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

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	
TOTAL	

Do not write outside the box

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

0 1 This question is about enthalpy changes for calcium chloride and magnesium chloride.

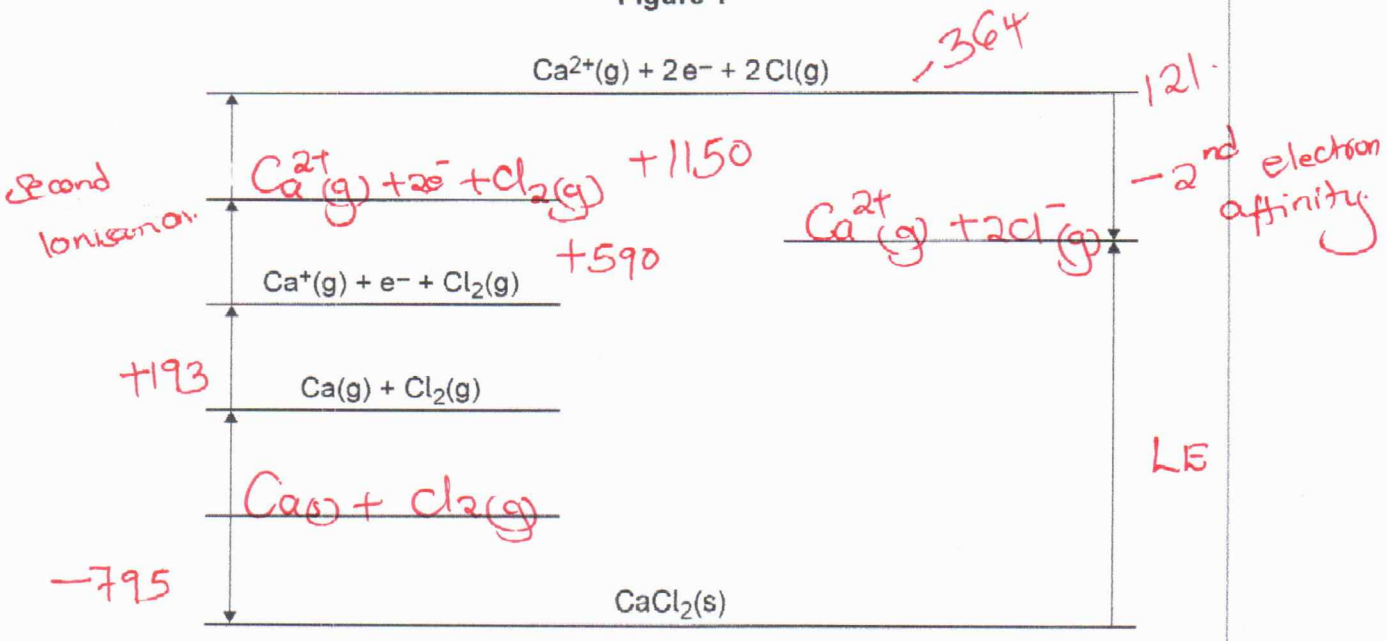
0 1 . 1 State the meaning of the term enthalpy change.

[1 mark]

Its the heat change at Constant pressure.

Figure 1 shows an incomplete Born–Haber cycle for the formation of calcium chloride.

Figure 1



0 1 . 2 Complete **Figure 1** by writing the formulas, including state symbols, of the appropriate species on each of the three blank lines.

[3 marks]

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0 1 . 3 **Table 1** shows some enthalpy data.

Table 1

	Enthalpy change / kJ mol^{-1}
Enthalpy of formation of calcium chloride	–795
Enthalpy of atomisation of calcium	+193
First ionisation energy of calcium	+590
Second ionisation energy of calcium	+1150
Enthalpy of atomisation of chlorine	+121
Electron affinity of chlorine	–364

Use **Figure 1** and the data in **Table 1** to calculate a value for the enthalpy of lattice dissociation of calcium chloride.

