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]

Do not write outside the box

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

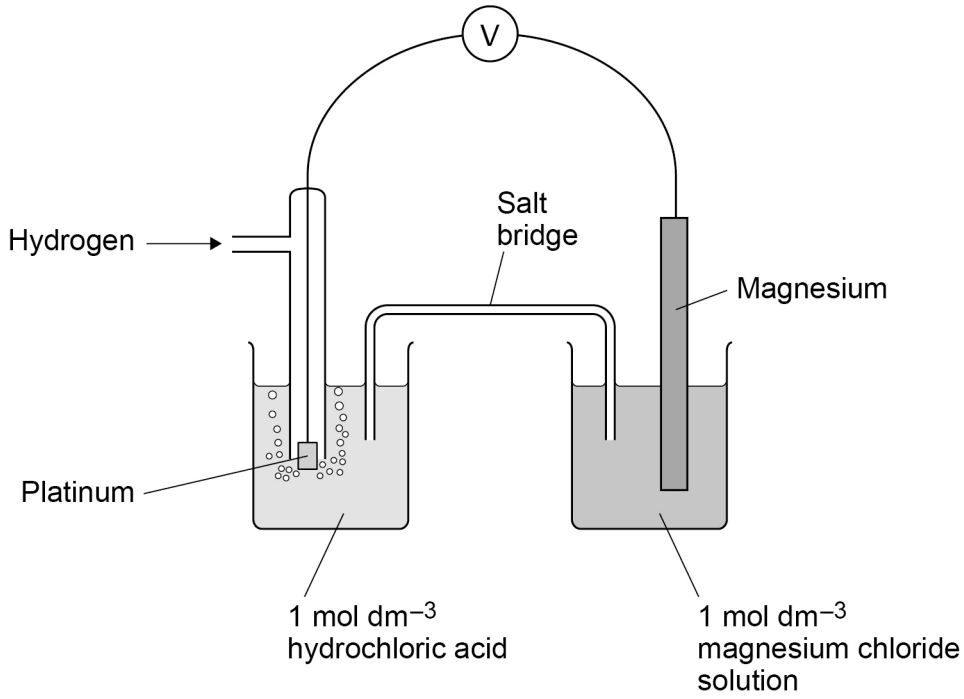
Turn over ►

Do not write outside the box

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]

_____

_____

Do not write outside the box

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

Do not write outside the box

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

Do not write outside the box

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

Do not write outside the box

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

Do not write outside the box

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

Do not write outside the box

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]

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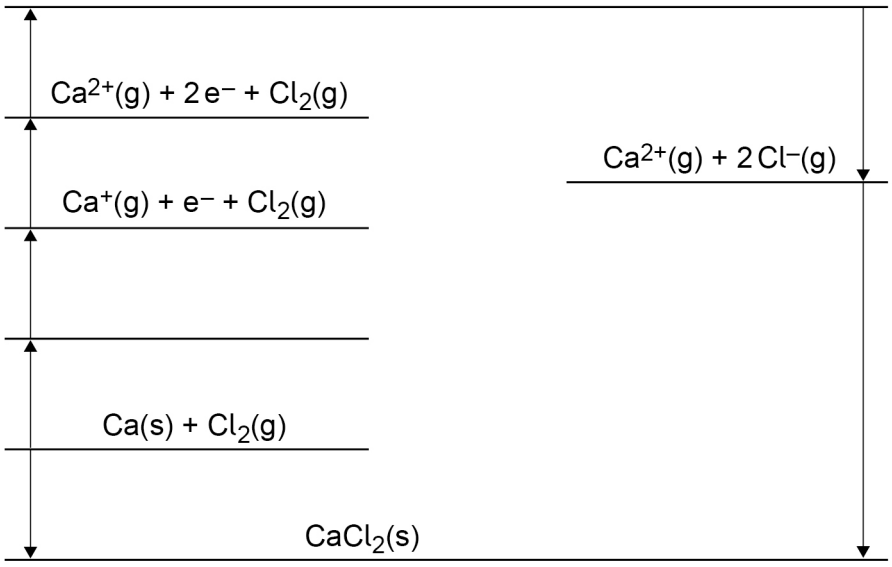
0 5 . 4 **Figure 2** shows an incomplete Born–Haber cycle for calcium chloride.

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 / 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}

Do not write outside the box

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]

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16

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

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]

Do not write outside the box

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

Turn over ►

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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]

Do not write outside the box

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

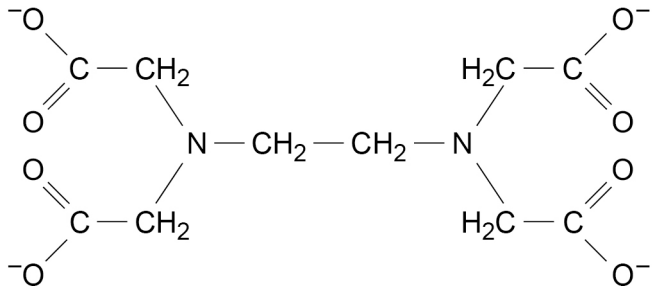
0 7 . 6 An excess of dilute sulfuric acid is added to the products of the reaction in Question **07.5**

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]

Turn over ►

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

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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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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

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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, $L = 6.022 \times 10^{23}$ mol^{-1}

[5 marks]

Mass number _____

Do not write outside the box

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

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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]

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 _____

Do not write outside the box

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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