

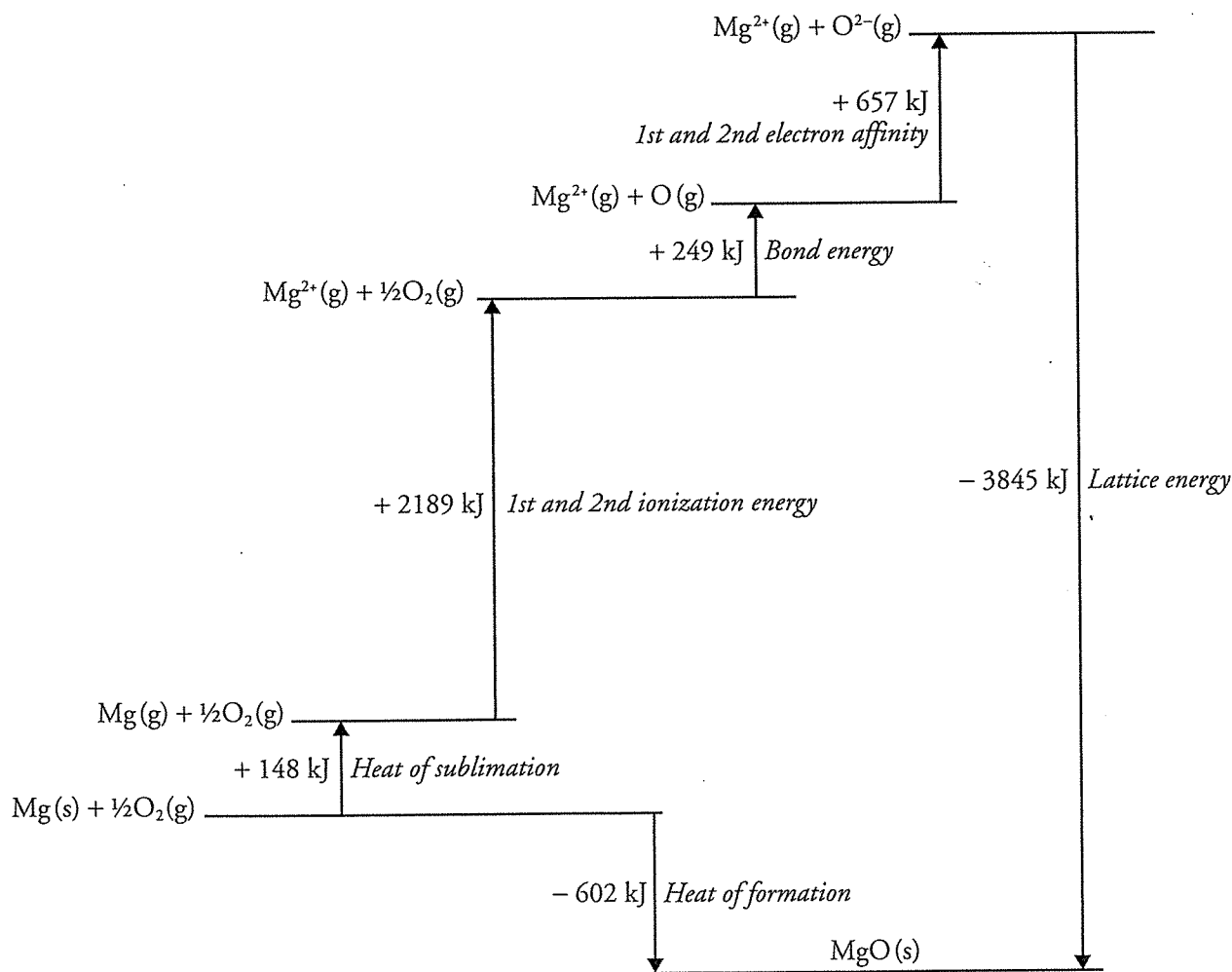
# Lattice Energy

How strong are the ionic bonds in an ionic solid?

## Why?

When comparing the strengths of covalent bonds we can use bond energy tables to estimate the energy released when a particular bond is formed. The more energy that is released, the stronger, or more stable the bond. Ionic bonds have a similar quantity called **lattice energy**. Lattice energy is defined as the change in energy when ions in their gaseous state form an ionic solid. It is very difficult to directly measure lattice energies for ionic substances, so they are usually theoretically calculated from other data. In this activity, we will look at the variables that determine the magnitude of the lattice energy.

