

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

Thursday 11 January 2024 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	
TOTAL	



J A N 2 4 C H O 3 0 1

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ANSWER IN THE SPACES PROVIDED**



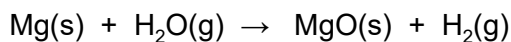
Answer **all** questions in the spaces provided.

0 1

This question is about Period 3 elements and their compounds.

0 1 . 1

Magnesium reacts rapidly with steam in a redox reaction.



Give **two** observations in this reaction.

Explain, by reference to oxidation states, why this is a redox reaction.

[4 marks]

Observation 1 bright white light (flame)

Observation 2 white solid (powder) forms

Explanation Mg is oxidised: its oxidation state increases from 0 in Mg to +2 in MgO.

H is reduced: its oxidation state decreases from +1 in H₂O to 0 in H₂.

0 1 . 2

Phosphorus reacts with chlorine to form PCl₅

In the solid state, PCl₅ exists as two ions PCl₄⁺ and PCl₆⁻

Name the shape of the PCl₄⁺ ion.

Give the bond angle in the PCl₄⁺ ion.

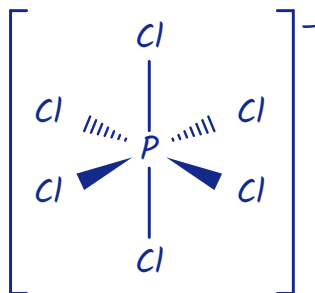
Draw the structure of PCl₆⁻ showing clearly the 3D shape of the ion.

[3 marks]

Shape of PCl₄⁺ tetrahedral

Bond angle in PCl₄⁺ 109.5°

Structure of PCl₆⁻

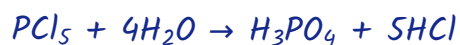


Turn over ►



0 1 . 3 Write an equation for the reaction of PCl_5 with water.

[1 mark]



0 1 . 4 A Period 3 element reacts with oxygen to form an acidic oxide.
The oxide contains 53% of oxygen by mass.

Identify the Period 3 element.

Tick (✓) **one** box.

[1 mark]

Silicon

☒

Sulfur

☐

Phosphorus

☐

0 1 . 5 Aluminium oxide is amphoteric.
This means that aluminium oxide reacts with acids and with alkalis.

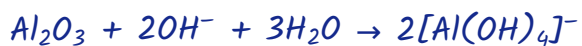
Write **two** ionic equations to show how aluminium oxide is amphoteric.

[2 marks]

Equation 1



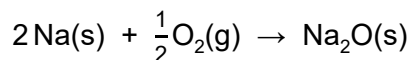
Equation 2



0 2

This question is about thermodynamics.

Sodium reacts with oxygen to form sodium oxide.



0 2 . 1

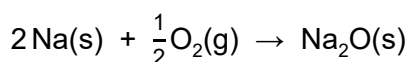
Give **two** observations in this reaction.

[2 marks]

Observation 1 yellow (orange) flame

Observation 2 white solid (powder) forms

0 2 . 2



The entropy change (ΔS) for this reaction is $-131.7 \text{ J K}^{-1} \text{ mol}^{-1}$

Table 1 shows some standard entropy values.

Table 1

	$S^\ominus / \text{J K}^{-1} \text{ mol}^{-1}$
Na(s)	51.0
Na ₂ O(s)	72.8

Use the data to calculate a value for the standard entropy for O₂(g)

Comment on the difference in the standard entropy values for O₂ and for Na

[4 marks]

