1. The table below shows the enthalpy changes needed to calculate the lattice enthalpy of calcium oxide, CaO.

process	**enthalpy change/ kJ mol^{-1}**
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1150
first electron affinity of oxygen	–141
second electron affinity of oxygen	+ 791
enthalpy change of formation of calcium oxide	–635
enthalpy change of atomisation of calcium	+178
enthalpy change of atomisation of oxygen	+248

(a) (i) Explain why the second ionisation energy of calcium is **more endothermic** than the first ionisation energy of calcium.

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.....

.....

[2]

(ii) Suggest why the second electron affinity of oxygen is positive.

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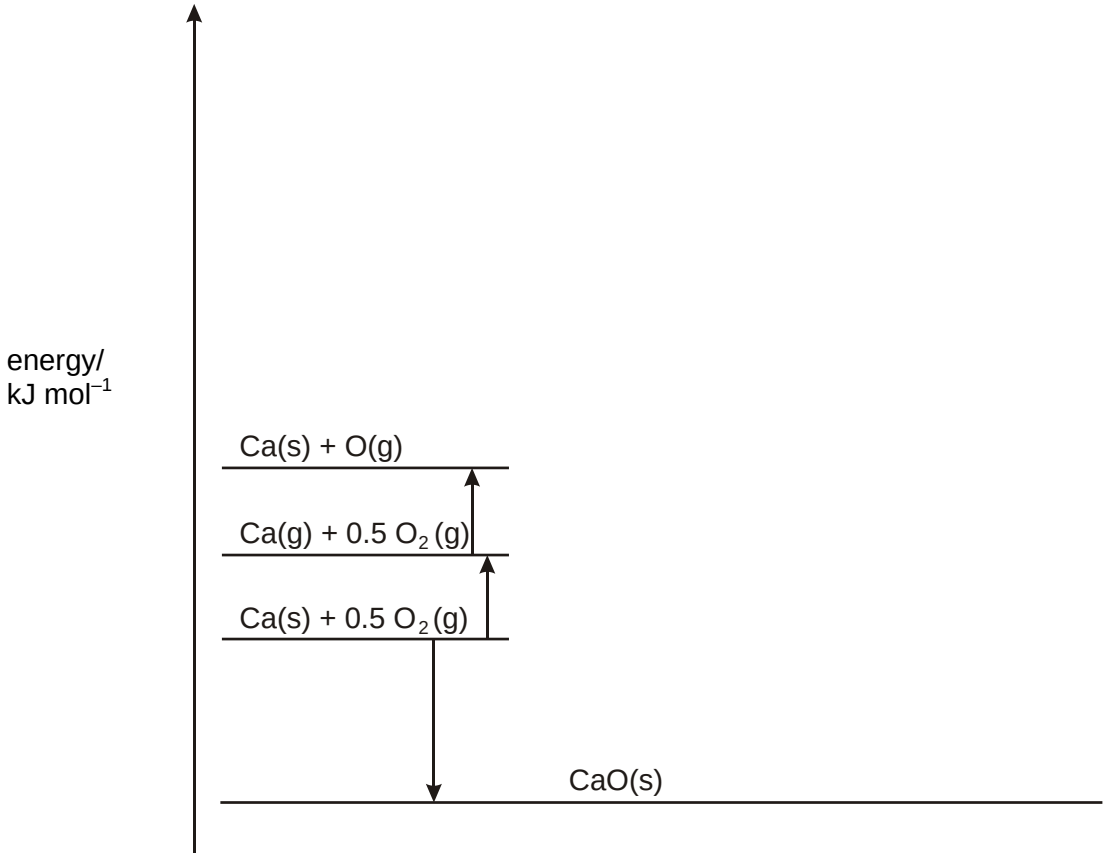
.....

.....

[2]

(b) Complete the Born–Haber cycle for calcium oxide below.

Use the data in the table to calculate the lattice enthalpy of calcium oxide.



lattice enthalpy = ... kJ mol^{-1}

[5]

(c) The lattice enthalpies of calcium oxide and magnesium oxide are different.

Comment on this difference.

In your answer you should make clear how the sizes of the lattice enthalpies are related to any supporting evidence.

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.....

[3]

[Total 12 marks]

2. Most metals can be extracted by reduction from compounds obtained from their naturally-occurring ores.

Metals such as calcium and magnesium are normally extracted by electrolysis but it is feasible that calcium oxide could be reduced by carbon as shown in the equation below.

$$CaO(s) + C(s) \rightarrow Ca(s) + CO(g)$$

Use the data in the table below to help you answer parts (i)–(iii) below.