## Model 1 – The Born-Haber Cycle



1. What ionic substance is being used to illustrate the concept of lattice energy in Model 1?  
*The lattice energy of magnesium oxide is illustrated in Model 1.*

2. According to the *Why?* box on the previous page, what is the definition of lattice energy? Label the arrow in Model 1 that represents lattice energy.

*The lattice energy is the change in energy when ions in their gaseous state form an ionic solid.*

*See Model 1.*

3. The lattice energy is theoretically calculated from five other energies. They are listed below with their definitions. Label the remaining arrows in Model 1 with these five energies.
- 1st and 2nd electron affinity—The energy needed to add two electrons to an atom to form an anion.
  - 1st and 2nd ionization energy—The energy needed to remove an electron from an atom to form a cation.
  - Bond energy—The energy needed to break a covalent bond between atoms.
  - Heat of formation—The energy change when a compound is formed from its component elements in their natural state.
  - Heat of sublimation—The energy needed to change from a solid state into a gaseous state.

*See Model 1.*

4. Verify that the lattice energy shown in Model 1 can be calculated using the five other energy values. Show your calculation here.



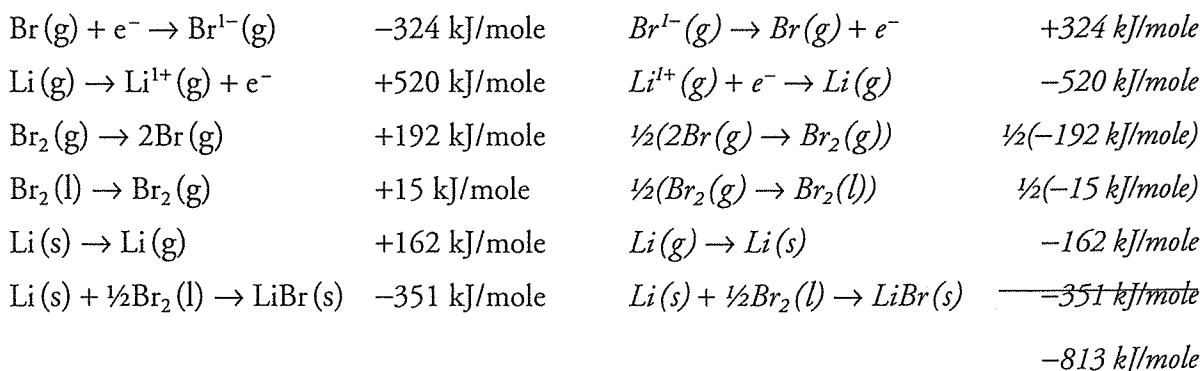
$$148 \text{ kJ} + 2189 \text{ kJ} + 249 \text{ kJ} + 657 \text{ kJ} + 602 \text{ kJ} = 3845 \text{ kJ}$$

5. If you look up the bond energy for an  $\text{O}_2$  molecule, you will find literature values of 498 kJ/mole. Explain why the energy associated with breaking the bonds in the oxygen molecules in Model 1 is listed as half that value.

*The breaking of one mole of oxygen molecules into single atoms will form two moles of oxygen atoms. Only half of that is needed to produce one mole of magnesium oxide.*



6. Use the information below to calculate the lattice energy for lithium bromide. *Hint:* Consider that only one bromine atom is needed for lithium bromide. Also consider that  $\text{Br}_2(l)$  must be vaporized to  $\text{Br}_2(g)$ . This heat of vaporization was not necessary in the case of  $\text{MgO}$ .



7. Consider the definition of lattice energy. Would you predict that lattice energies are always exothermic? Justify your reasoning.

