Surname _____

Forename(s) _____

Centre Number _____

Candidate Number _____

Candidate Signature _____

I declare this is my own work.

A-level

CHEMISTRY

Paper 1 Inorganic and Physical Chemistry

7405/1

Monday 10 June 2024 Morning

Time allowed: 2 hours

[Turn over]

2

On the front of this book, write your surname and forename(s), your centre number, your candidate number and add your signature.

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.**
- **Answer ALL questions.**

- **You must answer the questions in the spaces provided. Do NOT write 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.**

DO NOT TURN OVER UNTIL TOLD TO DO SO

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Answer ALL questions in the spaces provided.

0 1

This question is about atomic structure.

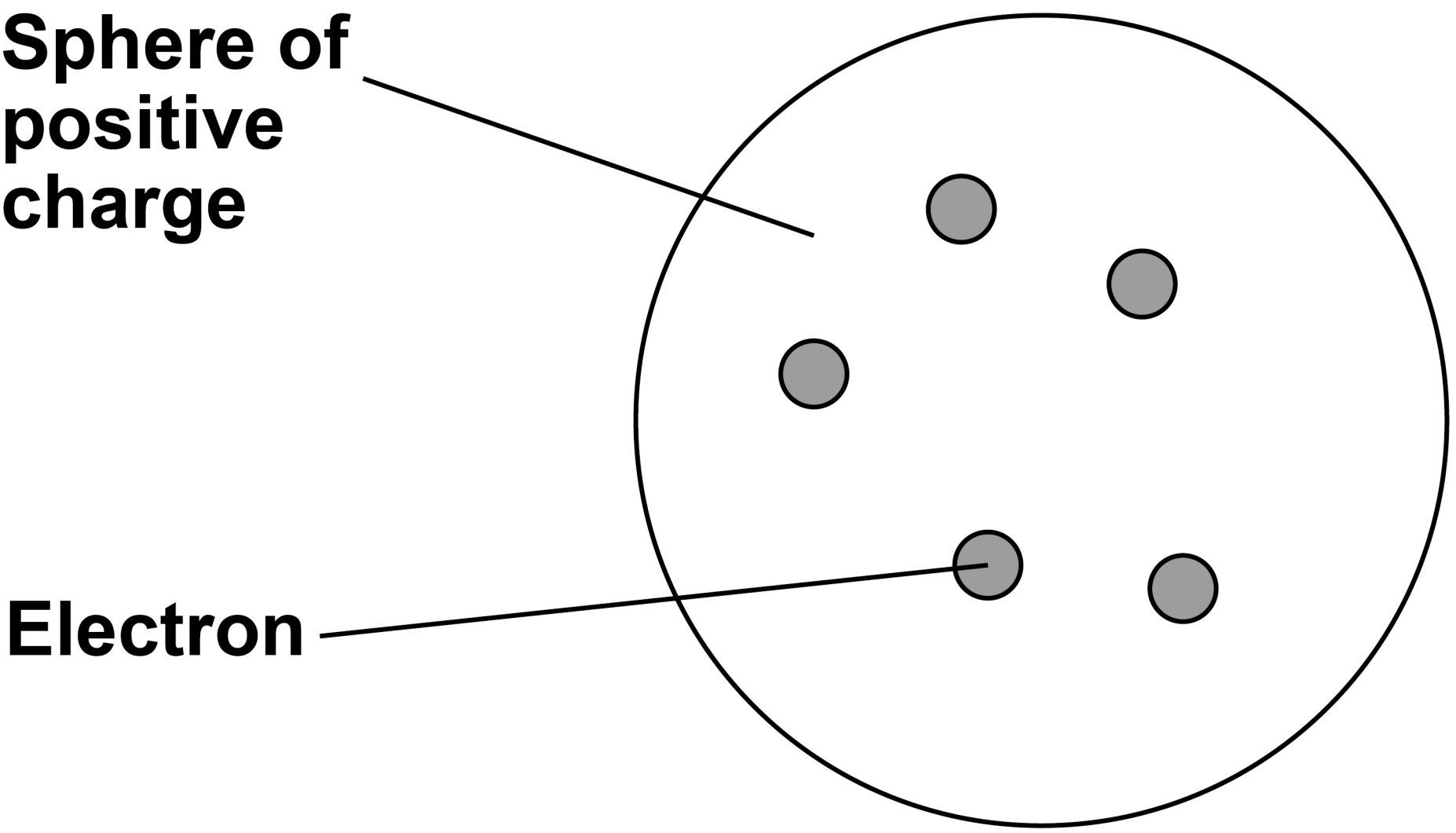
[Turn over]

