

OCR A-LEVEL CHEMISTRY A • H432

CHEMISTRY



EXAM QUESTION PACK

5.2 ENTHALPY, ENTROPY AND FREE ENERGY

SCORE

/396

PERCENTAGE

%

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1(a) Born—Haber cycles can be used to calculate enthalpy changes indirectly.

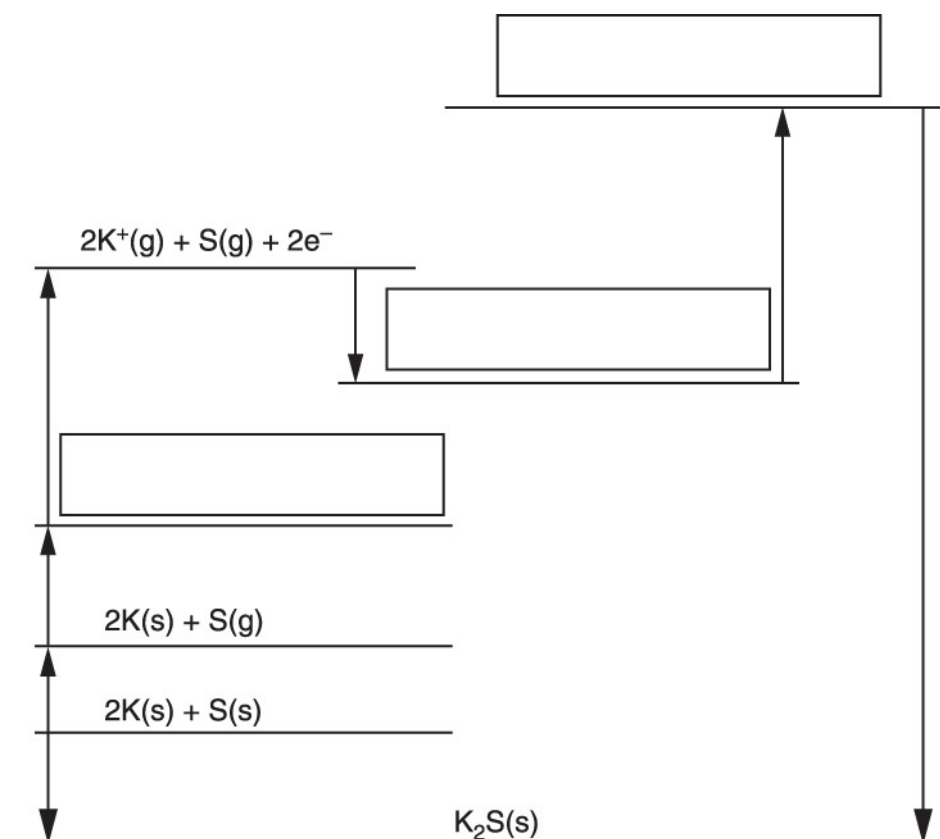
The table below shows enthalpy changes for a Born—Haber cycle involving potassium sulfide, K_2S .

	Enthalpy change / kJ mol^{-1}
Formation of potassium sulfide, K_2S	–381
1st electron affinity of sulfur	–200
2nd electron affinity of sulfur	+640
Atomisation of sulfur	+279
1st ionisation energy of potassium	+419
Atomisation of potassium	+89

(i) The incomplete Born—Haber cycle below can be used to determine the lattice enthalpy of potassium sulfide.

In the boxes, write the species present at each stage in the cycle.

Include state symbols for the species.



[3]

(ii) Define, in words, the term *lattice enthalpy*.

[2]

(iii) Using the Born—Haber cycle, calculate the lattice enthalpy of potassium sulfide.

lattice enthalpy = _____ kJ mol^{-1} [2]

(b) Several ionic radii are shown below.

Ion	Na ⁺	K ⁺	Rb ⁺	Cl ⁻	Br ⁻	I ⁻
Radius / pm	95	133	148	181	195	216

Predict the order of melting points for NaBr, KI and RbCl from lowest to highest.

Explain your answer.

Lowest melting point -----

Highest melting point -----

Explanation -----

[3]

2(a) This question looks at different aspects of entropy.

Three processes are given below.

For each process, state and explain whether the change would be accompanied by an increase or decrease in entropy.

(i) The freezing of water.

increase or decrease

explanation

[1]

(ii) The reaction of calcium carbonate with hydrochloric acid.

increase or decrease

explanation

[1]

(iii) The formation of $\text{O}_3(\text{g})$ from $\text{O}_2(\text{g})$.

increase or decrease

explanation

[1]

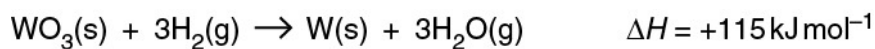
(b) The enthalpy and entropy changes of a reaction both have a negative sign.

Discuss how the feasibility of this reaction will change as the temperature increases.

----- [2]

- (c) The metal tungsten is obtained on a large scale from its main ore, wolframite.
 Wolframite contains tungsten(VI) oxide, WO_3 .

Tungsten is extracted from wolframite by reduction with hydrogen:



Standard entropies are given in the table below.

Substance	$\text{WO}_3(\text{s})$	$\text{H}_2(\text{g})$	$\text{W}(\text{s})$	$\text{H}_2\text{O}(\text{g})$
$S^\ominus / \text{J K}^{-1} \text{ mol}^{-1}$	76	131	33	189

- (i) Calculate the free energy change, ΔG , in kJ mol^{-1} , for this reaction at 25°C .

Show your working.

ΔG at 25°C = _____ kJ mol^{-1} [2]

- (ii) Calculate the minimum temperature, in K, at which this reaction becomes feasible.

Show your working.

minimum temperature = _____ K [2]

- 3(a) Electrochemical cells contain two redox systems, one providing electrons and the other accepting electrons. The tendency to lose or gain electrons is measured using values called standard electrode potentials.

Define the term *standard electrode potential*.

Include all standard conditions in your answer.

----- [2]

- (b) The table below shows two redox systems and their standard electrode potentials, $E^\ominus$.

Redox system	$E^\ominus / \text{V}$
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80

A standard $\text{Cu}^{2+}(\text{aq}) / \text{Cu}(\text{s})$ half-cell is connected to a standard $\text{Ag}^+(\text{aq}) / \text{Ag}(\text{s})$ half-cell. The potential of the cell is measured.

Water is then added to the $\text{Cu}^{2+}(\text{aq}) / \text{Cu}(\text{s})$ half-cell. This changes the position of equilibrium in the half-cell. The cell potential increases.

- (i) Write down the equation for the overall cell reaction.

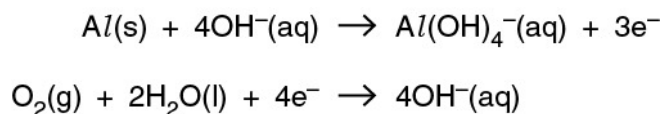
----- [1]

- (ii) Explain, in terms of equilibrium, why the cell potential increases.

----- [3]

(c) Aluminium—oxygen cells are being investigated for powering vehicles.

The **reactions** at each electrode are shown below.



- (i) The standard electrode potential for the $\text{O}_2 / \text{OH}^{\text{-}}$ redox system is +0.40 V.
The standard cell potential of an aluminium—oxygen cell is 2.71 V.

What is the standard electrode potential of the aluminium redox system in this cell?

standard electrode potential = _____ V [1]

- (ii) Construct the overall cell equation for an aluminium—oxygen cell.

[2]

- 4(a) A student carries out an investigation to prepare and analyse a sample of barium ferrate(VI), BaFeO_4 . The steps in the investigation are shown below.

Step 1

The student adds solid iron(III) oxide to a hot aqueous solution containing an excess of hydroxide ions. The student bubbles chlorine gas through the mixture.

A solution forms containing aqueous ferrate(VI) ions, $\text{FeO}_4^{2-}(\text{aq})$, and aqueous chloride ions.

Step 2

The student adds aqueous barium chloride to the resulting solution.

A precipitate of impure barium ferrate(VI) forms.

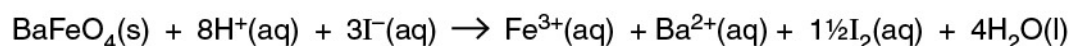
The precipitate is filtered, washed with distilled water and dried.

The student obtains 0.437 g of impure solid barium ferrate(VI).

Step 3

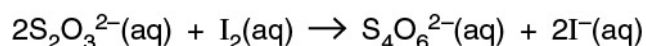
An excess of acidified aqueous potassium iodide is added to the solid from **step 2**.

The BaFeO_4 reacts as shown below, and the impurity does not react. A solution forms containing aqueous iodine, $\text{I}_2(\text{aq})$.



Step 4

The student determines the amount of I_2 formed by carrying out a titration with aqueous sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$.



26.4 cm^3 of $0.100 \text{ mol dm}^{-3}$ $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ are required to reach the end point.

Construct an equation for the oxidation of iron(III) oxide (**step 1**).

-----[2]

(b) Write an ionic equation for the formation of barium ferrate(VI) (**step 2**).

Include state symbols.

-----[1]

(c) In **step 3**, what is the reducing agent?

Explain your answer in terms of electrons.

reducing agent -----

explanation -----

[2]

(d) The solid sample of barium ferrate(VI) obtained in step 2 is impure.

Determine the percentage, by mass, of barium ferrate(VI) in the 0.437 g of solid formed in **step 2**.

Give your answer to **one** decimal place.

percentage of barium ferrate(VI) = ----- % [4]

(e) When the solution is not alkaline, ferrate(VI) ions react with water.
The reaction forms a gas with a density of $1.333 \times 10^{-3} \text{ g cm}^{-3}$, measured at room temperature and pressure, and an orange–brown precipitate.

- Determine the formulae of the gas and the precipitate.
- Write an equation for the reaction that takes place.

gas _____

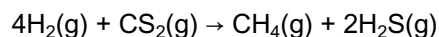
precipitate _____

equation

[3]

5 This question looks at two reactions involving sulfur compounds.

Hydrogen reacts with carbon disulfide as shown below.



For this reaction, $\Delta H = -234 \text{ kJ mol}^{-1}$ and $\Delta S = -164 \text{ J K}^{-1} \text{ mol}^{-1}$.

(i) Why does the reaction have a negative entropy change?

----- [1]

(ii) Standard entropies are shown in the table below.

substance	$\text{CS}_2(\text{g})$	$\text{CH}_4(\text{g})$	$\text{H}_2\text{S}(\text{g})$
$S^\ominus / \text{J K}^{-1} \text{ mol}^{-1}$	238	186	206

Calculate the standard entropy for H_2 .

$S^\ominus = \text{-----} \text{ J K}^{-1} \text{ mol}^{-1}$ [2]

(iii) Explain, with a calculation, whether this reaction is feasible at 25°C .

Show your working.

----- [3]

(iv) Explain, with a calculation, the significance of temperatures above 1154°C for this reaction.

6(a) Iron(II) iodide, FeI_2 , is formed when iron metal reacts with iodine.

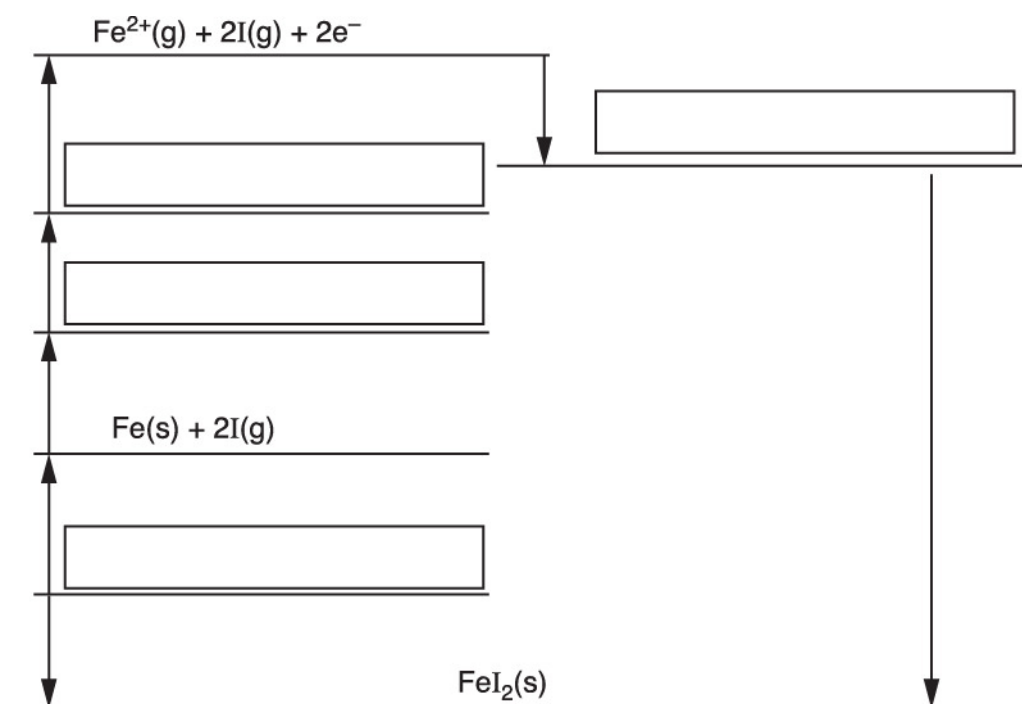
The table below shows enthalpy changes involving iron, iodine and iron(II) iodide.

	Enthalpy change / kJ mol^{-1}
Formation of iron(II) iodide	-113
1st electron affinity of iodine	-295
1st ionisation energy of iron	+759
2nd ionisation energy of iron	+1561
Atomisation of iodine	+107
Atomisation of iron	+416

(i) The incomplete Born–Haber cycle below can be used to determine the lattice enthalpy of iron(II) iodide.

In the boxes, write the species present at each stage in the cycle.

Include state symbols for the species.



[4]

(ii) Define the term *lattice enthalpy*.

----- [2]

(iii) Calculate the lattice enthalpy of iron(II) iodide.

lattice enthalpy = _____ kJ mol^{-1} [2]

(b) Some electrode potentials for ions are shown below.

$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}(\text{s})$	$E^{\circ} = -0.44\text{V}$
$\text{Fe}^{3+}(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}^{2+}(\text{aq})$	$E^{\circ} = +0.77\text{V}$
$\frac{1}{2}\text{I}_2(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{I}^{-}(\text{aq})$	$E^{\circ} = +0.54\text{V}$
$\frac{1}{2}\text{Br}_2(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Br}^{-}(\text{aq})$	$E^{\circ} = +1.09\text{V}$
$\frac{1}{2}\text{Cl}_2(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Cl}^{-}(\text{aq})$	$E^{\circ} = +1.36\text{V}$

(i) Complete the electron configurations for Fe^{2+} and Br^{-} .

Fe^{2+} : 1s^2 -----
 Br^{-} : 1s^2 -----

[2]

(ii) Predict the products of reacting $\text{Fe}(\text{s})$ separately with $\text{I}_2(\text{aq})$, $\text{Br}_2(\text{aq})$ and $\text{Cl}_2(\text{aq})$.

Explain your predictions using the electrode potential data above.

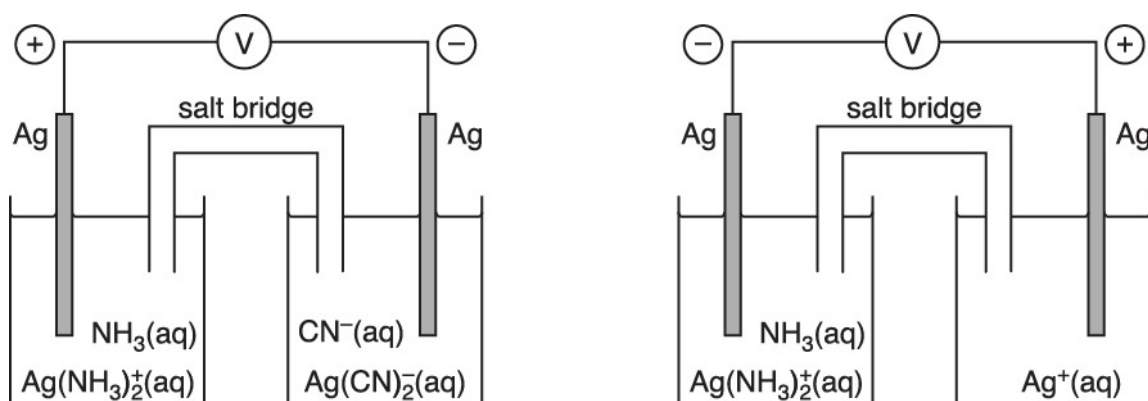
[3]

7(a) Three redox systems, C, D and E are shown in Table 6.1.

C	$\text{Ag}(\text{NH}_3)_2^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s}) + 2\text{NH}_3(\text{aq})$
D	$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$
E	$\text{Ag}(\text{CN})_2^-(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s}) + 2\text{CN}^-(\text{aq})$

Table 6.1

The two cells below were set up in an experiment to compare the standard electrode potentials of redox systems C, D and E. The signs on each electrode are shown.



List the three redox systems in order by adding the labels C, D and E to the table below.

$E^\ominus$	redox system
Most negative	
↑	
Least negative	

[1]

- (b) A standard cell is set up between redox system **D** in **Table 6.1** and a standard hydrogen half-cell. The standard cell potential of redox system **D** is +0.34 V.

The cell delivers a current for a length of time.

The pH of the solution in the standard hydrogen half-cell decreases.

- (i) What is the pH of the solution in a standard hydrogen half-cell?

pH = _____ [1]

- (ii) Explain, in terms of electrode potentials and equilibrium, why the pH of the solution in the hydrogen half-cell decreases as this cell delivers current.

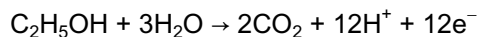
----- [2]

- (iii) Write the equation for the overall cell reaction that takes place in this cell.

----- [1]

- (c) Direct-ethanol fuel cells (DEFCs) are being developed in which the fuel is ethanol rather than hydrogen.

The half-equation for the reaction at the ethanol electrode of the DEFC is shown below:



- (i) State **one** important difference between a fuel cell and a modern storage cell.

----- [1]

- (ii) Suggest **one** advantage of using ethanol, rather than hydrogen, in a fuel cell for vehicles.

----- [1]

- (iii) The overall reaction in a DEFC is the same as for the complete combustion of ethanol.

Write the equation for the overall reaction in a DEFC.

----- [1]

- (iv) Deduce the half-equation for the reaction at the oxygen electrode in a DEFC.

----- [1]

- (v) Using oxidation numbers, show that oxidation and reduction take place in a DEFC.

Oxidation: -----

Reduction: -----

----- [2]

8(a) Chromite is the main ore of chromium. The chromium-containing compound in chromite is $\text{Fe}(\text{CrO}_2)_2$. The percentage of chromium in a sample of chromite can be determined using the method below.

Step 1

A 5.25 g sample of chromite ore is heated with sodium peroxide, Na_2O_2 .



Water is added to the resulting mixture.

Na_2CrO_4 dissolves in the water forming a solution containing CrO_4^{2-} ions.

Step 2

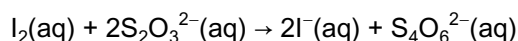
The mixture from **Step 1** is filtered and the filtrate is made up to 1.00 dm^3 in a volumetric flask.

A 25.0 cm^3 sample of this alkaline solution is pipetted into a conical flask and an excess of aqueous potassium iodide is added.

- A redox reaction takes place between I^- ions, CrO_4^{2-} ions and H_2O .
- In this reaction 1 mol CrO_4^{2-} forms 1.5 mol I_2 .

Step 3

The resulting mixture is titrated with $0.100 \text{ mol dm}^{-3}$ sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ to estimate the I_2 present:



The average titre of $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ is 25.5 cm^3 .

In **Step 1** Na_2O and NaFeO_2 react with water forming an alkaline solution containing a brown precipitate. This is **not** a redox reaction.

Write equations for:

- the reaction of Na_2O with water
- the reaction of NaFeO_2 with water.

----- [2]

- (b) Determine the percentage, by mass, of chromium in the ore.

Give your answer to **one** decimal place.

[6]

(c) This part refers to **Step 2** of the method.

In the redox reaction between I^- ions, CrO_4^{2-} ions and H_2O :

- CrO_4^{2-} ions, are reduced to chromium(III) ions, Cr^{3+}
- I^- ions are oxidised to iodine, I_2
- Construct an overall equation for the redox reaction and write half equations for the oxidation and reduction.

Overall equation:

Half equations:

[3]

- 9 The lattice enthalpy of calcium chloride can be calculated using **three** of the enthalpy changes below.

Which enthalpy change is **not** required?

- A enthalpy change of solution of calcium chloride
- B enthalpy change of hydration of Cl^- ions
- C enthalpy change of formation of calcium chloride
- D enthalpy change of hydration of Ca^{2+} ions

Your answer

☐

[1]

- 10 Which redox reaction contains the largest change in oxidation state for sulfur?

- A $\text{H}_2\text{SO}_4 + 8\text{HI} \rightarrow \text{H}_2\text{S} + 4\text{I}_2 + 4\text{H}_2\text{O}$
- B $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$
- C $\text{S}_2\text{O}_3^{2-} + 2\text{H}^+ \rightarrow \text{SO}_2 + \text{S} + \text{H}_2\text{O}$
- D $\text{S} + 6\text{HNO}_3 \rightarrow \text{H}_2\text{SO}_4 + 6\text{NO}_2 + 2\text{H}_2\text{O}$

Your answer

☐

[1]

- 11 A student is asked to calculate ΔG at 25 °C for the combustion of butan-1-ol. The teacher provides two pieces of information.

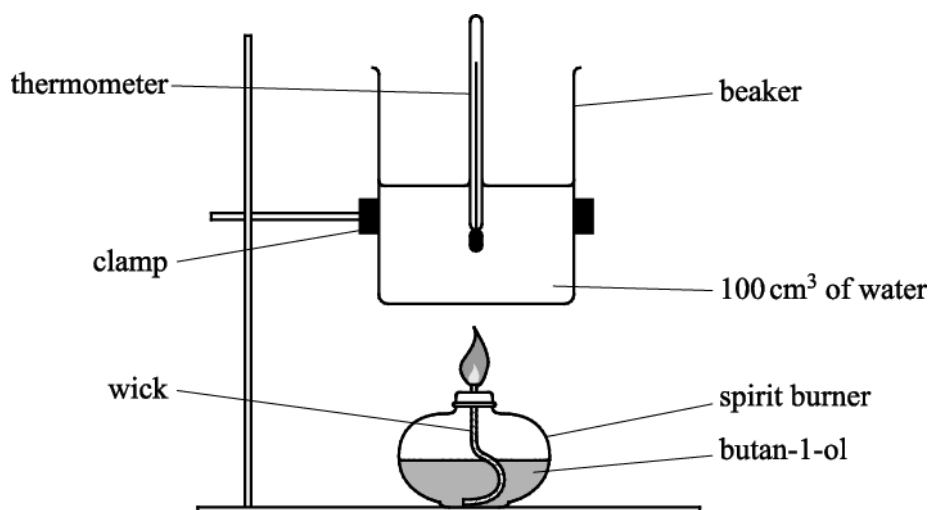
- The equation for the combustion of butan-1-ol.



- Standard entropies of butan-1-ol, oxygen, carbon dioxide and water.

	$\text{CH}_3(\text{CH}_2)_3\text{OH}(\text{l})$	$\text{O}_2(\text{g})$	$\text{CO}_2(\text{g})$	$\text{H}_2\text{O}(\text{l})$
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	228	205	214	70

The student carries out an experiment using the apparatus below and obtains the following results. The specific heat capacity of water is $4.18 \text{ J g}^{-1} \text{K}^{-1}$.

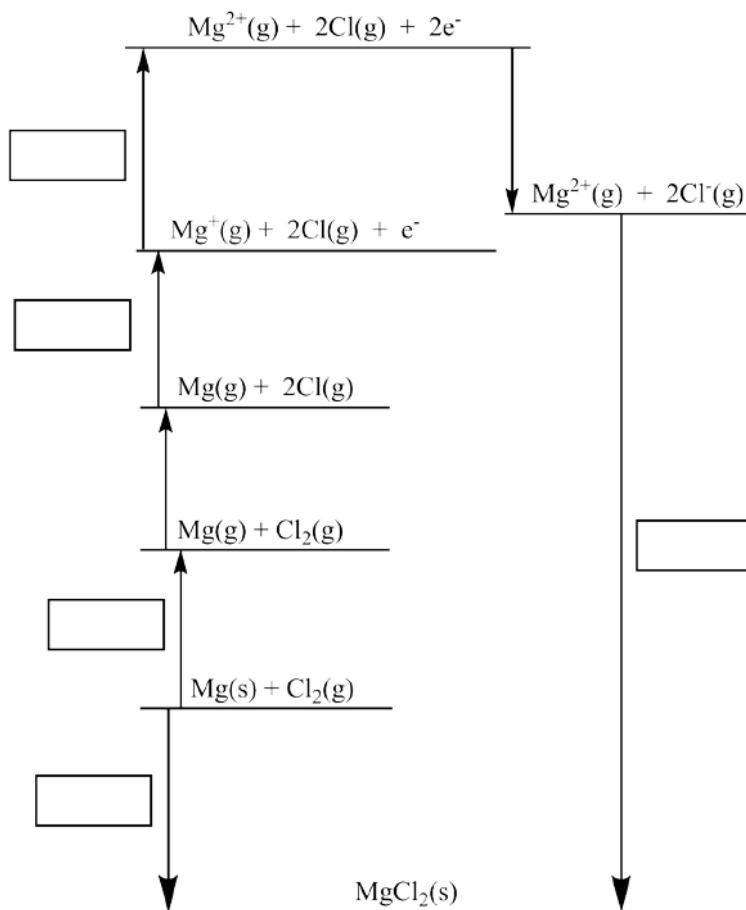


Mass of burner and butan-1-ol before burning / g	98.997
Mass of burner and butan-1-ol after burning / g	98.738
Initial temperature / °C	18.5
Maximum temperature reached / °C	39.0

Use the information on the previous page to calculate ΔG , in kJ mol^{-1} , for the combustion of butan-1-ol according to Equation 2 at 25 °C.

Show all your working.

$$\Delta G = \text{-----} \text{ kJ mol}^{-1} \text{ [7]}$$



[3]

(ii) Use the Born–Haber cycle to calculate the lattice enthalpy of magnesium chloride.

lattice enthalpy = _____ kJ mol^{-1} [2]

13(a) Table 21.1 below gives the standard electrode potentials for seven redox systems.

You need to use this information to answer the questions below.

Redox system	Equation	$E^\ominus/V$
1	$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51
2	$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	+1.33
3	$\text{Br}_2(\text{aq}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^-(\text{aq})$	+1.09
4	$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
5	$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
6	$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
7	$\text{Ce}^{3+}(\text{aq}) + 3\text{e}^- \rightleftharpoons \text{Ce}(\text{s})$	-2.33

Table 21.1

- (i) Outline an experimental setup that could be used in the laboratory to measure the standard cell potential of an electrochemical cell based on redox systems 4 and 5.

In your answer you should include details of the apparatus, solutions and the standard conditions required to measure this standard cell potential.

[4]

- (ii) An electrochemical cell can be made based on redox systems 2 and 4.

The standard cell potential is +0.53 V.

State and explain the effect on the cell potential of this cell if the concentration of silver ions is increased.

----- [2]

- (b) From Table 21.1, predict the oxidising agent(s) that **will not** oxidise $\text{Fe}^{2+}(\text{aq})$ to $\text{Fe}^{3+}(\text{aq})$.

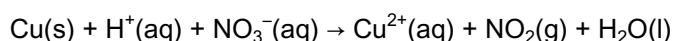
----- [1]

- (c) An aqueous solution of iron(II) bromide is mixed with an excess of acidified solution containing manganate(VII) ions.

Using Table 21.1, give the formulae of the products of any reactions that take place.

----- [2]

- 14 An unbalanced equation for a redox reaction is shown below.



What is the balancing number for H^+ when the equation is balanced using the smallest whole numbers?

- A 2
B 4
C 6
D 8

Your answer

[1]

- 15 Which property is **not** correct for calcium?

- A It acts as an oxidising agent
B It forms a basic oxide
C It reacts with water to form hydrogen gas
D Its hydroxide is more alkaline than magnesium hydroxide

Your answer

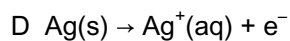
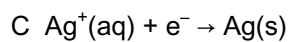
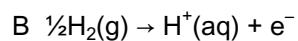
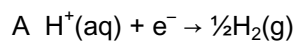
[1]

16 A standard cell is set up from $\text{H}^+(\text{aq})|\text{H}_2(\text{g})$ and $\text{Ag}^+(\text{aq})|\text{Ag}(\text{s})$ half cells.

The standard electrode potentials of the redox systems are shown below.



What is the reaction at the negative electrode of the cell?



Your answer

[1]

17(a) Enthalpy changes of solution can be determined both indirectly from other enthalpy changes, and directly from the results of experiments.

The table below shows the enthalpy changes that can be used to determine the enthalpy change of solution of calcium chloride, CaCl_2 , indirectly.

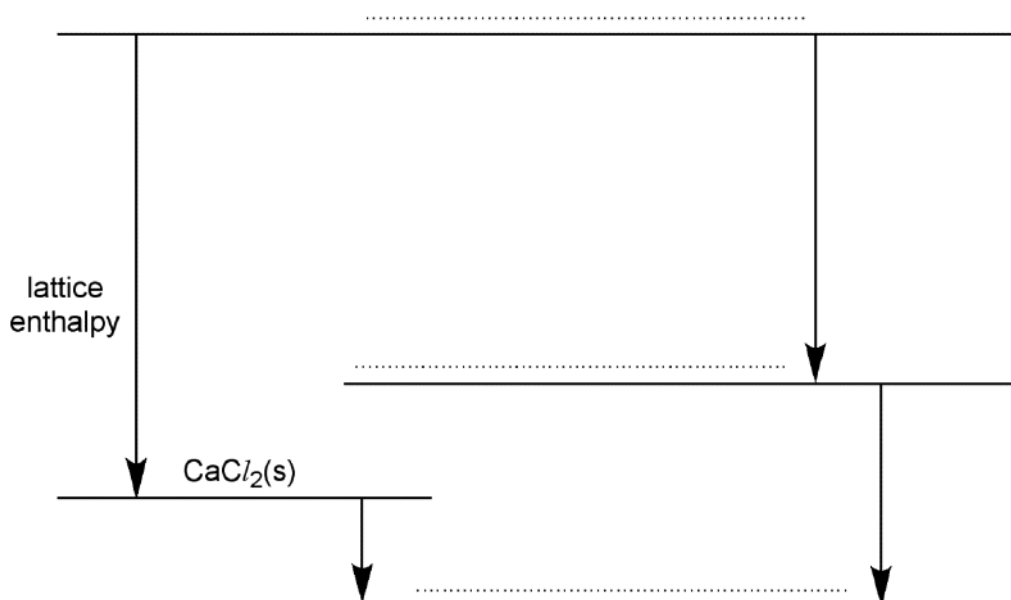
Enthalpy change	Energy / kJ mol^{-1}
Hydration of calcium ions	-1616
Hydration of chloride ions	-359
Lattice enthalpy of calcium chloride	-2192

Explain what is meant by the term *enthalpy change of solution*.

----- [1]

(b) The diagram below shows an incomplete energy cycle that can be used to determine the enthalpy change of solution, $\Delta_{\text{sol}}H$, of CaCl_2 .

(i) On the **three** dotted lines, add the species present, including state symbols.



[3]

(ii) Calculate the enthalpy change of solution of CaCl_2 .

$$\Delta_{\text{sol}}H = \text{-----} \text{ kJ mol}^{-1} \text{ [2]}$$

(iii) The table shows enthalpy changes of hydration.

Ion	Enthalpy change of hydration / kJ mol ⁻¹
aluminium ion	-4741
calcium ion	-1616
magnesium ion	-1963
sodium ion	-424

Explain the differences between these enthalpy changes of hydration.

[3]

(c) **Student 1** carries out an experiment to determine the enthalpy change of solution, $\Delta_{\text{sol}}H$, of CaCl_2 directly.

The student follows the method outlined below.

- Weigh an empty polystyrene cup and weigh the bottle containing CaCl_2 .
- Add about 50 cm^3 of water to the cup and measure the temperature of the water.
- Add the CaCl_2 to the cup, stir the mixture, and record the maximum temperature.
- Weigh the polystyrene cup + final solution, and weigh the empty bottle.

Results

Mass of bottle + CaCl_2	28.38 g
Mass of empty bottle	22.82 g

Mass of polystyrene cup + final solution	85.67 g
Mass of polystyrene cup	35.46 g
Initial temperature of water	22.0 °C
Final temperature of solution	53.5 °C

(i) Calculate $\Delta_{\text{sol}}H$, in kJ mol^{-1} , for calcium chloride.

Give your answer to an **appropriate** number of significant figures.

Assume that the density and specific heat capacity, c , of the solution have the same values as water.

$\Delta_{\text{sol}}H =$ _____ kJ mol^{-1} [4]

(ii) **Student 2** carries out the same experiment but uses twice the mass of CaCl_2 . All other quantities are very similar to **Student 1**'s experiment.

Predict any differences between the temperature change and the calculated value of $\Delta_{\text{sol}}H$ from the experiments of the two students. Explain your reasoning.