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

$$-131.7 = 72.8 - [2(51.0) + \frac{1}{2}S(\text{O}_2)]$$

$$\frac{1}{2}S(\text{O}_2) = 72.8 - 102.0 + 131.7 = 102.5$$

$$S(\text{O}_2) = 2 \times 102.5 = 205 \text{ J K}^{-1} \text{ mol}^{-1}$$

Entropy for O₂(g) 205 J K⁻¹ mol⁻¹

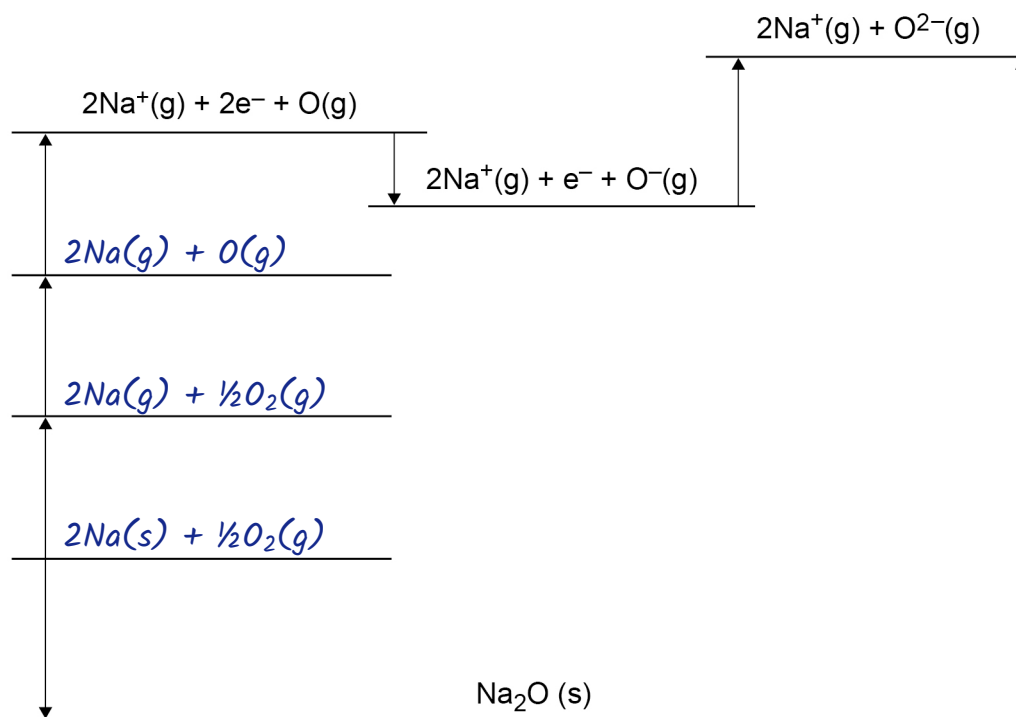
Comment O₂ is a gas so its particles are much more disordered (more ways of arranging the energy); sodium is a solid so it is more ordered and has a lower entropy.

Turn over ►



0 2 . 3 **Figure 1** shows an incomplete Born–Haber cycle for the formation of sodium oxide.

Figure 1



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

[3 marks]



0 2 . 4 Table 2 shows some enthalpy change data.

Table 2

	Enthalpy change / kJ mol^{-1}
Enthalpy of formation of $\text{Na}_2\text{O}(\text{s})$	-416
Enthalpy of atomisation of sodium	+109
Enthalpy of atomisation of oxygen	+248
First ionisation energy for $\text{Na}(\text{g})$	+494
First electron affinity of oxygen	-142
Second electron affinity of oxygen	+844

Use **Figure 1** and the data in **Table 2** to calculate a value, in kJ mol^{-1} , for the enthalpy of lattice dissociation of $\text{Na}_2\text{O}(\text{s})$

[2 marks]

$$2\Delta H_a(\text{Na}) + \Delta H_a(\text{O}) + 2\text{IE}(\text{Na}) + \text{EA}_1(\text{O}) + \text{EA}_2(\text{O}) = \Delta H_f(\text{Na}_2\text{O}) + \Delta H_L(\text{Na}_2\text{O})$$

$$2(109) + 248 + 2(494) + (-142) + 844 = -416 + \Delta H_L$$

$$2156 = -416 + \Delta H_L$$

$$\Delta H_L = 2156 + 416 = +2572 \text{ kJ mol}^{-1}$$

Enthalpy of lattice dissociation of $\text{Na}_2\text{O}(\text{s})$ +2572 kJ mol^{-1}

Question 2 continues on the next page

Turn over ►



0 2 . 5 Table 3 shows some more enthalpy change data.

