

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

Forename(s)

Candidate signature

I declare this is my own work.

A-level CHEMISTRY

Paper 1 Inorganic and Physical Chemistry

Tuesday 2 June 2020

Afternoon

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	
10	
11	
TOTAL	



Answer all questions in the spaces provided.

Do not write
outside the
box

0 1 This question is about enthalpy changes.

0 1 . 1 Figure 1 shows a Born–Haber cycle for the formation of strontium chloride, SrCl_2

Figure 1

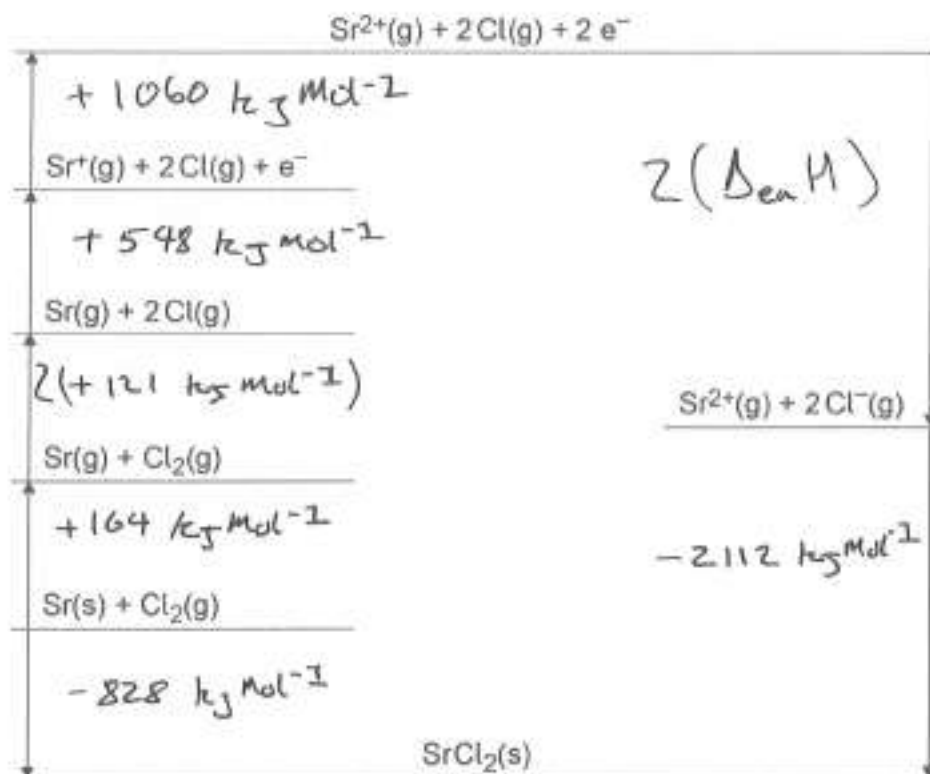


Table 1 shows some thermodynamic data.

Table 1

	Enthalpy change / kJ mol^{-1}
First ionisation energy of strontium	+548
Second ionisation energy of strontium	+1060
Enthalpy of atomisation of chlorine	+121
Enthalpy of atomisation of strontium	+164
Enthalpy of formation of strontium chloride	-828
Enthalpy of lattice formation of strontium chloride	-2112

$\Delta_{\text{1st IE}} H$
 $\Delta_{\text{2nd IE}} H$
 $\Delta_a H(\text{Cl})$
 $\Delta_a H(\text{Sr})$
 $\Delta_f H$
 $\Delta_{\text{LE}} H$



Use the data in Table 1 to calculate a value for the electron affinity of chlorine.

[3 marks]

$$\Delta_f H = \Delta_a H(\text{Sr}) + 2(\Delta_a H(\text{Cl})) + \Delta_{1^{\text{st}} \text{IE}} H(\text{Sr}) + \Delta_{2^{\text{nd}} \text{IE}} H(\text{Sr}) + 2(\Delta_{\text{ae}} H) + \Delta_{\text{LE}} H(\text{Sr})$$

$$\Delta_{\text{ae}} H = \Delta_f H - \frac{(\Delta_a H(\text{Sr}) + 2(\Delta_a H(\text{Cl})) + \Delta_{1^{\text{st}} \text{IE}} H + \Delta_{2^{\text{nd}} \text{IE}} H + \Delta_{\text{LE}} H)}{2}$$

$$\Delta_{\text{ae}} H = \frac{-730}{2}$$

$$= -365 \text{ kJ mol}^{-1}$$

Electron affinity -365 kJ mol⁻¹

0 1 2 Draw a line from each substance to the enthalpy of lattice formation of that substance. [1 mark]

Substance	Enthalpy of lattice formation / kJ mol ⁻¹
MgCl ₂	-2018
MgO	-2493
BaCl ₂	-3889

Question 1 continues on the next page

Turn over ►



Table 2 shows the theoretical lattice enthalpy, based on a perfect ionic model, and an experimental value for the enthalpy of lattice formation of silver chloride.