[2 marks]

$-795 + LE = 193 + 590 + 1150 + (2 \times 121) + 2 \times -364$

$193 + 590 + 1150 + 242 - 728$

$-795 + LE = +1447$

$LE = +1447 + 795$

$= 2242 \text{ kJ mol}^{-1}$

Enthalpy of lattice dissociation +2242 kJ mol^{-1}

Question 1 continues on the next page

Do not write outside the box

0 1 . 4 Magnesium chloride dissolves in water.

Give an equation, including state symbols, to represent the process that occurs when the enthalpy of solution of magnesium chloride is measured.

[1 mark]

$MgCl_{2(s)} \longrightarrow Mg^{2+}_{(aq)} + 2Cl^-_{(aq)}$

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

Table 2

	Enthalpy change / kJ mol^{-1}
Enthalpy of lattice dissociation of $MgCl_2$	+2493
Enthalpy of hydration of $Mg^{2+}(g)$	–1920
Enthalpy of hydration of $Cl^-(g)$	–364

Use your answer to Question **01.4** and the data in **Table 2** to calculate a value for the enthalpy of solution of magnesium chloride.

[2 marks]

$\Delta H_{soln} = \Delta H_{LaH} + \Delta H_{hyd.}$

$= +2493 + (-1920 + (2 \times -364)$

$= +2493 - 1920 - 728$

Enthalpy of solution -155 kJ mol^{-1}

0 1 . 6 The enthalpy of hydration of $Ca^{2+}(g)$ is -1650 kJ mol^{-1}

Suggest why this value is less exothermic than that of $Mg^{2+}(g)$

[2 marks]

Ca^{2+} ion is bigger in size than Mg^{2+}. It therefore has weaker attraction to the partially negative oxygen atom in a water molecule.

11

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0 2 This question is about atomic structure.

0 2 . 1 Define the mass number of an atom.

[1 mark]

Its the sum total of protons and neutrons in the nucleus of an atom.

0 2 . 2 Complete **Table 3** to show the numbers of neutrons and electrons in the species shown.

[2 marks]

46 − 22 = 24

49 − 22 = 27.

Table 3

	Number of protons	Number of neutrons	Number of electrons
^{46}Ti	22	24	22
$^{49}Ti^{2+}$	22	27	20

0 2 . 3 A sample of titanium contains four isotopes, ^{46}Ti, ^{47}Ti, ^{48}Ti and ^{49}Ti
This sample has a relative atomic mass of 47.8
In this sample the ratio of abundance of isotopes ^{46}Ti, ^{47}Ti and ^{49}Ti is 2:2:1

Calculate the percentage abundance of ^{46}Ti in this sample.

[3 marks]

$$47.8 = \frac{(46 \times 2y) + (47 \times 2y) + 48(100 - 5y) + (49 \times y)}{100}$$

$47.8 = 92y + 94y + 4800 - 240y + 49y$

$$47.8 = \frac{235y + 4800 - 240y}{100}$$

$4780 - 4800 = 235y - 240y$

$-20 = -5y$

$y = 4$

$2y = 2 \times 4$

$= 8.$

Abundance of ^{46}Ti 8. %

6

Turn over ▶

Do not write outside the box

0 3 This question is about elements in Period 3 and their compounds.

0 3 . 1 When a piece of sodium is added to 200 cm^3 of water in a large beaker a vigorous reaction occurs. The temperature of the water increases by 25 °C

Give an equation, including state symbols, for the reaction of sodium with water.

Suggest why it is dangerous to react a similar piece of sodium with 10 cm^3 of water in a boiling tube.

[2 marks]

Equation

$2Na(s) + 2H_2O(l) \longrightarrow 2NaOH(aq) + H_2(g)$.

Why it is dangerous The reaction is highly exothermic this can cause the reactants to shoot out of the tube.

0 3 . 2 Give an equation for the reaction of phosphorus(V) oxide with water.

Suggest a pH for the solution formed.

[2 marks]

Equation

$P_4O_{10} + 6H_2O \longrightarrow 4H_3PO_4$

pH It's a strong acid - PH 2.

