

Please write clearly in block capitals.

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I declare this is my own work.

# A-level CHEMISTRY

## Paper 1 Inorganic and Physical Chemistry

Monday 12 June 2023

Morning

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	
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10	
<b>TOTAL</b>	





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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]

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$\text{Cr}(\text{PF}_3)_6$  is a complex of chromium that contains molecules of  $\text{PF}_3$

0 1 . 2

The electron pair repulsion theory can be used to predict the shape of a  $\text{PF}_3$  molecule.

Draw the shape of a  $\text{PF}_3$  molecule.

Include any lone pairs of electrons that influence the shape.

Name the shape.

[2 marks]

Shape

Name of shape \_\_\_\_\_

0 1 . 3

Suggest why the oxidation state of chromium is zero in  $\text{Cr}(\text{PF}_3)_6$

[1 mark]

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The compound  $[\text{Cr}(\text{NH}_3)_4\text{Cl}_2]\text{Cl}$  contains ammonia molecules.

0 1 . 4

Deduce the oxidation state of chromium in  $[\text{Cr}(\text{NH}_3)_4\text{Cl}_2]\text{Cl}$

[1 mark]

---

0 1 . 5

Name the type of bond between N and H in ammonia.

[1 mark]

---

0 1 . 6

The compound  $[\text{Cr}(\text{NH}_3)_4\text{Cl}_2]\text{Cl}$  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]

$\text{CrCl}_3 + 5\text{H}_2\text{O} \rightarrow$  \_\_\_\_\_

10

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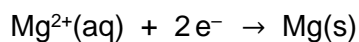




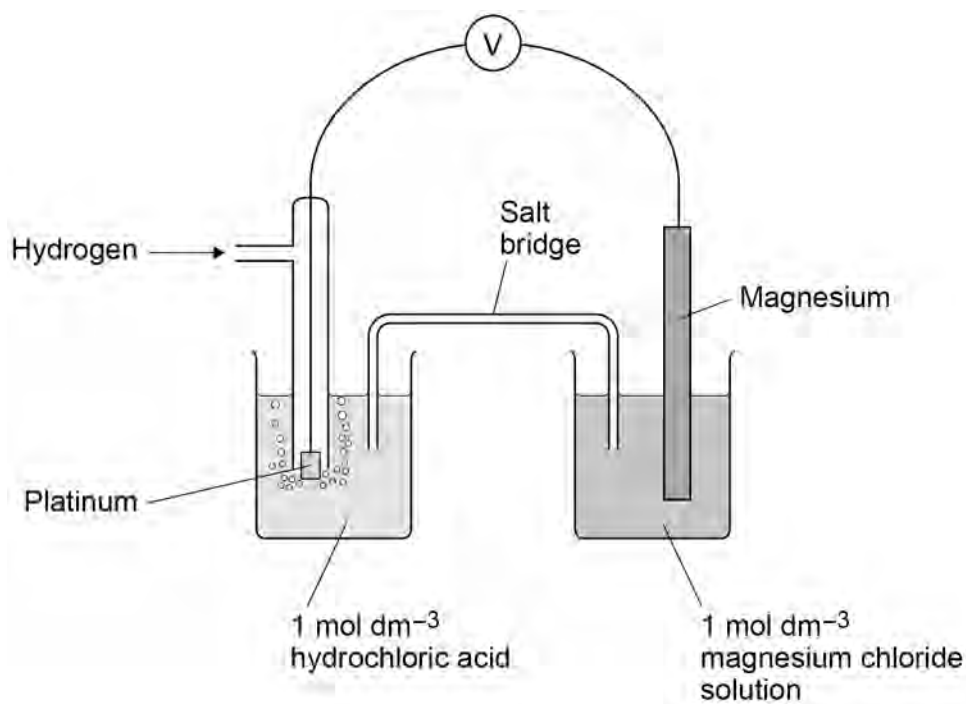
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0 2

**Figure 1** shows a cell used to measure the standard electrode potential for the half-cell



**Figure 1**



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]**

\_\_\_\_\_

\_\_\_\_\_





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



**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

**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]

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5

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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]

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0 3 . 2

Give an equation for the reaction between sulfur dioxide and water.