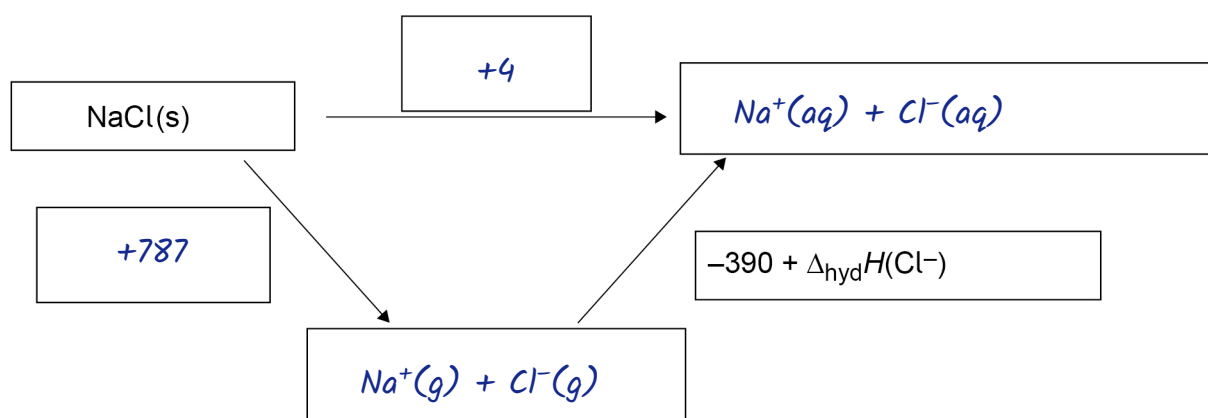
Table 3

	Enthalpy change / kJ mol^{-1}
Enthalpy of lattice dissociation of NaCl(s)	+787
Enthalpy of hydration of $\text{Na}^+(\text{g})$	-390
Enthalpy of hydration of $\text{Cl}^-(\text{g})$	to be calculated
Enthalpy of solution of NaCl(s)	+4

Complete the Hess' Cycle by adding the appropriate species and values.

Use the data in **Table 3** to calculate a value, in kJ mol^{-1} , for the enthalpy of hydration of $\text{Cl}^-(\text{g})$

[2 marks]



$$+4 = +787 + (-390) + \Delta H_{\text{hyd}}(\text{Cl}^-)$$

$$\Delta H_{\text{hyd}}(\text{Cl}^-) = +4 - 787 + 390 = -393 \text{ kJ mol}^{-1}$$

Enthalpy of hydration of $\text{Cl}^-(\text{g})$ -393 kJ mol^{-1}

0 2 . 6 Suggest why there is no data book value for the enthalpy of solution of $\text{Na}_2\text{O(s)}$

[1 mark]

Na_2O reacts with water to form NaOH (an alkaline solution) rather than simply dissolving.



Turn over for the next question

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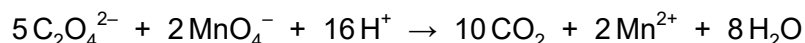
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0 3

This question is about the reaction of ethanedioate ions ($\text{C}_2\text{O}_4^{2-}$) with manganate(VII) ions (MnO_4^-)



The reaction between $\text{C}_2\text{O}_4^{2-}$ and MnO_4^- is slow at the start because the activation energy is high. The reaction then speeds up when some Mn^{2+} ions are formed.

0 3 . 1

Explain why the reaction has a high activation energy.

[1 mark]

Both reactant ions ($\text{C}_2\text{O}_4^{2-}$ and MnO_4^-) are negatively charged, so they repel each other.

0 3 . 2

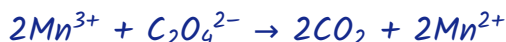
Write **two** equations to show how Mn^{2+} ions act as a catalyst for this reaction.

[2 marks]

Equation 1



Equation 2



A student completes an experiment to determine whether a solid is lithium ethanedioate, sodium ethanedioate, or potassium ethanedioate.