Table 2

	Theoretical	Experimental
Enthalpy of lattice formation / kJ mol^{-1}	-770	-905

0 1 . 3

State why there is a difference between the theoretical and experimental values.

[1 mark]

The theoretical value does not take into account the covalent character present

0 1 . 4

Table 3 shows enthalpy of hydration values for ions of some Group 1 elements.

Table 3

	$\text{Li}^+(\text{g})$	$\text{Na}^+(\text{g})$	$\text{K}^+(\text{g})$
Enthalpy of hydration / kJ mol^{-1}	-519	-406	-322

Explain why the enthalpy of hydration becomes less exothermic from Li^+ to K^+

[2 marks]

The charge density of the ions decreases and so the attraction between the metal ions and the $\text{O}^{\delta-}$ of water decreases



0 1 . 5

Calcium bromide dissolves in water.

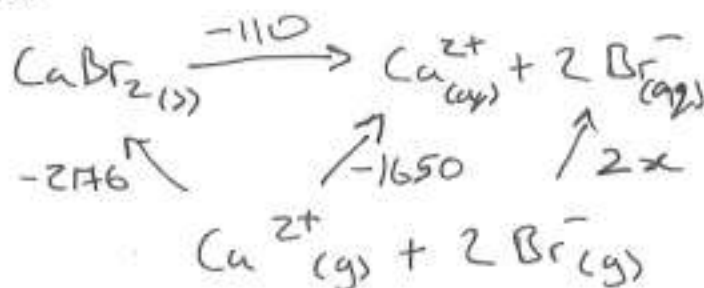
Table 4 shows some enthalpy data.

Table 4

	Enthalpy change / kJ mol ⁻¹
Enthalpy of solution of calcium bromide	-110
Enthalpy of lattice formation of calcium bromide	-2176
Enthalpy of hydration of calcium ions	-1650

Use the data in Table 4 to calculate the enthalpy of hydration, in kJ mol⁻¹, of bromide ions.

[3 marks]



$$\Delta_{\text{sol}}H = \Delta_{\text{lattice}}H + \Delta_{\text{hyd}}H(\text{Ca}^{2+}) + 2\Delta_{\text{hyd}}H(\text{Br}^{-})$$

$$-110 = 2176 + (-1650) + 2(\Delta_{\text{hyd}}(\text{Br}^{-}))$$

$$\begin{aligned}
 2\Delta_{\text{hyd}}(\text{Br}^{-}) &= \frac{2176 - 1650}{2} = -636 & \Delta_{\text{hyd}}(\text{Br}^{-}) &= \frac{-636}{2} \\
 & & &= -318 \text{ kJ mol}^{-1}
 \end{aligned}$$

Enthalpy of hydration of bromide ions -318 kJ mol⁻¹

10

Turn over for the next question

Turn over ►



0 2

This question is about the isotopes of chromium.

0 2.1

Give the meaning of the term relative atomic mass.

[2 marks]

The average mass of one mole of
an element relative to $1/12^{\text{th}}$ the
mass of one mole of carbon-12

0 2.2

A sample of chromium containing the isotopes ^{50}Cr , ^{52}Cr and ^{53}Cr has a
relative atomic mass of 52.1

The sample contains 86.1% of the ^{52}Cr isotope.

Calculate the percentage abundance of each of the other two isotopes.

[4 marks]

$$\% \text{ } ^{50}\text{Cr} \text{ \& } ^{53}\text{Cr} = 100 - 86.1 = 13.9\%$$

$$\% \text{ } ^{50}\text{Cr} = x \quad \% \text{ } ^{53}\text{Cr} = 13.9 - x$$

$$52.1 = \frac{(x \times 50) + (52 \times 86.1) + 53(13.9 - x)}{100}$$

$$52.1 = \frac{50x + 4477.2 + 736.7 - 53x}{100}$$

$$52.1 = \frac{50x + 5213.9 - 53x}{100}$$

$$\frac{100 \times 52.1}{3} = \frac{5213.9}{3} = x \quad x = 1.3$$

Abundance of ^{50}Cr 1.3 % Abundance of ^{53}Cr 12.6 %



0 2 . 3

State, in terms of the numbers of fundamental particles, **one** similarity and **one** difference between atoms of ^{50}Cr and ^{53}Cr

[2 marks]

Similarity Same number of protons

Difference different number of neutrons

The sample of chromium is analysed in a time of flight (TOF) mass spectrometer.

0 2 . 4

Give **two** reasons why it is necessary to ionise the isotopes of chromium before they can be analysed in a TOF mass spectrometer.