[1 mark]

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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

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Observation

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0 3 . 5

Give an equation to show how an excess of magnesium oxide reacts with phosphoric acid ( $\text{H}_3\text{PO}_4$ ).

[1 mark]

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6

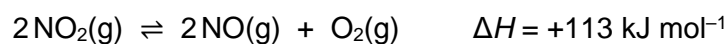




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0 4

Nitrogen dioxide decomposes at a high temperature.



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  $\text{NO}_2$  \_\_\_\_\_

Mole fraction of  $\text{NO}$  \_\_\_\_\_

Mole fraction of  $\text{O}_2$  \_\_\_\_\_

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  $\text{NO}_2$

If you were unable to answer Question 04.1 you should assume that the mole fraction of  $\text{NO}_2$  is 0.380. This is **not** the correct answer.

[1 mark]

Partial pressure \_\_\_\_\_ kPa

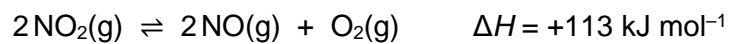
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**0 4 . 3** **Table 1** shows the mole fractions of the three gases in a different equilibrium mixture.



**Table 1**

Gas	Mole fraction
NO <sub>2</sub>	0.310
NO	0.460
O <sub>2</sub>	0.230

For this equilibrium mixture,  $K_p = 59.7 \text{ kPa}$

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





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**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]

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

11

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0 5

This question is about metal chlorides.

0 5 . 1

**Table 2** shows some enthalpy change data.

**Table 2**

	Enthalpy change / $\text{kJ mol}^{-1}$
$\text{Ca}^{2+}(\text{g}) \rightarrow \text{Ca}^{2+}(\text{aq})$	-1650
$\text{Cl}^{-}(\text{g}) \rightarrow \text{Cl}^{-}(\text{aq})$	-364
$\text{Ca}^{2+}(\text{g}) + 2\text{Cl}^{-}(\text{g}) \rightarrow \text{CaCl}_2(\text{s})$	-2237

Use the data in **Table 2** to calculate the molar enthalpy change when calcium chloride dissolves in water.

[2 marks]

Molar enthalpy change \_\_\_\_\_  $\text{kJ mol}^{-1}$

0 5 . 2

Use your answer to Question **05.1** to deduce how the temperature changes when calcium chloride dissolves in water.

[1 mark]

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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]

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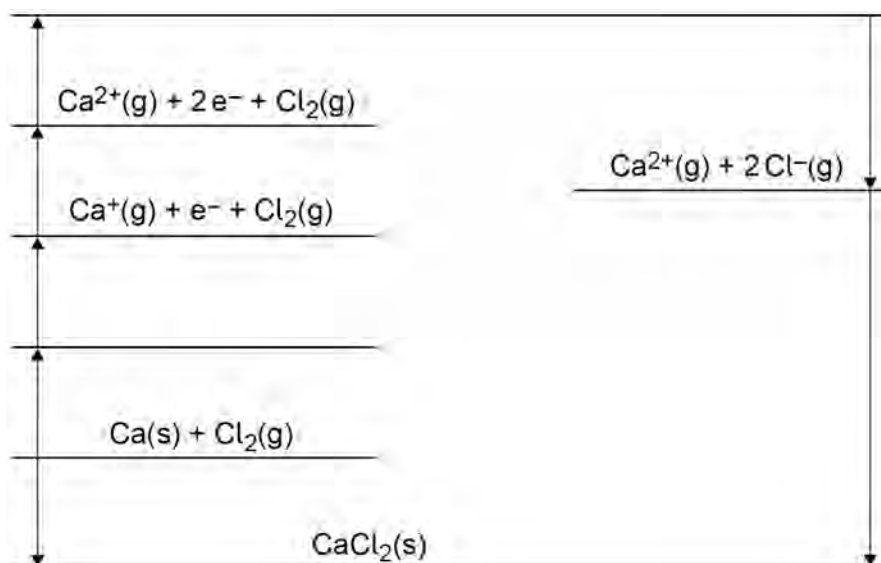




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**0 5 . 4** Figure 2 shows an incomplete Born–Haber cycle for calcium chloride.