Method

1. Dissolve 1.775 g of the solid metal ethanedioate in about 100 cm^3 water.
2. Make the solution up to 250 cm^3 with dilute sulfuric acid in a volumetric flask and mix well.
3. Use a pipette to transfer a 25.0 cm^3 portion of the solution into a conical flask.
4. Warm the flask to about 50°C in a water bath.
5. Add $0.0200\text{ mol dm}^{-3}$ potassium manganate(VII) from a burette until there is a permanent colour change.
6. Repeat until two titres are obtained that are within 0.10 cm^3 of each other.

Table 4, on page 11, shows data from the experiment.



Table 4

	Rough	1	2	3
Final burette reading / cm ³	22.40	22.80	44.55	24.65
Initial burette reading / cm ³	0.00	1.50	22.80	3.25
Titre volume / cm ³	22.40	21.30	21.75	21.40

0 3 . 3 Use appropriate results to determine the mean titre for this experiment.

Use the mean titre to calculate the M_r of the solid metal ethanedioate.

Identify the metal ion in the solid.

[6 marks]

Concordant titres: $(21.30 + 21.40) \div 2$

mean titre = 21.35 cm^3

Mean titre 21.35 cm³

$$n(\text{MnO}_4^-) = 21.35 \times 0.0200 \div 1000 = 4.27 \times 10^{-4} \text{ mol}$$

$$n(\text{C}_2\text{O}_4^{2-}) \text{ in } 25.0 \text{ cm}^3 = 4.27 \times 10^{-4} \times 5/2 = 1.0675 \times 10^{-3} \text{ mol}$$

$$n(\text{C}_2\text{O}_4^{2-}) \text{ in } 250 \text{ cm}^3 = 1.0675 \times 10^{-3} \times 10 = 1.0675 \times 10^{-2} \text{ mol}$$

$$M_r = \text{mass} \div \text{moles} = 1.775 \div (1.0675 \times 10^{-2}) = 166.3$$

$$M_r(\text{C}_2\text{O}_4) = 2(12.0) + 4(16.0) = 88.0$$

$$2A_r(\text{metal}) = 166.3 - 88.0 = 78.3, \text{ so } A_r = 39.1$$

$A_r = 39.1$ so the metal is potassium, K^+ (solid is $\text{K}_2\text{C}_2\text{O}_4$)

M_r of solid metal ethanedioate 166.3

Metal ion K^+

Turn over ►



0 3 . 4

Describe the colour change at the end point of this titration.

Give a reason for this colour change.

[2 marks]

Colour change colourless to (pale) pinkReason All the $C_2O_4^{2-}$ has reacted, so excess MnO_4^- remains unreacted, giving the pink colour.

11

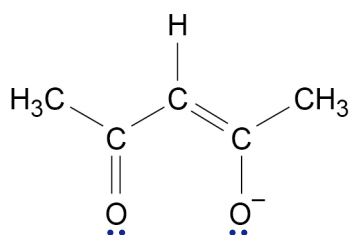
0 4

This question is about bidentate ligands and multidentate ligands.

0 4 . 1

Figure 2 shows the structure of the **acac** ion ($C_5H_7O_2^-$)The **acac** ion can act as a bidentate ligand.Draw **two** lone pairs on the structure to show how the **acac** ion can act as a bidentate ligand.

[1 mark]

Figure 2**acac** ion

0 4 . 2

The complex $Co(C_5H_7O_2)_3$ contains three **acac** ions.

Give the oxidation state of cobalt in this complex.

State the type of isomerism shown by the complex.

[2 marks]

Oxidation state of cobalt +3Type of isomerism optical

0 4 . 3

EDTA⁴⁻ is a multidentate ligand.

The EDTA⁴⁻ ion has six lone pairs of electrons that are donated when it forms a complex.

Write an equation for the reaction that occurs when an excess of EDTA⁴⁻ ions is added to a solution containing [Fe(H₂O)₆]²⁺

Explain, in terms of thermodynamics, why the complex formed is more stable than [Fe(H₂O)₆]²⁺

[6 marks]

Equation



Explanation

The number of particles increases from 2 on the left to 7 on the right.

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

The same number and type of bonds are broken and made (six Fe-O co-ordinate bonds broken, six co-ordinate bonds to EDTA formed).

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

Since $\Delta G = \Delta H - T\Delta S$, ΔG is negative, so the reaction is feasible and the EDTA complex is more stable.



