

Topical Questions of

Chemical Energetics

Compiled By

Faizan Saleem

Topic: Chemical Energetics (Born Haber Cycle)

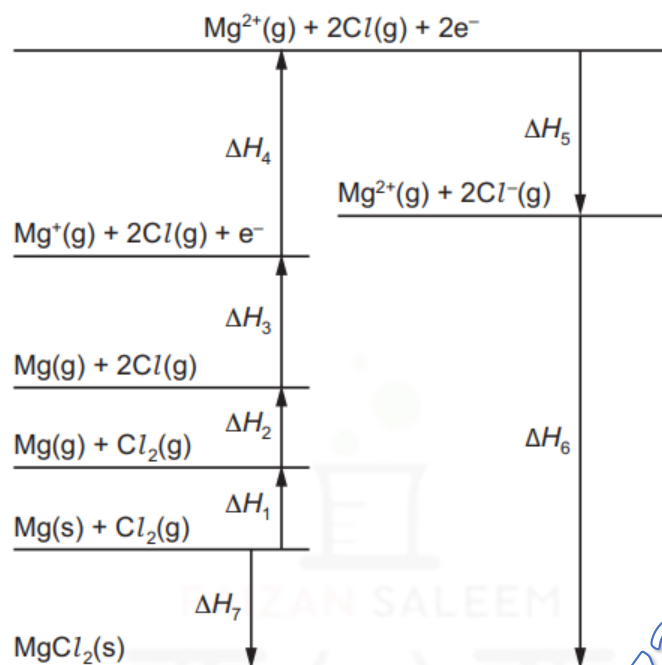
Question No 1

- (a) Complete the table using ticks (✓) to indicate whether the sign of each type of energy change, under standard conditions, is always positive, always negative or could be either positive or negative.

energy change	always positive	always negative	either positive or negative
electron affinity			
enthalpy change of atomisation			
ionisation energy			
lattice energy			

[2]

(b) The Born-Haber cycle for magnesium chloride is shown.



(i) Explain why ΔH_4 is greater than ΔH_3 .

.....
 [1]

(ii) What names are given to the enthalpy changes ΔH_6 and ΔH_7 ?

ΔH_6
 ΔH_7 [1]

(c) Chlorine is in Group 17.

Suggest the trend in the first electron affinity of the elements in Group 17. Explain your answer.

.....

 [2]

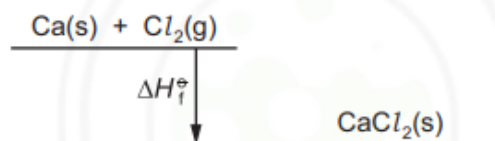
Question No 2

(a) Calcium metal reacts with chlorine gas to form calcium chloride, CaCl_2 .

- (i) Write an equation, including state symbols, to represent the lattice energy of calcium chloride, CaCl_2 .

..... [1]

- (ii) Complete a fully labelled Born-Haber cycle that could be used to calculate the lattice energy, $\Delta H_{\text{latt}}^\ominus$, for calcium chloride.



[2]

- (iii) Use your answer to (ii) and the following data, together with relevant data from the *Data Booklet*, to calculate a value for $\Delta H_{\text{latt}}^\ominus$ for calcium chloride.

standard enthalpy change of formation of $\text{CaCl}_2(\text{s})$, $\Delta H_f^\ominus$	-796 kJ mol^{-1}
standard enthalpy change of atomisation of $\text{Ca}(\text{s})$, $\Delta H_{\text{at}}^\ominus$	$+178 \text{ kJ mol}^{-1}$
electron affinity of chlorine atoms	-349 kJ mol^{-1}

$\Delta H_{\text{latt}}^\ominus = \dots\dots\dots \text{ kJ mol}^{-1}$ [3]

Question No 3

- (d) Use the data below, and other suitable data from the *Data Booklet*, to calculate the lattice energy of sodium oxide, $\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{O(s)}$.

energy change	value / kJ mol^{-1}
standard enthalpy change of formation of sodium oxide, $\Delta H_{\text{f}}^{\circ} \text{Na}_2\text{O(s)}$	–416
standard enthalpy change of atomisation of sodium, $\Delta H_{\text{at}}^{\circ} \text{Na(s)}$	+109
electron affinity of O(g)	–142
electron affinity of $\text{O}^-(\text{g})$	+844

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$\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{O(s)} = \dots\dots\dots \text{kJ mol}^{-1}$ [4]

- (e) State how $\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{S(s)}$ differs from $\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{O(s)}$.
Indicate this by placing a tick (✓) in the appropriate box in the table.

$\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{S(s)}$ is more exothermic than $\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{O(s)}$	$\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{S(s)}$ is the same as $\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{O(s)}$	$\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{S(s)}$ is less exothermic than $\Delta H_{\text{latt}}^{\circ} \text{Na}_2\text{O(s)}$

Explain your answer.

.....

.....

.....

[2]

Question No 4

- (c) (i) Use the data in the table below, and relevant data from the *Data Booklet*, to calculate the lattice energy, $\Delta H_{\text{latt}}^\ominus$, of potassium oxide, $\text{K}_2\text{O}(\text{s})$.

energy change	value / kJ mol^{-1}
enthalpy change of atomisation of potassium, $\Delta H_{\text{at}}^\ominus \text{K}(\text{s})$	+89
electron affinity of $\text{O}(\text{g})$	-141
electron affinity of $\text{O}^-(\text{g})$	+798
enthalpy change of formation of potassium oxide, $\Delta H_{\text{f}}^\ominus \text{K}_2\text{O}(\text{s})$	-361

$\Delta H_{\text{latt}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

- (ii) State whether the lattice energy of Na_2O would be more negative, less negative or the same as that of K_2O . Give reasons for your answer.

.....
..... [1]

Question No 5

- (d) (i) Write an equation to represent the lattice energy of PbCl_2 . Show state symbols.

.....

- (ii) Use the following data, together with appropriate data from the *Data Booklet*, to calculate a value for the lattice energy of PbCl_2 .

electron affinity of chlorine = -349 kJ mol^{-1}

enthalpy change of atomisation of lead = $+195 \text{ kJ mol}^{-1}$

enthalpy change of formation of $\text{PbCl}_2(\text{s})$ = -359 kJ mol^{-1}

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

- (iii) How might the lattice energy of PbCl_2 compare to that of PbBr_2 ? Explain your answer.

.....

.....

.....

[6]

Question No 6

- 1 Taken together, nitrogen and oxygen make up 99% of the air. Oxygen is by far the more reactive of the two gases, and most of the substances that react with air combine with the oxygen rather than with the nitrogen.

(a) State **one** reason why the molecule of nitrogen, N_2 , is so unreactive.

.....[1]

Despite the apparent lack of reactivity of N_2 , nitrogen atoms have been found to form bonds with almost all of the elements in the Periodic Table. Lithium metal reacts with nitrogen gas at room temperature to give lithium nitride, Li_3N . Magnesium produces magnesium nitride, Mg_3N_2 , as well as magnesium oxide, when heated in air.

- (b) Calculate the lattice energy of magnesium nitride using the following data, in addition to relevant data from the *Data Booklet*.

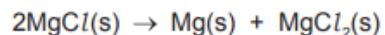
enthalpy change	value/ kJ mol^{-1}
atomisation of $Mg(s)$	+148
total of electron affinities for the change $N(g) \rightarrow N^{3-}(g)$	+2148
enthalpy of formation of $Mg_3N_2(s)$	-461

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

Question No 7

Magnesium(I) chloride, MgCl , is an unstable compound and readily decomposes as shown.



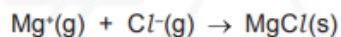
Use the following data to calculate the enthalpy change of this reaction.

$$\Delta H_f^\circ \text{MgCl(s)} = -106 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\circ \text{MgCl}_2\text{(s)} = -642 \text{ kJ mol}^{-1}$$

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

(c) (i) The equation for which ΔH is the lattice energy for MgCl is shown.



Use the equation, the following data, and relevant data from the *Data Booklet* to calculate a value for the lattice energy of MgCl . You might find it helpful to construct an energy cycle.

$$\text{electron affinity of Cl(g)} = -349 \text{ kJ mol}^{-1}$$

$$\text{enthalpy change of atomisation of Mg(s)} = +147 \text{ kJ mol}^{-1}$$

$$\text{enthalpy change of formation of MgCl(s)} = -106 \text{ kJ mol}^{-1}$$

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lattice energy $\text{MgCl} = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

- (ii) Suggest how the lattice energies of MgCl_2 and NaCl will compare to that of MgCl .
Explain your answers.

MgCl_2 and MgCl

.....

NaCl and MgCl

.....

[3]

- (d) Define the term *electron affinity*.

.....

..... [2]

Question No 8

Most car air bags contain a capsule of sodium azide, NaN_3 . In a crash, the NaN_3 decomposes into its elements.

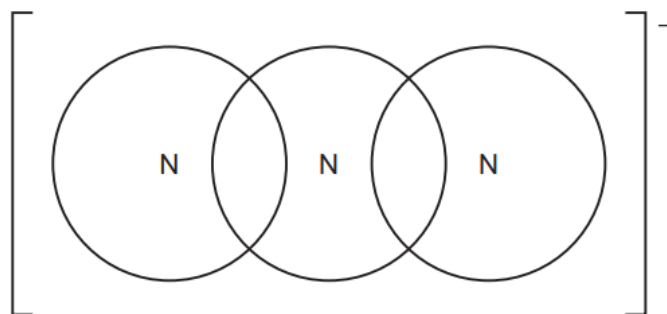
- (a) Write an equation for the decomposition of NaN_3 .

