OCR
Oxford Cambridge and RSA

Monday 12 June 2023 – 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 **28** pages.

ADVICE
- Read each question carefully before you start your answer.

Section A

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

Write your answer to each question in the box provided.

1 Which sample contains the greatest number of molecules?

A 35.0 g of C_2H_2

B 45.0 g of C_2H_6

C 60.0 g of C_4H_{10}

D 100.0 g of C_6H_6

Your answer ☐ **[1]**

2 0.688 g of an oxide of manganese is reduced by hydrogen gas to form manganese metal and 0.235 g of water.

What is the formula of the oxide of manganese?

A MnO

B MnO_2

C Mn_2O_3

D Mn_3O_4

Your answer ☐ **[1]**

3 How many hydrogen atoms are in 2.50 g of pharmacolite, $CaHAsO_4 \cdot 2H_2O$ (M_r = 216.0)?

A 6.97×10^{21}

B 2.09×10^{22}

C 2.79×10^{22}

D 3.48×10^{22}

Your answer ☐ **[1]**

4 40.0 cm^3 of 0.200 mol dm^{-3} HCl is added to 60.0 cm^3 of 0.100 mol dm^{-3} NaOH.

What is the concentration of the resulting solution?

A 0.0200 mol dm^{-3} HCl and 0.0200 mol dm^{-3} NaCl

B 0.0200 mol dm^{-3} HCl and 0.0400 mol dm^{-3} NaCl

C 0.0200 mol dm^{-3} HCl and 0.0600 mol dm^{-3} NaCl

D 0.0600 mol dm^{-3} HCl and 0.0200 mol dm^{-3} NaCl

Your answer ☐ **[1]**

5 Which compound has polar molecules?

A HCN

B BCl_3

C CO_2

D C_2F_4

Your answer ☐ **[1]**

6 Which element has the largest third ionisation energy?

A Li

B F

C Ne

D Na

Your answer ☐ **[1]**

7 The reaction below is first order with respect to reactant **X**.

X(aq) → products

When the initial concentration of **X** is 1.0 mol dm^{-3}, the half-life is 16 minutes.

What is the half-life when the initial concentration of **X** is 2.0 mol dm^{-3}?

A 2 minutes

B 4 minutes

C 8 minutes

D 16 minutes

Your answer ☐ **[1]**

8 Which compound requires the most energy to convert one mole into its gaseous ions?

A NaF

B Na_2O

C MgF_2

D MgO

Your answer ☐ **[1]**

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

Substance	$SO_2(g)$	$O_2(g)$	$SO_3(l)$
$S^{\ominus}$/J K^{-1} 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 $SO_3(l)$ from $SO_2(g)$ and $O_2(g)$?

A –508

B –254

C +254

D +508

Your answer ☐ **[1]**

10 What is the percentage dissociation of a 0.015 mol dm^{-3} solution of methanoic acid, HCOOH (K_a = 1.60 × 10^{-4} mol dm^{-3})?

A 0.016%

B 1.1%

C 1.82%

D 10.3%

Your answer ☐ **[1]**

11 A student adds aqueous potassium carbonate to one test tube and aqueous silver nitrate to a second test tube.

The student adds dilute hydrochloric acid to each test tube.

Which row has the correct observations?

	Aqueous potassium carbonate	**Aqueous silver nitrate**
A	no change	precipitate
B	no change	no change
C	effervescence	no change
D	effervescence	precipitate

Your answer ☐ **[1]**

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

	$E^{\ominus}$/V
$Li^+ + e^- \rightleftharpoons Li$	–3.04
$Li^+ + CoO_2 + e^- \rightleftharpoons LiCoO_2$	+1.16

Which statement is correct in a lithium-ion cell?

A The cell potential is 2.88 V.

B The reaction at the positive electrode is: $LiCoO_2 \rightarrow Li^+ + CoO_2 + e^-$

C The overall cell reaction is: $Li + CoO_2 \rightarrow LiCoO_2$

D The oxidation number of Co changes from +2 to +1.

Your answer ☐ **[1]**

13 Which substance(s) has/have induced dipole–dipole interactions (London forces) in the solid state?

1 C_2H_6

2 H_2O

3 Si

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

14 Which statement(s) is/are correct for the anti-cancer complex $Pt(NH_3)_2Cl_2$?

1 It has bond angles of 90º.

2 The oxidation number of Pt is +4.

3 It forms both optical and *cis-trans* isomers.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

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

$$2ClF_3(g) \rightleftharpoons Cl_2(g) + 3F_2(g) \qquad \Delta H = +318\,kJ\,mol^{-1}$$

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.

