

**OXFORD CAMBRIDGE AND RSA EXAMINATIONS**

**Monday 12 June 2023 – Morning**

**A Level Chemistry A**

**H432/01 Periodic table, elements and physical chemistry**

**Time allowed: 2 hours 15 minutes**

**plus your additional time allowance**

**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.**

**Centre number**

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**Candidate number**

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**First name(s)** \_\_\_\_\_

**Last name** \_\_\_\_\_

**READ INSTRUCTIONS OVERLEAF**



## **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 (\*).**

## **ADVICE**

**Read each question carefully before you start your answer.**

**BLANK PAGE**

## SECTION A

You should spend a **MAXIMUM OF 20 MINUTES** plus your additional time allowance on this section.

Write your answer to each question in the box provided.

1 Which sample contains the greatest number of molecules? [1]

A 35.0 g of  $\text{C}_2\text{H}_2$

B 45.0 g of  $\text{C}_2\text{H}_6$

C 60.0 g of  $\text{C}_4\text{H}_{10}$

D 100.0 g of  $\text{C}_6\text{H}_6$

Your answer

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? [1]

A  $\text{MnO}$

B  $\text{MnO}_2$

C  $\text{Mn}_2\text{O}_3$

D  $\text{Mn}_3\text{O}_4$

Your answer

**3 How many hydrogen atoms are in 2.50 g of pharmacolite,  $\text{CaHAsO}_4 \cdot 2\text{H}_2\text{O}$  ( $M_r = 216.0$ )? [1]**

**A  $6.97 \times 10^{21}$**

**B  $2.09 \times 10^{22}$**

**C  $2.79 \times 10^{22}$**

**D  $3.48 \times 10^{22}$**

**Your answer**

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

**What is the concentration of the resulting solution? [1]**

**A  $0.0200 \text{ mol dm}^{-3}$   $\text{HCl}$  and  $0.0200 \text{ mol dm}^{-3}$   $\text{NaCl}$**

**B  $0.0200 \text{ mol dm}^{-3}$   $\text{HCl}$  and  $0.0400 \text{ mol dm}^{-3}$   $\text{NaCl}$**

**C  $0.0200 \text{ mol dm}^{-3}$   $\text{HCl}$  and  $0.0600 \text{ mol dm}^{-3}$   $\text{NaCl}$**

**D  $0.0600 \text{ mol dm}^{-3}$   $\text{HCl}$  and  $0.0200 \text{ mol dm}^{-3}$   $\text{NaCl}$**

**Your answer**

**5 Which compound has polar molecules? [1]**

**A HCN**

**B BCl<sub>3</sub>**

**C CO<sub>2</sub>**

**D C<sub>2</sub>F<sub>4</sub>**

**Your answer**

**6 Which element has the largest third ionisation energy? [1]**

**A Li**

**B F**

**C Ne**

**D Na**

**Your answer**

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



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

What is the half-life when the initial concentration of X is  $2.0 \text{ mol dm}^{-3}$ ? [1]

- A 2 minutes
- B 4 minutes
- C 8 minutes
- D 16 minutes

Your answer

- 8 Which compound requires the most energy to convert one mole into its gaseous ions? [1]

- A NaF
- B  $\text{Na}_2\text{O}$
- C  $\text{MgF}_2$
- D MgO

Your answer

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

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

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

A -508

B -254

C +254

D +508

Your answer

10 What is the percentage dissociation of a  $0.015\text{mol dm}^{-3}$  solution of methanoic acid,  $\text{HCOOH}$  ( $K_a = 1.60 \times 10^{-4}\text{mol dm}^{-3}$ )? [1]

A 0.016%

B 1.1%

C 1.82%

D 10.3%

Your answer



- 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? [1]**

	<b>Aqueous potassium carbonate</b>	<b>Aqueous silver nitrate</b>
<b>A</b>	<b>no change</b>	<b>precipitate</b>
<b>B</b>	<b>no change</b>	<b>no change</b>
<b>C</b>	<b>effervescence</b>	<b>no change</b>
<b>D</b>	<b>effervescence</b>	<b>precipitate</b>