..... [1]

- (b) Complete the 'dot-and-cross' diagram for the azide ion, N_3^- .

Use the following key for the electrons.

- electrons from central nitrogen atom
- × electrons from the other two nitrogen atoms
- added electron(s) responsible for the overall negative charge



[3]

(c) Lattice energies are always negative showing that they represent exothermic changes.

(i) Explain what is meant by the term *lattice energy*.

.....
.....
..... [2]

(ii) Explain why lattice energy represents an exothermic change.

.....
..... [1]

(iii) Use the following data and any relevant data from the *Data Booklet* to calculate the standard enthalpy change of formation, ΔH_f° , of $\text{NaN}_3(\text{s})$.
Include a sign in your answer. Show all your working.

lattice energy, $\Delta H_{\text{latt}}^\circ$ of $\text{NaN}_3(\text{s})$	-732 kJ mol^{-1}
standard enthalpy change of atomisation, $\Delta H_{\text{at}}^\circ$ of $\text{Na}(\text{g})$	$+107 \text{ kJ mol}^{-1}$
standard enthalpy change, ΔH° , for $\frac{1}{2}\text{N}_2(\text{g}) + \text{e}^- \rightarrow \text{N}_3^-(\text{g})$	$+142 \text{ kJ mol}^{-1}$

ΔH_f° of $\text{NaN}_3(\text{s}) = \dots\dots\dots \text{ kJ mol}^{-1}$ [3]

(iv) The lattice energy, $\Delta H_{\text{latt}}^\circ$, of $\text{RbN}_3(\text{s})$ is -636 kJ mol^{-1} .

Suggest why the lattice energy of $\text{NaN}_3(\text{s})$, -732 kJ mol^{-1} , is more exothermic than that of $\text{RbN}_3(\text{s})$.

.....
..... [1]

[Total: 11]

Question No 9

(b) Strontium chloride, SrCl_2 , can be used to produce a red colour in fireworks.

(i) Draw the 'dot-and-cross' diagram for strontium chloride. Show outer shell electrons only.

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(ii) Use the following data, together with relevant data from the *Data Booklet*, to calculate a value for the lattice energy of strontium chloride. You may find it helpful to construct a Born-Haber cycle.

electron affinity per mole of chlorine atoms	-349 kJ mol^{-1}
standard enthalpy of atomisation of Sr(s)	$+164 \text{ kJ mol}^{-1}$
standard enthalpy of formation of $\text{SrCl}_2(\text{s})$	-830 kJ mol^{-1}

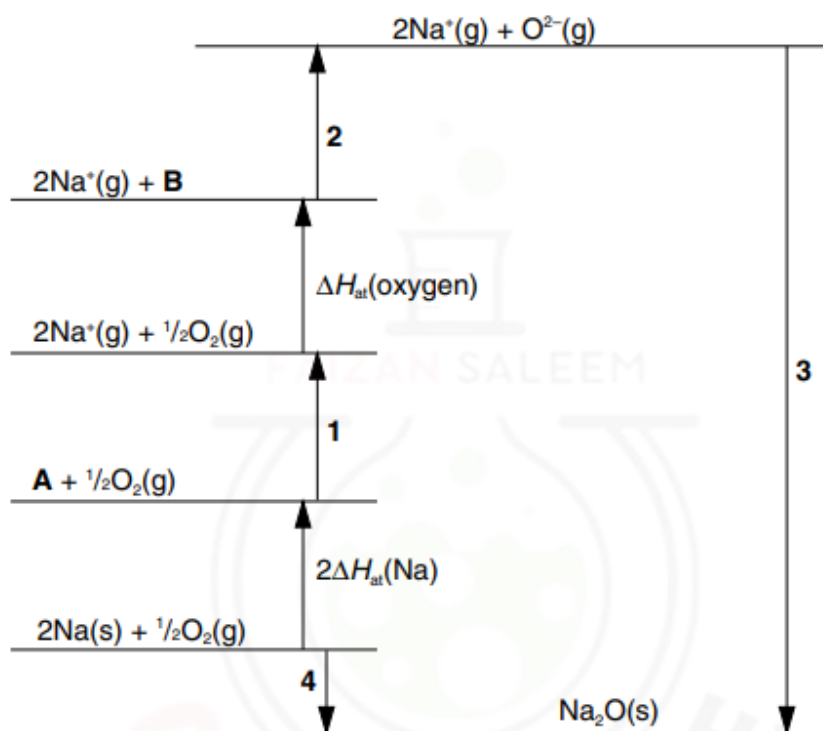
lattice energy = ... kJ mol^{-1}
[5]

Question No 10

- (a) Write an equation to represent the lattice energy of sodium oxide, Na_2O .

.....[1]

- (b) The Born-Haber cycle shown may be used to calculate the lattice energy of sodium oxide.



- (i) In the spaces below, identify the species **A** and **B** in the cycle, including the appropriate state symbols.

species **A** species **B**

- (ii) Identify the enthalpy changes labelled by the numbers **1** to **4** in the cycle.

1

2

3

4

[3]

© Calculate the Lattice Enthalpy.



Calculation of Different Enthalpies

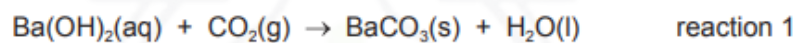
Question No 11

The table lists the standard enthalpy changes of formation, $\Delta H_f^\ominus$, for some compounds and aqueous ions.

species	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{Ba}^{2+}(\text{aq})$	-538
$\text{OH}^-(\text{aq})$	-230
$\text{CO}_2(\text{g})$	-394
$\text{BaCO}_3(\text{s})$	-1216
$\text{H}_2\text{O}(\text{l})$	-286

(b) (i) Reaction 1 occurs when $\text{CO}_2(\text{g})$ is bubbled through an aqueous solution of $\text{Ba}(\text{OH})_2$.

Use the data in the table to calculate the standard enthalpy change for reaction 1, $\Delta H_{r1}^\ominus$.



$\Delta H_{r1}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

If $\text{CO}_2(\text{g})$ is bubbled through an aqueous solution of $\text{Ba}(\text{OH})_2$ for a long time, the precipitated $\text{BaCO}_3(\text{s})$ dissolves, as shown in reaction 2.



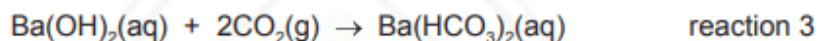
The standard enthalpy change for reaction 2, $\Delta H_{\text{r}2}^\ominus = -26 \text{ kJ mol}^{-1}$.

- (ii) Use this information and the data in the table to calculate the standard enthalpy change of formation of the $\text{HCO}_3^-(\text{aq})$ ion.

$$\Delta H_f^\ominus \text{HCO}_3^-(\text{aq}) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

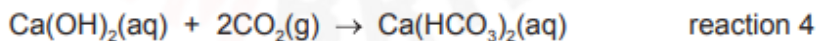
- (iii) The overall process is shown by reaction 3.

Use your answer to (ii), and the data given in the table, to calculate the standard enthalpy change for reaction 3, $\Delta H_{\text{r}3}^\ominus$.



$$\Delta H_{\text{r}3}^\ominus = \dots\dots\dots \text{ kJ mol}^{-1} \quad [1]$$

- (iv) How would the value of $\Delta H_{\text{r}3}^\ominus$ compare with the value of $\Delta H_{\text{r}4}^\ominus$ for the similar reaction with $\text{Ca}(\text{OH})_2(\text{aq})$ as shown in reaction 4?
Explain your answer.



.....
.....
..... [2]

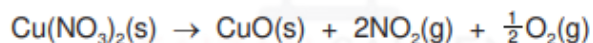
Question No 12

- (c) Copper(I) oxide and copper(II) oxide can both be used in the ceramic industry to give blue, green or red tints to glasses, glazes and enamels.

The table lists the $\Delta H_f^\ominus$ values for some compounds.

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{Cu}_2\text{O(s)}$	-168.6
CuO(s)	-157.3
$\text{Cu(NO}_3)_2\text{(s)}$	-302.9
$\text{NO}_2\text{(g)}$	+33.2

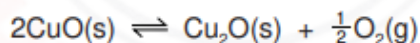
- (i) Copper(II) oxide can be produced in a pure form by heating copper(II) nitrate. Use suitable $\Delta H_f^\ominus$ values from the table to calculate the $\Delta H^\ominus$ for this reaction.



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

- (ii) Copper(I) oxide can be produced from copper(II) oxide.

- Use suitable $\Delta H_f^\ominus$ values from the table to calculate $\Delta H^\ominus$ for the reaction.



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

- Hence suggest whether a low or a high temperature of oxidation would favour the production of copper(I) oxide. Explain your reasoning.

.....
.....

