

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname StemUp Model Solution

Forename(s) _____

Candidate signature _____

I declare this is my own work.

INTERNATIONAL A-LEVEL CHEMISTRY (9620)

Unit 3: Inorganic 2 and Physical 2

Wednesday 15 January 2020 07:00 GMT Time allowed: 1 hour 30 minutes

Materials

For this paper you must have:

- the Periodic Table/Data Sheet, provided as an insert
- 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 80.

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



J A N 2 0 C H 0 3 0 1

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

0 1

This question is about thermodynamics.

The equation for a reaction used to manufacture hydrogen is shown.

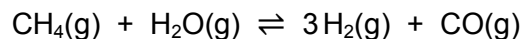


Table 1 shows some data for this reaction.

Table 1

	Enthalpy of formation $\Delta_f H / \text{kJ mol}^{-1}$	Entropy $S / \text{J K}^{-1} \text{mol}^{-1}$
$\text{CH}_4(\text{g})$	-75	186
$\text{H}_2\text{O}(\text{g})$	-242	189
$\text{H}_2(\text{g})$	0	131
$\text{CO}(\text{g})$	-111	214

0 1 . 1

Use data from **Table 1** to determine the enthalpy change, ΔH , in kJ mol^{-1} , for the reaction.

[2 marks]

$$\Delta H = \sum \Delta_f H (\text{products}) - \sum \Delta_f H (\text{reactants})$$

$$\Delta H = [(3 \times 0) + (-111)] - [(-75) + (-242)]$$

$$\Delta H = -111 - (-317) = +206 \text{ kJ mol}^{-1}$$

$$\Delta H \quad \underline{\quad +206 \quad} \quad \text{kJ mol}^{-1}$$



0 1 . 2

Use data from **Table 1** to determine the entropy change, ΔS , in $\text{J K}^{-1} \text{mol}^{-1}$, for the reaction.

[2 marks]

$$\Delta S = \Sigma S (\text{products}) - \Sigma S (\text{reactants})$$

$$\Delta S = [(3 \times 131) + 214] - [186 + 189]$$

$$\Delta S = 607 - 375 = +232 \text{ J K}^{-1} \text{mol}^{-1}$$

$$\Delta S \quad +232 \quad \text{J K}^{-1} \text{mol}^{-1}$$

0 1 . 3

Use your answers to **Question 01.1** and **Question 01.2** to calculate the Gibbs free-energy change, ΔG , in kJ mol^{-1} , at 25°C

State how your answer shows that this reaction is **not** feasible at 25°C

(If you were unable to answer **Questions 01.1** or **01.2**, you should assume that the values are $\Delta H = +220 \text{ kJ mol}^{-1}$ and $\Delta S = +278 \text{ J K}^{-1} \text{mol}^{-1}$

These are **not** the correct values.)

[2 marks]

$$\Delta G = \Delta H - T\Delta S \quad (T = 25 + 273 = 298 \text{ K})$$

$$\Delta G = +206 - (298 \times 0.232)$$

$$\Delta G = 206 - 69.1 = +137 \text{ kJ mol}^{-1}$$

$$\Delta G \quad +137 \quad \text{kJ mol}^{-1}$$

How answer shows reaction is not feasible

ΔG is positive ($\Delta G > 0$), so the reaction is not feasible at 25°C

Turn over ►



0 1 . 4

Use your answers to **Question 01.1** and **Question 01.2** to determine the minimum temperature, in °C, at which this reaction is feasible.

(If you were unable to answer **Questions 01.1** or **01.2**, you should assume that the values are $\Delta H = +220 \text{ kJ mol}^{-1}$ and $\Delta S = +278 \text{ J K}^{-1} \text{ mol}^{-1}$

These are **not** the correct values.)