0 3 . 3 Explain, in terms of crystal structure and bonding, why silicon(IV) oxide has a higher melting point than phosphorus(V) oxide.

[4 marks]

Silicon (IV) oxide has a giant Covalent structure that has several strong covalent bonds between atoms. These bonds require alot of energy to be broken. Phosphorous (V) oxide has a simple molecular structure where the molecules

Do not write outside the box

are held by weak van der waal forces which require less energy to overcome the weak forces.

0 3 . 4 An element in Period 3 forms an oxide that is insoluble in water.
This oxide reacts with sulfuric acid and with aqueous potassium hydroxide. - amphoteric Alluminium.

Give the formula for this oxide.

Give an equation for the reaction of this oxide with sulfuric acid.

[2 marks]

Formula Al_2O_3.

Equation

$Al_2O_3 + 3H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 3H_2O$.

0 3 . 5 Give the formula of a hydroxide of an element in Period 3 used in medicine.

[1 mark]

$Mg(OH)_2$ — antacid.

0 3 . 6 Identify the element in Period 3, from sodium to chlorine, that has the largest atomic radius.

[1 mark]

Sodium has a proton and an electron.

12

Turn over for the next question

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0 4 This question is about iron and its ions.

0 4 . 1 Discuss the role of iron as a heterogeneous catalyst in the Haber process.

$$3H_2 + N_2 \rightleftharpoons 2NH_3$$

Your answer should include:

- the meaning of the term heterogeneous catalyst
- how iron acts as a heterogeneous catalyst
- the factors that affect the efficiency and lifetime of the catalyst.

[6 marks]

A heterogenous catalyst is a catalyst in a ~~different~~ phase from reactants. A Catalyst speeds up the rate of a reaction by providing an alternative pathway with lower activation energy.

Hydrogen and Nitrogen adsorb onto the active sites of Iron, the bonds between Hydrogen and Nitrogen molecules are broken or weakened. The products then desorb from the surface

The efficiency of a catalyst is improved when large surface area of Iron is used and the active sites are not blocked by poisoning with sulfur

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0 4 . 2 Fe^{2+} ions catalyse the reaction between peroxodisulfate(VI) ions and iodide ions in aqueous solution.

$$S_2O_8^{2-}(aq) + 2I^-(aq) \rightarrow 2SO_4^{2-}(aq) + I_2(aq)$$

Explain why this reaction is slow before the catalyst is added.
Give **two** equations to show how Fe^{2+} ions catalyse this reaction.

[4 marks]

Why reaction is slow before catalyst added

Two negative ions repel each other.

It will have a high activation energy.

Equation 1

$2Fe^{2+} + S_2O_8^{2-} \rightarrow 2SO_4^{2-} + 2Fe^{3+}$.

Equation 2

$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$.

0 4 . 3 Give a reason why Zn^{2+} ions do **not** catalyse the reaction in Question **04.2**.

[1 mark]

Zn have only one stable oxidation state.

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0 4 . 4 Iron reacts with dilute hydrochloric acid to form iron(II) chloride and hydrogen.

$$Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$$

0.03

A 0.998 g sample of pure iron is added to 30.0 cm^3 of 1.00 mol dm^{-3} hydrochloric acid.

One of these reagents is in excess and the other reagent limits the amount of hydrogen produced in the reaction.

Calculate the maximum volume, in m^3, of hydrogen gas produced at 30 °C and 100 kPa.

Give your answer to 3 significant figures.

In your answer you should identify the limiting reagent in the reaction.

The gas constant, R = 8.31 J K^{-1} mol^{-1}

[6 marks]

Moles of Fe = $\frac{0.998}{55.8}$ = 0.0179 mol.

Moles of HCl = $\frac{1.00 \times 30}{1000}$ = 0.03 mol

HCl is the limiting reagent

A limiting reagent is in low supply.

Amount of H_2 produced = $\frac{0.03}{2}$

= 0.015 moles.