[2 marks]

- 1 So that the ions can be accelerated by the electric field
- 2 So that the ions can generate a current when they hit the detector

Question 2 continues on the next page

Turn over ►



0 2 . 5

A $^{53}\text{Cr}^+$ ion travels along a flight tube of length 1.25 m
The ion has a constant kinetic energy (KE) of 1.102×10^{-13} J

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

$$x^{1/2} = \sqrt{x}$$

m = mass of the ion / kg

v = speed of ion / m s^{-1}

Calculate the time, in s, for the $^{53}\text{Cr}^+$ ion to travel down the flight tube to reach the detector.

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

$$E_k = \frac{1}{2} m v^2 \quad \sqrt{\frac{2E_k}{m}} = v = \frac{d}{t}$$

$$m = \frac{53 \times 10^{-3}}{6.022 \times 10^{23}} \text{ [5 marks]}$$

$$= 8.8 \times 10^{-26} \text{ kg}$$

$$v = \frac{d}{t} = \sqrt{\frac{2E_k}{m}} \quad t = \frac{d}{\sqrt{2E_k/m}}$$

$$t = \frac{1.25}{\left(\frac{2(1.102 \times 10^{-13})}{8.8 \times 10^{-26}}\right)^{1/2}} = \frac{1.25}{1.58 \times 10^6}$$

$$= 7.9 \times 10^{-7} \text{ s}$$

Time 7.9×10^{-7} s

15



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ANSWER IN THE SPACES PROVIDED

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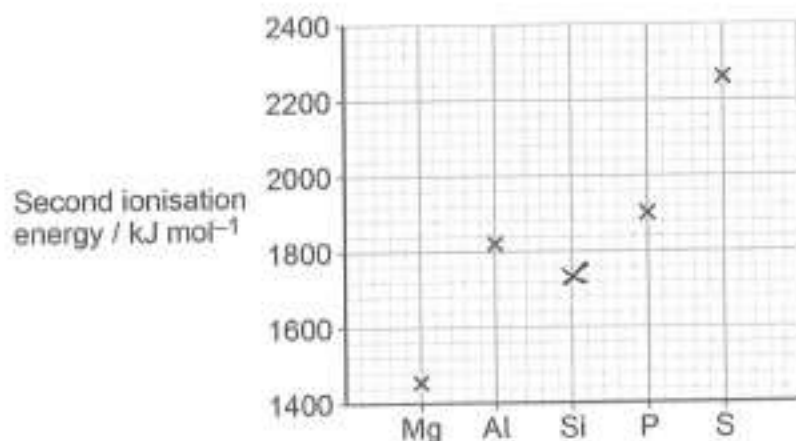
0 9

0 3

This question is about Period 3 elements.

Figure 2 shows the **second** ionisation energies of some elements in Period 3.

Figure 2



0 3 . 1

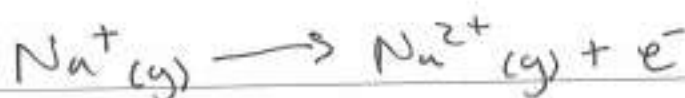
Draw a cross (x) on **Figure 2** to show the **second** ionisation energy of silicon.

[1 mark]

0 3 . 2

Identify the element in Period 3, from sodium to argon, that has the highest **second** ionisation energy.Give an equation, including state symbols, to show the process that occurs when the **second** ionisation energy of this element is measured.If you were unable to identify the element you may use the symbol **Q** in your equation. [2 marks]Element Na

Equation



0 3 . 3

Explain why the atomic radius decreases across Period 3, from sodium to chlorine.

[2 marks]

The number of protons in the nucleus increases across the period but shield stays roughly the same. As such attraction between the nucleus and outer electron increases



- 0 3 4 Identify the element in Period 3, from sodium to chlorine, that has the highest electronegativity.

[1 mark]

Chlorine, Cl

- 0 3 5 Phosphorus burns in air to form phosphorus(V) oxide.
Give an equation for this reaction.

[1 mark]



7

Turn over for the next question

Turn over ►



0 4 Propanoic acid (C_2H_5COOH) is a weak acid.

The acid dissociation constant (K_a) for propanoic acid is $1.35 \times 10^{-5} \text{ mol dm}^{-3}$ at 25°C

0 4 . 1 State the meaning of the term weak acid.

[1 mark]

An acid that only partially dissociates in water

0 4 . 2 Give an expression for the acid dissociation constant for propanoic acid.

[1 mark]

$$K_a = \frac{[H^+][C_2H_5COO^-]}{[C_2H_5COOH]}$$

0 4 . 3 A student dilutes 25.0 cm^3 of $0.500 \text{ mol dm}^{-3}$ propanoic acid by adding water until the total volume is 100.0 cm^3

Calculate the pH of this diluted solution of propanoic acid.