[2 marks]

for the reaction to be feasible, $\Delta G \leq 0$, so at the minimum temperature $\Delta G = 0$

$$\Delta H = T\Delta S, \text{ so } T = \Delta H \div \Delta S$$

$$T = 206 \div 0.232 = 888 \text{ K}$$

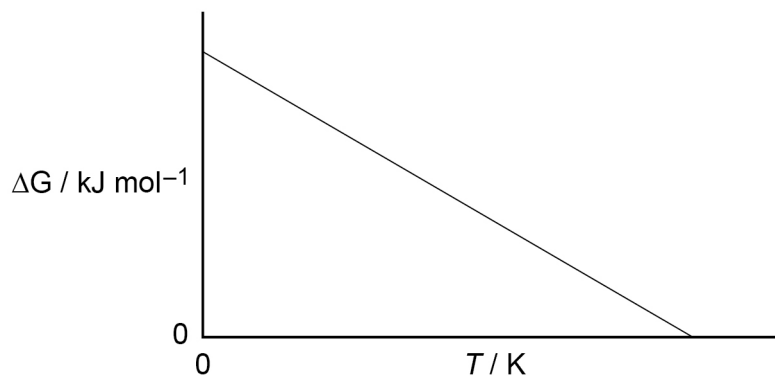
$$T = 888 - 273 = 615 \text{ }^{\circ}\text{C}$$

Temperature 615 °C



0 1 . 5

The graph shows how the free-energy change, ΔG , varies with temperature for a different reaction involving only gases.



Which of the following statements is correct about this graph?

[1 mark]

Tick (✓) **one** box.

There is a decrease in disorder during this reaction.

☐

The enthalpy change for this reaction is negative.

☐

The reaction becomes feasible at high temperature.

☒

9

Turn over for the next question

Turn over ►



0 2

This question is about compounds of silicon.

0 2 . 1

When chlorine gas is passed over a heated mixture of silicon dioxide and carbon, a reaction occurs to form silicon(IV) chloride and carbon monoxide.

Write an equation for this reaction.

[1 mark]



0 2 . 2

The melting points of two compounds of silicon are shown.

silicon dioxide	1713°C
silicon(IV) chloride	−69°C

Explain, in terms of structure and bonding, why silicon(IV) chloride has a lower melting point than silicon dioxide.

[4 marks]

Silicon(IV) chloride has a simple molecular structure.

Between the SiCl_4 molecules there are only weak van der Waals' forces, which need little energy to break, so it melts at a low temperature.

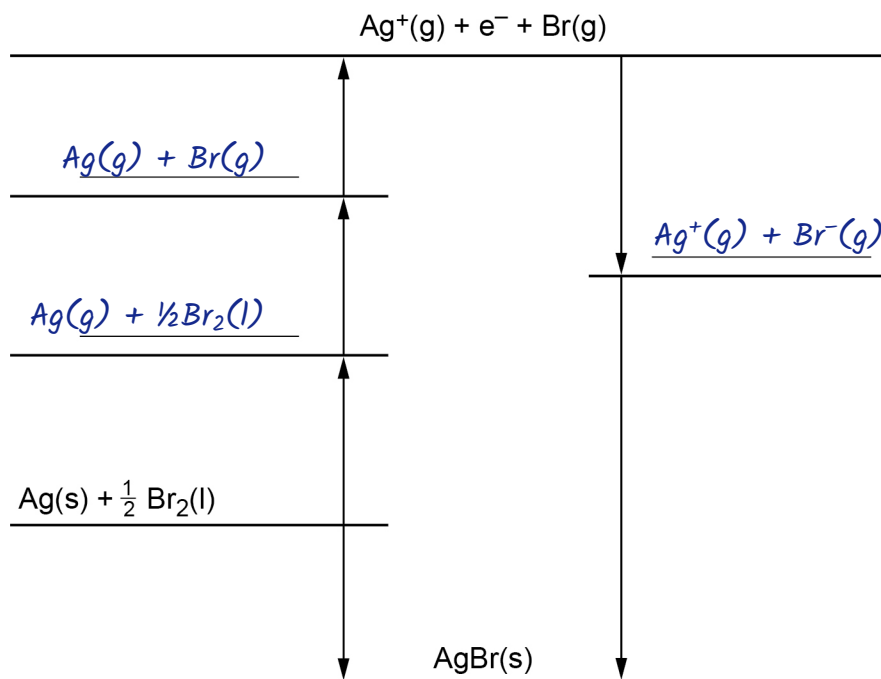
Silicon dioxide is macromolecular (a giant covalent lattice).

