A

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 12 June 2023 Morning

Time allowed: 2 hours

[Turn over]

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At 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.**

[Turn over]

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 complexes of the transition metal chromium.

0 1 . 1

State the meaning of the term transition metal complex. [1 mark]

$Cr(PF_3)_6$ is a complex of chromium that contains molecules of PF_3

0 1 . 2

The electron pair repulsion theory can be used to predict the shape of a PF_3 molecule.

On the opposite page, draw the shape of a PF_3 molecule.

Include any lone pairs of electrons that influence the shape.

Name the shape. [2 marks]

Shape

Name of shape _____

[Turn over]

0 1 . 3

Suggest why the oxidation state of chromium is zero in $Cr(PF_3)_6$ [1 mark]

The compound $[Cr(NH_3)_4Cl_2]Cl$ contains ammonia molecules.

0 1 . 4

Deduce the oxidation state of chromium in $[Cr(NH_3)_4Cl_2]Cl$ [1 mark]

0 1 . 5

Name the type of bond between N and H in ammonia. [1 mark]

0 1 . 6

The compound $[Cr(NH_3)_4Cl_2]Cl$ contains a complex ion that shows isomerism.

Draw the two isomers of the complex ion.

State the type of isomerism shown.
[3 marks]

Isomer 1

Isomer 2

Type of isomerism

0 1 . 7

Complete the equation to show the formation of ONE complex that contains chromium in its +3 oxidation state.
[1 mark]

