# Ionic Compounds

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Printed: November 25, 2013

# Concept 1 Ionic Compounds

## Lesson Objectives

The student will:

- describe how atoms form an ionic bond.
- state, in terms of energy, why atoms form ionic bonds.
- state the octet rule.
- give a brief description of a lattice structure.
- identify distinctive properties of ionic compounds.

## Vocabulary

- electrostatic attraction
- ionic bond
- lattice structure
- octet rule

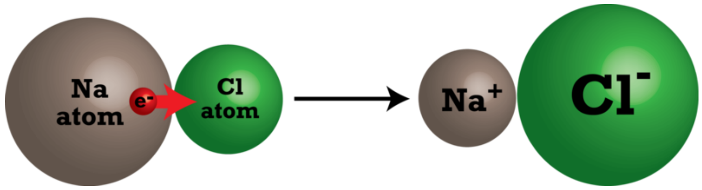
## Introduction

Collisions between atoms that tend to lose electrons (metals) and atoms that tend to gain electrons (nonmetals) are usually sufficient enough to remove the electrons from the metal atom and add them to the nonmetal atom. This transfer of electrons forms positive and negative ions, which in turn attract each other due to opposite charges. The compounds formed by this electrostatic attraction are said to be ionically bonded.

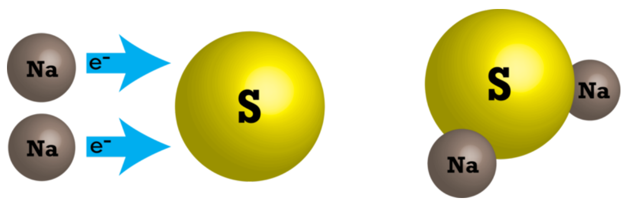
## Ionic Bonding

When an atom with a low ionization energy encounters an atom with high electron affinity, it is possible for an electron transfer to occur. The ionization of the metal atom requires an input of energy. This energy input is often accomplished simply by the collision of atoms due to particle motion. Once electrons have been removed from the metal atoms, the electrons are taken on by the nonmetal atoms and energy is released. The energy released provides sufficient energy for the reaction to continue. In some cases, a reaction of this sort must be heated in order to start the reaction, but once the reaction begins, the reaction itself provides enough energy to continue.

The process of transferring an electron from a sodium atom to a chlorine atom, as shown in the sketch below, produces oppositely charged ions, which then stick together because of **electrostatic attraction**. Electrostatic attraction is the attraction between opposite charges. The electrostatic attraction between oppositely charged ions is called an **ionic bond.** Notice in the sketch above that the sodium atom is larger than the chlorine atom before the collision, but after the electron transfer, the sodium ion is now smaller than the chloride ion. Recall that the sodium ion is smaller than a neon atom because it has one more proton in the nucleus than neon does, yet they both have the same electron configuration. The chloride ion is larger than an argon atom because while it has the same electron configuration as argon, it has one less proton in the nucleus than argon. The sodium ion now has high ionization energy and low electron affinity (just like a noble gas) so there is no reason for any further changes. The same is true for the chloride ion. These ions are chemically more stable than the atoms are.




If we had been examining sodium and sulfur atoms, the transfer process would be only slightly different. Sodium atoms have a single electron in their outermost energy level and therefore can lose only one electron. Sulfur atoms, however, require two electrons to complete their outer energy level. In such a case, two sodium atoms would be required to collide with one sulfur atom, as illustrated in the diagram below. Each sodium atom would contribute one electron for a total of two electrons, and the sulfur atom would take on both electrons. The two Na atoms would become $Na^+$ ions, and the sulfur atom would become a $S^{2-}$ ion. Electrostatic attractions would cause all three ions to stick together.



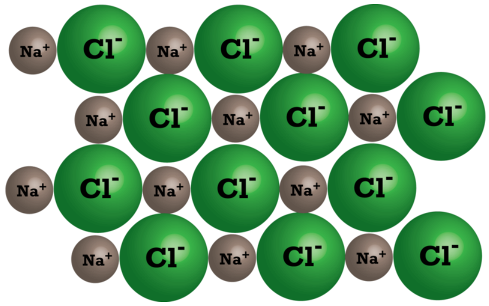

All the valence electrons for the main group elements are in *s* and *p* orbitals. When forming ions, main group metals will lose all of their valence electrons so that the resulting electron configuration will be the same as the previous noble gas. Usually, this means that the ion will have eight valence electrons. (Metals in the second row will form ions that have helium's electron configuration, which contains only two electrons.) Conversely, when nonmetals gain electrons to form anions, the new electron configuration will be the same as the following noble gas. The **octet rule** is an expression of the fact that when main group elements form ions, they tend to achieve a set of 8 valence electrons, which we know is a particularly stable configuration.