Give your answer to 2 decimal places.

[4 marks]

$$C_1V_1 = C_2V_2 \quad C_2 = \frac{C_1V_1}{V_2} = \frac{25 \times 10^{-3} \cdot 0.5}{100 \times 10^{-3}}$$

$$= 0.125 \text{ mol dm}^{-3}$$

$$[H^+] = \sqrt{K_a \cdot [C_2H_5COOH]} = (1.35 \times 10^{-5} \cdot 0.125)^{1/2}$$

$$= 1.30 \times 10^{-3} \text{ mol dm}^{-3}$$

$$\text{pH} = -\text{Log}(1.30 \times 10^{-3})$$

$$= 2.89$$

pH 2.89



0 4 . 4

A buffer solution with a pH of 4.50 is made by dissolving x g of sodium propanoate (C_2H_5COONa) in a solution of propanoic acid. The final volume of buffer solution is 500 cm^3 and the final concentration of the propanoic acid is 0.250 mol dm^{-3}

Calculate x in g

For propanoic acid, $K_a = 1.35 \times 10^{-5}\text{ mol dm}^{-3}$

[6 marks]

$$[H^+] = 10^{-\text{pH}} = 10^{-4.5} = 3.16 \times 10^{-5}\text{ mol dm}^{-3}$$

$$[C_2H_5COO^-] = \frac{[C_2H_5COOH] K_a}{[H^+]}$$

$$= \frac{0.250 \cdot 1.35 \times 10^{-5}}{3.16 \times 10^{-5}}$$

$$= 0.1068\text{ mol dm}^{-3}$$

$$M_r C_2H_5COONa = 96 \quad n C_2H_5COONa = 0.1068 \times 0.5$$

$$= 0.0534$$

$$m C_2H_5COONa = 0.0534 \cdot 96 = 5.13\text{ g}$$

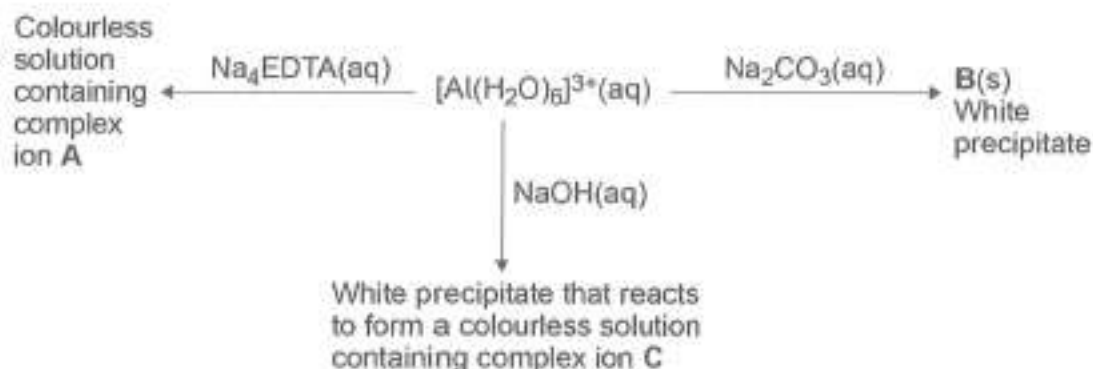
x 5.13 g

12

Turn over ►



0 5

Some reactions of the $[\text{Al}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ ion are shown.

0 5 . 1

Give the formula of the white precipitate B.

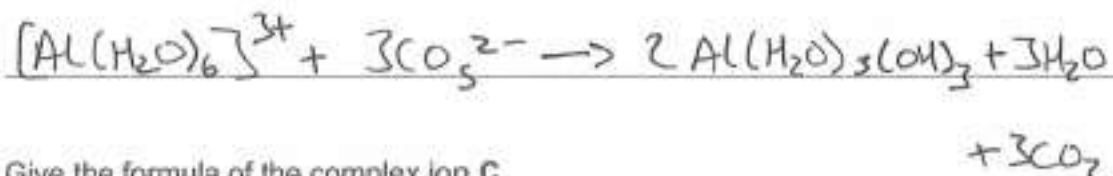
State **one** other observation when $\text{Na}_2\text{CO}_3(\text{aq})$ is added to a solution containing $[\text{Al}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ ions.

Give an equation for this reaction.

[3 marks]

Formula of B $\text{Al}(\text{H}_2\text{O})_3(\text{OH})_3$ Observation effervescence

Equation



0 5 . 2

Give the formula of the complex ion C.

