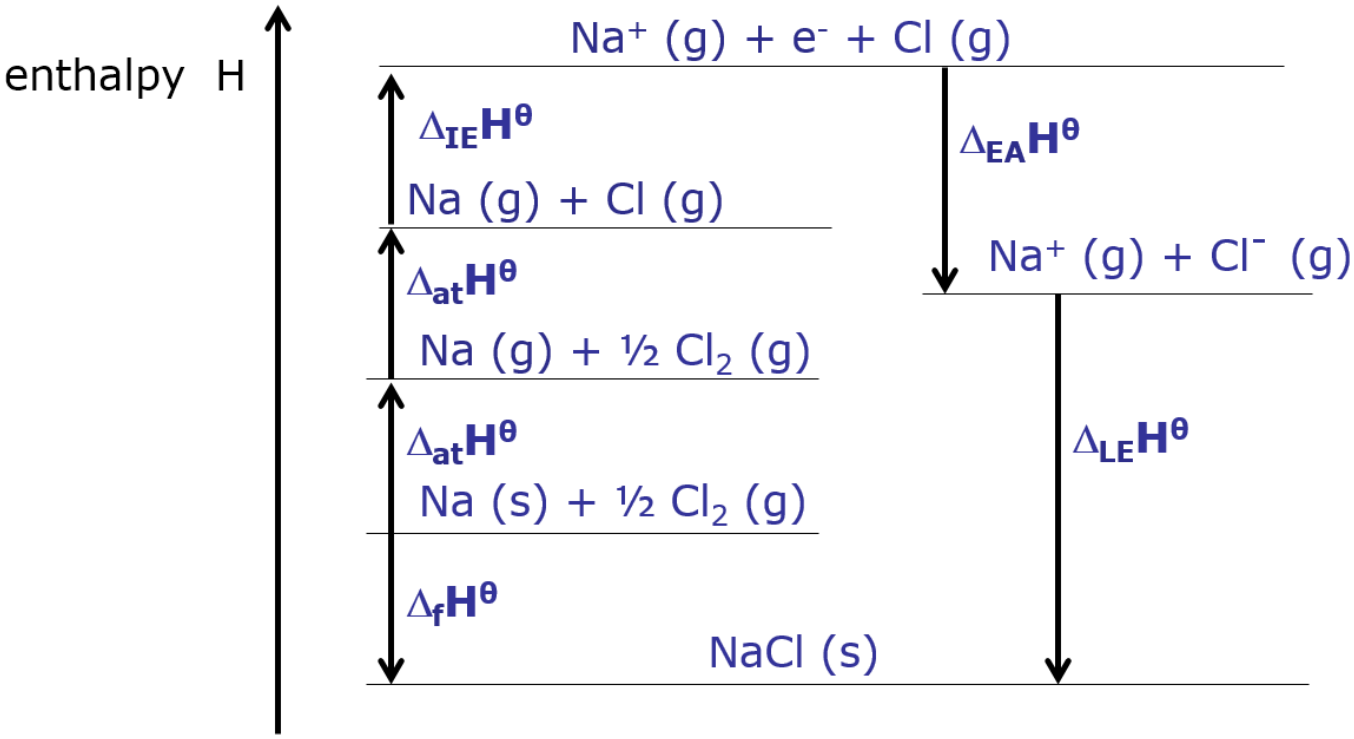
## Born-Haber cycle

e.g. for sodium chloride:

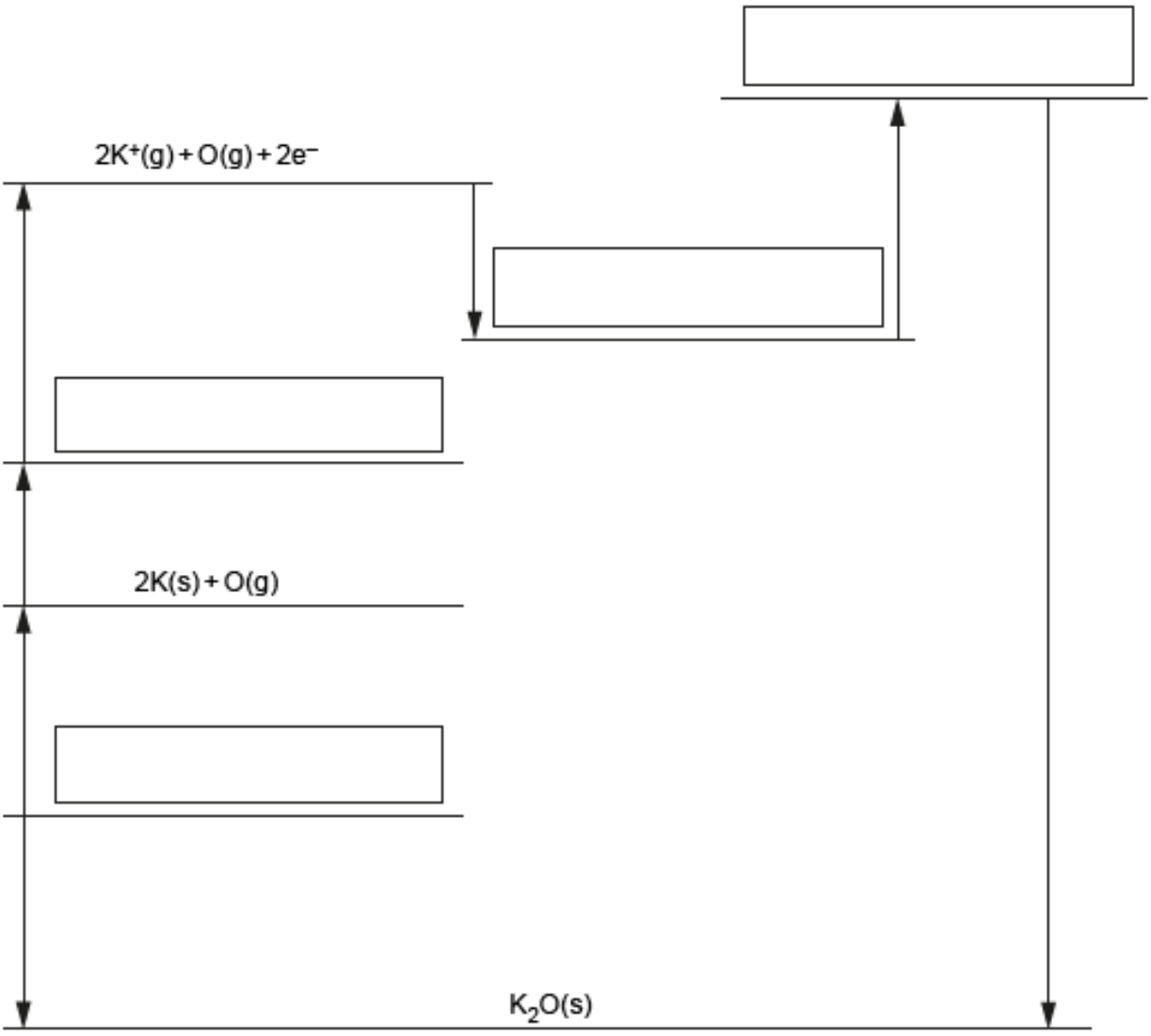


**(d)** The table below shows enthalpy changes involving potassium, oxygen and potassium oxide, $K_2O$.

| | **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.



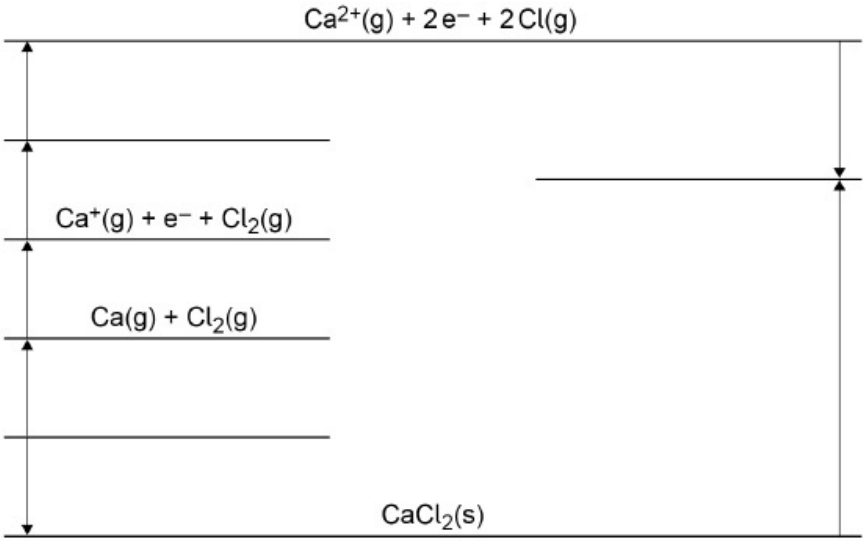

**[4]**

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

**[1 mark]**

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

**Figure 1**




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

**[3 marks]**

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

**Table 1**

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

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

**[2 marks]**

**(c)** The enthalpy change of solution for magnesium fluoride, $MgF_2$, can be determined indirectly using an energy cycle based on the enthalpy changes below.

| Enthalpy change | Energy / kJ mol$^{-1}$ |
|---|---|
| Lattice enthalpy of magnesium fluoride | –2926 |
| Hydration of magnesium ions | –1920 |
| Hydration of fluoride ions | –506 |

