

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

Tuesday 14 January 2025 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.

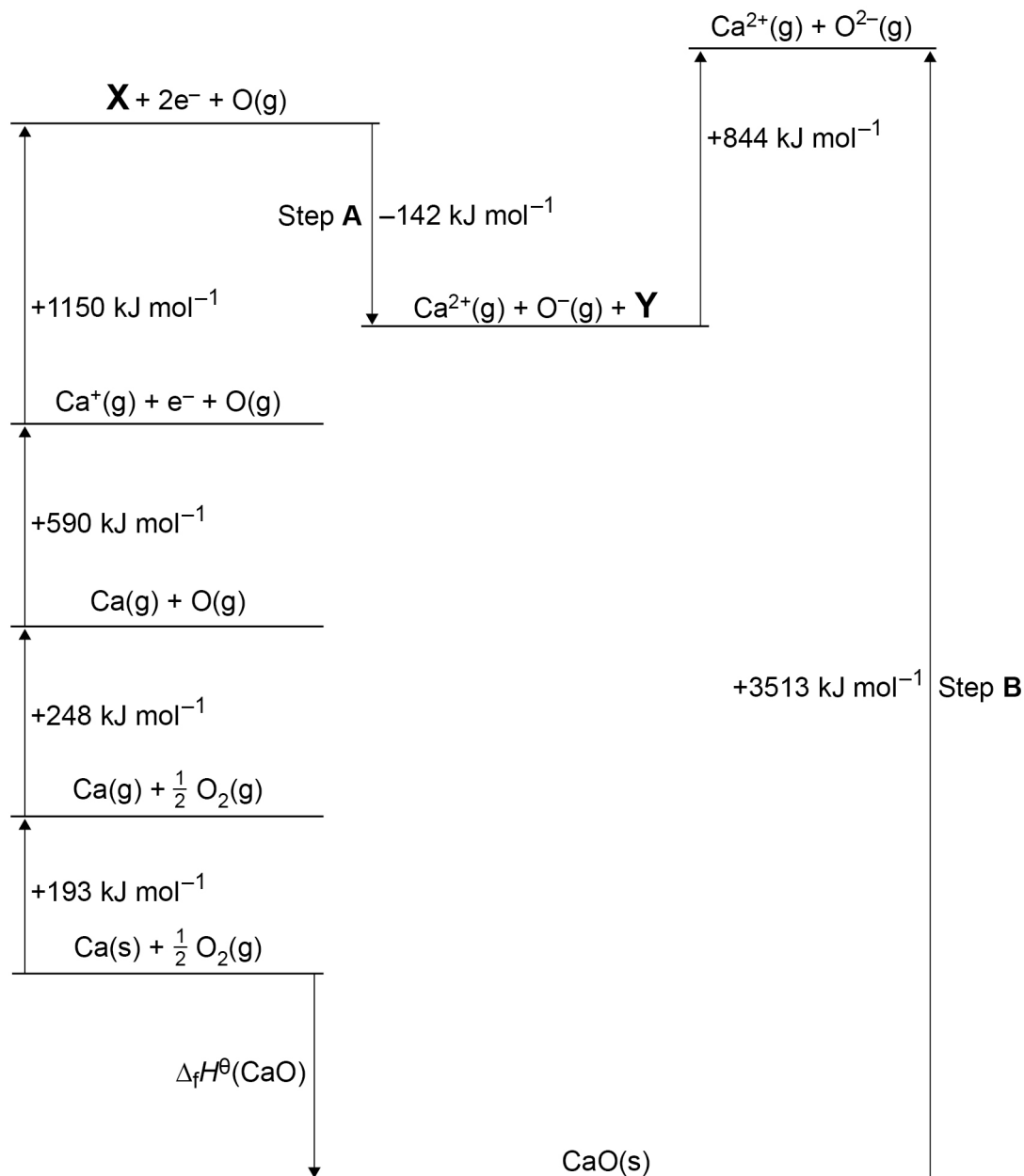
For Examiner's Use	
Question	Mark
1	
2	
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10	
TOTAL	



J A N 2 5 C H O 3 0 1

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

0 1

Figure 1 shows the Born–Haber cycle for calcium oxide.**Figure 1**

0 1 . 1

Identify species **X** and species **Y**.
Include state symbols where appropriate.**[1 mark]**Species **X** Ca²⁺(g)Species **Y** e⁻

0 1 . 2

Give the names of the enthalpy changes represented by Step A and Step B.