	CaO(s)	C(s)	Ca(s)	CO(g)
$\Delta H_f^{\ominus}$ /kJ mol^{-1}	–635	0	0	–110
$S^{\ominus}$/J K^{-1} mol^{-1}	39.7	5.7	41.4	197.6

(i) Calculate the standard enthalpy change for the CaO reduction in the equation.

$\Delta H^{\ominus}$ = ... kJ mol^{-1}

[1]

(ii) Calculate the standard entropy change for the CaO reduction in the equation.

$\Delta S^{\ominus}$ = ... J K^{-1} mol^{-1}

[1]

(iii) Calculate the minimum temperature at which the carbon reduction in the equation is feasible.

minimum temperature = ...

[5]

[Total 7 marks]

3. Use the standard electrode potentials in the table below to answer the questions that follow.

I	$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	$E^\ominus = -0.44$ V
II	$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	$E^\ominus = -0.26$ V
III	$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	$E^\ominus = 0.00$ V
IV	$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	$E^\ominus = +0.40$ V

An electrochemical cell was set up based on systems **I** and **II**.

(i) Write half-equations to show what has been oxidised and what has been reduced in this cell.

oxidation:

reduction:

[2]

(ii) Determine the cell potential of this cell.

E_{cell} = ... V

[1]

[Total 3 marks]

4. Use the standard electrode potentials in the table below to answer the questions that follow.

I	$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	$E^\ominus = -0.44$ V
II	$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	$E^\ominus = -0.26$ V
III	$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	$E^\ominus = 0.00$ V
IV	$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	$E^\ominus = +0.40$ V

An electrochemical fuel cell was set up based on systems **III** and **IV**.

(i) Construct an equation for the spontaneous cell reaction. Show your working.

[2]

(ii) Fuels cells based on systems such as **III** and **IV** are increasingly being used to generate energy.

Discuss **two** advantages and **two** disadvantages of using fuels cells for energy rather than using fossil fuels.

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.....

[4]

[Total 6 marks]

5. In this question, one mark is available for the quality of spelling, punctuation and grammar.

The lattice enthalpy of magnesium chloride, $MgCl_2$, can be determined using a Born-Haber cycle and the following enthalpy changes.

name of process	enthalpy change / kJ mol^{-1}
enthalpy change of formation of $MgCl_2(s)$	–641
enthalpy change of atomisation of magnesium	+148
first ionisation energy of magnesium	+738
second ionisation energy of magnesium	+1451
enthalpy change of atomisation of chlorine	+123
electron affinity of chlorine	–349

- Define, using an equation with $MgCl_2$ as an example, what is meant by the term *lattice enthalpy*.
- Construct a Born-Haber cycle for $MgCl_2$, including state symbols, and calculate the lattice enthalpy of $MgCl_2$.
- Explain why the lattice enthalpy of NaBr is much less exothermic than that of $MgCl_2$.

(Allow one and a half lined pages).

[11]

Quality of Written Communication [1]

[Total 12 marks]

6. The standard electrode potential of $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$ is +0.34 V.

(a) Define the term *standard electrode potential*.

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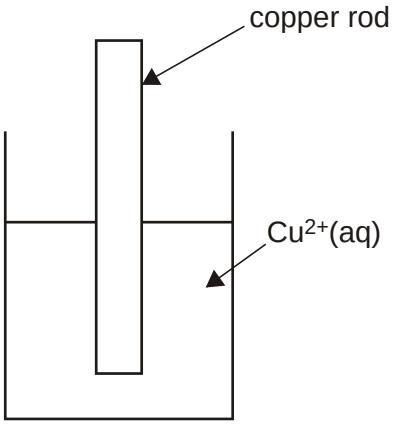
[3]

(b) Complete the diagram to show how the standard electrode potential of $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$ could be measured.



[3]

[Total 6 marks]

7. Chromium is an important metallic element. Its compounds have a number of different oxidation states.

(a) (i) Give one use of chromium metal and state the property of chromium that makes it suitable for this use.

.....

.....

[1]

(ii) Complete the electronic configuration of a chromium atom.

$1s^2 2s^2 2p^6$ .....

