3.7: Lattice Energy and the Born-Haber Cycle

An important enthalpy change is the Lattice Energy, which is the energy required to take one mole of a crystalline solid to ions in the gas phase. For $\mathrm{NaCl(s)}$, the lattice energy is defined as the enthalpy of the reaction

$$\mathrm{NaCl(s)} \rightarrow \mathrm{Na^+(g)} + \mathrm{Cl^-(g)}$$

with ΔH called the lattice energy (ΔH_{Lat}).

The Born-Haber Cycle

A very handy construct in thermodynamics is that of the thermodynamic cycle. This can be represented graphically to help to visualize how all of the pieces of the cycle add together. A very good example of this is the **Born-Haber cycle**, describing the formation of an ionic solid.

Two pathways can be envisioned for the formation. Added together, the two pathways form a cycle. In one pathway, the ionic solid if formed directly from elements in their standard states.

$$\mathrm{Na(s)} + \frac{1}{2}\mathrm{Cl_2} \rightarrow \mathrm{NaCl(s)}$$

with $\Delta H_f(NaCl)$.

The other pathway involves a series of steps that take the elements from neutral species in their standard states to ions in the gas phase.

$$Na(s) \rightarrow Na(g)$$

with $\Delta H_{sub}(Na)$

$$Na(g) \rightarrow Na^+(g) + e^-$$

with $1^{st}\ IP(Na)$

$$½Cl_2(g) \rightarrow Cl(g)$$

with $½D(Cl-Cl)$

$$Cl(g) + e^- \rightarrow Cl^-(g)$$

with $1^{st}EA(Cl)$

$$Na^+(g) + Cl^-(g) \rightarrow NaCl(s)$$

with $\Delta H_{Lat}(NaCl)$

It should be clear that when added (after proper manipulation if needed), the second set of reactions yield the first reaction. Because of this, the total enthalpy changes must all add.

$$\Delta H_{sub}(Na) + 1^{st}IP(Na) + ½D(Cl-Cl) + 1^{st}EA(Cl) + \Delta H_{lat}(NaCl) = \Delta H_f(NaCl)$$

This can be depicted graphically, the advantage being that arrows can be used to indicate endothermic or exothermic changes. An example of the Born-Haber Cycle for NaCl is shown below.

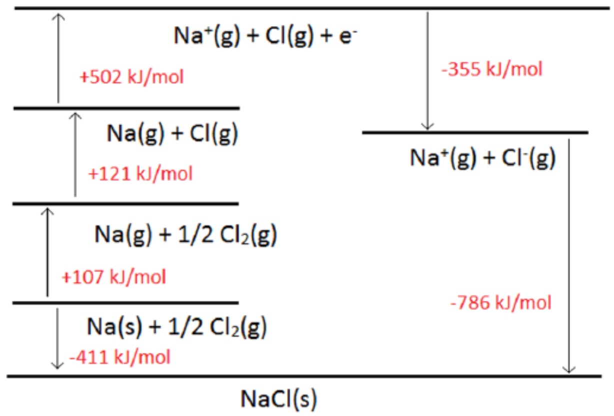

Figure 3.6.1: the Born-Haber Cycle for NaCl.

In many applications, all but one leg of the cycle is known, and the job is to determine the magnitude of the missing leg.

Exercise 3.7.1: Potassium Bromide

Find ΔH_f for KBr given the following data.

$$\mathrm{K(s)} \rightarrow \mathrm{K(g)}$$

with $\Delta H_{sub} = 89\, kJ/mol$

$$\mathrm{Br_2(l)} \rightarrow \mathrm{Br_2(g)}$$

with $\Delta H_{vap} = 31\, kJ/mol$

$$\mathrm{Br_2(g)} \rightarrow \mathrm{2\,Br(g)}$$

with $D(Br-Br) = 193\, kJ/mol$

$$\mathrm{K(g)} \rightarrow \mathrm{K^+(g)} + \mathrm{e^-}$$

with $1^{st}\, IP(K) = 419 kJ/mol$

$$\mathrm{Br(g)} + \mathrm{e^-} \rightarrow \mathrm{Br-(g)}$$

with $1^{st}\, EA(Br) = 194 kJ/mol$

$$\mathrm{K^+(g)} + \mathrm{Br-(g)} \rightarrow \mathrm{KBr(s)}$$

with $\Delta H_{Lat} = 672 kJ/mol$

Answer

$\Delta H_f = -246\, kJ/mol$

Note: This cycle required the extra leg of the vaporization of Br_2. Many cycles involve ions with greater than unit charge and may require extra ionization steps as well!