[4]

Question No 13

- (c) Use the following data, together with appropriate data from the *Data Booklet*, to calculate a value of $\Delta H_f^\circ(\text{MgO})$.

lattice energy of MgO(s)	=	$-3791 \text{ kJ mol}^{-1}$
enthalpy change of atomisation of Mg	=	$+148 \text{ kJ mol}^{-1}$
electron affinity of the oxygen atom	=	-141 kJ mol^{-1}
electron affinity of the oxygen anion, O^-	=	$+798 \text{ kJ mol}^{-1}$

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$\Delta H_f^\circ(\text{MgO}) = \dots\dots\dots \text{kJ mol}^{-1}$
[3]

- (d) Write equations, including state symbols, for the reactions, if any, of the following two oxides with water. Suggest values for the pH of the resulting solutions.

oxide	equation	pH of resulting solution
Na_2O		
MgO		

[3]

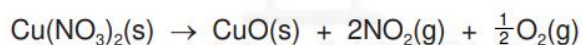
Question No 14

- (c) Copper(I) oxide and copper(II) oxide can both be used in the ceramic industry to give blue, green or red tints to glasses, glazes and enamels.

The table lists the ΔH_f° values for some compounds.

compound	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
$\text{Cu}_2\text{O(s)}$	-168.6
CuO(s)	-157.3
$\text{Cu(NO}_3)_2\text{(s)}$	-302.9
$\text{NO}_2\text{(g)}$	+33.2

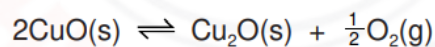
- (i) Copper(II) oxide can be produced in a pure form by heating copper(II) nitrate. Use suitable ΔH_f° values from the table to calculate the ΔH° for this reaction.



$\Delta H^\circ = \dots\dots\dots \text{kJ mol}^{-1}$

- (ii) Copper(I) oxide can be produced from copper(II) oxide.

- Use suitable ΔH_f° values from the table to calculate ΔH° for the reaction.



$\Delta H^\circ = \dots\dots\dots \text{kJ mol}^{-1}$

- Hence suggest whether a low or a high temperature of oxidation would favour the production of copper(I) oxide. Explain your reasoning.

.....

Solubility and Thermal Stability

Question No 15

- 1 (a) (i) What is meant by the term *enthalpy change of hydration*, $\Delta H_{\text{hyd}}^{\ominus}$?

.....
.....

- (ii) Write an equation that represents the $\Delta H_{\text{hyd}}^{\ominus}$ of the Mg^{2+} ion.

.....

- (iii) Suggest a reason why $\Delta H_{\text{hyd}}^{\ominus}$ of the Mg^{2+} ion is greater than $\Delta H_{\text{hyd}}^{\ominus}$ of the Ca^{2+} ion.

.....
.....

- (iv) Suggest why it is impossible to determine the enthalpy change of hydration of the oxide ion, O^{2-} .

.....
.....

[5]

- (b) The enthalpy change of solution for MgCl_2 , $\Delta H_{\text{sol}}^{\ominus}(\text{MgCl}_2(\text{s}))$, is represented by the following equation.



Describe the simple apparatus you could use, and the measurements you would make, in order to determine a value for $\Delta H_{\text{sol}}^{\ominus}(\text{MgCl}_2(\text{s}))$ in the laboratory.

.....
.....
.....
.....
.....
.....

[4]

(c) The table below lists data relevant to the formation of $\text{MgCl}_2(\text{aq})$.

enthalpy change	value / kJ mol^{-1}
$\Delta H_f^\ominus(\text{MgCl}_2(\text{s}))$	-641
$\Delta H_f^\ominus(\text{MgCl}_2(\text{aq}))$	-801
lattice energy of $\text{MgCl}_2(\text{s})$	-2526
$\Delta H_{\text{hyd}}^\ominus(\text{Mg}^{2+}(\text{g}))$	-1890

By constructing relevant thermochemical cycles, use the above data to calculate a value for

(i) $\Delta H_{\text{sol}}^\ominus(\text{MgCl}_2(\text{s}))$,

$$\Delta H_{\text{sol}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$$

(ii) $\Delta H_{\text{hyd}}^\ominus(\text{Cl}^-(\text{g}))$.

$$\Delta H_{\text{hyd}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$$

[3]

(d) Describe and explain how the solubility of magnesium sulfate compares to that of barium sulfate.

.....

.....

.....

.....

..... [4]

[Total: 16]

Question No 16

- 2 (a) Describe and explain how the solubilities of the sulfates of the Group II elements vary down the group.

.....

[3]

- (b) The following table lists some enthalpy changes for magnesium and strontium compounds.

enthalpy change	value for magnesium /kJ mol ⁻¹	value for strontium /kJ mol ⁻¹
lattice enthalpy of $M(OH)_2$	-2993	-2467
enthalpy change of hydration of $M^{2+}(g)$	-1890	-1414
enthalpy change of hydration of $OH^-(g)$	-550	-550

- (i) Use the above data to calculate values of $\Delta H_{\text{solution}}^\ominus$ for $Mg(OH)_2$ and for $Sr(OH)_2$.

$Mg(OH)_2$

$$\Delta H_{\text{solution}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$$

$Sr(OH)_2$

$$\Delta H_{\text{solution}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$$

- (ii) Use your results in (i) to suggest whether $Sr(OH)_2$ is more or less soluble in water than is $Mg(OH)_2$. State any assumptions you make.

.....

- (iii) Suggest whether $Sr(OH)_2$ would be more or less soluble in hot water than in cold. Explain your reasoning.

.....

[5]

Question No 17

- (a) The enthalpy change of solution, $\Delta H_{\text{sol}}^\circ$, of the Group 2 sulfates becomes more endothermic down the group.

State and explain the trend in the solubility of the Group 2 sulfates down the group.

.....

.....

.....

.....

..... [3]

Question No 18

- (a) Explain why the thermal stability of the Group 2 nitrates increases down the group.

.....

.....

..... [2]

- (b) Sodium nitrite, NaNO_2 , is a decomposition product from heating sodium nitrate, NaNO_3 .

A student analysed a sample of sodium nitrite by titration with aqueous cerium(IV) ions, $\text{Ce}^{4+}(\text{aq})$. The equation for the titration reaction is shown.



- 0.138 g of impure sodium nitrite was dissolved in water and made up to 100 cm^3 in a volumetric flask.
- 25.0 cm^3 of this solution required 21.80 cm^3 of $0.0400\text{ mol dm}^{-3}$ $\text{Ce}^{4+}(\text{aq})$ to reach the end-point.

You should assume the impurity does not react with $\text{Ce}^{4+}(\text{aq})$.

Calculate the percentage purity of the sample of sodium nitrite.

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..... % [3]

Question No 19

- (d) (i) Magnesium nitrate decomposes at a **lower** temperature than barium nitrate.

Explain why.

.....
.....
..... [2]

Question No 20

The temperature at which the Group 2 hydroxides and carbonates start to decompose increases down the group.

Suggest an explanation for this trend in the decomposition temperature of the Group 2 hydroxides.

.....
.....
..... [2]

Question No 21

- (a) Calcium has atomic number 20.

Complete the electronic structures for a

calcium atom, $1s^2 2s^2 2p^6$

calcium ion in the +2 oxidation state. $1s^2 2s^2 2p^6$

[1]

- (b) Calcium nitrate, $\text{Ca}(\text{NO}_3)_2$, is used in fertilisers and can be prepared by an acid-base reaction.

Write an equation for the preparation of calcium nitrate by an acid-base reaction.

..... [1]

- (c) (i) When anhydrous calcium nitrate is heated strongly, it decomposes to leave a white solid.

Identify this white solid and suggest **another** observation for this reaction.

.....
..... [1]

- (ii) The ease of thermal decomposition of the Group II nitrates **decreases** down the group.

Explain this trend.

.....
.....
..... [2]

(d) (i) What is meant by the term *standard enthalpy change of hydration*, $\Delta H_{\text{hyd}}^{\ominus}$?

.....

.....

..... [2]

(ii) Use the following data to calculate the lattice energy, $\Delta H_{\text{latt}}^{\ominus}$, of calcium nitrate, $\text{Ca}(\text{NO}_3)_2(\text{s})$. You may find it helpful to construct an energy cycle.

enthalpy change	value
$\Delta H_{\text{hyd}}^{\ominus}(\text{Ca}^{2+}(\text{g}))$	$-1650 \text{ kJ mol}^{-1}$
$\Delta H_{\text{hyd}}^{\ominus}(\text{NO}_3^{-}(\text{g}))$	-314 kJ mol^{-1}
enthalpy change of solution for $\text{Ca}(\text{NO}_3)_2(\text{s})$	-19 kJ mol^{-1}

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$\Delta H_{\text{latt}}^{\ominus} \text{Ca}(\text{NO}_3)_2(\text{s}) = \dots\dots\dots \text{ kJ mol}^{-1}$ [3]

(e) The standard enthalpy change of hydration for Ba^{2+} , $\Delta H_{\text{hyd}}^{\circ}(\text{Ba}^{2+}(\text{g}))$, is $-1305 \text{ kJ mol}^{-1}$.

Suggest an explanation for why the $\Delta H_{\text{hyd}}^{\circ}$ of the Ba^{2+} ion is **less** exothermic than the $\Delta H_{\text{hyd}}^{\circ}$ of the Ca^{2+} ion.

.....

.....

..... [2]

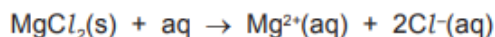
[Total: 12]

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Question No 22

- (a) The dissolving of an ionic compound in water is accompanied by an energy change, the enthalpy change of solution, ΔH_{sol} .



Describe, in terms of bond breaking and bond making, what happens to the solid ionic lattice when an ionic compound dissolves in water.

.....

 [2]

- (b) (i) What is meant by the term *enthalpy change of solution*, ΔH_{sol} ?