[1]

(b) The following equations relate to half-cells involving iron and chromium ions.

$$Fe^{3+} + e^- \rightleftharpoons Fe^{2+} \qquad E^{\ominus} = +0.77 \text{ V}$$

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O \qquad E^{\ominus} = +1.33 \text{ V}$$

A cell was set up by combining these two half-cells.

(i) Derive a balanced equation for the reaction that would occur when the cell is in use.
Explain your reasoning in terms of oxidation and reduction.

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.....

[3]

(ii) Determine the emf of the cell under standard conditions.

emf = ... V

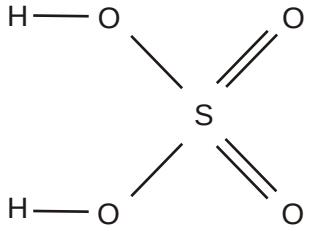
[1]

[Total 6 marks]

› ì**8.** In order to obtain full marks in this question, you must show **all** your working clearly.

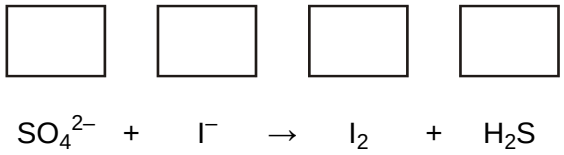
In its reactions, sulphuric acid, H_2SO_4, can behave as an acid, an oxidising agent and as a dehydrating agent.

The displayed formula of pure sulphuric acid is shown below.



Concentrated sulphuric acid will readily oxidise halide ions to the halogen.

The equation below represents the unbalanced equation for the oxidation of iodide ions by sulphuric acid.



$$H^+ \quad + \quad SO_4^{2-} \quad + \quad I^- \quad \rightarrow \quad I_2 \quad + \quad H_2S \quad + \quad H_2O$$

(i) Write the oxidation numbers of sulphur and iodine in the boxes above the equation.

[2]

(ii) Balance the equation above.

[1]

[Total 3 marks]

9. The table below shows the enthalpy changes needed to calculate the enthalpy change of formation of calcium oxide.

process	enthalpy change/kJ mol^{-1}
lattice enthalpy for calcium oxide	–3459
first ionisation energy for calcium	+590
second ionisation energy for calcium	+1150
first electron affinity for oxygen	–141
second electron affinity for oxygen	+798
enthalpy change of atomisation for oxygen	+249
enthalpy change of atomisation for calcium	+178

(a) (i) Explain why the first ionisation energy of calcium is endothermic.

.....

.....

[1]

(ii) Explain why the first electron affinity for oxygen is exothermic.

.....

.....

[1]

(b) (i) Draw a Born-Haber cycle for calcium oxide.

Include

- correct formulae and state symbols
- energy changes in kJ.

[3]

(ii) Use your Born-Haber cycle in (i) to calculate the enthalpy change of formation for calcium oxide.

enthalpy change of formation = ...

[2]

(iii) The lattice enthalpy for iron(II) oxide is –3920 kJ mol^{-1}.

Suggest a reason for the difference in lattice enthalpy between calcium oxide and iron(II) oxide.

.....

.....

[1]

[Total 8 marks]

10. The standard electrode potentials for some redox systems involving vanadium are shown below.
These are labelled **A**, **B**, **C** and **D**.

		$E^{\ominus}$/ V
A	$VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$	+1.00
B	$V^{3+} + e^- \rightleftharpoons V^{2+}$	–0.26
C	$V^{2+} + 2e^- \rightleftharpoons V$	–1.20
D	$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	+0.34

(a) Which of the vanadium species shown in **A**, **B**, **C** and **D** is the most powerful oxidising agent?

.....

[1]