T = 30 + 273

= 303K

P = 100 × 1000

= 100000

PV = nRT.

V = $\frac{nRT}{P}$

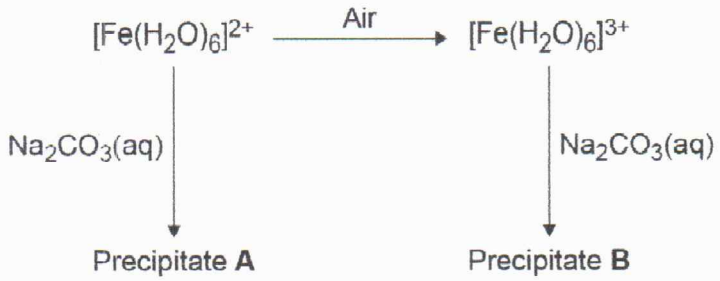
V = $\frac{0.015 \times 8.31 \times 303}{100,000}$

= 3.78×10^{-4}

Volume of hydrogen 3.78×10^{-4} m^3

Figure 2 shows some reactions of iron ions in aqueous solution.

Figure 2



0 4 . 5 Identify **A** and state its colour.

[2 marks]

Identity $FeCO_3$

Colour Green.

0 4 . 6 Give the formula of **B** and state its colour.

Give an ionic equation for the reaction of $[Fe(H_2O)_6]^{3+}$ with aqueous Na_2CO_3 to form **B**.

[3 marks]

Formula $Fe(H_2O)_3(OH)_3$

Colour brown.

Ionic equation

$2[Fe(H_2O)_6]^{3+} + 2CO_3^{2-} \longrightarrow 2[Fe(H_2O)_3(OH)_3]^{3+} + 3H_2O + 3CO_2$

Do not write outside the box

0 4 . 7 Explain why an aqueous solution containing $[Fe(H_2O)_6]^{3+}$ ions has a lower pH than an aqueous solution containing $[Fe(H_2O)_6]^{2+}$ ions.

[3 marks]

Fe^{3+} ion is a smaller ion compared to Fe^{2+}. It has a greater polarising power breaking more O-H bonds in water releasing H^+ ions hence a lower pH as it releases more H^+ ions

25

Turn over for the next question

Do not write outside the box

0 5 This question is about the equilibrium

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g)$$

0 5 . 1 State and explain the effect, if any, of a decrease in overall pressure on the equilibrium yield of SO_3

[3 marks]

Effect It would decrease Yield.

Explanation A decrease in pressure favours the side with more molecules, so the equilibrium shifts to the left

0 5 . 2 A 0.460 mol sample of SO_2 is mixed with a 0.250 mol sample of O_2 in a sealed container at a constant temperature.
When equilibrium is reached at a pressure of 215 kPa, the mixture contains 0.180 mol of SO_3

Calculate the partial pressure, in kPa, of SO_2 in this equilibrium mixture.

[4 marks]

	$2SO_2$	+ O_2	⟶ $2SO_3$
I	0.460	0.250	0
C	−2x	−x	+2x
E	0.28	0.16	0.180

Total mol = 0.28 + 0.16 + 0.18
= 0.62 mol.

Partial pressure of SO_2 = $\frac{0.28}{0.68} \times 215$
= 97.1 kPa.

Partial pressure of SO_2 97 kPa

Do not write outside the box

0 5 . 3 A different mixture of SO_2 and O_2 reaches equilibrium at a different temperature.

Table 4 shows the partial pressures of the gases at equilibrium.

Table 4

Gas	Partial pressure / kPa
SO_2	1.67×10^2
O_2	1.02×10^2
SO_3	1.85×10^2

Give an expression for the equilibrium constant (K_p) for this reaction.

Calculate the value of the equilibrium constant for this reaction and give its units.