To melt it, many strong covalent bonds between the Si and O atoms must be broken, which needs a lot of energy, so its melting point is much higher.



0 3

Figure 1 shows an incomplete Born–Haber cycle for the formation of silver bromide, AgBr(s) .

Figure 1

0 3 . 1

Complete **Figure 1** by writing the formulas, including state symbols, of the appropriate species on each of the three blank lines.

[3 marks]

Question 3 continues on the next page

Turn over ►



0 3 . 2

Table 2 shows some enthalpy data.

Table 2

Enthalpy change	$\Delta H / \text{kJ mol}^{-1}$
Atomisation of silver	+289
First ionisation energy of silver	+732
Atomisation of bromine	+112
Enthalpy of formation of silver bromide	-100
Lattice formation of silver bromide	-890

Calculate the electron affinity of bromine.

[2 marks]

$$\Delta_f H = \Delta_{at} H(\text{Ag}) + IE_1(\text{Ag}) + \Delta_{at} H(\text{Br}) + EA(\text{Br}) + \Delta_L H(\text{AgBr})$$

$$-100 = 289 + 732 + 112 + EA + (-890)$$

$$EA = -100 - 289 - 732 - 112 + 890 = -343 \text{ kJ mol}^{-1}$$

Electron affinity -343 kJ mol⁻¹

0 3 . 3

In Table 2, the value of the enthalpy of lattice formation of silver bromide is an experimental value.

A theoretical value for the enthalpy of lattice formation can be calculated using a perfect ionic model.

Explain why the experimental value is more exothermic than the theoretical value.

[2 marks]

The perfect ionic model assumes the ions are perfect spheres with only ionic attraction. In reality AgBr has some covalent character (the Ag⁺ ion distorts the Br⁻ ion), so the forces holding the lattice together are stronger.



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0 4

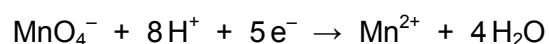
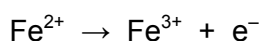
Hydrated ammonium iron(II) sulfate has the formula $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$

The value of x in this formula can be calculated using results from this redox titration.

Method

- Dissolve a known mass of hydrated ammonium iron(II) sulfate in dilute sulfuric acid to make 250cm^3 of solution.
- Titrate 25.0cm^3 portions of this solution with a solution of potassium manganate(VII).

The half-equations for the reactions that occur during this titration are shown.



Results

Mass of hydrated ammonium iron(II) sulfate	8.37 g
Mean titre of potassium manganate(VII) solution	22.85cm^3
Concentration of potassium manganate(VII) solution	0.0187mol dm^{-3}

0 4

1

State the colour change at the end-point of the titration.

[1 mark]

colourless to (pale) pink



0 4 . 2

Use the results to calculate the relative formula mass of $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$

[4 marks]

$$n(\text{MnO}_4^-) = 0.0187 \times 22.85 \div 1000 = 4.273 \times 10^{-4} \text{ mol}$$

$$\text{Fe}^{2+} : \text{MnO}_4^- = 5 : 1$$

$$n(\text{Fe}^{2+}) \text{ in } 25.0 \text{ cm}^3 = 5 \times 4.273 \times 10^{-4} = 2.136 \times 10^{-3} \text{ mol}$$

$$n(\text{Fe}^{2+}) \text{ in } 250 \text{ cm}^3 = 10 \times 2.136 \times 10^{-3} = 0.02136 \text{ mol}$$

$$M_r = 8.37 \div 0.02136 = 392 \text{ (391.8)}$$

Relative formula mass 392

0 4 . 3

Deduce the value of x in $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$

(If you were unable to calculate the relative formula mass in **Question 04.2**, you should use the value 356.0

This is **not** the correct value.)