*Yes, consider that energy is required to melt most ionic compounds, or to destroy their crystal lattices. By Hess's law then, energy must be released when an ionic solid is formed from its elements.*



## Model 2 – Atom Size and Charge

Data Set A

	Lattice energy (kJ/mol)
LiCl	-830
NaCl	-770
KCl	-700
RbCl	-680
CsCl	-660

Data Set B

	Lattice energy (kJ/mol)
NaCl	-770
MgCl <sub>2</sub>	-2530
Na <sub>2</sub> O	-2570
MgO	-3930
Al <sub>2</sub> O <sub>3</sub>	-15270

8. Consider the data presented in Model 2.
- Which set of data could be analyzed to show the effect atomic size has on lattice energy? Explain your choice.  
*Data Set A lists several compounds where the metal atoms in the lattice are all +1 charge, but have different radii.*
  - Which set of data could be analyzed to show the effect ion charge has on lattice energy? Explain your choice.  
*Data Set B lists several compounds where the cations and anions have different charges.*



9. Refer to Model 2.

- As the ions in the solid lattice get bigger, thus making the bond length longer, what happens to the lattice energy of the solid? *Note:* Ignore the sign on the lattice energy. The sign is indicating that energy is released. You are interested in the magnitude of the lattice energy.  
*The amount of energy released is less as the metal atom in the lattice gets larger.*
- Describe how your answer in part *a* relates to the law of Coulombic attraction between charged particles?  
*Part a is consistent with the Coulombic law. As the ion gets larger, and the bond length gets larger, the attraction between the ions will decrease. Thus, less energy will be released when the bond is formed.*



10. Refer to Model 2.

- When the ions in the solid lattice have higher charges, what happens to the lattice energy of the solid?  
*The compounds in Data Set B that have +1/-1 charges release less energy when the lattice is formed than those that have +2/-2 or +3/-2. As the charges on the ions get larger, the lattice energy gets larger.*
- Describe how your answer in part *a* relates to the law of Coulombic attraction between charged particles.  
*Part a is consistent with the Coulombic law. As the ion charges get larger, the attraction between the ions is stronger. Thus, more energy will be released when the bond is formed.*



11. Work individually on this question and then discuss your answers as a group. Which compound in each row would have the larger lattice energy? Be prepared to justify your reasoning.

MgO	MgCl <sub>2</sub>	<i>MgO—the charges are larger (+2/-2 vs. +2/-1)</i>
MgCl <sub>2</sub>	MgF <sub>2</sub>	<i>MgF<sub>2</sub>—the fluoride ion is smaller than the chloride ion</i>
MgO	CaO	<i>MgO—the magnesium ion is smaller than the calcium ion</i>
AlCl <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	<i>Al<sub>2</sub>O<sub>3</sub>—the charges are larger (+3/-2 vs. +3/-1)</i>

12. Match the ionic compounds below to their lattice energy.

Compound	Lattice Energy kJ/mole
LiF	-2800
Li <sub>2</sub> O	-2240
KF	-1030
KBr	-820
K <sub>2</sub> O	-680

## Extension Questions

13. The lattice energy (attractive force) of an ionic solid can be approximated using the Coulombic force equation shown below. Use your understanding of lattice energy and Coulombic attraction to answer the following.

$$F = k \frac{q_1 q_2}{r^2}$$

- a. Identify each of the variables in the equation.

$F$	$k$	$q_1$ and $q_2$	$r$
force	constant	charges	distance between ions

- b. When you calculate the force between a positive and negative ion, will the force be positive or negative? Explain your reasoning.

*When the charges are multiplied, they will result in a negative number. There are no other values in the equation that are negative, so the resulting force will be negative.*

- c. When you calculate the force between two negative ions will the force be positive or negative. Explain your reasoning.

*When the charges are multiplied, they will result in a positive number. There are no other values in the equation that are negative, so the resulting force will be positive.*

- d. How are attractive and repulsive forces distinguished when calculating forces?

*Attractive forces are given a negative force value and repulsive forces are given a positive force value.*

14. Most heats of formation for ionic compounds are exothermic—energy is released when the compound forms from its elements in their natural state. However, some are endothermic overall.

- a. Refer to Model 1. What must be true about the relative magnitudes of the energies involved in that model to make a heat of formation for an ionic compound endothermic?

*The lattice energy must be smaller than the sum of the energies needed to turn the elements in their natural state into gaseous ions (sublimation, vaporization, ionization and electron affinity energies).*

- b. Would an ionic compound with an endothermic heat of formation be as shelf stable (can be stored for a long time without decomposing) as an ionic compound with an exothermic heat of formation? Explain your reasoning.

*The compound would most likely not be shelf stable if it had a heat of formation that was endothermic. This means the elements in their natural state are more stable than the compound. This would mean decomposition was thermodynamically favorable.*