[3 marks]

$K_p = \dfrac{(pp\ SO_3)^2}{(pp\ SO_2)^2 \times (pp\ O_2)}$

$= \dfrac{(1.85 \times 10^2)^2}{(1.67 \times 10^2)^2 \times 1.02 \times 10^2}$

$= 1.20 \times 10^{-2}$

$\dfrac{(kPa)^2}{(kPa)^2 \times kPa}$

K_p 1.20×10^{-2}

Units kPa^{-1}

Do not write outside the box

0 5 . 4 What is the effect on the value of K_p if the pressure of this equilibrium mixture is increased at a constant temperature?

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g)$$

[1 mark]

Tick (✓) **one** box.

The value of K_p

increases. ☐

stays the same. ☑

decreases. ☐

Kp has no effect on equilibrium

11

Turn over for the next question

Do not write outside the box

0 6 This question is about pH.

Pure water dissociates slightly.

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq) \qquad \Delta H = +57 \text{ kJ mol}^{-1}$$

The equilibrium constant, $K_c = \dfrac{[H^+][OH^-]}{[H_2O]}$

The ionic product of water, $K_w = [H^+][OH^-]$

0 6 . 1 Explain why $[H_2O]$ is not shown in the K_w expression.

[1 mark]

Water is almost constant

Table 5 shows how K_w varies with temperature.

Table 5

Temperature / °C	K_w / mol² dm⁻⁶
10	2.93×10^{-15}
20	6.81×10^{-15}
25	1.00×10^{-14}
30	1.47×10^{-14}
50	5.48×10^{-14}

0 6 . 2 Explain why the value of K_w increases as the temperature increases.

[2 marks]

The forward reaction is endothermic an increase in temperature causes equilibrium to shift to the Right hand side increasing Kw.

Do not write outside the box

0 6 . 3 Give the expression for pH.

Calculate the pH of pure water at 50 °C
Give your answer to 2 decimal places.

Explain why water is neutral at 50 °C

[4 marks]

Expression $pH = -\log_{10}[H^+]$

Calculation

$[H^+]^2 = 5.48 \times 10^{-14}$

$H^+ = \sqrt{5.48 \times 10^{-4}}$

$= 2.34 \times 10^{-7}$

$pH = -\log_{10} 2.34 \times 10^{-7}$

$= 6.63$

pH 6.63

Explanation Dissociation of a water molecule gives one H^+ and on OH^-.