**Your answer**

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

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

Which statement is correct in a lithium-ion cell? [1]

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

Your answer

☐

**13 Which substance(s) has/have induced dipole–dipole interactions (London forces) in the solid state? [1]**

**1     $\text{C}_2\text{H}_6$**

**2     $\text{H}_2\text{O}$**

**3     $\text{Si}$**

**A    1, 2 and 3**

**B    Only 1 and 2**

**C    Only 2 and 3**

**D    Only 1**

**Your answer**

14 Which statement(s) is/are correct for the anti-cancer complex  $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ ? [1]

- 1 It has bond angles of  $90^\circ$ .
- 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

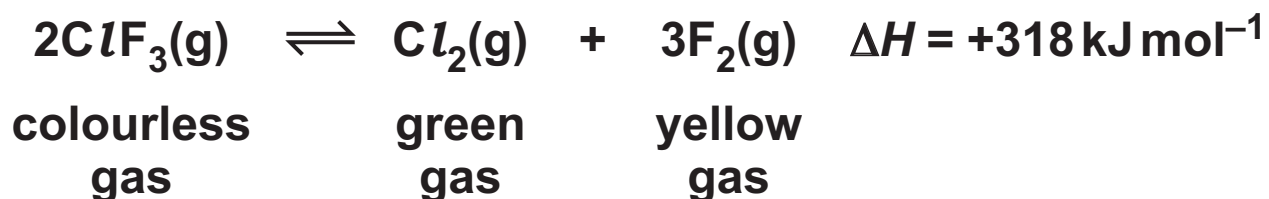
C Only 2 and 3

D Only 1

Your answer

☐

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



**Which statement(s) is/are correct? [1]**

- 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**

☐

## SECTION B

**16** This question is about energy changes.

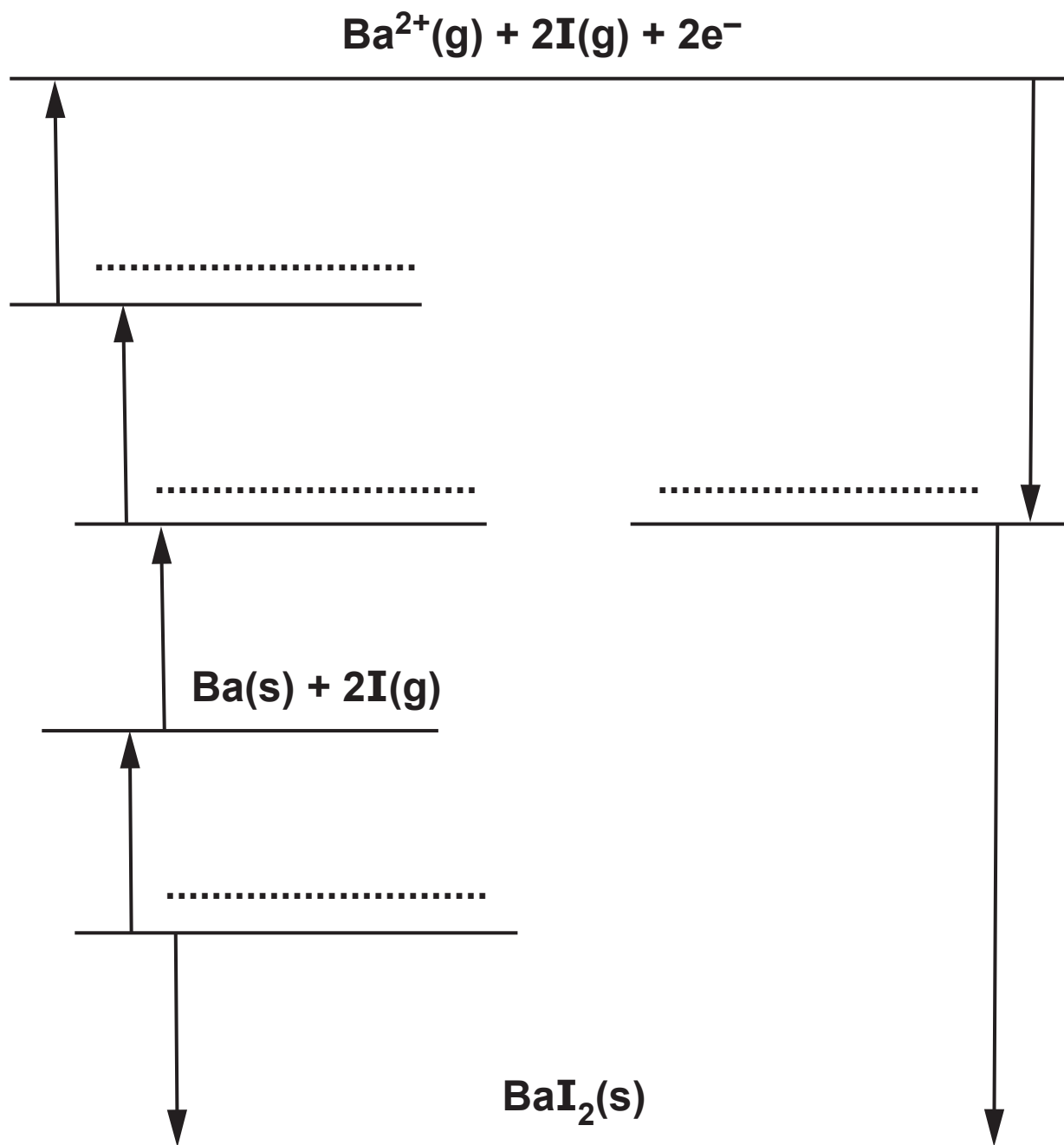
- (a)** Lattice enthalpies can be determined indirectly using Born-Haber cycles.