[2 marks]

$$M_r \text{ of } (\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 = (2 \times 18.0) + 55.8 + (2 \times 96.1) = 284.0$$

$$\text{mass of water} = 392 - 284.0 = 108$$

$$x = 108 \div 18.0 = 6$$

x 6

7

Turn over ►

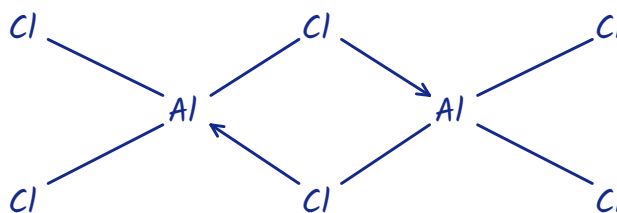
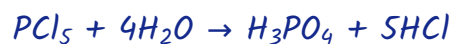


0 5

This question is about some oxides and chlorides of Period 3 elements.

0 5 . 1Sodium burns in air to form the oxide Na_2O State **two** observations that could be made during this reaction.**[2 marks]**Observation 1 bright yellow (orange) flameObservation 2 white solid (white powder / ash) forms**0 5 . 2**Aluminium reacts with chlorine to form the chloride Al_2Cl_6 Draw the structure of Al_2Cl_6

You should represent covalent bonds by a line (—) and co-ordinate bonds by an arrow (→).

[2 marks]**0 5 . 3**Write an equation for the reaction of PCl_5 with water.**[1 mark]**

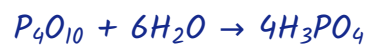
0 5 . 4

Write an equation for the reaction of P_4O_{10} with water.

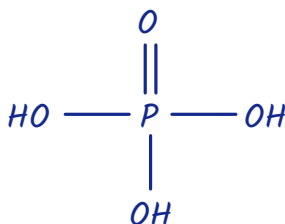
Draw the structure of the acid formed.

[2 marks]

Equation



Structure



 7

Turn over for the next question

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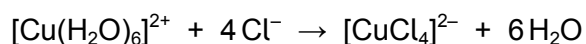


0 6

This question is about complexes containing transition metal ions.

0 6 . 1

The equation for a ligand substitution reaction in aqueous solution is shown.



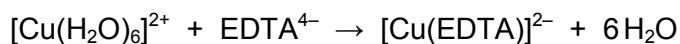
Complete **Table 3** to show the features of each of the copper-containing species in this reaction.

[3 marks]**Table 3**

Feature	$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$	$[\text{CuCl}_4]^{2-}$
Colour	<i>blue</i>	yellow-green
Shape	octahedral	<i>tetrahedral</i>
Oxidation state of copper	+2	<i>+2</i>

0 6 . 2

The equation for another ligand substitution reaction in aqueous solution is shown.



The enthalpy change for this reaction is very small.

Explain why $[\text{Cu}(\text{EDTA})]^{2-}$ is more stable than $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$

[2 marks]

The number of particles increases from 2 to 7 (one EDTA^{4-} replaces six H_2O ligands), so there is an increase in entropy (disorder), ΔS is positive.

Since $\Delta H \approx 0$, $\Delta G = \Delta H - T\Delta S$ is negative, so the complex formed is more stable (chelate effect).



0 6 . 3

A solution containing $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ ions appears deep blue when visible light passes through it.

Explain why it has a blue colour.

[3 marks]

The complex ion absorbs some wavelengths (frequencies) of visible light.

This energy is used to move (excite) d electrons from a lower to a higher energy level ($\Delta E = h\nu$).

The ions absorb red/orange light (lower frequency, longer wavelength) and the remaining light, mainly blue, is transmitted, so the solution looks blue.

0 6 . 4

A metal-aqua ion in aqueous solution has a concentration of approximately 0.3 mol dm^{-3}

Describe how a colorimeter can be used to measure the concentration of this solution accurately.

[3 marks]

Prepare a series of solutions of the metal-aqua ion of known concentration covering the range around 0.3 mol dm^{-3} (e.g. 0.1 to 0.5 mol dm^{-3}).

