16–18 years

Born–Haber cycles

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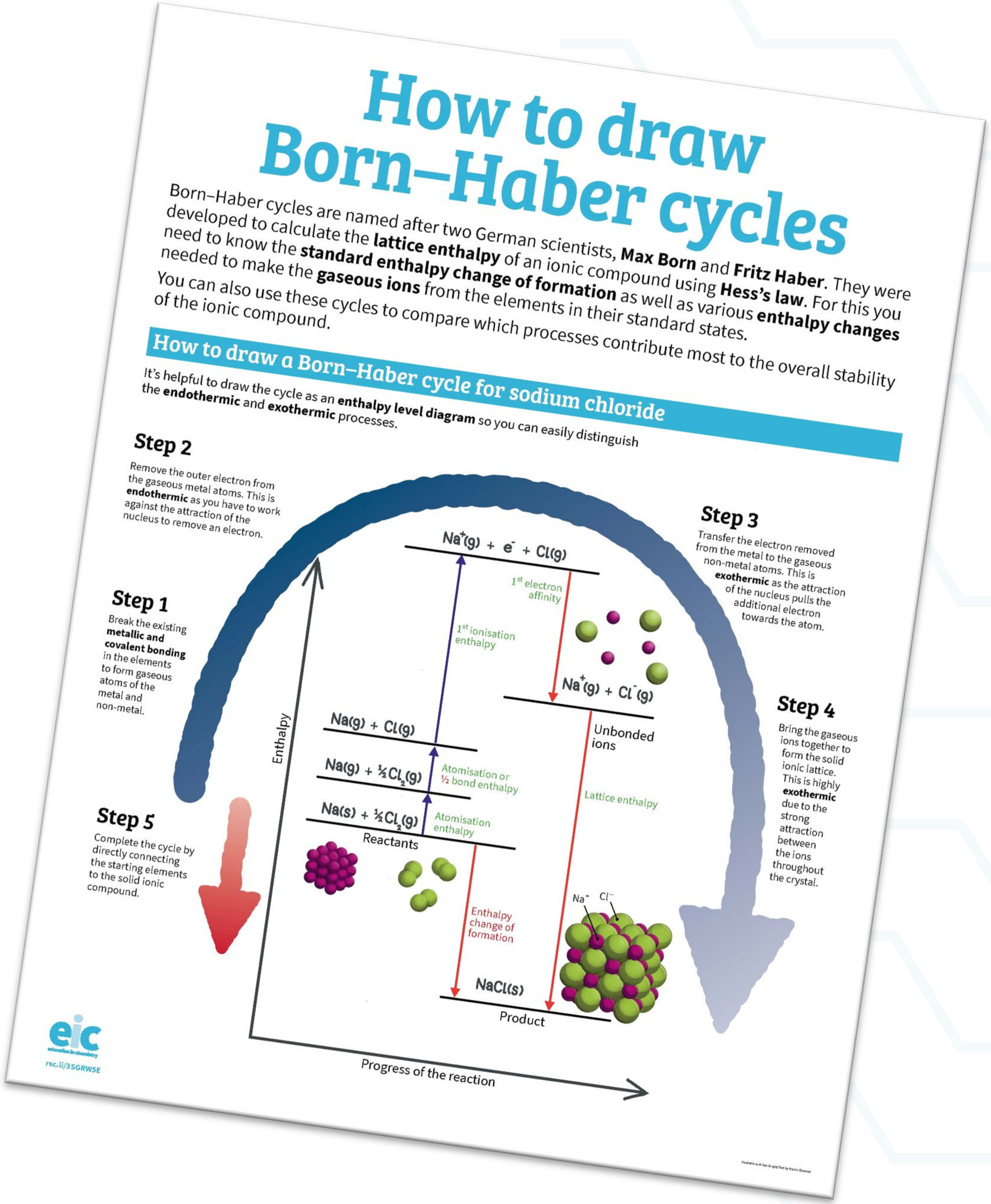
Introduction

Born–Haber cycles were developed to calculate the lattice enthalpy of an ionic compound using Hess's law.

For this you need to know the standard enthalpy change of formation as well as the various enthalpy changes needed to make the gaseous ions from the elements in their standard states.