The table below shows the energy changes that are needed to determine the lattice enthalpy of barium iodide,  $\text{BaI}_2$ .

Energy term	Energy change / $\text{kJ mol}^{-1}$
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<sup>-1</sup> [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 / $\text{kJ mol}^{-1}$	Second ionisation energy / $\text{kJ mol}^{-1}$
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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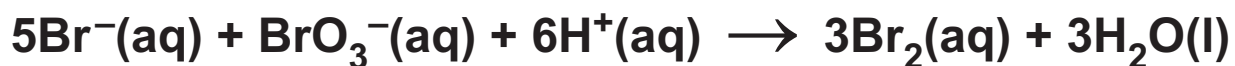
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[4]

**17\* Bromine, Br<sub>2</sub>, can be produced by the reaction:**



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

**Explain how the reaction orders can be determined from the student's results, and determine the rate equation and rate constant for this reaction. [6]**

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Experiment	$[\text{Br}^-]$ /mol dm <sup>-3</sup>	$[\text{BrO}_3^-]$ /mol dm <sup>-3</sup>	$[\text{H}^+]$ /mol dm <sup>-3</sup>	Initial rate /mol dm <sup>-3</sup> s <sup>-1</sup>
1	$2.00 \times 10^{-2}$	$1.20 \times 10^{-1}$	$8.00 \times 10^{-2}$	$2.52 \times 10^{-4}$
2	$6.00 \times 10^{-2}$	$1.20 \times 10^{-1}$	$8.00 \times 10^{-2}$	$7.56 \times 10^{-4}$
3	$4.00 \times 10^{-2}$	$6.00 \times 10^{-2}$	$8.00 \times 10^{-2}$	$2.52 \times 10^{-4}$
4	$2.00 \times 10^{-2}$	$6.00 \times 10^{-2}$	$4.00 \times 10^{-1}$	$3.15 \times 10^{-3}$

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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  $10.5^\circ\text{C}$ .**