0 5

This question is about the reactions of three aqueous solutions (**P**, **Q** and **R**).
The aqueous solutions each contain a different transition metal ion: Fe^{3+} , Fe^{2+} or Cu^{2+}

A student adds three different reagents to the three solutions.

Table 5 shows some observations from the experiments.

Table 5

	Test 1 Add $\text{NH}_3(\text{aq})$ drop by drop until in excess	Test 2 Add $\text{Na}_2\text{CO}_3(\text{aq})$	Test 3 Add concentrated $\text{HCl}(\text{aq})$
P	Blue precipitate formed Blue precipitate reacts to give deep blue solution with excess	Blue–green precipitate formed	Solution turns from blue to yellow–green
Q	Green precipitate formed No further change with excess	Green precipitate formed	
R	Brown precipitate formed No further change with excess	Brown precipitate formed Effervescence	

0 5 . 1

Write an equation for the reaction in **Test 1** for the formation of the deep blue solution.

[1 mark]



0 5 . 2

The wavelength of the light absorbed by the deep blue solution formed in **Test 1** is 650 nm

Calculate the energy gap (ΔE), in J, between the ground state and the excited state of the d electrons.

You should assume that all the light absorbed is because of the movement of electrons between d orbitals.

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

The speed of light, $c = 3.00 \times 10^8$ m s⁻¹

[2 marks]

$$\Delta E = hc \div \lambda$$

$$\Delta E = (6.63 \times 10^{-34} \times 3.00 \times 10^8) \div (650 \times 10^{-9})$$

$$\Delta E = 3.06 \times 10^{-19} \text{ J}$$

$$\Delta E \quad 3.06 \times 10^{-19} \quad \text{J}$$

0 5 . 3

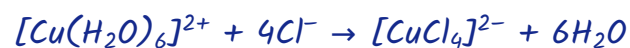
State the type of reaction that occurs when solution **P** reacts with concentrated HCl

Write an equation for this reaction.

[2 marks]

Type of reaction ligand substitution

Equation



0 5 . 4

Identify a reagent, or combination of reagents, used in a test-tube reaction to show that solution **P** also contains sulfate(VI) ions.

Describe the expected observation(s).

[2 marks]

Reagent(s) acidified barium chloride, $\text{BaCl}_2(\text{aq})$ (with HCl)

Observation(s) white precipitate forms

Turn over ►



Table 5 is repeated here.

Table 5

	Test 1 Add $\text{NH}_3(\text{aq})$ drop by drop until in excess	Test 2 Add $\text{Na}_2\text{CO}_3(\text{aq})$	Test 3 Add concentrated $\text{HCl}(\text{aq})$
P	Blue precipitate formed Blue precipitate reacts to give deep blue solution with excess	Blue–green precipitate formed	Solution turns from blue to yellow–green
Q	Green precipitate formed No further change with excess	Green precipitate formed	
R	Brown precipitate formed No further change with excess	Brown precipitate formed Effervescence	

0 5 . 5 Solution **Q** forms a green precipitate when it reacts in **Test 1**, and a green precipitate when it reacts in **Test 2**.

Give the formula for each green precipitate.

[2 marks]

Formula of green precipitate formed in **Test 1** $\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2$

Formula of green precipitate formed in **Test 2** FeCO_3

0 5 . 6 Write an equation for the reaction that occurs when solution **R** reacts in **Test 2**.

[1 mark]



