AQA

Please write clearly in block capitals.

Centre number | | | | | | Candidate number | | | | |

Surname _____

Forename(s) _____

Candidate signature _____

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 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |
| **TOTAL** | |

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

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**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

**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]**

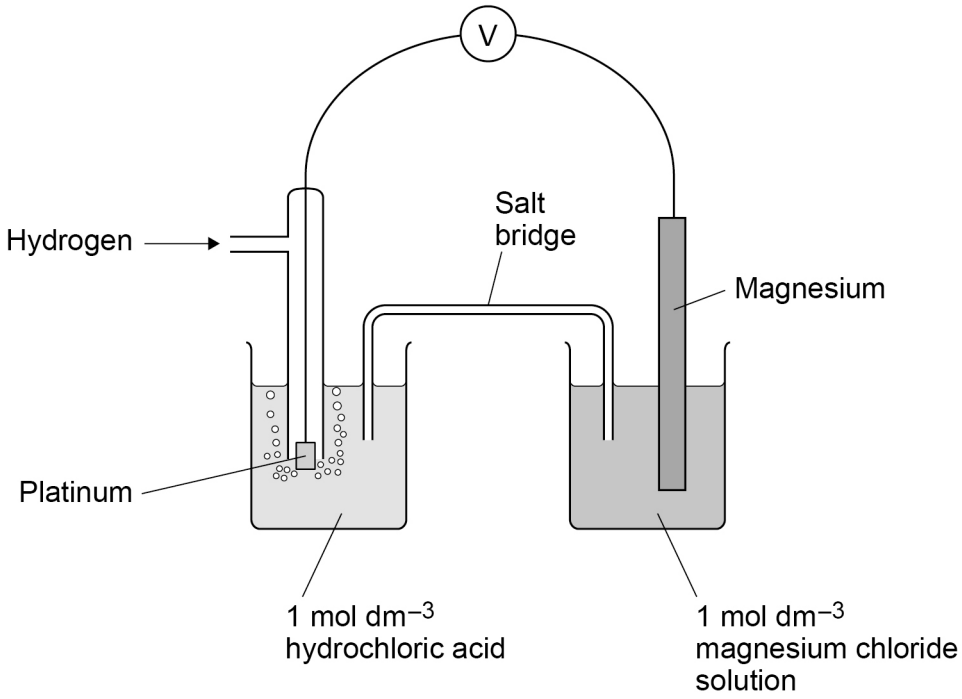
$CrCl_3 + 5\,H_2O \rightarrow$ _____

10

**0 2** **Figure 1** shows a cell used to measure the standard electrode potential for the half-cell

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

**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]**

_____

_____

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

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

**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** is replaced by a bulb.

Give an equation for the overall reaction that occurs when the cell is operating.

**[1 mark]**

5



**Turn over for the next question**

**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.

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

**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 $O_2$ _____

**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

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

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

**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

**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**

**Turn over for the next question**

**0 5** This question is about metal chlorides.

**0 5 . 1** **Table 2** shows some enthalpy change data.

**Table 2**

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

**0 5 . 2** Use your answer to Question **05.1** to deduce how the temperature changes when calcium chloride dissolves in water.

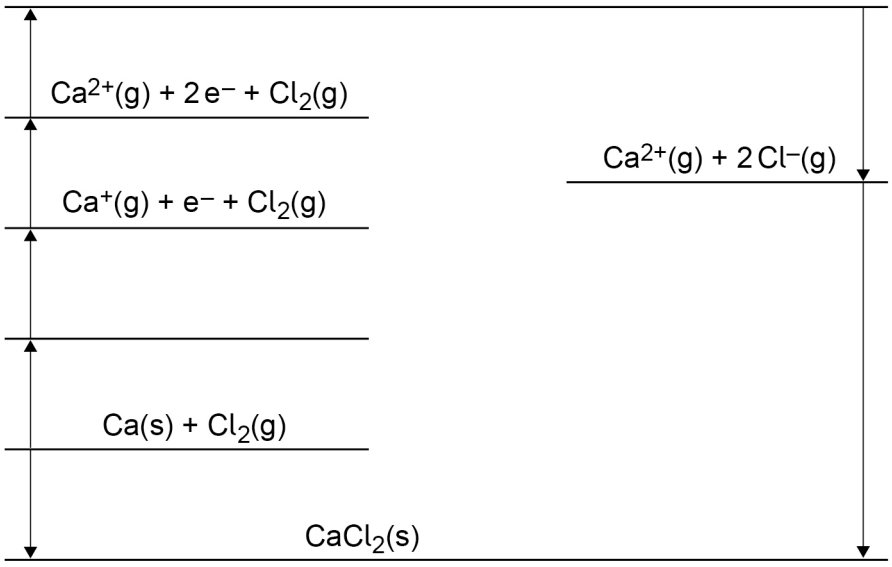
**[1 mark]**

**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]**

**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** 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]**

**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]**

*Do not write outside the box*



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 _____

**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

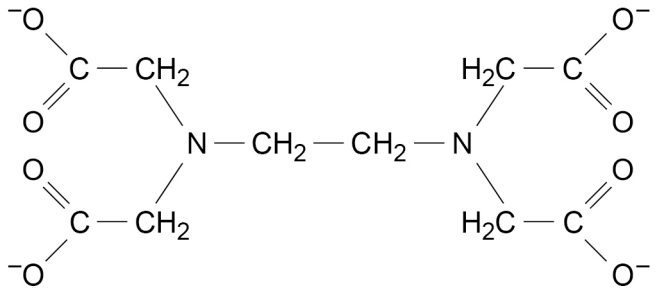
**0 7 . 6** An excess of dilute sulfuric acid is added to the products of the reaction in Question **07.5**

Identify the aluminium species produced.

**[1 mark]**

**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.

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

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

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

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

Use the information given to calculate the $M_r$ of $Al_2(SO_4)_3.xH_2O$

Calculate $x$
Give your answer as an integer.

**[7 marks]**

$M_r$ _____

$x$ _____

17

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**ANSWER IN THE SPACES PROVIDED**

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**0 8** This question is about fuel cells.

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

$$CH_3OH(l) + 1\tfrac{1}{2}O_2(g) \rightarrow CO_2(g) + 2\,H_2O(l) \qquad EMF = +1.20\ V$$

**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]**

**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]**

**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 _____

**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 $^{87}Sr$ _____ %

$A_r$ _____

**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 _____

**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]**

_____

_____

_____

_____

**13**

**END OF QUESTIONS**

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