Using a suitable colour filter, zero the colorimeter with water, then measure the absorbance of each standard solution.

Plot a calibration graph of absorbance against concentration, measure the absorbance of the unknown solution and read its concentration off the graph.

Question 6 continues on the next page

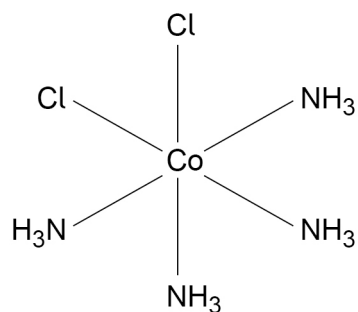
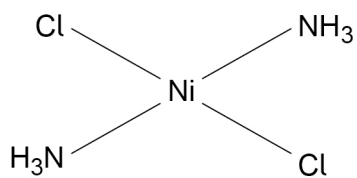
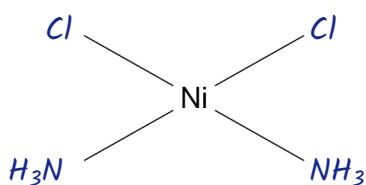
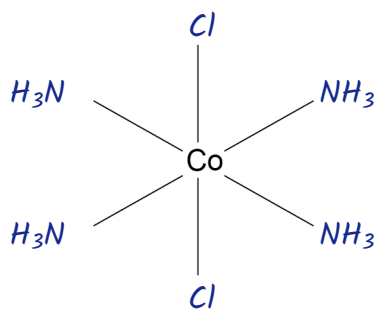
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0 6 . 5

Many metal complexes exist as *cis-trans* isomers.

Complete the diagrams to show the missing ligands.

[2 marks]**Cis isomer****Trans isomer**

13



0 7

This question is about Brønsted–Lowry acids and bases.

0 7 . 1

Phosphoric acid dissociates in three stages as shown.

Write equations to show how the HPO_4^{2-} ion can act either as an acid or as a base.**[2 marks]**

As an acid



As a base



0 7 . 2

Chloric(VII) acid (HClO_4) is a strong acid.An aqueous solution of this acid has a concentration of 1.57 mol dm^{-3}

Calculate the pH of this solution.

Give your answer to two decimal places.

[1 mark]

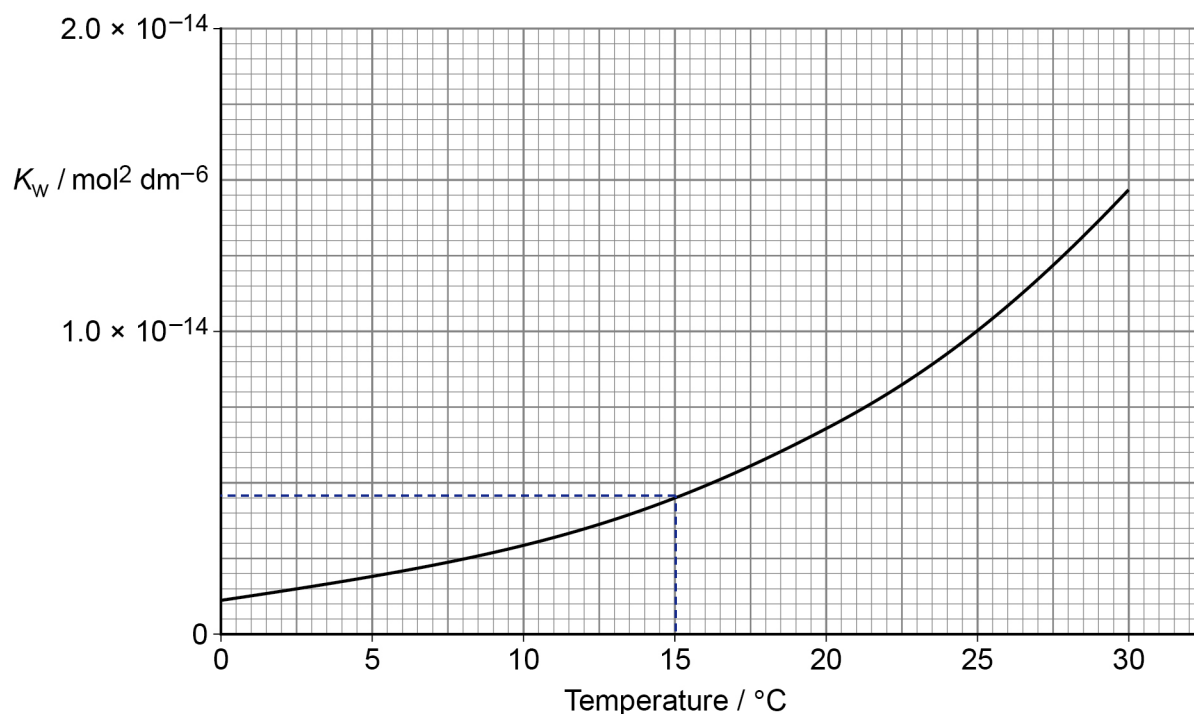
strong acid, fully dissociated: $[\text{H}^+] = 1.57 \text{ mol dm}^{-3}$

