

Please write clearly in block capitals.

Centre number

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Candidate number

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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.

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]

$\text{Cr}(\text{PF}_3)_6$ 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 $\text{Cr}(\text{PF}_3)_6$

[1 mark]



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

Turn over ►



0 2

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

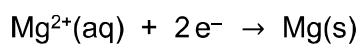
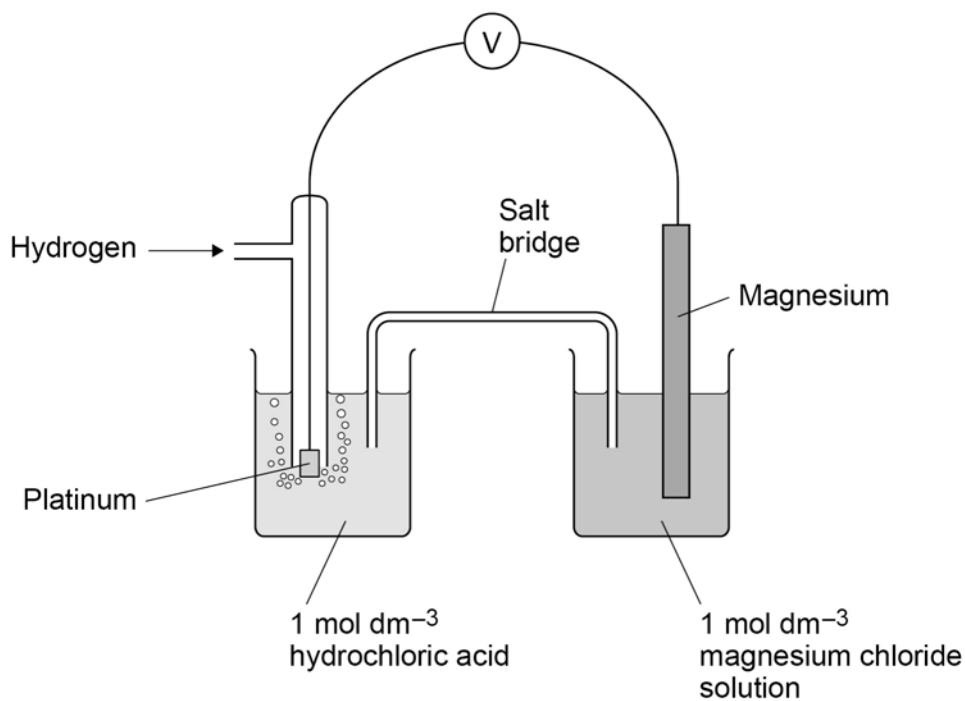


Figure 1



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]



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]

5

Turn over for the next question

Turn over ►



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).

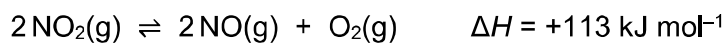
[1 mark]

6



0 4

Nitrogen dioxide decomposes at a high temperature.

**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

Turn over ►

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

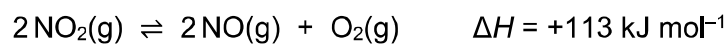


Table 1

Gas	Mole fraction
NO ₂	0.310
NO	0.460
O ₂	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



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

Turn over ►



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}
$\text{Ca}^{2+}(\text{g}) \rightarrow \text{Ca}^{2+}(\text{aq})$	-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 _____ 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.

