



## Activity 8

# How Atoms Interact with Each Other

### What Do You See?



### GOALS

In this activity you will:

- Relate patterns in ionization energies of elements to patterns in their electron arrangements.
- Use your knowledge of electron arrangements and valence electrons to predict formulas for compounds formed by two elements.
- Contrast ionic bonding and covalent bonding.
- Draw electron-dot diagrams for simple molecules with covalent bonding.

### What Do You Think?

You have learned that the chemical behavior of an atom is determined by the arrangement of the atom's electrons, specifically the valence electrons. The salt that you put on your food is chemically referred to as NaCl—sodium chloride.

- How might the valence electrons of sodium (Na) and chlorine (Cl) interact to create the bond in NaCl?

Record your ideas about this question in your *Active Chemistry* log. Be prepared to discuss your responses with your small group and the class.

### Investigate

1. In *Activity 3* you read that John Dalton assumed that chemical compounds formed from two elements combined in the simplest possible combination. In *Activity 6* you began to see that an atom's chemical behavior reflects its excess or deficiency of electrons relative to an atom of the closest noble gas on the periodic table. Use the list of ionization energies in *Activity 6* to answer the following questions:
  - a) Which atoms have the smallest values for first ionization energies? (Remember, the first ionization energy is the amount of energy required to remove the first electron.)

- b) Where are these atoms located on the periodic table?
- c) What do you observe about the amount of energy required to remove the second electron from atoms of the elements identified in (a)?
- d) Use your understanding of the arrangement of electrons in this group of elements to suggest a reason for the pattern you noted in (c).
- e) Which atoms have the smallest values for second ionization energies? Where are these atoms located on the periodic table?
- f) Use your understanding of the arrangement of electrons in this group of elements to suggest a reason for the pattern you noted in (e).
2. Once you recognize the role of an atom's electron arrangement—especially the valence electrons—in an atom's chemical activity, you can often predict formulas for compounds formed by two chemical elements. (Recall that valence electrons are the electrons located in the highest energy level, the levels designated by the sublevel having the highest numbers.)

Sodium (Na) has one valence electron in the 3s sublevel. By losing that electron, the sodium atom becomes a sodium ion and it has the same stable electron arrangement as neon.

- a) What is the stable electron arrangement of neon?
- b) What is the stable electron arrangement of sodium after the 3s sublevel electron has been removed?

- c) What is the electric charge on the resulting Na ion?

Consider a chlorine atom.

- d) How many valence electrons does a chlorine atom have?
- e) How many electrons would a chlorine atom have to lose in order to have a stable electron arrangement like neon?
- f) How many electrons does a chlorine atom need to gain to have the same number of electrons as an argon atom?
- g) Gaining one electron is much easier than losing seven electrons. When a chlorine atom gains an electron, a chloride ion is formed. The original chlorine atom was electrically neutral. It gained a negative electron to form the ion. What is the electric charge (sign and value) on the resulting ion?



Sodium reacts violently with chlorine gas.



- h) Each chlorine atom is capable of accepting one electron to become more stable. Each sodium atom is capable of losing one electron to become more stable. It certainly sounds as if a relationship is in store for the chlorine and sodium atoms. Describe how you think the compound sodium chloride (NaCl) is formed.
- i) Look at the *What Do You See?* illustration at the beginning of *Activity 7*. Describe what you see in terms of bonding.
3. Consider the reaction between aluminum and zinc chloride (similar to the reaction in *Activity 3*). The zinc atom in zinc chloride has two valence electrons located in the 4s sublevel. You can note the two valence electrons in the electron arrangement marked on the periodic table.

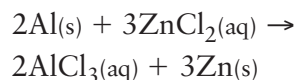
In order to acquire the rather stable electron configuration of argon atoms, the zinc atoms give up their two valence electrons to form zinc ions. Since the original zinc atom was electrically neutral and it lost two negative electrons to form the ion, the resulting ion has a positive charge with a magnitude two times the charge on the electron. It has a plus two charge.

- a) Each chlorine atom is capable of accepting one electron. How many chlorine atoms are needed to accept the two electrons that zinc atoms have to give?
- b) When writing the formula for a compound, the number of atoms necessary to balance the loss and gain of electrons can be designated through the use of a

subscript, such as the 2 in H<sub>2</sub>O. There are 2 hydrogen atoms linked to every oxygen atom. How would you write the formula for the compound zinc chloride?