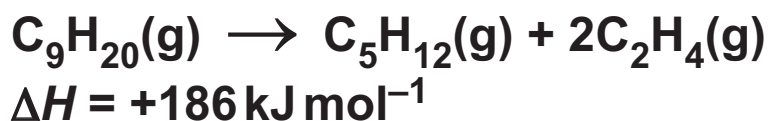
**The spirit burner decreased in mass by 0.133 g.**

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

$$\Delta_c H (C_7H_{16}) = \text{_____} \text{ kJ mol}^{-1} \text{ [3]}$$

- (b) Nonane,  $\text{C}_9\text{H}_{20}$ , can be broken down by heat to form pentane,  $\text{C}_5\text{H}_{12}$ , and ethene,  $\text{C}_2\text{H}_4$ .

**REACTION 1**



The enthalpy changes of combustion of  $\text{C}_9\text{H}_{20}(\text{g})$  and  $\text{C}_2\text{H}_4(\text{g})$  are shown in the table below.

Hydrocarbon	$\Delta_c H / \text{kJ mol}^{-1}$
$\text{C}_9\text{H}_{20}(\text{g})$	−6171
$\text{C}_2\text{H}_4(\text{g})$	−1411

Use  $\Delta H$  in REACTION 1 and the enthalpy changes of combustion in the table to determine the enthalpy change of combustion of  $\text{C}_5\text{H}_{12}(\text{g})$ .

$$\Delta_c H (\text{C}_5\text{H}_{12}(\text{g})) = \underline{\hspace{2cm}} \text{ kJ mol}^{-1} \quad [2]$$

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

**REACTION 2**



- (i) Predict the sign of the entropy change,  $\Delta S$ , for REACTION 2.

Explain your reasoning.

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[1]