**(i)** Explain what is meant by **enthalpy change of solution**.

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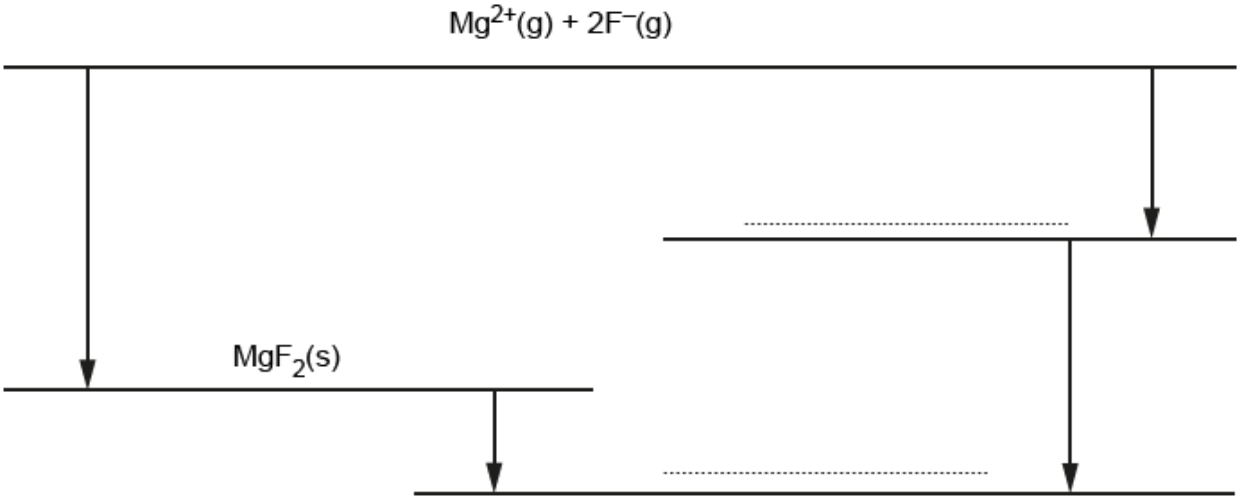
..... **[1]**

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




**[2]**

**(iii)** Calculate the enthalpy change of solution of $MgF_2$.

**(iv)** The enthalpy changes of solution of the magnesium halides show a trend from $MgF_2$ to $MgI_2$.

Explain why it is difficult to predict whether the enthalpy change of solution becomes more exothermic or less exothermic down the group from $MgF_2$ to $MgI_2$.

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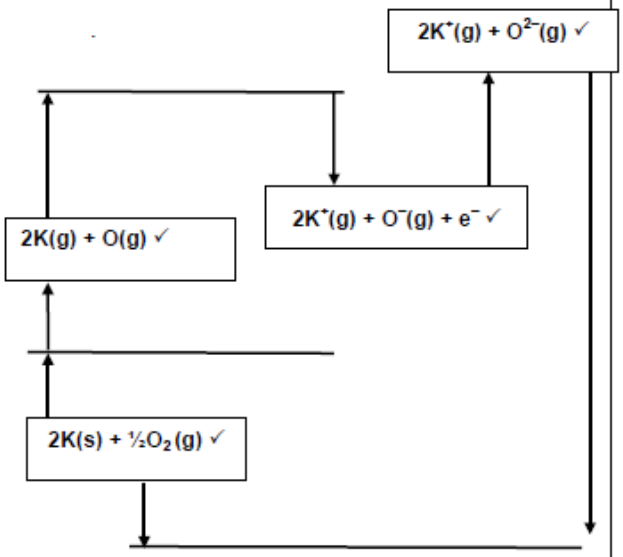
..... **[4]**

| Question | | | Answer | Marks | AO element | Guidance |
|---|---|---|---|---|---|---|
| 16 | (d) | (i) |  | 4 | 1.2 ×4 | Mark each marking point independently<br>Correct species **AND** state symbols required for each mark<br>For e-, **ALLOW** e<br>For e⁻ **only**, **IGNORE** any state symbols added |
| 16 | | (ii) | **FIRST CHECK THE ANSWER ON ANSWER LINE**<br>**If answer = –2277 (kJ mol$^{-1}$) award 2 marks** | 2 | 2.2 ×2 | IF there is an alternative answer, check to see if there is any ECF credit possible using |

