A

AQA

**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**

**At the top of the page, write your surname and forename(s), your centre number, your candidate number and add your signature.**

**[Turn over]**

JUN237405101

**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.**
- **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**

**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.**

**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]**

_____

_____

**[Turn over]**

**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]**

$CrCl_3 + 5\ H_2O \longrightarrow$ _____

**[Turn over]**

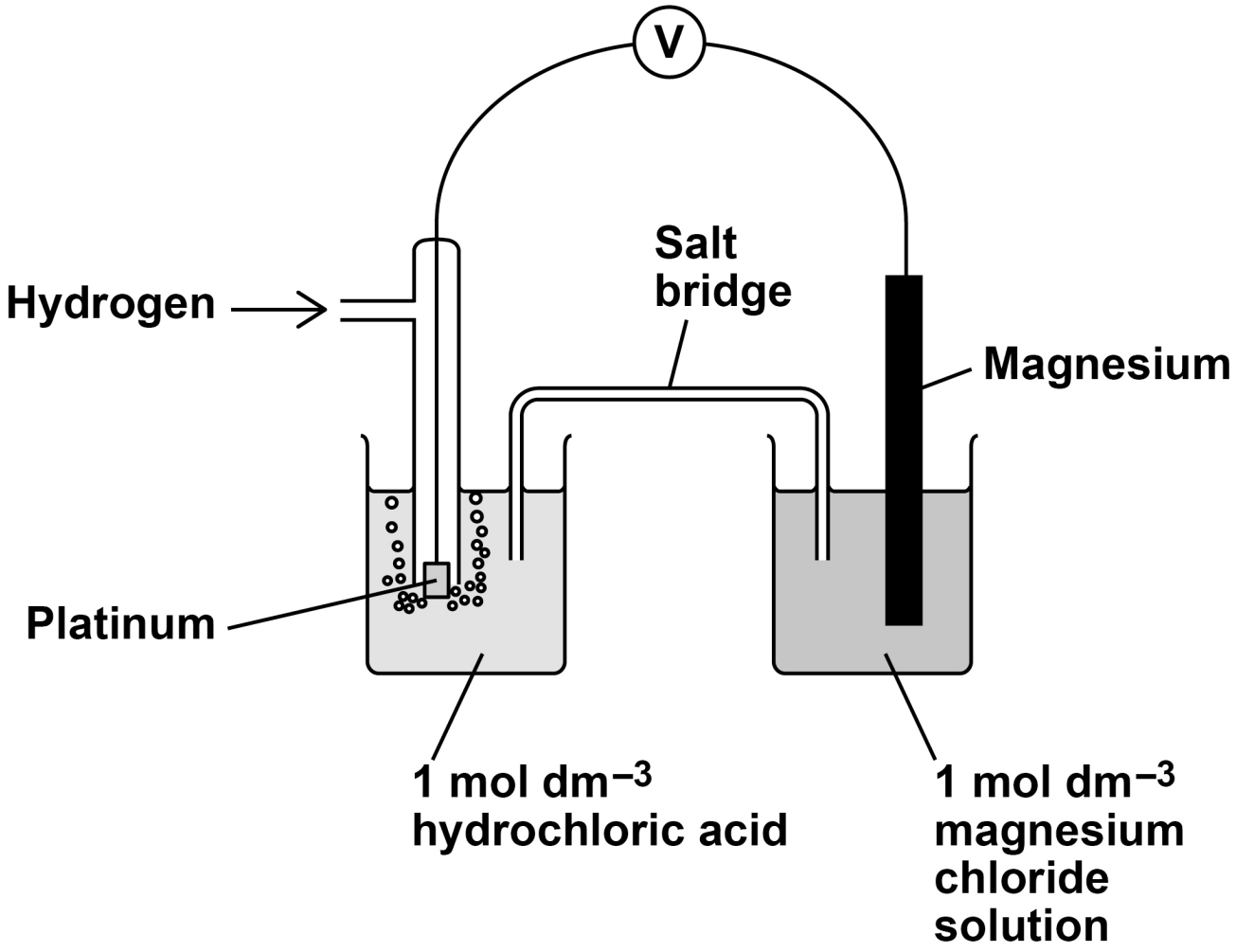
**10**

**0 2**

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

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

**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]**

_____

_____

_____

**[Turn over]**

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

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

**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**

**0 2 . 4**

**The voltmeter V shown in FIGURE 1, on page 10, is replaced by a bulb.**

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

---

**[Turn over]**

**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]**

**[Turn over]**

**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]**

---

**[Turn over]**

**6**

**0 4**

**Nitrogen dioxide decomposes at a high temperature.**

$$2\ NO_2(g) \rightleftharpoons 2\ NO(g) + O_2(g) \qquad \Delta H = +113\ kJ\ mol^{-1}$$

**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, on the opposite page, 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]**



