

Born–Haber cycles

Learning objectives

- 1 Construct Born–Haber cycles involving singly and doubly charged cations and anions.
- 2 Compare the relative sizes of the enthalpy changes involved in different Born–Haber cycles.
- 3 Explain the relative magnitudes of enthalpy changes involving transferring electrons from and to atoms and ions.
- 4 Calculate an unknown enthalpy change using Hess's Law, given suitable data about the other enthalpy changes in a Born–Haber cycle.

Introduction

This activity uses a set of cut out arrows drawn to scale to represent the component enthalpy changes that make up Born–Haber cycles for the formation of NaCl(s), MgCl₂(s), Na₂O(s) and MgO(s) from their elements. You will need to decide the correct arrangement of enthalpy changes for each cycle and make sure that the endothermic arrows point up and the exothermic arrows point down.

Before you start, you should be familiar with the types of enthalpy changes involved in a Born–Haber cycle: enthalpy of atomisation, ionisation enthalpy, first electron affinity and lattice enthalpy.

Part 1: Born–Haber cycle for NaCl

Start by constructing the Born–Haber cycle for the formation of NaCl(s).

- Lay out the cards on a flat surface.
- Place the elements Na(s) and $\frac{1}{2}\text{Cl}_2(\text{g})$ on the surface.
- Use the blue enthalpy change arrows to construct the route to form NaCl(s) via the bond breaking, electron transfer and bond making steps.
- Finally use the red enthalpy change of formation arrow to connect the elements Na(s) and $\frac{1}{2}\text{Cl}_2(\text{g})$ directly to NaCl(s).

Check that your cycle is correct before answering the questions below.

Questions

1. Write equations for the following processes.
 - (a) The enthalpy change of atomisation of Na(s).
 - (b) The enthalpy change of atomisation of Cl₂(g).
 - (c) The lattice enthalpy of NaCl(s).

- State the type of bonding associated with the three changes in Q1 above.
- Explain why $\frac{1}{2}$ of the bond enthalpy of $\text{Cl}_2(\text{g})$ has the same value as the enthalpy change of atomisation of $\text{Cl}_2(\text{g})$.
- Sketch a Born–Haber cycle for potassium chloride, $\text{KCl}(\text{s})$ and use relevant data from the NaCl cycle, plus the additional data below to calculate a value for the lattice enthalpy of potassium chloride.

Enthalpy change	$\Delta H^\ominus / \text{kJ mol}^{-1}$
Atomisation enthalpy of potassium	+ 90
First ionisation energy of potassium	+ 419
Enthalpy change of formation of potassium chloride	- 437

- Explain why the lattice enthalpy of potassium chloride is lower in magnitude than the lattice enthalpy of sodium chloride.
- To what extent do you agree with the statement made by a student to explain that ionic bonding occurs because “sodium atoms want to lose their outer electron”? Explain your answer.

Part 2: Born–Haber cycles for MgCl_2 , Na_2O and MgO

Now try constructing the more complicated cycles for each of the above ionic compounds. You will see that the lattice enthalpies for these compounds are much larger than for NaCl , so you will need a much larger surface to work on. Note also the following additional features that you will need to include.

- The second ionisation enthalpy for magnesium ions.
- The need to double the atomisation and electron affinity/first ionisation enthalpy for the singly charged ions combining with a doubly charged ion.
- The large endothermic second electron affinity of oxide ions.

Check that your cycles are correct before answering the questions below.

Questions

- Explain why the second ionisation enthalpy of magnesium is higher than the first ionisation enthalpy of magnesium.
- Explain why the second electron affinity of oxygen is endothermic.
- Explain why the lattice enthalpy of magnesium chloride is significantly greater in magnitude than the lattice enthalpy of sodium chloride.
- Potassium oxide, $\text{K}_2\text{O}(\text{s})$, has a lattice enthalpy of $-2237 \text{ kJ mol}^{-1}$. Sketch a Born–Haber cycle for potassium oxide, and use relevant data from the Na_2O cycle, and the table above, to calculate a value for the enthalpy of formation of potassium oxide.