## Properties of Ionic Compounds

When ionic compounds are formed, we are almost never dealing with just a single positive ion or a single negative ion. When ionic compounds are formed in laboratory conditions, many cations and anions are formed at the same time. The positive and negative ions are not just attracted to a single oppositely charged ion. The ions are attracted to several of the oppositely charged ions. The ions arrange themselves into organized patterns where each ion is surrounded by several ions of the opposite charge.

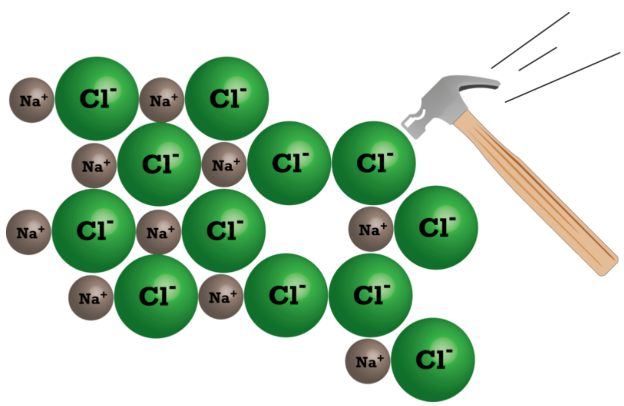
The organized patterns of positive and negative ions are called **lattice structures**. There are a number of different ionic lattice structures. The lattice structure that forms for a particular ionic compound is determined by the relative sizes of the ions and by the charge on the ions. Because ionic compounds form these large lattice structures in the solid phase, they are not referred to as molecules, but rather as lattice structures or crystals.

The image below shows the solid structure of sodium chloride. Only one layer is shown. When layers are placed above and below this one, each sodium ion would be touching six chloride ions – the four surrounding ones, one above, and one below. Each chloride ion will be touching six sodium ions in the same way.




When electrons are transferred from metallic atoms to nonmetallic atoms during the formation of an ionic bond, the electron transfer is permanent. The electrons now belong to the nonmetallic ion. If the ionic lattice structure is taken apart by melting it to a liquid, vaporizing it to a gas, or dissolving it in water, the particles come apart in the form of ions. The electrons that were transferred go with the negative ion when the ions separate. The electrostatic attraction between the oppositely charge ions is quite strong, and therefore ionic compounds have very high melting and boiling points. Sodium chloride (table salt), for example, must be heated to around 800°C to melt and around 1500°C to boil.

If you look again at the image, you can see that negative ions are surrounded by positive ions and vice versa. If part of the lattice is shifted downward, negative ions will then be next to negative ions. Since like charges repel, the structure will break up. As a result, ionic compounds tend to be brittle solids. If you attempt to hammer down on ionic substances, they will shatter. This is very different from metals, which can be hammered into different shapes without the metal atoms separating from each other.




Ionic substances generally dissolve readily in water. When an ionic compound has been melted or dissolved in water, there are ions present that have the ability to move around in the liquid. It is specifically the presence of the mobile ions that allow electric current to be conducted by ionic liquids and ionic solutions. In comparison, non-ionic compounds that are dissolved in water or are in liquid form do not conduct electric current.

The process of gaining or losing electrons completely changes the chemical properties of the substances. The chemical and physical properties of an ionic compound will bear no resemblance to the properties of the elements which formed the ions. For example, sodium is a metal that is shiny, an excellent conductor of electric current, and reacts violently with water. Chlorine is a poisonous gas. When sodium and chlorine are chemically combined to form sodium chloride (table salt), the product has an entirely new set of properties. We could sprinkle sodium chloride on our food, which is not something we would do if we expected it to poison us or to explode when it touches water.

## Lesson Summary

- Ionic bonds are the resulting electrostatic attraction holding ions together when electrons transfer from metal atoms to nonmetal atoms.
- The octet rule is an expression of the tendency for atoms to gain or lose the appropriate number of electrons so that the resulting ion has either completely filled or completely empty outer energy levels.
- Ionic compounds form ionic crystal lattices rather than molecules.
- Ionic compounds have very high melting and boiling points.
- Ionic compounds tend to be brittle solids.
- Ionic compounds are generally soluble in water, and the resulting solutions will conduct electricity.
- Ionic compounds have chemical properties that are unrelated to the chemical properties of the elements from which they were formed.

## Further Reading / Supplemental Links

This website provides more information about ionic compounds.

- http://misterguch.brinkster.net/ionic.html

This video is a ChemStudy film called "Electric Interactions in Chemistry." The film is somewhat dated but the information is accurate.

- http://www.youtube.com/watch?v=o9TaQLVCFDM

## Review Questions

1. What takes place during the formation of an ionic bond?
2. What effect does the transfer of electrons have on the nuclei of the atoms involved?
3. Hydrogen gas and chlorine gas are not acids, but when hydrogen and chlorine combine to form hydrogen chloride, the compound is an acid. How would you explain this?
4. Why do we not refer to molecules of sodium chloride?