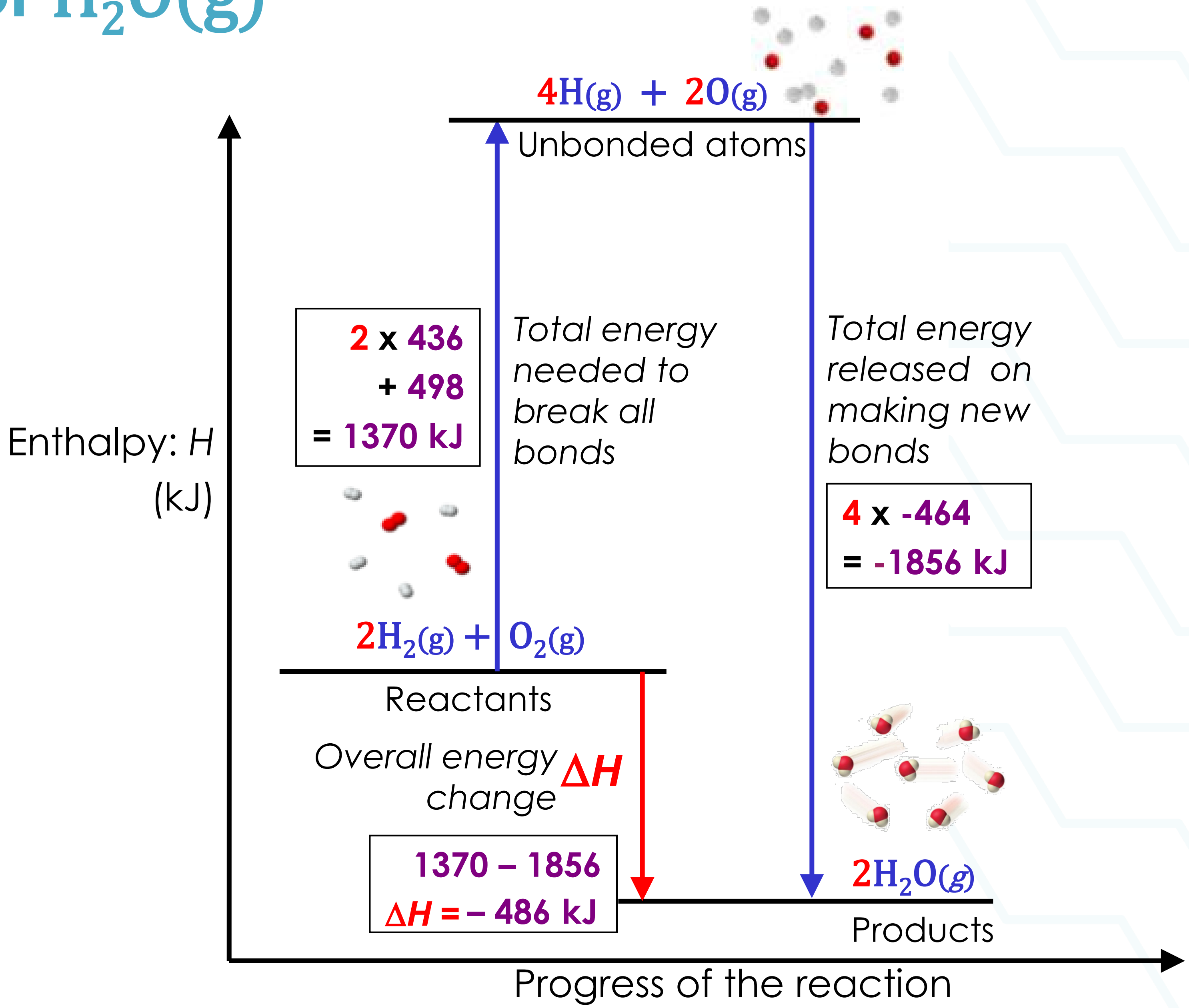


Learning objectives

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.

Formation of $H_2O(g)$

For covalent molecules, **bond enthalpies** give the relative strengths of all the bonds broken and made.