| Question | | | Answer | Marks | AO element | Guidance |
|---|---|---|---|---|---|---|
| | | | –363 – (2 × +89 +249 + 2 × 419 – 141 + 790) ✓<br><br>–363 – 1914<br>= –2277 ✓ (kJ mol$^{-1}$) | | | working below<br><br>**See list below for marking of answers from common errors**<br><br>**ALLOW** for 1 mark **ONE** mistake with sign **OR** use of 2 ×:<br>+2277 (wrong sign)<br>–601 (2 × –419 instead of 2 × +419)<br>–697 (–790 instead of +790)<br>–1551 (+363 instead of –363)<br>–1858 (2 × +419 not used for K)<br>–1921 (2 × –89 instead of 2 × +89)<br>–2152.5 or –2153 (+249 ÷ 2)<br>–2188 (2 × +89 not used for K)<br>–2280 (rounded to 3SF)<br>–2559 (+141 instead of –141)<br><br>**For other answers**, check for a **single** transcription error or calculator error which could merit 1 mark |

| Question | Answers | Additional comments/Guidelines | Mark |
|---|---|---|---|
| 01.1 | Heat (energy) change at constant pressure | Ignore conditions even if wrong<br>Ignore energy change | 1 |

| Question | Answers | Additional comments/Guidelines | Mark |
|---|---|---|---|
| 01.2 | M2 $Ca^{2+}(g) + 2\ e^- + Cl_2(g)$ | Alternative M2 $Ca^+(g) + e^- + 2\ Cl(g)$ | 1 |
| | M3 $Ca^{2+}(g) + 2\ Cl^-(g)$ | | 1 |
| | M1 $Ca(s) + Cl_2(g)$ | | 1 |

| Question | Answers | Additional comments/Guidelines | Mark |
|---|---|---|---|
| 01.3 | M1 $-795 + LE = 193 + 590 + 1150 + (\mathbf{2} \times 121) + (\mathbf{2} \times -364)$ | Numbers and factors used correctly from cycle | 1 |
| | M2 $LE = (+)\ 2242\ (kJ\ mol^{-1})$ | Rearrangement to calculate LE<br>If one or both factors of 2 missing award 1 mark for (+) 2485, (+)2121 or (+)2606 ($kJ\ mol^{-1}$)<br>Allow 1 mark for – 2242 ($kJ\ mol^{-1}$) | 1 |

| Question | Answers | Additional comments/Guidelines | Mark |
|---|---|---|---|
| 01.4 | $MgCl_2(s) \rightarrow Mg^{2+}(aq) + 2\ Cl^-(aq)$ | Allow $MgCl_2(s) \rightleftharpoons Mg^{2+}(aq) + 2\ Cl^-(aq)$<br>Allow $MgCl_2(s) + aq \rightleftharpoons Mg^{2+}(aq) + 2\ Cl^-(aq)$ | 1 |

| Question | | | Answer | Marks | AO element | Guidance |
|---|---|---|---|---|---|---|
| | (c) | (i) | (enthalpy change for) **1 mole** of a compound/substance/solid/solute **dissolving** ✓ | 1 | AO1.1 | **IGNORE** 'energy released' **OR** 'energy required'<br><br>For dissolving, **ALLOW** forms aqueous/hydrated ions<br>**IGNORE** ionic **OR** covalent<br>**DO NOT ALLOW** dissolving elements<br>**DO NOT ALLOW** response that implies formation of **1 mole** of aqueous ions |
| | (c) | (ii) | $Mg^{2+}(aq) + 2F^{-}(g)$ ✓<br><br>$Mg^{2+}(aq) + 2F^{-}(aq)$ ✓ | 2 | AO2.2 ×2 | **ALLOW** $Mg^{2+}(g) + 2F^{-}(aq)$<br><br>**ALLOW** $MgF_2(aq)$ |
| | (c) | (iii) | –6 (kJ mol$^{-1}$) ✓<br><br>$\Delta_{sol}H$ ($MgF_2$) = – (–2926) + (2 × –506) + (–1920) | 1 | AO2.2 | **1 mark ONLY** |
| | (c) | (iv) | **Ionic radius**<br>Halide **ion** gets larger down the group ✓<br><br>**Lattice enthalpy**<br>Lattice enthalpy is less exothermic down group **OR** halide ion has less attraction for $Mg^{2+}$ ✓<br><br>**Hydration enthalpy**<br>Hydration enthalpy is less exothermic down group **OR** halide ion has less attraction for $H_2O$ ✓<br><br>**Enthalpy of solution**<br>Difficult to predict whether lattice enthalpy or hydration enthalpy has bigger effect ✓ | 4 | AO1.2 ×3<br><br>AO3.2 | **ALLOW ORA** throughout<br>**ALLOW** ions closer together in $MgF_2$ **OR** further apart in $MgI_2$<br>**DO NOT ALLOW** atomic radius<br><br>**ALLOW** $MgI_2$ is less exothermic than $MgF_2$ for LE and hydration enthalpy -as trend 'down the group'.<br><br>**ALLOW** less negative/more positive **BUT** **IGNORE** is smaller/less |
| | | | **Total** | 14 | | |