$$\text{pH} = -\log(1.57) = -0.20$$

pH -0.20**Question 7 continues on the next page****Turn over ►**

0 7 . 3 The value of the ionic product of water (K_w) varies with temperature as shown in **Figure 2**.

Figure 2



Use information from **Figure 2** and the expression for K_w to calculate the pH of water at 15 °C

Give your answer to two decimal places.

[3 marks].

from the graph, at 15 °C: $K_w = 0.45 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$

pure water: $[H^+] = [OH^-]$, so $K_w = [H^+]^2$

$[H^+] = \sqrt{(0.45 \times 10^{-14})} = 6.7 \times 10^{-8} \text{ mol dm}^{-3}$

$pH = -\log(6.7 \times 10^{-8}) = 7.17$

pH 7.17



0 7 . 4

Ethanoic acid is a weak acid with $pK_a = 4.76$ at 25°C An aqueous solution of ethanoic acid has a concentration of 0.83 mol dm^{-3} Calculate the concentration, in mol dm^{-3} , of hydrogen ions in this solution at 25°C **[3 marks]**

$$K_a = 10^{-4.76} = 1.74 \times 10^{-5} \text{ mol dm}^{-3}$$

$$K_a = [H^+]^2 \div [HA], \text{ so } [H^+] = \sqrt{K_a[HA]}$$

$$[H^+] = \sqrt{(1.74 \times 10^{-5} \times 0.83)} = 3.80 \times 10^{-3} \text{ mol dm}^{-3}$$

Concentration of hydrogen ions 3.80×10^{-3} mol dm^{-3}

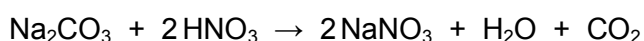
0 7 . 5

A student does a titration, using a suitable indicator, to determine the concentration of a solution of nitric acid.

Method

- Dissolve 7.02g of hydrated sodium carbonate ($\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$) in water and make the solution up to 250 cm^3
- Titrate 25.0 cm^3 portions of this solution with the nitric acid solution.
- Calculate the mean titre of the nitric acid solution.

The equation for the reaction is shown.

The student's mean titre was 21.65 cm^3 Determine the concentration, in mol dm^{-3} , of the nitric acid solution.**[4 marks]**

$$M_r(\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}) = 286.0$$

$$n(\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}) = 7.02 \div 286.0 = 0.02455 \text{ mol}$$

$$n(\text{Na}_2\text{CO}_3) \text{ in } 25.0 \text{ cm}^3 = 0.02455 \div 10 = 0.002455 \text{ mol}$$

$$n(\text{HNO}_3) = 2 \times 0.002455 = 0.004909 \text{ mol}$$

$$[\text{HNO}_3] = 0.004909 \div 0.02165 = 0.227 \text{ mol dm}^{-3}$$

Concentration 0.227 mol dm^{-3}

13

Turn over ►



0 8

This question is about solutions containing metal ions.