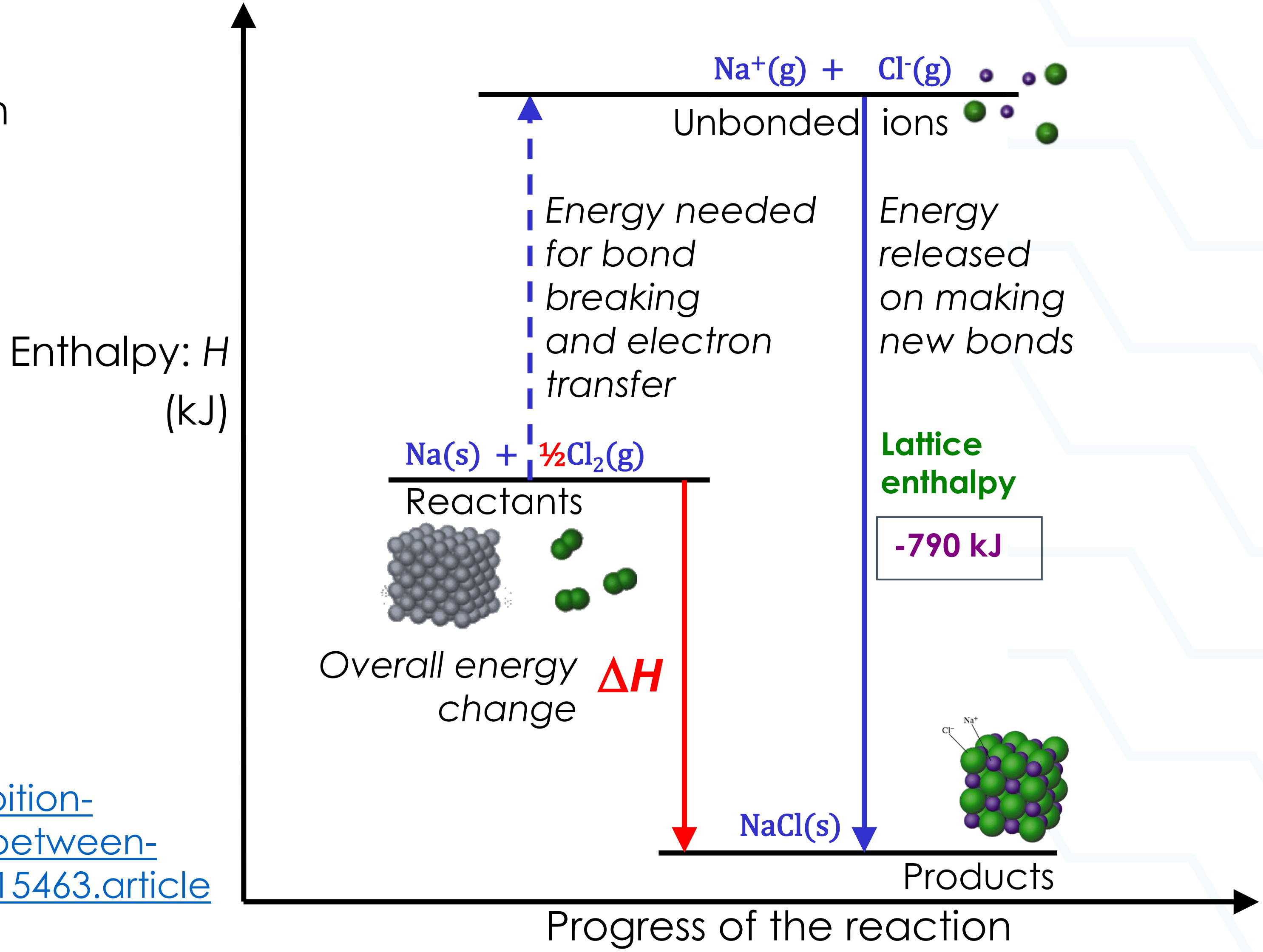


Bond	ΔH° (kJ mol^{-1})
H – H	436
O = O	498
O – H	464

Formation of NaCl(s)

For ionic compounds, different types of bonding and electron transfer are involved.

Watch a demonstration of this reaction: https://edu.rsc.org/exhibition-chemistry/the-reaction-between-sodium-and-chlorine/4015463.article



Formation of NaCl(s)