[2 marks]

Step A (first) electron affinity of oxygenStep B lattice dissociation enthalpy of calcium oxide

0 1 . 3

Use Figure 1 to calculate the standard enthalpy of formation of calcium oxide.

[2 marks]

$$\Delta_f H^\ominus(\text{CaO}) + 3513 = 193 + 248 + 590 + 1150 - 142 + 844$$

$$\Delta_f H^\ominus(\text{CaO}) + 3513 = 2883$$

$$\Delta_f H^\ominus(\text{CaO}) = 2883 - 3513 = -630 \text{ kJ mol}^{-1}$$

$$\Delta_f H^\ominus(\text{CaO}) \quad \underline{-630} \quad \text{kJ mol}^{-1}$$

5

Turn over for the next question

Turn over ►



0 2

A student does an experiment to determine the enthalpy of solution of magnesium chloride.

Method

- 25.0 cm³ of distilled water are transferred into a plastic cup.
- 1.57 g of magnesium chloride are added to the water in the cup.
- The mixture is stirred so that the magnesium chloride dissolves.
- The temperature of the mixture is monitored using a thermometer.

The temperature rise is 14.2 °C

0 2 . 1

Calculate a value for the enthalpy of solution, in kJ mol⁻¹, of magnesium chloride.

The specific heat capacity of water = 4.18 J K⁻¹ g⁻¹

Assume that the density of the solution = 1.00 g cm⁻³

[3 marks]

$$q = mc\Delta T = 25.0 \times 4.18 \times 14.2 = 1483.9 \text{ J}$$

$$M_r(\text{MgCl}_2) = 24.3 + 2(35.5) = 95.3$$

$$n(\text{MgCl}_2) = 1.57 \div 95.3 = 0.01647 \text{ mol}$$

$$\Delta H = -q \div n = -1.4839 \div 0.01647 = -90.1 \text{ kJ mol}^{-1}$$

Enthalpy of solution -90.1 kJ mol⁻¹

0 2 . 2

Explain why the enthalpy of solution of magnesium hydroxide cannot be determined using the same method.

[1 mark]

Magnesium hydroxide is insoluble (has a very low solubility) in water, so it would not dissolve in 25.0 cm³ of water and no temperature change could be measured.



Table 1 shows some enthalpy change data.

Table 1

	$\Delta H / \text{kJ mol}^{-1}$
Enthalpy of hydration of magnesium ions	-1920
Enthalpy of hydration of chloride ions	-364
Lattice dissociation enthalpy of magnesium chloride	+2493

0 2 3

Use the data in **Table 1** to calculate the enthalpy of solution, in kJ mol^{-1} , of magnesium chloride.

[2 marks]

$$\Delta_{\text{sol}}H = \Delta H_{\text{latt diss}} + \Delta H_{\text{hyd}}(\text{Mg}^{2+}) + 2\Delta H_{\text{hyd}}(\text{Cl}^-)$$

$$\Delta_{\text{sol}}H = 2493 + (-1920) + 2(-364)$$

$$\Delta_{\text{sol}}H = -155 \text{ kJ mol}^{-1}$$

Enthalpy of solution -155 kJ mol^{-1}

6

Turn over ►



0 3

This question is about water.