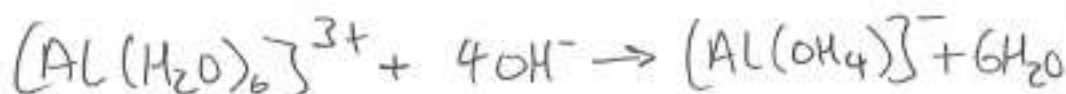
State **one** condition needed for the formation of C from $[\text{Al}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ and $\text{NaOH}(\text{aq})$.

Give an equation for this reaction.

[3 marks]

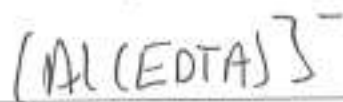
Formula of C $[\text{Al}(\text{OH})_4]^-$ Condition excess NaOH

Equation



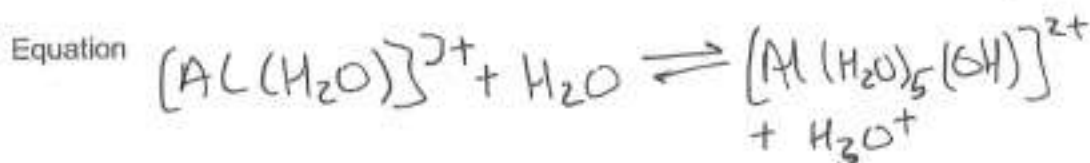
0 5 . 3 Deduce the formula of the complex ion A.

[1 mark]



0 5 . 4 Explain, with the use of an equation, why a solution containing $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$ has a pH < 7

[3 marks]



Explanation Al^{3+} has a small ionic size and so a high charge density. This weakens the OH bond, releasing H^+ ions

10

Turn over for the next question

Turn over ►



0 6

Methanol can be manufactured in a reversible reaction as shown.

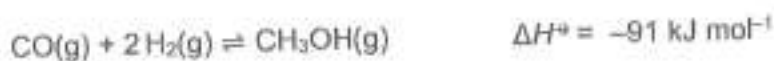
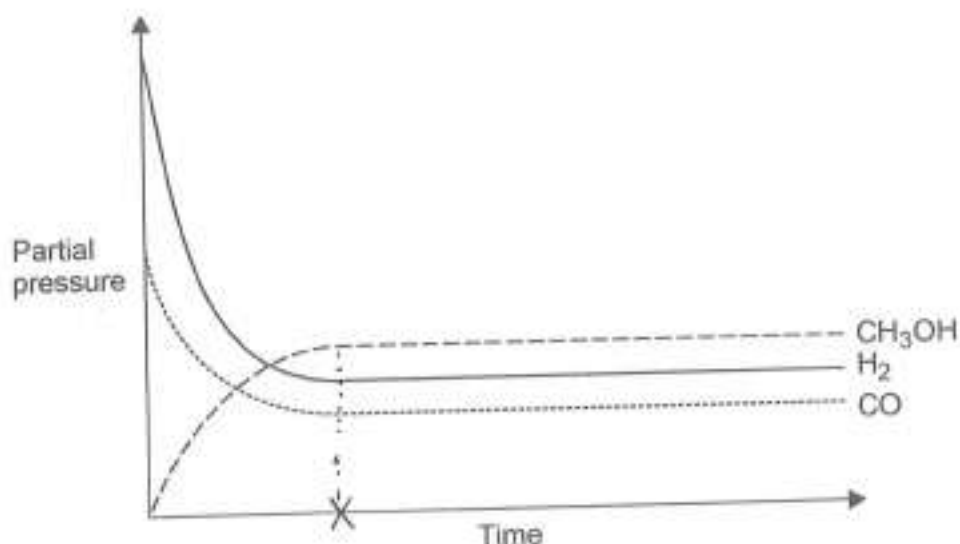


Figure 3 shows how the partial pressures change with time at a constant temperature.

Figure 3



0 6 . 1

Draw a cross (x) on the appropriate axis of Figure 3 when the mixture reaches equilibrium.

[1 mark]

0 6 . 2

A 0.230 mol sample of carbon monoxide is mixed with hydrogen in a 1:2 mol ratio and allowed to reach equilibrium in a sealed flask at temperature T . At equilibrium the mixture contains 0.120 mol of carbon monoxide. The total pressure of this mixture is $1.04 \times 10^4 \text{ kPa}$.

Calculate the partial pressure, in kPa, of hydrogen in the equilibrium mixture.

[4 marks]

$$n_{\text{H}_2 \text{ Eqm}} = 0.24$$

$$P_{\text{H}_2} = 1.04 \times 10^4 \times 0.51$$

$$n_{\text{Total}} = 0.47$$

$$= 5310 \text{ kPa}$$

$$\frac{n_{\text{H}_2}}{n_{\text{Tot}}} = \frac{0.24}{0.47} = 0.51$$

Partial pressure of hydrogen 5310 kPa



06.3 Give an expression for the equilibrium constant (K_p) for this reaction.

State the units.