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 _____

_____

_____

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]

---

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 1.88×10^{-12} J

The ion takes 3.00×10^{-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 _____

[Turn over]

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

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[Turn over]

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 20.

0 2 . 1

Suggest why the solution is kept until no more solid needs to be added. [1 mark]

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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]

[Turn over]

0 2 . 4

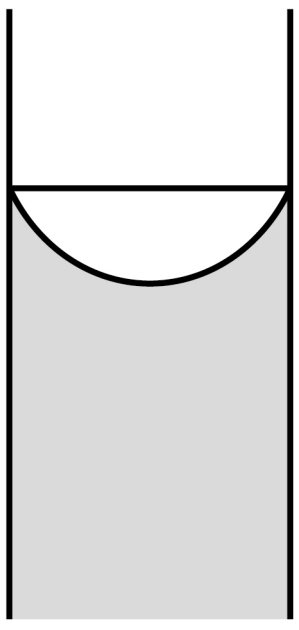
The diagrams in FIGURE 2, below and on the opposite page, show the part of a pipette with the graduation line.

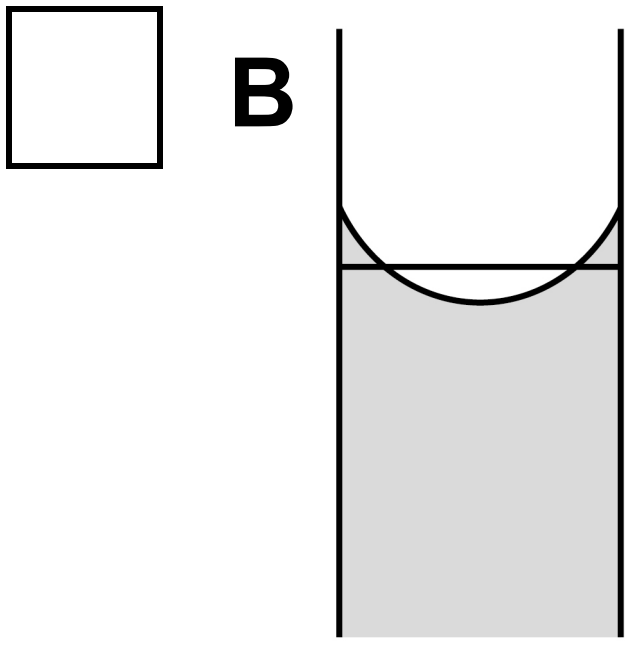
Which diagram identifies the pipette that is correctly filled? [1 mark]