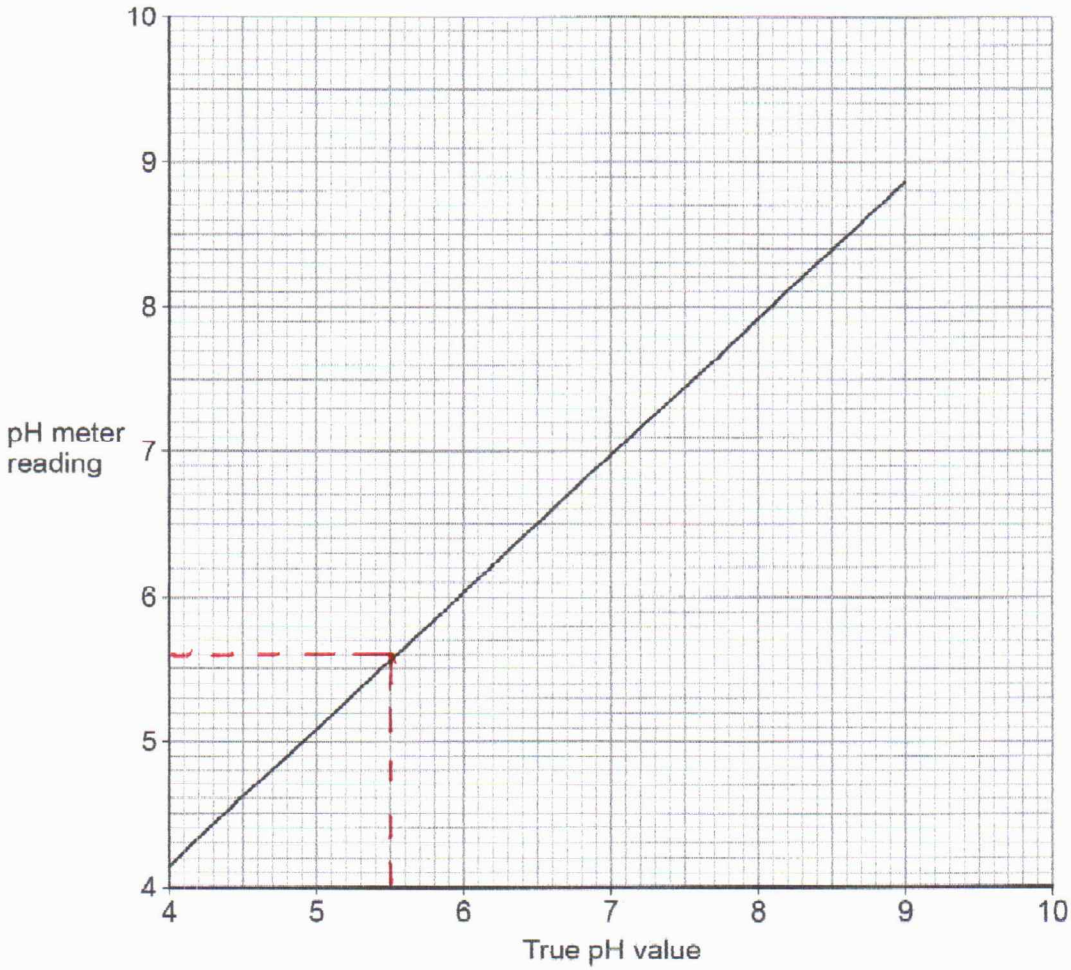
$H^+ = OH^-$

Question 6 continues on the next page

A pH meter is calibrated using a calibration graph.
To create the calibration, the pH meter is used to measure the pH of separate solutions, each with a known, accurate pH.

Figure 3 shows the calibration graph.

Figure 3



0 6 . 4 Use **Figure 3** to give the true pH value when the pH meter reading is 5.6

[1 mark]

5·5.

0 6 . 5 Suggest why the pH probe is washed with distilled water between each of the calibration measurements.

[1 mark]

To remove any residual solution that would interfere with the readings.

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0 6 . 6 The calibrated pH meter is used to monitor the pH during a titration of hydrochloric acid with sodium hydroxide.

Explain why the volume of sodium hydroxide solution added between each pH measurement is smaller as the end point of the titration is approached.

[1 mark]

To avoid missing the end-point

Figure 4 shows the pH curve for a titration of hydrochloric acid with sodium hydroxide solution.

Figure 4

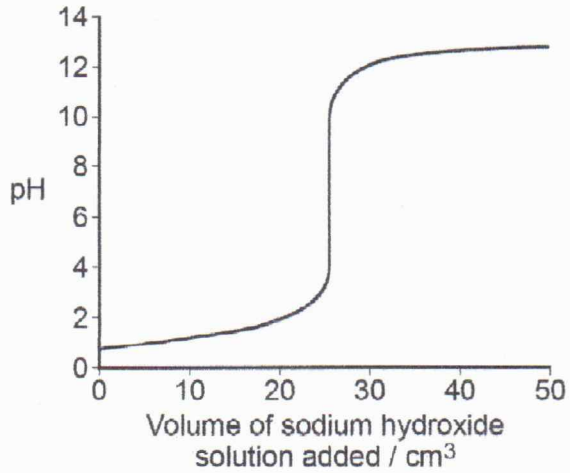

Table 6 shows data about some indicators.

Table 6

Indicator	pH range	Colour at low pH	Colour at high pH
Bromocresol green	3.8 – 5.4	yellow	blue
Phenol red	6.8 – 8.4	yellow	red
Thymolphthalein	9.3 – 10.5	colourless	blue

The student plans to do the titration again using one of the indicators in **Table 6** to determine the end point.

0 6 . 7 State why all three of the indicators in **Table 6** are suitable for this titration.