 ----- [2]

18 Concentrated nitric acid, HNO_3 , is an oxidising agent. For example, concentrated HNO_3 reacts with sulfur to form sulfuric acid, nitrogen dioxide and one other product.

- Using oxidation numbers, show the element that is oxidised and the element that is reduced in this reaction. Ensure that the oxidation numbers have signs.
- Construct the balanced equation for this reaction.

element oxidised _____ oxidation number change: from _____ to _____

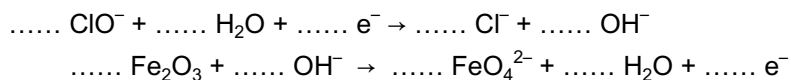
element reduced _____ oxidation number change: from _____ to _____

equation _____ [4]

19 Fe_2O_3 can be oxidised by ClO^- ions under alkaline conditions in a redox reaction.

Unbalanced half-equations for this reaction are shown below.

Balance the half-equations and construct an overall equation for the reaction.

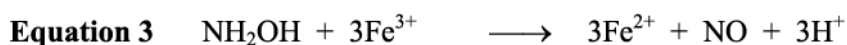


overall equation: _____ [3]

20 Hydroxylamine, NH_2OH , is a strong reducing agent.

When heated in aqueous solution, NH_2OH reduces Fe^{3+} ions to Fe^{2+} ions.

A student suggests the three possible equations for the reaction, shown below.



The student plans to carry out an investigation to determine which equation is correct.

The method is outlined below.

- Stage 1** Using a pipette, add 25.0 cm^3 of $4.32 \times 10^{-2} \text{ mol dm}^{-3}$ NH_2OH to a conical flask.
Add 10 cm^3 of 1 mol dm^{-3} H_2SO_4 to the conical flask followed by an excess of a solution containing $0.0400 \text{ mol dm}^{-3}$ $\text{Fe}^{3+}(\text{aq})$.
- Stage 2** Boil the mixture for 5 minutes and allow to cool.
- Stage 3** Titrate the cooled mixture with $2.00 \times 10^{-2} \text{ mol dm}^{-3}$ $\text{KMnO}_4(\text{aq})$.

(a) Determine the minimum volume of $0.0400 \text{ mol dm}^{-3}$ $\text{Fe}^{3+}(\text{aq})$ that the student should plan to use in **Stage 1**.

Explain your reasoning.

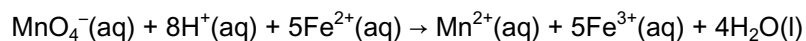
volume = ... cm³

explanation:

[4]

(b) In the student's titration, 21.6 cm³ of KMnO₄(aq) is required to reach the end point.

The equation that takes place during the titration is shown below.



Analyse the student's results to determine which of the three equations is correct.

Show **all** your working.

[3]

(c) The student intends to repeat the procedure to check their results.

There is insufficient time for the student to repeat all three stages and the student decides to omit **Stage 2**, the boiling stage. Unfortunately the resulting titre is much less than the original titre.

The student rejects the results from the repeated procedure.

(i) Suggest the purpose of the boiling in **Stage 2** and reasons for the second titre being much less than the original titre.

-----[2]

- (ii) The main reason for insufficient time is the need to boil and cool the mixture for each titration.

Suggest how the procedure could be modified so that **Stage 2** does not need to be carried out repeatedly.

Give your reasoning.

-----[1]

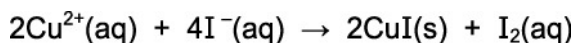
21(a) This question is about redox reactions of transition elements.

Hydrated copper(II) sulfate can crystallise with different numbers of water of crystallisation, x . Compound A has the formula $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$.

A student carries out an iodine–thiosulfate titration to find the value of x and the formula of Compound A. The method is outlined below.

Step 1 A weighed sample of A is dissolved in water and made up to 250.0 cm^3 .

Step 2 A 25.00 cm^3 sample of this solution is pipetted into a conical flask, followed by an excess of KI(aq) .



Step 3 The resulting mixture is titrated with $0.120 \text{ mol dm}^{-3} \text{Na}_2\text{S}_2\text{O}_3(\text{aq})$.



Mass readings

Mass of weighing bottle + A = 17.95 g

Mass of weighing bottle = 12.35 g

Titration readings

Titration	Trial	1	2	3
Final burette reading / cm^3	22.50	44.30	22.15	43.85
Initial burette reading / cm^3	0.00	22.50	0.00	22.15
Titre / cm^3				

Table 2.1

(i) Complete Table 2.1 and calculate the mean titre that the student should use for analysing their results.

mean titre = _____ cm^3 [1]

(ii) The uncertainty in each burette reading is $\pm 0.05 \text{ cm}^3$.

Calculate the percentage uncertainty in the titre obtained from **titration 3**.
Give your answer to **two** decimal places.

percentage uncertainty = _____ % [1]

(iii) In **step 2**, why is an excess of KI (aq) added?

_____ [1]

(iv) As the end point of the titration is approached, the student adds a solution to accurately detect the end point.

State the solution and explain the colour change observed at the end point.

_____ [2]

(v) Determine the formula of compound **A**.

Show your working.

formula of compound **A** = _____ [4]

- (b) A student carries out two experiments based on redox reactions of iron and chromium.

Use the standard electrode potentials below to help you answer the questions that follow.

$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}(\text{s})$	$E^{\ominus} = -0.44 \text{ V}$
$2\text{H}^{+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{H}_2(\text{g})$	$E^{\ominus} = 0.00 \text{ V}$
$\text{Fe}^{3+}(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}^{2+}(\text{aq})$	$E^{\ominus} = +0.77 \text{ V}$
$\text{O}_2(\text{g}) + 4\text{H}^{+}(\text{aq}) + 4\text{e}^{-}$	$\rightleftharpoons$	$2\text{H}_2\text{O}(\text{l})$	$E^{\ominus} = +1.23 \text{ V}$
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^{+}(\text{aq}) + 6\text{e}^{-}$	$\rightleftharpoons$	$2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	$E^{\ominus} = +1.33 \text{ V}$
$\text{Cl}_2(\text{g}) + 2\text{e}^{-}$	$\rightleftharpoons$	$2\text{Cl}^{-}(\text{aq})$	$E^{\ominus} = +1.36 \text{ V}$
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^{+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$2\text{H}_2\text{O}(\text{l})$	$E^{\ominus} = +1.78 \text{ V}$

For each experiment, identify the species causing the observations shown in bold text and write overall equations for any reactions taking place.

State symbols are **not** required in the equations.

(i) **Experiment 1**

- 1 The student adds iron filings to dilute hydrochloric acid.

A **green solution** forms and **gas bubbles** are seen.

- 2 The student bubbles air through the green solution.

The solution turns an **orange-brown colour**.

1:

2:

[3]

(ii) **Experiment 2**

The student heats a **green solution** of chromium(III) sulfate with dilute acid and hydrogen peroxide, H_2O_2 .

The solution turns an **orange colour**.

[3]

22(a) This question is about four enthalpy changes, A–D, that can be linked to the dissolving of potassium sulfate, K_2SO_4 , in water.

	Name of enthalpy change	Enthalpy change / kJ mol^{-1}
A	lattice enthalpy of potassium sulfate	–1763
B	enthalpy change of solution of potassium sulfate	+24
C	enthalpy change of hydration of potassium ions	–320
D	enthalpy change of hydration of sulfate ions	

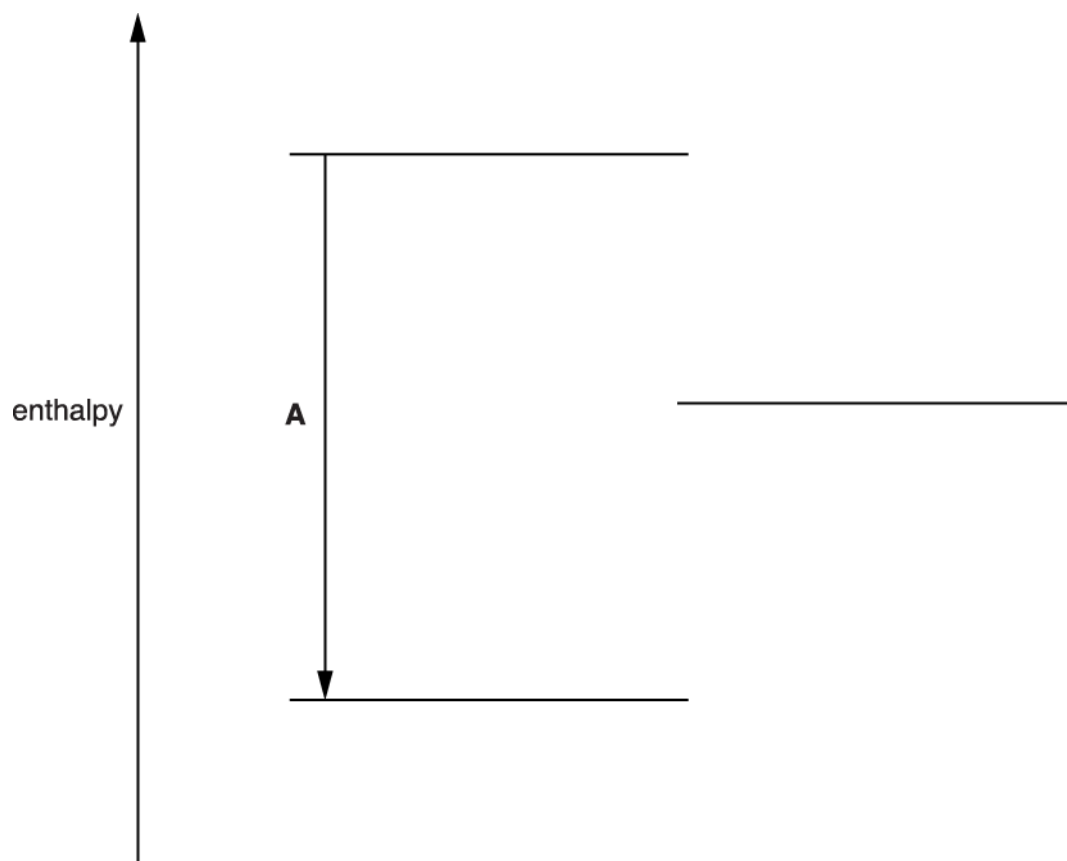
Table 3.1

Define the term *enthalpy change of hydration*.

[2]

- (b) The diagram below is an incomplete energy cycle linking the four enthalpy changes in Table 3.1. One of the four energy levels is missing.

Include state symbols for all species.



(i) Complete the energy cycle as follows.

- Add the missing energy level to the diagram. Add the species on all **four** energy levels.
- Add arrows to show the direction of the three missing enthalpy changes. Label these enthalpy changes using the letters **B–D** from **Table 3.1**.

[5]

(ii) Calculate the enthalpy change of hydration of sulfate ions.

$\Delta H =$ _____ kJ mol^{-1} [1]

(c) The entropy change of solution of K_2SO_4 is $+225 \text{ J K}^{-1} \text{ mol}^{-1}$.

(i) Suggest, in terms of the states of the particles involved, why this entropy change is positive.

-----[1]

(ii) Explain, using a calculation, why K_2SO_4 dissolves in water at 25°C , despite the enthalpy change of solution being endothermic.

-----[3]

23(a) Redox reactions can be used to generate electrical energy from electrochemical cells.

A student investigates the redox systems shown in Table 6.1 below.

	Redox system	$E^\ominus/V$
1	$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	-1.66
2	$Cr^{3+}(aq) + e^- \rightleftharpoons Cr^{2+}(aq)$	-0.41
3	$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	-0.26
4	$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
5	$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
6	$FeO_4^{2-}(aq) + 8H^+(aq) + 3e^- \rightleftharpoons Fe^{3+}(aq) + 4H_2O(l)$	+2.20

Table 6.1

Define the term *standard electrode potential*.

Include all standard conditions in your answer.

[2]

(b) The student sets up a standard cell based on redox systems 3 and 4.

- (i) Draw a labelled diagram to show how the student could have set up this cell to measure the standard cell potential.

On your diagram,

- show the charge carriers in the circuit joining the two half cells
- label the signs of the electrodes.

[5]

- (ii) What is the standard cell potential of this cell?

standard cell potential = _____ V [1]

24 In some gold mines, cyanide is used to extract gold from its ore.

Gold metal in the ore reacts with cyanide ions, water and oxygen to form a water-soluble complex ion, $[\text{Au}(\text{CN})_2]^-$, with a bond angle of 180° . Hydroxide ions are also formed.

(i) Name the shape of $[\text{Au}(\text{CN})_2]^-$.

-----[1]

(ii) Using oxidation numbers, show that a redox reaction takes place.

-----[2]

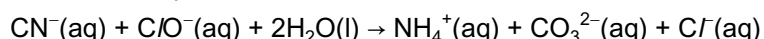
(iii) Construct the overall equation for this reaction.

State symbols are **not** required.

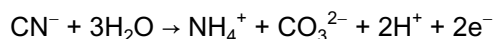
-----[2]

(iv) Some owners of gold mines remove cyanide ions from waste by adding oxidising agents, such as chlorate(I) ions, before discharge into watercourses.

The overall equation is shown below.



The oxidation half-equation is:



Construct the reduction half-equation.

State symbols are **not** required.

25(a) Hydrated copper(II) methanoate, $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$, is a copper salt.

A student carries out the procedure below to prepare $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$ and to determine the value of x in its formula.

Step 1

The student prepares $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$ by reacting a copper compound with aqueous methanoic acid to form $\text{Cu}(\text{HCOO})_2(\text{aq})$ and allowing the solvent to evaporate.

Step 2

The student dissolves 2.226 g of $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$ in water and makes up the solution to 250.0 cm^3 .

Step 3

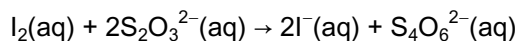
Using a pipette, the student adds 25.0 cm^3 of this solution to a conical flask followed by an excess of $\text{KI}(\text{aq})$.

The $\text{Cu}^{2+}(\text{aq})$ ions react to form a precipitate of copper(I) iodide and $\text{I}_2(\text{aq})$.

In this reaction, 2 mol Cu^{2+} form 1 mol I_2 .

Step 4

The student titrates the iodine in the resulting mixture with $0.0420 \text{ mol dm}^{-3} \text{Na}_2\text{S}_2\text{O}_3(\text{aq})$.



23.5 cm^3 $0.0420 \text{ mol dm}^{-3} \text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ is required to reach the end point.

Complete the electron configuration of copper in

$\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$: $1s^2$ _____

copper(I) iodide: $1s^2$ _____ [2]

- (b) Choose a suitable copper compound for **step 1**, and write the full equation for the reaction that would take place to form $\text{Cu}(\text{HCOO})_2(\text{aq})$.

State symbols are **not** required.

----- [1]

- (c) Write an ionic equation, including state symbols, for the reaction in **step 3**.

----- [1]

(d) In **step 4**, the student adds a solution to observe the end point accurately.

Name the solution and state the colour change at the end point.

Solution added: _____

Colour change: _____ [2]

(e) Determine the value of x in $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$.

Show your working.

[5]

26 Which equation matches the enthalpy change of atomisation of iodine?

- A $\text{I}_2(\text{g}) \rightarrow 2\text{I}(\text{g})$
- B $\frac{1}{2}\text{I}(\text{g}) \rightarrow \text{I}(\text{g})$
- C $\text{I}_2(\text{s}) \rightarrow 2\text{I}(\text{g})$
- D $\frac{1}{2}\text{I}_2(\text{s}) \rightarrow \text{I}(\text{g})$

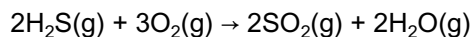
Your answer

[1]

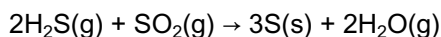
27(a) Much of the sulfur required for production of sulfuric acid is obtained from sulfur impurities in natural gas, such as hydrogen sulfide, H_2S .

The H_2S is converted into sulfur in two steps.

Step 1: Some of the H_2S is reacted with oxygen to form sulfur dioxide, SO_2 .



Step 2: The remaining H_2S is reacted with the SO_2 to produce sulfur.



(i) Construct the overall equation for the two steps above.

-----[1]

(ii) A natural gas supply contains 16.0% H_2S by volume.

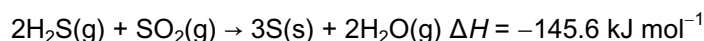
The $\text{H}_2\text{S}(\text{g})$ in $1.50 \times 10^8 \text{ dm}^3$ of this natural gas supply, measured at RTP, is processed into sulfur with an overall percentage yield of 95.0%.

Calculate the mass of sulfur, in g, obtained from $1.50 \times 10^8 \text{ dm}^3$ of natural gas supply.

Give your answer to **three** significant figures and in standard form.

mass of sulfur = ----- g [3]

(b) The enthalpy change for the equation in **step 2** is shown below.



Standard entropies, S , and enthalpy changes of formation, $\Delta_f H$, are given in the table.

Substance	H ₂ S(g)	SO ₂ (g)	S(s)	H ₂ O(g)
$S / \text{J mol}^{-1} \text{K}^{-1}$	205.7	248.1	31.8	188.7
$\Delta_f H / \text{kJ mol}^{-1}$	-20.6		0	-241.8

- (i) Calculate ΔG at 25 °C, and explain whether the reaction in **step 2** is feasible at 25 °C.

Calculate the temperature, in K, at which the feasibility changes.

Show your working and explain your reasoning.

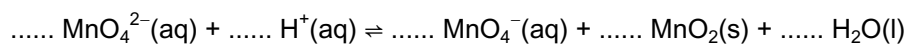
[5]

- (ii) Calculate $\Delta_f H$ for SO₂(g).

$\Delta_f H$ for SO₂(g) = _____ kJ mol⁻¹ [2]

28(a) When heated with dilute acid, $\text{MnO}_4^{2-}(\text{aq})$ ions disproportionate into MnO_4^{-} and MnO_2 .

(i) Balance the equation for this disproportionation reaction.



[1]

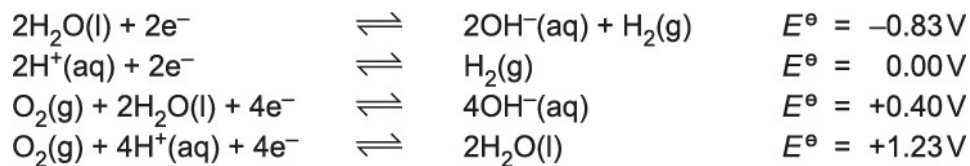
(ii) Although $\text{MnO}_4^{2-}(\text{aq})$ ions disproportionate in acidic conditions, $\text{MnO}_4^{2-}(\text{aq})$ ions are stable under alkaline solutions.

Explain this difference in stability, in terms of equilibrium.

[2]

- (b) Hydrogen fuel cells generate energy from redox reactions. Hydrogen fuel cells have been developed to operate in either an acidic or alkaline electrolyte.

Standard electrode potentials for several redox systems are shown below.



Using this information, show how acidic and alkaline hydrogen fuel cells produce the same overall cell equation and cell potential, despite different reactions taking place at each electrode.

[4]

- A student dissolves cobalt(II) chloride in water. A pink solution forms containing the hexaaqua complex ion **B**.
- The student adds an excess of concentrated ammonia solution to the pink solution until there is no further change.
- A pale brown solution forms which contains the complex ion $[\text{Co}(\text{NH}_3)_6]^{2+}$.

(i) Write the equation for the formation of $[\text{Co}(\text{NH}_3)_6]^{2+}$ from complex ion **B**.

State the type of reaction.

Equation

Type of reaction [2]

(ii) Draw a 3-D diagram of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ ion.

On your diagram, show the value of the bond angles involving Co.

[2]

(iii) A solution containing $[\text{Co}(\text{NH}_3)_6]^{2+}$ is reacted as outlined below.

- The solution is warmed with aqueous hydrogen peroxide, $\text{H}_2\text{O}_2(\text{aq})$.
The H_2O_2 oxidises cobalt(II) to cobalt(III), to form a red-brown solution containing a six-coordinate complex ion **C**.
- Concentrated hydrochloric acid is added to the red-brown solution.
Yellow crystals of a complex **D** are formed.

Complex **D** has the percentage composition by mass:

Co, 22.03%; N, 31.41%, H, 6.73%; Cl, 39.83%.

Determine the formulae of C and D, showing clearly the ligands and any charges.

Show all your working.

[4]

- (iv) Write half equations and an overall equation for the oxidation of $[\text{Co}(\text{NH}_3)_6]^{2+}$ to C by hydrogen peroxide in (iii).

Half equations

Overall equation

[3]

30(a) Concentrated sulfuric acid is a powerful oxidising agent. Concentrated sulfuric acid oxidises hydrogen iodide, HI, to form iodine, hydrogen sulfide and one other product.

Construct an equation for this reaction.

[2]

(b) A student carries out an experiment to find the enthalpy change of solution, $\Delta_{\text{sol}}H$, of sulfuric acid using the following method.

1. A plastic cup is weighed.
2. Approximately 100 cm³ of distilled water is added to the cup.
3. The temperature of the water in the plastic cup is measured.
4. A bottle containing concentrated sulfuric acid is weighed.
5. The sulfuric acid is poured into the plastic cup. The solution formed is stirred with the thermometer.
6. The maximum temperature reached by the solution is recorded.
7. The plastic cup containing the solution is weighed.
8. The empty bottle is weighed.

The student's results are shown in the table below:

Mass readings

Mass of bottle + H ₂ SO ₄ /g	25.66
Mass of empty bottle/g	14.38

Mass of plastic cup/g	8.74
Mass of plastic cup + solution formed/g	122.16

Temperature readings

Maximum temperature reached by solution/°C	32.0
Initial temperature of distilled water/°C	21.5

- (i) Use the student's results to calculate the enthalpy change of solution of sulfuric acid, in kJ mol^{-1} .

Assume that the specific heat capacity, c , of the solution is the same as for water.

Give your answer to an **appropriate** number of significant figures.

enthalpy change of solution, $\Delta_{\text{sol}}H$, = _____ kJ mol^{-1} [4]

- (ii) The student's thermometer has a maximum error of $\pm 0.5^\circ\text{C}$.

Calculate the percentage uncertainty in the student's temperature change.

Give your answer to **one** decimal place.

percentage uncertainty = _____ % [1]

- (iii) The student carries out a second experiment using 150 cm^3 of distilled water instead of 100 cm^3 of distilled water. The mass of concentrated sulfuric acid is the same as in the first experiment.

- The temperature change, ΔT
- The calculated value of $\Delta_{\text{sol}}H$ for H_2SO_4 .

31 A cell is constructed from the two redox systems below.



- 1 The cell potential is 1.14 V.
- 2 The reaction at the copper electrode is $\text{Cu(s)} \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-$.
- 3 The silver electrode increases in mass.

- Your answer

[1]

32(a) This question is about redox, electrode potentials and feasibility.

Table 22.1 shows standard electrode potentials for four redox systems.

You need to use this information to answer the questions below.

Redox system	Equation	$E^\ominus / \text{V}$
1	$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
2	$\text{SO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{SO}_3^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.17
3	$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
4	$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51

Table 22.1

A standard cell is set up in the laboratory based on redox systems 1 and 3 and the standard cell potential is measured.

(i) Draw a labelled diagram to show how this cell could be set up to measure its standard cell potential.

Include details of the apparatus, solutions and the standard conditions required to measure this standard cell potential.

Standard conditions

----- [4]

(ii) Predict the standard cell potential of this cell.

standard cell potential = ...V [1]

(b) In **Table 22.1**, what is the strongest reducing agent and the strongest oxidising agent?

Strongest reducing agent

Strongest oxidising agent

[2]

(c) Electrode potentials can be used to predict the feasibility of reactions.

Construct an overall equation for the predicted reaction between the species in redox systems 2 and 4.

.....[2]

- 33 Sodium oxide, Na_2O , can be prepared by the redox reaction of NaNO_2 and sodium metal. Nitrogen gas is also formed.

(i) What is the systematic name for NaNO_2 ?

----- [1]

(ii) Using oxidation numbers, with signs, show the element that is oxidised and the element that is reduced in this reaction.

Element oxidised -----

Oxidation number change from ----- to -----

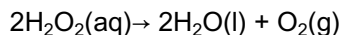
Element reduced -----

Oxidation number change from ----- to -----

[2]

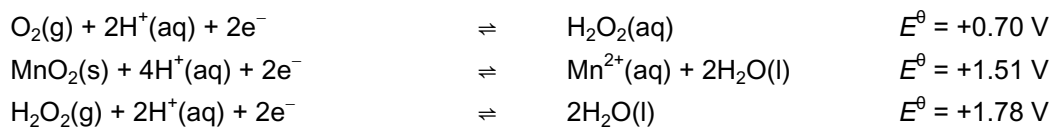
(iii) Construct the equation for this reaction.

Equation ----- [1]



This reaction is catalysed by manganese dioxide, $\text{MnO}_2(\text{s})$.

Standard electrode potentials are shown below.



Using the electrode potentials, explain how MnO_2 is able to act as a catalyst for the decomposition of hydrogen peroxide.

Your answer should include relevant equations.

[4]

35 Two changes are described below.

For each change,

- write an equation, including state symbols,
- state and explain how the entropy changes.

(i) The reaction of aqueous barium nitrate with aqueous sodium sulfate.

Full equation with state symbols

Explanation of entropy change .-----

----- [2]

(ii) The change that accompanies the standard enthalpy change of atomisation of iodine.

Equation with state symbols

Explanation of entropy change .-----

----- [2]

36(a) This question is about free energy changes, ΔG , enthalpy changes, ΔH , and temperature, T .

The Gibbs' equation is shown below.

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

A chemist investigates a reaction to determine how ΔG varies with T .

The results are shown in Fig. 18.1.

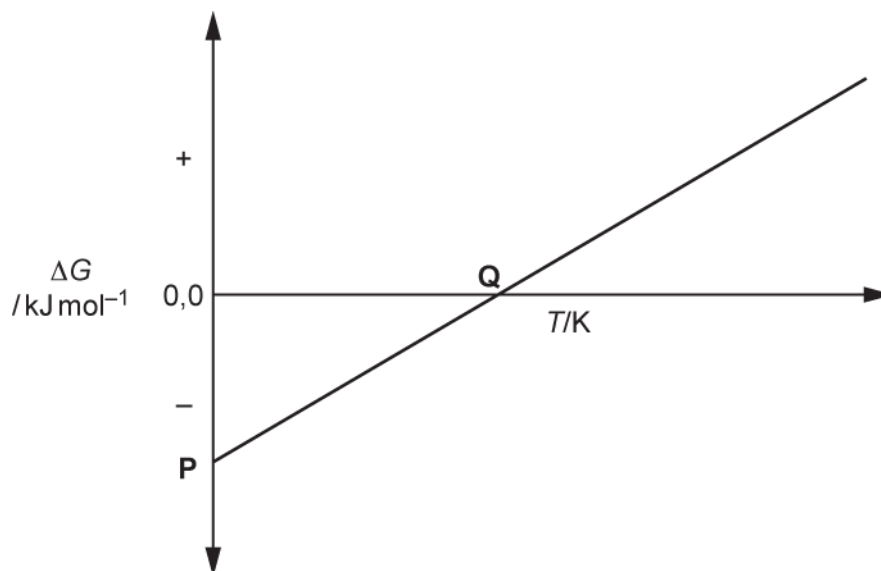


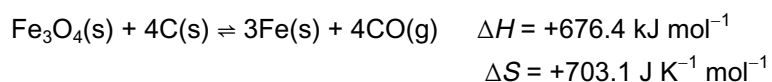
Fig. 18.1

What is significant about the gradient of the line and the values P and Q shown in Fig. 18.1?
Explain your reasoning.

[4]

- Iron can be extracted from its ore Fe_3O_4 using carbon.
- Several equilibria are involved including **equilibrium 18.1**, shown below.

equilibrium 18.1



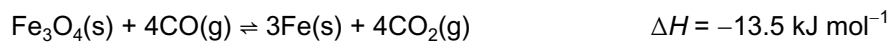
- (i) Why is **equilibrium 18.1** a *heterogeneous* equilibrium?
-
-
- [1]

- (ii) Write the expression for K_p for equilibrium 18.1.

- (iii) The forward reaction in **equilibrium 18.1** is only feasible at high temperatures.
- Show that the forward reaction is **not** feasible at 25 °C.
 - Calculate the minimum temperature, in K, for the forward reaction to be feasible.

minimum temperature = _____ K [3]

(iv) Another equilibrium involved in the extraction of iron from Fe_3O_4 is shown below.



Enthalpy changes of formation, $\Delta_f H$, for $\text{Fe}_3\text{O}_4(\text{s})$ and $\text{CO}_2(\text{g})$ are shown in the table.

Compound	$\Delta_f H / \text{kJ mol}^{-1}$
$\text{Fe}_3\text{O}_4(\text{s})$	-1118.5
$\text{CO}_2(\text{g})$	-393.5

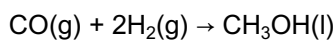
Calculate the enthalpy change of formation, $\Delta_f H$, for $\text{CO}(\text{g})$.

$\Delta_f H$, for $\text{CO}(\text{g}) =$ kJ mol^{-1}
[3]

37 The table below shows standard entropies, $S^\ominus$

Substance	CO(g)	H ₂ (g)	CH ₃ OH(l)
$S^\ominus / \text{J mol}^{-1} \text{K}^{-1}$	197.6	130.6	239.7

What is the entropy change, $\Delta S^\ominus$, in $\text{J mol}^{-1} \text{K}^{-1}$, for the following reaction?



A -219.1

B -88.5

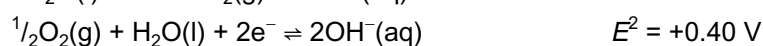
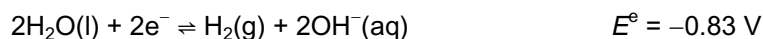
C +88.5

D +219.1

Your answer

[1]

38 The redox equilibria for a hydrogen–oxygen fuel cell in alkaline solution are shown below.



What is the equation for the overall cell reaction?

A $\text{H}_2\text{(g)} + 4\text{OH}^-\text{(aq)} \rightarrow 3\text{H}_2\text{O(l)} + \frac{1}{2}\text{O}_2\text{(g)}$

B $3\text{H}_2\text{O(l)} + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{(g)} + 4\text{OH}^-\text{(aq)}$

C $\text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{(g)} + \frac{1}{2}\text{O}_2\text{(g)}$

D $\text{H}_2\text{(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{H}_2\text{O(l)}$

Your answer

[1]

39 Which enthalpy change(s) is/are endothermic?

- 1 The bond enthalpy of the C–H bond
- 2 The second electron affinity of oxygen
- 3 The standard enthalpy change of formation of magnesium

- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

[1]

Table 16.1 shows enthalpy changes that can be used to determine the enthalpy change of hydration of fluoride ions, F^- .

Enthalpy change	Energy / kJ mol^{-1}
Hydration of Ca^{2+}	-1609
Solution of CaF_2	+13
Lattice enthalpy of CaF_2	-2630

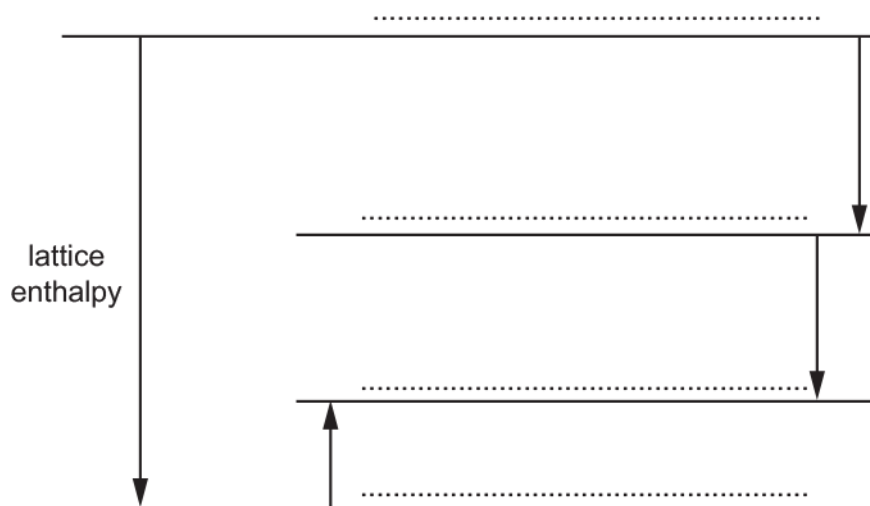
Table 16.1

- (i) Explain what is meant by the term *enthalpy change of hydration*.

----- [2]

- (ii) The enthalpy change of hydration of F^- can be determined using the enthalpy changes in **Table 16.1** and the incomplete energy cycle below.

On the dotted lines, add the species present, including state symbols.



[4]

(iii) Calculate the enthalpy change of hydration of fluoride ions, F^- .

enthalpy change of hydration = ... kJ mol^{-1} [2]

(iv) Predict how the enthalpy changes of hydration of F^- and Cl^- would differ.

Explain your answer.

----- [2]

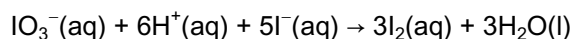
- 41 Compound **B** is an iodate(V) salt of a Group 1 metal.
The iodate(V) ion has the formula IO_3^- .