0 3 . 1

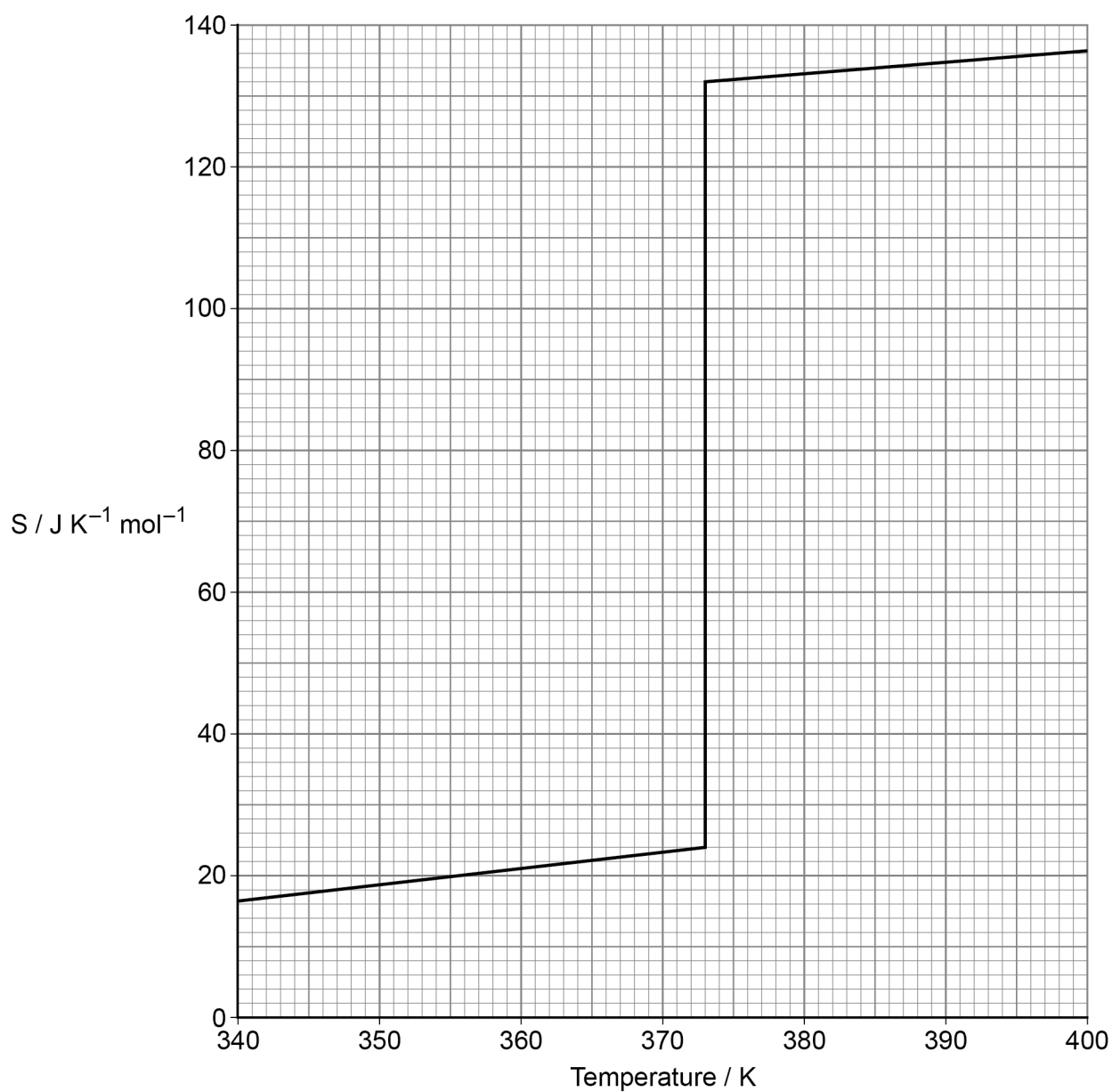
State why the entropy of water is zero at a temperature of 0 K

[1 mark]

At 0 K the particles are stationary and perfectly ordered, so there is no disorder.

Figure 2 shows how the entropy of a sample of water varies with temperature.

Figure 2



- 0 3 . 2** Use **Figure 2** to determine the entropy change, in $\text{J K}^{-1} \text{mol}^{-1}$, when water boils.