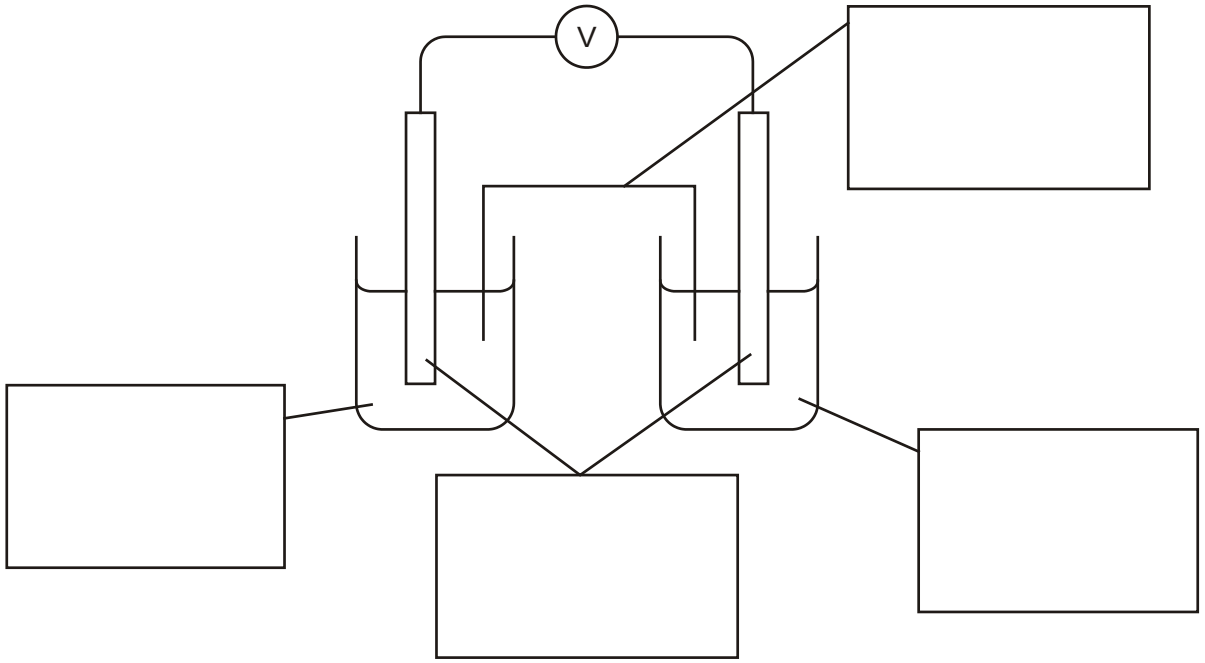
(b) A student wishes to set up a cell with a standard cell potential of 0.60V.

(i) Which two of the redox systems, **A**, **B**, **C** or **D**, should he choose?

.....

[1]

(ii) Complete the labelling of the following diagram which shows the cell with a standard cell potential of 0.60V.



[4]

(iii) The emf of this cell is only 0.60 V under standard conditions. What do you understand by the expression *standard conditions*?

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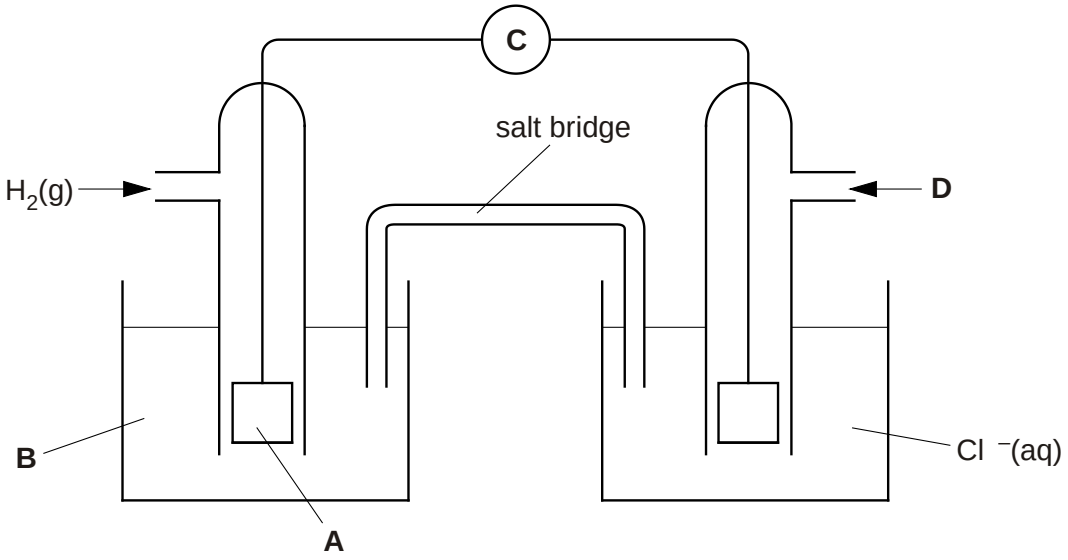
[1]

[Total 7 marks]

11. The standard electrode potential of the $\frac{1}{2}Cl_2/\ Cl^-$ half-cell may be measured using the following apparatus.