A student carries out a titration to find the formula of compound **B**.

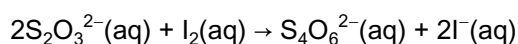
Step 1: The student dissolves 1.55 g of **B** in water and makes up the solution to 250.0 cm^3 in a volumetric flask.

Step 2: The student pipettes 25.00 cm^3 of the solution of **B** into a conical flask, followed by 10 cm^3 of dilute sulfuric acid and an excess of KI(aq) .

The iodate(V) ions are reduced to iodine, as shown below.



Step 3: The resulting mixture is titrated with $0.150 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$.



The student repeats **step 2** and **step 3** until concordant titres are obtained.

Titration readings

Titration	Trial	1	2	3
Final burette reading / cm^3	24.00	47.40	23.75	47.05
Initial burette reading / cm^3	0.00	24.00	0.00	23.20
Titre / cm^3				

Table 20.1

- (i) Complete **Table 20.1** and calculate the mean titre that the student should use for analysing the results.

mean titre = ... cm^3 [2]

- (ii) The uncertainty in each burette reading is $\pm 0.05 \text{ cm}^3$.

Calculate the percentage uncertainty in the titre obtained from **titration 1**.

Give your answer to **two** decimal places.

percentage uncertainty = ... % [1]

(iii) Describe and explain how the student should determine the end point of this titration accurately.

----- [2]

(iv) Determine the relative formula mass and formula of the Group 1 iodate(V), **B**.

Show your working.

relative formula mass of **B** = ...
formula of **B** = ... [5]

42(a) This question is about some reactions of d block elements and their ions.

Table 21.1 shows standard electrode potentials which will be needed within this question.

$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{Zn}(\text{s})$	$E^{\ominus} = -0.76 \text{ V}$
$\text{Cr}^{3+}(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Cr}^{2+}(\text{aq})$	$E^{\ominus} = -0.42 \text{ V}$
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{Ni}(\text{s})$	$E^{\ominus} = -0.25 \text{ V}$
$\text{I}_2(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$2\text{I}^{-}(\text{aq})$	$E^{\ominus} = +0.54 \text{ V}$
$\text{Fe}^{3+}(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}^{2+}(\text{aq})$	$E^{\ominus} = +0.77 \text{ V}$
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^{+}(\text{aq}) + 6\text{e}^{-}$	$\rightleftharpoons$	$2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	$E^{\ominus} = +1.33 \text{ V}$
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^{+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$2\text{H}_2\text{O}(\text{l})$	$E^{\ominus} = +1.78 \text{ V}$

Table 21.1

A standard cell is set up in the laboratory with the cell reaction shown below.



(i) Draw a labelled diagram to show how this cell could be set up to measure its standard cell potential.

Include details of apparatus, solutions and the standard conditions required.

Standard conditions -----

----- [4]

(ii) Predict the standard cell potential of this cell.

standard cell potential = ... V [1]

(b) Use the information in **Table 21.1** to help you answer both parts of this question.

(i) Write the overall equation for the oxidation of Fe^{2+} by acidified H_2O_2 .

-----[1]

(ii) Zinc reacts with acidified $\text{Cr}_2\text{O}_7^{2-}$ ions to form Cr^{2+} ions in two stages.

Explain why this happens in terms of electrode potentials and equilibria.

Include overall equations for the reactions which occur.

-----[4]

(c) * Three different reactions of copper compounds are described below.

- Reaction 1:** Aqueous copper(II) sulfate reacts with excess aqueous ammonia in a ligand substitution reaction. A deep-blue solution is formed, containing an octahedral complex ion, **C**, which is a trans isomer.
- Reaction 2:** Copper(I) oxide reacts with hot dilute sulfuric acid in a disproportionation reaction. A blue solution, **D**, and a brown solid, **E** are formed.
- Reaction 3:** Copper(II) oxide reacts with warm dilute nitric acid in a neutralisation reaction, to form a blue solution. Unreacted copper(II) oxide is filtered off, and the solution is left overnight in an evaporating basin.
A hydrated salt, **F**, crystallises, with the percentage composition by mass:
Cu, 26.29%; H, 2.48%; N, 11.59%; O, 59.63%.

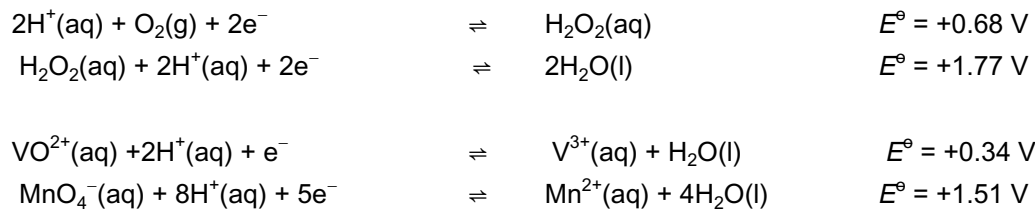
Identify **C–F** by formulae or structures, as appropriate.

Include equations, any changes in oxidation number, and working.

[6]

43 Hydrogen peroxide can act as an oxidising agent or as a reducing agent.

Some standard electrode potentials are shown below.



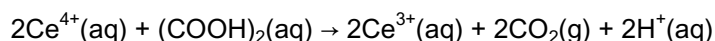
Use this information to write an equation for a reaction in which hydrogen peroxide acts as a reducing agent.

-----[2]

44 Ethanedioic acid, $(\text{COOH})_2$, is present in rhubarb leaves.

A student carries out a redox titration using aqueous cerium(IV) sulfate, $\text{Ce}(\text{SO}_4)_2(\text{aq})$, to determine the percentage, by mass, of ethanedioic acid in rhubarb leaves.

In the titration, $\text{Ce}^{4+}(\text{aq})$ ions oxidise ethanedioic acid in hot acid conditions:



$\text{Ce}^{4+}(\text{aq})$ ions have a yellow colour. $\text{Ce}^{3+}(\text{aq})$ ions are colourless.

The student weighs 82.68 g of rhubarb leaves and extracts ethanedioic acid from the leaves.

The ethanedioic acid is added to dilute sulfuric acid to form a colourless solution which is made up to 250.0 cm^3 with distilled water.

The student heats 25.00 cm^3 of this solution to 70°C and titrates this volume with $0.0500 \text{ mol dm}^{-3} \text{ Ce}(\text{SO}_4)_2$ from the burette.

The student repeats the titration to obtain concordant (consistent) titres.

Titration results

The trial titre has been omitted.

	1	2	3
Final reading/ cm^3	24.30	47.80	23.65
Initial reading/ cm^3	1.05	24.30	0.50

(i) This titration is self-indicating and the student does not need to add an indicator.

What colour change would the student observe at the end point?

Colour change from to [1]

(ii) Calculate the percentage, by mass, of ethanedioic acid in the rhubarb leaves.

Give your answer to an **appropriate** number of significant figures.

percentage of ethanedioic acid =----- % [6]

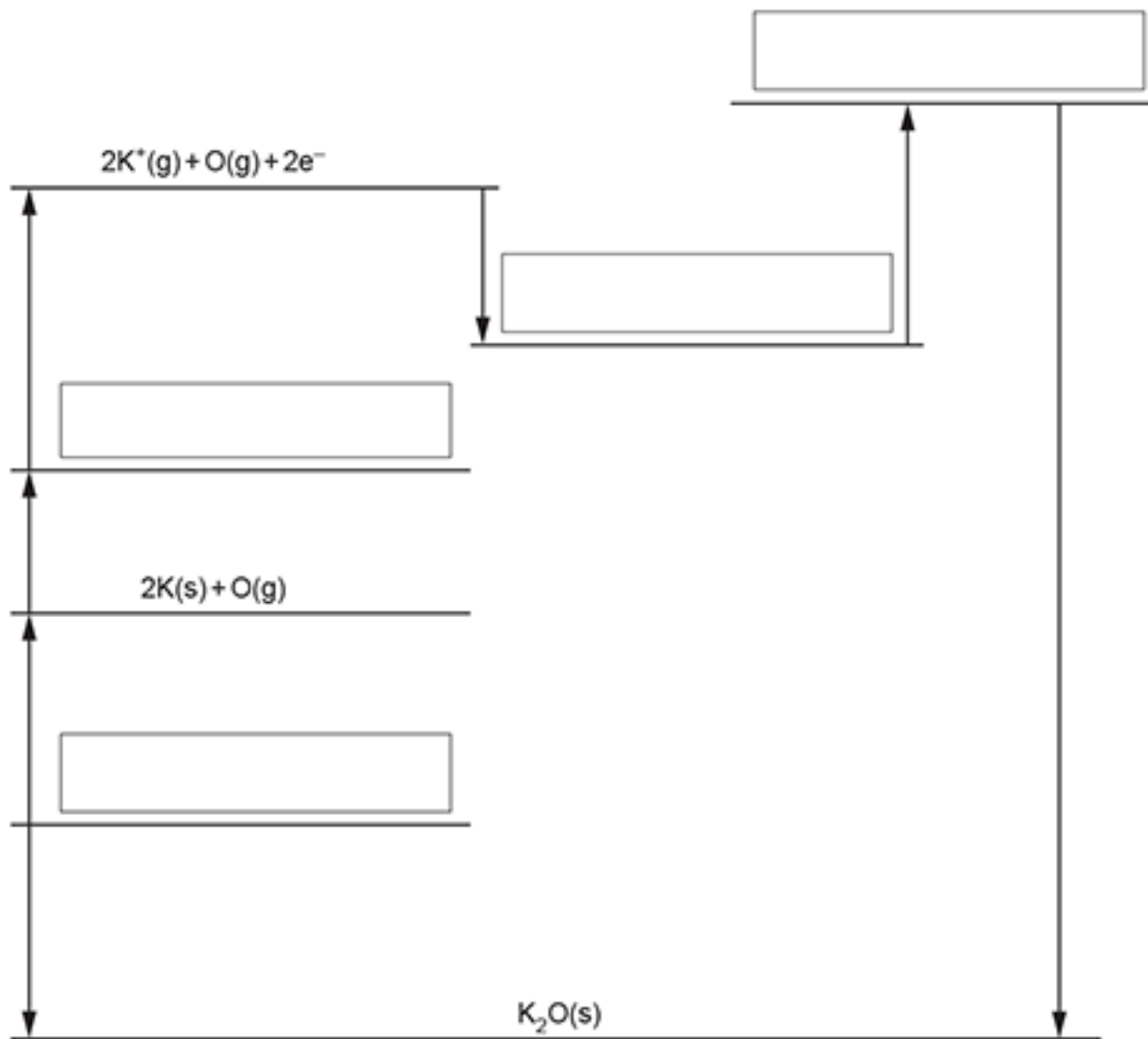
45(a) The table below shows enthalpy changes involving potassium, oxygen and potassium oxide, K_2O .

	Enthalpy change / kJ mol^{-1}
formation of potassium oxide	-363
1st electron affinity of oxygen	-141
2nd electron affinity of oxygen	+790
1st ionisation energy of potassium	+419
atomisation of oxygen	+249
atomisation of potassium	+89

(i) The incomplete Born–Haber cycle below can be used to determine the lattice enthalpy of potassium oxide.

In the boxes, complete the species present in the cycle.

Include state symbols for the species.



[4]

(ii) Calculate the lattice enthalpy of potassium oxide.

lattice enthalpy = ... kJ mol^{-1} [2]

- (b) Sir Humphry Davy discovered several elements including sodium, potassium, magnesium, calcium and strontium.

A similar Born–Haber cycle to potassium oxide in the part above can be constructed for sodium oxide.

- (i) The first ionisation energy of sodium is more endothermic than that of potassium.

Explain why.

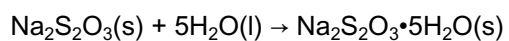
[2]

- (ii) The lattice enthalpy of sodium oxide is more exothermic than that of potassium oxide.

Explain why.

[2]

- 46 The standard enthalpy change of reaction, $\Delta_r H^\ominus$, and the standard free energy change, $\Delta G^\ominus$, for converting anhydrous sodium thiosulfate to hydrated sodium thiosulfate are shown below.



$$\Delta_r H^\ominus = -55.8 \text{ kJ mol}^{-1}$$

$$\Delta G^\ominus = -16.1 \text{ kJ mol}^{-1}$$

Standard entropies are given in the table.

Compound	$S^\ominus / \text{J K}^{-1} \text{ mol}^{-1}$
$\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}(\text{s})$	372.4
$\text{H}_2\text{O}(\text{l})$	69.9

Determine the **standard** entropy, $S^\ominus$, of anhydrous sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3(\text{s})$.

Give your answer to **3** significant figures.

$S^\ominus$ $\text{J K}^{-1} \text{ mol}^{-1}$ [4]

47 Four redox systems relevant to hydrogen–oxygen fuel cells are shown below.

	E° / V
$\text{H}_2\text{O}(\text{l}) + \text{e}^- \rightleftharpoons \text{OH}^-(\text{aq}) + \frac{1}{2}\text{H}_2(\text{g})$	−0.83
$\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \frac{1}{2}\text{H}_2(\text{g})$	0.00
$\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightleftharpoons 2\text{OH}^-(\text{aq})$	+0.40
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}(\text{l})$	+1.23

Which statement(s) is/are correct for an alkaline hydrogen–oxygen fuel cell?

- 1 The reaction at the positive electrode is: $\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2\text{O}(\text{l})$
- 2 The overall cell reaction is: $\text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$.
- 3 The cell potential is 1.23 V.

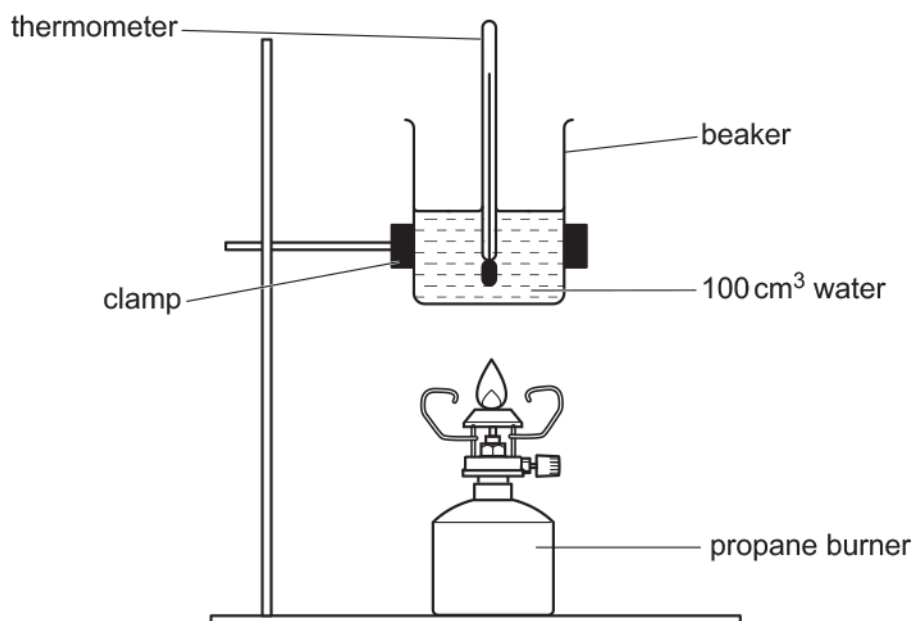
- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

[1]

- 48 Propane, C_3H_8 , (boiling point $-42\text{ }^\circ\text{C}$) is used as 'camping gas'. A student plans to determine the enthalpy change of combustion of propane, $\Delta_c H(\text{C}_3\text{H}_8)$.

The student carries out an experiment using the apparatus below.



Results

Mass of propane burner before burning / g	99.218
Mass of propane burner after burning / g	98.976
Initial temperature / $^\circ\text{C}$	21.60
Maximum temperature reached / $^\circ\text{C}$	46.10

- (i) Determine the enthalpy change of combustion of propane, in kJ mol^{-1} .

Give your answer to 3 significant figures.

$$\Delta_c H(C_3H_8) = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

- (ii) The student finds that the experimental enthalpy change $\Delta_c H(C_3H_8)$ is much less exothermic than the accurate standard enthalpy change $\Delta_c H(C_3H_8)$ in databases.

One reason could be that the student's experiment had not been carried out under standard conditions.

Suggest **two** other reasons for this difference in enthalpy change.

1

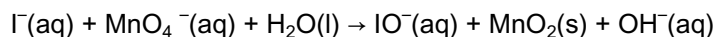
.....

2

.....

[1]

- 49 Iodide ions, $I^-(aq)$, react with $MnO_4^-(aq)$. The unbalanced equation is shown below.



What is the ratio of $MnO_2(s)$ to $OH^-(aq)$ in the balanced equation?

- A 1 : 3
B 1 : 2
C 1 : 1
D 3 : 2

Your answer

[1]

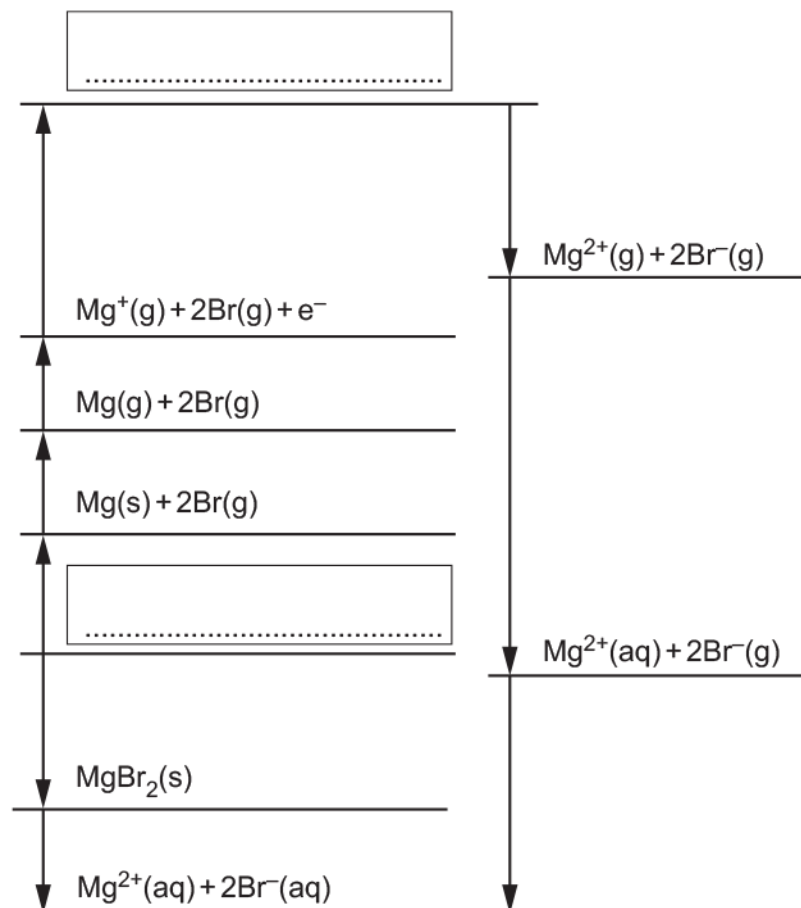
The enthalpy change of hydration of bromide ions can be determined using the enthalpy changes in **Table 16.2**.

Enthalpy change	Energy / kJ mol^{-1}
1st ionisation energy of magnesium	+736
2nd ionisation energy of magnesium	+1450
atomisation of bromine	+112
atomisation of magnesium	+148
electron affinity of bromine	-325
formation of magnesium bromide	-525
hydration of bromide ion	to be calculated
hydration of magnesium ion	-1926
solution of magnesium bromide	-186

Table 16.2

(i) An incomplete energy cycle based on **Table 16.2** is shown below.

On the dotted lines, add the species present, including state symbols.



[2]

(ii) Using your completed energy cycle in (i), calculate the enthalpy change of hydration of bromide ions.

enthalpy change of hydration = ... kJ mol^{-1} [2]

(iii) Write the equation for the lattice enthalpy of magnesium bromide and calculate the lattice enthalpy of magnesium bromide.

Equation

Calculation

lattice enthalpy = ... kJ mol^{-1} [3]

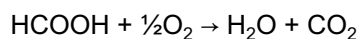
Redox system	Half-equation	$E^\ominus / \text{V}$
1	$\text{CO}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{HCOOH}(\text{aq})$	-0.11
2	$\text{HCOOH}(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{HCHO}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	-0.03
3	$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
4	$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51

Table 19.1

Methanoic acid, HCOOH, can be used in a fuel cell. As with all fuel cells, the fuel (HCOOH) is supplied at one electrode and the oxidant (oxygen) at the other electrode.

The standard cell potential for this fuel cell is 1.34 V.

The overall reaction is shown below.



Using the information in Table 19.1, deduce the half-equation for the reaction at the oxygen electrode, and calculate the standard electrode potential for the oxygen half-cell.

half-equation _____

standard electrode potential = _____ V

[2]

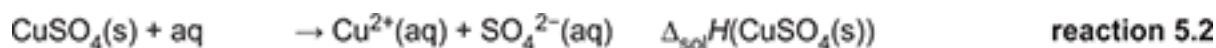
52 This question is about copper(II) sulfate, CuSO_4 , and sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3$.

The enthalpy change of reaction, $\Delta_r H$, for converting anhydrous copper(II) sulfate to hydrated copper(II) sulfate is difficult to measure directly by experiment.



The enthalpy changes of solution of anhydrous and hydrated copper(II) sulfate can be measured by experiment. The reactions are shown below.

In the equations, 'aq' represents an excess of water.



Experiment 1

A student carries out an experiment to find $\Delta_{\text{sol}} H(\text{CuSO}_4(\text{s}))$ for reaction 5.2.

Student's method

- Weigh a bottle containing $\text{CuSO}_4(\text{s})$ and weigh a polystyrene cup.
- Add about 50 cm^3 of water to the polystyrene cup and measure its temperature.
- Add the $\text{CuSO}_4(\text{s})$, stir the mixture, and measure the final temperature.
- Weigh the empty bottle and weigh the polystyrene cup with final solution.

Mass readings

Mass of bottle + $\text{CuSO}_4(\text{s})$ / g	28.04
Mass of empty bottle / g	20.06
Mass of polystyrene cup / g	23.43
Mass of polystyrene cup + final solution / g	74.13

Temperature readings

Initial temperature of water / °C	20.5
Temperature of final solution / °C	34.0

Experiment 2

The student carries out a second experiment with $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (reaction 5.3). The student uses the same method as in **Experiment 1**.

The student calculates $\Delta_{\text{sol}}H(\text{CuSO}_4 \cdot 5\text{H}_2\text{O}(\text{s}))$ as $+8.43 \text{ kJ mol}^{-1}$.

- (i) *Calculate $\Delta_{\text{sol}}H(\text{CuSO}_4(\text{s}))$ for **reaction 5.2** and determine the enthalpy change of **reaction 5.1**, Δ_rH .

Assume that the specific heat capacity, c , of the solution is the same as for water.

Show your working, including an energy cycle linking the enthalpy changes.

[6]

(ii) The thermometer had an uncertainty in each temperature reading of $\pm 0.1\text{ }^{\circ}\text{C}$.

The student calculates a 20% uncertainty in the temperature change in **Experiment 2**.

Calculate the temperature change in **Experiment 2**.

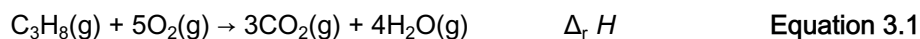
temperature change = ... $^{\circ}\text{C}$ [1]

- 53 Propane, C_3H_8 , (boiling point -42°C) is used as 'camping gas'. A student plans to determine the enthalpy change of combustion of propane, $\Delta_c H$ (C_3H_8).

The student determines the standard enthalpy change of combustion of propane using the bond enthalpies in the table. An experiment is not needed.

Bond	Bond enthalpy / kJ mol^{-1}
C–H	+413
C–C	+347
C=O	+805
O=O	+498
O–H	+464

The bond enthalpies can be used to determine the standard enthalpy change of reaction, $\Delta_r H$, for **equation 3.1**:



Enthalpy change of vaporisation, $\Delta_{\text{vap}} H$

The standard enthalpy change of vaporisation of water, $\Delta_{\text{vap}} H$, is the enthalpy change for the conversion of 1 mol of $\text{H}_2\text{O}(\text{l})$ into 1 mol of $\text{H}_2\text{O}(\text{g})$ under standard conditions:



Determine the standard enthalpy change of combustion of propane (boiling point -42°C) using the $\Delta_r H$ value for **equation 3.1** and $\Delta_{\text{vap}} H$ for water.

Blank lined paper for writing.

54 A student is provided with a sample of a metal **M**.

The student analyses metal **M** using a 'back-titration' technique:

- The metal is reacted with excess acid.
- The resulting solution is titrated to determine the amount of acid remaining after the reaction.

Stage 1

The student adds 100 cm³ of 2.10 mol dm⁻³ HCl(aq) to 6.90 g of **M**.

An excess of HCl(aq) has been used to ensure that all of metal **M** reacts.

A redox reaction occurs, forming a solution containing **M** in the +2 oxidation state.

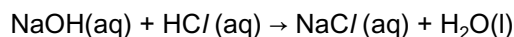
Stage 2

The resulting solution from **Stage 1** is made up to 250.0 cm³ with distilled water.

Stage 3

A 25.00 cm³ sample of the diluted solution from **Stage 2** is titrated with 0.320 mol dm⁻³ NaOH(aq).

The NaOH(aq) reacts with excess HCl(aq) that remains in **Stage 1**:



The student repeats the titration to obtain concordant titres.

Titration results (The trial titre has been omitted.)

The burette readings have been recorded to the nearest 0.05 cm³.

	1	2	3
Final reading / cm ³	27.80	37.55	32.20
Initial reading / cm ³	0.50	10.00	5.00

- (i) In **Stage 1**, a redox reaction takes place between **M** and HCl(aq), forming hydrogen and a solution containing **M** in the +2 oxidation state.

Write an overall equation, with state symbols, for this reaction. Write half-equations for the oxidation and reduction processes.

Overall equation _____

Oxidation half-equation _____

Reduction half-equation _____

[3]

(ii) In **Stage 1**, suggest **two** observations that would confirm that all of metal **M** has reacted.

1 _____

2 _____

[2]

(iii) In **Stage 3**, write the ionic equation for the reaction taking place in the titration.

_____ [1]

(iv) Metal **M** can be identified following the steps below.

1. The amount, in mol, of excess $\text{HCl}(\text{aq})$ that remains after the reaction of **M** with $\text{HCl}(\text{aq})$.
2. The amount, in mol, of $\text{HCl}(\text{aq})$ that reacted with **M**.
3. The identity of metal **M**.

Analyse the results to identify metal **M**.

Metal M = ... [6]

- 55 Methanol, CH₃OH, can be made industrially by the reaction of carbon monoxide with hydrogen, as shown in **equilibrium 1**.



Standard entropy values are given below.

Substance	CO(g)	H ₂ (g)	CH ₃ OH(g)
$S^\ominus / \text{J K}^{-1} \text{ mol}^{-1}$	198	131	238

A chemist proposed producing methanol at 525 K using **equilibrium 1**.

Explain, with a calculation, whether the production of methanol is feasible at 525 K.

[5]

56(a) Standard electrode potentials for four redox systems are shown in Table 19.1.

Redox system	Half-equation	$E^\ominus / \text{V}$
1	$\text{CO}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{HCOOH}(\text{aq})$	-0.11
2	$\text{HCOOH}(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{HCHO}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	-0.03
3	$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
4	$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51

Table 19.1

A student sets up a standard cell in the laboratory based on redox systems 3 and 4.

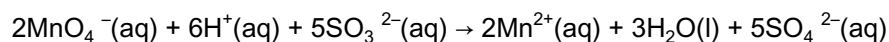
Draw a labelled diagram to show how this cell could be set up to measure its standard cell potential at 298 K.

[3]

- 57 Sodium sulfite(IV), Na_2SO_3 , is used as a preservative in some foods.
Food safety legislation allows a maximum of 850 mg Na_2SO_3 per kg of burger meat.

A chemist determines the amount of Na_2SO_3 in a sample of burger meat using a manganate(VII) titration.

- Step 1** The Na_2SO_3 from 525 g of burger meat is extracted to form a solution containing $\text{SO}_3^{2-}(\text{aq})$ ions.
Step 2 The solution from **step 1** is made up to 250.0 cm^3 in a volumetric flask with water.
 25.0 cm^3 of this diluted solution is pipetted into a conical flask.
Step 3 The pipetted solution from **step 2** is acidified with dilute sulfuric acid and then titrated with $0.0100 \text{ mol dm}^{-3}$ potassium manganate(VII), KMnO_4 .



12.60 cm^3 of $\text{KMnO}_4(\text{aq})$ is required to reach the endpoint.

Analyse the results to determine whether the burger meat complies with food safety legislation.