[1 mark]

From the graph at 373 K: S rises from 24 to 132

$$\Delta S = 132 - 24 = +108 \text{ J K}^{-1} \text{mol}^{-1}$$

Entropy change +108 $\text{J K}^{-1} \text{mol}^{-1}$

- 0 3 . 3** When a substance boils, the free-energy change, ΔG , is equal to zero.

Use your answer to Question **03.2** to determine the enthalpy change, in kJ mol^{-1} , when water boils.

(If you were unable to answer Question **03.2**, use entropy change = $65.0 \text{ J K}^{-1} \text{mol}^{-1}$. This is **not** the correct value.)

[2 marks]

$$\Delta G = \Delta H - T\Delta S = 0, \text{ so } \Delta H = T\Delta S$$

$$\Delta H = 373 \times (108 \div 1000)$$

$$\Delta H = 40.3 \text{ kJ mol}^{-1}$$

Enthalpy change +40.3 kJ mol^{-1}

- 0 3 . 4** **Figure 2** shows the entropy change for water at 373 K. There is also an entropy change at 273 K.

State why the entropy change at 373 K is much larger than the entropy change at 273 K.

[1 mark]

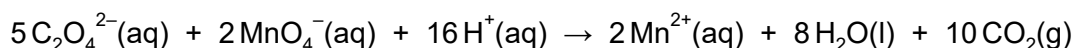
The change in disorder is much larger on boiling (liquid to gas) than on melting (solid to liquid).

Turn over ►



0 4

$\text{Na}_2\text{C}_2\text{O}_4$ can be used to determine the concentration of a solution of KMnO_4



Method

- 0.910 g of anhydrous $\text{Na}_2\text{C}_2\text{O}_4$ is dissolved in some distilled water and the solution is made up to 150 cm^3 using dilute sulfuric acid in a volumetric flask.
- 25.0 cm^3 of this solution are transferred to a conical flask and the solution is warmed to $60\text{ }^{\circ}\text{C}$
- KMnO_4 solution is added from a burette until there is a permanent colour change.

22.35 cm^3 of KMnO_4 solution are needed.

0 4 . 1

Determine the concentration, in mol dm^{-3} , of the $\text{Na}_2\text{C}_2\text{O}_4$ solution.
Calculate the concentration, in mol dm^{-3} , of the KMnO_4 solution.

[5 marks]

$$n(\text{Na}_2\text{C}_2\text{O}_4) = 0.910 \div 134.0 = 6.79 \times 10^{-3} \text{ mol}$$

$$[\text{Na}_2\text{C}_2\text{O}_4] = 6.79 \times 10^{-3} \times 1000 \div 150 = 0.0453 \text{ mol dm}^{-3}$$

Concentration of $\text{Na}_2\text{C}_2\text{O}_4$ 0.0453 mol dm^{-3}

$$n(\text{C}_2\text{O}_4^{2-}) \text{ in } 25.0\text{ cm}^3 = 0.0453 \times 25.0 \div 1000 = 1.13 \times 10^{-3} \text{ mol}$$

$$n(\text{MnO}_4^{-}) = 1.13 \times 10^{-3} \times 2/5 = 4.53 \times 10^{-4} \text{ mol}$$

$$[\text{KMnO}_4] = 4.53 \times 10^{-4} \times 1000 \div 22.35$$

$$[\text{KMnO}_4] = 0.0203 \text{ mol dm}^{-3}$$

Concentration of KMnO_4 0.0203 mol dm^{-3}



0 4 . 2 State the colour change at the end point.

[1 mark]

colourless to (pale) pink

0 4 . 3 The solution in the conical flask is warmed to 60 °C before the KMnO_4 is added because the reaction is slow.

State why this reaction is slow.

[1 mark]

*Both ions (MnO_4^- and $\text{C}_2\text{O}_4^{2-}$) are negative, so they repel each other:
the activation energy is high.*

This reaction is an example of an autocatalysed reaction.

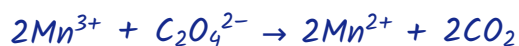
0 4 . 4 Write two equations to show how the reaction between $\text{C}_2\text{O}_4^{2-}$ ions and MnO_4^- ions is catalysed.