$CrCl_3 + 5\ H_2O \longrightarrow$ _____

10

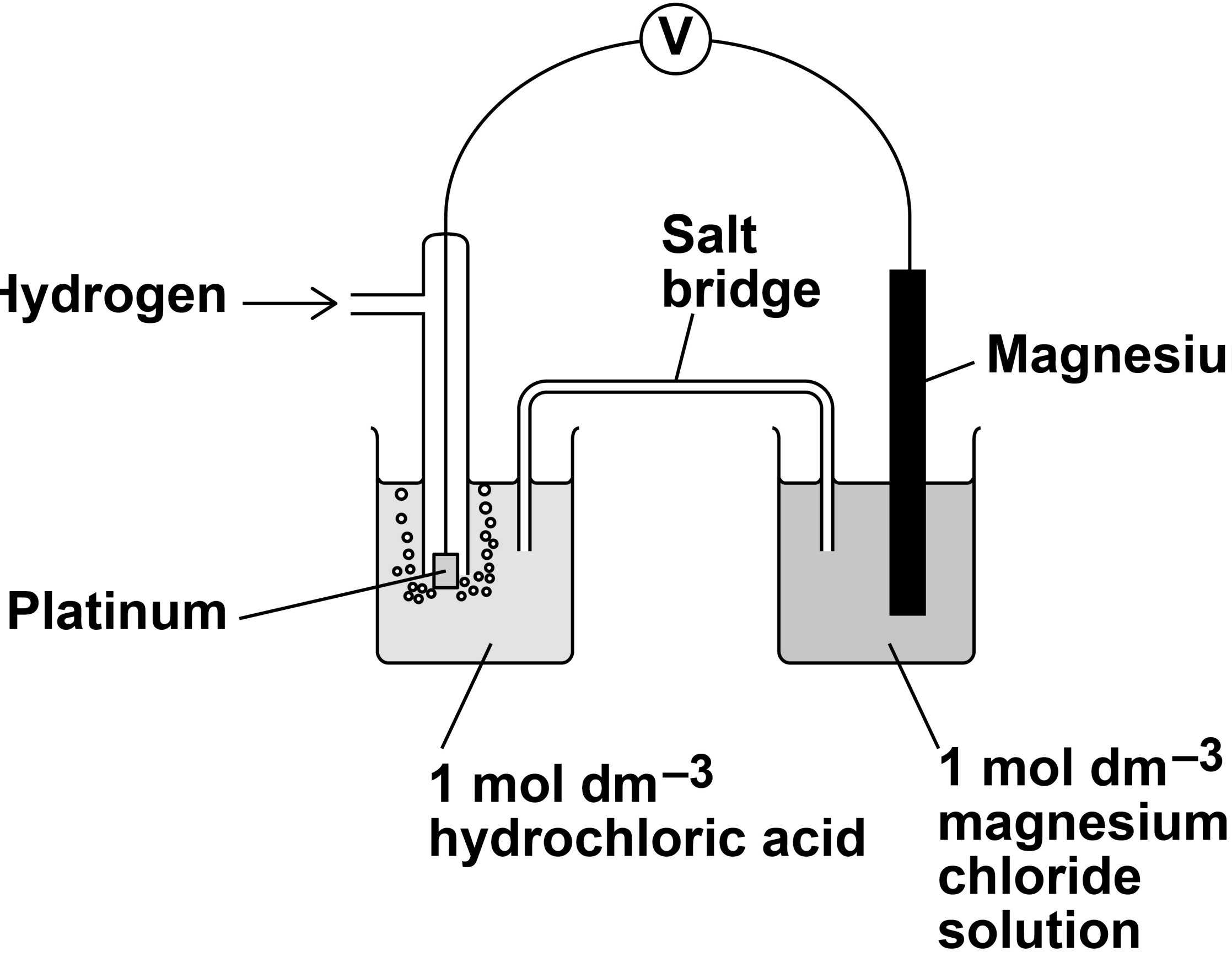
0 2

FIGURE 1, on page 14, shows a cell used to measure the standard electrode potential for the half-cell

$Mg^{2+}(aq) + 2\ e^- \longrightarrow Mg(s)$

[Turn over]

FIGURE 1


V
Salt bridge
Hydrogen
Magnesium
Platinum
1 mol dm^{-3} hydrochloric acid
1 mol dm^{-3} magnesium chloride solution

0 2 . 1

State the purpose of the salt bridge.

Identify an ionic compound that could be used in the salt bridge. [2 marks]

Purpose _____

_____

_____

Identity _____

_____

_____

0 2 . 2

State how, if at all, the EMF of this cell will change if the surface area of the platinum electrode is increased.
[1 mark]

The standard electrode potential, $E^{\ominus}$ for the half-cell is shown.

$$Mg^{2+}(aq) + 2\,e^{-} \longrightarrow Mg(s) \quad E^{\ominus} = -2.38\ V$$

0 2 . 3

Water is added to the beaker containing the magnesium chloride solution.

What is the effect on the magnitude of the EMF of the cell? [1 mark]