10



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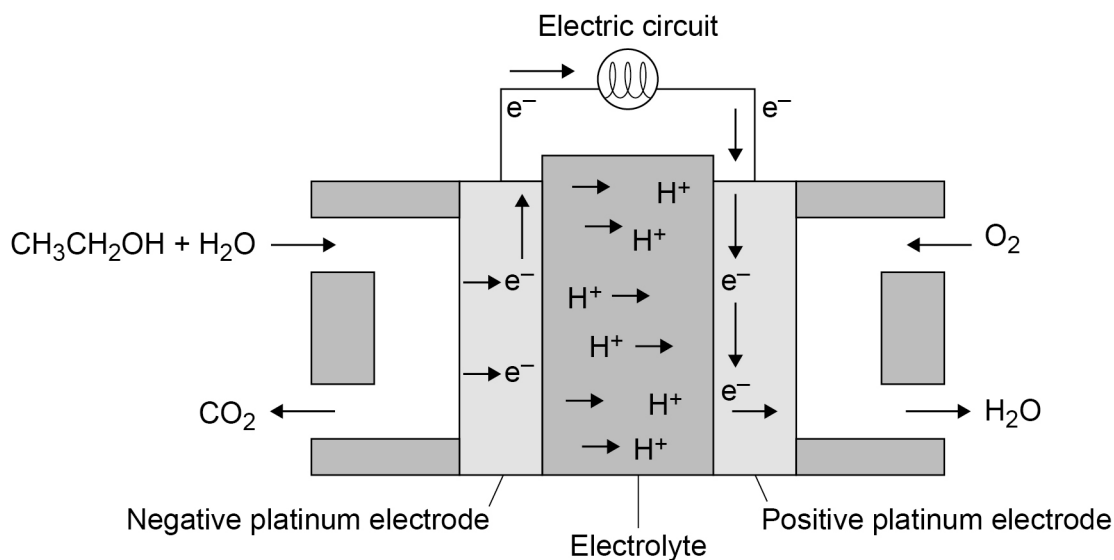


0 6

This question is about fuel cells.

Figure 3 shows an ethanol fuel cell.

Figure 3



When the cell is in use:

- At the positive electrode, oxygen reacts with hydrogen ions to form water.
- At the negative electrode, ethanol reacts with water to form carbon dioxide and hydrogen ions.

0 6 . 1

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

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

Write the equation for the overall reaction that occurs in the ethanol fuel cell.

[3 marks]

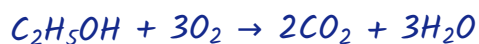
Positive electrode



Negative electrode



Overall cell reaction



0 6 . 2 The EMF of the ethanol fuel cell is 1.14 V

The electrode potential for the positive electrode is 1.23 V

Calculate the electrode potential for the negative electrode.

[1 mark]

$$1.23 - 1.14 = 0.09$$

Electrode potential +0.09 V

0 6 . 3 State what must be done to maintain a constant EMF during the use of this fuel cell.

[1 mark]

Keep a continuous supply of ethanol (fuel) to the cell, so the ethanol concentration stays constant.

Ethanol fuel cells are being developed as a possible alternative to the alkaline hydrogen–oxygen fuel cell to power vehicles.

In the alkaline hydrogen–oxygen fuel cell, the reactions that occur at each platinum electrode are

Positive platinum electrode $\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$

Negative platinum electrode $2\text{H}_2 + 4\text{OH}^- \rightarrow 4\text{H}_2\text{O} + 4\text{e}^-$

0 6 . 4 Give the conventional cell representation for the alkaline hydrogen–oxygen fuel cell.

[2 marks]

$\text{Pt} \mid \text{H}_2(\text{g}) \mid \text{OH}^-(\text{aq}), \text{H}_2\text{O}(\text{l}) \parallel \text{O}_2(\text{g}) \mid \text{H}_2\text{O}(\text{l}), \text{OH}^-(\text{aq}) \mid \text{Pt}$

0 6 . 5 State **one** disadvantage of the alkaline hydrogen–oxygen fuel cell compared with the ethanol fuel cell.

[1 mark]

Hydrogen is a gas (ethanol is a liquid), so hydrogen is more difficult to store and transport safely; it is also highly flammable.



07

This question is about acids and bases.

07.1

Define pH

[1 mark]

$$pH = -\log_{10}[H^+]$$

07.2

Some concentrated hydrochloric acid contains 38.0 g of HCl in 100 g of acid.
The concentrated acid solution has a density of 1.19 g cm⁻³

Calculate the concentration, in mol dm⁻³, of the solution.
Give your answer to three significant figures.