[5]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1	a	i	$2K^+(g) + S^{2-}(g)$ ✓ $2K^+(g) + S^-(g) + e^-$ ✓ $2K(g) + S(g)$ ✓	3	Mark each marking point independently Correct species AND state symbols required for each mark For S^{2-}, DO NOT ALLOW S^{-2} For e^-, ALLOW e For e^- only, IGNORE any state symbols added ALLOW k and s <i>It can be very difficult distinguishing K from k; S from s</i> Examiner's Comments Many candidates successfully completed the Born-Haber cycle to obtain all three marks. The species including any ionic charges and state symbols were almost always correct but sometimes one or more state symbols had been omitted. The commonest error was in the number of electrons in the middle stage; some showed two electrons and the electron was more often omitted entirely. Candidates are advised to check carefully between stages in the cycle to ensure that all species charges and state symbols are accounted for and included.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	(The enthalpy change that accompanies) the formation of one mole of a(n ionic) compound from its gaseous ions (under standard conditions) ✓✓ Award marks as follows. 1st mark: formation of compound from gaseous ions 2nd mark: one mole for compound only DO NOT ALLOW 2nd mark without 1st mark Note: A definition for enthalpy change of formation will receive no marks	2	IGNORE 'Energy needed' OR 'energy required' ALLOW one mole of compound is formed / made from its gaseous ions ALLOW as alternative for compound: lattice, crystal, substance, solid IGNORE: $2K^+(g) + S^{2-}(g) \rightarrow K_2S(s)$ (question asks for words) ALLOW 1 mark (special case) for absence of 'gaseous' only, i.e. the formation of one mole of a(n ionic) compound from its ions (under standard conditions) ✓ Examiner's Comments The majority of candidates had learnt the definition for lattice enthalpy and scored two marks. When fewer marks were awarded, the more common reasons were for responses in terms of a mole of gaseous ions, or omission of the mole altogether. Occasionally some weaker candidates confused the definition with that for the enthalpy change of formation and so referred to forming a mole of the ionic compound from its constituent elements. Such responses gained no credit.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = $-2116 \text{ (kJ mol}^{-1}\text{)}$ award 2 marks $-381 - (2 \times +89 + 279 + 2 \times +419 - 200 + 640)$ ✓ $-381 - 1735$ $= -2116$ ✓ (kJ mol^{-1})	2	IF there is an alternative answer, check to see if there is any ECF credit possible using working below. See list below for marking of answers from common errors ALLOW for 1 mark ONE mistake with sign OR use of 2: -2027 (2×89 not used for K) -1697 (2×419 not used for K) -2516 ($+200$ rather than -200 for S 1st electron affinity) $(+2116)$ (wrong sign) -1354 ($+381$ instead of -381) $(+1354)$ ($+1735$ instead of -1735) -836 (-640 instead of $+640$) -1558 (-279 instead of $+279$) -1760 (-2×89 instead of $+2 \times 89$) -439 (-2×419 instead of $+2 \times 419$) -2120 (rounded to 3SF) For other answers, check for a single transcription error or calculator error which could merit 1 mark DO NOT ALLOW any other answers, e.g. -1608 (2 errors: 2×89 and 2×419 not used for K) -846 (3 errors:) Examiner's Comments Most candidates correctly calculated the lattice enthalpy using a correct sequence of enthalpy values. The commonest mistakes were omission of '2' for either the atomisation or ionisation of potassium or use of incorrect signs. Candidates are advised to check carefully that any balancing numbers are linked to the correct enthalpy changes in the cycle. Answer = $-2116 \text{ kJ mol}^{-1}$

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	b	Lowest melting point KI RbCl Highest melting point NaBr Correct order ✓ Mark 2nd and 3rd marking points independently Attraction and ionic size linked: Greater attraction from smaller ions / closer ions / larger charge density ✓ <i>Comparison needed</i> Energy AND attraction / breaking bonds linked: More energy / heat to overcome attraction (between ions) OR More energy / heat to break (ionic) bonds ✓	3	FULL ANNOTATIONS MUST BE USED ORA throughout Response must clearly refer to ions for explanation marks 2nd and 3rd marking point must be comparative DO NOT ALLOW incorrect named particles, e.g. 'atoms', 'molecules', Na, Cl, Cl₂, 'atomic', etc DO NOT ALLOW responses using nuclear size or attraction DO NOT ALLOW responses linked with loss of electrons IGNORE larger electron density ALLOW smaller sum of radii gives a greater ionic attraction IGNORE NaBr has greater ionic attraction IGNORE NaBr has smallest ionic radius (<i>not focussing on size of each ion</i>) ASSUME bonds broken are ionic unless otherwise stated DO NOT ALLOW incorrect named particles, e.g. 'atoms', 'molecules', Na, Cl, Cl₂, 'atomic', etc Note: Comparison for energy only (<i>i.e. link between more energy and breaking bonds / overcoming attraction</i>) Examiner's Comments This descriptive part caused more problems. Candidates were expected to apply their knowledge and understanding of lattice enthalpies to supplied data. The predicted order of melting points based on the sum of the ionic radii gave the easiest mark, although some showed the order the opposite way round. The explanation proved to be much harder. Candidates

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					were expected to relate ionic size with attraction and then to the energy required to overcome the attractive force. Precision in language is always essential here and many candidate spoilt their response by use of incorrect particles. It was very common to see terms such as 'atomic radius, molecules, van der Waals' forces and ionic radius of NaBr. Some candidates simply compared the radii, the skill required for the first marking point.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
2	a	i	(entropy) decreases AND (solid / ice has) less disorder / more order / fewer ways of arranging energy / less freedom / less random molecules ✓	1	ORA decreases and reason required for mark ASSUME change is for freezing of water unless otherwise stated DO NOT ALLOW atoms are more ordered Examiner's Comments This part was usually answered, the best responses linking the state change from liquid to solid with increased order and a decrease in entropy.
		ii	(entropy) increases AND (CO ₂) gas is formed ✓ <i>Could be from equation with CO₂(g)</i>	1	increases and reason required for mark ASSUME gas is CO₂ unless otherwise stated BUT DO NOT ALLOW an incorrect gas (e.g. H₂) ALLOW more gas Examiner's Comments Candidates were expected to predict an increase in entropy from formation of a gas (CO₂). This was communicated either in text or as an equation with state symbols and both approaches were credited.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	entropy decreases AND 3 mol O₂ form 2 mol O₃ OR 3O₂ → 2O₃ OR 3 mol gas form 2 mol gas ✓	1	decreases and reason required for mark For mol, ALLOW molecules ALLOW multiples, e.g. $1\frac{1}{2}\text{O}_2 \rightarrow \text{O}_3$; $\text{O}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{O}_3$ ALLOW O₂ + O → O₃ Note: DO NOT ALLOW 2 mol gas forms 1 mol gas unless linked to O₂ + O → O₃ IGNORE reaction forms fewer moles / molecules Examiner's Comments This part caused more problems as candidates were expected to recognise the different gaseous moles on formation of ozone. Candidates were expected to state the 3:2 ratio from 3O₂(g) → 2O₃(g) or 2:1 ratio from O₂ + O → O₃(g); the best responses did this, either by quoting the molar ratio or from use of the equation. Vaguer responses such as 'fewer moles' were not credited. Strangely, some candidates gave a 'correct' response for the reverse reaction.
	b		CARE: responses involve changes of negative values Feasibility AND ΔG Reaction becomes / is less feasible / not feasible AND ΔG increases OR ΔG becomes / is less negative / more positive OR ΔG > 0 OR ΔH – TΔS > 0 OR ΔH – TΔS becomes / is less negative / more positive OR ΔH > TΔS ✓ OR TΔS becomes / is more negative than ΔH ✓ Effect on TΔS TΔS becomes more negative OR TΔS decreases	2	FULL ANNOTATIONS MUST BE USED As alternative for 'less feasible' ALLOW 'less spontaneous' OR a comment that implies 'reaction no longer take place' ALLOW for ΔG increases ΔG < 0 only at low T DO NOT ALLOW TΔS > ΔH (<i>comparison wrong way round</i>) NOTE: Last statement automatically scores 2nd mark ALSO IGNORE significance IGNORE magnitude for 1st marking point DO NOT ALLOW TΔS increases

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			OR $-T\Delta S$ becomes more positive OR $-T\Delta S$ increases OR magnitude of $T\Delta S$ increases OR $T\Delta S$ increases ✓		IGNORE significance APPROACH BASED ON TOTAL ENTROPY: Feasibility with increasing temperature Reaction becomes less feasible / not feasible AND $\Delta S - \Delta H / T$ OR ΔS_{total} decreases / less positive ✓ Effect on $\Delta H / T$ $\Delta H / T$ is less negative OR $\Delta H / T$ increases OR $-\Delta H / T$ decreases OR magnitude of $\Delta H / T$ decreases ✓ Examiner's Comments Comparison of negative numbers is a difficult skill, shown by the many contradictions seen in the candidate responses. The key to success here was to compare the two key terms, ΔH and $T\Delta S$ and to relate these to feasibility from the sign of ΔG. Problems arose in responses that ignored the negative signs leading to ambiguous statements. The required '$T\Delta S$ becomes more negative' was often communicated as '$T\Delta S$ increases'. The latter term is ambiguous, its meaning depending on whether the sign is included or omitted. The comparison of $T\Delta S$ with ΔH caused more problems with many responses seen of $T\Delta S > \Delta H$. Mathematically, the opposite is true as both values are negative. The better approach was to communicate this relationship in text as '$T\Delta S$ is more negative than ΔH.' The responses from the best candidates used this precise language but many candidates did not score marks here because of the ambiguity.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 75.962 OR 75.96 OR 76.0 OR 76, award 2 marks ----- $\Delta S = (33 + 3 \times 189) - (76 + 3 \times 131)$ $= (+)131 \text{ (J K}^{-1} \text{ mol}^{-1}) \checkmark$ $\Delta G = 115 - (298 \times 0.131)$ $= (+) 75.962 \text{ OR } 75.96 \text{ OR } 76.0 \text{ OR } 76 \text{ (kJ K}^{-1} \text{ mol}^{-1}) \checkmark$	2	DO NOT ALLOW -131 ALLOW ECF from incorrect calculated value of ΔS Examiner's Comments Almost all candidates successfully showed that the entropy change was $131 \text{ J K}^{-1} \text{ mol}^{-1}$. The majority then went on to use the Gibbs equation to obtain the correct value of ΔG. It was only the weaker candidates who succumbed to use of 131, rather than 0.131 in the expression, resulting in a negative absolute temperature. Some candidates used 25°C instead of 298 K. Candidates are advised to check that correct provided values had been used: a common transcription error was use of -155 instead of -115 for the ΔH value. Answer: $76.0 \text{ kJ K}^{-1} \text{ mol}^{-1}$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 878 OR 877.9 OR 877.86, award 2 marks ----- (Minimum temperature when) $\Delta G = 0$ OR $\Delta H - T\Delta S = 0$ OR (For feasibility) $\Delta G = 0$ OR $\Delta G < 0$ OR $\Delta H - T\Delta S < 0$ OR $T = \frac{\Delta H}{\Delta S} \checkmark$ $T = \frac{115}{0.131} = 878 \text{ K} \checkmark$	2	ALLOW total entropy statement: $\Delta S(\text{total}) = 0$ OR $\Delta S(\text{total}) > 0$ ALLOW ECF from incorrect calculated value of ΔS from 2(c)(i) ALLOW 878 up to calculator value of 877.862595 correctly rounded Examiner's Comments This part was answered correctly by almost all candidates, using the provided ΔH value and the candidate's calculated ΔS value from (c)(i). Some candidates unexpectedly converted their correct K value into °C. The only significant error seen here was with incorrect rounding. Answer: 878 K
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
3	a		Definition The e.m.f. (of a half-cell) compared with / connected to a (standard) hydrogen half-cell / (standard) hydrogen electrode ✓ Standard conditions <i>Units essential</i> Temperature of 298 K / 25°C AND (solution) concentrations of 1 mol dm⁻³ AND pressure of 100 kPa OR 10⁵ Pa OR 1 bar ✓	2	As alternative for e.m.f., ALLOW voltage OR potential difference OR p.d. OR electrode potential OR reduction potential OR redox potential ALLOW / (standard) hydrogen cell IGNORE S.H.E. (as abbreviation for standard hydrogen electrode) ALLOW 1M DO NOT ALLOW 1 mol ALLOW 1 atmosphere / 1 atm OR 101 kPa OR 101325 Pa Examiner's Comments This definition was well known with most candidates achieving both marks. An error was more likely for the units of the standard conditions, usually 1 mol and 1 mol dm³ for concentration. A less common error was comparison with a hydrogen fuel cell.
	b	i	2Ag⁺(aq) + Cu(s) → 2Ag(s) + Cu²⁺(aq) ✓	1	State symbols not required ALLOW ⇌ provided that reactants on LHS Examiner's Comments This proved to be a relatively easy mark although some showed the equation the wrong way round or did not balance the silver species on one side of the equation.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Assume $\text{Cu}^{2+} \text{Cu}$ OR Cu half cell unless otherwise stated. $[\text{Cu}^{2+}]$ decreases OR $< 1 \text{ mol dm}^{-3}$ AND Equilibrium (shown in table) shifts to left ✓ more electrons are released by Cu ✓ The cell has a bigger difference in E ✓	3	FULL ANNOTATIONS MUST BE USED ----- ALLOW $[\text{Cu}^{2+}]$ less than standard concentration / 1 mol dm^{-3} DO NOT ALLOW water reacts with Cu^{2+} OR Cu ALLOW E (for $\text{Cu}^{2+} \text{Cu}$) is less positive / more negative / decreases IGNORE standard electrode potential (<i>Cell no longer standard</i>) IGNORE $E^\ominus$ decreases CARE DO NOT ALLOW statements about silver E changing (CON) IGNORE just 'cell potential increases' (in the question) <i>The final mark is more subtle and is a consequence of the less positive E value of the copper half cell</i> Examiner's Comments This part was designed to be very demanding and this proved to be the case with weaker candidates made little if any headway. The key requirements were a decreased concentration of copper ions resulting in an equilibrium shift to the left, increasing the electron flow from the copper electrode and decreasing the electrode potential of the copper half cell. This results in a larger difference in electrode potential between the two half cells and an increase in the cell potential. Even able candidates often responded in terms of the standard electrode potential changing which can never be the case. Many candidates suggested that the added water would react with copper ions forming a copper hydroxide precipitate with an equilibrium shift to the right. To score well required a very good understanding of equilibrium in the context of electrode potentials.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	$E = -2.31 \text{ (V)}$ ✓	1	± sign AND 2.31 required for the mark Examiner's Comments In past exams, candidates have found it easy to calculate a standard cell potential. This slightly different slant on the question produced far more incorrect responses with +2.31 V (wrong sign) and 3.11 V (wrong subtraction) being common. Answer: -2.31 V
		ii	$4\text{Al(s)} + 4\text{OH}^-(\text{aq}) + 3\text{O}_2(\text{g}) + 6\text{H}_2\text{O(l)} \rightarrow 4\text{Al(OH)}_4^-(\text{aq})$ species ✓ balance ✓	2	IGNORE state symbols ALLOW multiples ALLOW 1 mark for an equation in which OH^- are balanced but have not been cancelled, e.g. $4\text{Al(s)} + 16\text{OH}^-(\text{aq}) + 3\text{O}_2(\text{g}) + 6\text{H}_2\text{O(l)} \rightarrow 4\text{Al(OH)}_4^-(\text{aq}) + 12\text{OH}^-(\text{aq})$ ALLOW 1 mark if charge on Al(OH)_4 is omitted, i.e. $4\text{Al(s)} + 4\text{OH}^-(\text{aq}) + 3\text{O}_2(\text{g}) + 6\text{H}_2\text{O(l)} \rightarrow 4\text{Al(OH)}_4(\text{aq})$ ALLOW 1 mark for an 'correct equation' reversed, i.e. $4\text{Al(OH)}_4^-(\text{aq}) \rightarrow 4\text{Al(s)} + 4\text{OH}^-(\text{aq}) + 3\text{O}_2(\text{g}) + 6\text{H}_2\text{O(l)}$ Examiner's Comments The attempts at this equation were impressive with many securing both marks for the correct balanced equation. One mark was available and awarded often for the following: a correctly balanced equation but with hydroxide ions not cancelled; the correct equation but reversed; an otherwise correct equation but with the charge missing from the Al(OH)_4^- ion.
			Total	9	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
4	a	$\text{Fe}_2\text{O}_3 + 3\text{Cl}_2 + 10\text{OH}^- \rightarrow 2\text{FeO}_4^{2-} + 6\text{Cl}^- + 5\text{H}_2\text{O} \checkmark\checkmark$ First mark for all 6 species Second mark for balancing	2	ALLOW multiples ALLOW oxidation half equation for two marks $\text{Fe}_2\text{O}_3 + 10\text{OH}^- \rightarrow 2\text{FeO}_4^{2-} + 5\text{H}_2\text{O} + 6\text{e}^-$ Correct species would obtain 1 mark – <i>question: equation for oxidation</i> ALLOW variants forming H^+ for 1 mark, e.g: $\text{Fe}_2\text{O}_3 + 3\text{Cl}_2 + 5\text{OH}^- \rightarrow 2\text{FeO}_4^{2-} + 6\text{Cl}^- + 5\text{H}^+$ $\text{Fe}_2\text{O}_3 + 3\text{Cl}_2 + 5\text{OH}^- \rightarrow 2\text{FeO}_4^{2-} + 5\text{HCl} + \text{Cl}^-$ Examiner's Comments The information needed to write the equation was largely within the information provided for step 1. In step 1, candidates were provided with three reactants and two of the products. They were also told that the reaction was carried out using an excess of hydroxide ions, so any potential H^+ ions produced would be neutralised to water. Only the very best candidates were able to interpret this information to score both marks for the correct equation. Many attempts seen did not start with iron(III) oxide. When arriving at a complete equation, candidates are recommended to check the overall charge on either side. This must balance, a feature not seen in the majority of responses. One mark was available for an equation with all species correct, including water as the third product, or a 'correct' equation but with H^+ produced.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		$\text{Ba}^{2+}(\text{aq}) + \text{FeO}_4^{2-}(\text{aq}) \rightarrow \text{BaFeO}_4(\text{s})$ ✓	1	Balanced ionic equation AND state symbols required DO NOT ALLOW +2 or –2 for ionic charges Examiner's Comments As with 8(a), the relevant information was mostly included within the referenced part: step 2. The responses were very disappointing as the required equation is very similar to a simple precipitation reaction between silver and halide ions. The requirement for state symbols was clearly stated but often omitted from otherwise correct equations.
	c		Reason can ONLY be correct from correct reducing agent ----- <i>reducing agent:</i> I^- OR KI ✓ I^- adds / donates / loses electrons AND to FeO_4^{2-} OR to BaFeO_4 OR to Fe(VI) or to Fe(+6) ✓ ALLOW Fe(6+) OR Fe^{6+}	2	IGNORE H^+ OR acidified ALLOW iodide / potassium iodide but DO NOT ALLOW iodine ALLOW I^- loses electrons AND to form I_2 ALLOW Fe(6+) OR Fe^{6+} Examiner's Comments The majority of candidates identified iodide ions or potassium iodide as the oxidising agent. Iodine was often recognised as the product but the explanation was usually in terms of oxidation number despite the question asking for electrons – very much a case of reading the question. Precise language was also required as iodine and iodide are rather different, especially as iodine is the product. The best responses discussed the species being reduced, BaFeO_4 or Fe(VI).

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	d	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 51.8%, award 4 marks. ----- $n(\text{S}_2\text{O}_3^{2-}) \text{ used} = 0.1000 \times \frac{26.4}{1000} = 2.64 \times 10^{-3} \text{ (mol) } \checkmark$ $n(\text{FeO}_4^{2-}) = \frac{1}{2} \times \frac{2}{3} \times 2.64 \times 10^{-3} = 8.8(0) \times 10^{-4} \text{ (mol) } \checkmark$ Mass BaFeO₄ in sample $= 8.8 \times 10^{-4} \times 257.1 \text{ g} = 0.226248 \text{ g } \checkmark$ $\% \text{ purity} = \frac{0.226248}{0.437} \times 100 = 51.8\% \checkmark$ MUST be to one decimal place (in the question) ----- As an alternative for the final two marks, ALLOW: $\text{Theoretical amount of BaFeO}_4 = \frac{0.437}{257.1} = 0.00170 \text{ (mol) } \checkmark$ $\% \text{ purity} = \frac{8.8 \times 10^{-4}}{1.70 \times 10^{-3}} \times 100 = 51.8\% \checkmark$	4	FULL ANNOTATIONS MUST BE USED ----- For alternative answers, look first at common ECFs below. Then check for ECF credit possible using working below IF a step is omitted but subsequent step subsumes previous, then award mark for any missed step ----- Working must be to at least 3 SF throughout until final % mark BUT ignore trailing zeroes, ie for 0.880 allow 0.88 ECF answer above $\times \frac{1}{2} \times \frac{2}{3}$ This mark may be seen in 2 steps via I₂ but the mark is for both steps combined ECF $257.1 \times$ answer above $\text{ECF } \frac{\text{answer above}}{0.437} \times 100$ ALLOW 51.7% FROM 0.226 g BaFeO₄ (earlier rounding) ----- Common ECFs: No $\times \frac{2}{3}$ for $n(\text{FeO}_4^{2-})$: % purity = 77.7%/77.6% 3 marks No $\div 2$ for $n(\text{FeO}_4^{2-})$: % purity = 25.9% 3 marks 24.6 used instead of 26.4: % purity = 48.2% 3 marks Examiner's Comments After the information-finding demands of parts (a)–(c), candidates were on much firmer territory here with a stock redox titration problem. Many candidates secured all 4 marks and most were able to obtain some marks along the way. The hardest mark was the step from the initial amount of Na₂S₂O₃ to the amount of BaFeO₄. Answer: 51.8%

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	e		gas: O₂ ✓ precipitate: Fe(OH)₃ ✓ equation: $2\text{FeO}_4^{2-} + 5\text{H}_2\text{O} \rightarrow 1\frac{1}{2}\text{O}_2 + 2\text{Fe(OH)}_3 + 4\text{OH}^-$ ✓ OR $2\text{FeO}_4^{2-} + \text{H}_2\text{O} + 4\text{H}^+ \rightarrow 1\frac{1}{2}\text{O}_2 + 2\text{Fe(OH)}_3$	3	DO NOT ALLOW names IGNORE a balancing number shown before a formula ALLOW Fe(OH)₃(H₂O)₃ ALLOW multiples ALLOW $2\text{FeO}_4^{2-} + 11\text{H}_2\text{O} \rightarrow 1\frac{1}{2}\text{O}_2 + 2\text{Fe(OH)}_3(\text{H}_2\text{O})_3 + 4\text{OH}^-$ Examiner's Comments This part required candidates to construct an equation for an unfamiliar reaction. Candidates were reasonably competent in identifying the gas as O₂ and precipitate as Fe(OH)₃. Unfortunately, some responded with 'oxygen' despite the formulae being asked for in the question. The correct equation proved to be the hardest mark on the paper, being seen extremely rarely. As with the equation in 8(a), often the overall charge didn't balance on either side of the equation, a consideration that would have led to many more correct responses.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
5		i	5 mol / molecules (of gas) forms 3 mol / molecules (of gas) ✓	1	ALLOW reaction forms fewer moles / molecules IF stated, numbers of molecules MUST be correct IGNORE comments related to ΔG OR disorder (even if wrong) Examiner's Comments This part was usually answered correctly in terms of fewer moles or molecules of gaseous products, with most candidates linking also to decreasing disorder. A significant number just mentioned decreasing disorder without including the reason for the decrease.
		ii	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = $(+131 \text{ J K}^{-1} \text{ mol}^{-1})$, award 2 marks ----- $-164 = (186 + 2 \times 206) - (4 \times S + 238)$ OR $4 S = 164 + (186 + 2 \times 206) - 238$ ✓		NOTE: IF any values are omitted, DO NOT AWARD any marks. e.g. -164 may be missing ALLOW FOR 1 mark

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$S = (+)131 \text{ (J K}^{-1} \text{ mol}^{-1})$ ✓	2	–131 wrong final sign 49 wrong sign for 164 79.5 no use of 2 524 no division by 4 38 wrong sign for 186 –75 wrong sign for 206 250 wrong sign for 238 Any other number: CHECK for ECF from 1st marking point for expressions using ALL values with ONE error only e.g. one transcription error:, e.g. 146 for 164 Examiner's Comments Although this part required candidates to calculate a standard entropy, rather than the more common entropy change assessed in previous exam papers, most candidates dealt with the problem with ease. Examiners rewarded partial success, usually where there was one incorrect sign or omitting to divide by 4. Answer: $S = +131 \text{ J K}^{-1} \text{ mol}^{-1}$
		iii	NOTE: DO NOT ALLOW answer to (ii) for ΔG calculation ----- ΔG calculation: 2 marks $\Delta G = -234 - 298 \times -0.164$ ✓		ALLOW ΔG correctly calculated from 3 SF up to calculator value of –185.128 ALLOW working in J, <i>ie</i>: $\Delta G = -234000 - 298 \times -164$ ✓
		iii	$= -185 \text{ (kJ mol}^{-1})$ ✓ IGNORE units (even if wrong) –185 subsumes 1st mark)	2	$= -185000 \text{ (J mol}^{-1})$ ✓ ALLOW 1 mark for use of 25 OR mixture of kJ and J, e.g. $\Delta G = -234 - 25 \times -0.164 = -229.9$ $\Delta G = -234 - 298 \times -164 = +48638$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Feasibility comment for negative ΔG answer: 1 mark (Forward) reaction is feasible / spontaneous AND $\Delta G < 0$ / $\Delta H - T\Delta S < 0$ ✓	1	ALLOW ECF if calculated value for ΔG is +ve Then 'correct' response for 3rd mark would be not feasible / not spontaneous AND $\Delta G > 0$ / $\Delta H - T\Delta S > 0$ Examiner's Comments The majority of candidates used the Gibbs equation to obtain the correct value of ΔG. Many weak candidates used -164, rather than -0.164, in the expression, resulting in a positive value for ΔG. A few used 25°C instead of 298 K. Candidates are far more adept with this calculation that used to be the case. The comment on feasibility was marked dependent on the sign obtained for ΔG. Answer: $\Delta G = -185\text{ kJ mol}^{-1}$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iv	$(\Delta G =) -234 - 1427 \times \frac{-164}{1000} = 0$ (calculator 0.028(kJ) OR 28 (J)) ✓ 2 nd mark only available if 1 st mark has been awarded (Above 1427K / 1154°C), reaction is not feasible / not spontaneous ✓ OR 1427 K is maximum temperature that reaction happens	2	ALLOW (When $\Delta G = 0$) $T = \frac{-234}{-0.164} = 1427 \text{ K OR } \frac{-234000}{-164} = 1427 \text{ K}$ For 2nd mark, IF ΔG is +ve from (iii) ALLOW ECF for: Above 1427 K, reaction is feasible / spontaneous OR 1427 K is minimum temperature that reaction happens IGNORE LESS feasible IGNORE comparisons of the signs of $T\Delta S$ and ΔH, e.g <i>IGNORE $T\Delta S$ is more negative than ΔH</i> Examiner's Comments Although answered well, this part discriminated well. Two strategies were seen. The first and more common repeated the ΔG calculation from (iii) to show that ΔG was just positive (0.028 kJ mol⁻¹) and hence that the reaction was now not feasible. The second strategy showed that 1427K and therefore 1154°C is the temperature at which ΔG has a value of 0 kJ mol⁻¹. Although most candidates were successful here, many weaker candidates seemed unaware of what to do. It was then common to see random numbers being used and °C, instead of K, in the ΔG expression (much more common than in (iii)). The best candidates also identified that the reaction becomes unfeasible above 1147°C. The explanation was marked consequentially of the sign obtained in (iii).
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
6	a	i	Mark each marking point independently	4	Correct species AND state symbols required for each marks ALLOW e for e⁻ TAKE CARE: In top left box, e⁻ may be in centre of response and more difficult to see than at end. There is only ONE correct response for each line <i>From the gaps in the cycle, there is NO possibility of any ECF</i> Examiner's Comments Many candidates completed the Born-Haber cycle to obtain three out of the four available marks. Strangely, very few candidates showed the correct species in the bottom box for the elements under standard conditions. Almost invariable, iodine was shown incorrectly, usually as I₂(g) or 2I(g). The other three boxes were usually correct although sometimes state symbols had been omitted or electrons had been included together with the gaseous ions in the top right box. Candidates are advised to check carefully between stages in the cycle to ensure that all species charges and state symbols are included and accounted for.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	(The enthalpy change that accompanies) the formation of one mole of a(n ionic) compound from its gaseous ions (under standard conditions) ✓✓ Award marks as follows. 1st mark: formation of compound from gaseous ions 2nd mark: one mole for compound only DO NOT ALLOW 2nd mark without 1st mark DO NOT ALLOW any marks for a definition for enthalpy change of formation BUT note the two concessions in guidance	2	IGNORE 'Energy needed' OR 'energy required' ALLOW one mole of compound is formed / made from its gaseous ions ALLOW as alternative for compound: lattice, crystal, substance, solid IGNORE: $\text{Fe}^{2+}(\text{g}) + 2\text{I}^{-}(\text{g}) \rightarrow \text{FeI}_2(\text{s})$ (Part of cycle) ALLOW 1 mark for absence of 'gaseous' only, i.e. the formation of one mole of a(n ionic) compound from its ions (under standard conditions) ✓ ALLOW 1 mark for ΔH_f definition with 'gaseous': the formation of one mole of a(n ionic) compound from its gaseous elements (under standard conditions) ✓ Examiner's Comments The majority of candidates had learnt the definition for lattice enthalpy and scored two marks. When fewer marks were awarded, the more common reasons were for responses in terms of a mole of gaseous ions, or omission of the mole altogether. Occasionally, some weaker candidates confused the definition with that for the enthalpy change of formation and so referred to forming a mole of the ionic compound from its constituent elements. Such responses gained no credit.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance																						
		iii	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = $-2473 \text{ (kJ mol}^{-1}\text{)}$ award 2 marks ----- $(-113) = 416 + (2 \times +107) + 759 + 1561 + (2 \times -295) + \Delta H_{LE}(\text{FeI}_2)$ OR $\Delta H_{LE}(\text{FeI}_2) = -113 - (416 + (2 \times +107) + 759 + 1561 + (2 \times -295))$ OR $-113 - 2360 \checkmark$ $= -2473 \checkmark \text{ (kJ mol}^{-1}\text{)}$	2	IF there is an alternative answer, check to see if there is any ECF credit possible using working below. See list below for marking of answers from common errors ----- ALLOW for 1 mark: <table><tr><td>+2473</td><td>wrong sign</td></tr><tr><td>-2661</td><td>107 and -295 used instead of 2×107 and 2×-295</td></tr><tr><td>-2366</td><td>+107 used instead of 2×107</td></tr><tr><td>-2768</td><td>-295 used instead of 2×-295</td></tr><tr><td>-3653</td><td>wrong sign for 295</td></tr><tr><td>-2247</td><td>wrong sign for 113</td></tr><tr><td>-1641</td><td>wrong sign for 416</td></tr><tr><td>-2045</td><td>wrong sign for 2×107</td></tr><tr><td>-955</td><td>wrong sign for 750</td></tr><tr><td>+649</td><td>wrong sign for 1561</td></tr><tr><td>-3653</td><td>wrong sign for 2×-295</td></tr></table> Any other number: CHECK for ECF from 1st marking point for expressions with ONE error only e.g. one transcription error: e.g. +461 instead of +416 Examiner's Comments Most candidates correctly calculated the lattice enthalpy using a correct sequence of enthalpy values. The commonest mistake was the omission of '2' for either the atomisation or ionisation of iodine, leading to answers of -2366 or $-2661 \text{ kJ mol}^{-1}$, or use of incorrect signs. There were more transcription errors seen than in previous session, most notably, -113 shown as -133. Candidates are advised to check carefully that any balancing numbers are linked to the correct enthalpy changes in the cycle and to double check values for possible transcription errors. Answer = $-2473 \text{ kJ mol}^{-1}$	+2473	wrong sign	-2661	107 and -295 used instead of 2×107 and 2×-295	-2366	+107 used instead of 2×107	-2768	-295 used instead of 2×-295	-3653	wrong sign for 295	-2247	wrong sign for 113	-1641	wrong sign for 416	-2045	wrong sign for 2×107	-955	wrong sign for 750	+649	wrong sign for 1561	-3653	wrong sign for 2×-295
+2473	wrong sign																										
-2661	107 and -295 used instead of 2×107 and 2×-295																										
-2366	+107 used instead of 2×107																										
-2768	-295 used instead of 2×-295																										
-3653	wrong sign for 295																										
-2247	wrong sign for 113																										
-1641	wrong sign for 416																										
-2045	wrong sign for 2×107																										
-955	wrong sign for 750																										
+649	wrong sign for 1561																										
-3653	wrong sign for 2×-295																										

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	Fe ²⁺ : 1s ² 2s ² 2p ⁶ 3s ² 3p ⁶ 3d ⁶ ✓	2	ALLOW 4s before 3d, ie 1s²2s²2p⁶3s²3p⁶4s²3d¹⁰4p⁶ ALLOW 1s² written after answer prompt (<i>ie</i> 1s² twice)
		i	Br ⁻ : 1s ² 2s ² 2p ⁶ 3s ² 3p ⁶ 3d ¹⁰ 4s ² 4p ⁶ ✓		

ALLOW upper case D, etc and subscripts, e.g. 4S₂3D₁

ALLOW for Fe²⁺ 4s⁰

DO NOT ALLOW [Ar] as shorthand for 1s²2s²2p⁶3s²3p⁶

Look carefully at 1s²2s²2p⁶3s²3p⁶ – there may be a mistake

Examiner's Comments

Few candidates produced two incorrect electron configurations but there were many mistakes seen for either species. For Fe²⁺, the commonest error was for loss of electrons from the 3d rather than 4s sub-shell of an Fe atom. For a Br⁻ ion, it was common to see the electron configuration of a Br atom. Surprisingly a common error was to see 4p⁴ rather than 4p⁶ from loss rather than gain of an electron. Only just over half the candidates showed two correct configurations so clearly more care is needed when answering.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	With Cl_2 AND Br_2 AND I_2 products are Fe^{2+} (AND halide ion) FeCl_2 AND FeBr_2 AND FeI_2 ✓ OR Evidence that two electrode potentials have been compared for at least ONE reaction, ✓ e.g. $\text{Fe} -0.44$ AND $\text{Cl}_2 +1.36$ e.g. Iron has more / most negative electrode potential With Cl_2 AND Br_2, products are Fe^{3+} (AND halide ion) FeCl_3 AND FeBr_3 ?	3	FULL ANNOTATIONS NEEDED ALLOW products within equations (even if equations are not balanced) IF stated, IGNORE reactants ALLOW response in terms of positive 'cell reactions', e.g $\text{Fe} + \text{Cl}_2 \rightarrow \text{Fe}^{2+} + 2\text{Cl}^-$ $E = (+)1.80 \text{ V}$ IGNORE comments about reducing and oxidising agents and electrons Examiner's Comments The majority of candidates predicted that Fe would react with all three halogens to form Fe^{2+} ions, supported by equations and electrode potential data. Many simply stated that Fe has the more negative E value (or the halogens the more positive value). It was also common to see cell voltages used, such as $+0.98 \text{ V}$ for a reaction between iron and iodine. Both approaches were credited. The most able candidates correctly predicted that Fe^{2+} ions, initially formed from the reaction of iron with bromine and chlorine, would then be oxidised to Fe^{3+}. The best answers showed exceptional understanding. Candidates are advised to consider all the information supplied in a question as the majority had ignored completely the $\text{Fe}^{3+}/\text{Fe}^{2+}$ data.
			Total	13	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance								
7	a		<table><tr><td>E°</td><td>redox system</td></tr><tr><td>Most negative</td><td>E</td></tr><tr><td></td><td>C</td></tr><tr><td>Least negative</td><td>D</td></tr></table> ✓	E°	redox system	Most negative	E		C	Least negative	D	1	ALL 3 correct for 1 mark Examiner's Comments This part required candidates to apply their knowledge and understanding to three cells. Just over half the candidates were able to list the redox systems by E value. There was no clear pattern with incorrect responses.
E°	redox system												
Most negative	E												
	C												
Least negative	D												
	b	i	pH = 0 ✓	1	Guidance Examiner's Comments Surprisingly, this part caused many candidates a problem with less than half the candidates obtaining the correct answer of 0 V. The commonest incorrect responses seen were pH values of 1 or even 7. Answer: pH = 0 V								
		ii	H redox system is more negative (e.g. has a more –ve E OR less +ve E OR is –ve electrode) OR H redox system releases electrons (May be in equation, e.g. $\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$) ✓ Equilibrium shifts to increase $[\text{H}^+]$ OR H^+ OR standard hydrogen equation shifts to increase $[\text{H}^+]$ OR H^+ ✓	2	ALLOW ORA, <i>ie</i> Ag redox system (D) has more positive E / less negative E ALLOW equilibrium sign IGNORE H is more reactive ORA IGNORE direction of equilibrium shift Examiner's Comments This part discriminated well with many candidates unable to interpret the information. Although the question asked for an explanation in terms of electrode potentials and equilibrium, these were often absent in the responses. Surprisingly, many identified the incorrect polarity for the hydrogen half-cell and then concluded that a decrease in pH is a result of a decrease, rather than an increase in $[\text{H}^+(\text{aq})]$. To score well required a very good understanding of equilibrium in the context of electrode potentials.								

