Please write clearly in block capitals.

Centre number | | | | | | Candidate number | | | | |

Surname ____________________

Forename(s) ____________________

Candidate signature ____________________
I declare this is my own work.

A-level
CHEMISTRY

Paper 1 Inorganic and Physical Chemistry

Monday 10 June 2024 Morning Time allowed: 2 hours

Materials
For this paper you must have:
- the Periodic Table/Data Booklet, provided as an insert (enclosed)
- a ruler with millimetre measurements
- a scientific calculator, which you are expected to use where appropriate.

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do **not** write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 105.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8	
9	
TOTAL	

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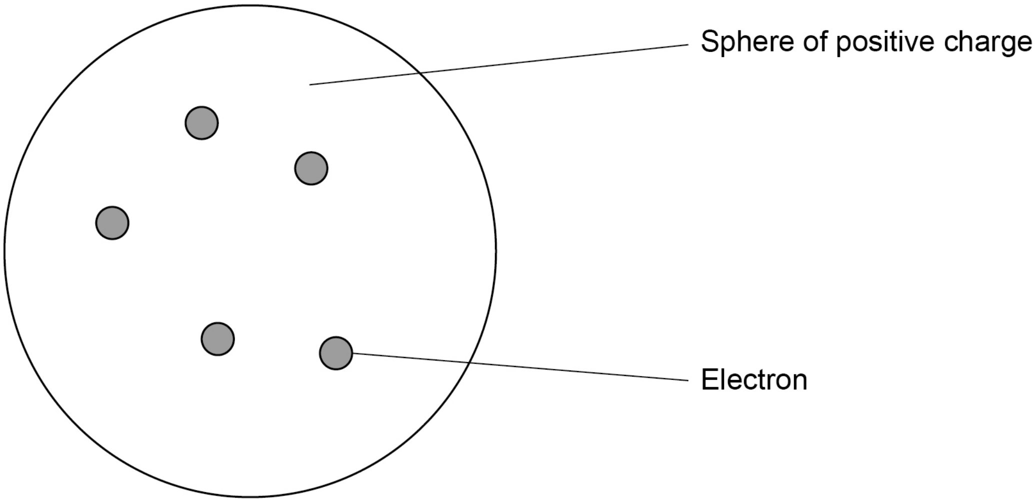
Answer **all** questions in the spaces provided.

0 1 This question is about atomic structure.

0 1 . 1 In 1897 JJ Thomson discovered the electron. He suggested that atoms were positively charged spheres with electrons embedded within them.

Figure 1 represents an atom using Thomson's model.

Figure 1



Suggest the identity of this atom.

Give **two** differences between the modern model of an atom and the Thomson model of an atom.

[3 marks]

Identity ____________________

Difference 1 ____________________

____

Difference 2 ____________________

____

Do not write outside the box

0 1 . 2 Tellurium has a relative atomic mass of 127.6
Iodine has a relative atomic mass of 126.9

Define relative atomic mass.

Suggest **one** property of tellurium that justifies its position before iodine in the modern Periodic Table.

[3 marks]

Definition ____________________

____

____

Justification ____________________

____

____

0 1 . 3 A sample of tellurium is analysed in a time of flight (TOF) mass spectrometer using electron impact ionisation.

Give an equation, including state symbols, for this ionisation.

[1 mark]

____

Question 1 continues on the next page

0 1 . 4 In the TOF mass spectrometer an ion of an isotope of tellurium, with mass number **y**, travels along a 1.25 m flight tube with a kinetic energy of 1.88 x 10^{-12} J

The ion takes 3.00 x 10^{-7} s to reach the detector.

$$KE = \frac{1}{2} mv^2$$

KE = kinetic energy / J
m = mass / kg
v = speed / m s^{-1}

Calculate the mass, in g, of 1 mole of these tellurium ions.

Use your answer to suggest the mass number **y** of the tellurium isotope.

The Avogadro constant, $L = 6.022 \times 10^{23}$ mol^{-1}

[5 marks]

Mass ____________________ g

Mass number **y** ____________________

Do not write outside the box

0 1 . 5 Tellurium has several other isotopes.
Two of these isotopes are ^{126}Te and ^{124}Te
A different sample of tellurium is analysed using a TOF mass spectrometer.

Which statement about kinetic energy (*KE*) is correct?

[1 mark]

Tick (✓) **one** box.