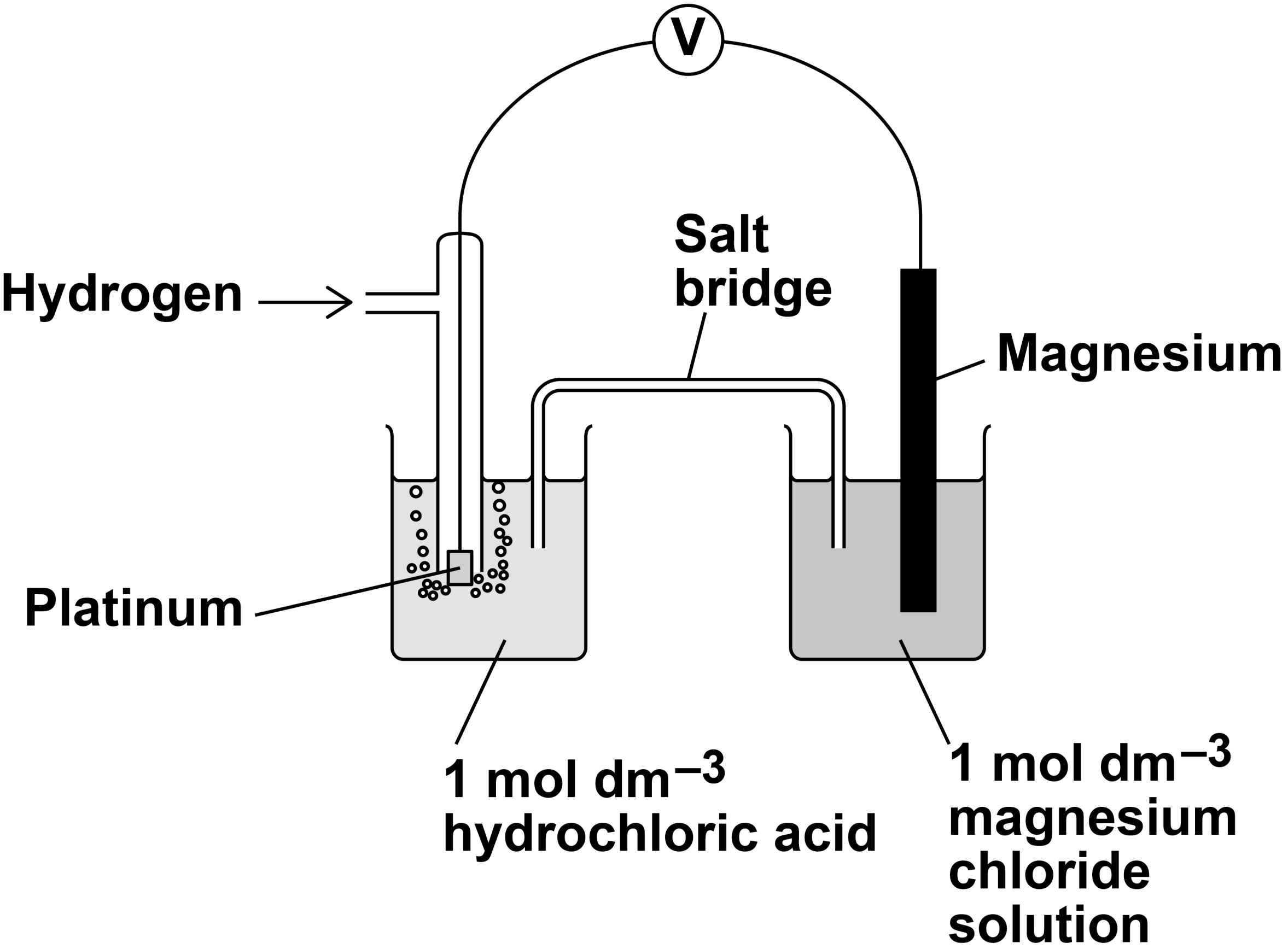
Tick (✓) ONE box.

☐ **EMF increases**

☐ **EMF stays the same**

☐ **EMF decreases**

REPEAT OF FIGURE 1



0 2 . 4

The voltmeter V shown in FIGURE 1 is replaced by a bulb.

Give an equation for the overall reaction that occurs when the cell is operating. [1 mark]

5

0 3

This question is about Period 3 elements and their oxides.

0 3 . 1

Give an equation for the reaction between phosphorus and an excess of oxygen. [1 mark]

0 3 . 2

Give an equation for the reaction between sulfur dioxide and water. [1 mark]

---

0 3 . 3

Give the displayed formula for the anion formed when sulfur trioxide reacts with water. [1 mark]

0 3 . 4

Give an equation for the reaction of magnesium with steam.

State one observation made. [2 marks]

Equation

Observation _____

0 3 . 5

Give an equation to show how an excess of magnesium oxide reacts with phosphoric acid (H_3PO_4). [1 mark]

6

0 4

Nitrogen dioxide decomposes at a high temperature.

$$2\ NO_2(g) \rightleftharpoons 2\ NO(g) + O_2(g)$$

$$\Delta H = +113\ kJ\ mol^{-1}$$

0 4 . 1

A 0.317 mol sample of nitrogen dioxide is placed in a sealed flask and heated at a constant temperature until equilibrium is reached.

At equilibrium, the flask contains 0.120 mol of oxygen.

Calculate the mole fraction of each substance at equilibrium. [3 marks]

Mole fraction of NO_2 _____

Mole fraction of NO _____

Mole fraction of O_2 _____

[Turn over]

0 4 . 2

The total pressure in the flask in Question 04.1 is 120 kPa at equilibrium.