[1 mark]

All have colour changes within the steep vertical part in the titration curve.

Do not write outside the box

0 6 . 8 36.25 cm^3 of 0.200 mol dm^{-3} sodium hydroxide solution are added to 25.00 cm^3 of 0.150 mol dm^{-3} hydrochloric acid.

Calculate the pH of the final solution at 25 °C

$K_w = 1.00 \times 10^{-14}$ $mol^2\ dm^{-6}$ at 25 °C

[5 marks]

Amount of $OH^- = \frac{36.25}{1000} \times 0.2 = 7.25 \times 10^{-3}$

Amount of $H^+ = \frac{25}{1000} \times 0.15 = 3.75 \times 10^{-3}$

Amount of OH^- in excess $= 7.25 \times 10^{-3} - 3.75 \times 10^{-3}$

$= 3.50 \times 10^{-3}$ mol.

Conc of $OH = \frac{\text{moles}}{\text{Total vol.}} = \frac{3.50 \times 10^{-3}}{\left(\frac{61.25}{1000}\right)}$

$= 5.71 \times 10^{-2}$

$K_w = [H^+][OH^-]$

$H^+ = \frac{K_w}{[OH^-]} = \frac{1.00 \times 10^{-14}}{5.71 \times 10^{-2}}$

$= 1.75 \times 10^{-13}$

$pH = -\log_{10}[H^+]$

$= -\log_{10} 1.75 \times 10^{-13}$

pH 12.76

16

Do not write outside the box

0 7 This question is about thermodynamics.
Consider the reaction shown.

$$2\,Al_2O_3(s) + 3\,C(s) \rightarrow 4\,Al(s) + 3\,CO_2(g)$$

Table 7 shows some thermodynamic data.

Table 7

Substance	$Al_2O_3(s)$	$Al(s)$	$C(s)$	$CO_2(g)$
$\Delta_f H^{\ominus}$/ kJ mol^{-1}	−1669	0	0	−394
$S^{\ominus}$/ J K^{-1} mol^{-1}	51	28	6	214

0 7 . 1 Explain why the standard entropy value for carbon dioxide is greater than that for carbon.

[1 mark]

Carbon dioxide gas is more disordered than carbon.

0 7 . 2 State the temperature at which the standard entropy of aluminium is 0 J K^{-1} mol^{-1}

[1 mark]

0 K.

Do not write outside the box

0 7 . 3 Use the equation and the data in **Table 7** to calculate the minimum temperature, in K, at which this reaction becomes feasible.

[7 marks]

$\Delta H = P - R$

$(-394 \times 3) - (-1699 \times 2)$

$= 2156 \text{ kJ mol}^{-1}$

$\Delta S = P - R$

$((28 \times 4) + (214 \times 3)) - ((51 \times 2) + (6 \times 3))$

$= 634 \text{ J K}^{-1} \text{ mol}^{-1} = 0{\cdot}634 \text{ kJ K}^{-1} \text{ mol}^{-1}$

$\Delta G = \Delta H - T\Delta S$

$\Delta H = T\Delta S$

$T = \frac{\Delta H}{\Delta S}$

$= \frac{2156}{0{\cdot}634} = 3400 \text{ K}$

Minimum temperature 3400 K

9

Do not write outside the box

0 8 This question is about electrode potentials and electrochemical cells.

0 8 . 1 State the meaning of the term electrochemical series.

[1 mark]

Its a list of electrode potentials in order (highest - lowest)

Table 8 shows some electrode potentials.