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

Section B

16 This question is about energy changes.

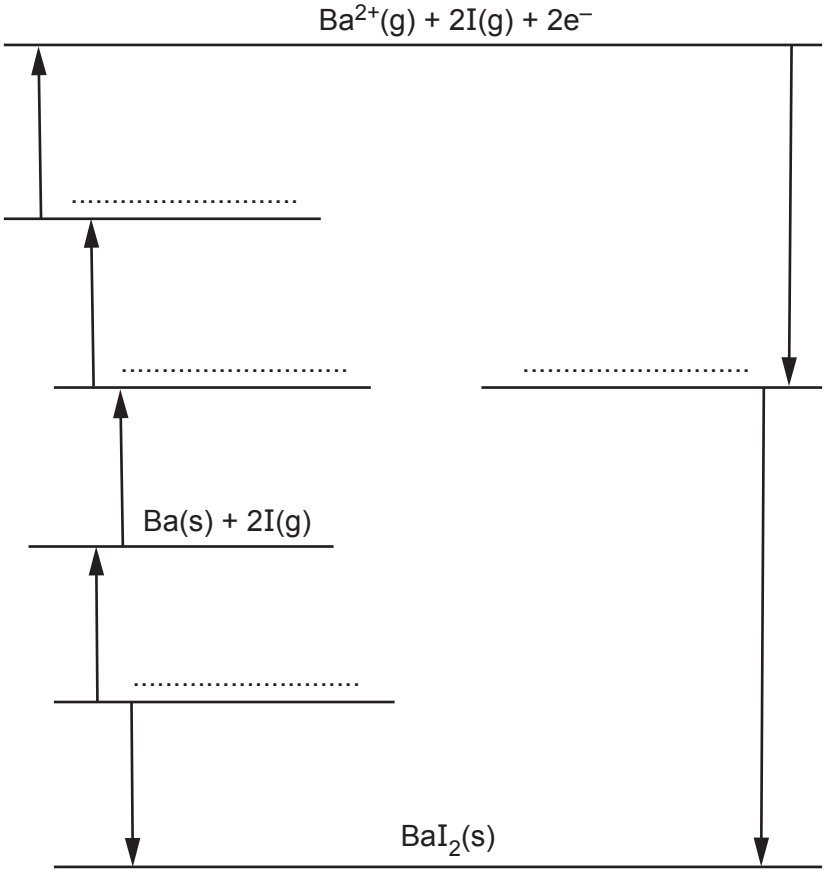
(a) Lattice enthalpies can be determined indirectly using Born-Haber cycles.

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

(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]

(ii) Calculate the lattice enthalpy of barium iodide.

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

(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.

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..... **[4]**

17* Bromine, Br_2, can be produced by the reaction:

$5Br^-(aq) + BrO_3^-(aq) + 6H^+(aq) \rightarrow 3Br_2(aq) + 3H_2O(l)$

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.

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Additional answer space if required.

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18 This question is about enthalpy changes of reactions involving hydrocarbons.

(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}) = ... kJ mol^{-1} **[3]**

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

$C_9H_{20}(g) \rightarrow C_5H_{12}(g) + 2C_2H_4(g)$ $\Delta H = +186\,kJ\,mol^{-1}$ **Reaction 1**

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

Hydrocarbon	$\Delta_c H$ / 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 $C_5H_{12}(g)$.

$\Delta_c H\,(C_5H_{12}(g))$ = ... kJ mol^{-1} **[2]**

(c) Ethene can be produced from ethanol, as shown in **Reaction 2** below.

$C_2H_5OH(g) \rightarrow C_2H_4(g) + H_2O(g)$ **Reaction 2**

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

Explain your reasoning.