Calculate the partial pressure, in kPa, of NO_2

If you were unable to answer Question 04.1 you should assume that the mole fraction of NO_2 is 0.380. This is NOT the correct answer. [1 mark]

Partial pressure _____ kPa

BLANK PAGE

[Turn over]

0 4 . 3

TABLE 1 shows the mole fractions of the three gases in a different equilibrium mixture.

$$2\,NO_2(g) \rightleftharpoons 2\,NO(g) + O_2(g)$$

$$\Delta H = +113\ kJ\ mol^{-1}$$

TABLE 1

GAS	MOLE FRACTION
NO_2	0.310
NO	0.460
O_2	0.230

For this equilibrium mixture,
K_p = 59.7 kPa

Give an expression for K_p for this reaction.

Use your expression and the data in TABLE 1 to calculate the total pressure, in kPa, in the flask. [3 marks]

K_p

Total pressure _____ kPa

[Turn over]

0 4 . 4

The equilibrium mixture in Question 04.3 is compressed into a smaller volume.

Deduce the effect, if any, of this change on the equilibrium yield of oxygen and on the value of K_p [2 marks]

Effect on yield of oxygen _____

_____

Effect on K_p _____

_____

0 4 . 5

The equilibrium mixture in Question 04.3 is allowed to reach equilibrium at a lower temperature.

Explain why the equilibrium yield of oxygen decreases. [2 marks]

0 5

This question is about metal chlorides.

0 5 . 1

TABLE 2 shows some enthalpy change data.

TABLE 2

	Enthalpy change / kJ mol^{-1}
$Ca^{2+}(g) \longrightarrow Ca^{2+}(aq)$	–1650
$Cl^{-}(g) \longrightarrow Cl^{-}(aq)$	–364
$Ca^{2+}(g) + 2\,Cl^{-}(g) \longrightarrow CaCl_2(s)$	–2237

Use the data in TABLE 2 to calculate the molar enthalpy change when calcium chloride dissolves in water. [2 marks]

Molar enthalpy change

_____ **kJ mol^{-1}**

[Turn over]

0 5 . 2

Use your answer to Question 05.1 to deduce how the temperature changes when calcium chloride dissolves in water. [1 mark]

0 5 . 3

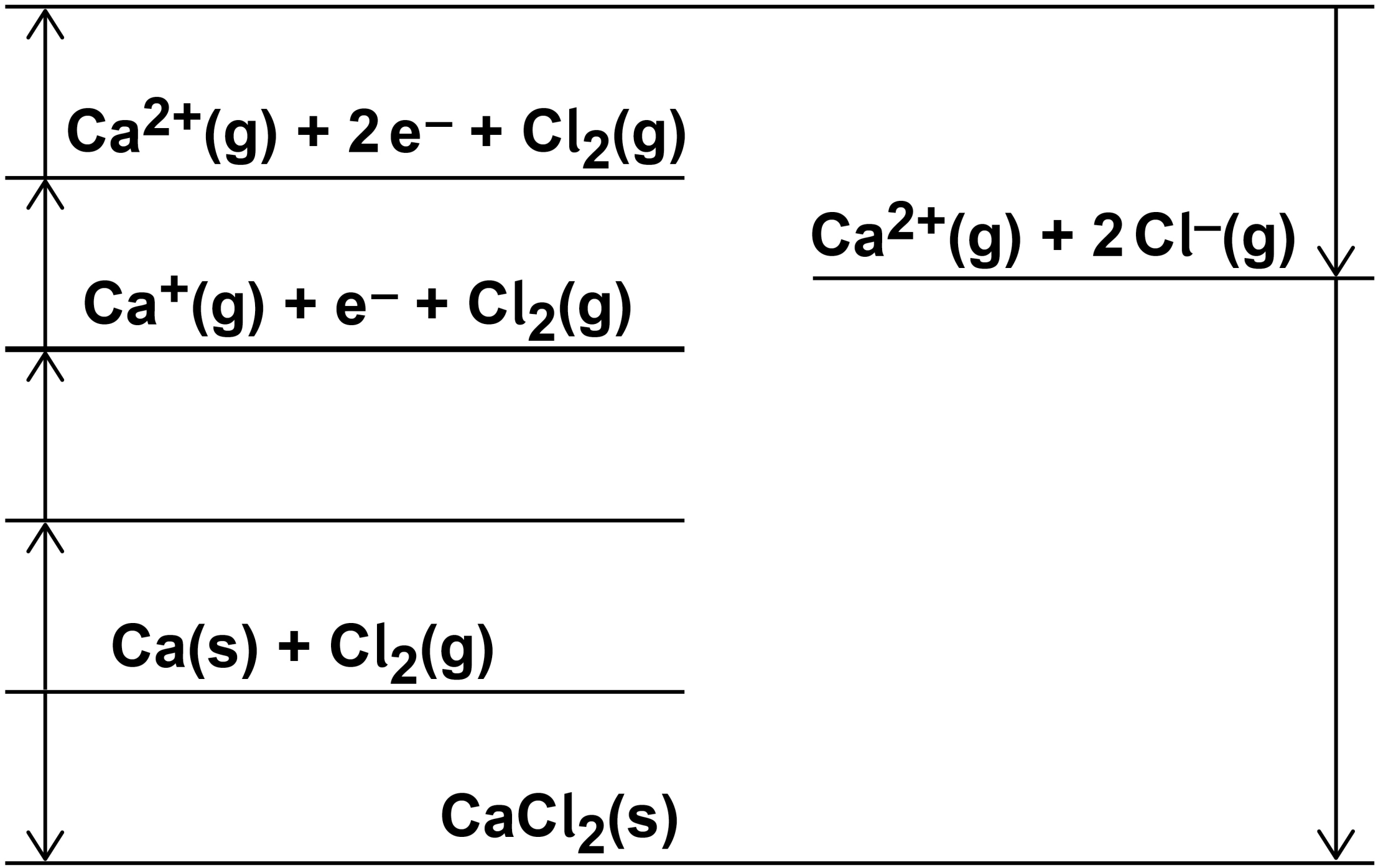
Explain why the enthalpy of hydration of fluoride ions is more negative than the enthalpy of hydration of chloride ions.
[2 marks]