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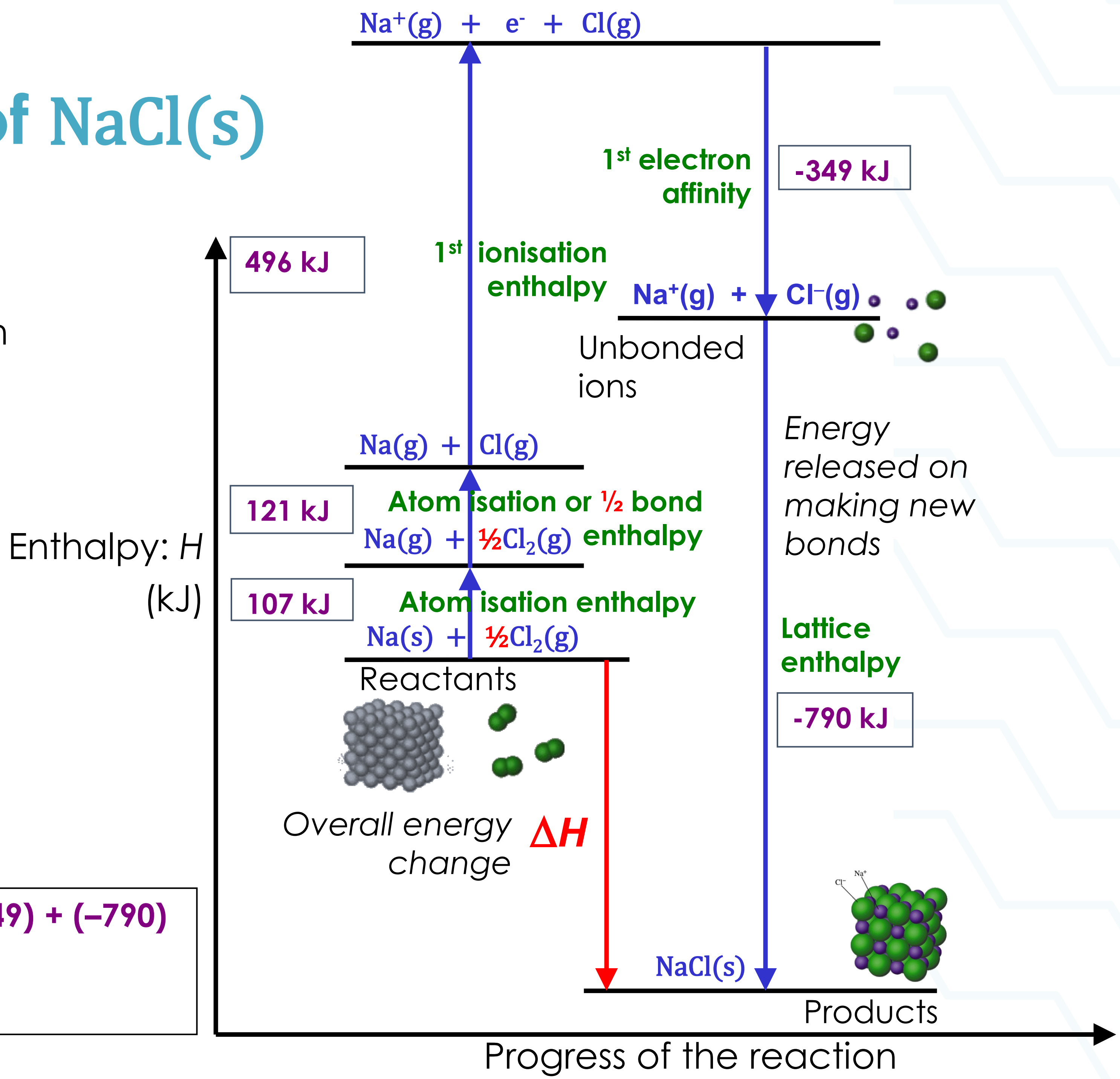
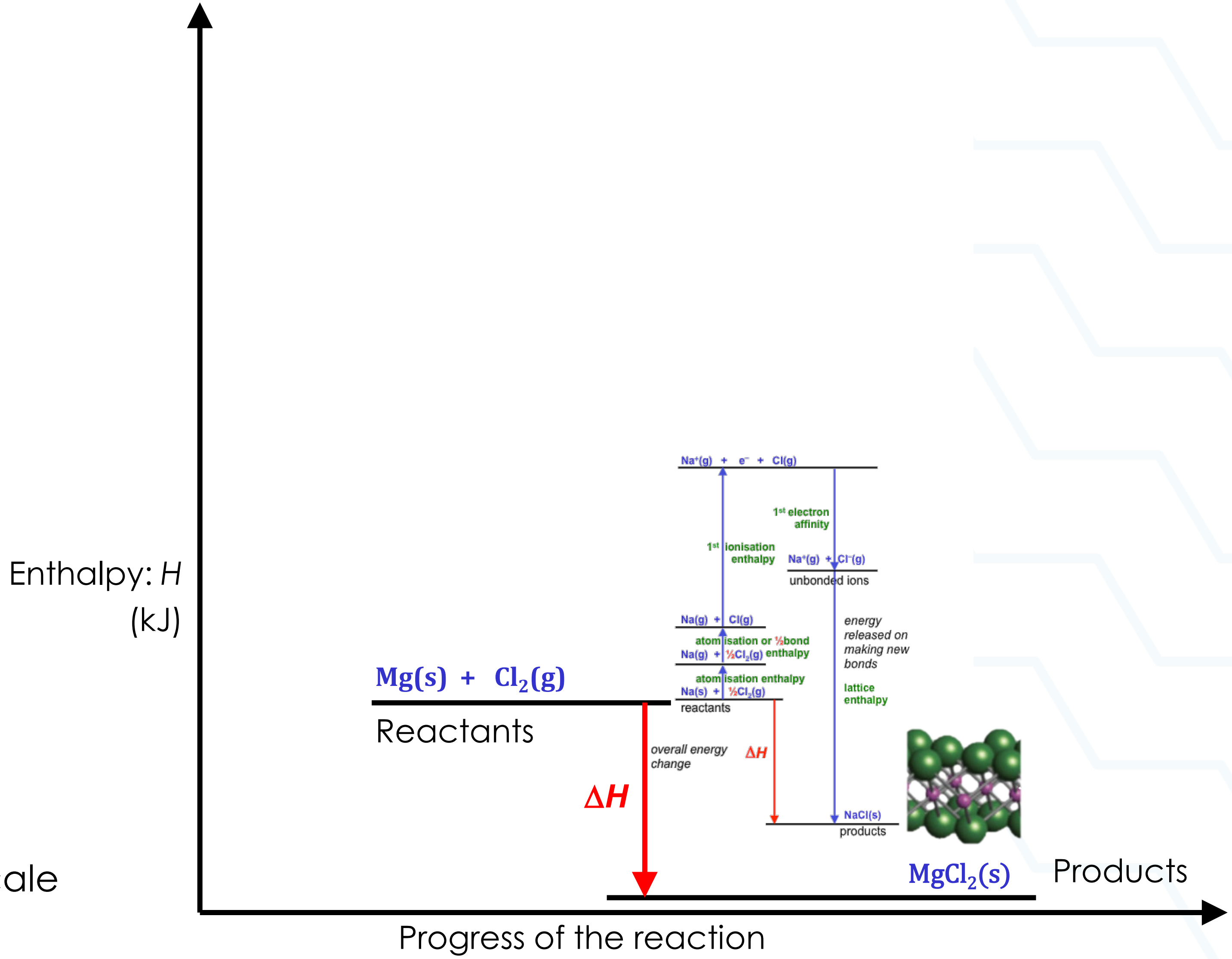