**Figure 2**



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

**[2 marks]**

**0 5 . 5** Table 3 shows some enthalpy change data.

**Table 3**

	Enthalpy change / $\text{kJ mol}^{-1}$
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** and data from **Table 3** to calculate the second ionisation energy of calcium.

**[2 marks]**

Second ionisation energy \_\_\_\_\_  $\text{kJ mol}^{-1}$

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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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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 / $\text{kJ mol}^{-1}$	
	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]

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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<sup>3</sup> of 0.100 mol dm<sup>-3</sup> barium hydroxide solution.

**[1 mark]**

Mass \_\_\_\_\_ g

**0 6 . 2**

The mass of barium hydroxide from Question **06.1** is dissolved in a beaker containing 150 cm<sup>3</sup> of distilled water.

Describe how this solution is used to make 250 cm<sup>3</sup> of the 0.100 mol dm<sup>-3</sup> barium hydroxide solution.

**[3 marks]**

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**0 6 . 3**

Before the first titration, the 25 cm<sup>3</sup> pipette is rinsed with a small volume of the 0.100 mol dm<sup>-3</sup> barium hydroxide solution.

State why it is good practice to rinse the pipette in this way.

**[1 mark]**

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**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]**

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**0 6 . 5** In a different experiment, 0.952 g of solid barium hydroxide is used to make 250 cm<sup>3</sup> of standard barium hydroxide solution.

25.0 cm<sup>3</sup> of this barium hydroxide solution reacts with exactly 24.50 cm<sup>3</sup> of hydrochloric acid.

Calculate the concentration of the hydrochloric acid.

**[3 marks]**

Concentration \_\_\_\_\_ mol dm<sup>-3</sup>

**0 6 . 6** The uncertainty in the 25.0 cm<sup>3</sup> of solution from the pipette is  $\pm 0.05$  cm<sup>3</sup>

The total uncertainty in the 24.50 cm<sup>3</sup> of solution from the burette is  $\pm 0.15$  cm<sup>3</sup>

Calculate the total percentage error in using the pipette and burette.

**[1 mark]**

Percentage error \_\_\_\_\_

**10**

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0 7

This question is about complexes containing the aluminium ion.

0 7 . 1

Give the electron configuration of the  $\text{Al}^{3+}$  ion.

[1 mark]

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0 7 . 2

When anhydrous aluminium sulfate,  $\text{Al}_2(\text{SO}_4)_3$ , is added to water a solution forms that contains the complex aluminium ion,  $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$

Give the equation for the reaction.

[1 mark]

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0 7 . 3

Explain why the solution containing  $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$  is acidic.

[2 marks]

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0 7 . 4

State why the concentration of aluminium sulfate solution can **not** be determined by colorimetry.

[1 mark]

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**0 7 . 5** An excess of aqueous ammonia is added to a solution containing  $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$

Give an ionic equation for the reaction and state one observation.

**[2 marks]**

Equation

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Observation 

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**0 7 . 6** An excess of dilute sulfuric acid is added to the products of the reaction in Question **07.5**

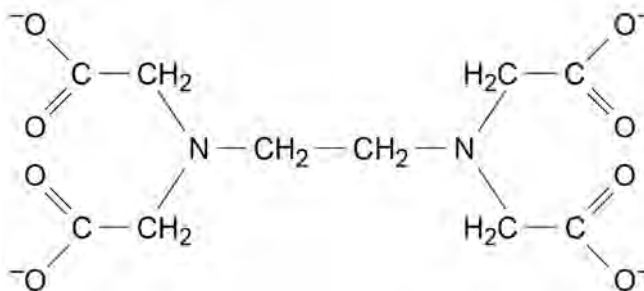
Identify the aluminium species produced.

**[1 mark]**

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**0 7 . 7** **Figure 3** shows the structure of the  $\text{EDTA}^{4-}$  ion.

**Figure 3**



Atoms of two different elements in  $\text{EDTA}^{4-}$  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]**

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0 7 . 8

Hydrated aluminium sulfate,  $\text{Al}_2(\text{SO}_4)_3 \cdot x\text{H}_2\text{O}$ , is soluble in water.