.....
 [1]

- (ii) Use the following data to calculate the standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$ of chloride ions, $\text{Cl}^{-}(\text{g})$.
 You may find it helpful to construct an energy cycle.

enthalpy change	value
$\Delta H_{\text{hyd}}^{\ominus} (\text{Mg}^{2+}(\text{g}))$	$-1925 \text{ kJ mol}^{-1}$
lattice energy of $\text{MgCl}_2(\text{s})$	$-2524 \text{ kJ mol}^{-1}$
enthalpy change of solution for $\text{MgCl}_2(\text{s})$	-155 kJ mol^{-1}

$\Delta H_{\text{hyd}}^{\ominus} (\text{Cl}^{-}(\text{g})) = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

(iii) The enthalpy change of hydration for Na^+ , $\Delta H_{\text{hyd}}^\ominus(\text{Na}^+(\text{g}))$, is -410 kJ mol^{-1} .

Suggest an explanation for why the $\Delta H_{\text{hyd}}^\ominus$ of the Na^+ ion is **less** exothermic than the $\Delta H_{\text{hyd}}^\ominus$ of the Mg^{2+} ion.

.....
.....
..... [2]

(c) Describe and explain how the solubility of the Group II sulfates varies down the group.

.....
.....
.....
.....
.....
.....
.....
..... [4]

[Total: 11]

Question No 23

(e) (i) What is meant by the term *lattice energy*?

.....
.....

(ii) Explain why the lattice energy of calcium phosphate is **less** exothermic than that of magnesium phosphate.

.....
.....
..... [3]

Question No 24

(c) Strontium nitrate, $\text{Sr}(\text{NO}_3)_2$, can also be used to produce a red colour in fireworks.

(i) Strontium nitrate can easily be prepared from strontium carbonate, SrCO_3 .

Suggest an equation for this preparation of strontium nitrate.

.....

(ii) Write an equation for the reaction that occurs when strontium nitrate is heated.

.....

[2]

(d) Describe and explain the trend in the thermal stabilities of the nitrates of the Group II elements.

.....

.....

.....

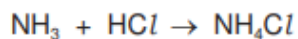
.....

..... [3]

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Question No 25

- (a) Gaseous ammonia reacts with gaseous hydrogen chloride to form solid ammonium chloride.

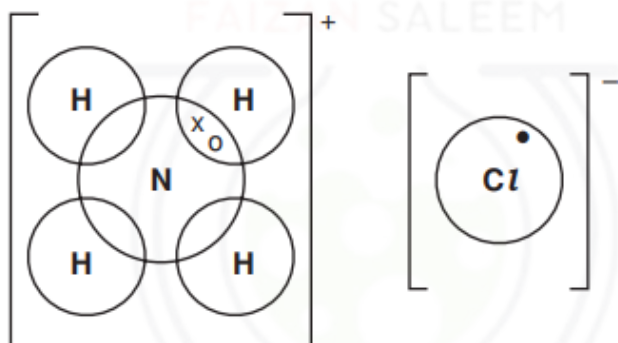


The bonding in ammonium chloride includes ionic, covalent and co-ordinate (dative covalent) bonds.

Complete the following 'dot-and-cross' diagram of the bonding in ammonium chloride. For **each** of the six atoms show **all** the electrons in its outer shell. Three electrons have already been included.

Use the following code for your electrons.

- electrons from chlorine
- x electrons from hydrogen
- o electrons from nitrogen



[3]

- (b) When a sample of dry ammonia is needed in the laboratory, the gas is passed through a tower containing lumps of solid calcium oxide, CaO.

- (i) Suggest why the usual drying agent for gases, concentrated H_2SO_4 , is **not** used for ammonia.

.....

- (ii) Write an equation for the reaction between CaO and H_2O .

.....

- (iii) Suggest why CaO rather than MgO is used to dry ammonia.

.....

[3]

(c) (i) Write an equation showing the thermal decomposition of calcium nitrate, $\text{Ca}(\text{NO}_3)_2$.

.....

(ii) State and explain how the thermal stabilities of the nitrates vary down Group II.

.....

.....

.....

.....

[4]

[Total: 10]



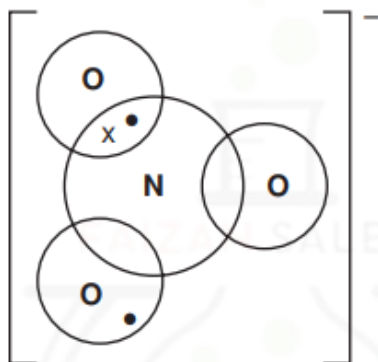
Question No 26

- (a) The nitrate ion, NO_3^- , contains a dative covalent bond.

Complete the following 'dot-and-cross' diagram of the bonding in the nitrate ion. For **each** of the four atoms show **all** the electrons in its outer shell. Three electrons have already been included.

Use the following code for your electrons.

- electrons from oxygen
- x electrons from nitrogen
- added electron(s) responsible for the overall negative charge



[3]

- (b) (i) Write an equation showing the action of heat on magnesium nitrate, $\text{Mg}(\text{NO}_3)_2$.

.....

- (ii) Describe and explain the trend that is observed in the thermal stabilities of the Group II nitrates.

.....

.....

.....

.....

[4]

- (c) When concentrated nitric acid, HNO_3 , is added to copper turnings, a brown gas is evolved. Use data from the *Data Booklet* to construct an ionic equation for this reaction.

.....

.....

[2]

[Total: 9]

Question No 27

- (a) (i) State how the solubilities of the hydroxides of the Group 2 elements vary down the group.

..... [1]

- (ii) Explain the factors that are responsible for this variation.

.....
.....
.....
.....
..... [3]

- (c) Metal peroxides contain the O-O^- ion.

The peroxides of the Group 2 elements, MO_2 , decompose on heating to produce a single gas and the solid oxide, MO , only.

- (i) Write an equation for the thermal decomposition of strontium peroxide, SrO_2 .

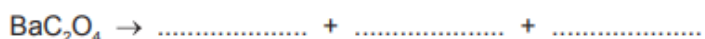
..... [1]

- (ii) Suggest how the temperature at which thermal decomposition of MO_2 occurs varies down Group 2.
Explain your answer.

.....
.....
.....
.....
..... [3]

- (d) (i) The ethanedioates of the Group 2 elements, MC_2O_4 , decompose on heating to produce a mixture of two different gases and the solid oxide, MO , only.

Complete the equation for the thermal decomposition of barium ethanedioate.



[1]

Question No 28

- (a) Describe and explain the variation in the solubilities of the hydroxides of the Group 2 elements.

.....

.....

.....

.....

.....

..... [4]

The table lists the standard enthalpy changes of formation, $\Delta H_f^\ominus$, for some compounds and aqueous ions.

species	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{Ba}^{2+}(\text{aq})$	-538
$\text{OH}^-(\text{aq})$	-230
$\text{CO}_2(\text{g})$	-394
$\text{BaCO}_3(\text{s})$	-1216
$\text{H}_2\text{O}(\text{l})$	-286

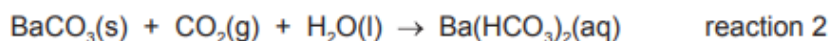
- (b) (i) Reaction 1 occurs when $\text{CO}_2(\text{g})$ is bubbled through an aqueous solution of $\text{Ba}(\text{OH})_2$.

Use the data in the table to calculate the standard enthalpy change for reaction 1, $\Delta H_{r1}^\ominus$.



$$\Delta H_{r1}^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

If $\text{CO}_2(\text{g})$ is bubbled through an aqueous solution of $\text{Ba}(\text{OH})_2$ for a long time, the precipitated $\text{BaCO}_3(\text{s})$ dissolves, as shown in reaction 2.



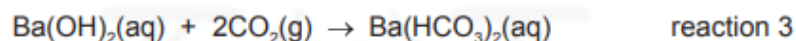
The standard enthalpy change for reaction 2, $\Delta H_{\text{r}2}^\ominus = -26 \text{ kJ mol}^{-1}$.

- (ii) Use this information and the data in the table to calculate the standard enthalpy change of formation of the $\text{HCO}_3^-(\text{aq})$ ion.

$$\Delta H_f^\ominus \text{HCO}_3^-(\text{aq}) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

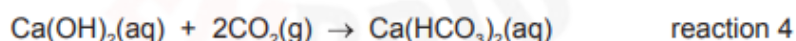
- (iii) The overall process is shown by reaction 3.

Use your answer to (ii), and the data given in the table, to calculate the standard enthalpy change for reaction 3, $\Delta H_{\text{r}3}^\ominus$.



$$\Delta H_{\text{r}3}^\ominus = \dots\dots\dots \text{ kJ mol}^{-1} \quad [1]$$

- (iv) How would the value of $\Delta H_{\text{r}3}^\ominus$ compare with the value of $\Delta H_{\text{r}4}^\ominus$ for the similar reaction with $\text{Ca}(\text{OH})_2(\text{aq})$ as shown in reaction 4?
Explain your answer.



.....

 [2]

Question No 29

- (a) Magnesium nitrate, $\text{Mg}(\text{NO}_3)_2$, is very soluble in water. When a hot saturated solution of magnesium nitrate is cooled, crystals of the hydrate, $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, are formed. In the crystals, six water molecules bond to each Mg^{2+} ion, and some of these water molecules are **also** bonded to the nitrate ions.

- (i) Suggest the type of bonding that occurs between

H₂O and Mg²⁺, ...

H₂O and NO₃⁻.

[2]

- (ii) Describe the arrangement of the water molecules around the Mg^{2+} ion.