The *KE* of $^{126}Te^{+}$ is greater than the *KE* of $^{124}Te^{+}$ ☐

The *KE* of $^{126}Te^{+}$ is the same as the *KE* of $^{124}Te^{+}$ ☐

The *KE* of $^{126}Te^{+}$ is less than the *KE* of $^{124}Te^{+}$ ☐

13

Turn over for the next question

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ANSWER IN THE SPACES PROVIDED

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0 2 This question is about an experiment to determine the solubility of strontium hydroxide in water at 20 °C

Strontium hydroxide is slightly soluble in water. Strontium hydroxide solution reacts in a similar way to calcium hydroxide solution.

- Some solid strontium hydroxide is added to approximately 1 dm^3 of distilled water in a stoppered flask.
- The mixture is kept at 20 °C. Every day, the mixture is checked. If no solid is present in the flask, more solid strontium hydroxide is added.
- On the day when no more solid needs to be added, the flask is opened and the mixture is filtered into another flask and stoppered.
- A 25.0 cm^3 sample of the filtrate is transferred to a conical flask with a pipette and a few drops of indicator added.
- This sample is titrated with 0.100 mol dm^{-3} hydrochloric acid.
- The titration is repeated several times with further samples of the filtrate. The results are shown in **Table 1** on page 8.

0 2 . 1 Suggest why the solution is kept until no more solid needs to be added.

[1 mark]

____

____

0 2 . 2 Suggest why it is important to remove the undissolved strontium hydroxide before the titration.

[1 mark]

____

____

0 2 . 3 After the filtration, the solution is stored in a stoppered flask.

Suggest a reason for stoppering the flask.

[1 mark]

____

____

Question 2 continues on the next page

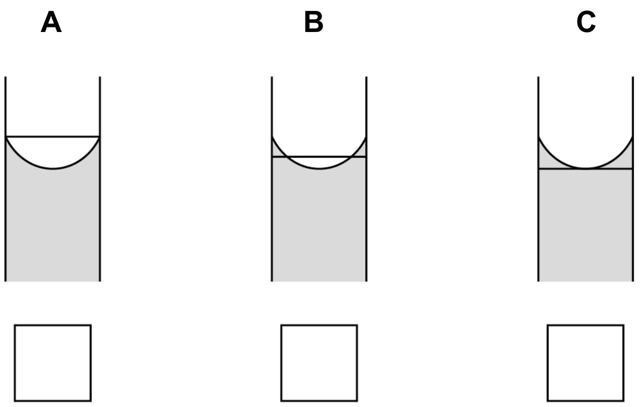
0 2 . 4 The diagrams in **Figure 2** show the part of a pipette with the graduation line.

Which diagram identifies the pipette that is correctly filled?

[1 mark]

Tick (✓) **one** box.

Figure 2



0 2 . 5 Solubility can be quoted as 'g of solute per 100 cm^3 of solution'.

Table 1 shows the results of the titrations between strontium hydroxide and hydrochloric acid. These can be used to determine the solubility of strontium hydroxide.

Table 1

Titration	**Rough**	**1**	**2**	**3**
Final burette reading / cm^3	34.40	38.00	41.05	37.00
Initial burette reading / cm^3	0.00	5.55	8.05	4.60
Titre / cm^3	34.40	32.45	33.00	32.40

Give the equation for the reaction between strontium hydroxide and hydrochloric acid.

Use the results in **Table 1** to calculate the mean titre.

Use the mean titre to calculate the solubility of strontium hydroxide, in g per 100 cm^3 of solution, at 20 °C

[6 marks]

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Equation

Mean titre ____________________ cm^3

Solubility of strontium hydroxide ________________________ g per 100 cm^3 solution

10

Turn over for the next question

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0 3 This question is about aqueous ions of the metal iron.

When an aqueous $[Fe(H_2O)_6]^{3+}$ ion reacts with ethanedioate ions, an iron(III) complex ion **X** is formed.

The only ligands in **X** are ethanedioate ions.

0 3 . 1 Draw the structure of **X**.

Include the charge.

[2 marks]

0 3 . 2 The formation of **X** is an example of the chelate effect.

Explain the meaning of the chelate effect.

[2 marks]

Question 3 continues on the next page

Do not write outside the box

0 3 . 3 Outline how Fe^{2+} ions catalyse the reaction between $S_2O_8^{2-}$ ions and I^- ions in aqueous solution.

In your answer you should include

- a sketch graph to show how the concentration of $S_2O_8^{2-}$ ions changes over time
- an explanation of how Fe^{2+} ions catalyse the reaction, including equations
- an overall equation for the reaction.

[6 marks]

Do not write outside the box

Do not write outside the box

0 3 . 4 A student adds dilute ammonia solution to a solution containing $[Fe(H_2O)_6]^{2+}$ ions.

Give the formula of the precipitate that forms.

