Lattice Enthalpy

1. This question is about magnesium, bromine and magnesium bromide.

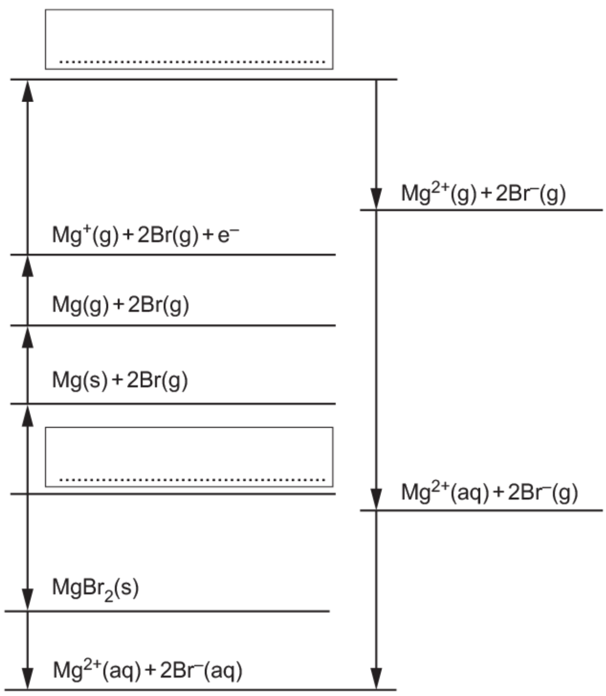
The enthalpy change of hydration of bromide ions can be determined using the enthalpy changes in **Table 16.2**.

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

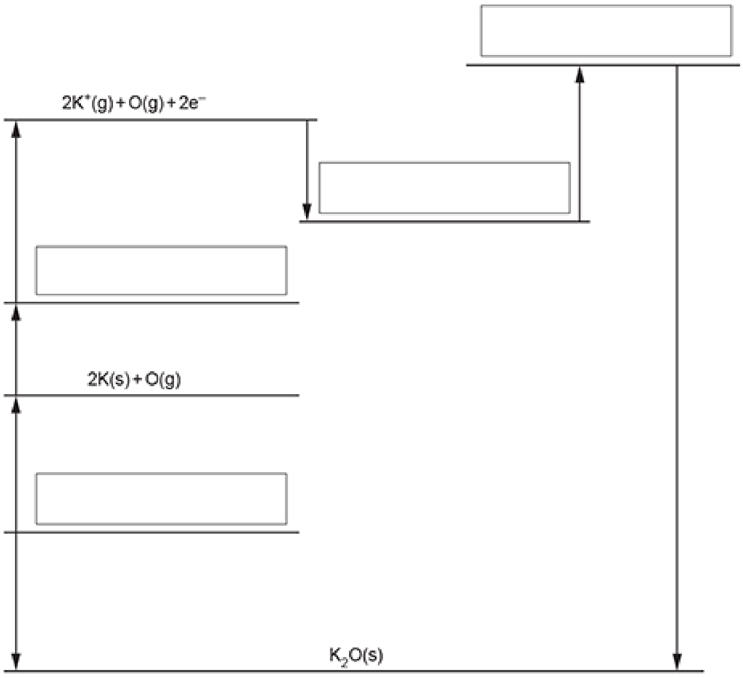
lattice enthalpy = ... kJ mol^{-1} **[3]**

2(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]**

3. This question is about copper(II) sulfate, $CuSO_4$, and sodium thiosulfate, $Na_2S_2O_3$.

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.

$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4{\cdot}5H_2O(s)$ $\Delta_r H$ **reaction 5.1**

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.

$CuSO_4(s) + aq \rightarrow Cu^{2+}(aq) + SO_4^{2-}(aq)$ $\Delta_{sol}H(CuSO_4(s))$ **reaction 5.2**

$CuSO_4{\cdot}5H_2O(s) + aq \rightarrow Cu^{2+}(aq) + SO_4^{2-}(aq)$ $\Delta_{sol}H(CuSO_4{\cdot}5H_2O(s))$ **reaction 5.3**

Experiment 1
A student carries out an experiment to find $\Delta_{sol}H(CuSO_4(s))$ for **reaction 5.2.**

Student's method

- Weigh a bottle containing $CuSO_4(s)$ and weigh a polystyrene cup.
- Add about 50 cm^3 of water to the polystyrene cup and measure its temperature.
- Add the $CuSO_4(s)$, 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 + $CuSO_4(s)$ / 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 $CuSO_4{\cdot}5H_2O$ (**reaction 5.3**). The student uses the same method as in **Experiment 1**.

The student calculates $\Delta_{sol}H(CuSO_4{\cdot}5H_2O(s))$ as +8.43 kJ mol^{-1}.

i. *Calculate $\Delta_{sol}H(CuSO_4(s))$ for **reaction 5.2** and determine the enthalpy change of **reaction 5.1**, $\Delta_r H$.

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 ± 0.1 °C.