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$\text{H}_2 + 2\text{Ag}^+ \rightarrow 2\text{Ag} + 2\text{H}^+$ ✓	1	ALLOW multiples e.g. $\frac{1}{2}\text{H}_2 + \text{Ag}^+ \rightarrow \text{Ag} + \text{H}^+$ State symbols NOT required ALLOW equilibrium sign Examiner's Comments Perhaps influenced by incorrect polarity, many equations were shown the wrong way round. Many equations were not balanced by charge with Ag^+ and Ag often having no balancing number.
	c	i	Fuel reacts with oxygen / oxidant to give electrical energy / voltage ✓	1	ALLOW named fuel. e.g. hydrogen / H_2; ethanol; methanol, etc ALLOW fuel cell requires constant supply of fuel AND oxygen / an oxidant OR fuel cell operates continuously as long as a fuel AND oxygen / an oxidant are added IGNORE 'reactants' 'products' and comments about pollution and efficiency Examiner's Comments Many responses seen here were far too vague. It was common to see answers about a fuel reacting but with no reference to oxygen. Responses in terms of less pollution or greenhouse gases gained no credit.
		ii	ethanol is a liquid OR is less volatile		Assume that 'it' refers to ethanol
		ii	OR ethanol is easier to store / transport / stored more safely		ALLOW ORA throughout
		ii	OR hydrogen is explosive / more flammable		IGNORE ethanol has a higher boiling point

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	OR ethanol has more public / political acceptance ✓	1	IGNORE H₂ is a gas IGNORE 'produces no CO₂' OR less pollution IGNORE comments about efficiency IGNORE comments about biomass and renewable Examiner's Comments Most candidates were credited here, recognising that ethanol is a liquid and can therefore be more easily stored or transported.
		iii	C ₂ H ₅ OH + 3O ₂ → 2CO ₂ + 3H ₂ O →	1	Correct species AND balancing needed ALLOW multiples ALLOW C₂H₆O for formula of ethanol IGNORE state symbols Examiner's Comments Almost all candidates wrote correct species but the equation was not always balanced correctly with 3½O₂ or 2O₂ being the commonest errors. Candidates need to take great care when balancing an equation containing an alcohol to account for the O atom with the alcohol formula.
		iv	O ₂ + 4H ⁺ + 4e ⁻ → 2H ₂ O ✓	1	Correct species AND balancing needed ALLOW multiples, e.g. 3O₂ + 12H⁺ + 12e⁻ → 6H₂O ½O₂ + 2H⁺ + 2e⁻ → H₂O ALLOW e (ie no - sign) ALLOW O₂ + 2H₂O + 4e⁻ → 4OH⁻ OR 3O₂ + 6H₂O + 12e⁻ → 12OH⁻ IGNORE state symbols Examiner's Comments The equations seen were impressive with nearly half the candidates providing an equation that could be credited. The examiners credited many different balancing numbers of O₂ + 4H⁺ + 4e⁻ → 2H₂O. The commonest seen were multiples using ½O₂ and especially 3O₂. As correct answers often showed no working, perhaps the oxygen half equation had been memorised by many candidates.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		v	oxidation: C from -2 to +4 '+' sign not required ✓ reduction: O from 0 to -2 ✓	2	ALLOW 2- and 4+ ALLOW $C^{2-} \rightarrow C^{4+}$ ALLOW 0 and 2- ALLOW $O^0 \rightarrow O^{2-}$ ALLOW 1 mark if correct oxidation numbers shown for BOTH C and O but wrong way around (<i>ie</i> C on reduction line and O on oxidation line) IGNORE O_2 reduced IGNORE any reference to electron transfer (<i>not in question</i>) Examiner's Comments This part required identification of oxidation and reduction in an unfamiliar context. The reduction of O was far easier than the oxidation of C and this was reflected in 1/2 being the commonest mark awarded. Discrimination was very good with able candidates collecting both marks.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
8	a		Equations can be in either order $\text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{NaOH}$ ✓ $\text{NaFeO}_2 + 2\text{H}_2\text{O} \rightarrow \text{Fe}(\text{OH})_3 + \text{NaOH}$ ✓	2	ALLOW multiples throughout IGNORE state symbols ALLOW $\text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{Na}^+ + 2\text{OH}^-$ DO NOT ALLOW equations with uncanceled species. e.g. $\text{Na}_2\text{O} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2\text{O}$ ALLOW $2\text{NaFeO}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + 2\text{NaOH}$ OR $2\text{NaFeO}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + 2\text{Na}^+ + 2\text{OH}^-$ Examiner's Comments The information needed to write the equation was within the information provided for step 1 and the stem. Candidates were much more successful with the first than the second equation. The clue that an alkaline solution had been formed should have helped with the identification of NaOH as a product of both reactions. The brown precipitate provided a clue that $\text{Fe}(\text{OH})_3$ had been formed although the examiners also credited an equation producing Fe_2O_3.
	b		FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 33.7%, award 6 marks. IF there is an alternative answer, check to see if there is any ECF credit possible using working below ----- amount $\text{S}_2\text{O}_3^{2-}$ used = $0.1000 \times \frac{25.50}{1000}$ = 2.550×10^{-3} (mol) ? amount $\text{I}_2 = 2.550 \times 10^{-3} \div 2$ 1.275×10^{-3} (mol) ✓ amount CrO_4^{2-} $\frac{2}{3} \times 1.275 \times 10^{-3}$ OR $1.275 \times 10^{-3} \div 1.5$ = $8.5(00) \times 10^{-4}$ (mol) ✓ amount CrO_4^{2-} in original $1000 \text{ cm}^3 = 40 \times 8.5(00) \times 10^{-4}$ = $3.4(00) \times 10^{-2} \text{ mol}$ ✓	6	FULL ANNOTATIONS MUST BE USED IF a step is omitted but subsequent step subsumes previous, then award mark for any missed step Working: at least 3 SF throughout until final % mark BUT ignore trailing zeroes, ie for 0.490 allow 0.49 ----- ECF answer above $\div 2$ ECF answer above $\div 1.5$ ECF answer above $\times 40$

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	Mass of Cr / Cr³⁺ in ore = 52.0 × 3.4(00) × 10⁻² g 1.768 g ✓ Percentage Cr in ore = $\frac{1.768}{5.25} \times 100$ = 33.7% ✓ MUST be to one decimal place (in the question)		ECF answer above × 52.0 IMPORTANT: The last two marks are ONLY available by using 52.0 for Cr ----- Common ECFs: 0.8% × 40 missing 5 marks (scaling error) 0.84% × 40 missing 4 marks (scaling error and 2 DP) 33.68% 5 marks (2 DP) 16.8% 5 marks (divide Cr somewhere by 2) 144.9%; 72.5% 4 marks (Final 2 marks unavailable) Use of M(Fe(CrO₂)₂) = 223.8 instead of M(Cr). Examiner's Comments Many candidates were on firm territory with a redox titration problem. The majority went through a well-rehearsed sequence of steps to obtain four marks for reaching the amount of CrO₄²⁻ ions in the original solution. Sometimes, candidates used the 1:1.5 molar ratio for CrO₄²⁻ : I₂ the wrong way around to obtain 1.9125 × 10⁻³ rather than 8.50 × 10⁻⁴ mol CrO₄²⁻. More candidates had problems in scaling up by 40 to obtain the original amount of CrO₄²⁻ as 3.40 × 10⁻² mol. Strangely many used a factor of 4 instead. The last two marks proved to be more elusive, with many candidates calculating the percentage of Fe(CrO₂)₂ rather than Cr in the sample of chromite. The responses seen show just how far candidates have travelled since early structured titration calculations for AS to complex unstructured calculations at the end of the A-level course. Answer: 33.7%

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		<i>Overall:</i> $\text{CrO}_4^{2-} + 3\text{I}^- + 4\text{H}_2\text{O} \rightarrow \text{Cr}^{3+} + 1\frac{1}{2}\text{I}_2 + 8\text{OH}^-$ ✓ CrO <i>Half equations:</i> $\text{CrO}_4^{2-} + 4\text{H}_2\text{O} + 3\text{e}^- \rightarrow \text{Cr}^{3+} + 8\text{OH}^-$ ✓ CrO $2\text{I}^- \rightarrow \text{I}_2 + 2\text{e}^-$ ✓	3	ALLOW multiples and equilibrium signs throughout IGNORE state symbols throughout e.g. $2\text{CrO}_4^{2-} + 6\text{I}^- + 8\text{H}_2\text{O} \rightarrow 2\text{Cr}^{3+} + 3\text{I}_2 + 16\text{OH}^-$ ALLOW equation using H^+. i.e. $\text{CrO}_4^{2-} + 3\text{I}^- + 8\text{H}^+ \rightarrow \text{Cr}^{3+} + 1\frac{1}{2}\text{I}_2 + 4\text{H}_2\text{O}$ OR $2\text{CrO}_4^{2-} + 6\text{I}^- + 16\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{I}_2 + 8\text{H}_2\text{O}$ ALLOW CrO_4^{2-} half equation using H^+. i.e. $\text{CrO}_4^{2-} + 8\text{H}^+ + 3\text{e}^- \rightarrow \text{Cr}^{3+} + 4\text{H}_2\text{O}$ Examiner's Comments This part required candidates to construct three equations for an unfamiliar reaction. The examiners allowed equations using H^+ rather than OH^-. It was then possible to credit many candidates with the full three marks with many excellent responses seen. Predictably the equations involving CrO_4^{2-} were more difficult but even some weaker candidates were able to construct an equation for the oxidation of iodide ions. The very best candidates did manage to construct the equations in alkaline conditions.
			Total	11	
9			C	1	
			Total	1	
10			A	1	
			Total	1	

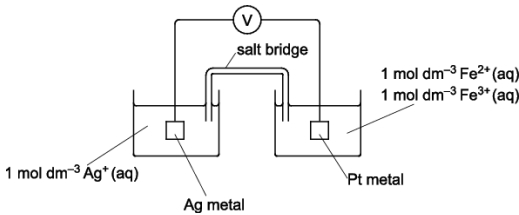
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
11			ΔH calculation from experiment $q = 100 \times 4.18 \times 20.5$ OR 8569 J OR 8.569 kJ (1) Amount of butan-1-ol = $\frac{0.259}{74} = 3.5 \times 10^{-3}$ mol (1) $\Delta H = -2448 \text{ kJ mol}^{-1}$ (1) ΔS calculation $\Delta S = S_{\text{products}} - S_{\text{reactants}}$ $\Delta S = (4 \times 214) + (5 \times 70) - [(228) + (6 \times 205)]$ OR $\Delta S = 1206 - 1458$ (1) $\Delta S = -252 \text{ J K}^{-1} \text{ mol}^{-1}$ OR $-0.252 \text{ kJ K}^{-1} \text{ mol}^{-1}$ (1) ΔG calculation $\Delta G = \Delta H - T\Delta S$ $\Delta G = -2448 - (298 \times -0.252)$ (1) $\Delta G = -2373 \text{ (kJ mol}^{-1})$ (1)	7	allow calculator value for $\Delta H = -2448.285714$ correctly rounded to three or more significant figures mark for use of correct expression with ΔS in $\text{kJ K}^{-1} \text{ mol}^{-1}$ allow three or more sig figs for ΔG
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
12	a		Lattice enthalpy of MgCl_2 is more exothermic than CaCl_2 ... (1) because magnesium ion / Mg^{2+} is smaller (than calcium ions / Ca^{2+}) OR Mg^{2+} has a greater charge density ... (1) ... therefore the attraction between Mg^{2+} and Cl^- is greater (than between Ca^{2+} and Cl^-) (1)	3	ora throughout allow 'charge density' here only allow magnesium / Mg is smaller do not allow Mg^{2+} has a smaller atomic radius do not allow chlorine ions do not allow Mg has greater attraction allow 'attracts with more force' for greater attraction but do not allow 'greater force' (could be repulsion)
	b	i	F B G E D FIVE correct (3) FOUR correct (2) THREE correct (1)	3	allow 1450 736 G 76 -642 if only one or two correct, award 0 marks.
		ii	$-642 - (+76 + (2 \times 150) + 736 + 1450 + (2 \times -349))$ (1) $-642 - 1864 = -2506$ (1) (kJ mol^{-1})	2	allow for 1 mark: -2705 (2×150 and 2×349 not used for C) -2356 (2×150 not used for C) -2855 (2×349 not used for C) +2506 (wrong sign) do not allow any other answers
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
13	a	i	 Half-cells (2 marks) Ag(s) and $1 \text{ mol dm}^{-3} \text{Ag}^+(\text{aq})$ $1 \text{ mol dm}^{-3} \text{Fe}^{2+}(\text{aq})$ AND $1 \text{ mol dm}^{-3} \text{Fe}^{3+}(\text{aq})$ AND Pt metal Complete circuit (1 mark) salt bridge AND voltmeter AND wires Standard conditions (1 mark) 298 K / 25 °C AND 100 kPa / 101 kPa pressure	4	ALLOW 1 atm
		ii	(Electrode potential of) Ag^+ / Ag becomes more positive ... therefore, E_{cell} becomes smaller OR less positive.	2	ALLOW equilibrium Ag / Ag^+ shifts to right ALLOW more negative 2nd mark only available if deduced from 1st mark ALLOW ECF for 2nd mark
	b		Ce^{3+} and Zn^{2+}	1	
	c		Mn^{2+} , H_2O , Fe^{3+} , Br_2 Three species correct Four species correct	2	
			Total	9	
14			B	1	
			Total	1	
15			A	1	
			Total	1	
16			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
17	a		solution: (enthalpy change for) 1 mole of a compound / substance / solid / solute dissolving in water	1	IGNORE 'energy released' OR 'energy required' For dissolving, ALLOW forms aqueous / hydrated ions DO NOT ALLOW dissolving elements IGNORE ionic OR covalent DO NOT ALLOW response that implies formation of 1 mole of aqueous ions
	b	i		3	Correct species AND state symbols required for each mark. (mark independently) On middle line, ALLOW $\text{Ca}^{2+}(\text{g}) + 2\text{Cl}^-(\text{aq})$ (i.e. Cl^- hydrated before Ca^{2+}) On bottom line, ALLOW $\text{CaCl}_2(\text{aq})$
		ii	FIRST CHECK THE ANSWER ON ANSWER LINE IF answer = $-142 \text{ (kJ mol}^{-1}\text{)}$ award 2 marks ----- $\Delta_{\text{sol}}H(\text{CaCl}_2) = [-1616 + (2 \times -359)] - (-2192)$ OR $-2334 + 2192$ $= -142 \text{ (kJ mol}^{-1}\text{)}$	2	IF there is an alternative answer, check to see if there is any ECF credit possible using the working shown. IF ALL 3 relevant values from the information at the start of Q3 have NOT been used, award zero marks unless one number has a transcription error, where 1 mark can be awarded ECF
		iii	Comparison of size $\text{Ca}^{2+} > \text{Mg}^{2+}$ Comparison of charge $\text{Na}^+ < \text{Mg}^{2+} < \text{Al}^{3+}$ Comparison of attraction between ions size AND charge linked to greater attraction to H_2O ✓	3	IGNORE comparison of size: $\text{Na}^+ > \text{Mg}^{2+} > \text{Al}^{3+}$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	FIRST CHECK THE ANSWER ON ANSWER LINE IF answer = $-132 \text{ (kJ mol}^{-1}\text{)}$ award 4 marks ----- Correctly calculates energy released in J OR kJ $= 50.21 \times 4.18 \times 31.5 = 6611 \text{ (J) OR } 6.611 \text{ (kJ)}$ Correctly calculates $n(\text{CaCl}_2)$ $= \frac{5.56}{111.1} = 0.05(00) \text{ mol}$ Correctly calculates ΔH value in J OR kJ In J: $= (-)\frac{6611}{0.0500} \text{ OR } (-)132,220 \text{ (J)}$ OR In kJ: $= (-)\frac{6.611}{0.0500} \text{ OR } (-)132.22 \text{ (kJ)}$ <i>(Sign ignored and / or more than 3 SF)</i> Correct $\Delta_{\text{sol}}H$ in kJ AND sign AND 3SF $= -132 \text{ (kJ mol}^{-1}\text{)}$	4	FULL ANNOTATIONS MUST BE USED ----- ALLOW calculator value of 6611.1507 down to 3SF value of 6610 DO NOT ALLOW fewer than 3 SF IGNORE units for this mark, i.e. just ALLOW correctly calculated number in either J or kJ ALLOW ECF from $n(\text{CaCl}_2)$ AND / OR Energy released IGNORE absence of – sign and 3 SF requirement Final mark requires – sign, kJ AND 3 SF
		ii	Temperature change is double / $\times 2$ / 63°C AND $\Delta_{\text{sol}}H$ is the same Twice the energy produced in the same volume AND ratio of energy produced to mass or number of moles is the same OR $\frac{q}{n}$ is the same	2	ALLOW temperature reached would be 85°C
			Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
18			Element oxidised: sulfur / S 0 to +6 Element reduced: nitrogen / N +5 to +4 $6\text{HNO}_3 + \text{S} \rightarrow 6\text{NO}_2 + \text{H}_2\text{SO}_4 + 2\text{H}_2\text{O}$ Correct species Balance	4	ALLOW 5+, 4+ and 6+ Signs required ALLOW $4\text{H}^+ + 6\text{NO}_3^- + \text{S} \rightarrow 6\text{NO}_2 + \text{SO}_4^{2-} + 2\text{H}_2\text{O}$
			Total	4	
19			$\text{..C/O}^- + \text{..H}_2\text{O} + 2\text{..e}^- \rightarrow \text{..Cl}^- + 2\text{..OH}^-$ $\text{Fe}_2\text{O}_3 + 10\text{..OH}^- \rightarrow 2\text{..FeO}_4^{2-} + 5\text{..H}_2\text{O} + 6\text{..e}^-$ $\text{Fe}_2\text{O}_3 + 3\text{..C/O}^- + 4\text{..OH}^- \rightarrow 2\text{..FeO}_4^{2-} + 3\text{..Cl}^- + 2\text{..H}_2\text{O}$	3	ALLOW multiples throughout
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20	a		$n(\text{NH}_2\text{OH}) = 4.32 \times 10^{-2} \times 0.0250 = 1.08 \times 10^{-3} \text{ mol}$ $n(\text{Fe}^{3+}) = 3 \times 1.08 \times 10^{-3} = 3.24 \times 10^{-3} \text{ mol}$ (assuming Equation 3) $\text{volume} = \frac{3.24 \times 10^{-2} \times 1000}{0.0400} = 81.0 \text{ cm}^3$ Explanation: minimum amount of Fe^{3+} required is maximum amount theoretically required to react with all NH_2OH , i.e. if Equation 3 is correct (greatest amount of Fe^{3+} required) (<i>owtte</i>)	4	Factor 3 must be included in second mark for ECF on third mark. ALLOW 2 sig figs
	b		$n(\text{MnO}_4^-) = 2.00 \times 10^{-2} \times \frac{21.6}{1000} = 4.32 \times 10^{-4} \text{ (mol)}$ $n(\text{Fe}^{2+}) = 4.32 \times 10^{-4} \times 5 = 2.16 \times 10^{-3} \text{ (mol)}$ Ratio $\text{NH}_2\text{OH} : \text{Fe}^{2+}$ OR $\text{NH}_2\text{OH} : \text{Fe}^{2+}$ $= 1.08 \times 10^{-3} : 2.16 \times 10^{-3} = 1 : 2$ AND Equation 2 is correct	3	Working must be to at least 3 sig figs throughout until final numerical answer BUT ignore trailing zeroes, e.g. for 0.490 allow 0.49 ECF answer above $\times 5$ This mark is only possible from correct answers above, i.e. no ECF
	c	i	Boiling speeds up the reaction OR Ensures that reaction is complete (Titre is less because) there is less Fe^{2+}	2	
		ii	In Stage 1 , increase quantities so that there is sufficient solution for more than one titration	1	ALLOW increase scale of Stage 1
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
21	a	i	Titres correct and ALL recorded to 2 decimal places Titre: 22.50 21.80 22.15 21.70 AND mean titre = 21.75 (cm³) ✓	1	Working not required for mean titre
		ii	Percentage uncertainty = $\frac{0.05 \times 2}{21.70} \times 100 = 0.46\%$ ✓ 2 DP required	1	ALLOW ECF from incorrect subtraction in (i)
		iii	(Excess KI) ensures that all I ₂ is formed for titration ✓	1	ALLOW All Cu ²⁺ converted to CuI/Cu(I)
		iv	Add starch ✓ Blue to colourless AND all I₂ has reacted ✓	2	
		v	$n(\text{S}_2\text{O}_3^{2-})$ in titration = $\frac{0.120 \times 21.75}{1000} = 2.61 \times 10^{-3}$ (mol) ✓ $n(\text{I}_2) = 1.305 \times 10^{-3}$ (mol) OR $n(\text{Cu}^{2+}) = 2.61 \times 10^{-3}$ (mol) AND $n(\text{Cu}^{2+})$ in original 250 cm³ = $10 \times 2.61 \times 10^{-3} = 2.61 \times 10^{-2}$ (mol) Mass of A (CuSO₄•xH₂O) used = 17.95 – 12.35 = 5.60 (g) $M(\text{CuSO}_4 \cdot x\text{H}_2\text{O}) = \frac{5.60}{2.61 \times 10^{-2}} = 214.6$ (g mol⁻¹) ✓ $x = \frac{214.6 - 159.6}{18.0} = 3.05 = 3$ Formula = CuSO₄•3H₂O	4	ALLOW ECF from incorrect mean titre in (i) ECF from $n(\text{S}_2\text{O}_3^{2-})$ ECF from $n(\text{Cu}^{2+})$ BUT DO NOT ALLOW incorrect mass ECF from $M(\text{CuSO}_4 \cdot x\text{H}_2\text{O})$ AND x = nearest whole number

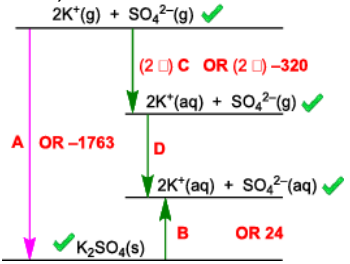
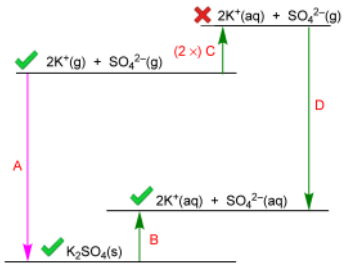
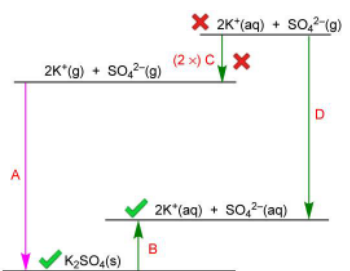
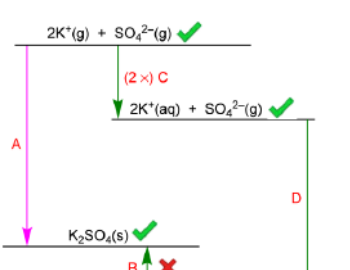
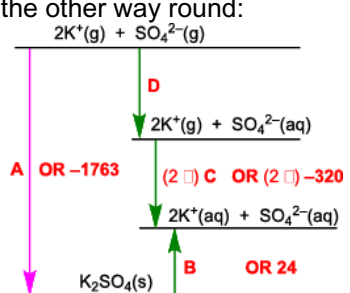
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	green solution: $\text{Fe}^{2+}(\text{aq})$ OR $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ AND gas bubbles: $\text{H}_2(\text{g})$ AND orange-brown solution: $\text{Fe}^{3+}(\text{aq})$ OR $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ ✓ $\text{Fe}(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Fe}^{2+}(\text{aq}) + \text{H}_2(\text{g})$ ✓ $4\text{Fe}^{2+}(\text{aq}) + \text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) \rightarrow 4\text{Fe}^{3+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$ ✓	3	State symbols are not required in this part IGNORE, even if incorrect ALLOW full equation: $\text{Fe}(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{FeCl}_2(\text{aq}) + \text{H}_2(\text{g})$
		ii	orange solution: $\text{Cr}_2\text{O}_7^{2-}$ AND green solution (anywhere) Cr^{3+} OR $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ ✓ $2\text{Cr}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + 3\text{H}_2\text{O}_2(\text{aq}) \rightarrow \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 8\text{H}^+(\text{aq})$ H^+, H_2O and e^- all cancelled ✓✓	3	State symbols are not required in this part IGNORE, even if incorrect IGNORE $\text{Cr}(\text{VI})$ <i>The question asks for species</i> ALLOW 1 mark for $\text{H}^+/\text{H}_2\text{O}/\text{e}^-$ not cancelled, e.g. $2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l}) + 3\text{H}_2\text{O}_2(\text{aq}) + 6\text{H}^+(\text{aq}) \rightarrow \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{H}_2\text{O}(\text{l})$ ✓
			Total	15	

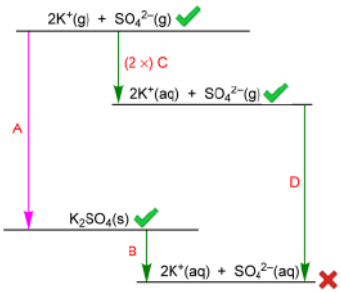
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
22	a		(enthalpy change for) 1 mole of gaseous ions OR 1 mole of hydrated ions / aqueous ions ✓ gaseous ions forming aqueous / hydrated ions ✓	2	one mole can be stated just once EITHER with gaseous ions OR with aqueous ions, e.g. 1 mole of gaseous ions forms hydrated ions / aqueous ions - Gaseous ions form 1 mole of hydrated ions / aqueous ions ALLOW 1 mol for 1 mole IGNORE 'energy released' OR 'energy required' For 2nd mark IGNORE gaseous ions are hydrated IGNORE gaseous ions dissolve in water <i>Particles formed not stated</i> ALLOW 1 mark for: 1 mole of gaseous IONS forms aqueous / hydrated atoms / particles / molecules Examiner's Comments This question assessed enthalpy changes in aqueous solutions. Most candidates were awarded both marks for a clear definition stating that 1 mole of gaseous ions formed 1 mole of aqueous ions. Some candidates instead gave a definition for enthalpy change of solution.

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
b i	4 marks for species AND state symbols on all 4 energy levels (including added energy level)  1 mark for B, C AND D labels OR enthalpy values AND arrow directions correct ✓ ALLOW $K_2SO_4(aq)$ for $2K^+(aq) + SO_4^{2-}(aq)$ ALLOW arrows not touching lines. Direction is important: • FROM $2K^+(g) + SO_4^{2-}(g)$ line • FROM $K_2SO_4(s)$ line Extra energy line placed ABOVE top line 3 out of 4 marks awarded for energy lines and species. Top arrow is shown FROM $2K^+(g) + SO_4^{2-}(g)$ and arrow directions correct. Letter labels correct so last mark is awarded. 4/5 marks  Extra energy line placed BELOW bottom line 3 out of 4 marks awarded for energy lines and species.	5	IF extra energy level is above top line OR below bottom line, DO NOT ALLOW mark for species on this line. Same as left-hand response BUT top arrow shown TO $2K^+(g) + SO_4^{2-}(g)$ so last mark not awarded 3/5 marks  Same as left-hand response BUT bottom arrow shown TO $K_2SO_4(s)$ so last mark not awarded 3/5 marks  ALLOW C and D with associated labels, the other way round: 

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	Top arrow is shown FROM $K_2SO_4(s)$ and arrow directions correct. Letter labels correct so last mark is awarded. 4/5 marks  '2 x' is NOT required – <i>part of calculation mark</i>		State symbols are essential IF no extra energy level is shown with C and D combined forming $2K^+(aq) + SO_4^{2-}(aq)$, • No mark for the extra energy level with species • No mark for labels as C and D are combined Therefore 3 max for species on energy levels provided Examiner's Comments This question assessed enthalpy changes in aqueous solutions. Many candidates successfully completed the energy cycle to obtain all marks. Correct species and state symbols are essential in such cycles and marks could not be awarded for species such as $K^-(g)$ or $SO_4^-(g)$. Poorly-prepared candidates often scored no marks at all, having shown random species on the energy levels. Candidates are advised to ensure that the state symbols (s) and (g) are clearly distinguished.
ii	$\Delta H(\text{hydration}) SO_4^{2-} = -1099 \text{ (kJ mol}^{-1}\text{)}$ ✓	1	ONLY correct answer Examiner's Comments This question assessed enthalpy changes in aqueous solutions. Although many candidates correctly calculated the lattice enthalpy, errors were common. A common error was use of -320 (instead of 2×-320) giving -1419. Answer = $-1099 \text{ kJ mol}^{-1}$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	Aqueous particles are more disordered than solid (particles) OR Solid particles are more ordered than aqueous (particles) ✓	1	For particles, ALLOW ions DO NOT ALLOW molecules / atoms ALLOW 'When the state changes from solid to aqueous, disorder increases' For more disordered, ALLOW less ordered / more freedom / more ways of arranging energy / more random For aqueous particles, ALLOW particles in solution IGNORE dissolved Examiner's Comments This question assessed enthalpy changes in aqueous solutions. In this part, candidates needed to recognise that solid particles are forming aqueous particles with an increase in disorder. Many candidates incorrectly used 'liquid' instead of aqueous and others started from gaseous particles, perhaps confusing enthalpy change of solution with hydration.