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

(ii) **Reaction 2** is repeated:

$C_2H_5OH(g) \rightarrow C_2H_4(g) + H_2O(g)$ **Reaction 2**

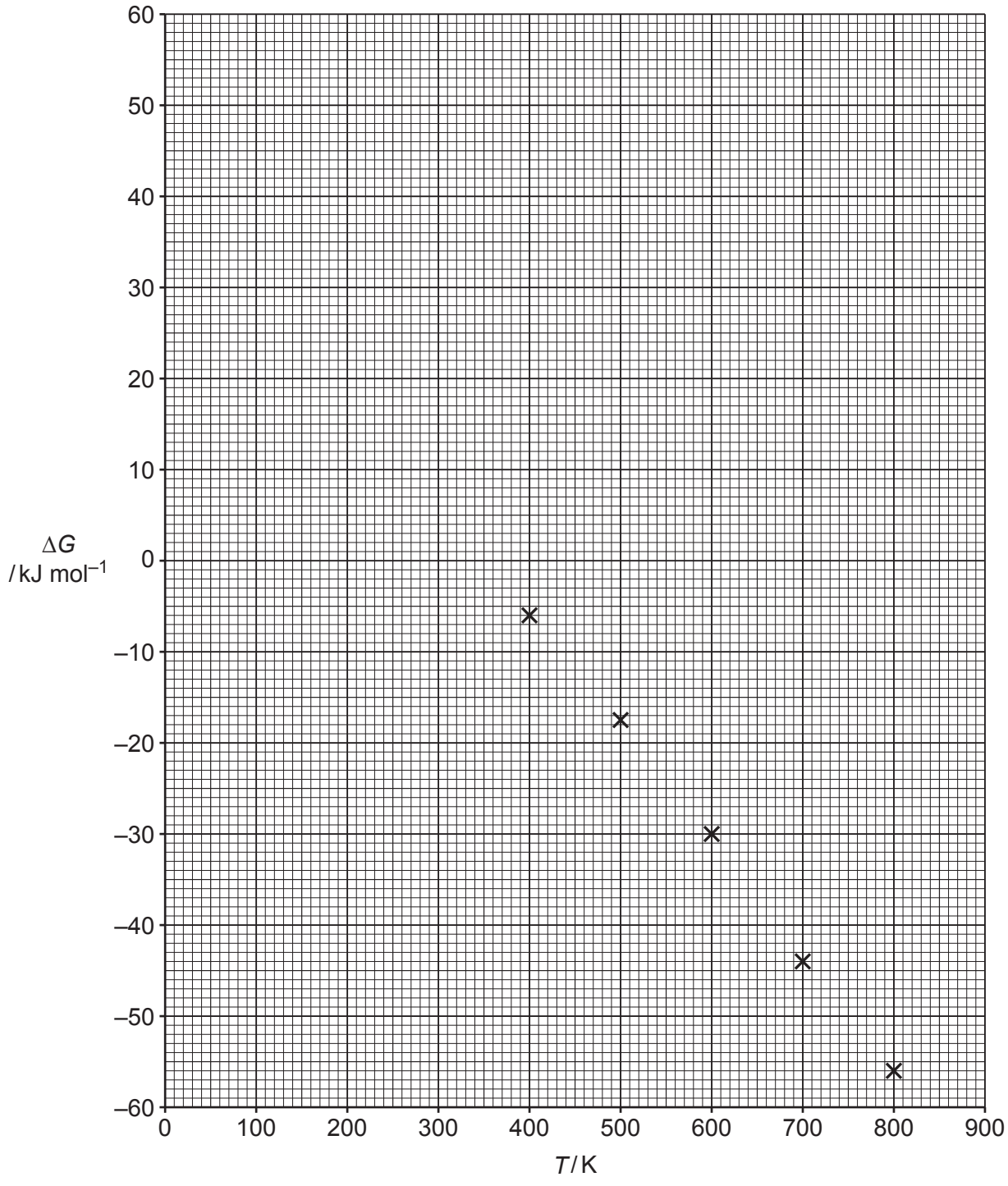
The Gibbs equation is shown below.

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

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**.

ΔS = ... $J K^{-1} mol^{-1}$

minimum T = ... K

ΔH = ... $kJ mol^{-1}$

[5]

19 This question is about oxides of nitrogen.

(a) An investigation is carried out on the equilibrium system shown below.

$2NO_2(g) \rightleftharpoons N_2O_4(g)$ $\Delta H = -57.4\,kJ\,mol^{-1}$

(i) A sealed flask containing 6.00 moles of $NO_2(g)$ is heated to a constant temperature and allowed to reach equilibrium.

The equilibrium mixture contains 5.40 mol of $NO_2(g)$, and the total pressure is 5.00 atm.

Determine the value of K_p and give your answer to **3** significant figures.

Include an expression for K_p and the units of K_p in your answer.