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

Aqueous  $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$  ions react to form a stable complex when treated with an excess of  $\text{EDTA}^{4-}$  ions.

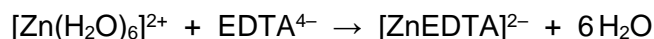
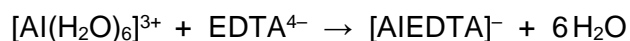
The excess of  $\text{EDTA}^{4-}$  ions is determined by titration with  $\text{ZnSO}_4$  solution.

Method

- Dissolve 1.036 g of  $\text{Al}_2(\text{SO}_4)_3 \cdot x\text{H}_2\text{O}$  in distilled water and make up to  $250 \text{ cm}^3$
- Add  $25.0 \text{ cm}^3$  of this solution to  $50.0 \text{ cm}^3$  of a solution containing  $\text{EDTA}^{4-}$  ions of concentration  $0.0100 \text{ mol dm}^{-3}$
- Determine the excess of  $\text{EDTA}^{4-}$  ions by titrating with  $\text{ZnSO}_4$  solution in the presence of an indicator.

The excess of  $\text{EDTA}^{4-}$  ions requires  $18.00 \text{ cm}^3$  of  $0.0105 \text{ mol dm}^{-3}$   $\text{ZnSO}_4$  solution to react completely.

The equations for the reactions are



For  $\text{Al}_2(\text{SO}_4)_3$   $M_r = 342.3$





Use the information given to calculate the  $M_r$  of  $\text{Al}_2(\text{SO}_4)_3 \cdot x\text{H}_2\text{O}$

Calculate  $x$

Give your answer as an integer.

[7 marks]

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$M_r$  \_\_\_\_\_

$x$  \_\_\_\_\_

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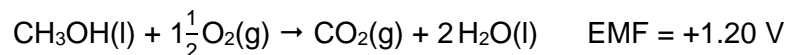


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0 8

This question is about fuel cells.

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



0 8 . 1

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

Give a half-equation for this reaction.

[1 mark]

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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]

---

0 8 . 3

The standard electrode potential for the  $\text{CO}_2 / \text{CH}_3\text{OH}$  electrode is +0.03 V

Calculate the standard electrode potential for the  $\text{O}_2 / \text{H}_2\text{O}$  electrode.

[1 mark]

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0 8 . 4

State why a fuel cell does **not** need to be electrically recharged.

[1 mark]

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0 8 . 5

Suggest **one** advantage of using methanol, rather than hydrogen, in a fuel cell for use in cars.

[1 mark]

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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  $\text{Sr}^+$  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  $7.02 \times 10^{-20} \text{ J}$   
An ion takes  $9.47 \times 10^{-4} \text{ s}$  to travel along a 95.0 cm flight tube.

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

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

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

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

[5 marks]

Mass number \_\_\_\_\_





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**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 \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**0 9 . 4** A sample of strontium contains three isotopes,  $^{86}\text{Sr}$ ,  $^{87}\text{Sr}$  and  $^{88}\text{Sr}$   
82% of the sample is  $^{88}\text{Sr}$   
The other isotopes are in a 1:2 ratio of  $^{86}\text{Sr} : ^{87}\text{Sr}$

Calculate the percentage abundance of  $^{87}\text{Sr}$  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  $^{87}\text{Sr}$  \_\_\_\_\_ %

$A_r$  \_\_\_\_\_

**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

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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]

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1 0 . 2

Give the expression for the acid dissociation constant ( $K_a$ ) for propanoic acid ( $\text{CH}_3\text{CH}_2\text{COOH}$ ).

[1 mark]

$K_a$

1 0 . 3

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

For propanoic acid,  $\text{p}K_a = 4.87$

[4 marks]

pH \_\_\_\_\_





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1 0 . 4 For butanoic acid,  $K_a = 1.51 \times 10^{-5} \text{ mol dm}^{-3}$

20.0 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> sodium hydroxide solution are added to  
25.0 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> butanoic acid solution.

Calculate the pH of the solution formed.

[5 marks]

pH \_\_\_\_\_

1 0 . 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]

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13

END OF QUESTIONS





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