..... [1]

- (iii) Describe in detail what you would observe when crystals of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ are heated in a boiling tube, gently at first and then more strongly.
Write equations for any reactions that occur.

.....

.....

.....

..... [4]

[4]

- (iv) Calculate the percentage **loss** in mass when $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ is heated strongly to constant mass.

percentage loss = ... % [2]

- (b) Explain why the Group 2 nitrates become more stable to heat down the group.

.....
.....
.....
.....
..... [2]

- (c) Magnesium nitrate and silver nitrate, AgNO_3 , decompose on heating to produce the same gases. Silver nitrate also produces silver metal during decomposition.

Write an equation for the decomposition of AgNO_3 .

..... [1]

[Total: 12]

Question No 30

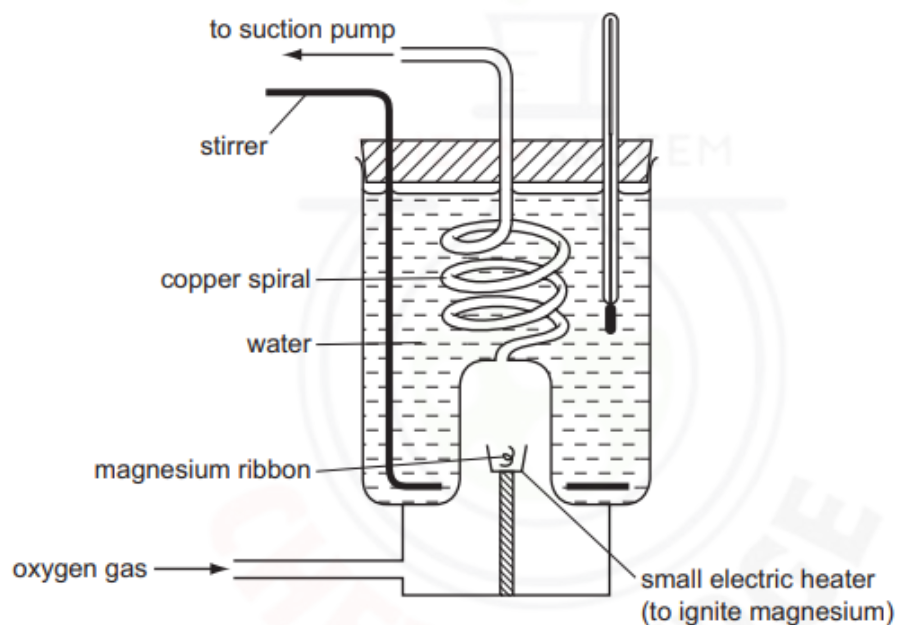
- (a) (i) What is meant by the term *lattice energy*?

.....
.....

- (ii) Write an equation to represent the lattice energy of MgO.

.....
[3]

- (b) The apparatus shown in the diagram can be used to measure the enthalpy change of formation of magnesium oxide, $\Delta H_f^\circ(\text{MgO})$.



List the measurements you would need to make using this apparatus in order to calculate $\Delta H_f^\circ(\text{MgO})$.

.....
.....
.....
..... [3]

- (c) Use the following data, together with appropriate data from the *Data Booklet*, to calculate a value of $\Delta H_f^\circ(\text{MgO})$.

lattice energy of MgO(s)	=	$-3791 \text{ kJ mol}^{-1}$
enthalpy change of atomisation of Mg	=	$+148 \text{ kJ mol}^{-1}$
electron affinity of the oxygen atom	=	-141 kJ mol^{-1}
electron affinity of the oxygen anion, O^-	=	$+798 \text{ kJ mol}^{-1}$

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$\Delta H_f^\circ(\text{MgO}) = \dots\dots\dots \text{kJ mol}^{-1}$
[3]

- (d) Write equations, including state symbols, for the reactions, if any, of the following two oxides with water. Suggest values for the pH of the resulting solutions.

oxide	equation	pH of resulting solution
Na_2O		
MgO		

[3]

[Total: 12]

Question No 31

- (a) Describe and explain the trend in the solubility of the hydroxides down Group 2.

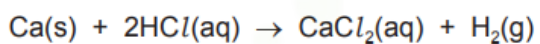
.....

.....

.....

..... [3]

- (b) Calcium reacts vigorously with $\text{HCl}(\text{aq})$ producing $\text{H}_2(\text{g})$.



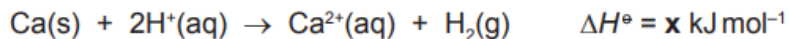
- (i) How would you expect the enthalpy change for this reaction to compare with the enthalpy change for the reaction where $\text{HNO}_3(\text{aq})$ is used in place of HCl but all other conditions are the same?
Explain your answer.

.....

..... [1]

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(ii) The ionic equation for this reaction is shown.



Construct a **fully labelled** Hess' Law cycle to connect each side of this equation to the relevant gas phase ions.

Use your cycle, the following data, **and** data from the *Data Booklet*, to calculate a value for **x**.

standard enthalpy of atomisation of Ca(s), $\Delta H^\ominus_{\text{at}}(\text{Ca})$	+178 kJ mol ⁻¹
standard enthalpy of hydration of Ca ²⁺ (g), $\Delta H^\ominus_{\text{hyd}}(\text{Ca}^{2+})$	-1576 kJ mol ⁻¹
standard enthalpy of hydration of H ⁺ (g), $\Delta H^\ominus_{\text{hyd}}(\text{H}^+)$	-1090 kJ mol ⁻¹

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(c) The standard enthalpy change for the reaction between Ca(s) and CH₃CO₂H(aq) is **less negative** than **x** by 2 kJ mol⁻¹.

Suggest an explanation for this.

.....

..... [2]

Question No 32

- (b) (i) Describe and explain the trend in the thermal stabilities of the nitrates of the Group II elements down the group.

.....

.....

.....

.....

..... [3]

When lithium nitrate, LiNO_3 , is heated, it readily decomposes giving off a brown gas. This reaction is similar to that which occurs when magnesium nitrate is heated, but it does not occur with other Group I nitrates.

- (ii) Suggest an equation for the action of heat on LiNO_3 .

..... [1]

- (iii) Suggest why the Group I nitrates other than LiNO_3 do **not** decompose in this way when heated.

.....

..... [1]

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Marking Scheme

Question No 1

Question	Answer				Marks																				
2(a)	<table><tr><td>enthalpy change</td><td>positive</td><td>negative</td><td>either positive or negative</td></tr><tr><td>electron affinity</td><td></td><td></td><td>✓</td></tr><tr><td>enthalpy change of atomisation</td><td>✓</td><td></td><td></td></tr><tr><td>enthalpy change of ionisation</td><td>✓</td><td></td><td></td></tr><tr><td>lattice enthalpy</td><td></td><td>✓</td><td></td></tr></table>				enthalpy change	positive	negative	either positive or negative	electron affinity			✓	enthalpy change of atomisation	✓			enthalpy change of ionisation	✓			lattice enthalpy		✓		2
	enthalpy change	positive	negative	either positive or negative																					
	electron affinity			✓																					
	enthalpy change of atomisation	✓																							
	enthalpy change of ionisation	✓																							
lattice enthalpy		✓																							
2(b)(i)	the second electron is removed from a (more) positively charged ion				1																				
2(b)(ii)	ΔH_6 is lattice (energy / enthalpy) AND ΔH_7 is (energy / enthalpy of) formation				1																				
2(c)	the electron affinity becomes less exothermic / negative down the Group 17				1																				
	electron affinity depends (mainly) on the electron-nucleus distance which increases down Group 17				1																				

Question No 2

Question	Answer	Mark
2 (a) (i)	$\text{Ca}^{2+}(\text{g}) + 2\text{Cl}^{-}(\text{g}) \rightarrow \text{CaCl}_2(\text{s})$ (state symbols required)	1
(ii)	$\text{Ca}^{2+}(\text{g}) + 2\text{Cl}(\text{g}) (+ 2\text{e}^{-})$ $\uparrow$ 2nd I.E. of Ca $\uparrow$ 1st I.E. of Ca $\uparrow$ EA of Cl $\times$ 2 $\uparrow$ Atomisation/ΔH_{at} of Ca $\uparrow$ $E(\text{Cl}-\text{Cl})/2\Delta H_{\text{at}}$ of Cl $\uparrow$ $\Delta H_f^\ominus \text{CaCl}_2(\text{s})$ $\downarrow$ $\Delta H_{\text{latt}}^\ominus$	2
(iii)	$\Delta H_{\text{latt}}^\ominus = -796 - 242 - 178 - 590 - 1150 + (2 \times 349) = -2258 \text{ kJ mol}^{-1}$	3

Question No 3

1(d)	use of (2×109) or 218 and (2×494) or 988	1
	use of (0.5×496) or 248	1
	use of 416, 142, 844	1
	evaluation of expression correctly $\Delta H_{\text{lat}} = -416 - (2 \times 109) - (0.5 \times 496) - (2 \times 494) - (-142 + 844) = -2572$	1
1(e)	the lattice energy of Na_2S is less exothermic	1
	the sulfide ion is larger than the oxide ion / S^{2-} larger than O^{2-} / ionic radii quoted 0.184 nm and 0.140 nm AND less attraction (between the ions)/bonds are weaker	1