[1 mark]

0 3 . 5 The student adds sodium carbonate solution to a solution containing $[Fe(H_2O)_6]^{2+}$ ions.

State **one** observation the student would make.

Give an equation for the reaction.

[2 marks]

Observation

Equation

0 3 . 6 A solution containing $[Fe(H_2O)_6]^{2+}$ ions changes to a yellow-brown colour after several hours in contact with air.

The student adds sodium carbonate to the yellow-brown solution.

Give an equation for the reaction with sodium carbonate.

[1 mark]

14

Do not write outside the box

0 4 This question is about some gas mixtures at equilibrium.

This reaction can be used to make hydrogen.

$$H_2O(g) + CO(g) \rightleftharpoons H_2(g) + CO_2(g) \qquad \Delta H = -41 \text{ kJ mol}^{-1}$$

0 4 . 1 A mixture of 2.00 mol of $H_2O(g)$ and 2.00 mol of $CO(g)$ is allowed to reach equilibrium at a constant temperature in a 20 dm^3 container.
At equilibrium, there are 0.92 mol of $H_2(g)$.

Calculate the mole fraction of $H_2(g)$ in the equilibrium mixture.

[2 marks]

Mole fraction of $H_2(g)$ ______________________

0 4 . 2 State why the equilibrium constant (K_p) for this reaction has no units.

[1 mark]

____

____

____

Question 4 continues on the next page

Do not write outside the box

0 4 . 3 The temperature of the equilibrium mixture formed in Question **04.1** is increased.

How does the amount of H_2(g) change when the new position of equilibrium is reached?

[1 mark]

Tick (✓) **one** box.

The amount decreases. ☐

The amount does not change. ☐

The amount increases. ☐

Ethanol can be made from ethene and steam.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g) \qquad \Delta H = -45 \text{ kJ mol}^{-1}$$

Table 2 shows the mole fractions of each of the gases in an equilibrium mixture at 6000 kPa

Table 2

Gas	**Mole fraction**
Ethene	0.645
Steam	0.323
Ethanol	0.0321

Do not write outside the box

0 4 . 4 Give an expression for K_p for this reaction.

Calculate the value of K_p at 6000 kPa

State the units.

[4 marks]

K_p

Units ____________________________

0 4 . 5 State the effect, if any, of an increase in volume of the container on the value of K_p for this reaction at a constant temperature.

[1 mark]

____

____

9

Turn over for the next question

Do not write outside the box

0 5 This question is about chlorine.

0 5 . 1 Give an equation to show how chlorine forms an acidic solution in water.

[1 mark]

0 5 . 2 Give an equation for the reaction between chlorine and cold, dilute aqueous sodium hydroxide.

[1 mark]

0 5 . 3 In acidic conditions, ClO_3^- ions oxidise Cl^- ions to form Cl_2

Deduce a half-equation for the oxidation of Cl^- to Cl_2

Deduce a half-equation for the reduction of ClO_3^- to Cl_2

Deduce the overall equation for this reaction.

[3 marks]

Half-equation for the oxidation of Cl^- to Cl_2

Half-equation for the reduction of ClO_3^- to Cl_2

Overall equation

Do not write outside the box

0 5 . 4 Give the equation for the reaction of solid sodium chloride with concentrated sulfuric acid.

State the role of the chloride ions in this reaction.

[2 marks]

Equation

Role

0 5 . 5 Draw the shape of the Cl_3^- ion.
Include any lone pairs of electrons that influence the shape.

[1 mark]

0 5 . 6 Chlorine forms an ion with the Group 3 element thallium (Tl).

State and explain the bond angle in $TlCl_2^+$

[2 marks]

Bond angle

Explanation

10

Do not write outside the box

0 6 This question is about vanadium ions.

Table 3 shows some standard electrode potential values.

Table 3

	***E*°** **/ V**
$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$	+1.23
$VO_2^+(aq) + 2H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l)$	+1.00
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightarrow V^{3+}(aq) + H_2O(l)$	+0.34
$V^{3+}(aq) + e^- \rightarrow V^{2+}(aq)$	–0.26
$Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$	–0.44
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	–0.76
$V^{2+}(aq) + 2e^- \rightarrow V(s)$	–1.20
$Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$	–2.38

0 6 . 1 Use the data in **Table 3** to explain why Zn reduces an aqueous solution of VO_2^+ ions to V^{2+} ions, but does not reduce it any further.

[2 marks]

0 6 . 2 Identify the species in **Table 3** that can reduce an aqueous solution of VO_2^+ to V

[1 mark]

Do not write outside the box

0 6 . 3 Two half-cells $Fe^{2+}(aq)$ / $Fe(s)$ and $VO^{2+}(aq)$ / $V^{3+}(aq)$ are connected.