ΔH = 107 + 121 + 496 + (–349) + (–790)
= 724 – 1139
= –415 kJ

Formation of $MgCl_2(s)$

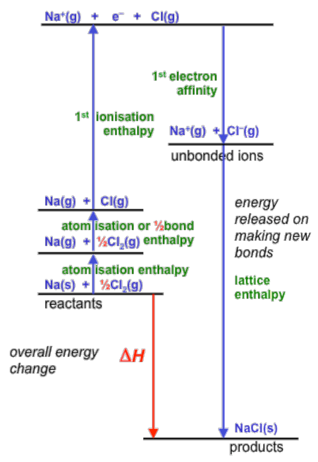
When doubly charged ions are involved, the energy transfers get larger, so we have to zoom out a bit.



Here is the NaCl cycle for scale

Formation of $MgCl_2(s)$

Notice the need to add in the 2nd ionisation enthalpy of Mg and double the atomisation and 1st electron affinity of Cl.



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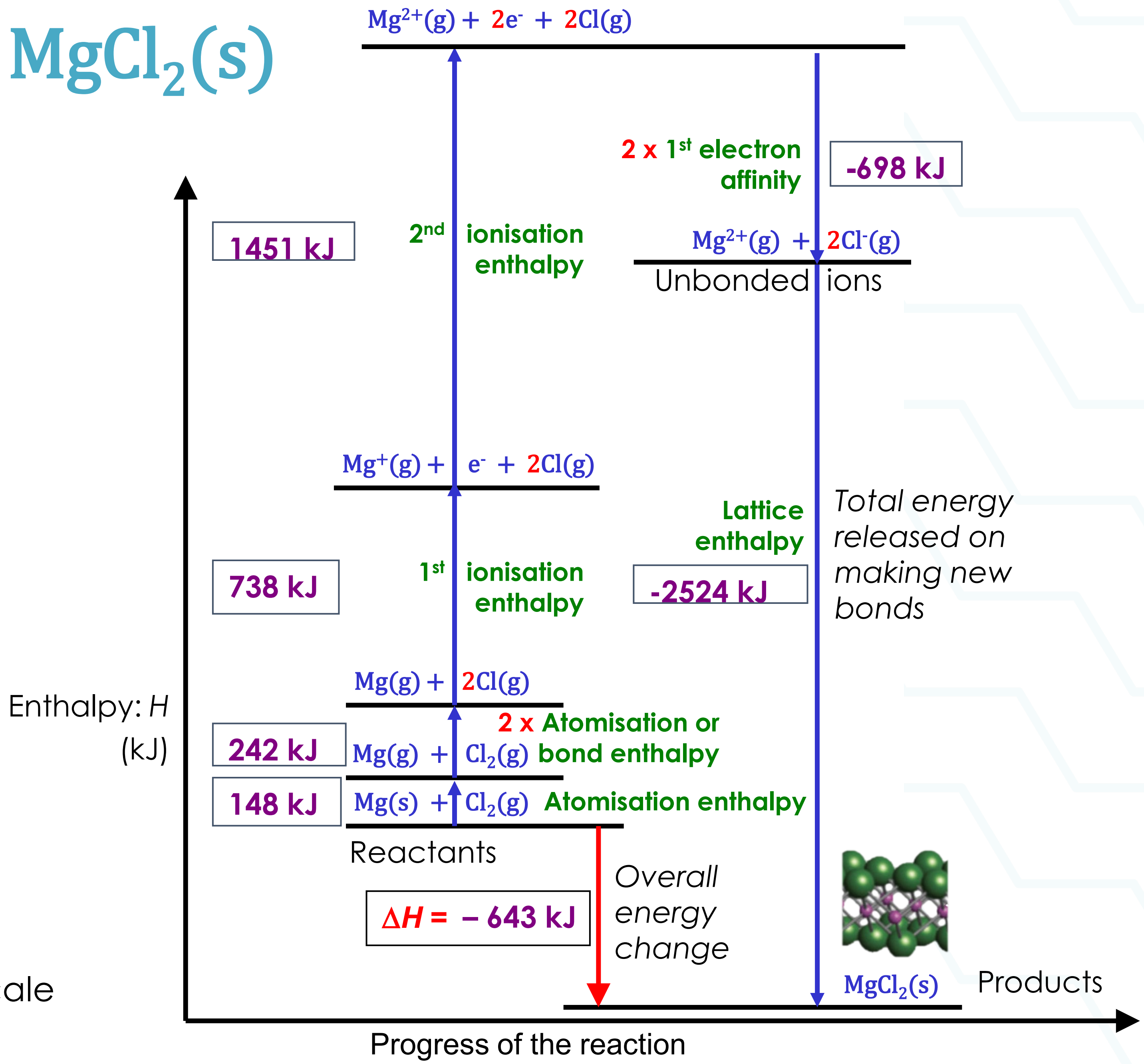
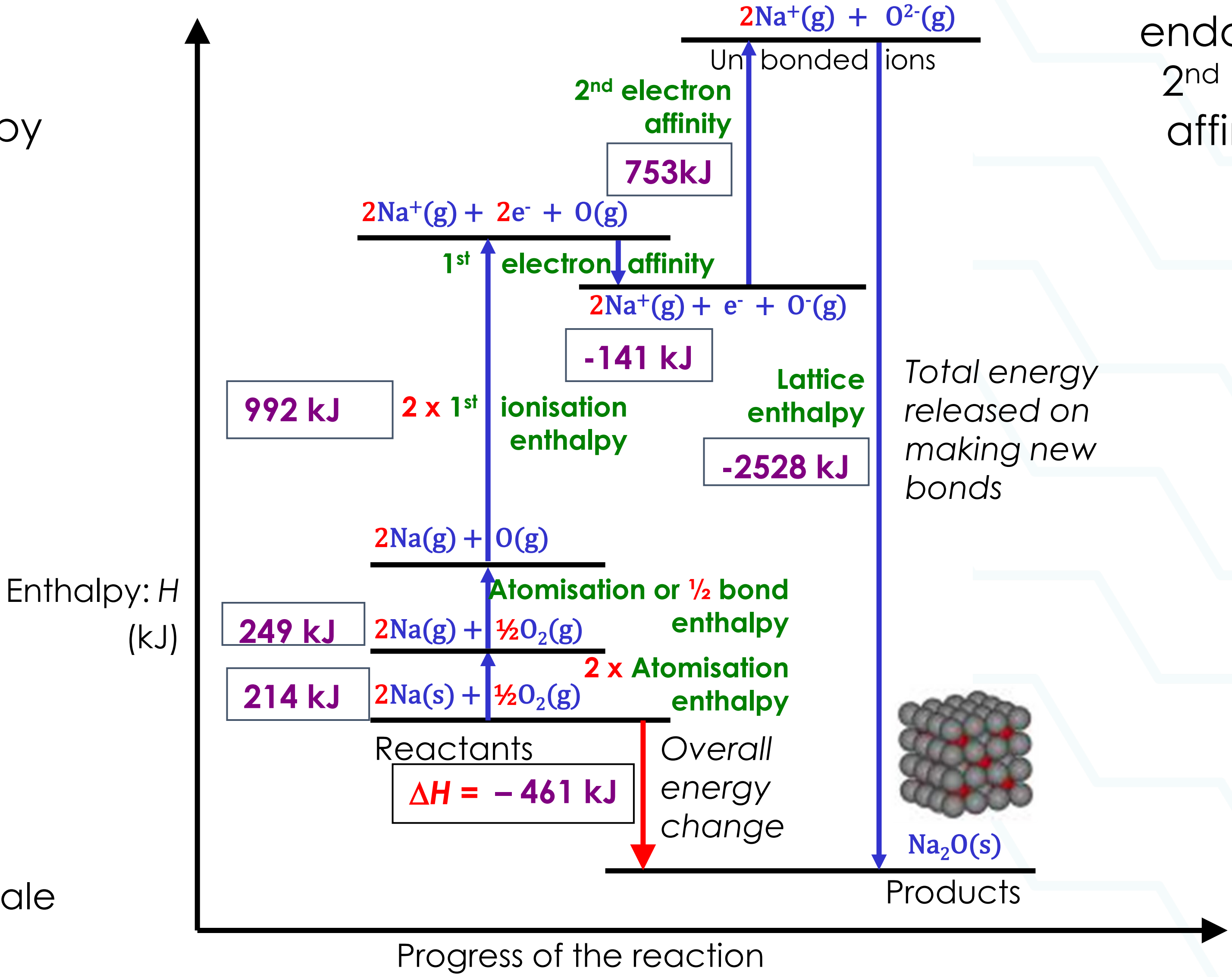