(a) Suggest suitable labels for **A**, **B**, **C** and **D**.

A .....

B .....

C .....

D .....

[2]

(b) The half cell reactions involved are shown below.

$$\frac{1}{2}Cl_2 + e^- \rightleftharpoons Cl^- \qquad E^\ominus = +1.36\ V$$

$$H^+ + e^- \rightleftharpoons \frac{1}{2}H_2 \qquad E^\ominus = 0.00V$$

(i) Use an arrow to show the direction of flow of electrons in the diagram of the apparatus. Explain your answer.

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[2]

(ii) The values of $E^{\ominus}$ are measured under standard conditions. What are the standard conditions?

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.....

.....

[2]

(c) The half cell reaction for $ClO_3^-/\frac{1}{2}Cl_2$ is shown below.

$$ClO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}Cl_2 + 3H_2O \qquad E^{\ominus} = +1.47\ V$$

What does this tell you about the oxidising ability of ClO_3^- compared with Cl_2?

Explain your answer.

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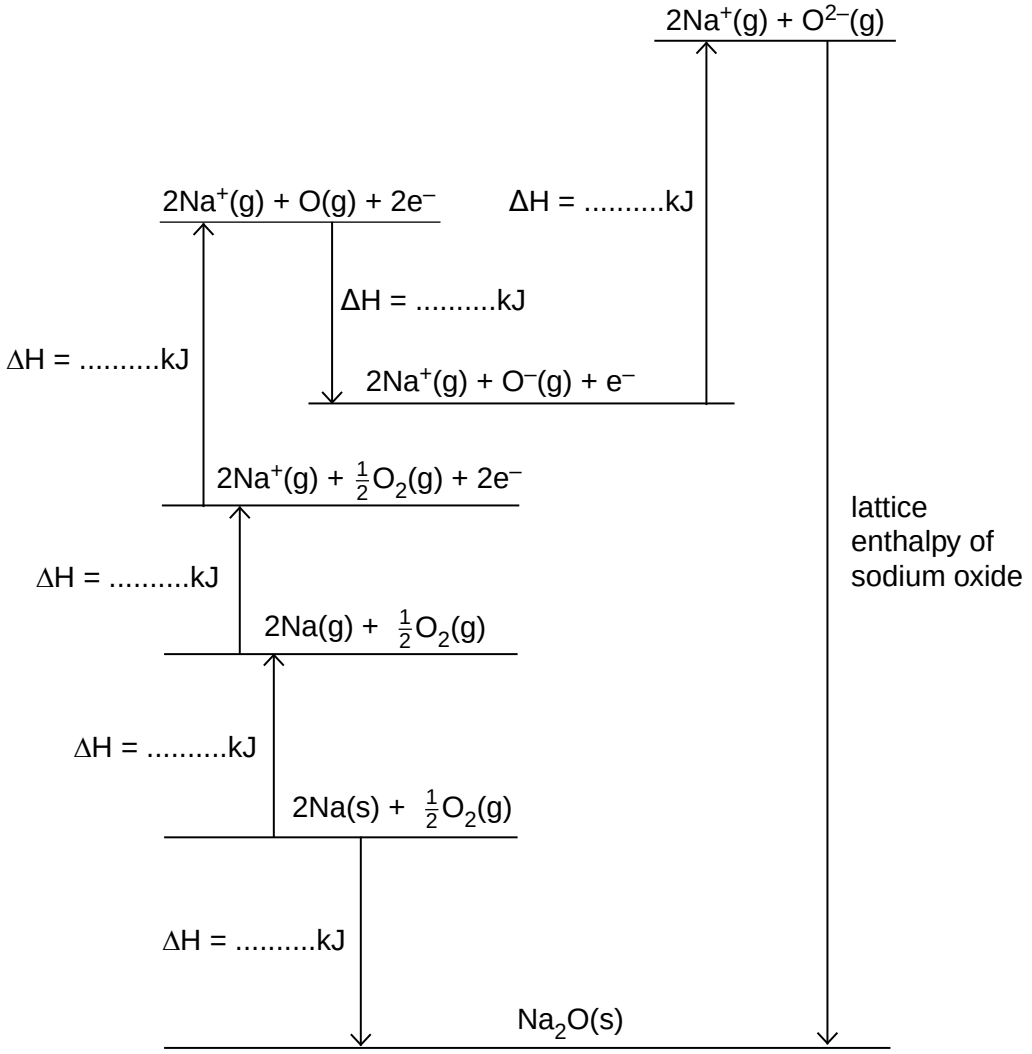
[2]