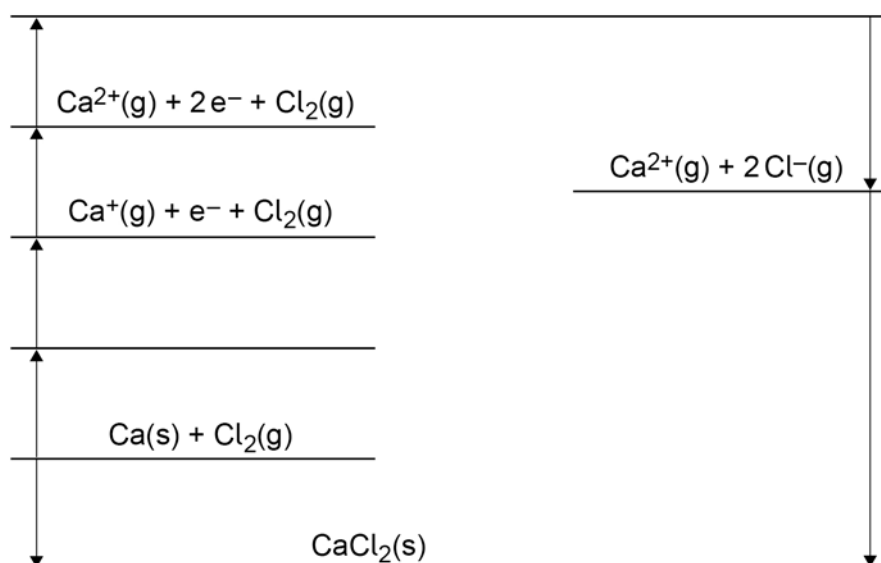
[2 marks]



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}

Turn over ►



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]



[illegible]

Turn over ►



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 cm³ 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 cm³ of distilled water.

Describe how this solution is used to make 250 cm³ of the 0.100 mol dm⁻³ barium hydroxide solution.

[3 marks]

0 6 . 3

Before the first titration, the 25 cm³ 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 cm³ of standard barium hydroxide solution.

25.0 cm³ of this barium hydroxide solution reacts with exactly
24.50 cm³ 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 cm³ of solution from the pipette is ± 0.05 cm³

The total uncertainty in the 24.50 cm³ of solution from the burette is ± 0.15 cm³

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

[1 mark]

Percentage error _____

10

Turn over ►



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, $\text{Al}_2(\text{SO}_4)_3$, 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]

0	7	.	3
---	---	---	---

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

[2 marks]

0	7	.	4
---	---	---	---

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

[1 mark]



07.5

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

Observation

07.6

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

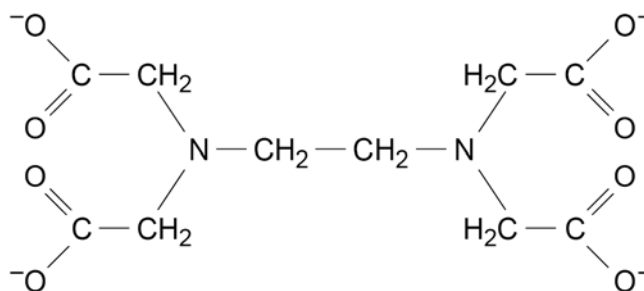
Identify the aluminium species produced.

[1 mark]

07.7

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, $\text{Al}_2(\text{SO}_4)_3 \cdot x\text{H}_2\text{O}$, 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 EDTA^{4-} ions.

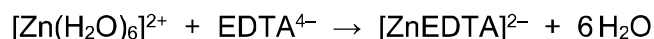
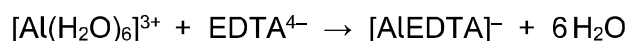
The excess of EDTA^{4-} ions is determined by titration with ZnSO_4 solution.

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 cm^3
- Add 25.0 cm^3 of this solution to 50.0 cm^3 of a solution containing EDTA^{4-} ions of concentration $0.0100 \text{ mol dm}^{-3}$
- 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 $0.0105 \text{ mol dm}^{-3}$ 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]

M_r _____

x _____

17

Turn over ►



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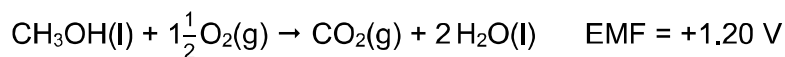
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0 8

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]

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]

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]



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 $7.02 \times 10^{-20} \text{ J}$
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 (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 _____



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]



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 ($\text{CH}_3\text{CH}_2\text{COOH}$).

[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 _____



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

20.0 cm³ of 0.100 mol dm⁻³ sodium hydroxide solution are added to
25.0 cm³ 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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