[2 marks]

$$K_p = \frac{P_{\text{CH}_3\text{OH}}}{P_{\text{H}_2}^2 \cdot P_{\text{CO}}}$$

$$\frac{\cancel{\text{Pa}}}{\cancel{\text{Pa}}^2 \cdot \cancel{\text{Pa}} = \text{Pa}^{-2}}$$

Units Pa⁻²

06.4 Some more carbon monoxide is added to the mixture in Question 06.2. The new mixture is allowed to reach equilibrium at temperature T .

State the effect, if any, on the partial pressure of methanol and on the value of K_p

[2 marks]

Effect on partial pressure of methanol Increases

Effect on value of K_p no effect

06.5 State the effect, if any, of the addition of a catalyst on the value of K_p for this equilibrium.

Explain your answer.

[2 marks]

Effect on value of K_p no effect

Explanation the rates of forward and backwards reactions will increase by the same amount. No concentration changes

11

Turn over for the next question

Turn over ►



07

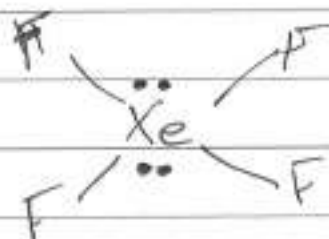
The melting point of XeF_4 is higher than the melting point of PF_3 .

Explain why the melting points of these two compounds are different.

In your answer you should give the shape of each molecule, explain why each molecule has that shape and how the shape influences the forces that affect the melting point.

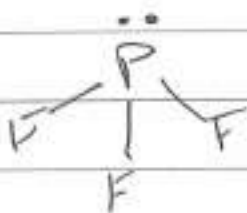
[6 marks]

XeF_4 has 4 bonding pairs of electrons with two lone pairs situated on the central Xe. As the lone pairs repel the other electron pairs more than bonding pairs, the XeF_4 molecule adopts a square planar shape:



This shape maximises the distance between electron pairs.

In PF_3 , there are 3 bonding pairs and only one lone pair. This lone pair pushes the the P-F bonding pairs down out of a triangular plane to form a pyramidal shape:



The flat nature of the XeF_4 molecules means they are able get closer to one another. This increases the strength of the Van der Waals (VdW) forces between them. PF_3 is unable pack as densely meaning its VdW forces are weaker than those of XeF_4 . XeF_4 also has a larger electron cloud than PF_3 . This further increases the strength of its VdW forces over those of PF_3 .

The stronger VdW forces of XeF_4 will require more energy to overcome than those in PF_3 and so XeF_4 has a higher melting point.



0 8

A student does an experiment to determine the percentage by mass of sodium chlorate(I), NaClO, in a sample of bleach solution.

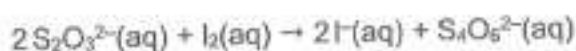
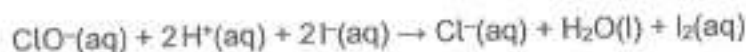
Method:

- Dilute a 10.0 cm^3 sample of bleach solution to 100 cm^3 with distilled water.
- Transfer 25.0 cm^3 of the diluted bleach solution to a conical flask and acidify using sulfuric acid.
- Add excess potassium iodide to the conical flask to form a brown solution containing $\text{I}_2(\text{aq})$.
- Add $0.100 \text{ mol dm}^{-3}$ sodium thiosulfate solution ($\text{Na}_2\text{S}_2\text{O}_3$) to the conical flask from a burette until the brown solution containing $\text{I}_2(\text{aq})$ becomes a colourless solution containing $\text{I}^-(\text{aq})$.

The student uses 33.50 cm^3 of sodium thiosulfate solution.

The density of the original bleach solution is 1.20 g cm^{-3} .

The equations for the reactions in this experiment are



0 8 . 1

Use all the information given to calculate the percentage by mass of NaClO in the original bleach solution.

Give your answer to 3 significant figures.

[7 marks]

$$n(\text{S}_2\text{O}_3^{2-}) = 33.50 \times \frac{0.1}{1000} = 0.00335 \text{ moles}$$

$$n\text{I}_2 = \frac{n\text{S}_2\text{O}_3^{2-}}{2} = 0.001675 \text{ moles}$$

$$n\text{ClO}^- \text{ in } 25 = 0.001675 \text{ in } 100 = n \times 25 \times 4 = 0.00670$$

$$m \text{ NaClO} = 0.00670 \times 74.5 = 0.499 \text{ g}$$

$$m \text{ Bleach} = 10 \times 1.20 = 12 \text{ g} \quad \% \text{ NaClO} = \frac{0.499}{12} \times 100$$

Percentage by mass 4.16%



0 8 . 2

The total uncertainty from two readings and an end point error in using a burette is $\pm 0.15 \text{ cm}^3$

What is the total percentage uncertainty in using the burette in this experiment?