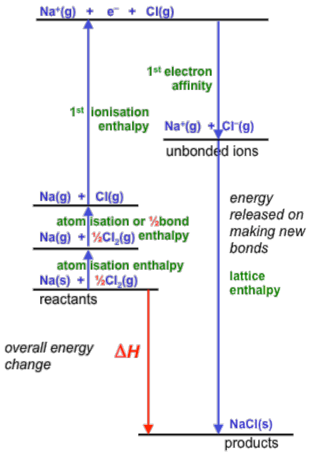
Formation of an ionic compound with 2+ and 1- ions

Formation of $Na_2O(s)$

This time we need to double the atomisation and 1st ionisation enthalpy of Na and add in the 2nd electron affinity of O.

Notice the exothermic 1st electron affinity followed by the endothermic 2nd electron affinity of O.

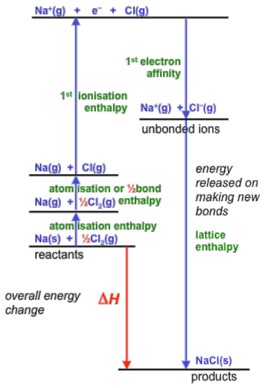




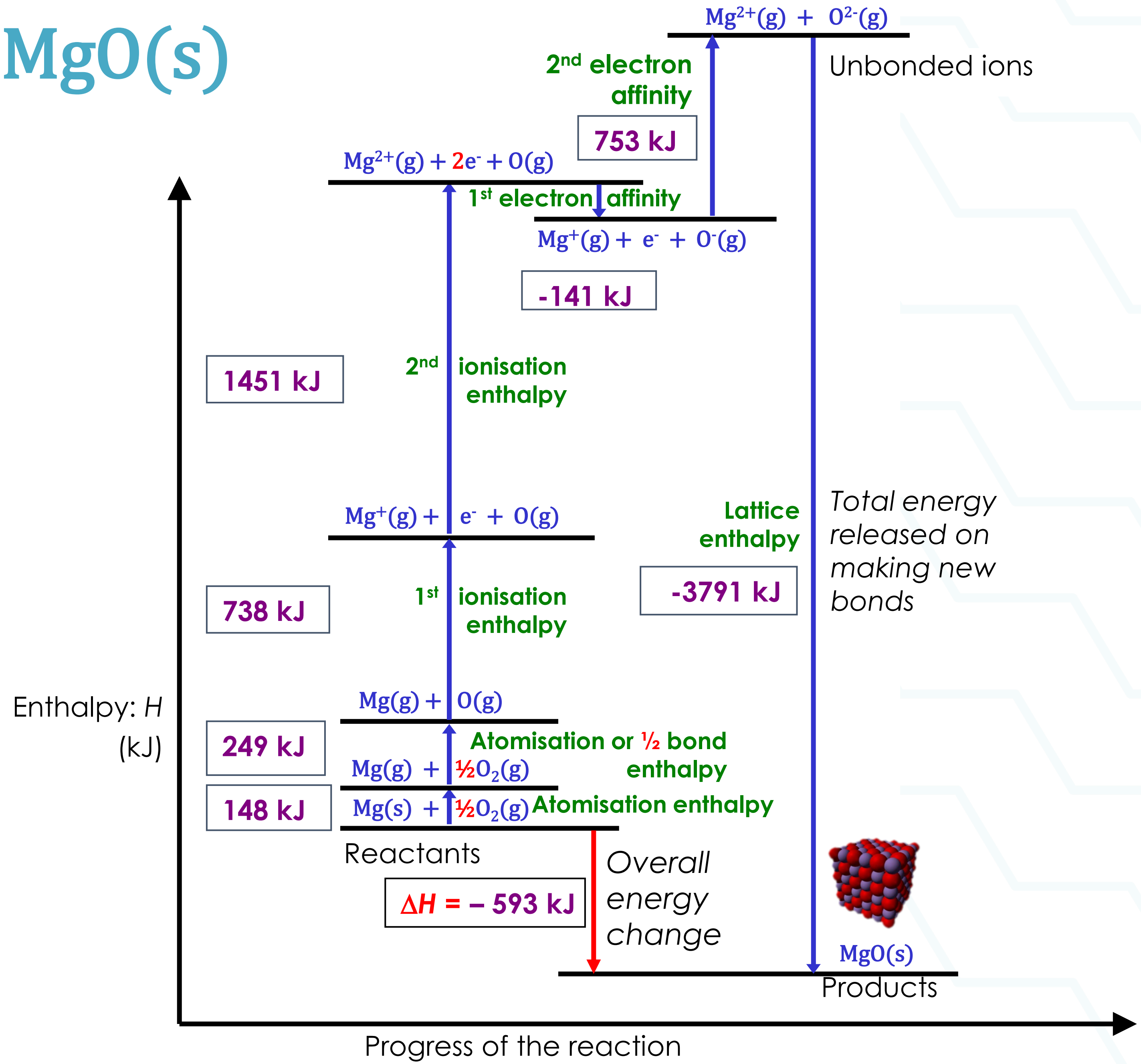
Here is the NaCl cycle for scale

Formation of MgO(s)

The lattice enthalpy is now so large, we have to zoom out a bit more.