- c) Look at the *What Do You See?* illustration at the beginning of this activity. Describe what you see in terms of bonding.
4. Aluminum chloride is another material formed in reactions.
- a) Consider an atom of aluminum. How many valence electrons does an aluminum atom have?
- b) How many electrons does an aluminum atom need to give up to reach the same chemical stability as a neon atom?
- c) What are aluminum atoms called after they give up their valence electrons? What is their electric charge (sign and value)?
- d) How many chlorine atoms are needed to accept the electrons given up by an aluminum atom?
- e) How would you write the formula for the compound aluminum chloride?
5. In a reaction between aluminum and zinc chloride, aluminum replaces the zinc in the zinc chloride, forming aluminum chloride and zinc.

The reaction is:



Create a model to explain how the valence electrons change places during the reaction.

## ChemTalk

### FORMING COMPOUNDS

#### The Octet Rule

In this activity you explained the formation of the compounds that you investigated by how the electrons are transferred or shared between atoms. Some scientists explain these observations using the **octet rule**. This rule states that atoms tend to gain or lose electrons during chemical reactions so that the atoms have an outer shell configuration of eight electrons. The exceptions to this are the transition elements. The octet rule works well with almost all of the elements found in the first three rows of the periodic table.

You should note that the name of all of the compounds that you have studied have all started with the name of the metal and then followed with the nonmetal part. The second thing that you should note is that all of these compounds are binary (meaning two parts).

**Binary compounds** always end with the suffix “ide” (except for a few compounds with common names like water and ammonia).

#### Covalent and Ionic Bonds

You may have noticed that the column headed by carbon in the periodic table has not received a lot of attention so far. In *Activity 7* you learned that atoms of these elements contain four valence electrons. Atoms with a small number of valence electrons give up electrons, and atoms with a large number of valence electrons gain additional electrons to have the same electron arrangement as an atom of the nearest noble gas. Except for helium, with two valence electrons, the noble gases each have eight valence electrons. What do atoms of carbon do? Do they give up their four valence electrons, or gain four more?

In actuality, atoms of carbon do neither. Instead of giving or taking electrons, carbon atoms share electrons with atoms of other elements. Instead of giving or taking electrons to form what are called **ionic bonds**, carbon atoms share electrons with atoms of other elements to form what are called **covalent bonds**. In fact, all nonmetallic elements whose atoms have four or more valence electrons can form covalent bonds by sharing electrons. This sharing results in a situation in which each atom is associated with eight valence electrons, as is characteristic of an atom of a noble gas.



#### Chem Words

**octet rule:** the rule that states that atoms tend to gain or lose electrons during chemical reactions so that the atoms have an outer shell configuration of eight electrons.

**binary compound:** a compound formed from the combining of two different elements.

**ionic bond:** the attraction between oppositely charged ions.

**covalent bond:** a bond produced by sharing of a pair of electrons between two atoms.



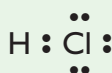
### Chem Words

**bonding electrons:** the two electrons that are shared between two atoms.

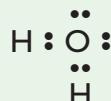
**nonbonding electron pair (or lone pair):** a pair of electrons that are not used in forming a bond, but are located as a pair on the atom.

Covalent bonding can be illustrated using electron-dot diagrams (sometimes called Lewis structures). In these diagrams each valence electron is indicated by a dot (or other appropriate symbol) around the chemical symbol for the element in question. Consider the following covalent compound illustrations:

Hydrogen chloride contains one hydrogen atom and one chlorine atom.



Water contains two hydrogen atoms and one oxygen atom.



Carbon dioxide contains one carbon atom and two oxygen atoms.



You can count eight electrons around the chlorine in hydrogen chloride (note that hydrogen can only have two electrons). In water the oxygen has eight electrons around it and hydrogen again has only two electrons. Carbon dioxide shows that oxygen contains eight electrons and carbon has eight electrons as well. These shared electrons in these examples all produce stable covalent compounds.

Let's take a look at how the electron-dot structures were formed.

The electron-dot structure of hydrogen has a single dot for its only electron and looks like this:  $\text{H}\cdot$ .

When two hydrogen atoms combine to form molecular hydrogen ( $\text{H}_2$ ), you draw the resulting electron-dot structure like this:  $\text{H}:\text{H}$ .

You can represent the two electrons forming the bond with two dots as shown, or with a dash ( $\text{H}-\text{H}$ ).

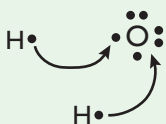
The table below shows the electron-dot structures for the first 20 elements.