[2 marks]

Equation 1



Equation 2



Turn over for the next question

Turn over ►



0 5

This question is about acids, bases and pH

0 5 . 1

Calculate the pH of the solution formed when 15.0 cm³ of distilled water are added to 25.0 cm³ of 0.150 mol dm⁻³ hydrochloric acid.
Give your answer to **two** decimal places.

[3 marks]

$$n(\text{H}^+) = 25.0 \times 0.150 \div 1000 = 3.75 \times 10^{-3} \text{ mol}$$

$$\text{total volume} = 25.0 + 15.0 = 40.0 \text{ cm}^3$$

$$[\text{H}^+] = 3.75 \times 10^{-3} \times 1000 \div 40.0 = 0.09375 \text{ mol dm}^{-3}$$

$$\text{pH} = -\log(0.09375) = 1.03$$

pH 1.03**0 5 . 2**

Calculate the pH of a 0.650 mol dm⁻³ solution of barium hydroxide at 298 K
Give your answer to **two** decimal places.

The ionic product of water, $K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ at 298 K

[3 marks]

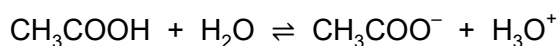
$$[\text{OH}^-] = 2 \times 0.650 = 1.30 \text{ mol dm}^{-3}$$

$$[\text{H}^+] = K_w \div [\text{OH}^-] = 1.00 \times 10^{-14} \div 1.30 = 7.69 \times 10^{-15} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log(7.69 \times 10^{-15}) = 14.11$$

pH 14.11

Ethanoic acid is a weak acid and ionises in water as shown.



For ethanoic acid, the acid dissociation constant, $K_a = 1.76 \times 10^{-5} \text{ mol dm}^{-3}$ at 298 K

0 5 . 3

What is the effect on the value of this K_a if the concentration of a solution of ethanoic acid is increased?

Tick (✓) **one** box.

[1 mark]

Increases

☐

Remains constant

☒

Decreases

☐

0 5 . 4

Calculate the mass, in g, of sodium ethanoate (CH_3COONa) that needs to be dissolved in 25.0 cm^3 of $0.150 \text{ mol dm}^{-3}$ ethanoic acid to produce a solution with $\text{pH} = 4.50$ at 298 K

[4 marks]

$$[\text{H}^+] = 10^{-4.50} = 3.16 \times 10^{-5} \text{ mol dm}^{-3}$$

$$K_a = [\text{H}^+][\text{CH}_3\text{COO}^-] \div [\text{CH}_3\text{COOH}]$$

$$[\text{CH}_3\text{COO}^-] = K_a \times [\text{CH}_3\text{COOH}] \div [\text{H}^+]$$

$$[\text{CH}_3\text{COO}^-] = 1.76 \times 10^{-5} \times 0.150 \div 3.16 \times 10^{-5} = 0.0835 \text{ mol dm}^{-3}$$

$$n(\text{CH}_3\text{COONa}) = 0.0835 \times 25.0 \div 1000 = 2.09 \times 10^{-3} \text{ mol}$$

$$M_r(\text{CH}_3\text{COONa}) = 82.0$$

$$\text{mass} = 2.09 \times 10^{-3} \times 82.0 = 0.171 \text{ g}$$

Mass of sodium ethanoate 0.171 g

11

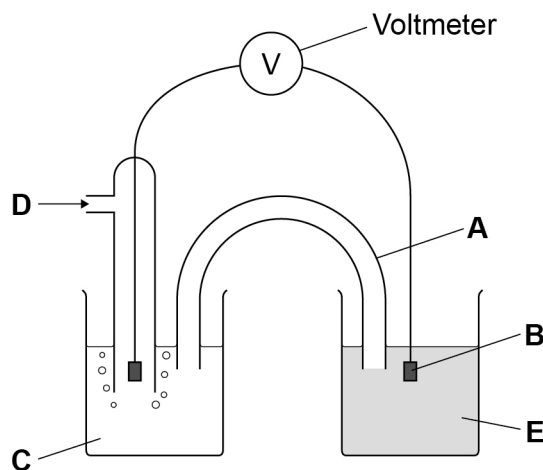
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0 6

Figure 3 represents the cell used to measure the standard electrode potential for the $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) / \text{Cr}^{3+}(\text{aq})$ electrode.