Here is the NaCl cycle for scale



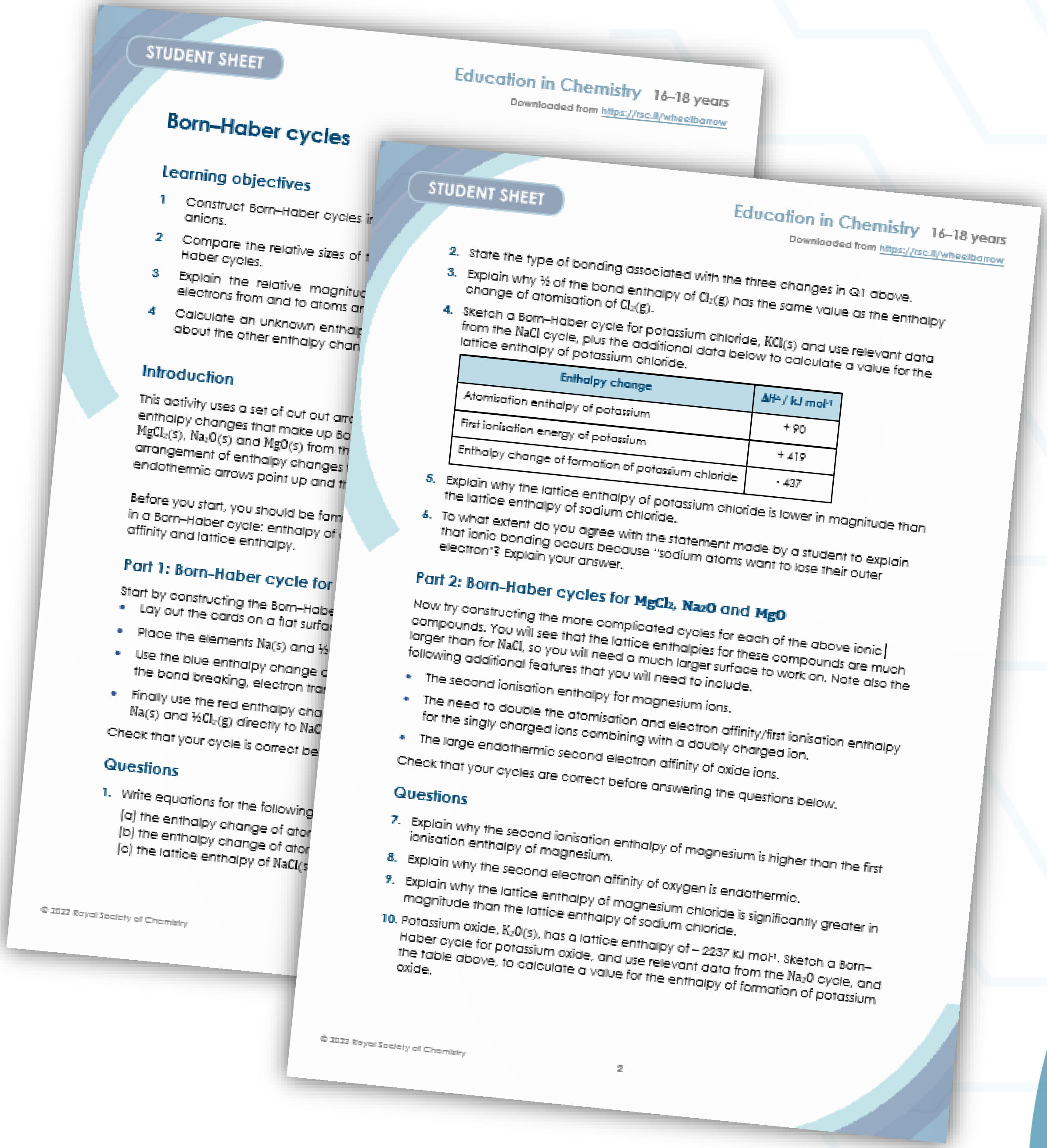
Formation of an ionic compound with 2+ and 2- ions

Worksheet

Now have a go at the activities in the worksheet.

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 $NaCl(s)$, $MgCl_2(s)$, $Na_2O(s)$ 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.



STUDENT SHEET

Education in Chemistry 16–18 years

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2. State the type of bonding associated with the three changes in Q1 above.

3. Explain why ½ of the bond enthalpy of $Cl_2(g)$ has the same value as the enthalpy change of atomisation of $Cl_2(g)$.

4. Sketch a Born–Haber cycle for potassium chloride, $KCl(s)$ 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	ΔH° / kJ mol^{-1}
Atomisation enthalpy of potassium	+ 90
First ionisation energy of potassium	+ 419
Enthalpy change of formation of potassium chloride	- 437

5. Explain why the lattice enthalpy of potassium chloride is lower in magnitude than the lattice enthalpy of sodium chloride.

6. 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

7. Explain why the second ionisation enthalpy of magnesium is higher than the first ionisation enthalpy of magnesium.

8. Explain why the second electron affinity of oxygen is endothermic.

9. Explain why the lattice enthalpy of magnesium chloride is significantly greater in magnitude than the lattice enthalpy of sodium chloride.

10. Potassium oxide, $K_2O(s)$, has a lattice enthalpy of – 2237 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.

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Data

The values for some of the standard enthalpy changes involved in Born–Haber cycles vary between different data books. Below is a summary of the values used in this resource, which may differ slightly from those seen in textbooks or exam questions.

	$\Delta H^{\ominus}$ / kJ mol^{-1}			
Enthalpy change	**Sodium**	**Magnesium**	**Chlorine**	**Oxygen**
Atomisation enthalpy	+107	+148	+121	+249
First ionisation enthalpy	+496	+738		
Second ionisation enthalpy		+1451		
First electron affinity			-349	-141
Second electron affinity				+753

	$\Delta H^{\ominus}$ / kJ mol^{-1}			
Enthalpy change	**Sodium chloride**	**Magnesium chloride**	**Sodium oxide**	**Magnesium oxide**
Lattice enthalpy	-790	-2524	-2528	-3791
Enthalpy change of formation	-415	-643	-461	-593