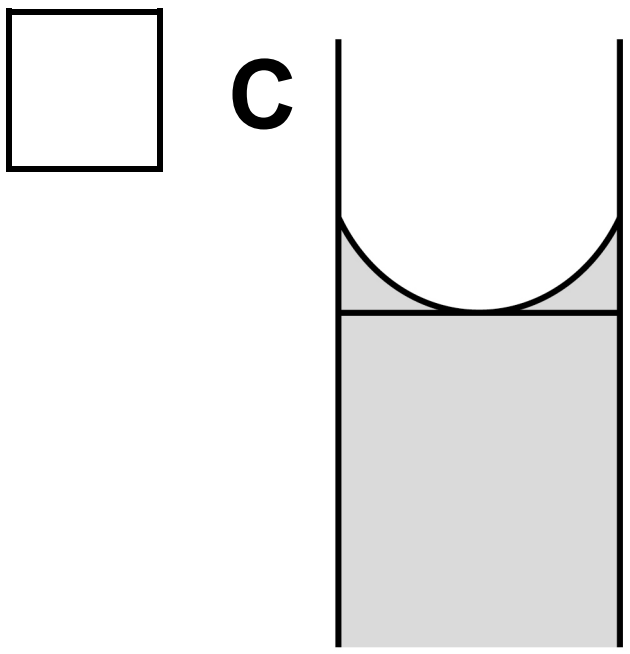
Tick (✓) ONE box.

FIGURE 2

☐ **A**







[Turn over]

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

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[Turn over]

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

Use the results in TABLE 1, on page 20, 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]

Equation

Mean titre _____ **cm^3**

Solubility of strontium hydroxide

_____ g per 100 cm^3 solution

[Turn over]

10

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]

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[Turn over]

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]

[Turn over]

30

[Turn over]

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]

---

0 4

This question is about some gas mixtures at equilibrium.

This reaction can be used to make hydrogen.

$$H_2O(g) + CO(g) \rightleftharpoons H_2(g) + CO_2(g)$$

$\Delta H = -41 \text{ kJ mol}^{-1}$

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 $H_2(g)$ _____

[Turn over]

0 4 . 2

State why the equilibrium constant (K_p) for this reaction has no units. [1 mark]

0 4 . 3

The temperature of the equilibrium mixture formed in Question 04.1, on page 36, 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.**

[Turn over]

Ethanol can be made from ethene and steam.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)$$

$$\Delta H = -45 \text{ kJ mol}^{-1}$$

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

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

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]

[Turn over]

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

[Turn over]

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

0 6

This question is about vanadium ions.

TABLE 3, on page 50, shows some standard electrode potential values.

[Turn over]

TABLE 3

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

REPEAT OF TABLE 3

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

0 6 . 2

Identify the species in TABLE 3 that can reduce an aqueous solution of VO_2^+ to V [1 mark]

---

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

[Turn over]

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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.

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

The excess of zinc is removed by filtration and washed.

[Turn over]

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

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

Calculate the percentage purity of the NH_4VO_3

Give your answer to 3 significant figures, on the opposite page. [4 marks]

Percentage purity _____

10

[Turn over]

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 _____

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[Turn over]

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 _____

[Turn over]

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]

BLANK PAGE

[Turn over]