$\text{H}\cdot$							$\text{He}:\cdot\cdot$
$\text{Li}\cdot$	$\cdot\text{Be}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{B}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{C}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{N}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{O}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{F}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{Ne}}}\cdot$
$\text{Na}\cdot$	$\cdot\text{Mg}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{Al}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{Si}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{P}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{S}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{Cl}}}\cdot$	$\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{Ar}}}\cdot$
$\text{K}\cdot$	$\cdot\text{Ca}\cdot$						

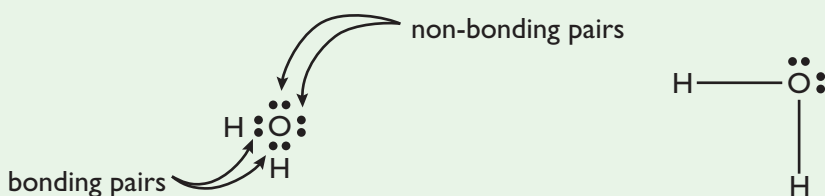
Notice that the electrons shown are only the valence electrons, not all the electrons of the element. Notice also that the electron-dot structures are identical for elements in columns. This is why Li and Na and K have such similar characteristics, as do F and Cl.

To write electron-dot structures for molecules, you can follow these simple guidelines using water as an example:

1. Start with the dot structure of each atom. Determine where bonding can occur (look for unpaired electrons).



2. Redraw the structure showing bonds as pairs of electrons between the elements. Any unbonded electron pairs remain with the original element.



Note that the two electrons forming the bond between the oxygen and the hydrogen (which can also be represented as a dash as in second structure) are called **bonding electrons**. The two pairs of electrons placed on the oxygen are called **nonbonding electron pairs, or lone pairs**. The oxygen has a total of eight electrons around it. This follows the octet rule.

## Checking Up

1. When naming a binary compound, which element is named first, the metal or the nonmetal? Give an example to explain your answer.
2. Explain the difference between an ionic and a covalent bond.
3. Draw electron-dot diagrams showing covalent bonding in the following compounds:
  - a) water (two atoms of hydrogen, one atom of oxygen). Note: Since the noble gas nearest hydrogen is helium, with only two valence electrons, hydrogen atoms need be associated with only two valence electrons.
  - b) methane (four atoms of hydrogen, one atom of carbon)
  - c) ammonia (three atoms of hydrogen, one atom of nitrogen)
  - d) carbon tetrachloride (four atoms of chlorine, one atom of carbon)

## What Do You Think Now?

At the beginning of the activity you were asked:

- How might the valence electrons of sodium (Na) and chlorine (Cl) interact to create the bond in NaCl?

In the *Investigate* you described how sodium chloride (NaCl) forms. Describe how calcium bromide (CaBr<sub>2</sub>) forms. That is, for this binary compound, show which element will lose electron(s) and which one will gain electron(s).



## Chem Essential Questions

### What does it mean?

Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your *Active Chemistry* log.

MACRO	NANO	SYMBOLIC
<i>Sodium and chlorine can combine to make salt. Hydrogen and oxygen can combine to make water. From investigations in this chapter, list one chemical reaction that you have observed.</i>	<i>The sharing of electrons between two atoms is a covalent bond. When the electron(s) of one element is transferred to another atom it is called an ionic bond. Describe what happens to the electrons when sodium and chlorine combine to create NaCl.</i>	<i>In order to help you keep track of the electrons during bond formation you can use a symbolic structure called Lewis diagrams. Show the creation of NaCl using a Lewis diagram.</i>

### How do you know?

Sodium chloride is written as NaCl and is composed of one Na ion and one chloride ion. Calcium chloride is written as CaCl<sub>2</sub> and is composed of one Ca ion and two chloride ions. How would you know that two chloride ions are required to create calcium chloride?

### Why do you believe?

The recipe to make brownies requires one cup of sugar and 8 oz of chocolate and one oven. If you wanted to double the recipe, how much sugar, chocolate and oven(s) are required?

### Why should you care?

Knowing the number of valence electrons for the elements will make it easy to write correct formulas for compounds. How will your game include fun and creative ways for naming compounds as they form?

## Reflecting on the Activity and the Challenge

In this activity, you learned that atoms of two chemical elements will interact with each other in order to achieve a stable electron arrangement like that of nearby noble gases. The way in which atoms interact is based on their excess or deficiency of electrons relative to atoms of the closest noble gas on the periodic table. An atom's excess or deficiency of electrons relative to the closest noble gas is readily indicated by the position of an element on the periodic table. In this way, the periodic table can be used to predict the chemical formulas when two elements interact to form a compound. This information can be deduced from the periodic table. Perhaps you can invent a way to make this more explicit as you create your periodic-table game. How might you incorporate this information into your game to meet the *Chapter Challenge*?