[2 marks]

$$\text{mass of HCl in } 1 \text{ cm}^3 = 0.380 \times 1.19 = 0.4522 \text{ g}$$

$$\text{concentration} = (0.4522 \div 36.5) \times 1000$$

$$\text{concentration} = 12.4 \text{ mol dm}^{-3}$$

Concentration 12.4 mol dm⁻³**07.3**

A teacher needs to make 4.00 dm³ of a dilute solution of hydrochloric acid with a pH of 0.80 using the concentrated solution.

Use your answer to Question **07.2** to calculate the volume, in cm³, of concentrated HCl that is needed to prepare this dilute aqueous solution.

(If you were unable to answer Question **07.2**, you should assume that the concentration of the concentrated HCl is 7.25 mol dm⁻³
This is **not** the correct answer.)

[3 marks]

$$[H^+] = 10^{-0.80} = 0.158 \text{ mol dm}^{-3}$$

$$n(\text{HCl}) \text{ needed} = 0.158 \times 4.00 = 0.632 \text{ mol}$$

$$\text{volume} = n \div c = 0.632 \div 12.4 = 0.0510 \text{ dm}^3$$

$$\text{volume} = 0.0510 \times 1000 = 51.0 \text{ cm}^3$$

Volume 51.0 cm³

07.4

1.50 g of barium hydroxide ($M_r = 171.3$) is dissolved in water to give 100 cm³ of aqueous barium hydroxide.

Calculate the pH of this solution at 298 K
Give your answer to two decimal places.

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

[4 marks]

$$n(\text{Ba}(\text{OH})_2) = 1.50 \div 171.3 = 8.757 \times 10^{-3} \text{ mol}$$

$$n(\text{OH}^-) = 2 \times 8.757 \times 10^{-3} = 0.01751 \text{ mol}$$

$$[\text{OH}^-] = 0.01751 \times 1000 \div 100 = 0.175 \text{ mol dm}^{-3}$$

$$[\text{H}^+] = K_w \div [\text{OH}^-] = 1.00 \times 10^{-14} \div 0.175$$

$$[\text{H}^+] = 5.71 \times 10^{-14} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log(5.71 \times 10^{-14}) = 13.24$$

pH 13.24

07.5

1.50 g of calcium hydroxide is added to water to give 100 cm³ of aqueous calcium hydroxide.

Explain why the pH of this solution is lower than the pH of the barium hydroxide solution prepared in Question 07.4.

[1 mark]

Calcium hydroxide is less soluble in water than barium hydroxide, so fewer OH⁻ ions are in solution.

Question 7 continues on the next page

Turn over ►



A weak acid, HA, has an acid dissociation constant (K_a) of $1.86 \times 10^{-5} \text{ mol dm}^{-3}$ at 298 K

0 7 . 6 Calculate the pK_a for this weak acid at 298 K

Give your answer to two decimal places.

[1 mark]

$$pK_a = -\log K_a = -\log(1.86 \times 10^{-5}) = 4.73$$

pK_a 4.73

0 7 . 7 10.0 cm³ of 0.350 mol dm⁻³ aqueous sodium hydroxide are added to 25.0 cm³ of a 0.250 mol dm⁻³ aqueous solution of HA

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

[5 marks]

$$n(\text{NaOH}) = 10.0 \times 0.350 \div 1000 = 3.50 \times 10^{-3} \text{ mol}$$

$$n(\text{HA}) = 25.0 \times 0.250 \div 1000 = 6.25 \times 10^{-3} \text{ mol}$$

$$n(\text{HA}) \text{ in excess} = 6.25 \times 10^{-3} - 3.50 \times 10^{-3} = 2.75 \times 10^{-3} \text{ mol}$$

$$n(\text{A}^-) \text{ formed} = 3.50 \times 10^{-3} \text{ mol}$$

$$[\text{H}^+] = K_a \times [\text{HA}] \div [\text{A}^-] = 1.86 \times 10^{-5} \times (2.75 \times 10^{-3}) \div (3.50 \times 10^{-3})$$

$$[\text{H}^+] = 1.46 \times 10^{-5} \text{ mol dm}^{-3}$$

$$pH = -\log(1.46 \times 10^{-5}) = 4.84$$

pH 4.84

17

END OF QUESTIONS



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2 8



2 4 1 X C H 0 3