Question No 4

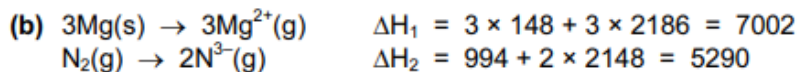
1(c)(i)	$\text{LE} = \Delta H_f - 2(\Delta H_{\text{at}} + \text{IE}) - \frac{1}{2}(\text{O}=\text{O}) - (\text{EA}_1 + \text{EA}_2)$ $= -361 - 2(89) - 2(418) - 496/2 - (-141 + 798)$ $= -2280 \text{ (kJ mol}^{-1}\text{) correct answer scores [3]}$	3 1 1 1
1(c)(ii)	LE of Na_2O will be more negative AND as $\text{Na}^{(+)}$ is smaller / larger charge density / smaller radii AND so greater attraction (between the ions) OR (ionic) bonds will be stronger	1

Question No 5

- (d) (i) $\text{Pb}^{2+}(\text{g}) + 2\text{Cl}^{-}(\text{g}) \longrightarrow \text{PbCl}_2(\text{s})$ [1]
- (ii) $\Delta H_f = \Delta H_{\text{at}} + E(\text{Cl} - \text{Cl}) + 1^{\text{st}} \text{IE} + 2^{\text{nd}} \text{IE} + 2 \times E_A(\text{Cl}) + \text{LE}$
 $-359 = 195 + 242 + 716 + 1450 - 2 \times 349 + \text{LE}$
 $\text{LE} = 2 \times 349 - 359 - 195 - 242 - 716 - 1450$
 $\text{LE} = -2264 \text{ (kJ mol}^{-1}\text{)}$ [3]
- (iii) $\text{LE}(\text{PbCl}_2) > \text{LE}(\text{PbBr}_2)$ or more exothermic or stronger lattice [1]
 because Cl^{-} / chloride anion has smaller radius / size than Br^{-} / bromide [1]

Question No 6

- 1 (a) $\text{N}\equiv\text{N}$ triple bond is (very) strong
or the N_2 molecule has no polarity [1]

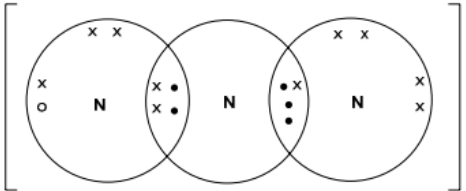
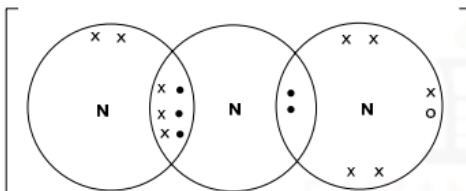


$\text{LE} = -\Delta H_1 - \Delta H_2 - 461 = -12,753 \text{ (kJ mol}^{-1}\text{)}$ (-[1] for each error) [3]

Question No 7

5(b)	enthalpy change = $(-642) - (2 \times -106) = -430$	1
5(c)(i)	$-106 = 147 + 121 + 736 + (-349) + \text{lattice energy}$ lattice energy = -761	3
5(c)(ii)	MgCl_2 more exothermic / negative / bigger than MgCl and NaCl more exothermic / negative / bigger than MgCl	1
	(reason for MgCl_2) higher charge / lower radius of Mg^{2+} cation	1
	(reason for NaCl) smaller radius of Na^+ cation	1
5(d)	energy change when 1 mole of atoms / ions each gain an electron or energy change when 1 mole of atoms / ions gain 1 mole of electrons	1
	gaseous	1

Question No 8

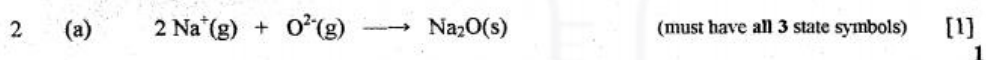
Question	Answer	Marks
2(a)	$\text{NaN}_3 \rightarrow \text{Na} + 1.5\text{N}_2$	1 1
2(b)	 all atoms must have 8 outer electrons coding for electrons correct = 16 (10 × 5 • 1 □) central N must have 8 bonding electrons (inc. 5 • and no non-bonded electrons) allow 	1 1 1 3
2(c)(i)	(energy change) when 1 mole of an (ionic) compound is formed or (energy change) when 1 mole of an <u>ionic</u> solid/lattice/crystal is formed (from) gas (phase) ions/gaseous ions (under standard conditions)	1 1 2
2(c)(ii)	forming an (ionic) bond	1 1

Question	Answer	Marks
2(c)(iii)	use of ΔH_{f1} 494 (kJ mol ⁻¹) $\Delta H_f^\circ = +107 + 494 + 142 - 732$ $\Delta H_f^\circ = +11$ (kJ mol ⁻¹)	1 1 1 3
2(c)(iv)	(ionic) radius/size of Na^+ is smaller (so stronger attraction to azide ion) OR ionic radius increases down the group	1 1
	Total:	11

Question No 9

(b) (i)	 correct charges correct electrons	1 1
(ii)	Lattice energy = $\Delta H_f(\text{SrCl}_2) - (\Delta H_{\text{atom}}(\text{Sr}) + \Delta H_{11}(\text{Sr}) + \Delta H_{12}(\text{Sr}) + \Delta H_{\text{atom}}(\text{Cl}) + 2\Delta H_{\text{ea}}(\text{Cl}))$ $= +(-830) - (+164 + 548 + 1060 + 242 + (2 \times -349))$ $= -2146 \text{ (kJ mol}^{-1}\text{)}$	1 1 1 [5]

Question No 10



- (b) (i) A: (2)Na(g)
B: O(g) [NOT O⁻(g)]
- (ii) 1: (first) ionisation energy (of sodium) *or* IE *or* ΔH_i
 2: first **and** second electron affinities (of oxygen) *or* $\text{EA}_1 + \text{EA}_2$
 (if B was stated as O⁻(g) rather than O(g), allow ½-mark for EA_2 only)
 3: lattice energy (of Na₂O) *or* LE *or* ΔH_{lat}
 4: enthalpy change of formation *or* ΔH_f (of Na₂O) *or* $2\Delta H_c$
 [for parts (i) and (ii) award ½ mark for each correct answer. Total the halves and round down]

[3]
3

(c) $\Delta H_f = 2\Delta H_{\text{at}}(\text{Na}) + 2 \text{IE}_1(\text{Na}) + \Delta H_{\text{at}}(\text{O}) + (\text{EA}_1 + \text{EA}_2)(\text{O}) + \text{LE}$
 $-414 = 2(107) + 2(494) + 496/2 + (-141 + 798) + \text{LE}$
 $\therefore \text{LE} = -2521 \text{ (kJ mol}^{-1}\text{)}$

correct answer, including sign [3]

allow [1] for use of the 6 correct values, i.e. the 4 on the question paper and 2 obtained from the data book: 496 and 494 (be aware that the "494" may appear as "988" and the "496" as "248" and the "798-141" as "657")

allow [1] for use of the correct multipliers for the values used, (i.e. if $\text{IE}(\text{Na})$ has been omitted, don't penalise for not multiplying 494 by 2). There are three multipliers: x2, x2 and x½. Some candidates are using the bond energy of O-O rather than O=O, in which case you can allow 150/2 for this mark (they will have forfeited the previous mark)

allow [2] for a correctly calculated answer from just one incorrect piece of data.

3

- (d) (i) higher/bigger/more (i.e. more negative) [1]

doubly charged cation *or* bigger charge (density) of cation *or* smaller cation [1]

- (ii) furnace linings *or* refractory material *or* crucibles [1]

high melting point [1]

4

Total: 11

Question No 11

1(b)(i)	$\Delta H_{r1} - (538 + 2 \times 230 + 394) = -(1216 + 286)$	1
	$\Delta H_{r1} - 1392 = -1502$	
	$\Delta H_{r1} = -110$	1
1(b)(ii)	let $\Delta H_f(\text{HCO}_3^-(\text{aq})) = y$	1
	$2y - 538 = -1216 - 394 - 286 - 26$	
	$y = -692$	1
1(b)(iii)	$\Delta H_{r3} - 538 - 2(230 + 394) = -538 - 2(692)$	1
	$\Delta H_{r3} = -136$	
1(b)(iv)	ΔH_{r3} will be identical to ΔH_{r4} , / unchanged	1
	as the reaction is the same, or:	
	$2\text{OH}^-(\text{aq}) + 2\text{CO}_2(\text{g}) \longrightarrow 2\text{HCO}_3^-(\text{aq})$ or	1
	metal ions stay in solution/metal ions are unchanged / are spectators	

Question	Answer	Marks
1(c)	more gaseous moles are being consumed (in reaction 3) or more CO₂ moles are being consumed (in reaction 3)	1
	ΔS is therefore expected to be more negative/less positive for reaction 3.	1

Question No 12

- (c) (i) $\Delta H^\circ = +2 \times 33.2 - 157.3 + 302.9 = (+) 212 \text{ kJ mol}^{-1}$ ecf [2]
- (ii) $\Delta H^\circ = -168.6 + 2 \times 157.3 = (+) 146 \text{ kJ mol}^{-1}$ **allow** ecf from (c)(i) [1]
high T / temperature since ΔH is positive / endothermic [1]