0 8 . 1

Explain why a solution containing $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ ions is more acidic than a solution containing $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ ions.

[2 marks]

Fe^{3+} has a greater charge density (higher charge, smaller size) than Fe^{2+} , so it is more polarising.

It attracts the bonding electrons in the O–H bonds of the water ligands more strongly, weakening them, so H^+ ions are released more readily.

A student adds some aqueous reagents, each in excess, to separate solutions containing metal-aqua ions.

Table 4 shows these tests and the observations recorded.

Table 4

Test	Metal-aqua ion	Reagent added to excess	Observations
1	$[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$	NaOH	green precipitate X
2	$[\text{Al}(\text{H}_2\text{O})_6]^{3+}$	Na_2CO_3	white precipitate Y
3	$[\text{Al}(\text{H}_2\text{O})_6]^{3+}$	NaOH	white precipitate that dissolves in excess NaOH to form a colourless solution Z
4	M	NH_3	brown precipitate



0 8 . 2

Give the formulas of **X**, **Y** and **Z**.

[3 marks]

Green precipitate **X** $\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2$ White precipitate **Y** $\text{Al}(\text{H}_2\text{O})_3(\text{OH})_3$ Colourless solution **Z** $[\text{Al}(\text{OH})_4]^-$

0 8 . 3

Give **one** other observation that the student could make in Test 2.

[1 mark]

effervescence (bubbles of gas / fizzing)

0 8 . 4

The student repeats Test 3, but does **not** add an excess of aqueous NaOH
The student filters off the white precipitate and adds an excess of hydrochloric acid to the precipitate.

Write an equation for the reaction that occurs between the acid and the precipitate.

[1 mark]



0 8 . 5

The white precipitate reacts with aqueous NaOH in Test 3 and reacts with hydrochloric acid in **Question 08.4**.

State the term used to describe this behaviour.

[1 mark]

amphoteric

0 8 . 6

Give the formula of metal-aqua ion **M** in Test 4.

[1 mark]



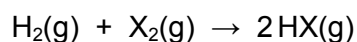
9

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0 9

The equation for the reaction between two diatomic molecules is shown.



The value of the rate constant, k , for this reaction varies with temperature.

Table 5 shows some data.

Table 5

T/K	$\frac{1}{T}/\text{K}^{-1}$	$k/\text{mol}^{-1}\text{dm}^3\text{s}^{-1}$	$\ln k$
568	1.76×10^{-3}	8.27×10^{-5}	-9.40
625	1.60×10^{-3}	2.13×10^{-3}	-6.15
719	1.39×10^{-3}	0.105	-2.25
806	1.24×10^{-3}	1.82	0.60

0 9

1

Complete **Table 5**.

[2 marks]