[1 mark]

Tick (✓) **one** box.

0.45%

0.90%

1.34%

8

Turn over for the next question

Turn over ►

0 9 This question is about sodium halides.

0 9 . 1 State what is observed when silver nitrate solution is added to sodium fluoride solution.

[1 mark]

Colourless solution

0 9 . 2 State one observation when solid sodium chloride reacts with concentrated sulfuric acid.

Give an equation for the reaction.

State the role of the chloride ions in the reaction.

[3 marks]

Observation misty white fumes

Equation



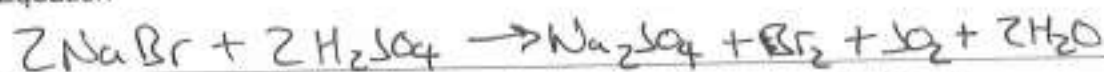
Role Base

0 9 . 3 Give an equation for the redox reaction between solid sodium bromide and concentrated sulfuric acid.

Explain, using oxidation states, why this is a redox reaction.

[3 marks]

Equation



Explanation The Br changes from Br^- to Br^0 and is oxidised. Na goes from Na^+ to Na^+ so there is no change. S goes from 6^+ to 4^- and is reduced.

0 9 . 4 State what is observed when aqueous chlorine is added to sodium bromide solution.

Give an ionic equation for the reaction.

[2 marks]

Observation yellow solution

Ionic equation



1 0

Methanol is formed when carbon dioxide and hydrogen react.

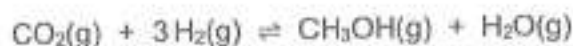


Table 5 contains enthalpy of formation and entropy data for these substances.

Table 5

	CO ₂ (g)	H ₂ (g)	CH ₃ OH(g)	H ₂ O(g)
$\Delta_f H / \text{kJ mol}^{-1}$	-394	0	-201	-242
$S / \text{J K}^{-1} \text{mol}^{-1}$	214	131	238	189

1 0 . 1

Use the equation and the data in Table 5 to calculate the Gibbs free-energy change (ΔG), in kJ mol^{-1} , for this reaction at 890 K

[6 marks]