**11**

**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]**

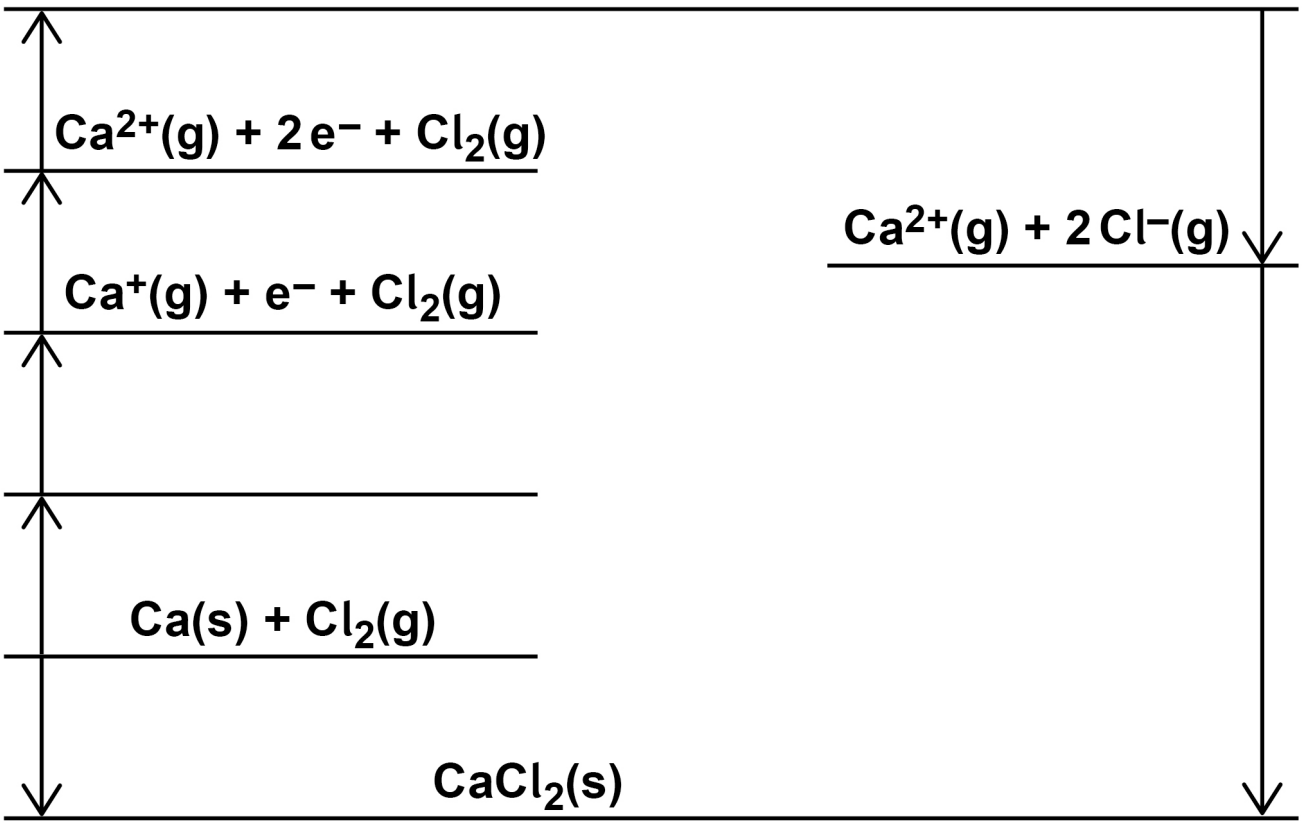
**0 5 . 3**

**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 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]**

**[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 29, and data from TABLE 3 to calculate the second ionisation energy of calcium.**
**[2 marks]**

**Second ionisation energy**

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

**0 5 . 6**

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

_____

_____

_____

**[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]

16

**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**

**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]**



**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** _____

**[Turn over]**

**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**

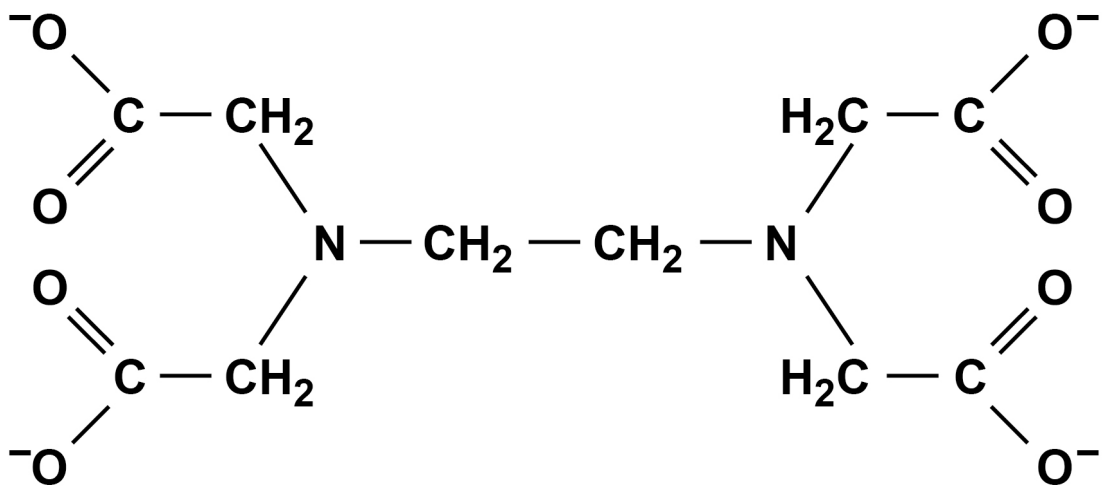
**Identify the aluminium species produced. [1 mark]**

**[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]**

**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 49 and 50, 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* _____

**[Turn over]**

17

**0 8**

**This question is about fuel cells.**

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

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

**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]**

---

**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]**

---

---

**[Turn over]**

**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**

**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]**

---

**[Turn over]**

**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 $7.02 \times 10^{-20}$ J**
**An ion takes $9.47 \times 10^{-4}$ 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* = $6.022 \times 10^{23}$ $mol^{-1}$**
**[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** _____

_____

_____

_____

**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]**

_____

**[Turn over]**

**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]**

**1 0 . 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** _____

**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]**

**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.**

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| For Examiner's Use | |
|---|---|
| Question | Mark |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |
| **TOTAL** | |