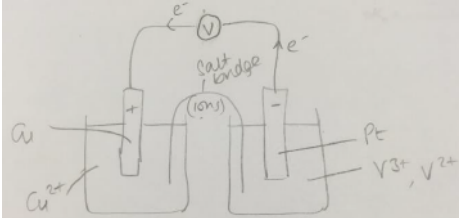
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Calculation (2 marks) $\Delta G = 24 - (298 \times 0.225)$ OR $24 - 67.05$ (in kJ) OR $24000 - (298 \times 225)$ OR $24000 - 67050$ (in J) ✓ Calculation of ΔG (IGNORE UNITS) $\Delta G = -43$ (kJ mol⁻¹) OR -43000 (J mol⁻¹) ✓ Subsumes 1st calculation mark Reason for solubility Calculated value of ΔG that is negative AND Statement that: ΔG is negative OR $\Delta G < 0$ OR $-43 < 0$ OR $\Delta H - T\Delta S < 0$ OR $T\Delta S > \Delta H$ ✓	3	Contact TL if solely entropy approach rather than ΔG ALLOW -43.1 OR -43.05 (calculator value) ALLOW 1 calculation mark (IGNORE units) for $-67.(026)$ OR -67026 ECF from 225 instead of 0.225 $18.(375)$ OR $+18.375$ ECF from 25 instead of 298 ALLOW other ECF from ONE error in 1st step of calc, e.g. incorrect value for ΔH such as -1099 from 3bii $\rightarrow -1166.05$ TAKE CARE that same units used for ΔH and ΔS NO reason mark from a +ve value of ΔG Examiner's Comments This question assessed enthalpy changes in aqueous solutions. The majority of candidates recognised that the Gibbs' equation was required. Usually the correct enthalpy change of $+24$ kJ mol⁻¹ was used to obtain a negative value for ΔG. The majority then went on to link the negative value to feasibility for the dissolving process. A significant number of candidates used the wrong enthalpy change (or no enthalpy change at all) or mixed units of J and kJ. Answer: $\Delta G = -43$ kJ mol⁻¹
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
23	a		Definition The e.m.f. (of a half-cell) compared with / connected to a (standard) hydrogen half-cell / (standard) hydrogen electrode ✓ Standard conditions <i>Units essential</i> Temperature of 298 K / 25°C AND (solution) concentrations of 1 mol dm⁻³ AND pressure of 100kPa OR 10⁵ Pa OR 1 bar ✓	2	For e.m.f., ALLOW voltage OR potential difference / p.d. OR electrode / reduction / redox potential ALLOW e.m.f. of a cell..... ALLOW /(standard) hydrogen cell IGNORE S.H.E. (as abbreviation for standard hydrogen electrode) DO NOT ALLOW hydrogen fuel cell ALLOW 1M OR 1 mol/dm³ DO NOT ALLOW 1 mol OR 1 mole ALLOW 1 atmosphere / 1 atm OR 101 kPa OR 101325 Pa Examiner's Comments This definition was well known with most candidates achieving both marks. An error was more likely for the units of the standard conditions, usually 1 mol and 1 mol dm³ for concentration. A less common error was comparison with a hydrogen fuel cell.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	Complete circuit with voltmeter AND labelled salt bridge linking two half-cells ✓  Cu electrode in Cu^{2+} ✓ Pt electrode in V^{2+} AND V^{3+} ✓ Cu shown as + AND Pt shown as – ✓ electrons in wire AND ions in salt bridge ✓ <i>On diagram or stated</i>	5	Half cells can be drawn in either order Half cells must show electrodes dipping into solutions ALLOW small gaps in circuit DO NOT ALLOW half-cell with H_2 added IGNORE any stated concentrations IGNORE 'anode' and 'cathode' In salt bridge, ALLOW any stated ion that may be present, e.g. K^+, NH_4^+, NO_3^-, Cu^{2+}, V^{2+}, V^{3+} IGNORE direction of travel of ions and electrons. ALLOW Cu half cell as + AND V half cell as– Examiner's Comments Most candidates drew a full circuit with half cells containing the correct species in a suitably labelled diagram. The signs of the electrodes were usually correct but the charge carriers were omitted much more often than they were included. The overall quality of the diagrams was poor, usually resembling drawings or even rough sketches.
		ii	0.60 OR 0.6 (V) ✓	1	IGNORE any sign Examiner's Comments This part was answered correctly by almost all candidates. Answer: standard cell potential = 0.60 V

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	c	Definitions: 1 mark Oxidising agent removes / accepts / gains electrons OR increases oxidation number (of another species) AND Reducing agent adds / donates / loses electrons OR decreases oxidation number (of another species) ✓ Oxidising agent: 2 marks Cr^{3+} oxidises Al OR Cr^{3+} acts as oxidising agent AND $3\text{Cr}^{3+} + \text{Al} \rightarrow 3\text{Cr}^{2+} + \text{Al}^{3+}$ ✓ <i>Explanation (dependent on Cr^{3+} oxidising Al above)</i> <i>E</i> of redox system 2 ($\text{Cr}^{3+}/\text{Cr}^{2+}$) is more positive /less negative (than <i>E</i> of system 1 (Al^{3+}/Al)) ORA, i.e. in terms of 1 being more negative (than 2) ✓ Reducing agent: 3 marks Cr^{3+} reduces $\text{FeO}_4^{2-}/(\text{H}^+)$ ✓ $2\text{Cr}^{3+} + 2\text{FeO}_4^{2-} + 2\text{H}^+ \rightarrow \text{Cr}_2\text{O}_7^{2-} + 2\text{Fe}^{3+} + \text{H}_2\text{O}$ ✓ <i>Explanation (dependent on Cr^{3+} reducing FeO_4^{2-} above)</i> <i>E</i> of redox system 5 ($\text{Cr}_2\text{O}_7^{2-}/\text{Cr}^{3+}$) is less positive / more negative (than <i>E</i> of system 6 ($\text{FeO}_4^{2-}/\text{Fe}^{3+}$)) ORA, i.e. in terms of 6 being more positive (than 5) ✓	6	FULL ANNOTATIONS MUST BE USED ----- ALLOW oxidising agent decreases its oxidation number AND reducing agent increases its oxidation number IGNORE oxidising agent oxidises / is reduced OR reducing agent reduces / is oxidised In equations, • IGNORE state symbols (even if incorrect) • ALLOW $\rightleftharpoons$ in equation IF more than one equation shown for Cr^{3+} as oxidising agent, CON and zero marks for 2 oxidising agent marks IGNORE equations with Cr^{2+} as reactant Explanations MUST be in terms of positive / negative: IGNORE 'higher' <i>E</i> OR 'greater' ALLOW $E_{\text{cell}} = +1.25 \text{ V}$ (+ sign required) IF more than one equation shown for Cr^{3+} as a reducing agent, CON and zero marks for 3 reducing agent marks IGNORE equations with Cr^{2+} as reactant Explanations MUST be in terms of positive / negative: IGNORE 'higher' <i>E</i> OR 'greater' ALLOW $E_{\text{cell}} = +0.87 \text{ V}$ (+ sign required) Examiner's Comments Although most candidates produced lengthy answers to this part, there was often little that could be rewarded. The terms oxidising agent and reducing agent were usually described but the expected response needed to be in terms of electrons or oxidation number. An alarming number of candidates claimed that an oxidising agent is oxidised and a reducing

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					agent reduced. Many candidates went on to discuss the role of Cr^{3+} ions in oxidising aluminium, with a correct equation. The expected explanation in terms of electrode potentials was seen more rarely. The role of Cr^{3+} in reducing FeO_4^{2-} was seen much more rarely. The commonest responses showed a list of equations, all showing reactions of Cr^{2+} rather than Cr^{3+}. The best candidates produced superb answers demonstrating excellent understanding of electrode potentials. When comparing electrode potentials, candidates are advised to use terms such 'more negative' or 'more positive, rather than 'greater' or 'higher', which are ambiguous when comparing negative numbers. An alternative approach in terms of positive cell potentials were seen and credited, although the positive sign was required.
			Total	14	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
24		i	linear ✓	1	IGNORE planar Examiner's Comments Most candidates identified the shape as linear.
		ii	Au / Gold has been oxidised from 0 to +1 ✓ O / Oxygen / O₂ has been reduced from 0 to -2 ✓	2	IF Ag referred to, rather than Au, treat as a slip and apply BOD ALLOW 0 to 1 (i.e. no + sign for +1) ALLOW 1 mark for ALL oxidation numbers correct with no oxidised or reduced OR oxidation and reduction wrong way round, e.g. Au goes from 0 to +1 and O goes from 0 to -2 ✓ Au is reduced from 0 to +1 and O is oxidised from 0 to -2 ✓ Examiner's Comments Although most identified correct oxidation numbers, a significant number thought that the CN⁻ ion was reduced. Overall though, candidates demonstrated a good understanding of basic redox.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	IGNORE any charges shown within complexes (treat as rough working) $4\text{Au} + 8\text{CN}^- + 2\text{H}_2\text{O} + \text{O}_2 \rightarrow 4[\text{Au}(\text{CN})_2]^- + 4\text{OH}^-$ ✓✓ First mark for all 6 species Second mark for balancing	2	IF Ag referred to, rather than Au, treat as a slip and apply BOD IGNORE state symbols CARE: In $[\text{Au}(\text{CN})_2]^-$, – sign is OUTSIDE square brackets For 1st mark, IGNORE e^- present ALLOW 1 mark for balanced equation with CN^- missing, i.e. $4\text{Au} + 2\text{H}_2\text{O} + \text{O}_2 \rightarrow 4\text{Au}^+ + 4\text{OH}^-$ ALLOW 1 mark rogue e^- on either side ALLOW multiples, e.g. $2\text{Au} + 4\text{CN}^- + \text{H}_2\text{O} + \frac{1}{2}\text{O}_2 \rightarrow 2[\text{Au}(\text{CN})_2]^- + 2\text{OH}^-$ $\text{Au} + 2\text{CN}^- + \frac{1}{2}\text{H}_2\text{O} + \frac{1}{4}\text{O}_2 \rightarrow [\text{Au}(\text{CN})_2]^- + \text{OH}^-$ Examiner's Comments Almost all candidates wrote the correct species but balancing the equation was much more demanding. It was often balanced by species but not by charge and oxidation number.
		iv	$\text{ClO}^- + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{Cl}^- + \text{H}_2\text{O}$ ✓	1	IGNORE state symbols ALLOW e for electron ALLOW multiples Examiner's Comments Candidates found it easy to derive the correct half equation.
			Total	6	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
25	a	Cu^{2+}: $(1s^2) 2s^2 2p^6 3s^2 3p^6 3d^9$ ✓ Cu^+: $(1s^2) 2s^2 2p^6 3s^2 3p^6 3d^{10}$ ✓	2	IGNORE repeated $1s^2$ after $1s^2$ prompt on answer line ALLOW $4s^0$, either before or after 3d ALLOW upper case D, etc and subscripts, e.g.....$3S_2 3P^6$ DO NOT ALLOW [Ar] as shorthand for $1s^2 2s^2 2p^6 3s^2 3p^6$ Examiner's Comments The responses seen were very mixed. Able candidates scored the two marks easily but many errors were seen, particularly by removal of 3d electrons rather than 4s electrons from copper atoms to give the electron configurations of the ions (especially for Cu^+ in CuI).
	b	IGNORE any charges shown within formulae (treat as rough working) $\text{CuCO}_3 + 2\text{HCOOH} \rightarrow \text{Cu}(\text{HCOO})_2 + \text{H}_2\text{O} + \text{CO}_2$ OR $\text{CuO} + 2\text{HCOOH} \rightarrow \text{Cu}(\text{HCOO})_2 + \text{H}_2\text{O}$ OR $\text{Cu}(\text{OH})_2 + 2\text{HCOOH} \rightarrow \text{Cu}(\text{HCOO})_2 + 2\text{H}_2\text{O}$ ✓	1	IGNORE state symbols In formula of HCOOH / HCOO, ALLOW H, C and O in ANY order ALLOW H_2CO_3 for H_2O and CO_2 in carbonate equation ALLOW $(\text{HCOO})_2\text{Cu}$ for $\text{Cu}(\text{HCOO})_2$ DO NOT ALLOW equation with CuSO_4 Examiner's Comments Most candidates attempted an equation using CuO, $\text{Cu}(\text{OH})_2$ or CuCO_3. Marks were then sometimes lost by not balancing the equation. It was not uncommon to see equations using CuSO_4 or CuCl_2 as reactant and consequently this mark was often not awarded.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$2\text{Cu}^{2+} + 4\text{I}^{-} \rightarrow 2\text{CuI(s)} + \text{I}_2$ ✓ State symbol for CuI(s) ONLY required	1	ALLOW multiples, e.g. $\text{Cu}^{2+} + 2\text{I}^{-} \rightarrow \text{CuI(s)} + \frac{1}{2}\text{I}_2$ IGNORE other state symbols, even if incorrect Examiner's Comments This equation proved to be much more difficult than in 8(b), with only the best candidates producing a correctly balanced equation. As with 4(c) and 7(b)(iii), equations were often unbalanced in terms of charge and oxidation number.
	d		Starch ✓ Blue / black to colourless / white ✓ MARK INDEPENDENTLY	2	IGNORE 'brown' in composite colour with blue or black, i.e. ALLOW blue / brown to colourless ALLOW black / brown to colourless DO NOT ALLOW just 'it turns colourless / is decoloured' <i>Initial colour required</i> IGNORE clear for colourless Examiner's Comments Most candidates seemed unaware that starch is used to identify the end point in iodine–thiosulfate titrations. Even when starch was given, the colour change was often incorrect. Random responses were seen to this part, e.g. methyl orange, phenolphthalein, potassium manganate and sodium thiosulfate.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	e		WORKING REQUIRED Correct answer: $x = 4$ required evidence of working ----- $n(\text{S}_2\text{O}_3^{2-}) \text{ OR } n(\text{Cu}^{2+}) = \frac{0.0420 \times 23.5}{1000} = 9.87 \times 10^{-4} \text{ (mol) } \checkmark$ In 250.0 cm^3 solution, $n(\text{Cu}^{2+}) = 9.87 \times 10^{-3} \text{ (mol) } \checkmark$ $M(\text{Cu}(\text{HCOO})_2 \cdot 4\text{H}_2\text{O}) = \frac{2.226}{9.87 \times 10^{-3}} = 225.5 \text{ (g mol}^{-1}\text{) } \checkmark$ $x(\text{H}_2\text{O})$ has mass of $225.5 - M(\text{Cu}(\text{HCOO})_2)$ $= 225.5 - 153.5$ $= 72(.0) \checkmark$ $x = \frac{72(.0)}{18(.0)} = 4$ WHOLE NUMBER needed AND evidence of working $\checkmark$	5	FULL ANNOTATIONS MUST BE USED ----- At least 3 SF required throughout <i>Alternative approach for final 3 marks based on mass:</i> mass $\text{Cu}(\text{HCOO})_2 = 9.87 \times 10^{-3} \times 153.5 = 1.515 \text{ g } \checkmark$ $n(\text{H}_2\text{O}) = \frac{2.226 - 1.515}{18(.0)} = \frac{0.711}{18(.0)} = 0.0395 \text{ (mol) } \checkmark$ $x = \frac{0.0395}{9.87 \times 10^{-3}} = 4 \checkmark$ ALLOW $\text{Cu}(\text{HCOO})_2 \cdot 4\text{H}_2\text{O}$ ----- COMMON ERRORS for 4 marks $x = 117$ (calc 116.78) <i>Use of 9.87×10^{-4} (no scaling $\times 10$) $\rightarrow M = 2255.319$</i> $x = 17$ (calc 16.53) 4 marks <i>Use of 4.935×10^{-4} (Use of $0.5 \times 9.87 \times 10^{-3}$)</i> Check $n(\text{Cu}^{2+})$ for other ECFs Check for ECFs from incorrect $M(\text{anhydr salt})$ Actual = 153.5 Examiner's Comments Many candidates were on firm territory with a redox titration problem. The majority went through a well-rehearsed sequence of steps to obtain all five marks for showing that x was 4. Where '4' had not been obtained, marks could still be awarded for intermediate working if correct. Answer: $x = 4$
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
26			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
27	a	i	$2\text{H}_2\text{S}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{S}(\text{s}) + 2\text{H}_2\text{O}(\text{g}) \checkmark$	1	ALLOW multiples, e.g. $6\text{H}_2\text{S}(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 6\text{S}(\text{s}) + 6\text{H}_2\text{O}(\text{g})$
		ii	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 3.05×10^7 (g) award 3 marks ----- volume of H_2S $= 1.50 \times 10^8 \times 16(0)/100 = 2.4(0) \times 10^7$ dm^3 of $\text{H}_2\text{S} \checkmark$ $n(\text{H}_2\text{S}) (= n(\text{S}))$ $2.4(0) \times 10^7 / 24.0 \text{ mol} = 1(00) \times 10^6$ $\text{mol} \checkmark$ Mass S = $1(00) \times 10^6 \times 95(0)/100 \times 32.1$ $= 3.05 \times 10^7$ (g) $\checkmark$	3	ALLOW ECF from incorrect volume of H_2S 3 SF AND standard form required

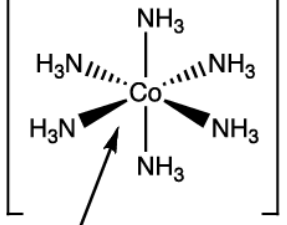
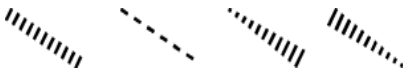
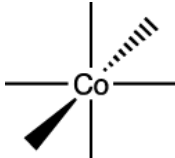
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	FIRST, CHECK FOR A VALUE OF ΔG. IF answer = $-89.96(34)$ (kJ mol^{-1}) award 3 marks ----- ΔS calculation (2 marks) $\Delta S = (3 \times 31.8) + (2 \times 188.7) - [(2 \times 205.7) + (248.1)]$ OR $\Delta S = 472.8 - 659.5 \checkmark$ $\Delta S = -186.7 \text{ J mol}^{-1} \text{ K}^{-1}$ OR $-0.1867 \text{ kJ mol}^{-1} \text{ K}^{-1} \checkmark$ ΔG calculation (1 mark) $\Delta G = \Delta H - T \Delta S = -145.6 - (298 \times -0.1867)$ $= -89.96(34) (\text{kJ mol}^{-1}) \checkmark$ Comment (1 mark) – sign shows the (forward) reaction is feasible $\checkmark$ Temperature at which feasibility changes (1 mark) $T = \frac{\Delta H}{\Delta S} = \frac{-145.6}{-0.1867} = 780 \text{ k}$ AND comment that ΔG OR $\Delta H - T \Delta S = 0$ $\checkmark$	5	ALLOW $(-)$ 187 OR 0.187 ALLOW ECF from incorrect ΔH ALLOW -90 up to calculator value of -89.9634 correctly rounded ORA for comment about – sign required for feasibility
		ii	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = -296.8 (kJ mol^{-1}) award 2 marks ----- Correct expression $-145.6 = (2 \times -241.8) - (2 \times -20.6 + \Delta_f H(\text{SO}_2)) \checkmark$ Calculation of $\Delta_f H(\text{SO}_2)$ formation $\Delta_f H(\text{SO}_2) = (2 \times -241.8) - (2 \times -20.6) + 145.6$ $= -296.8 (\text{kJ mol}^{-1}) \checkmark$	2	ALLOW ECF ALLOW 1 mark for $(+)$296.8 <i>Subtraction the wrong way around</i>
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
28	a	i	$3 \text{MnO}_4^{2-} + 4 \text{H}^+ \rightarrow 2 \text{MnO}_4^- + \text{MnO}_2 + 2 \text{H}_2\text{O}$ ✓	1	ALLOW 1 in front of MnO_2
		ii	In acidic conditions (Concentration of) H^+ increases AND equilibrium (position) shifts to the right to reduce concentration of H^+/remove H^+ ✓ In alkaline conditions OH^- reacts with H^+ AND equilibrium (position) shifts to the left to increase concentration of H^+/add H^+ ✓	2	ALLOW $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$
	b		In acid: $\text{H}_2(\text{g}) \rightarrow 2\text{H}^+(\text{aq}) + 2\text{e}^-$ AND $\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$ ✓ $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$ AND Cell potential = $1.23 - 0.00 = 1.23 \text{ (V)}$ ✓ In alkali: $2\text{OH}^-(\text{aq}) + \text{H}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + 2\text{e}^-$ AND $\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightarrow 4\text{OH}^-(\text{aq})$ ✓ $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$ AND Cell potential = $0.40 - (-0.83) = 1.23 \text{ (V)}$ ✓	4	ALLOW $\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$ ALLOW $\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$
			Total	7	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
29	i $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 6\text{NH}_3 \rightarrow [\text{Co}(\text{NH}_3)_6]^{2+} + 6\text{H}_2\text{O} \checkmark$ ligand substitution $\checkmark$	2	ALLOW ligand exchange
	ii  bond angle = 90° 3 -D Shape $\checkmark$ bond angle 90° $\checkmark$ Bonds must be to N of NH₃ ligands	2	IGNORE charges (anywhere) and labels (even if wrong) Square brackets NOT required Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper OR 4 lines, 1 'out wedge' and 1 'in wedge': For bond into paper, ALLOW:  ALLOW following geometry throughout: 
	iii Empirical formula of complex D Co : N : H : Cl $\frac{22.03}{58.9} : \frac{31.41}{14.0} : \frac{6.73}{1.00} : \frac{39.83}{35.5}$ OR 0.374 : 2.24 : 6.73 : 1.12 $\checkmark$ = 1 : 6 : 18 : 3 = CoN₆H₁₈Cl₃ $\checkmark$ complex ion C [Co(NH₃)₆]³⁺ $\checkmark$ complex D [Co(NH₃)₆]³⁺[Cl⁻]₃ $\checkmark$	4	Correct empirical formula subsumes previous mark ALLOW [Co(NH₃)₆]³⁺ 3Cl⁻

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iv	Half equations $[\text{Co}(\text{NH}_3)_6]^{2+} \rightarrow [\text{Co}(\text{NH}_3)_6]^{3+} + \text{e}^- \checkmark$ $\text{H}_2\text{O}_2 + 2\text{e}^- \rightarrow 2\text{OH}^- \checkmark$ Overall equation $2[\text{Co}(\text{NH}_3)_6]^{2+} + \text{H}_2\text{O}_2 \rightarrow 2[\text{Co}(\text{NH}_3)_6]^{3+} + 2\text{OH}^- \checkmark$	1	ALLOW multiples throughout ALLOW $\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}$ ALLOW $2[\text{Co}(\text{NH}_3)_6]^{2+} + \text{H}_2\text{O}_2 + 2\text{H}^+ \rightarrow 2[\text{Co}(\text{NH}_3)_6]^{3+} + 2\text{H}_2\text{O}$
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
30	a		$\text{H}_2\text{SO}_4 + 8\text{HI} \rightarrow 4\text{I}_2 + \text{H}_2\text{S} + 4\text{H}_2\text{O}$ All species correct OR $\text{H}_2\text{SO}_4 : \text{HI}$ ratio = 1 : 8 ✓ Equation complete and balanced ✓	2	
	b	i	FIRST, CHECK THE ANSWER ON ANSWER LINE IF $\Delta_{\text{sol}}H = -43.3 \text{ (kJ mol}^{-1}\text{)}$ award 4 marks <i>Energy released in J OR kJ</i> $= 113.42 \times 4.18 \times 10.5 = 4978 \text{ (J) OR } 4.978 \text{ (kJ) } \checkmark$ <i>Correctly calculates $n(\text{H}_2\text{SO}_4)$</i> $\frac{11.28}{98.1} = 0.115 \text{ (mol) } \checkmark$ ΔH value in J OR kJ Answer MUST divide energy by $n(\text{H}_2\text{SO}_4)$ $(-)\frac{4978}{0.115} \text{ OR } (-)43286 \text{ (J)}$ OR $(-)\frac{4978}{0.115} \text{ OR } (-)43.3 \text{ (kJ) } \checkmark$ <i>(Sign ignored and/or more than 3 SF)</i> Correct $\Delta_{\text{sol}}H$ in kJ AND – sign AND 3 SF $= -43.3 \text{ (kJ mol}^{-1}\text{)} \checkmark$	4	FULL ANNOTATIONS MUST BE USED Calculator: 4978.0038 DO NOT ALLOW less than 3 SF IGNORE units ALLOW correctly calculated number in J OR kJ Calculator 0.1149847095 ALLOW ECF from $n(\text{H}_2\text{SO}_4)$ AND/OR Energy Calculator from 4978 and 0.115 = 43286.95652 From unrounded values, = 43292.74581 IGNORE absence of – sign and 3 SF requirement Final mark requires – sign, kJ AND 3 SF NOTE: Use of 100 for $m \rightarrow 4389 \text{ J}$ ECF available for $\rightarrow -38.2 \text{ kJ mol}^{-1}$ (3 marks)
		ii	$\frac{0.5}{10.5} \times 100 \times 2 = 9.5\% \checkmark$ <i>One decimal place required</i>	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Predictions ΔT is less AND $\Delta_{\text{sol}}H$ is the same ✓ Reason for ΔT less (same) energy/heat spread over larger volume (of water) ✓ $\Delta T = 7^{\circ}\text{C}$ ✓ Reason for $\Delta_{\text{sol}}H$ same Same energy released per mole of H_2SO_4 ✓	4	ALLOW heat spread over more water ALLOW 6–8 °C Note: m is ~ 1/3 larger. $q = mc\Delta T$ and so ΔT will be ~ 1/3 smaller ALLOW $\Delta_{\text{sol}}H$ is for dissolving 1 mol
			Total	11	
31			C	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
32	a	i	<i>Circuit:</i> complete circuit AND voltmeter AND <i>labelled</i> salt bridge linking two half-cells ✓ <i>Half cells:</i> Pt AND Fe²⁺ AND Fe³⁺ ✓ Zn AND Zn²⁺ ✓ <i>Standard conditions:</i> 1 mol dm⁻³ (solution(s)) AND 298 K / 25°C ✓	4	Electrodes / salt bridge must at least touch the surface ALLOW small gaps in circuit wires ALLOW half cells drawn either way around ALLOW 1 mol / dm³ OR 1 M ALLOW 1 mol dm⁻³/1M if omitted here but shown for just one solution in diagram IGNORE pressure DO NOT ALLOW 1 mol(e) for concentration Examiner's Comments A significant number of candidates handicapped themselves by failing to draw a simple circuit. Diagrams with electrodes not entering solutions, salt bridges not labelled or not entering solutions were frequently seen. Most candidates scored the mark for the Zn electrode but less scored the mark for the Pt electrode in the Fe²⁺(aq)/Fe³⁺(aq) mixture. The last mark, for the conditions (including concentrations of 1.00 mol dm⁻³), was almost universally scored even by those who omitted the solutions in their diagram.
		ii	1.53 (V) ✓	1	IGNORE sign Examiner's Comments This was the most successfully answered one mark question on the paper.
	b		<i>strongest reducing agent:</i> Zn ✓ <i>strongest oxidizing agent:</i> MnO₄⁻ ✓	2	NOTE: H⁺ has been ignored Examiner's Comments Most candidates were able to use the standard electrode potentials given in the question to work out that zinc (Zn(s)) was the strongest reducing agent and that manganate(VII) ions were the strongest oxidising agent.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		AWARD 2 marks for correct balancing AND all species cancelled on both sides of equation: $2\text{MnO}_4^- + 6\text{H}^+ + 5\text{SO}_3^{2-} \rightarrow 2\text{Mn}^{2+} + 3\text{H}_2\text{O} + 5\text{SO}_4^{2-}$ ✓ ✓ AWARD 1 mark for correct balancing but not all species (H_2O, H^+) cancelled on both sides of equation ✓ e.g. $2\text{MnO}_4^- + 16\text{H}^+ + 5\text{SO}_3^{2-} + 5\text{H}_2\text{O}$ $\rightarrow 2\text{Mn}^{2+} + 8\text{H}_2\text{O} + 5\text{SO}_4^{2-} + 10\text{H}^+$	2	ALLOW correct multiples e.g. $\text{MnO}_4^- + 3\text{H}^+ + 2\frac{1}{2}\text{SO}_3^{2-}$ $\rightarrow \text{Mn}^{2+} + 1\frac{1}{2}\text{H}_2\text{O} + 2\frac{1}{2}\text{SO}_4^{2-}$ IGNORE state symbols e.g. $\text{MnO}_4^- + 8\text{H}^+ + 2\frac{1}{2}\text{SO}_3^{2-} + 2\frac{1}{2}\text{H}_2\text{O}$ $\rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O} + 2\frac{1}{2}\text{SO}_4^{2-} + 5\text{H}^+$ Examiner's Comments This was successfully answered by the majority of candidates.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
33		i	sodium nitrate(III)	1	ALLOW sodium nitrite OR sodium nitrite(III) Examiner's Comment: This part was very poorly answered, the most common answer being sodium nitrate. The examiners were expecting sodium nitrate(III) but the mark scheme was extended to also allow sodium nitrite. Sodium(III) nitrate was sometimes seen, indicating that candidates are not fully conversant with rules for showing oxidation states in names.
		ii	Sodium / Na oxidised from 0 to +1 ✓ Nitrogen / N reduced from +3 to 0 ✓	2	ALLOW 1+ for +1 and 3+ for +3 ALLOW N₂ for nitrogen ALLOW 1 mark for elements AND all oxidation numbers correct, but N on oxidised line and Na on reduced line '+' is required in +3 and +1 oxidation numbers Examiner's Comment: This part was generally answered well although a significant number of candidates managed to get one of the oxidation numbers wrong, usually for N. It was rare to see the sign for an oxidation number omitted.
		iii	$2\text{NaNO}_2 + 6\text{Na} \rightarrow 4\text{Na}_2\text{O} + \text{N}_2$ ✓ IGNORE state symbols	1	ALLOW multiples, e.g. $\text{NaNO}_2 + 3\text{Na} \rightarrow 2\text{Na}_2\text{O} + \frac{1}{2}\text{N}_2$ ✓ Examiner's Comment: The examiners were impressed with the responses for this part with just over half the candidates producing a correct balanced equation for this unfamiliar reaction. Most used whole numbers for balancing but it was common to also see the half-multiple version including $\frac{1}{2}\text{N}_2$.
			Total	4	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
34	ALLOW equilibrium sign in equations provided reactants on left Reaction of H₂O₂ with MnO₂: $\text{H}_2\text{O}_2 + \text{MnO}_2 + 2\text{H}^+ \rightarrow \text{O}_2 + \text{Mn}^{2+} + 2\text{H}_2\text{O}$ ✓ Reaction of H₂O₂ with Mn²⁺: $\text{H}_2\text{O}_2 + \text{Mn}^{2+} \rightarrow \text{MnO}_2 + 2\text{H}^+$ ✓ Use of <i>E</i> data Use of <i>E</i> data to support equation(s) above or half direction of provided half equations (one including MnO₂) ✓ <i>Also look for evidence around half equations</i> MnO₂ regenerated / reformed ✓ <i>Must be linked to an equation showing MnO₂ as reactant and an equation showing MnO₂ as product</i>	4	ALLOW correct multiples IGNORE state symbols ----- ALLOW uncanceled H₂O and H⁺ $\text{H}_2\text{O}_2 + \text{MnO}_2 + 4\text{H}^+ \rightarrow \text{O}_2 + \text{Mn}^{2+} + 2\text{H}_2\text{O} + 2\text{H}^+$ $\text{H}_2\text{O}_2 + \text{Mn}^{2+} + 2\text{H}_2\text{O} + 2\text{H}^+ \rightarrow \text{MnO}_2 + 4\text{H}^+ + 2\text{H}_2\text{O}$ <i>Examples</i> • More negative <i>E</i> moves to left ORA • Reduction half equation to the right ORA • Most positive <i>E</i> is reduced ORA • Calculated <i>E</i> cell = +0.81 V (<i>from top 2</i>) OR +0.27 V (<i>from bottom 2</i>) ALLOW combining of equations above to show that MnO₂ is used and reformed Examiner's Comment: Many candidates found this part challenging and there was a wide variety of answers and marks awarded. There were two equations to construct showing how MnO₂, and Mn²⁺ react with H₂O₂. Many combined the two equations involving H₂O₂ to obtain the overall equation for the decomposition of H₂O₂ which was given at the top of the paper. Of the equations seen, many had species uncanceled. Many candidates only tackled one of the equations. Candidates were expected to provide evidence for their equations based on the electrode potentials provided. Use of this data was patchy and only the best candidates linked the relative <i>E</i> values to the direction of movement or redox details.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					A significant number gave cell potentials. Regeneration of MnO_2 was well understood but often just stated with no reference to the equations. This part discriminated very well.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
35		i	<i>Equation</i> $\text{Ba}(\text{NO}_3)_2(\text{aq}) + \text{Na}_2\text{SO}_4(\text{aq}) \rightarrow \text{BaSO}_4(\text{s}) + 2\text{NaNO}_3(\text{aq})$ ✓ <i>Entropy change and explanation</i> entropy decreases OR entropy change negative AND (BaSO_4) solid / ppt has less disorder / more order / fewer ways of arranging energy / less freedom / less random particles / dispersal of energy ✓	2	ALLOW multiples M2 is dependent on $\text{BaSO}_4(\text{s})$ (even if formula is incorrect – eg $\text{Ba}(\text{SO}_4)_2(\text{s})$) seen as a product in the attempted equation as long as reactants are not solid. BaSO_4 solid / ppt may be assumed from $\text{BaSO}_4(\text{s})$ seen in the attempted equation. Examiner's Comments Candidates who correctly identified barium sulfate as a solid product tended to realise that entropy had decreased, although a significant number failed to state that this decrease in entropy was as a result of less disorder being created.
		ii	<i>Equation</i> $\frac{1}{2} \text{I}_2(\text{s}) \rightarrow \text{I}(\text{g})$ ✓ <i>state symbols required</i> <i>Entropy change and explanation</i> entropy increases OR entropy change positive AND gas has more disorder / less order / more ways of arranging energy / more freedom / more random particles / more dispersal of energy ✓	2	DO NOT ALLOW $\text{I}_2(\text{s}) \rightarrow 2\text{I}(\text{g})$ DEPENDENT on $\frac{1}{2}\text{I}_2(\text{s}) \rightarrow \text{I}(\text{g})$ OR $\text{I}_2(\text{s}) \rightarrow 2\text{I}(\text{g})$ Examiner's Comments Most candidates failed to produce a correct equation for the standard enthalpy change of atomisation of iodine. Of those who were able to produce the correct equation, a significant number failed to state that the increase in entropy was as a result of increased disorder being created.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
36	a		$\Delta G = \Delta H - T\Delta S$ linked to $y = mx + c$ (somewhere) ✓ gradient = $-\Delta S$ ✓ P: ΔH / enthalpy change ✓ Q: (temperature) for reaction to be feasible/unfeasible OR (temperature) at which feasibility changes ✓	4	Could be: $\Delta G = -\Delta S T + \Delta H$ – sign required ALLOW $\Delta S = -\text{gradient}$ ALLOW 'point of feasibility' For Feasibility: ALLOW can take place/happen OR is spontaneous IGNORE 'minimum/maximum temperature' Examiner's Comments For the minority of candidates who recognised that the Gibbs' equation could be expressed in $y = mx + c$ format, this question was very straightforward. For others, the realisation that Q was the point at which feasibility changed was the only mark scored.
	b	i	(Species have) different states / phases ✓	1	Examiner's Comments All but a few candidates realised that the term heterogeneous equilibrium could be applied because carbon monoxide was in a different physical state to the other reactants and products.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$(K_p =) p(\text{CO(g)})^4 \checkmark$	1	Allow species without state symbols and without brackets, e.g. P_{CO}^4, $pp\text{CO}^4$, PCO^4, $p(\text{CO}^4)$ etc. DO NOT ALLOW square brackets Examiner's Comments Marks were awarded for less than perfect versions of $K_p = p(\text{CO(g)})^4$. As long as a 'p' or a 'P' was seen and curved, rather than square, brackets, along with the correct power, the mark was awarded. This was to differentiate between the candidates who knew that only the partial pressures of gaseous species should feature in a K_p expression from the candidates who used all four species to write the expression.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	ΔG at 25 C $\Delta G = \Delta H - T\Delta S = 676.4 - (298 \times 0.7031)$ $= (+) 467 \text{ (kJ mol}^{-1}\text{) OR (+) 466876}$ $\text{(J mol}^{-1}\text{) } \checkmark$ <i>Non-feasibility statement</i> Non-feasible when $\Delta G > 0$ OR $\Delta G > 0$ OR $\Delta H > T\Delta S \checkmark$ <i>Minimum temperature</i> minimum temperature = $\frac{\Delta H}{\Delta S} = \frac{676.4}{0.7031}$ $= 962(.0) \text{ K } \checkmark$	3	IGNORE units ALLOW (+) 467 up to calculator value of 466.8762 correctly rounded ECF for any positive value determined in M1 ALLOW 962 up to calculator value of 962.0253165 correctly rounded Examiner's Comments Candidates coped well with the calculation and, apart from a significant number of rounding errors, could provide a positive value of ΔG and therefore could show the reaction to not be feasible. Candidates were also able to calculate that the minimum temperature required for the reaction to be feasible was 962.023165 K which was sensibly rounded to 962 K. A significant number of candidates chose to give 963 K as the final answer despite showing a correct value to several decimal places in their working.