Calculate the EMF of this cell.

Give the conventional representation for this cell.

Give a half-equation for the reaction that occurs at the negative electrode.

[3 marks]

EMF __________

Cell representation

Half-equation

Question 6 continues on the next page

Do not write outside the box

0 6 . 4 0.151 g of impure NH_4VO_3 is added to dilute sulfuric acid to form a solution containing aqueous VO_2^+ ions.

All the VO_3^- ions are converted to VO_2^+ ions.

These VO_2^+ ions are reduced to aqueous V^{2+} ions by reaction with an excess of zinc.

$$2VO_2^+(aq) + 8H^+(aq) + 3Zn(s) \rightarrow 3Zn^{2+}(aq) + 2V^{2+}(aq) + 4H_2O(l)$$

The excess of zinc is removed by filtration and washed.

The filtrate, containing the V^{2+} ions, is titrated with a 0.0200 mol dm^{-3} solution of acidified $KMnO_4$

29.43 cm^3 of $KMnO_4$ solution are needed to oxidise all the V^{2+} ions to VO_2^+ ions.

The ionic equation for the reaction of MnO_4^- ions with V^{2+} ions is

$$3MnO_4^-(aq) + 5V^{2+}(aq) + 4H^+(aq) \rightarrow 2H_2O(l) + 3Mn^{2+}(aq) + 5VO_2^+(aq)$$

Calculate the percentage purity of the NH_4VO_3
Give your answer to 3 significant figures.

[4 marks]

Percentage purity ______________________________

10

Do not write outside the box

0 7 At 40 °C the ionic product of water, $K_w = 2.92 \times 10^{-14}$ mol^2 dm^{-6}

0 7 . 1 Give the expression for K_w

Calculate the pH of pure water at 40 °C
Give your answer to 2 decimal places.

[3 marks]

K_w

pH ____________________________

0 7 . 2 35.0 cm^3 of 0.150 mol dm^{-3} aqueous sodium hydroxide are mixed with 20.0 cm^3 of a 0.100 mol dm^{-3} solution of hydrochloric acid.
The temperature of the solution formed is 40 °C

Calculate the pH of the solution formed.
Give your answer to 2 decimal places.

[5 marks]

pH ____________________________

8

Do not write outside the box

0 8 This question is about enthalpy changes.

0 8 . 1 Theoretical values for enthalpies of lattice dissociation can be calculated using a perfect ionic model.

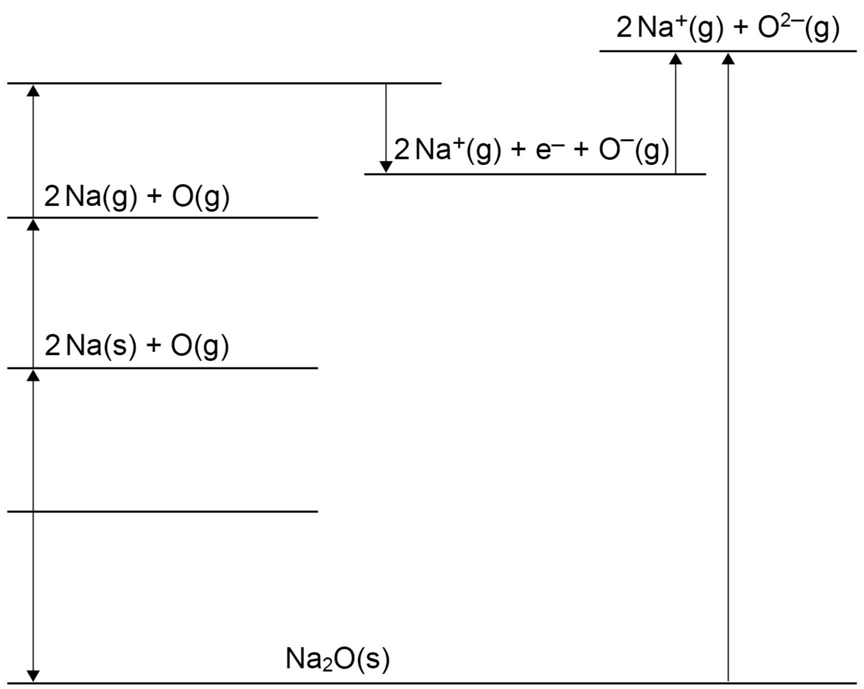
State the meaning of the term perfect ionic model.