Question No 13

- (c) $\Delta H = 148 + 736 + 1450 + 496/2 - 141 + 798 - 3791$
 $= -552 \text{ kJ mol}^{-1}$ [3]
[3]
- (d) $\text{Na}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{aq/l}) \longrightarrow 2\text{NaOH}(\text{aq})$ [1]
 $\text{MgO}(\text{s}) + \text{H}_2\text{O}(\text{aq/l}) \longrightarrow \text{Mg}(\text{OH})_2(\text{s})$ or $\text{Mg}(\text{OH})_2(\text{aq})$ [1]
pH 12.5-14 [NaOH] **AND** 8-10.5 [Mg(OH)₂] respectively [1]
[3]

Question No 14

(c) (i) $\Delta H^\circ = +2 \times 33.2 - 157.3 + 302.9 = (+) 212 \text{ kJ mol}^{-1}$ ecf [2]

(ii) $\Delta H^\circ = -168.6 + 2 \times 157.3 = (+) 146 \text{ kJ mol}^{-1}$ **allow** ecf from (c)(i) [1]
high T/temperature since ΔH is positive/endothermic [1]

Question No 15

1 (a) (i) enthalpy/energy change/released when 1 mol of ions... [1]
in the gas phase (are dissolved in) water [1]

(ii) $\text{Mg}^{2+}(\text{g}) + \text{aq (or H}_2\text{O)} \rightarrow \text{Mg}^{2+}(\text{aq})$ or $[\text{Mg}(\text{H}_2\text{O})_6]^{2+}$ [1]

(iii) Mg^{2+} has a smaller radius/size or greater charge density than Ca^{2+} (**ions** required) [1]

(iv) O^{2-} reacts with water to give OH^- or equation: $\text{O}^{2-} + \text{H}_2\text{O} \rightarrow 2\text{OH}^-$ [1]
[5]

(b) (apparatus: "insulated" calorimeter, water and thermometer)

- measure (known volume/mass of) water or stated volume of water (into calorimeter)
- take the temperature (of the water – NOT the MgCl_2)
- weigh out known mass of MgCl_2 or stated mass of MgCl_2
- take final/highest/constant temperature or record temperature change/rise $4 \times [1]$
[4]

(c) (i) $\Delta H^\circ_{\text{sol}} = 641 - 801 = -160 \text{ kJ mol}^{-1}$ [1]

(ii) $\Delta H^\circ_{\text{hyd}} = (1890 - 2526 - 160)/2 = -398 \text{ kJ mol}^{-1}$ [2]
[3]

(d)

- solubility: $\text{MgSO}_4 > \text{BaSO}_4$ or decreases down the group
- because ΔH_{sol} is more endothermic for BaSO_4 or more exothermic for MgSO_4
- due to larger r_{ion} or smaller charge density of Ba^{2+} (ion has to be mentioned)
- leading to smaller LE and HE or LE and HE decrease
- but difference in HE (between Mg^{2+} and Ba^{2+}) is larger than the difference in LE (between MgSO_4 and BaSO_4)
- or HE is dominant or HE decreases more than LE

any 4 points [4]

[4]

[Total: 16]

Question No 16

- 2 (a) less soluble down group (1)
- lattice energy and hydration energies both decrease (i.e. become less negative) (1)
- but H.E. decreases more (than L.E.) or change in H.E. outweighs L.E. (1)
- so ΔH_{sol} becomes more endothermic / less exothermic (1) [4]
- (b) (i) for Mg: $\Delta H = 2993 - 1890 - (2 \times 550) = (+)3 \text{ (kJ mol}^{-1}\text{)}$ (1)
- for Sr: $\Delta H = 2467 - 1414 - (2 \times 550) = -47 \text{ (kJ mol}^{-1}\text{)}$ (1)
- (ii) Sr(OH)_2 should be **more** soluble in water, **and** ΔH is more exothermic / negative (1)
- Assuming "other factors" (e.g. ΔS , or temperature etc.) are the same (1)
- (iii) Sr(OH)_2 should be **less** soluble in hot water, **because** ΔH is negative / exothermic (1) [5]

Question No 17

Answer	Marks
M1 solubility decreases (down the Group) [1] M2 because lattice energy and hydration energy decreases OR lattice energy and hydration energy become less exothermic / more endothermic [1] M3 because hydration energy decreases to a greater extent (than does ΔH_{Latt}) [1]	3

Question No 18

Answer	Marks
ionic radius / ion size increases OR charge density decreases (down the group) [1] less polarisation / distortion of anion / nitrate ion / NO_3^- / nitrate group OR N-O / N=O bond is less weakened / distorted / polarised OR more energy to break N-O / N=O bond [1]	2
- moles of $\text{Ce}^{4+} = 0.0400 \times 21.8 / 1000 = 8.72 \times 10^{-4}$ (moles of Ce^{4+}) - moles of $\text{NO}_2^- = 8.72 \times 10^{-4} / 2 = 4.36 \times 10^{-4}$ in 25 cm^3 (use of 2:1 ratio correctly) - moles of $\text{NO}_2^- = 4.36 \times 10^{-4} \times 4 = 1.74(4) \times 10^{-3}$ in 100 cm^3 (use of 4:1 ratio correctly) - mass $\text{NaNO}_2 = 1.74(4) \times 10^{-3} \times (23.0 + 14.0 + 32.0) = 0.120 \text{ g}$ (use of M_r correctly) % purity = $0.120 / 0.138 = 86.96\%$ (use of 0.0138 correctly) two points = [1] four points = [2] all five points = [3]	3

Question No 19

(d)(i)	Mg ²⁺ ion is smaller than Ba ²⁺ ion or ionic radii increase down group or	1
	(Mg ²⁺) distorts/polarises/the anion/nitrate group/nitrate ion /NO ₃ ⁽¹⁾⁻ /NO ₃ ion more easily (than Ba ²⁺) or	1

Question No 20

cations become bigger / ionic radius increases	1
polarisation/distortion of anion / hydroxide ion decreases	1

Question No 21

Question	Marking point	Marks
1 (a)	Ca 3s ² 3p ⁶ 4s ² and Ca ²⁺ 3s ² 3p ⁶	1
(b)	Ca(OH) ₂ + 2HNO ₃ → Ca(NO ₃) ₂ + 2H ₂ O or CaO + 2HNO ₃ → Ca(NO ₃) ₂ + H ₂ O	1
(c) (i)	CaO and brown gas	1
(ii)	the (cat)ion size / radii increases decreasing its ability to polarise the nitrate ion/N-O bond	2
(d) (i)	(energy change when) 1 mole of ions gaseous (ions) dissolve in water (to form an infinitely dilute solution) or gaseous (ions) form an aqueous solution	2
(ii)	$\Delta H_{\text{latt}}^{\circ} \text{Ca(NO}_3)_2 + \Delta H_{\text{sol}}^{\circ} \text{Ca(NO}_3)_2 = \Delta H_{\text{hyd}}^{\circ} \text{Ca}^{2+} + 2\Delta H_{\text{hyd}}^{\circ} \text{NO}_3^-$ $\Delta H_{\text{latt}}^{\circ} - 19 = -1650 + (2x - 314)$ -2259 kJ mol ⁻¹	3
1	Ca ⁽²⁺⁾ is a smaller (ion) or Ca ⁽²⁺⁾ has a larger charge density Ca ⁽²⁺⁾ has a stronger attraction / bond to H ₂ O	2
		<u>12</u>

Question No 22

Question	Marking Point	Marks	Total Marks
1	(a) ionic bonds break/bonds between Mg^{2+} and Cl^- break forces/bonds/attractions form between the ions and water	2	
	(b) (i) (the energy change) when 1 mole of a substance dissolves in water/becomes aq	1	
	(ii) $\Delta H_{\text{latt}}^\circ \text{MgCl}_2 + \Delta H_{\text{sol}}^\circ \text{MgCl}_2 = \Delta H_{\text{hyd}}^\circ \text{Mg}^{2+} + 2\Delta H_{\text{hyd}}^\circ \text{Cl}^-$ $-2524 - 155 = -1925 + 2\Delta H_{\text{hyd}}^\circ \text{Cl}^-$ $= -377 \text{ kJ mol}^{-1}$	2	
	(iii) magnesium/Mg is higher charge/sodium/Na is smaller charge magnesium/Mg is smaller/sodium/Na is larger Mg stronger attraction for water/Na weaker attraction for water any two	2	
	(c) - solubility decreases - lattice energy and hydration enthalpy decrease - hydration enthalpy decreases more rapidly/is dominant factor - so (enthalpy change of) solution becomes less exothermic/more endothermic	4	
			[Total: 11]

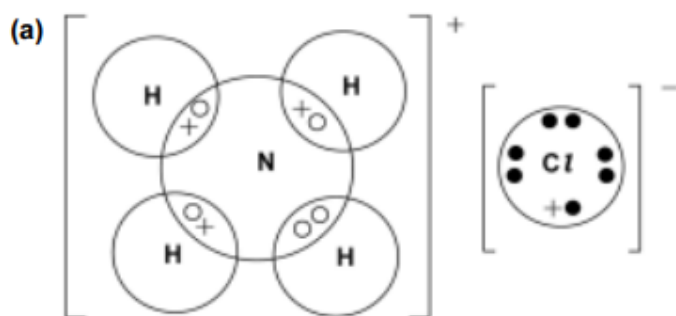
Question No 23

(e) (i)	(enthalpy change) when 1 mole of an ionic compound is formed from its gaseous ions	1 1	
(ii)	Mg^{2+} has a smaller (ionic) radii than Ca^{2+} OR Mg^{2+} is smaller than Ca^{2+}	1	[3]