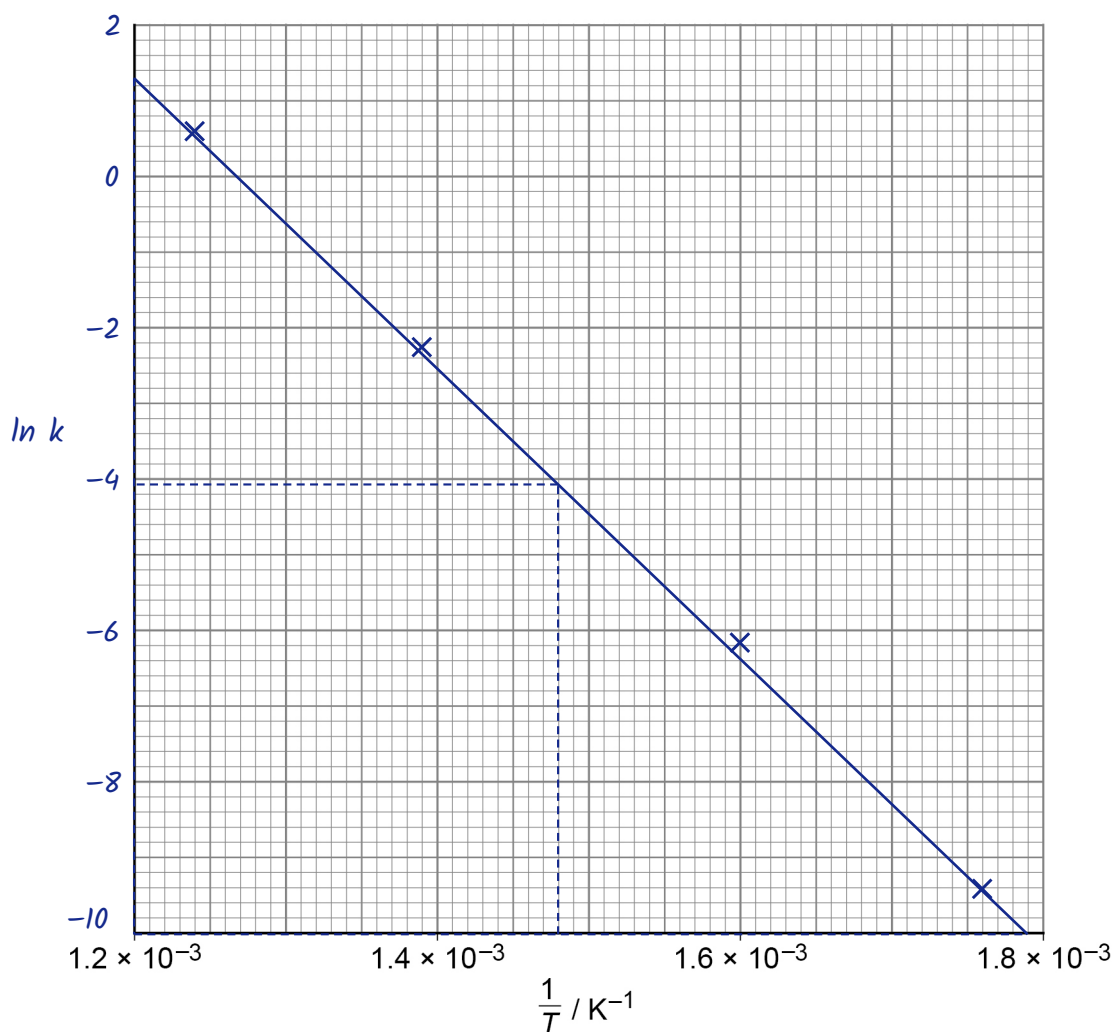
$$T = 1 \div (1.60 \times 10^{-3}) = 625 \text{ K}$$

$$k = e^{-2.25} = 0.105 \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$$



0 9 . 2 Draw a graph of $\ln k$ against $\frac{1}{T}$ on the grid.

[3 marks]



Question 9 continues on the next page

Turn over ►



09.3 The activation energy can be calculated using the equation

$$\ln k = \frac{-E_a}{RT} + \ln A$$

Use your graph from **Question 09.2** to calculate a value for the activation energy (E_a), in kJ mol^{-1} , for this reaction.

The gas constant, $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

[2 marks]

$$\text{gradient} = -E_a/R = (-10.0 - 1.3) \div ((1.79 - 1.20) \times 10^{-3})$$

$$\text{gradient} = -11.3 \div 5.9 \times 10^{-4} = -19\,150 \text{ K}$$

$$E_a = 19\,150 \times 8.31 = 159\,000 \text{ J mol}^{-1} = 159 \text{ kJ mol}^{-1}$$

Activation energy 159 kJ mol^{-1}

09.4 Use your graph from **Question 09.2** to determine a value for k at 675 K

[3 marks]

$$1/T = 1 \div 675 = 1.48 \times 10^{-3} \text{ K}^{-1}$$

$$\text{from the graph, at } 1/T = 1.48 \times 10^{-3}: \ln k = -4.0$$

$$k = e^{-4.0} = 0.0183 \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$$

k 0.0183 $\text{mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$

10

END OF QUESTIONS



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[illegible]

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