## Chem to Go

- Find the following pairs of elements in the periodic table on the back inside cover. Identify the excess or deficiency of electrons in each atom relative to an atom of the closest noble gas. Then predict the formula of the compound formed when these elements interact:
  - sodium and chlorine (to form sodium chloride)
  - calcium and oxygen (to form calcium oxide)
  - magnesium and chlorine (to form magnesium chloride)
  - aluminum and oxygen (to form aluminum oxide)
- In your *Active Chemistry* log, draw a simplified periodic table that contains only the first three rows of the periodic table. Your table should have three rows and eight columns. It should contain the elements with atomic numbers 1 through 18.
  - In the box for each element, write the symbol for the element.
  - In the columns headed by lithium, beryllium, and boron, indicate the charge (sign and value) of the ion formed when atoms of these elements give up electrons to get a more stable electron arrangement.
  - In the columns headed by nitrogen, oxygen, and fluorine, indicate how many electrons atoms of those elements gain to get a more stable electron arrangement.
- You know the formula for sodium chloride (NaCl). From this knowledge you can also write the formula for potassium chloride, cesium bromide, lithium iodide, and sodium fluoride.
  - What tool makes it possible for you to do this, even though you may have never investigated these compounds?
  - Using the periodic table, explain what information you used to help explain how you arrived at the formulas.
- The formula for calcium chloride is  $\text{CaCl}_2$ . From this knowledge you should be able to write the formulas of the alkaline earth metals (Group 2) and halogens combining.
  - Write the formula for magnesium bromide, strontium iodide, beryllium fluoride, barium chloride, and calcium iodide.
  - What information from the periodic table did you use to write the formulas of these compounds?
- A compound that was used previously is aluminum chloride ( $\text{AlCl}_3$ ). Use your understanding of why elements are grouped together and are called a family to write the formula for each of the following compounds:
  - boron fluoride
  - aluminum bromide
  - gallium iodide
  - indium (III) chloride
  - thallium (III) bromide



6. You have explored how the alkali, alkaline earth metals, and IIIA group (boron, aluminum, gallium, indium, and thallium) combine with the halogens. How do these metals combine with the group VIA elements (oxygen, sulfur, selenium, tellurium, and polonium)? Look at a few compounds such as sodium oxide that has a formula of  $\text{Na}_2\text{O}$ . Alkali metals like sodium have low ionization energy values. When they react to form an ionic compound, an electron is lost and they become the positive ion (cation) of the new compound. A nonmetal like oxygen has a high ionization energy value. In reacting to form an ionic compound it gains electrons, becoming the negative ion (anion) of the compound. Therefore, when the alkali metals combine with oxygen or other elements of group VIA, they should have a similar formula.

a) Write the formula for each of the following compounds:

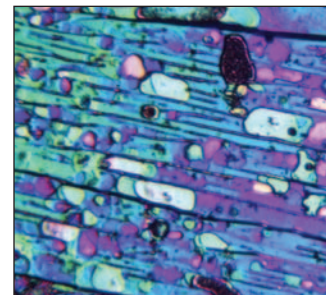
- i) potassium sulfide    ii) rubidium selenide    iii) lithium telluride  
iv) sodium sulfide    v) cesium oxide

You can do the same thing with the alkaline earth metals combining with the group VIA elements. Calcium oxide has the formula  $\text{CaO}$ . The alkaline earth metals have low ionization energies and react to form the positive ion with a +2 charge. Again, the nonmetal oxygen will form an anion with a charge of -2. Thus, the alkaline earth metals and the group VI elements will combine in a 1:1 ratio.

b) Write the formula for each of the following compounds:

- i) magnesium sulfide    ii) strontium selenide    iii) barium oxide  
iv) beryllium telluride    v) calcium sulfide

Finally, look at the group IIIA elements combining with the group VIA elements. Aluminum oxide has the formula  $\text{Al}_2\text{O}_3$ . The group IIIA elements have lower ionization energies than the Group VIA elements and form cations with a charge of +3. The oxygen or the Group VIA nonmetals like oxygen have a -2 charge in the ionic compounds. In order to make a whole-number exchange of electrons, six electrons must be transferred. (Remember to make sure that your formula has the correct number of electrons being transferred.)



c) Write the formula for the following compounds:

- i) boron sulfide    ii) aluminum selenide    iii) gallium telluride  
iv) indium (III) oxide    v) thallium (III) sulfide

## Inquiring Further

### Creating compounds with “inert” gases

For a long period of time the noble gases were called the inert elements because it was assumed that they were non-reactive and did not want to gain or lose electrons. Research to find out if compounds can be formed with the noble gases. Record your finding in your *Active Chemistry* log. If time permits, share your findings with the class.