0 5 . 4

FIGURE 2, on the opposite page, shows an incomplete Born–Haber cycle for calcium chloride.

Complete the Born–Haber cycle by writing the formulas of the missing species on each of the two blank lines. [2 marks]

FIGURE 2



[Turn over]

0 5 . 5

TABLE 3 shows some enthalpy change data.

TABLE 3

	Enthalpy change / kJ mol^{-1}
Enthalpy of atomisation of calcium	+193
First ionisation energy of calcium	+590
Enthalpy of atomisation of chlorine	+121
Electron affinity of chlorine	–364
Enthalpy of formation of calcium chloride	–795
Enthalpy of lattice formation of calcium chloride	–2237

Use FIGURE 2, on page 37, and data from TABLE 3 to calculate the second ionisation energy of calcium.
[2 marks]

Second ionisation energy

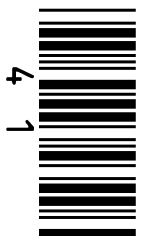
_____ **kJ mol^{-1}**

[Turn over]

0 4

0 5 . 6

Explain why the second ionisation energy of calcium is greater than the first ionisation energy of calcium. [1 mark]



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[Turn over]

0 5 . 7

TABLE 4 shows lattice enthalpies based on a perfect ionic model and lattice enthalpies from Born–Haber cycles for three metal chlorides.

TABLE 4

	Lattice enthalpy of dissociation / kJ mol^{-1}	
	Perfect ionic model	Born–Haber cycle
Calcium chloride	2223	2237
Potassium chloride	690	701
Silver chloride	770	905

Discuss the values in TABLE 4.

In your answer you should

- **compare the three values based on a perfect ionic model**
- **compare the values based on a perfect ionic model to the values from a Born–Haber cycle for each compound.**

[6 marks]

[Turn over]

[Turn over]

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0 6

The concentration of dilute hydrochloric acid can be found by titration using a standard solution of barium hydroxide.

0 6 . 1

Calculate the mass, in g, of solid barium hydroxide (M_r = 171.3) needed to prepare 250 cm^3 of 0.100 mol dm^{-3} barium hydroxide solution. [1 mark]

Mass _____ g

[Turn over]

0 6 . 2

The mass of barium hydroxide from Question 06.1 is dissolved in a beaker containing 150 cm^3 of distilled water.