[Total 8 marks]

12. The table below shows the enthalpy changes needed to construct a Born-Haber cycle for sodium oxide, Na_2O.

process	enthalpy change / kJ mol^{-1}
first ionisation energy of sodium	+495
first electron affinity of oxygen	–141
second electron affinity of oxygen	+791
enthalpy change of formation for sodium oxide	–416
enthalpy change of atomisation for sodium	+109
enthalpy change of atomisation for oxygen	+247

(a) Use the table of enthalpy changes to complete the Born-Haber cycle by putting in the correct numerical values on the appropriate dotted line.



[4]

(b) Use the Born-Haber cycle to calculate the lattice enthalpy of sodium oxide.

lattice enthalpy = ...kJ mol^{-1}

[2]

(c) Which one of the following compounds has the most exothermic lattice enthalpy?

- calcium bromide
- calcium chloride
- potassium bromide
- potassium chloride

Explain your answer in terms of the ions present.

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[4]

[Total 10 marks]

13. Some standard electrode potentials are shown below.

	$E^{\ominus}$/V
$Ag^{+} + e^{-} \rightleftharpoons Ag$	+ 0.80
$\frac{1}{2}Cl_2 + e^{-} \rightleftharpoons Cl^{-}$	+ 1.36
$Cu^{2+} + 2e^{-} \rightleftharpoons Cu$	+ 0.34
$Fe^{3+} + e^{-} \rightleftharpoons Fe^{2+}$	+ 0.77
$\frac{1}{2}I_2 + e^{-} \rightleftharpoons I^{-}$	+ 0.54

(a) Define the term *standard electrode potential*.

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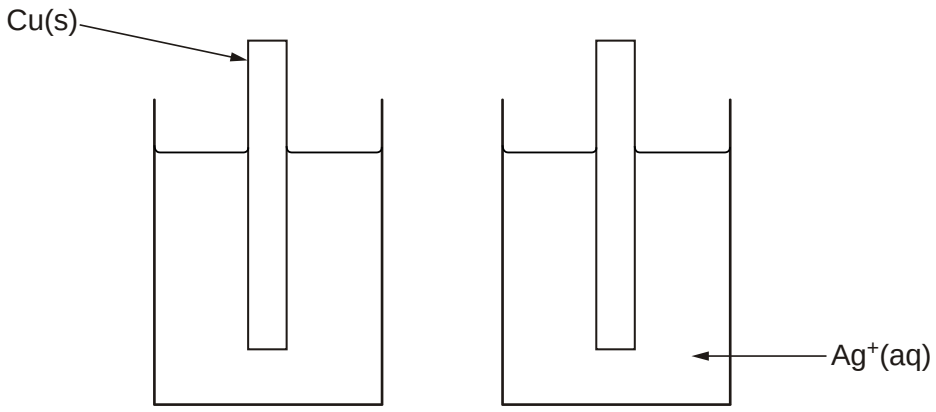
[3]

(b) The diagram below shows an incomplete cell consisting of Cu/Cu^{2+} and Ag/Ag^{+} half-cells.



(i) Complete and label the diagram to show how the cell potential of this cell could be measured.

[2]

(ii) On the diagram, show the direction of **electron** flow in the circuit if a current was allowed.

[1]

(iii) Calculate the standard cell potential.

standard cell potential = ……V

[1]

(iv) Write the overall cell reaction.

.....

[1]

(c) Chlorine will oxidise Fe^{2+} to Fe^{3+} but iodine will not. Explain why, using the electrode potential data.

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[2]

[Total 10 marks]

14. NO_2 reacts with oxygen and water to form nitric acid, HNO_3. In the atmosphere, this contributes to acid rain. Construct a balanced equation for this formation of nitric acid and use oxidation numbers to show that this is a redox reaction.