Figure 3



0 6 . 1

Name the piece of equipment, **A**.

State the purpose of **A**.

[2 marks]

Name of **A** salt bridge

Purpose of **A** completes the circuit by allowing ions to move

0 6 . 2

Name the substance used as **B**.

[1 mark]

platinum (platinum black)

0 6 . 3

The cell is operated at 298 K

Complete **Table 2** to identify substances **C** and **D**.

Include **one** essential condition for each substance.

[2 marks]

Table 2

	Identity	Condition
C	<u>HCl</u>	<u>1.00 mol dm⁻³</u>
D	<u>H₂</u>	<u>100 kPa</u>



0 6 . 4

A student suggested that solution **E** should be prepared by mixing equal volumes of 1.00 mol dm^{-3} aqueous acidified potassium dichromate(VI) solution and 1.00 mol dm^{-3} aqueous chromium(III) sulfate solution.

Describe how the mixture should be changed to allow the standard electrode potential for the $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) / \text{Cr}^{3+}(\text{aq})$ electrode to be measured.

Justify your answer.

[2 marks]

How mixture should be changed Mix 1.00 mol dm^{-3} $\text{Cr}_2(\text{SO}_4)_3$ with an equal volume of 2.00 mol dm^{-3} acidified $\text{K}_2\text{Cr}_2\text{O}_7$ instead.

Justification Mixing equal volumes halves each concentration, so $[\text{Cr}_2\text{O}_7^{2-}]$ and $[\text{Cr}^{3+}]$ are then both 1.00 mol dm^{-3} (standard conditions).

The standard electrode potential, $E^\ominus$, for the $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) / \text{Cr}^{3+}(\text{aq})$ electrode is $+1.33 \text{ V}$

0 6 . 5

Give the conventional representation for this cell.

[2 marks]

$\text{Pt} \mid \text{H}_2(\text{g}) \mid \text{H}^+(\text{aq}) \parallel \text{Cr}_2\text{O}_7^{2-}(\text{aq}), \text{H}^+(\text{aq}), \text{Cr}^{3+}(\text{aq}) \mid \text{Pt}$

0 6 . 6

Give the ionic equation that shows the overall reaction for this cell.

[1 mark]

$\text{Cr}_2\text{O}_7^{2-} + 8\text{H}^+ + 3\text{H}_2 \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$

0 6 . 7

The electrode on the left in **Figure 3** is replaced by a $\text{Cl}_2 / \text{Cl}^-$ electrode. The reading on the voltmeter changes to -0.03 V

Calculate the standard electrode potential, $E^\ominus$, for the $\text{Cl}_2 / \text{Cl}^-$ electrode.

[1 mark]

$E_{\text{cell}} = E_{\text{right}} - E_{\text{left}}; -0.03 = 1.33 - E^\ominus(\text{Cl}_2/\text{Cl}^-)$

$E^\ominus$ for the $\text{Cl}_2 / \text{Cl}^-$ electrode $+1.36$ V

11

Turn over ►



0 7

This question is about complexes with bidentate ligands.

0 7 . 1

Explain what is meant by bidentate ligand.