[1 mark]

0 8 . 2 Enthalpies of lattice dissociation can also be obtained from Born–Haber cycles.

Figure 3 shows an incomplete Born–Haber cycle for the formation of sodium oxide.

Figure 3



Complete **Figure 3** by writing formulas, including state symbols, of the appropriate species on each of the two blank lines.

[2 marks]

Do not write outside the box

0 8 . 3 **Table 4** shows some enthalpy changes.

Table 4

Enthalpy change	**Δ*H* / kJ mol^{-1}**
Enthalpy of atomisation of oxygen	+248
Enthalpy of atomisation of sodium	+109
Enthalpy of formation of sodium oxide	–416
First ionisation energy of sodium	+494
First electron affinity of oxygen	–142
Second electron affinity of oxygen	+844

Use the data in **Table 4** to calculate the enthalpy of lattice dissociation of sodium oxide.

[2 marks]

Enthalpy of lattice dissociation ______________________ kJ mol^{-1}

0 8 . 4 Explain why the second electron affinity of oxygen has a positive value.

[1 mark]

____

____

____

Question 8 continues on the next page

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0 8 . 5 Explain why the enthalpy of lattice dissociation for sodium oxide is greater than the enthalpy of lattice dissociation for sodium chloride.

[2 marks]

0 8 . 6 Sodium chloride dissolves in water.

Table 5 shows some more enthalpy changes.

Table 5

Enthalpy change	**ΔH / kJ mol^{-1}**
Enthalpy of hydration for Cl^- ions	–364
Enthalpy of hydration for Na^+ ions	–406
Enthalpy of lattice dissociation for NaCl	+771

Use the data in **Table 5** to calculate the enthalpy of solution for sodium chloride.

[2 marks]

Enthalpy of solution ____________________ kJ mol^{-1}

Do not write outside the box

0 8 . 7 Give a reason why data books do **not** contain a value for the enthalpy of solution of sodium oxide.

[1 mark]

____

____

0 8 . 8 Calculate the temperature, in °C, at which this reaction becomes feasible.

$$NaCl(s) \rightarrow Na(s) + \frac{1}{2}Cl_2(g) \qquad \Delta H = +411\ \text{kJ mol}^{-1}$$
$$\Delta S = +90.1\ \text{J K}^{-1}\ \text{mol}^{-1}$$

[3 marks]

Temperature ______________________ °C

14

Turn over for the next question

Do not write outside the box

0 9 This question is about metals and their compounds.

0 9 . 1 State why the atomic radius of calcium is greater than the atomic radius of magnesium.

[1 mark]

0 9 . 2 Magnesium reacts with steam.

Give an equation, including state symbols, for this reaction.

[1 mark]

Do not write outside the box

0 9 . 3 Similar-sized pieces of barium and magnesium are added to separate $100\ cm^3$ samples of dilute sulfuric acid. In each case the sulfuric acid is in excess.

The barium reacts quickly at first. After a few minutes the reaction stops, even though there is still some unreacted barium in the flask.

The magnesium reacts more slowly than the barium, but the reaction continues until all the magnesium has reacted.

Explain why

- the barium initially reacts more quickly than the magnesium
- the barium reaction stops before all the barium has reacted.

[3 marks]

Question 9 continues on the next page

Do not write outside the box

0 9 . 4 A metal nitrate **X**$(NO_3)_2$ completely decomposes when heated.

$$2\mathbf{X}(NO_3)_2(s) \rightarrow 2\mathbf{X}O(s) + 4NO_2(g) + O_2(g)$$

A 0.832 g sample of **X**$(NO_3)_2$ decomposes on heating to produce a total of 348 cm^3 of gas at 298 K and 100 kPa

Deduce the identity of metal **X**.

The ideal gas constant, R = 8.31 J K^{-1} mol^{-1}

[6 marks]

Identity of metal **X** ______________________

Do not write outside the box

0 9 . 5 Sodium reacts with aluminium and hydrogen to form solid $NaAlH_4$

Give an equation for this reaction.

Suggest why $NaAlH_4$ has a high melting point.

[3 marks]

Equation

Suggestion

0 9 . 6 Give the equation for the reaction between H_3PO_4 and an excess of NaOH

[1 mark]

Lithium is an important metal used in cells to power mobile phones.

0 9 . 7 In a lithium cell, a lithium cobalt oxide electrode and a lithium electrode are used.

Give the equation for the reaction that occurs at the positive electrode.

[1 mark]

0 9 . 8 Commercial electrochemical cells can be rechargeable or non-rechargeable.

State why lithium cells can be recharged.

[1 mark]

17

END OF QUESTIONS

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