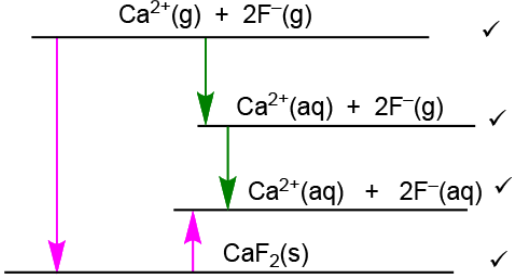
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iv	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = -110.5, Award 3 marks. ----- Correct expression $-13.5 = (4 \times -393.5) - (-1118.5 + 4 \times \Delta_f H(\text{CO}))$ ✓ Correct subtraction using ΔH and $\Delta_f H(\text{Fe}_3\text{O}_4)$ $4 \times \Delta_f H(\text{CO}) = (4 \times -393.5) - (-1118.5) + 13.5$ $= -442(.0) \text{ (kJ mol}^{-1}\text{)}$ ✓ Calculation of $\Delta_f H(\text{CO})$ formation $\Delta_f H(\text{CO}) = -\frac{442}{4} = -110.5 \text{ (kJ mol}^{-1}\text{)}$ ✓	3	For answer, ALLOW -111 (kJ mol⁻¹) ----- NOTE: IF any values are omitted, DO NOT AWARD any marks. e.g. -393.5 OR -13.5 may be missing ----- Common errors (+)110.5 <i>wrong / omitted sign</i> 2 marks (+)184.625 / 184.63 / 184.6 / 185 <i>No 4CO₂</i> 2 marks (+)738.5 / 739 <i>No 4CO₂ and no CO/4</i> 1 mark -117.25 / -117.3 / -117 <i>Wrong cycle</i> 2 marks -469 <i>Wrong cycle, no CO/4</i> 1 mark (+)177.875 / 177.88 / 177.9 / 178 <i>Wrong cycle, no 4CO₂</i> 1 mark -360.5 <i>Used 118.5</i> 2 marks Any other number: CHECK for ECF from 1st marking point for expressions using ALL values with ONE error only e.g. one transcription error:, e.g.395.3 for 393.5 Examiner's Comments The general method of determining $\Delta_f H(\text{CO})$ was known to most candidates, but many examples of avoidable errors were seen. For example, transcription errors in recording $\Delta_f H$ values (-393 for -393.5 and -118.5 for -1118.5). Candidates should be advised to show every step in their calculation. This would allow method marks to be applied in the absence of a correct final answer.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
37			A	1 (AO 1.2)	<u>Examiner's Comments</u> The correct answer to this was known by the more able candidates. Lower ability candidates struggled.
			Total	1	
38			D	1 (AO 2.5)	<u>Examiner's Comments</u> Most candidates knew the correct equation.
			Total	1	
39			B	1 (AO 1.1)	<u>Examiner's Comments</u> D was the common distractor given as the answer by many candidates, suggesting confusion with the first electron affinity and second electron affinity of oxygen.
			Total	1	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
40	i (enthalpy change when)✓ 1 mole of gaseous ions react✓ OR 1 mole of hydrated/aqueous ions are formed ✓ gaseous ions dissolve in water OR gaseous ions form aqueous/hydrated ions ✓	2	IGNORE 'energy released' OR 'energy required' <u>Examiner's Comments</u> Most candidates were able to state that one mole of gaseous ions was dissolved into water. Common errors seen included candidates referring to the dissolving of one mole of substance (i.e. the enthalpy change of solution); the use of the generic term 'solvent' rather than water; and dissolving of gaseous ions into one mole of water.
	ii 	4	Correct species AND state symbols required for each mark. (mark independently) On 2nd line, ALLOW $\text{Ca}^{2+}(\text{g}) + 2\text{F}^{-}(\text{aq})$ (i.e. F^{-} hydrated before Ca^{2+}) On 3rd line, ALLOW $\text{CaF}_2(\text{aq})$ DO NOT ALLOW when first seen but ALLOW ECF for '2' missing and for use of the following ions F^- F_2✓ Ca^{+3+} <u>Examiner's Comments</u> Most candidates were able to score some marks on this question with more able candidates scoring all 4 marks. Common errors included the omission of state symbols and the use of only one $\text{F}^{-}(\text{g})$ ion (often despite a correct formula of CaF_2 being seen on the bottom line). For some reason, many candidates write their lower case 's' in an identical way to their lower case 'g'. This means the examiner cannot distinguish between these state symbols on such scripts. Centres may wish to stress this point to prevent candidates losing marks unnecessarily.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = $-504 \text{ (kJ mol}^{-1}\text{)}$ award 2 marks IF answer = $-1008 \text{ (kJ mol}^{-1}\text{)}$ award 1 mark ----- $2 \times \Delta_{\text{hyd}}H(\text{F}^-)$ $= [-2630 + 13] - (-1609)$ OR $-2617 + 1609$ OR $-1008 \text{ (kJ mol}^{-1}\text{)}$ ✓ $\Delta_{\text{hyd}}H(\text{F}^-) = \frac{-1008}{2} = -504 \text{ ✓ (kJ mol}^{-1}\text{)}$	2	IF alternative answer, check to see if there is any ECF credit possible using working below. ‘-’ sign is needed. COMMON ERRORS for 1 mark: (+)2694: <i>signs all reversed</i> -2113: <i>sign wrong for -1609</i> -2126: <i>sign wrong for 2630</i> -517: <i>sign wrong for 13</i> +504: <i>sign wrong</i> IF ALL 3 relevant values from the information at the start of Q16a(iii) have NOT been used, award zero marks unless one number has a transcription error, where 1 mark can be awarded ECF <u>Examiner's Comments</u> Most candidates were able to do this relatively straightforward calculation by rearranging the values of the enthalpy changes associated with the energy cycle diagram. However, a significant number forgot to divide -1008 by 2 to score full marks.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iv	Correct comparison of Δ_{hyd} linked to sizes $\Delta_{\text{hyd}}H(\text{F}^-)$ more negative/exothermic (than $\Delta_{\text{hyd}}H(\text{Cl}^-)$) AND F^- has smaller size (than Cl^-) ✓ <i>Comparison of attraction between ions and water</i> F^- OR smaller sized ion linked to greater attraction to H_2O ✓	2	ORA IGNORE 'atomic' before radius when comparing size of ions IGNORE charge density IGNORE electronegativity IGNORE nuclear attraction DO NOT ALLOW 'forms stronger hydrogen bonds with water' OR 'forms stronger van der Waals' forces with water' ALLOW 'forms bonds' for attraction' DO NOT ALLOW F^- greater attraction to H_2O if given as larger ion Assume 'F' / 'Fluorine' means 'ions' but DO NOT ALLOW 'F molecules' <u>Examiner's Comments</u> When comparing enthalpy changes candidates need to be aware that descriptions such as 'bigger' or 'smaller' are meaningless as there are often negative signs involved. The correct description required here was that the enthalpy change of hydration of F^- ions would be more negative than that of Cl^- ions. Although some candidates wrote in terms of charge density, it was those candidates who related the smaller size of the F^- ion to the difference in enthalpy change of hydration who received credit and went on to say that this was as a consequence of greater attraction to water molecules.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
41		i	Titres correct and ALL recorded to 2 decimal places Titre: 24.00 23.40 23.75 23.85 ✓ mean titre = 23.80 (cm³) ✓	2	ALLOW 23.8 cm³ <u>Examiner's Comments</u> It is clear candidates are not as experienced at filling in titration tables as might be expected. Every value in a titration table should be recorded to a second decimal place to an accuracy of ± 0.05 cm³. The average titre should be calculated by averaging concordant titres, i.e. those within 0.10 cm³ of each other.
		ii	Percentage uncertainty $= \frac{0.05 \times 2}{23.40} \times 100 = 0.43 (\%) \checkmark$	1	ALLOW ECF from incorrect subtraction in (i) or incorrect mean ALLOW 0.42% from titre values 2, 3 or 4 or mean titre or trial titre. 2 DP required <u>Examiner's Comments</u> Candidates are unfamiliar with determination of percentage uncertainty. Marks were credited for any percentage uncertainty calculation correctly determined from any titre value, as many opted to choose the trial value as titre 1 or used an average titre.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Add starch (near the end point) ✓ Blue to colourless ✓	2	ALLOW blue/black OR black OR purple for colour of mixture ALLOW blue colour disappears (to colourless) IGNORE 'clear' IGNORE 'colorimetry' <u>Examiner's Comments</u> Only the higher ability candidates realised starch needed to be added close to the end-point and this made the resulting colour change (blue-black to colourless) easier to see. The common error was to assume this was an acid-base titration and indicators such as methyl orange or phenolphthalein should be added.
		iv	FIRST CHECK THE ANSWER ON THE ANSWER LINE IF B = RbIO_3 AND relative formula mass = 260.5 award 5 marks IF relative formula mass = 260.5 award 4 marks ----- $n(\text{S}_2\text{O}_3^{2-})$ in titration $= \frac{0.150 \times 23.80}{1000} = 3.57 \times 10^{-3} \text{ (mol) } \checkmark$ $n(\text{IO}_3^-)$ in titration $= 10 \times 5.95 \times 10^{-4} = 5.95 \times 10^{-3} \text{ (mol) } \checkmark$ $n(\text{IO}_3^-)$ in original 250 cm^3 $= \frac{3.57 \times 10^{-3}}{6} = 5.95 \times 10^{-4} \text{ (mol) } \checkmark$ Relative formula mass of B $= \frac{1.55}{5.95 \times 10^{-3}} = 260.5 \text{ (g mol}^{-1}\text{) } \checkmark$ Formula of B (must be derived from relative formula mass) Iodate of Group 1 metal that most closely matches calculated molar	5	ALLOW ECF from incorrect mean titre in (a)(i) ECF from $n(\text{S}_2\text{O}_3^{2-})$ in titration ALLOW a two-step calculation $n(\text{I}_2) = n(\text{S}_2\text{O}_3^{2-}) \div 2$ and $n(\text{IO}_3^-) = n(\text{I}_2) \div 3$ ECF from $n(\text{IO}_3^-)$ in titration ECF from $n(\text{IO}_3^-)$ in original 250 cm^3 IF scaling $\times 10$ is omitted, ALLOW ECF from $n(\text{IO}_3^-)$ in titration ALLOW ECF from incorrect RFM of B provided metal is from Group 1 ALLOW RbIO_3

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			mass of B Formula from 260.5 = RbIO_3 ✓		DO NOT ALLOW RbIO_3 without relative formula mass value. DO NOT ALLOW 260.4 (without working) and RbIO_3 IF B = RbIO_3 AND relative formula mass = 261 award 5 marks <u>Examiner's Comments</u> This unstructured calculation was done well by the higher ability candidates. Lower ability candidates struggled to show what they were attempting to calculate and in particular did not appreciate the 1 : 6 ratio of $\text{S}_2\text{O}_3^{2-}(\text{aq})$ to $\text{IO}_3^-(\text{aq})$. Candidates might be advised to start n (formula) = ... at the start of each line of calculation eg $n(\text{S}_2\text{O}_3^{2-}) = \dots \text{ mol}$ No credit was given to candidates who grasped the identity of the Group 1 iodate from nowhere and calculated the theoretical relative formula mass.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
42	a	i	<i>Circuit:</i> complete circuit AND voltmeter AND salt bridge linking two half-cells ✓ <i>Half cells:</i> Pt AND I^- AND I_2 ✓ Ni AND Ni^{2+} ✓ <i>Standard conditions:</i> 1 mol dm⁻³ solutions AND 298 K / 25°C ✓	4	Voltmeter must be shown AND salt bridge must be labelled ALLOW small gaps in circuit ALLOW half cells drawn either way around IGNORE 2 before $I^-(aq)$ DO NOT ALLOW $I_2(g)$ OR $I_2(s)$ OR $I_2(l)$ ALL conditions required BUT ALLOW 1 mol dm⁻³/1M if omitted here but shown for just one solution in diagram Look on diagram in addition to answer lines IGNORE pressure <i>Not relevant for this cell</i> DO NOT ALLOW 1 mol for concentration <u>Examiner's Comments</u> A significant number of candidates did not draw a simple circuit. Most candidates scored the mark for the Ni electrode but fewer scored the mark for the Pt electrode in the $I^-(aq)/I_2(aq)$ mixture. The last mark, for the conditions (including concentrations of 1.00 mol dm⁻³), was almost universally scored even by those who omitted the solutions in their diagram. Common errors were: diagrams with electrodes not entering solutions; salt bridges not labelled or not entering solutions; making solid iodine an electrode; and assuming iodine to be a gas and adapting a standard hydrogen electrode to accommodate this.
		ii	$E = 0.79$ (V) ✓	1	IGNORE sign <u>Examiner's Comments</u> This was the most successfully answered single mark question on the paper.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{Fe}^{2+}(\text{aq}) \rightarrow$ $2\text{Fe}^{3+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l}) \checkmark$	1	ALLOW multiples IGNORE state symbols, even if wrong <u>Examiner's Comments</u> Most candidates got the equation correct. Occasionally a number was omitted causing incorrect stoichiometry and occasionally the equation was reversed.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Equations $\begin{aligned} &3\text{Zn(s)} + \text{Cr}_2\text{O}_7^{2-}\text{(aq)} + 14\text{H}^+\text{(aq)} \\ &\quad \rightarrow 3\text{Zn}^{2+}\text{(aq)} + \\ &\quad 2\text{Cr}^{3+}\text{(aq)} + 7\text{H}_2\text{O(l)} \\ &\qquad\qquad\checkmark \end{aligned}$ $\text{Zn(s)} + 2\text{Cr}^{3+}\text{(aq)} \rightarrow \text{Zn}^{2+}\text{(aq)} + 2\text{Cr}^{2+}\text{(aq)} \checkmark$ Comparison of E values (seen once) E of Zn is more negative/less positive than E of $\text{Cr}_2\text{O}_7^{2-}$ OR E of Zn is more negative/less positive than E of Cr^{3+} ✓ Equilibrium shift related to E values More negative/less positive OR Zn system shifts left OR Less negative/more positive $\text{Cr}_2\text{O}_7^{2-}$ system shifts right OR Less negative/more positive Cr^{3+} system shifts right ✓	4	ALLOW multiples IGNORE state symbols, even if wrong ALLOW E_{cell} is (+) 2.09V for Zn/$\text{Cr}_2\text{O}_7^{2-}$ cell OR ALLOW E_{cell} is (+) 0.34V for Zn/Cr^{3+} cell IGNORE ‘lower/higher’ For ‘shifts left’: ALLOW ‘(Zn) is oxidised’ OR ‘electrons are lost (from Zn)’ For ‘shifts right’, ALLOW ‘(Cr) is reduced’ OR ‘electrons are gained’ <u>Examiner’s Comments</u> Only the higher ability candidates achieved full marks. Most candidates were able to come up with both redox equations and some could state that zinc was oxidised or chromium was reduced as a result of zinc having a more negative electrode potential than either chromium species. Common errors were: stating that zinc had a lower (not more negative) electrode potential; stating that zinc was an oxidising agent (as well as being oxidised); confusing the direction of change of equilibria shown; and not balancing the overall redox equations.

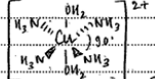
Mark Scheme

Question		Answer/Indicative content	Marks	Guidance																					
c		<i>Please refer to the marking instructions on page 5 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) All three reactions are covered in detail with C, D, E and F identified with clear explanations. <i>There is a well-developed line of reasoning which is clear and logically structured with clear chemical communication and few omissions. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) All three reactions are covered but explanations may be incomplete OR Two reactions are explained in detail. <i>There is an attempt at a logical structure with a line of reasoning. The information is relevant e.g. formulae may contain missing brackets or numbers and supported by some evidence.</i> Level 1 (1–2 marks) Make two simple explanations from any one reaction. OR Makes one simple explanation from each of two reactions <i>There is an attempt at a logical structure with a line of reasoning The information is in the most part relevant.</i> 0 marks No response worthy of credit.	6	Indicative scientific points may include: REACTION 1 (CuSO₄/NH₃) <i>Product</i> C : [Cu(NH₃)₄(H₂O)₂]²⁺ <i>Equation</i> [Cu(H₂O)₆]²⁺ + 4NH₃ → [Cu(NH₃)₄(H₂O)₂]²⁺ + 4H₂O <i>Structure of trans stereoisomer</i> Correct connectivity REACTION 2 (Cu₂O/H₂SO₄) <i>Products</i> D : CuSO₄ OR [Cu(H₂O)₆]²⁺ E: Cu <i>Equation</i> Cu₂O + H₂SO₄ → CuSO₄ + Cu + H₂O <i>Oxidation numbers</i> Cu(+1) → Cu(+2) + Cu(0) REACTION 3 (CuO/HNO₃) <i>Equation</i> CuO + 2HNO₃ → Cu(NO₃)₂ + H₂O <i>Molar ratios</i> <table><tr><td>Cu</td><td>:</td><td>H</td><td>:</td><td>N</td><td>:</td><td>O</td></tr><tr><td>26.29</td><td>:</td><td>2.49</td><td>:</td><td>11.59</td><td>:</td><td>59.63</td></tr><tr><td>63.5</td><td>:</td><td>1.0</td><td>:</td><td>14.0</td><td>:</td><td>16.0</td></tr></table> <i>Formula of F</i> CuH₆N₂O₉ F: Cu(NO₃)₂•3H₂O (OR Cu(NO₃)₂(H₂O)₃) Further guidance on use of wedges - Must contain 2 ‘out wedges’, 2 ‘in wedges’ and 2 lines in plane of paper OR 4 lines, 1 ‘out wedge’ and 1 ‘in wedge’: - For bond into paper, ALLOW: ALLOW following geometry:	Cu	:	H	:	N	:	O	26.29	:	2.49	:	11.59	:	59.63	63.5	:	1.0	:	14.0	:	16.0
Cu	:	H	:	N	:	O																			
26.29	:	2.49	:	11.59	:	59.63																			
63.5	:	1.0	:	14.0	:	16.0																			

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
			<u>Examiner's Comments</u> Many candidates had a stab at identifying C–F but neglected to include equations for the three reactions described or to show relevant working. Most candidates recognised C as the ammoniacal copper(II) ion but the formula was frequently incorrect and correct attempts at a ligand substitution equation from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ was rarely seen. Diagrams showing the <i>trans</i> isomer were attempted but often of poor quality due to incorrect linking. Candidates recognised D as being CuSO_4 but often did not identify E as Cu due to a lack of familiarity with this common disproportionation reaction. $\text{Cu}(\text{OH})_2(\text{s})$ was a common incorrect identification of E. Only the best responses described the oxidation number changes which made this a disproportionation reaction. F was identified by a percentage by mass calculation to determine an empirical formula and then by deduction to produce $\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$. Having done this, many candidates did not give the relatively simple equation for reaction 3 between copper(II) oxide and dilute nitric acid.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance																				
					Exemplar 2 (d)* Three different reactions of copper compounds are described below. Reaction 1: Aqueous copper(II) sulfate reacts with excess aqueous ammonia in a ligand substitution reaction. A deep-blue solution is formed, containing an octahedral complex ion, G, which is a <i>trans</i> isomer. $\Rightarrow 100$ Reaction 2: Copper(I) oxide reacts with hot dilute sulfuric acid in a disproportionation reaction. A blue solution, D, and a brown solid, E are formed. Reaction 3: Copper(II) oxide reacts with warm dilute nitric acid in a neutralisation reaction, to form a blue solution. Unreacted copper(II) oxide is filtered off, and the solution is left overnight in an evaporating basin. A hydrated salt, F, crystallises, with the percentage composition by mass: Cu, 26.29%; H, 2.48%; N, 11.59%; O, 59.63%. Identify C-F by formulae or structures, as appropriate. Include equations, any changes in oxidation number, and working. [6] ① $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$  <i>octahedral</i> <i>This is the trans isomer [C] because the H_2O ligands are 180° apart.</i> ② $Cu_2O + H_2SO_4(aq) \rightarrow Cu_2O + CuSO_4(aq) + H_2O(l)$ <i>brown solid blue solution</i> [E] [D] [NOTE] ③ $CuO + 2HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + H_2O(l)$ <table><thead><tr><th></th><th>Cu</th><th>H</th><th>N</th><th>O</th></tr></thead><tbody><tr><td>mass</td><td>26.29</td><td>2.48</td><td>11.59</td><td>59.63</td></tr><tr><td>rfm</td><td>63.5</td><td>1</td><td>14</td><td>16</td></tr><tr><td>mol</td><td>0.414</td><td>2.48</td><td>0.828</td><td>3.73</td></tr></tbody></table> Additional answer space if required. $1 : 6 : 2 : 9$ $\Rightarrow CuH_6N_2O_9$ A hydrated salt is made up of an anhydrous salt with water of crystallisation. $Cu(NO_3)_2 \cdot 3H_2O$ [F] <i>and molecular</i> $\Rightarrow$ This fits the empirical formula. NOTE: ② The oxidation number of Cu goes from +1 to 0 in Cu_2O, and from +1 to +2 in $CuSO_4(aq)$. Cu is reduced to form Cu and oxidised to form Cu^{2+} in $CuSO_4$. This exemplifies how considered structuring of candidate responses can enhance their clarity. The clear labelling of C-F in the response, along with numbering which corresponds to the reactions in the question stem, make the candidate's line of reasoning easy to follow. The underlining and annotations in the question stem show good practice in picking out and interpreting key information.		Cu	H	N	O	mass	26.29	2.48	11.59	59.63	rfm	63.5	1	14	16	mol	0.414	2.48	0.828	3.73
	Cu	H	N	O																					
mass	26.29	2.48	11.59	59.63																					
rfm	63.5	1	14	16																					
mol	0.414	2.48	0.828	3.73																					
			Total	16																					

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
43			$2\text{MnO}_4^- + 5\text{H}_2\text{O}_2 + 6\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 8\text{H}_2\text{O} + 5\text{O}_2$ Correctly balanced equation for $\text{MnO}_4^-/\text{H}_2\text{O}_2$ reaction but no cancelling of H^+ and/or e^- ✓ Overall equation correct with all species cancelled ✓	2	ALLOW multiples ALLOW $\rightleftharpoons$ instead of $\rightarrow$ sign ALLOW 1 mark for final equation with correct balancing numbers AND ONE small slip in a formula OR charge IGNORE annotations around equations, i.e. treat as rough working ALLOW 1 mark for: $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$ (H_2O_2 is acting as both reducing and oxidising agent) <u>Examiner's Comments</u> This part discriminated extremely well with many candidates obtaining either both marks or zero marks. Candidates needed to select the correct redox pairs, combine them and cancel H^+ and H_2O. Many otherwise correct equations did not receive credit as they contained basic balancing errors. As a final step in constructing an equation, candidates are recommended to check the formulae of their species and that the equation is balanced.
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
44		i	Colourless to yellow ✓	1	IGNORE clear for colourless <u>Examiner's Comments</u> Candidates were expected to apply their knowledge of the colour change in a manganate(VII) titration to this novel situation. Most candidates incorrectly showed the inverse colour change of yellow → colourless.
		ii	Mean titre $= \frac{(23.15 + 23.25)}{2} = 23.2(0) \text{ (cm}^3\text{)} \checkmark$ Analysis of results 5 marks $n(\text{Ce}^{4+}) = 23.20 \times \frac{0.0500}{1000} = 1.16 \times 10^{-3} \text{ (mol)} \checkmark$ $n((\text{COOH})_2) \text{ in } 25.0 \text{ cm}^3 = \frac{1.16 \times 10^{-3}}{2} = 5.8(0) \times 10^{-4} \text{ (mol)} \checkmark$ $n((\text{COOH})_2) \text{ in } 250 \text{ cm}^3$ $= 5.8(0) \times 10^{-4} \times 10 = 5.8(0) \times 10^{-3} \text{ (mol)} \checkmark$ Mass $(\text{COOH})_2 = 5.8(0) \times 10^{-3} \times 90.0 = 0.522 \text{ g} \checkmark$ $\% \text{ oxalic acid} = \frac{0.522 \times 100}{82.68} = 0.631\% \checkmark$ Percentage MUST be expressed to 3 SF	6	Common error: Incorrect mean from all 3 titres = 23.30 cm³ Use ECF throughout Intermediate values for working to at least 3 SF. TAKE CARE as value written down may be truncated value stored in calculator. Depending on rounding, either can be credited. COMMON ERRORS: Mean of 23.30 (use of all 3 titres) → 0.634%: 5 marks TAKE CARE for final answer of 0.63 seen. • No final mark as only 2 SF • 0.63 may have been rounded from 0.631 (from correct mean) OR from 0.634 (using mean from all 3 titres) Check back to mean titre. No ÷2 to <i>obtain</i> $n((\text{COOH})_2)$ → 1.26%: 5 marks from 23.20 → 1.27% 4 marks from 23.30 <u>Examiner's Comments</u> Most candidates answered this unstructured titration calculation well, with almost all responses gaining some credit. Most coped well with the 1:2 reaction stoichiometry and the need to scale up to 250 cm³. Common errors included the following. • Taking the mean of all three titres

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
			(23.30 cm³) instead of the closest titres (23.20 cm³). • Not considering the 1:2 stoichiometry. • Not scaling up to 250 cm³. • Giving the final answer to two rather than three significant figures; this was the most common error. The question required the final answer to be given to an appropriate number of significant figures. Many candidates seemed to be unaware that this reflects the least significant figures provided in the data, in this case three significant figures. Candidates are also advised to only round at the end of a multi-step calculation. Rounding of intermediate values introduces rounding errors in the final answer. The example shows a perfect response with each step clearly described, leading to the correct concentration of ethanedioic acid. Candidates should present their calculations clearly. If there is a mistake at any stage, this can be easily identified, allowing for error carried forward to be applied for any subsequent good method. Exemplar 6 mean titre value = $\frac{23.25 + 23.15}{2} = 23.20$ ✓ volume of Ce(SO₄)₂ = 0.0232 dm³ conc of Ce(SO₄)₂ = 0.05 mol dm⁻³ moles of Ce(SO₄)₂ = 1.16×10^{-3} mol 25 cm³ of ethanedioic acid reacts with 1.16×10^{-3} mol of Ce(SO₄)₂ moles of ethanedioic acid in 25 cm³ = 5.8×10^{-4} moles of ethanedioic acid in 250 cm³ = 5.8×10^{-3} mass of ethanedioic acid extracted: mass = moles × Mr = $5.8 \times 10^{-3} \times 90 = 0.522$ g $\frac{0.522}{82.68} \times 100 = 0.631\%$ percentage of ethanedioic acid = 0.631% ✓✓✓✓

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
45	a	i		4 (AO 1.2 ×4)	Mark each marking point independently Correct species AND state symbols required for each mark For e^-, ALLOW e For e^- only, IGNORE any state symbols added Examiner's Comments Some candidates wrote illegible state symbols where (g) and (s) were impossible to tell apart. Also, many candidates choose to write state symbols as a very small subscript e.g. $2K_{(s)} + \frac{1}{2}O_{2(g)}$. The convention is to use lower case letters of normal size e.g. $2K(s) + \frac{1}{2}O_2(g)$ Exemplar 1 In this exemplar it was impossible to tell if K had (s) or (g) as a state symbol. Consequently, no marks could be given.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	FIRST CHECK THE ANSWER ON ANSWER LINE If answer = $-2277 \text{ (kJ mol}^{-1}\text{)}$ award 2 marks $-363 - (2 \times +89 + 249 + 2 \times 419 - 141 + 790) \checkmark$ $-363 - 1914$ $= -2277 \checkmark \text{ (kJ mol}^{-1}\text{)}$	2 (AO 2.2 $\times 2$)	IF there is an alternative answer, check to see if there is any ECF credit possible using working below See list below for marking of answers from common errors ALLOW for 1 mark ONE mistake with sign OR use of 2 $\times$: +2277 (wrong sign) -601 (2×-419 instead of $2 \times +419$) -697 (-790 instead of $+790$) -1551 ($+363$ instead of -363) -1858 ($2 \times +419$ not used for K) -1921 (2×-89 instead of $2 \times +89$) -2152.5 or -2153 ($+249 \div 2$) -2188 ($2 \times +89$ not used for K) -2280 (rounded to 3SF) -2559 ($+141$ instead of -141) For other answers, check for a single transcription error or calculator error which could merit 1 mark Examiner's Comments Most candidates scored both marks. Candidates tended to forget the mole ratio of K meant its values should be multiplied by 2 in two places during this calculation.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	<i>For sodium</i> atomic radius smaller OR fewer shells ✓ nuclear attraction increases OR (outer) electron(s) experience more attraction ✓	2 (AO 1.1 ×2)	ALLOW 'Na/sodium is smaller' IGNORE smaller radius / fewer shells / less shielding if applied to ions but DO NOT ALLOW responses which refer to ions losing electrons DO NOT ALLOW molecules ALLOW energy levels for shells IGNORE fewer orbitals OR fewer sub-shells ALLOW less (electron) shielding OR electron repulsion between shells IGNORE just 'shielding' ALLOW more/stronger/bigger nuclear attraction etc IGNORE 'pull' for attraction IGNORE electrons more tightly held IGNORE 'nuclear charge' for 'nuclear attraction' IGNORE more energy (in question) ALLOW reverse argument for potassium throughout <u>Examiner's Comments</u> Candidates coped well with this question which was based on the AS part of the specification. Some candidates gave vague and unnecessarily long responses to this question.