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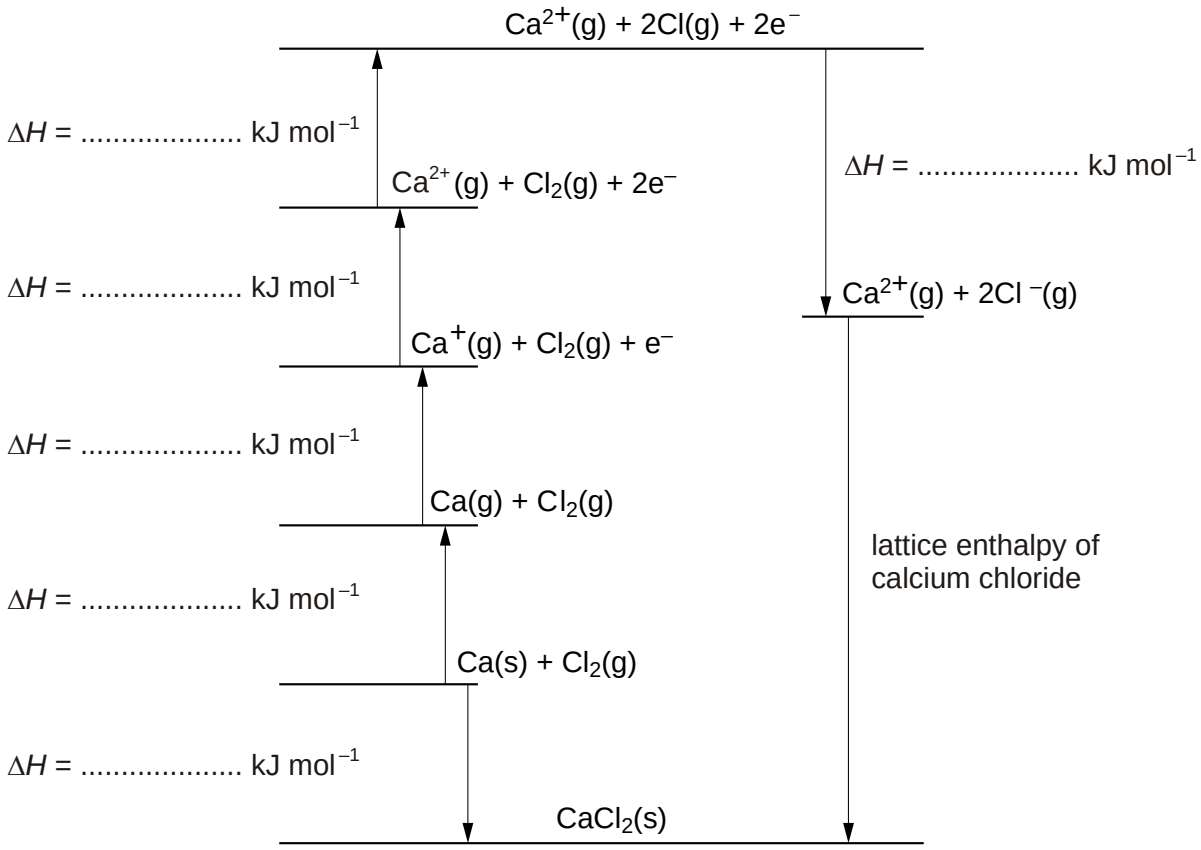
[Total 2 marks]

15. The table below shows the enthalpy changes needed to calculate the lattice enthalpy of calcium chloride, $CaCl_2$.

process	enthalpy change / kJ mol^{-1}
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1150
electron affinity of chlorine	–348
enthalpy change of formation for calcium chloride	–796
enthalpy change of atomisation for calcium	+178
enthalpy change of atomisation for chlorine	+122

(a) The Born-Haber cycle below can be used to calculate the lattice enthalpy for calcium chloride.



(i) Use the table of enthalpy changes to complete the Born-Haber cycle by putting in the correct numerical values on the appropriate dotted line.

[3]

(ii) Use the Born-Haber cycle to calculate the lattice enthalpy of calcium chloride.

answer ..... kJ mol^{-1}

[2]

(iii) Describe how, and explain why, the lattice enthalpy of magnesium fluoride differs from that of calcium chloride.

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[3]

(b) Explain why the first ionisation energy of calcium is less positive than the second ionisation energy.

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[2]

[Total 10 marks]

16. The carbonates and nitrates of Group 2 elements decompose when heated.

(a) Barium nitrate decomposes when heated to make barium oxide, nitrogen dioxide and oxygen.

$$2Ba(NO_3)_2(s) \rightarrow 2BaO(s) + 4NO_2(g) + O_2(g)$$

(i) Use oxidation states to explain why this decomposition reaction involves both oxidation **and** reduction.

