Electron Sharing—Covalent Bonds

Learning Outcomes
After completing this lesson, you will be able to:

- describe a covalent bond
- state the differences between covalent and ionic bonds
- explain the octet rule
- use the Bohr model to illustrate the formation of covalent bonds and electron sharing
- explain the term molecule
- describe a diatomic molecule

Key Words
octet rule
covalent compound
covalent bond
diatomic molecule
valence electron

Covalent Bonds
When two ions form ionic bonds, they transfer one or more electrons from a metal atom to a non-metal atom. As a result of the electron transfer, one ion has a positive charge (loses electrons) and one has a negative charge (gains electrons). An attraction exists between these ions, forming an ionic bond, holding them together as an ionic compound.

Many compounds, however, do not form ionic bonds. These compounds contain two or more non-metallic atoms. For example, CO₂ is made of two different non-metals, carbon and oxygen. These compounds are formed through the sharing of valence electrons. A covalent bond is formed when two or more non-metallic atoms share valence electrons.
Two hydrogen atoms form a covalent bond by sharing electrons to produce a hydrogen molecule.

- A molecule is the smallest unit of a covalent compound.
- A molecule has different characteristic properties from the atoms that form it.

The Bohr model for hydrogen shown below illustrates a covalent bond.

![Bohr model of hydrogen molecule]

Note: The electrons are shared in the outer orbits of both atoms. This covalent bond forms a molecule of hydrogen (H₂).

When two atoms of hydrogen come close to each other, the protons attract each other’s electrons. The force is not strong enough to cause an electron transfer (ionic bond), but it is strong enough to force the electrons to travel in both of the atoms’ orbits, spending most of the time in the position shown in the diagram, between the two nuclei. As a result, the two electrons are shared by both atoms. The hydrogen atom at the left “looks” at its orbit and “sees” two electrons; so does the one at the right. By sharing their electrons, both atoms are satisfied they have filled outer orbits (the outer orbits are the same as for helium) and are stable.

The two hydrogen atoms form a diatomic molecule (i.e., two atoms of hydrogen share electrons to make a single molecule of hydrogen gas).

A list of diatomic molecules is shown below. Many of these molecules, which you recognize as gases, are important to life. The elements forming diatomic gases are unstable as single atoms and combine almost instantaneously to form stable molecules.
Note that diatomic molecules are still classified as elements even though they are molecules. While it may seem strange that a molecule is called an element rather than a compound, remember that diatomic molecules are made of only one kind of atom.

<table>
<thead>
<tr>
<th>Name of Element</th>
<th>Symbol for One Atom of the Element</th>
<th>Formula for One Molecule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>H₂ (gas)</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>N₂ (gas)</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O</td>
<td>O₂ (gas)</td>
</tr>
<tr>
<td>Fluorine</td>
<td>F</td>
<td>F₂ (gas)</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl</td>
<td>Cl₂ (gas)</td>
</tr>
<tr>
<td>Bromine</td>
<td>Br</td>
<td>Br₂ (liquid)</td>
</tr>
<tr>
<td>Iodine I</td>
<td>I</td>
<td>I₂ (solid)</td>
</tr>
</tbody>
</table>

In each of the cases above, the outer energy levels of the atoms are “filled” with electrons. What does it mean for a energy level to be filled? A energy level is filled when it contains all the electrons it can hold in that particular energy level. When an energy level is filled, it has the same number of electrons as an inert gas and becomes itself inert or unreactive.

Hydrogen has a filled first energy level when it shares a single electron with another element. This need for another electron makes hydrogen extremely reactive. By sharing an electron with another hydrogen atom, the energy level becomes filled and a hydrogen molecule is produced. Helium already has two electrons in its outer orbit and is stable. For this reason helium gas does not react with other elements.

All other atoms need eight electrons to fill their outer orbits. A basic rule in chemistry is that an atom with eight electrons in its outer orbit is particularly stable. This need for eight electrons in a covalent bond is called the **octet rule**.
Covalent Compounds

Covalent compounds are formed when electrons are shared between non-metal atoms. (Keep in mind that outer orbit electrons are called valence electrons and “co” means share.) Explain why the term “covalent” compound is appropriate.

Intersecting circles on the outer orbit of a Bohr model atom illustrate how atoms can share electrons in a covalent bond. This way of representing covalent bonds is not completely correct but it is a good illustration.

Use the Bohr model to show how the following molecules are formed. Part of the molecule is included in each drawing. Your task is to complete the molecule.

a) methane CH$_4$

Notice that the formula for methane tells you that one carbon atom combines with four hydrogen atoms to form one molecule of methane. Draw three more hydrogen atoms like the one shown. Have the Bohr diagrams for each hydrogen atom intersect with the outer energy level of carbon so that they combine with each of the three remaining single electrons. Check the answers.
b) ammonia $\text{NH}_3$

Notice that the formula for ammonia tells you that one nitrogen atom combines with three hydrogen atoms to form one molecule of ammonia. Draw two more hydrogen atoms like the one shown. Have the Bohr diagrams for each hydrogen atom intersect with the outer energy level of nitrogen so that they combine with each of the two remaining single electrons. Check the answers.

c) water $\text{H}_2\text{O}$

d) hydrogen fluoride $\text{HF}$
Summary

- A covalent bond is formed between two non-metals that share electrons. Sometimes the two non-metals are the same kind of atom, as in diatomic molecules.
- The valence number on the periodic table is the number of electrons that the atom must share or transfer to produce a compound.
- Covalent compounds form bonds by sharing electrons. Ionic compounds form bonds by transferring electrons.
- The smallest particle formed by a covalent bond is a molecule. The smallest particle formed by an ionic bond is called a formula unit.
- A molecule has different properties from the atoms from which it is formed (i.e., water has different properties from hydrogen and oxygen).
- Diatomic molecules are formed when two of the same kinds of atoms combine to form a molecule. Hydrogen (H2) is an example of a diatomic molecule. Diatomic molecules are still elements.
- The octet rule applies to many atoms, particularly those in the first three periods. The octet rule states that an atom having eight electrons in its outer orbit is stable and no longer reactive. When covalent or ionic bonds are formed, the octet rule is satisfied, and the molecule or formula unit is stable. Notice that an atom that has satisfied the octet rule has an outer orbit configuration similar to an inert noble gas. Notice also that hydrogen and helium are stable with two electrons only.
- Covalent compounds are formed when two non-metals share electrons and combine to form a molecule. Covalent molecules are also formed when two atoms of the same kind form diatomic molecules.
- The Bohr model can be used to illustrate the formation of covalent bonds. The outer orbits of the Bohr atoms involved in the molecule intersect. The shared electrons can be placed on the intersecting orbits.
Learning Activity

1. How does a covalent bond differ from an ionic bond?

2. What is the octet rule?

3. What is a diatomic molecule?

4. What is the smallest unit of a covalent compound?

5. Why is it important that oxygen forms a diatomic molecule?

6. A list of pairs of atoms is shown below. Indicate whether each pair would form a compound using an ionic bond or a covalent bond.
   calcium and bromine
   hydrogen and oxygen
   carbon and oxygen
   lithium and oxygen
   phosphorus and chlorine
7. Complete the drawings below. One atom of carbon is combining with four atoms of fluorine to form one molecule of a compound.

a) What kind of bond is used to make the compound?

b) Place the proper number of electrons in the atoms in their proper orbits.