Describe how this solution is used to make 250 cm^3 of the 0.100 mol dm^{-3} barium hydroxide solution. [3 marks]

[Turn over]

0 6 . 3

Before the first titration, the 25 cm^3 pipette is rinsed with a small volume of the 0.100 mol dm^{-3} barium hydroxide solution.

State why it is good practice to rinse the pipette in this way. [1 mark]

0 6 . 4

Hydrochloric acid is added to the burette using a funnel.

State why it is good practice to remove the funnel from the burette before the titration. [1 mark]

0 6 . 5

In a different experiment, 0.952 g of solid barium hydroxide is used to make 250 cm^3 of standard barium hydroxide solution.

25.0 cm^3 of this barium hydroxide solution reacts with exactly 24.50 cm^3 of hydrochloric acid.

Calculate the concentration of the hydrochloric acid. [3 marks]

Concentration _____ mol dm^{-3}

0 6 . 6

The uncertainty in the 25.0 cm^3 of solution from the pipette is ±0.05 cm^3

The total uncertainty in the 24.50 cm^3 of solution from the burette is ±0.15 cm^3

Calculate the total percentage error in using the pipette and burette. [1 mark]

Percentage error _____

10

0 7

This question is about complexes containing the aluminium ion.

0 7 . 1

Give the electron configuration of the Al^{3+} ion. [1 mark]

0 7 . 2

When anhydrous aluminium sulfate, $Al_2(SO_4)_3$, is added to water a solution forms that contains the complex aluminium ion, $[Al(H_2O)_6]^{3+}$

Give the equation for the reaction.
[1 mark]

0 7 . 3

Explain why the solution containing $[Al(H_2O)_6]^{3+}$ is acidic. [2 marks]

0 7 . 4

State why the concentration of aluminium sulfate solution can NOT be determined by colorimetry. [1 mark]

0 7 . 5

An excess of aqueous ammonia is added to a solution containing $[Al(H_2O)_6]^{3+}$

Give an ionic equation for the reaction and state one observation. [2 marks]

Equation

Observation

0 7 . 6

An excess of dilute sulfuric acid is added to the products of the reaction in Question 07.5

Identify the aluminium species produced.