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[3]

(ii) Calculate the enthalpy change of reaction, ΔH_r, in kJ mol^{-1}, for the thermal decomposition of barium nitrate using the enthalpy changes of formation, ΔH_f, given in the table.

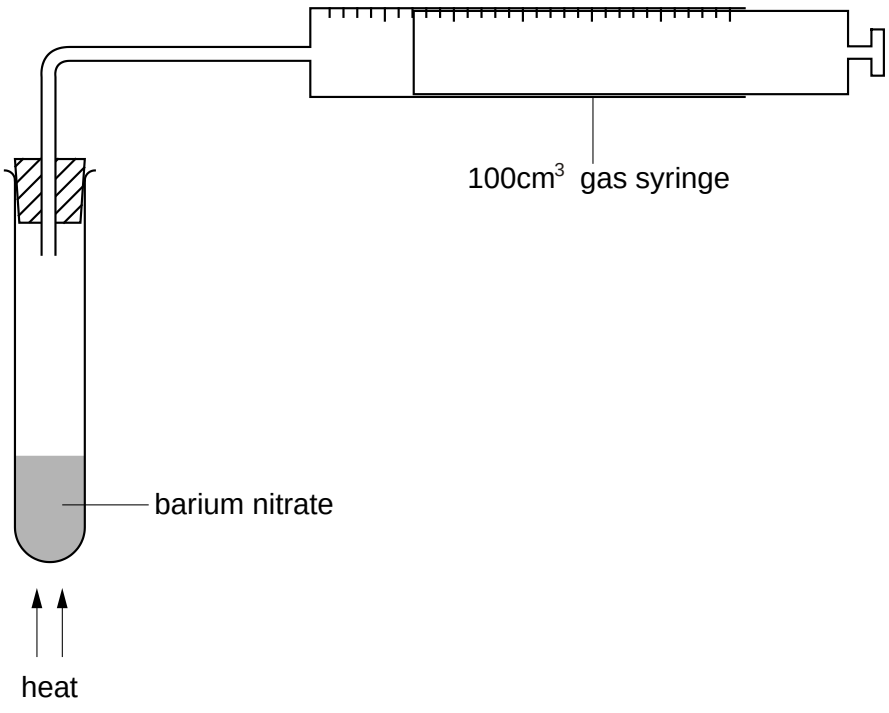
compound	ΔH_f /kJ mol^{-1}
$Ba(NO_3)_2(s)$	–992
BaO(s)	–558
$NO_2(g)$	+33

answer ..... kJ mol^{-1}

[3]

(b) A student investigates the volume of gas formed when barium nitrate is heated.

The diagram shows the apparatus the student uses.



(i) A 1.31 g sample of barium nitrate is completely decomposed.

Use the equation above to calculate the volume, in cm^3, of gas formed at room temperature and pressure.

1 mol of gas molecules occupies 24 000 cm^3 at room temperature and pressure.

answer ..... cm^3

[3]

(ii) Suggest **one** problem that the student may encounter when carrying out the investigation.

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[1]

[Total 10 marks]

17. Chlorine gas may be prepared in the laboratory by reacting hydrochloric acid with potassium manganate(VII). The following standard electrode potentials relate to this reaction.

$$\frac{1}{2}Cl_2 + e^- \rightleftharpoons Cl^- \qquad E^\ominus = +1.36\ V$$

$$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O \qquad E^\ominus = +1.52\ V$$

(a) Define the term *standard electrode potential*.

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.....

[3]

(b) Determine the standard cell potential for a cell constructed from these two redox systems.

[1]

[Total 4 marks]

18. Chlorine gas may be prepared in the laboratory by reacting hydrochloric acid with potassium manganate(VII). The following standard electrode potentials relate to this reaction.

$$\frac{1}{2}Cl_2 + e^- \rightleftharpoons Cl^- \qquad E^\ominus = +1.36\ V$$

$$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O \qquad E^\ominus = +1.52\ V$$

(a) Use the half-equations above to:

(i) construct an ionic equation for the reaction between hydrochloric acid and potassium manganate(VII);

.....

.....

.....

[2]

(ii) determine the oxidation numbers of chlorine and manganese before and after the reaction has taken place;

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.....

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[2]

(iii) state what is oxidised and what is reduced in this reaction.

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.....

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[2]

(b) If potassium manganate(VII) and very dilute hydrochloric acid are mixed, there is no visible reaction. Suggest why there is no visible reaction in this case.

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[1]

[Total 7 marks]