Question No 24

(c) (i)	$\text{SrCO}_3 + 2\text{HNO}_3 \rightarrow \text{Sr}(\text{NO}_3)_2 + \text{CO}_2 + \text{H}_2\text{O}$	1	
(ii)	$\text{Sr}(\text{NO}_3)_2 \rightarrow \text{SrO} + 2\text{NO}_2 + 0.5 \text{O}_2$	1	[2]
(d)	(down the group) nitrates become more stable / require a higher temperature to decompose as size/radius of ion increases OR charge density of ion decreases so polarisation/distortion of anion/nitrate ion/ NO_3^- /NO bond decreases	1 1 1	[3]

Question No 25



8 e⁻ around chlorine

[1]

1 H-electron (+) on the Cl⁻ ion

[1]

3 covalent (ox) and one dative (oo) around N

[1]

[3]

(b) (i) it would react (with H₂SO₄)

[1]

(ii) $\text{CaO} + \text{H}_2\text{O} \longrightarrow \text{Ca(OH)}_2$

[1]

(iii) CaO absorbs more water or CaO has greater affinity for water

[1]

[3]

(c) (i) $2\text{Ca(NO}_3)_2 \longrightarrow 2\text{CaO} + 4\text{NO}_2 + \text{O}_2$

[1]

(ii) (Down the group, the nitrates)

become more stable/stability increases

[1]

because the size/radius of ion (M^{2+}) increases

[1]

thus causing less polarisation/distortion
of the anion/ NO_3^- /N-O bond

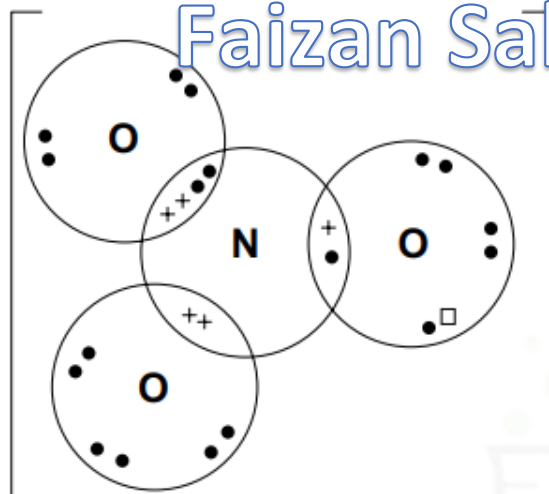
[1]

[4]

[Total: 10]

Question No 26

(a)



dative bond to an oxygen using two N electrons
 8 electrons around N in 1 double + 2 single
 a total of 24 electrons, including one, and *only* one " " (the extra electron, " ", can be in a bond or a lone pair)

[1]

[1]

[1]

[3]



[1]

(ii) (down the group)

nitrate becomes more stable *or* are more difficult to decompose *or* need a higher temperature to decompose

[1]

because there is less polarisation of the anion/nitrate ion/N-O bonds

[1]

as radius of M^{2+} /metal ion increases *or* charge density of the cation decreases

[1]

[4]



species [1]

balancing [1]

[2]

[Total: 9]

Question No 27

(a)(i)	(solubility) increases (down the group)	1
(a)(ii)	down the group: lattice energy or hydration energy decrease lattice energy decreases more than hydration energy enthalpy change of solution becomes more negative / exothermic	3
I(c)(i)	$2 \text{ SrO}_2 \longrightarrow 2 \text{ SrO} + \text{O}_2$	1
(c)(ii)	temperature will increase (down the group) charge density of cation decreases (down the group) this means less polarisation of the O_2^{2-} ion <i>or</i> weakens the O-O bond less	3
I(d)(i)	$\text{BaC}_2\text{O}_4 \longrightarrow \text{BaO} + \text{CO} + \text{CO}_2$	1

Question No 28

Question	Answer	Marks
1(a)	solubility increases down the group	1
	ΔH_{latt} and ΔH_{hyd} both decrease or ΔH_{latt} and ΔH_{hyd} both become less exothermic / more endothermic	1
	ΔH_{latt} decreases / changes more (than ΔH_{hyd} as OH^- being smaller than M^{2+})	1
	ΔH_{sol} becomes more exothermic / more negative / less endothermic / less positive	1
1(b)(i)	$\Delta H_{\text{r1}} - (538 + 2 \times 230 + 394) = -(1216 + 286)$	1
	$\Delta H_{\text{r1}} - 1392 = -1502$	
	$\Delta H_{\text{r1}} = \mathbf{-110}$	1
1(b)(ii)	let $\Delta H_f(\text{HCO}_3^-(\text{aq})) = y$	1
	$2y - 538 = -1216 - 394 - 286 - 26$	
	$y = \mathbf{-692}$	1
1(b)(iii)	$\Delta H_{\text{r3}} - 538 - 2(230 + 394) = -538 - 2(692)$	1
	$\Delta H_{\text{r3}} = \mathbf{-136}$	
1(b)(iv)	ΔH_{r3} will be identical to ΔH_{r4} , / unchanged	1
	as the reaction is the same, or: $2\text{OH}^-(\text{aq}) + 2\text{CO}_2(\text{g}) \longrightarrow 2\text{HCO}_3^-(\text{aq})$ or metal ions stay in solution/metal ions are unchanged / are spectators	1

Question No 29

Question	Answer	Marks
1 (a) (i)	dative (covalent) <i>or</i> coordinate Hydrogen / H (bonding)	2
(ii)	octahedral	1
(iii)	$\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O} \rightarrow \text{Mg}(\text{NO}_3)_2 + 6\text{H}_2\text{O}$ $\text{Mg}(\text{NO}_3)_2 \rightarrow \text{MgO} + 2\text{NO}_2 + \frac{1}{2}\text{O}_2$ <i>any three of</i> (solid) dissolves / turns to liquid condensation on tube <u>white</u> solid (forms/remains) brown fumes (evolved) gas formed that relights a glowing splint	4
(iv)	M_r values: $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O} = 256.3$ $\text{MgO} = 40.3$ or (loss in molar mass = $256.3 - 40.3 = 216$ percentage loss = $100 \times 216 / 256.3 = 84.3 / 84.4\%$	2
(b)	(cat)-ionic radius/ion size increases (down the group) less polarisation/distortion of nitrate ion/ NO_3^-	2
(c)	$2\text{AgNO}_3 \rightarrow 2\text{Ag} + 2\text{NO}_2 + \text{O}_2$	1
		[Total: 12]

Question No 30

- (a) (i) the enthalpy change/released when **1 mole is formed** [1]
of ionic lattice **from the gas phase ions** [1]
(ii) $\text{Mg}^{2+} + \text{O}^{2-} \longrightarrow \text{MgO}$ [1]
[3]
- (b) measurements needed:
volume/mass/weight of water (in calorimeter) [1]
initial + final temperature/temperature change/temperature rise (of the water) [1]
mass of Mg (used)/mass MgO [1]
Not volume/moles/mass of oxygen used [3]
- (c) $\Delta H = 148 + 736 + 1450 + 496/2 - 141 + 798 - 3791$
 $= \underline{-552} \text{ kJ mol}^{-1}$ [3]
[3]
- (d) $\text{Na}_2\text{O(s)} + \text{H}_2\text{O(aq/l)} \longrightarrow 2\text{NaOH(aq)}$ [1]
 $\text{MgO(s)} + \text{H}_2\text{O(aq/l)} \longrightarrow \text{Mg(OH)}_2\text{(s) or Mg(OH)}_2\text{(aq)}$ [1]
pH 12.5-14 [NaOH] **AND** 8-10.5 [Mg(OH)₂] respectively [1]
[3]

[Total: 12]

Question No 31

(a)	M1: solubility increases (down the group) M2: because lattice energy decreases faster than does ΔH_{hyd} M3: ΔH_{sol} / enthalpy of solution becomes more exothermic / less endothermic	3
(b) (i)	Should be the same / similar (enthalpy change), as (both acids) are fully ionised / strong acids	1

Question	Answer	Marks
(ii)	$\text{Ca(s)} + 2\text{H}^+(\text{aq}) \longrightarrow \text{Ca}^{2+}(\text{aq}) + \text{H}_2(\text{g})$ gas phase ions: $\text{Ca}^{2+}(\text{g}) + 2\text{H}^+(\text{g})$ $x = \Delta H_{\text{at}}(\text{Ca}) + \text{IE}(1) + \text{IE}(2) - 2\Delta H_{\text{hyd}}(\text{H}^+) + \Delta H_{\text{hyd}}(\text{Ca}^{2+}) - 2\text{IE}(\text{H}) - E(\text{H-H})$ $x = 178 + 590 + 1150 + 2(1090) - 1576 - 2(1310) - 436$ $x = -534 \text{ kJ mol}^{-1}$	4
(c)	$\text{CH}_3\text{CO}_2\text{H}$ is incompletely ionised / weak acid / weaker acid enthalpy change of ionisation (of CH_3COOH) is $+2 \text{ kJ mol}^{-1}$ or energy needed to ionise / dissociate (CH_3COOH)	2

Question No 32

(b) (i)	nitrates become more stable (down the group)	1
	as the ionic radius increases	1
	or charge density on cation/ion decreases	1
	decreasing its ability to distort/polarise the NO_3^- /nitrate ion	1
(ii)	$4\text{LiNO}_3 \longrightarrow 2\text{Li}_2\text{O} + 4\text{NO}_2 + \text{O}_2$	1
(iii)	the charge density of the other cations are too small (to polarise the anion sufficiently so the anion is more stable)	1