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

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

temperature change = ... °C **[1]**

4. This question is about enthalpy changes.

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

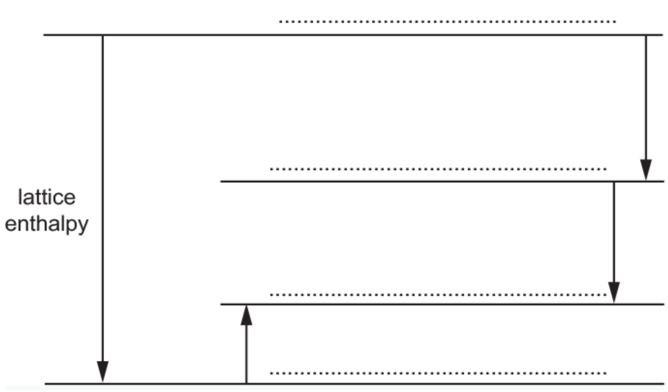
Enthalpy change	**Energy / kJ mol^{-1}**
Hydration of Ca^{2+}	−1609
Solution of CaF_2	+13
Lattice enthalpy of CaF_2	−2630

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]**

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

1. A plastic cup is weighed.

2. Approximately 100 cm^3 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_2SO_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, $\Delta_{sol}H$, = ... kJ mol^{-1} **[4]**

ii. The student's thermometer has a maximum error of ±0.5 °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.

Predict and explain the effect, if any, of the larger volume of water on the following:

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

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____ **[4]**

6(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.*

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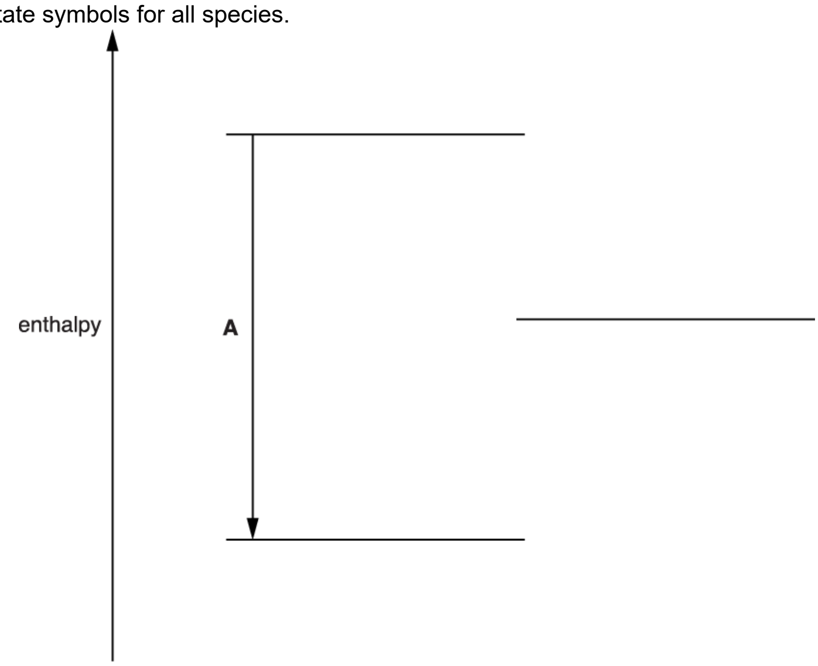
____ **[2]**

(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.

ΔH = ... kJ mol^{-1} **[1]**

(c). The entropy change of solution of K_2SO_4 is +225 J K^{-1} 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]**

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

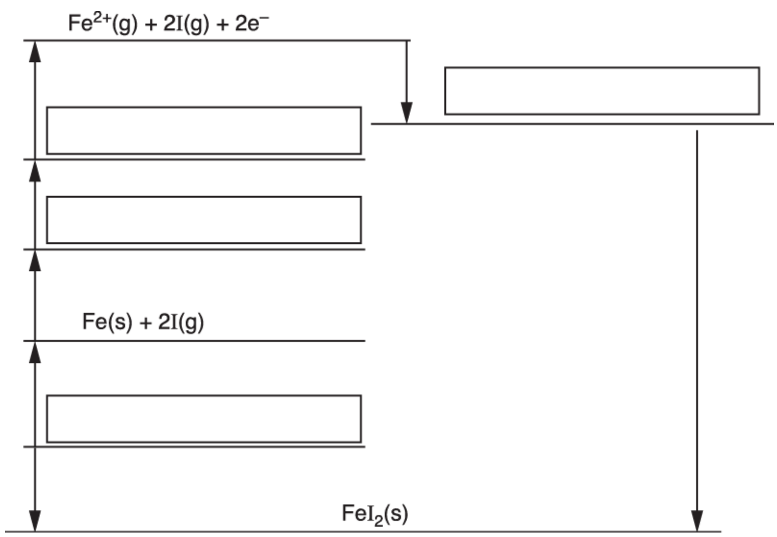
The table below shows enthalpy changes involving iron, iodine and iron(II) iodide.

	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*.