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Question			Answer/Indicative content	Marks	Guidance
		ii	<i>Comparison of size of cations</i> For sodium ions ionic radius of sodium / Na^+ is smaller ✓ <i>Comparison of attraction of cation and anion</i> Na^+ has stronger attraction to O^{2-} ✓	2 (AO 1.2 ×2)	comparison of IONS is essential ALLOW Na^+ has a larger charge density IGNORE 'Na has smaller atomic radius' but DO NOT ALLOW contradictory sentences eg 'Na+ ions have smaller atomic radius' IGNORE pull for attraction ALLOW 'sodium ion' and 'oxygen ion' IGNORE just 'oxygen' or just 'O' for oxygen ion ALLOW stronger attraction between oppositely charged ions Examiner's Comments Many candidates did not achieve full marks, often through ambiguous statements. A typical example is shown in the exemplar below. Exemplar 4 It takes less energy to form the bonds in sodium oxide as opposed to potassium oxide due to its smaller ionic size making it easier for the oxygen to bond. The exemplar here uses the vague term 'due its smaller ionic size'. It is unclear which of the ions the candidate is referring to (or if they're assuming that the metal oxide entity is an ion) and so they could not be given marks.. Also, it is oxygen ions that 'bond' – the reference to oxygen bonding in the response is not specific enough.
			Total	10	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
46	FIRST CHECK THE ANSWER IN ON ANSWER LINE If answer = (+)156 (J K⁻¹ mol⁻¹) award 4 marks ----- Part 1: Calc of $\Delta_r S$ Use of 298 K (seen anywhere) 1 mark ✓ • e.g. $-16.1 = -55.8 - 298 \times \Delta S$ ----- CORRECT use of Gibbs' equation 1 mark • using candidate's temperature (e.g. 298) ✓ • with -16.1 AND -55.8 • to calculate ΔS in <i>kJ OR J</i> ----- Part 2: Calc of $S(\text{Na}_2\text{S}_2\text{O}_3)$ 1 mark CORRECT use of standard S data in question ✓ Seen anywhere (could be within an expression) e.g. $372.4 - [S(\text{Na}_2\text{S}_2\text{O}_3) + (5 \times 69.9)]$ - OR $372.4 - (5 \times 69.9)$ - OR $372.4 - 349.5$ - OR 22.9 IGNORE sign, i.e. ALLOW -22.9, etc ----- CORRECT calculation of $S(\text{Na}_2\text{S}_2\text{O}_3)$ using candidate's calculated ΔS in Part 1 to 3 SF	4 AO2.4×4	Using 298 K, $\Delta S = \frac{-55.8 - (-16.1)}{298} = \frac{-39.7}{298}$ = -0.133... (kJ K⁻¹ mol⁻¹) OR -133... (J K⁻¹ mol⁻¹) Sign required IGNORE units Calculator: -0.133221 (kJ K⁻¹ mol⁻¹) -133.221 (J K⁻¹ mol⁻¹) ALLOW ECF from incorrect temperature. ----- Using -133: $S(\text{Na}_2\text{S}_2\text{O}_3) = 372.4 - 349.5 - (-133)$ = 22.9 + 133 = (+)156 (J K⁻¹ mol⁻¹) 3 SF required ALLOW ECF from incorrect $\Delta_r S$ (Part 1) Examiner's Comments This was a testing question. This question discriminated very well but lower ability candidates struggled to score marks. This unfamiliar scenario required candidates to first decide on a strategy for solving the problem. Candidates needed to use the Gibbs' equation and supplied data to determine the entropy change. They then needed to combine this value with other supplied data to determine the unknown standard entropy. The data provided were all standard, signified by the standard sign. Candidates were expected to use 298 K as the standard temperature to first determine the entropy change. Although many candidates chose 298 K, many different temperatures were seen, with 273 K and 286.5 K (the temperature change in 5a(i))

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Question			Answer/Indicative content	Marks	Guidance
					being common. Some candidates were obviously thrown by the absence of a stated temperature and many omitted T from their Gibbs' equation, using $\Delta G = \Delta H - \Delta S$ instead. This calculated value for ΔS (correct: -0.133 kJ) then needed to be combined with the supplied entropy data to determine the unknown standard entropy (correct: 156 J) to three significant figures. ECF could be applied during marking but this second calculation first required a unit conversion from kJ to J. Many candidates did not make this conversion. Some candidates made errors combining this information, e.g. incorrect signs, adding rather than subtracting and no unit conversions. Finally, some candidates, successful in their calculation, did not follow the instruction to quote their answer to three significant figures. Exemplar 5 shows a very clear response. The candidate has used the Gibbs' equation to determine ΔS first in kJ and then, in preparation for the second part of the determination, in J. The ΔS value is combined with the supplied entropy data to obtain the unknown entropy change, shown by 'x' in the response. This calculated value is then rounded to the required three significant figures. Exemplar 5 $\Delta G = \Delta H - T\Delta S$ $-16.1 = -55.8 - 298\Delta S$ $298\Delta S = -39.7$ $\Delta S = -0.1332214765 \text{ kJ K}^{-1} \text{ mol}^{-1}$ $= -133.2214765 \text{ J K}^{-1} \text{ mol}^{-1}$ $372.4 - (5 \times 69.9) - x = -133.2214765$ $x = 156.1214765$ $= 156$ $S^\circ = 156 \text{ J K}^{-1} \text{ mol}^{-1}$ [4]

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	4	
47			C	1 (AO2.1)	<u>Examiner's Comments</u> Only the higher attaining candidates opted for the correct answer of C. Many candidates thought statement 1 was correct, (giving option A as the answer), not realising that this equation refers to acidic conditions not alkaline conditions (as mentioned in the question). Others did not recognise that the cell potential was 1.23V (obtained by calculating the difference between +0.40 and -0.83), and so opted for option B.
			Total	1	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
48	FIRST, CHECK THE ANSWER ON ANSWER LINE IF $\Delta_c H = -1860$ OR -1850 (kJ mol^{-1}) with evidence of working, award 3 marks IF $\Delta_c H = -1862$, award 2 marks (not 3 SF) Energy released in J OR kJ $= 100 \times 4.18 \times 24.5 = \pm 10241$ (J) OR ± 10.241 (kJ) ✓ 3 SF minimum required Calculates $n(\text{C}_3\text{H}_8)$ $= \frac{0.242}{44(.0)} = 0.0055(0)$ (mol) ✓ Calculates $\Delta_c H$ with – sign AND 3 SF (appropriate) $\Delta_c H = \frac{10241}{0.0055 \times 1000} = -1862$ No mark $= -1860$ OR -1.86×10^3 (kJ mol^{-1}) ✓ – sign AND 3 SF required	3 (AO 2.4) (AO 2.4) (AO 2.8)	FULL ANNOTATIONS MUST BE USED ALLOW ECF throughout DO NOT ALLOW $c = 4.2 \rightarrow 10290$ Next 2 marks available by ECF $\rightarrow -1870$ ALLOW 10240/10200 J OR 10.24/10.2 kJ IGNORE units ALLOW ECF from initial 3 SF rounding to 10.2 kJ: $\pm \frac{10200}{0.0055 \times 1000} \rightarrow \pm 1854.545455$ ✓ $\rightarrow 1850$ ✓ Common errors $\Delta H = -54.6$ OR -54.7 2 marks by ECF from $mc\Delta T$ m wrong as 0.242 and ΔT wrong as 297.5 K $\rightarrow mc\Delta T$ wrong as 300.9391 (J) $\Delta H = -4.51$ 2 marks by ECF from $mc\Delta T$ m wrong as 0.242 and ΔT correct as 24.5) $\rightarrow mc\Delta T$ wrong as 24.78322 (J) $\Delta H = -22600$ 2 marks by ECF from $mc\Delta T$ m correct as 100 and ΔT wrong as 297.5) $\rightarrow mc\Delta T$ wrong as 124355 (J) Examiner's Comments Most candidates analysed the raw practical results supplied to correctly calculate the energy change as 10,241 J using $q = mc\Delta T$, and the amount of propane burnt as 0.0550 mol. Candidates usually determined the energy change per mole of propane as 1862 kJ. The question asked for the enthalpy change of combustion to 3 significant figures, which gives $-1860 \text{ kJ mol}^{-1}$. The mark for this final value was often not given because either the – sign was omitted or

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Question			Answer/Indicative content	Marks	Guidance
					the answer was not quoted to the required 3 significant figures. Candidates are advised to read the requirements of each question more closely to eliminate such errors. A double-check on significant figure requirements is recommended before moving on to the next question. Lower-attaining candidates often extracted the wrong data from the results table. Instead of the mass of water (100 cm^3), the mass of propane burnt (0.242 g) was often used in the $q = mc\Delta T$ calculation. Candidates are advised that the thermometer measures the temperature change of the material in which it is placed (the water).
		ii	Any two from: 1 MARK ONLY ✓ - Heat loss/released to surroundings - Incomplete combustion/reaction with oxygen or air OR not everything burns - Evaporation of water	1 (AO 1.2)	IGNORE incomplete 'reaction' <i>Needs link to combustion/burning/reaction with air/O₂</i> IGNORE evaporation of C₃H₈ <u>Examiner's Comments</u> One mark was available for identifying two reasons for the difference in enthalpy change. It was expected that candidates would respond with 'heat loss' and 'incomplete combustion'. Most candidates suggested heat loss but the other reason often suggested was equipment error, e.g. the thermometer did not reading correctly', 'the balance gave incorrect readings'. Candidates are advised that responses of faulty apparatus are unlikely to be creditworthy.
			Total	4	
49			C	1 (AO 2.6)	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
50		i	$\text{Mg}^{2+}(\text{g}) + 2\text{Br}(\text{g}) + 2\text{e}^{-} \checkmark$ $\text{Mg}(\text{s}) + \text{Br}_2(\text{l}) \checkmark$	2 (AO 1.2×2)	State symbols required. CARE: Liquid state symbol for Br_2 <u>Examiner's Comments</u> Many candidates got the second ionisation energy equation. Very few candidates got the correct state symbol on the lower line for Br_2, with solid being the common response.
		ii	FIRST CHECK THE ANSWER ON ANSWER LINE If answer = -346.5 award 2 marks ----- $2\Delta H_{\text{hyd}} =$ $-525 - 186 - (2 \times 112) - 148 - 736 - 1450$ $+ (2 \times -325) + 1926$ OR $-525 - 186 - 224 - 148 - 736 - 1450 + 650 + 1926$ OR $= -693 \checkmark$ $\Delta H_{\text{hyd}} = -346.5 (\text{kJ mol}^{-1}) \checkmark$	2 (AO 2.2×2)	ALLOW -347 (kJ mol^{-1}) for 2 marks. ALLOW for 1 mark ONE error with sign OR use of 2: -693 (not divided by 2 at the end) 346.5 (wrong sign on answer) Common errors for 1 mark -2272.5 (-1926 instead of 1926) -1386 (2 x -693 instead of -693) -996.5 (-650 instead of 650) -509 (2 x 325 not used) -290.5 (2 x 112 not used) -198.5 (148 instead of -148) -160.5 (186 instead of -186) -122.5 (224 instead of -224) 178.5 (525 instead of -525) 389.5 (736 instead of -736) 1103.5 (1450 instead of -1450) For other answers, check for a single transcription error or calculation error which could merit 1 mark DO NOT ALLOW any answer which involves two errors e.g. -453 (2 x 325 not used AND 2 x 112 not used)

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Equation: $\text{Mg}^{2+}(\text{g}) + 2\text{Br}^{-}(\text{g}) \rightarrow \text{MgBr}_2(\text{s})$ ✓ CHECK THE ANSWER ON ANSWER LINE If answer = -2433 award 2 marks ----- Lattice enthalpy = $\Delta_{\text{hy}}H(\text{Mg}^{2+}) + 2 \times \Delta_{\text{hy}}H(\text{Br}^{-}) - \Delta_{\text{sol}}H(\text{MgBr}_2)$ OR $-1926 + (2 \times -346.5) - (-186)$ OR $\Delta_{\text{f}}H(\text{MgBr}_2) - 2\Delta_{\text{at}}H(\text{Br}) - \Delta_{\text{at}}H(\text{Mg})$ $- 1\text{st IE}(\text{Mg}) - 2\text{nd IE}(\text{Mg}) - 2\Delta_{\text{ea}}H(\text{Br})$ OR $-525 - (2 \times 112) - 148 - 736 - 1450 - (2 \times -325)$ ✓ Lattice enthalpy = $-2433 \text{ kJ mol}^{-1}$ ✓	3 (AO 1.2) (AO 2.2 x 2)	State symbols required For other answers, check for a single transcription error or calculation error which could merit 1 mark DO NOT ALLOW any answer which involves two errors ALLOW ECF from incorrect answer to (ii) <u>Examiner's Comments</u> This Born Haber cycle combined the traditional cycle with the enthalpy solution/hydration cycle. Many candidates were successful in calculating the values from the information given and showed full working to complete the calculation. The commonest errors were not doubling the atomisation and electron affinity values (112 and 325) and not dividing the enthalpy of hydration by two. Some candidates did not show working or just listed numbers. Candidates should remember to provide written indications of what it is they are working out – presenting the calculations without any annotations can make it harder for error carried forward marks to be given if there is an error in their calculation. Some candidates did not produce an equation for (iii) and wrote the lattice enthalpy sum in its place.
			Total	7	
51			$2\text{H}^{+} + \frac{1}{2}\text{O}_2 + 2\text{e}^{-} \rightarrow \text{H}_2\text{O}$ ✓ $1.34 + (-0.11) = (+)1.23 \text{ (V)}$ ✓	2 (AO 2.6) (AO 2.2x1)	IGNORE state symbols ALLOW multiples
			Total	2	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
52	<i>Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) Calculates CORRECT enthalpy change with correct – signs for $\Delta_{\text{sol}}H$ ($\text{CuSO}_4(\text{s})$) for reaction 5.2 AND Δ_rH, for reaction 5.1. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Calculates a value of $\Delta_{\text{sol}}H$ ($\text{CuSO}_4(\text{s})$) for reaction 5.2 from the: Energy change AND Amount in mol of CuSO_4. <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i> Level 1 (1–2 marks) Processes experimental data to obtain the: Energy change from $mc\Delta T$ OR Amount in mol of CuSO_4. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks – No response or no response worthy of credit	6 AO3.1x4 AO3.2x2	<i>Indicative scientific points may include:</i> 1. Processing experimental data Energy change from $mc\Delta T$ - Energy in J OR kJ <i>Using 50.70 g, 50.0 g</i> $= 50.70 \times 4.18 \times 13.5 = 2861 \text{ (J) OR } 2.861 \text{ (kJ)}$ <i>3SF or more (2.861001 unrounded)</i> OR $50.0 \times 4.18 \times 13.5 = 2821.5 \text{ (J) OR } 2.8215 \text{ (kJ)}$ Amount in mol of CuSO_4 $n(\text{CuSO}_4) = \frac{7.98}{159.6} = 0.0500 \text{ (mol)}$ 2. $\pm$ value of $\Delta_{\text{sol}}H(\text{CuSO}_4(\text{s}))$ for reaction 5.2 From $m = 50.70 \text{ g} = \pm \frac{2.861}{0.0500} = \pm 57.22$ (kJ mol⁻¹) <i>(–57.22002 unrounded)</i> From $m = 50.0 \text{ g} = \pm \frac{2.8215}{0.0500} = \pm 56.43$ (kJ mol⁻¹) 3. CORRECT enthalpy changes for reactions 5.2 and 5.1 with signs (using 50.70 g ONLY) Reaction 5.2 = $-57.22 \text{ (kJ mol}^{-1}\text{)}$ <i>3SF or more with correct – sign</i> Reaction 5.1 $\Delta_rH = \Delta_{\text{sol}}H(\text{CuSO}_4(\text{s})) - \Delta_{\text{sol}}H(\text{CuSO}_4 \cdot 5\text{H}_2\text{O}(\text{s}))$ $= -57.22 - 8.43 = -65.65 \text{ (kJ mol}^{-1}\text{)}$ <i>3SF or more with correct – sign</i> NOTE: A clear and logically structured response would include an energy cycle ALLOW omission of trailing zeroes ALLOW minor slips <u>Examiner's Comments</u> This question was assessed by level of

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Question			Answer/Indicative content	Marks	Guidance
					response (LoR). Candidates were required to process raw experimental results to determine one enthalpy change, and then to determine a second enthalpy change by constructing and using an energy cycle. Levels were determined by the accuracy of the candidates' processing, calculations and use of the energy cycle. This question discriminated extremely well. Level 3 candidates used the mass of solution as 50.7 g with $mc\Delta T$ to obtain an energy change of 2861 J. They then divided this value by the moles of CuSO_4 that reacted (0.05 mol) to obtain the enthalpy change of $-57.22 \text{ kJ mol}^{-1}$. Finally, they constructed an energy cycle which they then used to obtain the second enthalpy change of $-65.65 \text{ kJ mol}^{-1}$. Level 2 candidates determined the first enthalpy change but may have used the approximate mass of 50 g for the mass of solution from the experimental method. Their energy cycle was often incorrect or absent, with the second enthalpy change calculated incorrectly. Level 1 candidates often calculated the initial energy change using $mc\Delta T$ but made little further correct progress. A significant number of lower ability candidates used the solid mass of copper sulfate in their calculation. Overall, mathematical skills were displayed well but some basic errors were made, particularly with subtractions. This may have been the result of mis-keying values into a calculator and believing the answer displayed. An example was the mass of the solution ($74.13 - 23.43$) being seen as 49.7 rather than 50.7. A significant number of candidates added or subtracted the mass of copper sulfate from 50.7 or 50 for their value of m in $mc\Delta T$, using for example 57.98 and 42.72. This limited the level that they could reach.

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Question			Answer/Indicative content	Marks	Guidance
					Exemplar 4 is an excellent response from a Level 3 candidate. All stages can be clearly followed, the initial energy change using $mc\Delta T$, the first enthalpy change using the energy change with the moles of copper sulfate, and the second enthalpy change including a clear energy cycle. Numbers are clearly shown and unrounded until the final values. This is an excellent response. Exemplar 4 $q = mc\Delta T$ $q = 50.7 \times 4.18 \times 13.5 = 2861.0017$ $= 2.861001 \text{ kJ}$ $n(\text{CuSO}_4) = \frac{7.98}{159.6} = 0.05$ $\Delta_{\text{sol}} H(\text{CuSO}_4) = \frac{-2.861001}{0.05} = -57.22002$ $= -57.22 \text{ kJ mol}^{-1}$ $\text{CuSO}_4 + 5\text{H}_2\text{O} \rightarrow \text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ $\begin{array}{ccc} -57.22002 & & -8.43 \text{ kJ mol}^{-1} \\ & \searrow & \swarrow \\ & \text{Cu}^{2+} + \text{SO}_4^{2-} & \end{array}$ Additional answer space if required $\Delta_{\text{r}} H (\text{reaction 5.1}) = -57.22002 - 8.43$ $= -65.65002 \text{ kJ mol}^{-1}$ $= -65.7 \text{ kJ mol}^{-1}$
		ii	Temperature change = $0.2 \times \frac{100}{20} = 1.0^\circ\text{C}$ ✓	1 AO 2.8	IGNORE direction of temperature change Working NOT required <u>Examiner's Comments</u> Just over half the candidates obtained the correct temperature change of 1°C. A common error was a temperature change of 0.5°C, the result of not considering that two temperature readings are made when calculating a temperature change.
			Total	7	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
53	Refer to marking instructions on page 5 of mark scheme for guidance on marking this question. Level 3 (5-6 marks) Calculates $\Delta_r H$ for reaction 3.1 correctly with correct sign AND Calculates a value for $\Delta_c H^\theta$ of propane using $\Delta_r H$ AND $\pm 4 \times \Delta_{\text{vap}} H$ <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3-4 marks) Calculates $\Delta_r H$ for reaction 3.1 correctly with correct sign OR Calculates bonds broken OR bonds made correctly to obtain a value of $\Delta_r H$ for reaction 3.1 AND attempts to link $\Delta_r H$ with $\Delta_{\text{vap}} H$ OR calculates $4 \times \Delta_{\text{vap}} H$ <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i> Level 1 (1-2 marks) Uses bond enthalpies for bonds broken and bonds made but may contain errors or omissions AND obtains a value for $\Delta_r H$. OR Calculates bonds broken OR bonds made correctly. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.	6 (AO) 2.4×2) (AO) 3.1×2) (AO) 3.2×2)	Indicative scientific points may include: Bond enthalpy calculation of $\Delta_r H$ Bonds broken $= (2 \times 347) + (8 \times 413) + (5 \times 498)$ $= (694) + (3304) + (2490)$ $= \pm 6488 \text{ kJ mol}^{-1}$ Bonds made $= (6 \times 805) + (8 \times 464)$ $= (4830) + (3712) = \pm 8542 \text{ kJ mol}^{-1}$ $\Delta_r H = 6488 - 8542 = -2054 \text{ kJ mol}^{-1}$ NOTE: 3 C–C → 6835 for bond broken: $\Delta H = -1707$ 2 C–C omitted from bonds broken gives: $\Delta H = -2748$ ----- Determination of $\Delta_c H(\text{C}_3\text{H}_8)$ $\Delta_c H^\theta$ of propane using $\Delta_r H$ AND $\pm 4 \times \Delta_{\text{vap}} H$ Correct $\Delta_c H(\text{C}_3\text{H}_8) = \Delta_r H - 4 \times \Delta_{\text{vap}} H$ $= -2054 - (4 \times 40.65)$ $= -2054 - 162.6$ $= -2216.6 / -2217 \text{ kJ mol}^{-1}$ Incorrect $\Delta_c H(\text{C}_3\text{H}_8) = -2054 + (4 \times 40.65)$ $= -2054 + 162.6$ $= -1891.4 / -1891 \text{ kJ mol}^{-1}$ NOTE: A clear and logically structured response would include a <u>correct</u> energy cycle for $\Delta_c H(\text{C}_3\text{H}_8)$ using $\Delta_r H$ AND $4 \times \Delta_{\text{vap}} H$ in energy cycle or expression: ALLOW trailing zeroes OR minor slips Examiner's Comments This question was assessed by LoR. Level 3 candidates calculated the enthalpy change for Equation 3.1 correctly as $-2054 \text{ kJ mol}^{-1}$. They linked $4 \times \Delta_{\text{vap}} H$ with the enthalpy change for Equation 3.1 in an energy cycle and calculated the enthalpy change of combustion as $-2054 - (4 \times 40.65) = -2216.6 \text{ kJ mol}^{-1}$. Most Level 3 candidates drew out bonds in the

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Question			Answer/Indicative content	Marks	Guidance
					molecules involved in Equation 3.1, which allowed them to visually count the bonds broken and bonds made. This strategy is recommended to all candidates for any calculation based on bond enthalpies and is much more likely to generate the correct enthalpy change than visualising the relevant bonds solely from the equation. Level 2 candidates often derived the correct enthalpy change for Equation 3.1 but then tried to link this value with $\Delta_{\text{vap}}H$ instead of $4 \times \Delta_{\text{vap}}H$. Other Level 2 candidates calculated ΔH correctly for either the bonds broken or bonds made and combine this value with $4 \times \Delta_{\text{vap}}H$. A common error was the omission of the 2 C–C bonds in propane, use of 3 C–C, instead of 2 C–C, bonds, or use of 4, rather than 8 O–H bonds. These errors could have been avoided by drawing out the bonds as described above. Level 1 candidates typically attempted to use the bond enthalpies to calculate energies for bonds broken and bonds made but made several errors. They then combined this value with $\Delta_{\text{vap}}H$. This question discriminated extremely well across different abilities.
			Total	6	

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Question	Answer/Indicative content	Marks	Guidance
54	i Overall equation AND state symbols: $\text{M(s)} + 2\text{HCl(aq)} \rightarrow \text{MCl}_2\text{(aq)} + \text{H}_2\text{(g)} \checkmark$ STATE SYMBOLS required in overall equation ONLY Half equations: Oxidation $\text{M} \rightarrow \text{M}^{2+} + 2\text{e}^- \checkmark$ Reduction $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$ OR $\text{H}^+ + \text{e}^- \rightarrow \frac{1}{2}\text{H}_2 \checkmark$	3 (AO 2.6×3)	All 3 marks are independent. IGNORE charges/oxidation numbers shown around overall equation. <i>Treat as rough working</i> ALLOW overall equation shown with some or all ions that are present e.g. (with state symbols) $\text{M} + 2\text{H}^+ \rightarrow \text{M}^{2+} + \text{H}_2$ $\text{M} + 2\text{HCl} \rightarrow \text{M}^{2+} + 2\text{Cl}^- + \text{H}_2$ $\text{M} + 2\text{H}^+ + 2\text{Cl}^- \rightarrow \text{M}^{2+} + 2\text{Cl}^- + \text{H}_2$ In half equations, IGNORE state symbols even is wrong BUT half equations MUST only have species that change. For charges on half equations, ALLOW M^{+2} for M^{2+} OR H^{+1} for H^+ ALLOW $\text{M} - 2\text{e}^- \rightarrow \text{M}^{2+}$ If BOTH half equations are correct but shown with oxidation and reduction the wrong way around, award 1 mark from the 2 marks for half equations Examiner's Comments This question required candidates to write an overall equation and half equations for oxidation and reduction. Many candidates made errors within one or more equations. The overall equation was often written without state symbols, despite the question instruction 'with state symbols'. The oxidation half equation was more likely to be correct than the reduction half equation, which often used Cl instead of H^+. When H^+ was used, the half equation was often unbalanced or electrons had been omitted. It is recommended that candidates carefully use the chemical information in the question.

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Question			Answer/Indicative content	Marks	Guidance
		ii	Bubbles/effervescence/fizzing stops ✓ M/metal/solid has disappeared/dissolved ✓	2 (AO 3.3×2)	Responses must imply that all fizzing has stopped and that all the solid has dissolved i.e. 'metal disappears' is not quite enough. 'All the metal disappears' is enough IGNORE constant mass IGNORE no increase in temperature <u>Examiner's Comments</u> Most candidates identified that all the metal would have reacted when it had all disappeared and that gas bubbles from the reaction would have stopped. Some responses did not emphasise that these observations would have stopped and this prevented credit being given.
		iii	$\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$ ✓	1 (AO 2.5)	ALLOW multiples e.g. $2\text{H}^+ + 2\text{OH}^- \rightarrow 2\text{H}_2\text{O}$ IGNORE state symbols, even if wrong <u>Examiner's Comments</u> The ionic equation for neutralisation of an acid with an alkali was well known and this question was answered correctly by most candidates.

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
iv	Mean titre 1 mark $= \frac{(27.30 + 27.20)}{2} = 27.25 \text{ (cm}^3\text{)} \checkmark$ Analysis of results 5 marks $n(\text{NaOH}) = 27.25 \times \frac{0.320}{1000} = 8.72 \times 10^{-3} \text{ (mol)} \checkmark$ $n(\text{HCl}) \text{ in } 25.0 \text{ cm}^3 = n(\text{NaOH})$ $n(\text{HCl}) \text{ in } 250 \text{ cm}^3$ $= 8.72 \times 10^{-3} \times 10 = 8.72 \times 10^{-2} \text{ (mol)} \checkmark$ $n(\text{HCl}) \text{ that reacted with M}$ $= 0.210 - 8.72 \times 10^{-2} = 0.1228 \text{ (mol)} \checkmark$ $n(\text{M}) \text{ that reacted} = \frac{0.1228}{2} = 0.0614 \text{ (mol)} \checkmark$ $A_r \text{ of M} = \frac{6.90}{0.0614} = 112.4 \text{ AND M} = \text{cadmium/Cd} \checkmark$ COMMON ERRORS: Mean of 27.35 (use of all 3 titres) $\rightarrow 8.752 \times 10^{-3} \rightarrow 8.752 \times 10^{-2} \rightarrow 0.12248$ $\rightarrow 0.06124 \rightarrow 112.7 \text{ AND Cd: 5 marks}$ No $\div 2$ to obtain $n(\text{M})$ $\rightarrow 56.2 \text{ AND Fe (from 27.25) 5 marks}$ $\rightarrow 56.3 \text{ AND Fe (from 27.35) 4 marks}$ No subtraction from 0.210 $A_r \text{ of M} = \frac{6.90}{0.0614} = 112.4 \text{ AND M} = \text{cadmium/Cd} \checkmark$ $\rightarrow 158.2 \text{ to } 158.3 \text{ AND Tb 5 marks}$ No $\times 10$ to obtain $n(\text{HCl})$ in 250 cm^3 5 marks $0.210 - 8.72 \times 10^{-3} = 0.20128 \text{ OR } 0.201$ $n(\text{M}) = 0.20128/2 = 0.10064$ $A_r = 6.90/0.10064 = 68.56 \rightarrow \text{Zn}$ No $\times 10$ and no $\div 2$ 4 marks $0.210 - 8.72 \times 10^{-3} = 0.20128$ $A_r = 6.9/0.20128 = 34.28 \rightarrow \text{Ca}$ Omitting initial titration calculation Zero marks $0.210/2 = 0.105 \rightarrow 6.9/0.105 = 65.71 \rightarrow \text{Zn}$	6 (AO 2.8×5) (AO 3.2)	FULL ANNOTATIONS MUST BE USED Common error: Incorrect mean from all 3 titres = 27.35 cm^3 Use ECF throughout Intermediate values for working to at least 3 SF. TAKE CARE: Value written down may be truncated calculator value. Depending on rounding, either can be credited. ALLOW 0.123 (mol) i.e. 3SF ALLOW 0.0615 (mol) IF 0.1228 rounded to 0.123 ALLOW 112.2 from 0.0615 AND Cd ALLOW A_r to nearest whole number ALLOW ECF for metal closest to calculated A_r DO NOT ALLOW Ga OR Sc (Form 3+ ions only) Examiner's Comments Candidates were presented with information about a back titration, a technique that they would be unlikely to have encountered during their course. The question stem to (iv) suggested a three-step strategy. Many candidates followed this guidance and were credited with many of the available marks. Marks were given for a correct method (by error carried forward) even if there was an error or omission in the multi-step calculation. This emphasises the importance of clear working. Most candidates determined the correct mean titre of 27.25 cm^3. A few candidates

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					did take the mean of all three titres rather than the closest. Most calculated that 8.72×10^{-3} mol of NaOH reacted with the same number of moles of HCl in the titration and then scaled up the HCl by a factor of 10 to 8.72×10^{-2} mol in the 250 cm³ volumetric flask. These steps are standard for many titration calculations and gave a route to three of the six available marks. The more difficult back titration steps then followed and the higher-attaining candidates recognised the need to subtract this amount of HCl from the original amount of HCl used to react with metal M. These candidates then divide this value by two to find the moles of M that reacted (from the 1 : 2 stoichiometry of M : HCl). The correct calculation then gave a relative atomic mass of M as 112 and its identity as cadmium. It was common for candidates to omit the division by two and to arrive at a relative atomic mass of 56 for iron. The mark scheme shows the variety of metals that candidates identified from their calculations, the errors made, and the error carried forward marks that resulted. Many lower-attaining candidates did not follow the 3 steps in the stem, using only the original amount of HCl and ignoring the titration. This approach was not credited with marks. A large range of marks was seen, and the question discriminated extremely well.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
55			FIRST CHECK THE ANSWER ON ANSWER LINE If answer = 25.55 kJ mol⁻¹ OR 25550 J mol⁻¹ award first 4 marks ----- ----- $\Delta S = 238 - (198 + 2 \times 131) \checkmark$ $= -222 \text{ (J K}^{-1} \text{ mol}^{-1}) \text{ OR } -0.222 \text{ (kJ K}^{-1} \text{ mol}^{-1}) \checkmark$ $\Delta G = \Delta H - T\Delta S$ OR $\Delta G = -91 - (525 \times -0.222)$ OR $\Delta G = -91000 - (525 \times -222) \checkmark$ $= 25.55 \text{ kJ mol}^{-1} \text{ OR } 25550 \text{ J mol}^{-1} \checkmark$ (Reaction is) not feasible AND $\Delta G > 0 \checkmark$	5 (AO 2.2×4) (AO 3.2×1)	ALLOW ECF IGNORE units at this stage Units for ΔG required ALLOW 26 kJ mol⁻¹ OR 26000 J mol⁻¹ up to calculator value.
			Total	5	

Mark Scheme

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56	a		Circuit Complete circuit AND voltmeter AND salt bridge linking two half-cells ✓ Half cells Ag AND Ag⁺ AND 1 mol dm⁻³ solution ✓ Pt AND H⁺ AND MnO₄⁻ AND Mn²⁺ AND 1 mol dm⁻³ /equimolar solution ✓	3 (AO 3.4×1) (AO 1.2×1) (AO 1.2×1)	Voltmeter must be shown AND salt bridge must be labelled ALLOW small gaps in circuit If species in BOTH half cells are correct but concentration of 1 mol dm⁻³ omitted, ALLOW 1 mark for BOTH half cells. ALLOW acidified as an alternative for H⁺ IGNORE stated pressure <i>Not relevant here as no gas</i> <u>Examiner's Comments</u> Most candidates drew a circuit containing a voltmeter and the silver half cell but very few candidates included the H⁺ in the MnO₄⁻/Mn²⁺ cell.

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	b		Comparison of E values <i>E</i> of redox system 4 ($\text{MnO}_4^-/\text{Mn}^{2+}$) is more positive/less negative than <i>E</i> of redox systems 2 (HCOOH/HCHO) OR 1 (CO_2/HCOOH) ✓ Equilibrium shift related to <i>E</i> values More negative/less positive/system 2 (HCOOH/HCHO) OR system 1 (CO_2/HCOOH) shifts left OR Less negative/more positive/system 4 ($\text{MnO}_4^-/\text{Mn}^{2+}$) shifts right ✓ • 2 and 4 $2\text{MnO}_4^- + 5\text{HCHO} + 6\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 5\text{HCOOH} + 3\text{H}_2\text{O}$ ✓ • 1 and 4 $2\text{MnO}_4^- + 5\text{HCOOH} + 6\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 5\text{CO}_2 + 8\text{H}_2\text{O}$ ✓	4 (AO 3.1×2) (AO 3.2×2)	IGNORE higher/lower ALLOW Overall $E_{\text{reaction}} = (+)1.54\text{V}$ OR $(+)1.62\text{V}$ For 'shifts left', ALLOW 'is oxidised' OR 'electrons are lost' OR 'reducing agent' For 'shifts right', ALLOW 'is reduced' OR 'electrons are gained' OR 'oxidising agent' IGNORE state symbols ALLOW multiples DO NOT ALLOW un-cancelled species, e.g. H^+, on both sides ALLOW for 1 mark two balanced equations with uncancelled species. ALLOW combined equation for 2 marks: $4\text{MnO}_4^- + 5\text{HCHO} + 12\text{H}^+ \rightarrow 4\text{Mn}^{2+} + 5\text{CO}_2 + 11\text{H}_2\text{O}$ Examiner's Comments Higher-attaining candidates described two oxidations starting from HCHO to end up with CO_2. Many candidates used the data correctly but stopped at the first oxidation to form HCOOH. Lower-attaining candidates did not state that the direction of reaction of redox equilibria is dependent on the relative negativity/positivity of the standard electrode potentials. Some candidates are still using higher/lower to compare the <i>E</i> cell values, and should be encouraged to instead use the phrasing 'more positive' or 'more negative'. Many candidates wrote a correct first equation, although some did not cancel down the H^+ and/or water.
			Total	7	

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Question			Answer/Indicative content	Marks	Guidance
57			$n(\text{MnO}_4^-) \text{ in titration}$ $= 0.01 \times \frac{12.6}{1000} = 1.26 \times 10^{-4} \checkmark$ $n(\text{SO}_3^{2-}) \text{ in } 25.0 \text{ cm}^3$ $= 1.26 \times 10^{-4} \times 2.5 = 3.15 \times 10^{-4} \text{ (mol)} \checkmark$ $n(\text{SO}_3^{2-}) \text{ in } 250 \text{ cm}^3$ $= 10 \times 3.15 \times 10^{-4} = 3.15 \times 10^{-3} \text{ (mol)} \checkmark$ $\text{mass Na}_2\text{SO}_3 \text{ in } 525 \text{ g meat}$ $= 3.15 \times 10^{-3} \times 126.1 = 0.397 \text{ (g)} \checkmark$ $\text{mass Na}_2\text{SO}_3 \text{ in } 1 \text{ kg of meat}$ $= 0.397215 \times \frac{1000}{525} = 0.7566 \text{ g OR } 756.6 \text{ mg}$ AND less than the maximum permitted level OR AW $\checkmark$	5 (AO 1.2×1) (AO 2.8×3) (AO 3.2×1)	ALLOW 3 SF or more throughout ALLOW ECF throughout Calculator = 0.397215 g ALLOW within range: 756 to 757 mg ALLOW 0.397 g<0.446 g per 525 g meat. <u>Examiner's Comments</u> This question asked the candidate to determine the amount of sodium sulfite in food. Many candidates gained full marks. Most candidates calculated the number of moles of MnO_4^- and SO_3^{2-} . Some candidates calculated the mass in 525 g of meat, although some used the wrong Mr, e.g. 80, for the sulfite ion. The lower ability candidates did not process the scaling to 1 Kg.
			Total	5	