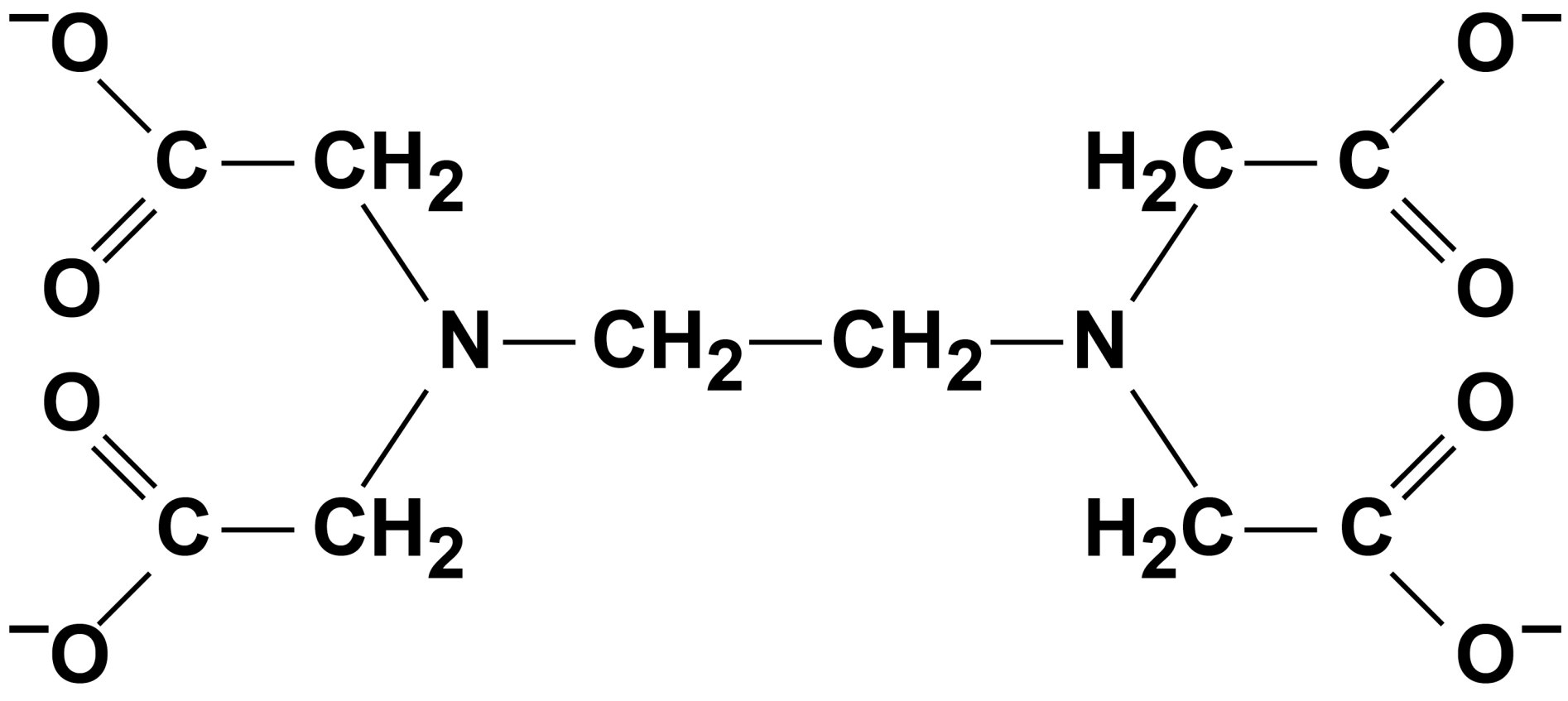
[1 mark]

[Turn over]

0 7 . 7

FIGURE 3 shows the structure of the $EDTA^{4-}$ ion.

FIGURE 3



Atoms of two different elements in $EDTA^{4-}$ can form co-ordinate bonds with an aluminium ion.

On FIGURE 3, draw circles around the atoms of TWO different elements that would link to an aluminium ion by a co-ordinate bond. [2 marks]

[Turn over]

0 7 . 8

Hydrated aluminium sulfate, $Al_2(SO_4)_3.xH_2O$, is soluble in water.

The relative formula mass and value of *x* can be found from a titration experiment.

Aqueous $[Al(H_2O)_6]^{3+}$ ions react to form a stable complex when treated with an excess of $EDTA^{4-}$ ions.

The excess of $EDTA^{4-}$ ions is determined by titration with $ZnSO_4$ solution.

Method

- Dissolve 1.036 g of $Al_2(SO_4)_3.xH_2O$ in distilled water and make up to 250 cm^3
- Add 25.0 cm^3 of this solution to 50.0 cm^3 of a solution containing $EDTA^{4-}$ ions of concentration 0.0100 mol dm^{-3}
- Determine the excess of $EDTA^{4-}$ ions by titrating with $ZnSO_4$ solution in the presence of an indicator.

[Turn over]

The excess of $EDTA^{4-}$ ions requires 18.00 cm^3 of 0.0105 mol dm^{-3} $ZnSO_4$ solution to react completely.

The equations for the reactions are

$[Al(H_2O)_6]^{3+} + EDTA^{4-} \longrightarrow [AlEDTA]^{-} + 6\,H_2O$

$[Zn(H_2O)_6]^{2+} + EDTA^{4-} \longrightarrow [ZnEDTA]^{2-} + 6\,H_2O$

For $Al_2(SO_4)_3$ $M_r = 342.3$

Use the information given on pages 64–66 to calculate the M_r of $Al_2(SO_4)_3.xH_2O$

Calculate x
Give your answer as an integer.
[7 marks]

M_r _____

x _____

0 8

This question is about fuel cells.