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____ **[2]**

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

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

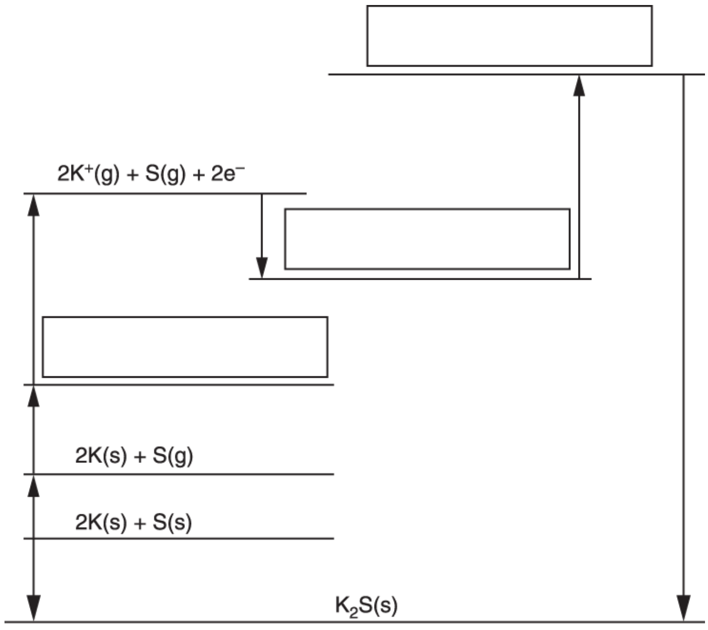
8(a). Born—Haber cycles can be used to calculate enthalpy changes indirectly.

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.

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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 Rb*Cl* from lowest to highest.

Explain your answer.

Lowest melting point ....

....

Highest melting point ....

Explanation

....

....

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[3]

9(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*.

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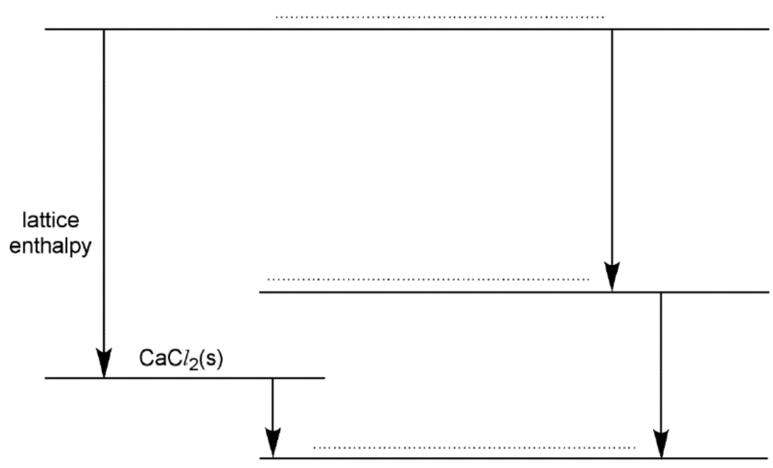
____ **[1]**

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

$\Delta_{sol}H$ = ...kJ mol^{-1} **[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.

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[3]

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

$\Delta_{sol}H$ = ... 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 $\Delta_{sol}H$ from the experiments of the two students. Explain your reasoning.

--- **[2]**

10(a). Lattice enthalpies give an indication of the strength of ionic bonding.

How would the lattice enthalpies of magnesium chloride and calcium chloride differ?

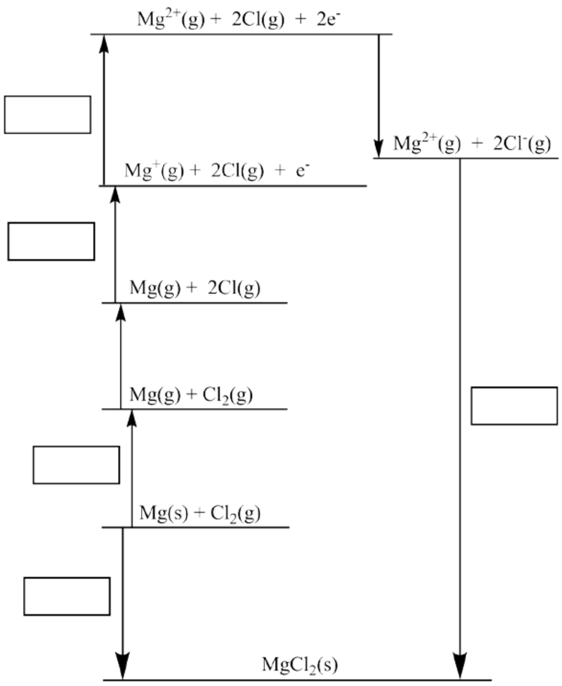
Explain your answer.

--- **[3]**

(b). The table below shows the enthalpy changes that are needed to determine the lattice enthalpy of magnesium chloride, $MgCl_2$.

Letter	Enthalpy change	Energy / kJ mol^{-1}
A	1st electron affinity of chlorine	−349
B	1st ionisation energy of magnesium	+736
C	atomisation of chlorine	+150
D	formation of magnesium chloride	−642
E	atomisation of magnesium	+76
F	2nd ionisation energy of magnesium	+1450
G	lattice enthalpy of magnesium chloride	

i. On the cycle below, write the correct letter in each box.



[3]

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

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

END OF QUESTION PAPER