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

**REACTION 2**



**The Gibbs equation is shown below.**

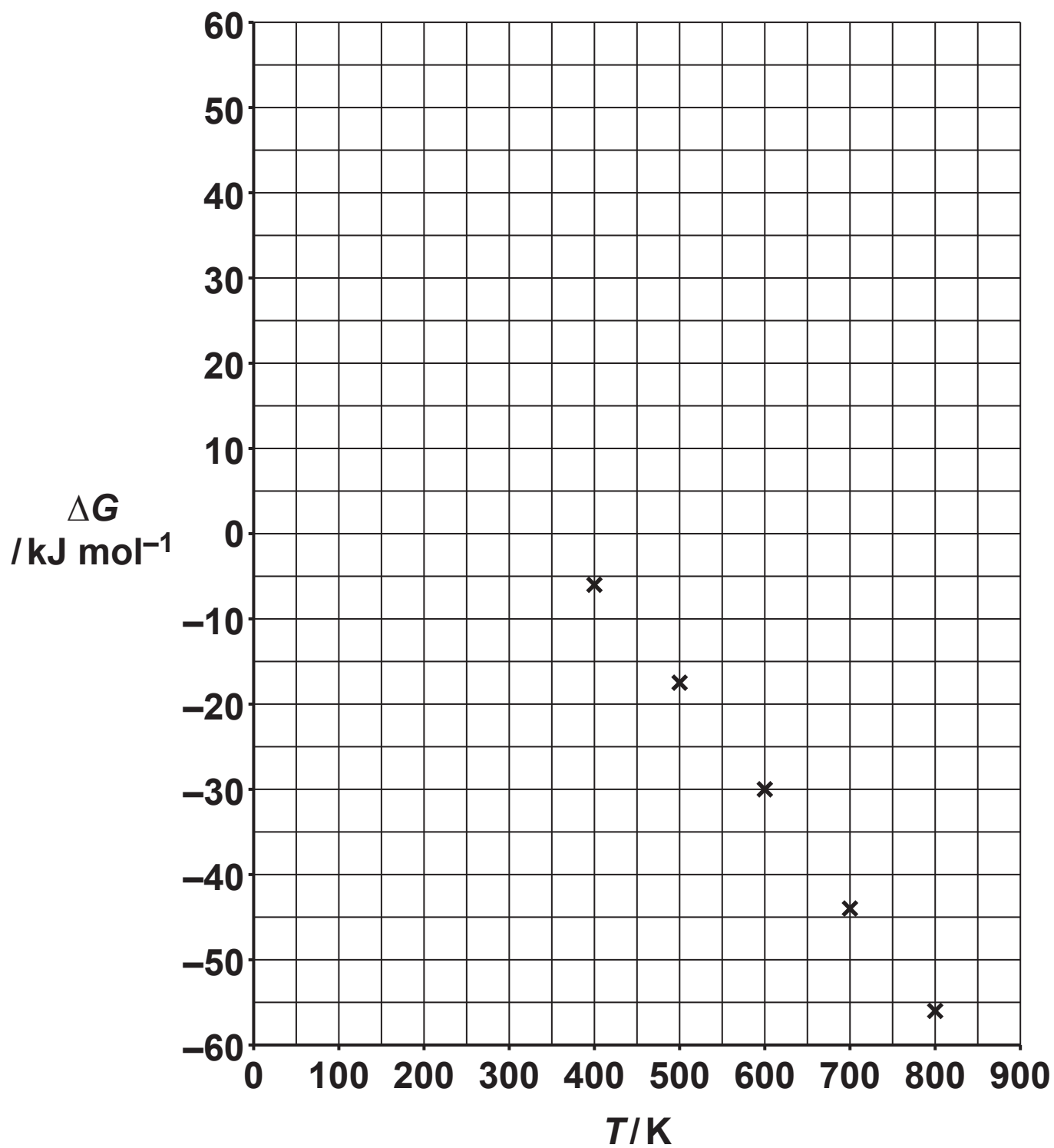
$$\Delta G = \Delta H - T\Delta S$$

**The enthalpy change,  $\Delta H$ , and the entropy change,  $\Delta S$ , can be assumed to be constant at different temperatures.**

**FIG. 18.1 shows values of the free energy change,  $\Delta G$ , in  $\text{kJ mol}^{-1}$ , 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  $\Delta S$ , in  $\text{J K}^{-1} \text{mol}^{-1}$ , for REACTION 2.

Determine the minimum temperature,  $T$ , at which the reaction is feasible.

Determine  $\Delta H$  for REACTION 2. [5]

$$\Delta S = \text{_____} \text{ JK}^{-1} \text{ mol}^{-1}$$

$$\text{minimum } T = \text{_____} \text{ K}$$

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

**19 This question is about oxides of nitrogen.**

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



- (i) A sealed flask containing 6.00 moles of  $\text{NO}_2(\text{g})$  is heated to a constant temperature and allowed to reach equilibrium.**

**The equilibrium mixture contains 5.40 mol of  $\text{NO}_2(\text{g})$ , 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  $\text{N}_2\text{O}_4(\text{g})$  formed at equilibrium.

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[3]

- (b)  $\text{N}_2\text{O}_4$  reacts fully with oxygen to form a different oxide of nitrogen, oxide A, as the only product.

Oxide A is collected and cooled to  $75.0^\circ\text{C}$  at a pressure of 101 kPa.

Under these conditions, oxide A is a gas that occupies a volume of  $74.0\text{ cm}^3$  and has a mass of 0.280 g.

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

molar mass = \_\_\_\_\_  $\text{g mol}^{-1}$

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**

<b>Temperature / °C</b>	<b><math>K_w / \text{mol}^2 \text{dm}^{-6}</math></b>
<b>25</b>	<b><math>1.00 \times 10^{-14}</math></b>
<b>40</b>	<b><math>2.92 \times 10^{-14}</math></b>

- (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  $250.0\text{ cm}^3$  solution of aqueous strontium hydroxide,  $\text{Sr}(\text{OH})_2$ . The solution contains  $0.145\text{ g}$  of strontium hydroxide.

