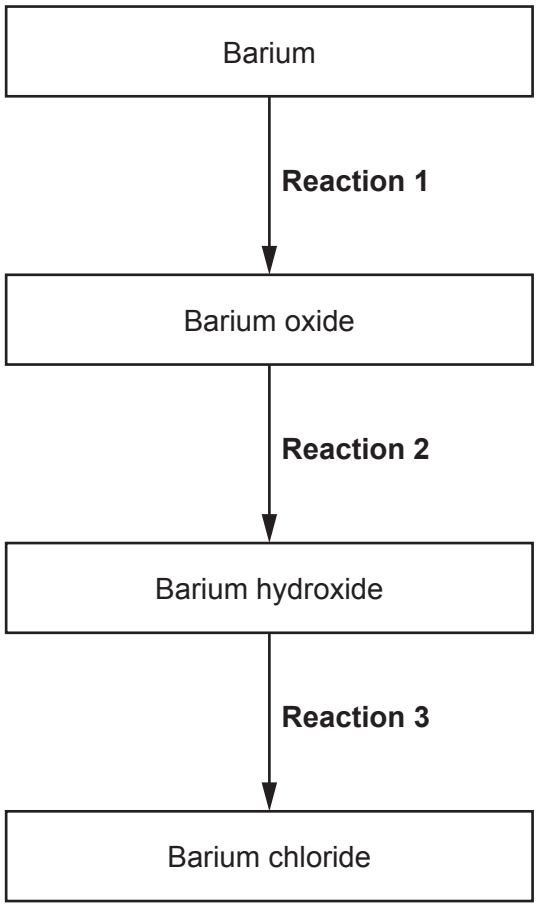
21 This question is about redox reactions and electrode potentials.

(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 .....

Reaction 2: equation .....

Reaction 3: type of reaction .....

[3]

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(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.

$IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$

A chemist finds that two KIO_3 tablets react with exactly 26.2 cm^3 0.150 mol dm^{-3} KI.

Calculate the mass, in mg, of KIO_3 in **one** tablet.

Give your answer to the nearest whole number.

mass KIO_3 = ... 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.

$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$

Include details of the apparatus, solutions and the standard conditions needed when measuring this standard electrode potential.

Standard conditions .....

.....

[4]

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(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	$E^{\ominus}$/V
1	$Li^+ + e^- \rightleftharpoons Li$	–3.04
2	$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$	–0.83
3	$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
4	$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	+0.40
5	$Li^+ + CoO_2 + e^- \rightleftharpoons LiCoO_2$	+1.16
6	$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	+1.23

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

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

..... **[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 .....

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Alkaline.....

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[3]

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Turn over for the next question

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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

s orbital	**p orbital**

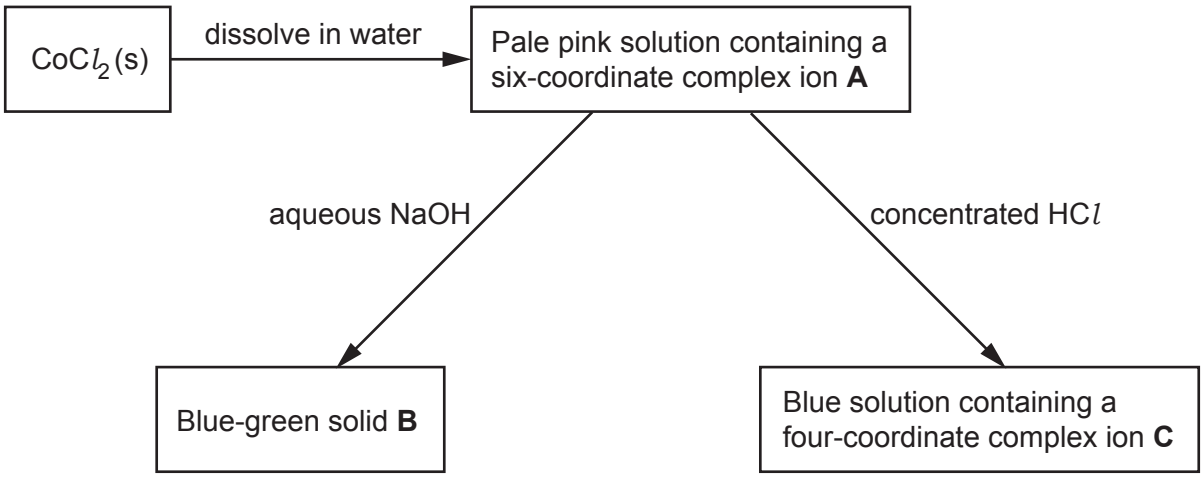
Electron configurations

Iron atom: $1s^2$ .....

Iron(II) ion $1s^2$ .....

[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**: .....

Solid **B**: .....

Complex ion **C**: .....

[3]

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(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**.

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..... **[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.

$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ $\qquad K_a = 4.27 \times 10^{-7}\ mol\ dm^{-3}$

- Explain, using ligand substitution, how haemoglobin transports oxygen around the body.
- Determine whether a sample of blood with a $[HCO_3^-] : [H_2CO_3]$ ratio of 8.5:1 is healthy.

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..... **[5]**

END OF QUESTION PAPER

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EXTRA ANSWER SPACE

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