[1 mark]

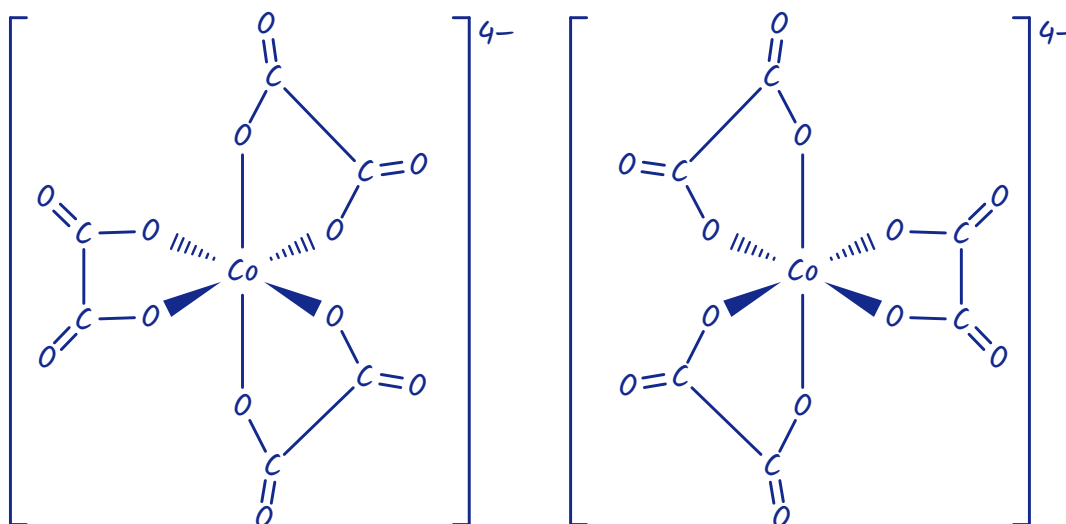
A ligand with two atoms that each donate a lone pair of electrons to the central metal ion (forming two co-ordinate bonds).

0 7 . 2

When an excess of sodium ethanedioate solution is added to an aqueous solution of cobalt(II) chloride, a pair of stereoisomers is formed.

Draw the displayed formula of each isomer.
Show clearly the charge on each complex.

[3 marks]



mirror images (optical isomers)



0 7 . 3

When an excess of ethane-1,2-diamine ($\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$) is added to a solution containing aqueous cobalt(II) ions, all the water ligands are replaced.

Write an equation for the reaction.

Explain the thermodynamic reasons why this reaction occurs.

[6 marks]

Equation



Explanation

The number of particles increases from 4 moles on the left to 7 moles on the right.

So the disorder increases and the entropy change, ΔS , is positive.

The same number of co-ordinate bonds (six) are broken and formed, and Co-O and Co-N bonds have similar bond enthalpies.

So the enthalpy change, ΔH , is approximately zero (very small).

Since $\Delta G = \Delta H - T\Delta S$, ΔG is negative ($\Delta G \leq 0$), so the reaction is feasible and occurs.

10

Turn over for the next question

Turn over ►



0 8

This question is about elements in Period 3.

0 8 . 1

Write equations, including state symbols, to show the reaction of phosphorus with excess oxygen and the reaction of phosphorus with excess chlorine.

State **one** observation that you would make in **both** reactions.**[3 marks]**

Equation with oxygen



Equation with chlorine



Observation

(bright) white flame

0 8 . 2

Write an equation to show the reaction of aluminium oxide with hydrochloric acid.

[1 mark]**0 8 . 3**

Aluminium oxide is added to an excess of water.

Describe what is observed.

[1 mark]

No visible change: the white solid remains (does not dissolve).



0 8 . 4

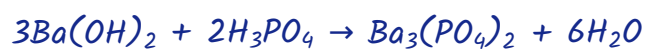
Sulfuric acid can be used to test for barium compounds.
Phosphoric acid can be used in a similar way to test for barium compounds.

Write an equation for the reaction between barium hydroxide and phosphoric acid.

Suggest what you would observe in this reaction.

[2 marks]

Equation



Observation white precipitate forms

7

Turn over for the next question

Turn over ►



0 9

This question is about the colours of transition metal ions.

0 9 . 1

Explain why an aqueous solution of copper(II) ions is blue.

[2 marks]

Cu^{2+} ions absorb some wavelengths of visible light (red) as d-orbital electrons are excited to a higher energy level (the d orbitals are split by the ligands).

The remaining blue wavelengths of light are transmitted (reflected), so the solution appears blue.