Write an equation for the reaction of strontium with water.

Calculate the pH of this  $250.0\text{ cm}^3$  solution of strontium hydroxide at  $40^\circ\text{C}$ .

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,  $\text{SrCO}_3$ , with an excess of dilute nitric acid,  $\text{HNO}_3$ . A gas is produced.**

**(i) Construct the equation for this reaction.**

\_\_\_\_\_ **[1]**

**(ii) The student then reacts 1.00 g of calcium carbonate,  $\text{CaCO}_3$ , with an excess of dilute nitric acid,  $\text{HNO}_3$ .**

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

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ **[2]**

- (d) A student reacts an excess of magnesium with 25.0 cm<sup>3</sup> of 0.500 mol dm<sup>-3</sup> hydrochloric acid, HCl.**

**The student also reacts an excess of magnesium with 25.0 cm<sup>3</sup> of 0.500 mol dm<sup>-3</sup> ethanoic acid, CH<sub>3</sub>COOH.**

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

\_\_\_\_\_ **[1]**

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

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ **[3]**

(e) Butanoic acid,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ , 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  $250\text{ cm}^3$  of  $0.376\text{ mol dm}^{-3}$  butanoic acid.

This buffer solution has a pH of 5.07 at  $25^\circ\text{C}$ .

Calculate the acid dissociation constant,  $K_a$ , of butanoic acid at  $25^\circ\text{C}$ .

Assume that the volume of the solution remains constant at  $250\text{ cm}^3$  when the potassium hydroxide is dissolved.

$$K_a = \text{_____} \text{ mol dm}^{-3} \text{ [4]}$$

**(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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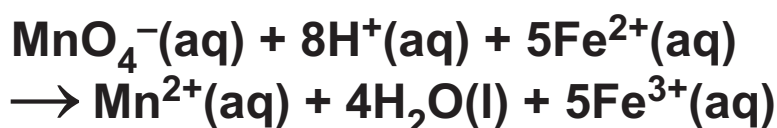
**[1]**

## 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<sup>3</sup> portions of river water are acidified with dilute sulfuric acid. Each portion is titrated with 0.00250 mol dm<sup>-3</sup> potassium manganate(VII) until a colour change is seen.



- (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 <sup>3</sup>	12.65	25.60	38.35
Initial volume / cm <sup>3</sup>	0.00	12.65	25.60
Titre volume / cm <sup>3</sup>			

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<sup>3</sup> [2]

- (iii) Determine the concentration, in mol dm<sup>-3</sup>, of iron(II) ions in the river water.

concentration = \_\_\_\_\_ mol dm<sup>-3</sup> [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  $250.0\text{ cm}^3$  sample of river water and warm gently.
- STEP 2** Cool the solution and remove excess zinc by filtration.
- STEP 3** Acidify  $25.0\text{ cm}^3$  portions of the filtrate from STEP 2. Then titrate each portion with  $0.00250\text{ mol dm}^{-3}$  potassium manganate(VII) until a colour change is seen.

The table opposite shows information about three redox systems.

Use the information in the table opposite to explain the reasons for STEP 1 and STEP 2.

Reason(s) for STEP 1 \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Reason(s) for STEP 2 \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

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

**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. [6]**

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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,  $\text{C}_2\text{O}_4^{2-}$ , is a bidentate ligand.

A complex ion of cobalt(III) contains two ethanedioate ligands and two water ligands.

Determine the charge of this complex ion AND the coordination number of cobalt in the complex ion.

Charge of complex ion \_\_\_\_\_

Coordination number of cobalt \_\_\_\_\_ [2]

- (d) An acidified solution containing  $\text{Cr}_2\text{O}_7^{2-}$  ions reacts with vanadium(III) ions in a redox reaction to form a solution containing  $\text{Cr}^{3+}$  ions and  $\text{VO}_2^+$  ions.

Construct the overall equation for this reaction.

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[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).**

[illegible]












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