$$\Delta H = (-201 + -242) - (-394)$$

$$= -49 \text{ kJ mol}^{-1}$$

$$\Delta S = -180 \text{ kJ mol}^{-1} \text{ K}^{-1}$$

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

$$= -49 - \left(890 \cdot \frac{-180}{1000} \right)$$

$$= -111 \text{ kJ mol}^{-1}$$

reaction
feasible at
this temp ΔG - 111 kJ mol^{-1}

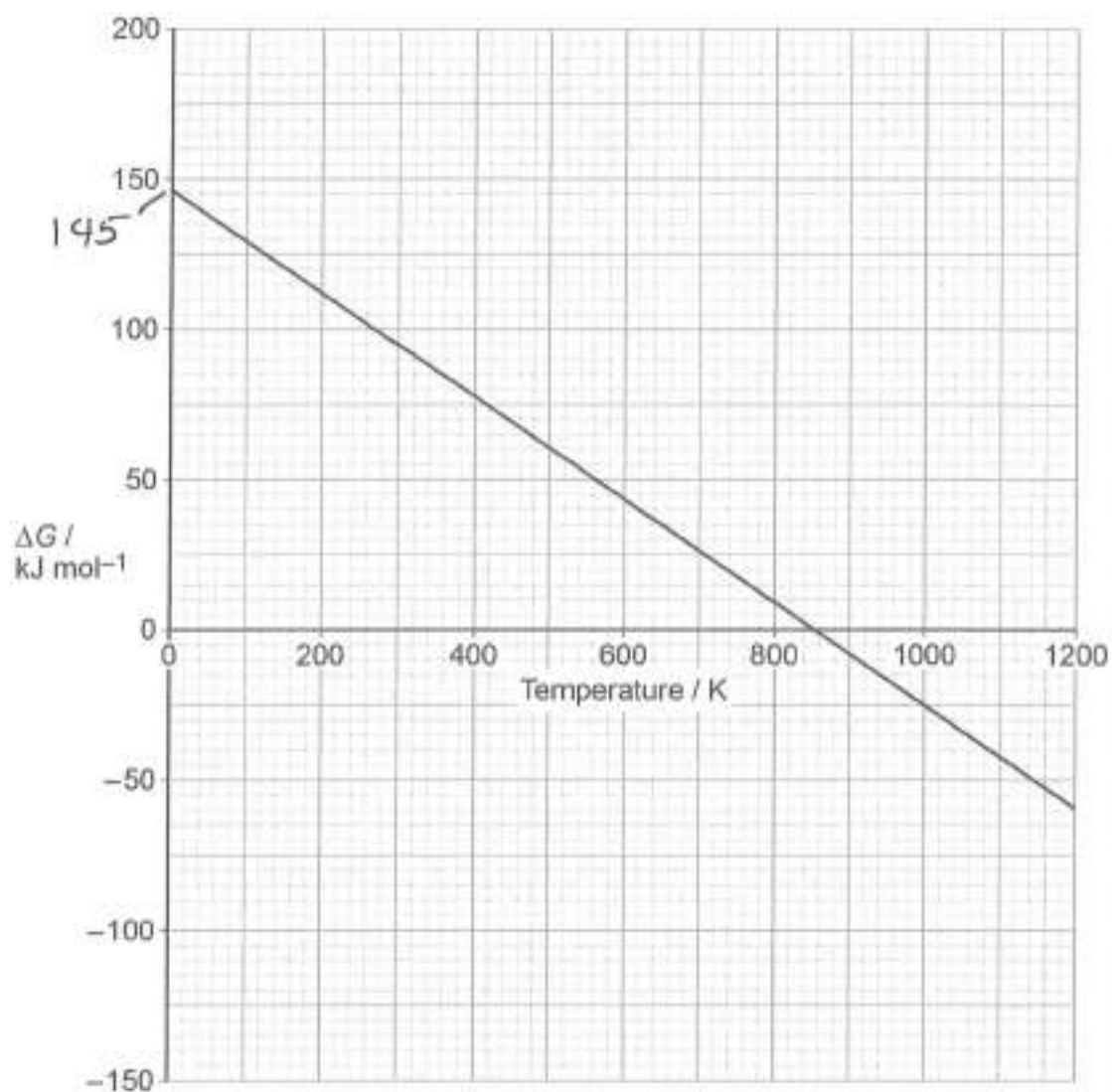
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Figure 4 shows how the Gibbs free-energy change varies with temperature in a different gas phase reaction.

The straight line graph for this gas phase reaction has been extrapolated to zero Kelvin.

Figure 4



1 0 . 2

Use the values of the intercept and gradient from the graph in Figure 4 to calculate the enthalpy change (ΔH), in kJ mol^{-1} , and the entropy change (ΔS), in $\text{J K}^{-1} \text{mol}^{-1}$, for this reaction.

[4 marks]

$$\Delta G = \Delta H - T \Delta S \quad y = mx + c$$

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

$$y = mx + y$$

$$\Delta H = 145 \text{ kJ mol}^{-1}$$

$$m = \frac{-145}{8450} = -0.170$$

$$\begin{aligned} \Delta S &= -m \times 1000 \\ &= +170 \text{ J K}^{-1} \text{ mol}^{-1} \end{aligned}$$

$$\Delta H \quad 145 \quad \text{kJ mol}^{-1}$$

$$\Delta S \quad 170 \quad \text{J K}^{-1} \text{ mol}^{-1}$$

1 0 . 3

State what Figure 4 shows about the feasibility of the reaction.

[1 mark]

below 845 K the value of ΔG is
above 0 and so for these temperatures
the reaction is not feasible

11

Turn over ►



1 1

This question is about a glucose–oxygen fuel cell.

When the cell operates, the glucose ($C_6H_{12}O_6$) molecules react with water at the negative electrode to form carbon dioxide and hydrogen ions.

Oxygen gas reacts with hydrogen ions to form water at the positive electrode.

1 1. 1

Deduce the half-equation for the reaction at the negative electrode.

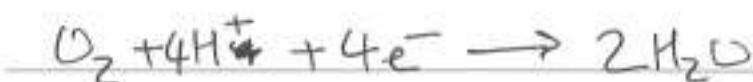
[1 mark]



1 1. 2

Deduce the half-equation for the reaction at the positive electrode.

[1 mark]



1 1. 3

Give the equation for the overall reaction that occurs in the Glucose–oxygen fuel cell.

[1 mark]

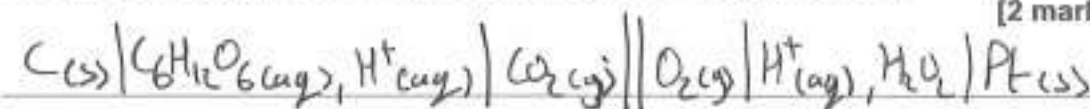


1 1. 4

The negative electrode is made of carbon and the positive electrode is made of platinum.

Give the conventional representation for the glucose–oxygen fuel cell.

[2 marks]



1 1. 5

State what must be done to maintain the EMF of this fuel cell when in use.

[1 mark]

Concentration of reactants must be kept constant

6

END OF QUESTIONS