K_p = ... units .....**[5]**

(ii) The sealed flask in **(a)(i)** is then heated to a higher temperature at an increased pressure. The system is allowed to reach equilibrium again.

Explain why it is difficult to predict how these changes in reaction conditions affect the amount of $N_2O_4(g)$ formed at equilibrium.

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..... **[3]**

(b) N_2O_4 reacts fully with oxygen to form a different oxide of nitrogen, oxide **A**, as the only product.

Oxide **A** is collected and cooled to 75.0 °C at a pressure of 101 kPa.

Under these conditions, oxide **A** is a gas that occupies a volume of 74.0 cm^3 and has a mass of 0.280 g.

Calculate the molar mass of oxide **A** and suggest its molecular formula.

molar mass = ... g mol^{-1}

molecular formula = ...

[5]

20 This question is about acids and bases.

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

Table 20.1

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

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

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

pH = ... **[2]**

(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.

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

(b) A student reacts strontium metal with water to make a 250.0 cm^3 solution of aqueous strontium hydroxide, $Sr(OH)_2$. 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.

Equation .....

Calculation

pH = ... **[5]**

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

(i) Construct the equation for this reaction.

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

(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.

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(d) A student reacts an excess of magnesium with 25.0 cm^3 of 0.500 mol dm^{-3} hydrochloric acid, HC*l*.

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

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

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

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..... **[3]**

(e) Butanoic acid, $CH_3CH_2CH_2COOH$, is a weak monobasic acid.

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

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

(ii) A buffer solution is prepared by dissolving 3.39 g of potassium hydroxide in 250 cm^3 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 cm^3 when the potassium hydroxide is dissolved.

K_a = ... mol dm^{-3} **[4]**

(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.

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

21 Some grass fertilisers contain compounds of iron.

During heavy rain, a fertiliser is washed into a nearby river causing the water to be polluted with a mixture of iron(II) and iron(III) ions.

(a) A student determines the concentration of iron(II) ions in a sample of river water by titration with potassium manganate(VII).

25.0 cm^3 portions of river water are acidified with dilute sulfuric acid. Each portion is titrated with 0.00250 mol dm^{-3} potassium manganate(VII) until a colour change is seen.

$MnO_4^-(aq) + 8H^+(aq) + 5Fe^{2+}(aq) \longrightarrow Mn^{2+}(aq) + 4H_2O(l) + 5Fe^{3+}(aq)$

(i) State the colour change seen at the end point of the titration.

from ..... to ..... **[1]**

(ii) The student's titration results are shown in the table below.
The trial titre has been omitted.

	1	**2**	**3**
Final volume / cm^3	12.65	25.60	38.35
Initial volume / cm^3	0.00	12.65	25.60
Titre volume / cm^3			

Complete the table above and calculate the mean titre that the student should use to determine the concentration of iron(II) ions in the river water.

mean titre = ... cm^3 **[2]**

(iii) Determine the concentration, in mol dm^{-3}, of iron(II) ions in the river water.

concentration = ... mol dm^{-3} **[3]**

(b) The student modifies the experiment in **(a)** to determine the combined concentration of iron(II) and iron(III) ions in the river water.

The student's method is shown below.

Step 1 Add excess zinc to a 250.0 cm^3 sample of river water and warm gently.

Step 2 Cool the solution and remove excess zinc by filtration.

Step 3 Acidify 25.0 cm^3 portions of the filtrate from **Step 2**. Then titrate each portion with 0.00250 mol dm^{-3} potassium manganate(VII) until a colour change is seen.

The table below shows information about three redox systems.

Redox system	Half-equation	$E^{\ominus}$/V
1	$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
2	$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
3	$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51

Use the information in the table above to explain the reasons for **Step 1** and **Step 2**.

Reason(s) for **Step 1** .....

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Reason(s) for **Step 2** .....

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[4]

22 This question is about the d-block elements in Period 4 of the periodic table (Sc to Zn).

(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.

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Additional answer space if required.

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(b) (i) Describe precipitation reactions using **either** copper **or** chromium ions as examples.

Include equations.

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

(ii) Describe ligand substitution reactions using **either** copper **or** chromium ions as examples.

Include equations.

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

(c) The ethanedioate ion, $C_2O_4^{2-}$, 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.

Charge of complex ion .....

Coordination number of cobalt ..... **[2]**

(d) An acidified solution containing $Cr_2O_7^{2-}$ 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]**

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).