In a methanol–oxygen fuel cell, the overall reaction is

$$CH_3OH(l) + 1\frac{1}{2} O_2(g) \longrightarrow CO_2(g) + 2\,H_2O(l)$$

EMF = +1.20 V

0 8 . 1

At the positive electrode, oxygen reacts with hydrogen ions to form water.

Give a half-equation for this reaction.
[1 mark]

0 8 . 2

At the negative electrode, methanol reacts with water to produce carbon dioxide and hydrogen ions.

Give a half-equation for this reaction.

[1 mark]

[Turn over]

0 8 . 3

The standard electrode potential for the CO_2 / CH_3OH electrode is +0.03 V

Calculate the standard electrode potential for the O_2 / H_2O electrode.

[1 mark]

0 8 . 4

State why a fuel cell does NOT need to be electrically recharged. [1 mark]

0 8 . 5

Suggest ONE advantage of using methanol, rather than hydrogen, in a fuel cell for use in cars. [1 mark]

5

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0 9

This is a question about time of flight (TOF) mass spectrometry.

0 9 . 1

Give the equation, including state symbols, for the formation of Sr^+ ions from Sr atoms by electron impact.
[1 mark]

0 9 . 2

A sample of strontium is analysed by TOF mass spectrometry.
The sample is ionised using electron impact.

The ions are accelerated to have a kinetic energy (*KE*) of 7.02×10^{-20} J
An ion takes 9.47×10^{-4} s to travel along a 95.0 cm flight tube.

$$KE = \frac{1}{2} mv^2$$

where *m* = mass (kg) and
***v* = speed (m s^{-1})**

Use the information given to deduce the mass number of this ion.

The Avogadro constant,
***L* = 6.022×10^{23} mol^{-1} [5 marks]**

Mass number _____

[Turn over]

0 9 . 3

Explain how the ions are detected in the TOF mass spectrometer.

State how the relative abundance of the ions is determined. [2 marks]

How ions are detected _____

_____

_____

How relative abundance is determined

_____

_____

_____

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[Turn over]

0 9 . 4

A sample of strontium contains three isotopes, ^{86}Sr, ^{87}Sr and ^{88}Sr
82% of the sample is ^{88}Sr
The other isotopes are in a 1:2 ratio of ^{86}Sr : ^{87}Sr

Calculate the percentage abundance of ^{87}Sr in this sample.

Use your answer to deduce the relative atomic mass (A_r) of the sample.

Give your answer to 1 decimal place.
[3 marks]

Abundance of ^{87}Sr _____ %

A_r _____

[Turn over]

0 9 . 5

Electrospray ionisation is used instead of electron impact for the ionisation of a protein in a mass spectrometry experiment.

Suggest why. [1 mark]

12

1 0

This question is about weak acids.

1 0 . 1

TABLE 5 shows the pH ranges of some indicators.

TABLE 5

INDICATOR	pH RANGE
Bromocresol green	3.8 – 5.4
Bromothymol blue	6.0 – 7.6
Thymol blue	8.0 – 9.6

Identify the indicator that is most suitable for use in a titration between propanoic acid and sodium hydroxide.
[1 mark]

---

1 0 . 2

Give the expression for the acid dissociation constant (K_a) for propanoic acid (CH_3CH_2COOH). [1 mark]

K_a

1 0 . 3

Calculate the pH of a 0.100 mol dm^{-3} propanoic acid solution.
Give your answer to 2 decimal places.

For propanoic acid, pK_a = 4.87

[4 marks]

pH _____

[Turn over]

10.4

For butanoic acid,
$K_a = 1.51 \times 10^{-5}$ mol dm^{-3}

20.0 cm^3 of 0.100 mol dm^{-3} sodium hydroxide solution are added to 25.0 cm^3 of 0.100 mol dm^{-3} butanoic acid solution.

Calculate the pH of the solution formed.
[5 marks]

pH _____

[Turn over]

10.5 A student plans to titrate butanoic acid solution with a solution of ethylamine.

Explain why this titration could NOT be done using an indicator. [2 marks]

END OF QUESTIONS

13

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.

Additional page, if required.

Write the question numbers in the left-hand margin.

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For Examiner's Use	
Question	Mark
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