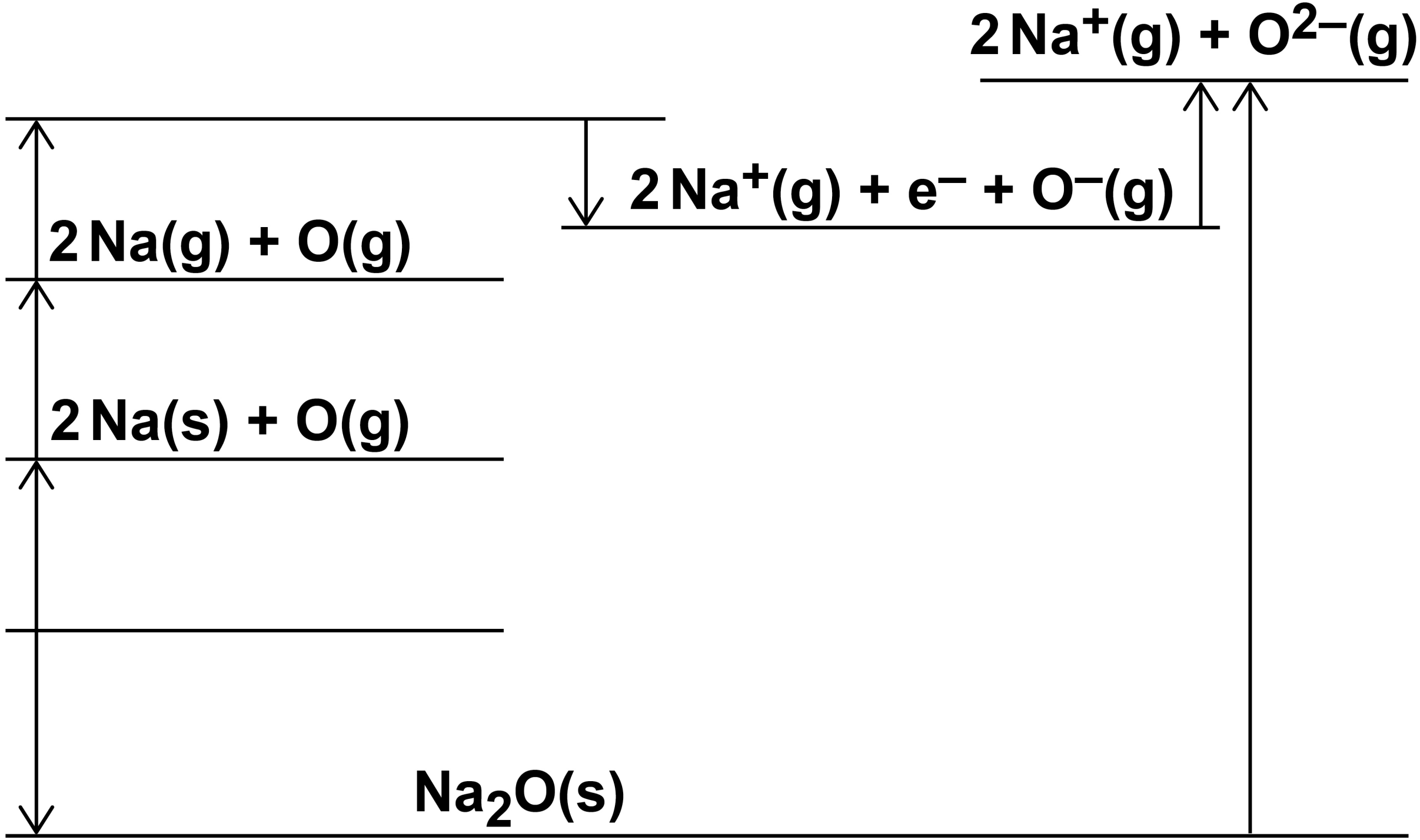
0 8 . 2

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

FIGURE 3, on the opposite page, shows an incomplete Born–Haber cycle for the formation of sodium oxide.

Complete FIGURE 3, on the opposite page, by writing formulas, including state symbols, of the appropriate species on each of the two blank lines. [2 marks]

FIGURE 3



[Turn over]

0 8 . 3

TABLE 4 shows some enthalpy changes.

TABLE 4

ENTHALPY CHANGE	ΔH / 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]

	kJ mol^{-1}
Enthalpy of lattice dissociation	

[Turn over]

0 8 . 4

Explain why the second electron affinity of oxygen has a positive value. [1 mark]

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}

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.

$$NaCl(s) \longrightarrow Na(s) + \frac{1}{2}Cl_2(g)$$

$\Delta H = +411$ kJ mol^{-1}

$\Delta S = +90.1$ J K^{-1} mol^{-1}

[3 marks]

Temperature _____ **°C**

[Turn over]

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]

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]

0 9 . 4

A metal nitrate $X(NO_3)_2$ completely decomposes when heated.

$$2\,X(NO_3)_2(s) \rightarrow 2\,XO(s) + 4\,NO_2(g) + O_2(g)$$

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 _____

[Turn over]

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]

END OF QUESTIONS

17

Additional page, if required.

Write the question numbers in the left-hand margin.

Additional page, if required.

Write the question numbers in the left-hand margin.

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For Examiner's Use	
Question	Mark
1	
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