$[\text{Ti}(\text{H}_2\text{O})_6]^{3+}$ has a single d-orbital electron.

The energy needed to excite this electron is $3.79 \times 10^{-19} \text{ J}$

0 9 . 2

Calculate the wavelength, in nm, of light that will be absorbed by this $[\text{Ti}(\text{H}_2\text{O})_6]^{3+}$ complex.

Planck's constant, $h = 6.63 \times 10^{-34} \text{ J s}$

The speed of light, $c = 3.00 \times 10^8 \text{ m s}^{-1}$

[2 marks]

$$\lambda = hc \div E = (6.63 \times 10^{-34} \times 3.00 \times 10^8) \div (3.79 \times 10^{-19})$$

$$\lambda = 5.25 \times 10^{-7} \text{ m} = 525 \text{ nm}$$

Wavelength 525 nm



09.3

Aqueous ammonia is added a drop at a time to an aqueous solution containing copper(II) ions until the ammonia is in excess.

Describe what is observed.

Write equations for any reactions that occur.

[4 marks]

The blue solution first forms a (pale) blue precipitate, which then dissolves in excess ammonia to give a dark (deep) blue solution.



8

Turn over for the next question

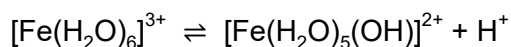
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1 0

This question is about the acidity of metal-aqua ions.

1 0 . 1

Iron(III) compounds dissolve in water to form $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ ions.The $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ ion dissociates as shown.Write an expression for the acid dissociation constant, K_a , for the $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ ion.Calculate the pH of a solution made when 1.35 g of iron(III) chloride are dissolved in water to make 750 cm^3 of aqueous solution.Give your answer to **two** decimal places.The value of $\text{p}K_a$ for the $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ ion is 2.22**[6 marks]**Expression for K_a

$$K_a = \frac{[[\text{Fe}(\text{H}_2\text{O})_5(\text{OH})]^{2+}][\text{H}^+]}{[[\text{Fe}(\text{H}_2\text{O})_6]^{3+}]}$$

Calculation

$$K_a = 10^{-2.22} = 6.03 \times 10^{-3} \text{ mol dm}^{-3}$$

$$M_r(\text{FeCl}_3) = 55.8 + 3(35.5) = 162.3$$

$$n(\text{Fe}^{3+}) = 1.35 \div 162.3 = 8.32 \times 10^{-3} \text{ mol}$$

$$[[\text{Fe}(\text{H}_2\text{O})_6]^{3+}] = 8.32 \times 10^{-3} \times 1000 \div 750 = 0.0111 \text{ mol dm}^{-3}$$

$$[\text{H}^+]^2 = K_a \times [[\text{Fe}(\text{H}_2\text{O})_6]^{3+}] = 6.03 \times 10^{-3} \times 0.0111$$

$$[\text{H}^+] = 8.17 \times 10^{-3} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log(8.17 \times 10^{-3}) = 2.09$$

pH 2.09

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Solutions containing $\text{Fe}^{3+}(\text{aq})$, $\text{Fe}^{2+}(\text{aq})$ or $\text{Al}^{3+}(\text{aq})$ ions are acidic.

State why solutions of $\text{Fe}^{2+}(\text{aq})$ are **less** acidic than $\text{Fe}^{3+}(\text{aq})$

Suggest why solutions of $\text{Al}^{3+}(\text{aq})$ are **more** acidic than $\text{Fe}^{3+}(\text{aq})$

[2 marks]

$\text{Fe}^{2+}(\text{aq})$ is less acidic than $\text{Fe}^{3+}(\text{aq})$ *Fe^{2+} has a lower charge (lower charge density) than Fe^{3+} , so it polarises the water ligands less and H^+ ions are released less readily.*

$\text{Al}^{3+}(\text{aq})$ is more acidic than $\text{Fe}^{3+}(\text{aq})$ *Al^{3+} has the same charge but a much smaller ionic radius than Fe^{3+} , so it has a higher charge density and polarises the O-H bonds in the water ligands more.*

8

END OF QUESTIONS



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