Table 8

	$E^{\ominus}$ / V
$[Fe(H_2O)_6]^{2+}(aq) + 2e^- \rightarrow Fe(s) + 6\,H_2O(l)$	–0.44
$H^+(aq) + e^- \rightarrow \frac{1}{2}\,H_2(g)$	0.00
$[Co(NH_3)_6]^{3+}(aq) + e^- \rightarrow [Co(NH_3)_6]^{2+}(aq)$	+0.11
$[Fe(H_2O)_6]^{3+}(aq) + e^- \rightarrow [Fe(H_2O)_6]^{2+}(aq)$	+0.77
$VO_2^+(aq) + 2\,H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l)$	+1.00
$[Co(H_2O)_6]^{3+}(aq) + e^- \rightarrow [Co(H_2O)_6]^{2+}(aq)$	+1.81

0 8 . 2 State **two** conditions needed for the following half-cell to have $E^{\ominus} = 0.00$ V

$$H^+(aq) + e^- \rightarrow \frac{1}{2}H_2(g)$$

[1 mark]

1 mol dm^{-3} 100 kPa.

298 K.

0 8 . 3 Identify the weakest reducing agent in **Table 8**.

[1 mark]

Most positive. $[Co(H_2O)_6]^{3+}$

Do not write outside the box

0 8 . 4 Use half-equations from **Table 8** to deduce an equation for the reduction of VO_2^+ to form VO^{2+} in aqueous solution by iron.

[2 marks]

$3VO_2^+ + 6H^+ + Fe + 3H_2O \rightarrow 3VO^{2+} + [Fe(H_2O)_6]^{3+}$

0 8 . 5 Use data from **Table 8** to explain why $[Co(H_2O)_6]^{3+}(aq)$ will undergo a redox reaction with $[Fe(H_2O)_6]^{2+}(aq)$

Give an equation for this reaction.

[2 marks]

Explanation $Co^{3+}/Co^{2+} > Fe^{3+}/Fe^{2+}$

Equation

$[Co(H_2O)_6]^{3+} + [Fe(H_2O)_6]^{2+} \rightarrow [Co(H_2O)_6]^{2+} + [Fe(H_2O)_6]^{3+}$

0 8 . 6 Suggest why the **two** cobalt(III) complex ions in **Table 8** have different electrode potentials.

[1 mark]

They have different ligands.

8

Turn over for the next question

Do not write outside the box

0 9 This question is about the development of lithium cells.
The value of $E^{\ominus}$ for lithium suggests that a lithium cell could have a large EMF.

Table 9 shows some electrode potential data.

Table 9

	$E^{\ominus}$ / V
$Li^+(aq) + e^- \rightarrow Li(s)$	–3.04
$2\,H_2O(l) + 2\,e^- \rightarrow H_2(g) + 2\,OH^-(aq)$	–0.83
$\frac{1}{2}\,I_2(s) + e^- \rightarrow I^-(aq)$	+0.54

0 9 . 1 Use data in **Table 9** to explain why an aqueous electrolyte is **not** used for a lithium cell.

[2 marks]

Lithium would react with the electrolyte
The electrochemical cell for Li^+/Li is more negative than that for water

0 9 . 2 In the 1970s lithium-iodine cells became a common power source for heart pacemakers. Lithium iodide is the final product of the cell reaction.

Use the data in **Table 9** to calculate the cell EMF of a standard lithium-iodine cell.

[1 mark]

0·54 − (−3·04) = +3.58V

0 9 . 3 An EMF value for a commercial lithium-iodine cell is 2.80 V

Suggest why this value is different from the value calculated in Question **09.2**.

[1 mark]

It does not use standard conditions.

Do not write outside the box

0 9 . 4 In some lithium cells, lithium perchlorate ($LiClO_4$) is used as the electrolyte.

Deduce the oxidation state of chlorine in $LiClO_4$

[1 mark]

$Li + Cl + 4O$

$+1 + Cl + (4 \times -2) = 0$

$Cl = 8 - 1$

$= +7$

In other lithium cells, lithium cobalt oxide electrodes **and** lithium electrodes are used.

0 9 . 5 Give an equation for the reaction that occurs at the positive lithium cobalt oxide electrode.

[1 mark]

$Li^+ + CoO_2 + e^- \rightarrow LiCoO_2$

0 9 . 6 Give an equation for the reaction that occurs at the negative lithium electrode.

[1 mark]

$Li \rightarrow Li^+ + e^-$

7

END OF QUESTIONS