Bonding Models

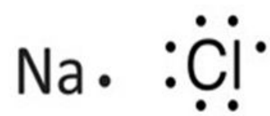
Reflect

Many scientists ran experiments in order to formulate the atomic model. Their experiments defined the atom as we know it today. Niels Bohr refined the structure of the atom by developing a model with a central nucleus surrounded by electrons moving in orbits and in different energy levels. Moving from the nucleus outward, each orbit represented higher energy than the previous one.

Although the Bohr model is no longer the current model of the atom (it is now known as the Quantum model), the idea of specific energy levels for electrons became an important one that endured even after the model itself was found to be inadequate.

Scientists today accept and continue to use the idea that each electron in an atom has a specific energy. They also accept the idea that electrons absorb or lose discrete quantities of energy called **quanta**. However, they reject Bohr's idea that electrons follow specific orbital paths around the nucleus. Instead, scientists now think that the exact location of an electron in an atom cannot be known at any given time. Instead, we can know only a range of probable locations. These locations are best described as **electron clouds** because they are three-dimensional spaces with fuzzy borders. Scientists use the term **orbital** when they refer to the location of an electron in this model.

You can use electron dot structures (also called Lewis structures) to show the valence electrons around an atom. For example, the element sodium has one valence electron, so it is written with one electron dot surrounding its elemental symbol (Na), as shown below. In contrast, the element chlorine has seven valence electrons, so it is written with seven electron dots surrounding its elemental symbol (Cl).



valence electrons: the negatively charged particles in the outer energy shell of an atom

Electron dot structures provide useful information about *compounds*—substances that consist of two or more types of atoms chemically bonded together. How do you think an electron dot structure is helpful when describing the chemical bonds that can form between elements?

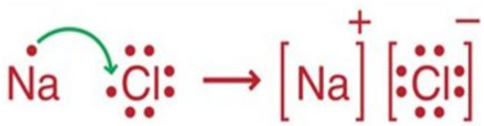
Molecular Bonding

The strength of chemical bonds depends on how the valence electrons are behaving in compound. Electrons can be shared equally, unequally, given away or gained. This behavior will determine the type of bond.

Lewis Dot Structures can be used to model molecular bonds because electron dot models show the number of valence electrons in each element. We can use these models to describe the electrons involved in a chemical bond between elements. Thus, electron dot formulas can show how bonds form between two atoms. We write electron dots slightly differently depending on the type of chemical bond.

Ionic Bonding
In *ionic bonds*, one or more valence electrons move from one atom (usually a metal) to another atom (usually a nonmetal). The atom that loses electrons becomes a positively charged ion, or *cation*; the atom that gains electrons becomes a negatively charged ion, or *anion*. The attraction between the newly formed cation and anion results in the formation of an ionic bond.

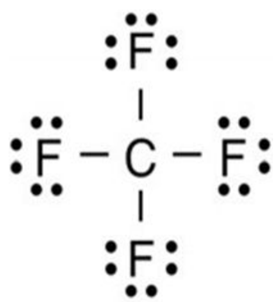
When writing the electron dot structure of an ionic bond, we place the anion and the cation in brackets beneath their respective charges. For example, sodium chloride (NaCl) is an ionic compound of sodium (Na) and chlorine (Cl). As you saw above, the electron dot structure of sodium contains one electron, and the electron dot structure of chlorine contains seven electrons. To form an ionic bond, one electron transfers from sodium to chlorine. This gives the anion, chloride, a stable nucleus surrounded by eight valence electrons. It also gives the cation, sodium, a stable nucleus surrounded by eight valence electrons.



An ionic bond forms when an electron moves from an atom of sodium (Na) to an atom of chlorine (left). The resulting ionic compound, sodium chloride (NaCl), consists of a positively charged cation (Na^+) and a negatively charged anion (Cl^-). Note how the cation and anion are placed within brackets on the right side of the chemical equation.

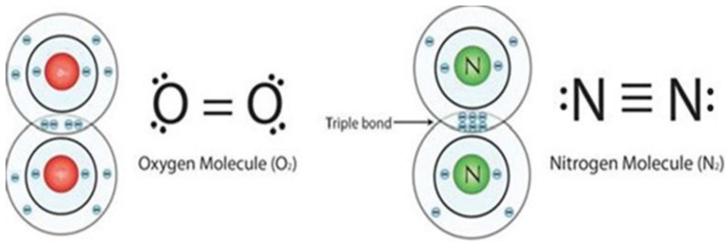
Covalent Bonding
In *covalent bonds*, atoms share valence electrons. A covalent compound, or *molecule*, may contain two or more atoms. Covalent bonds will usually occur between two non-metals, including most organic molecules. In molecules with more than two atoms, one atom is the central atom. We place electron pairs around all atoms to fulfill the **octet rule**, which is the tendency of most atoms to have eight valence electrons. For example, carbon tetrafluoride (CF_4) is a covalent compound containing one central carbon atom (C) surrounded by four fluorine atoms (F). A carbon atom has four valence electrons, and a fluorine atom has seven valence electrons. Therefore, in carbon tetrafluoride the carbon atom shares one valence fluorine atom. Due to this sharing of valence electrons, the carbon and fluorine atoms all fulfill the octet rule.

*An important exception to the octet rule is hydrogen; a hydrogen atom has at most two valence electrons.



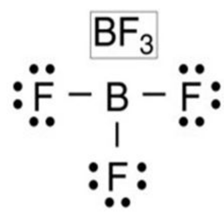
This Electron Dot Structure shows carbon tetrafluoride. The line between the central carbon atom (C) and each fluorine atom (F) represents a single chemical bond formed by two shared electrons. The remaining electrons are placed in pairs as dots around each fluorine atom.

Molecules can also form between atoms that share more than one electron pair. For example, in a molecule of oxygen gas (O_2), each oxygen atom (O) has six valence electrons and needs two electrons to complete its valence orbital. Thus, the two oxygen atoms share two electron pairs. The sharing of two electron pairs between atoms is a *double bond*. Similarly, the nitrogen atoms (N) in a molecule of nitrogen gas (N_2) share three electron pairs. This type of covalent bond is a *triple bond.* Double and triple bonds can also occur between different elements. The following diagrams show electron dot structures for double and triple bonds.

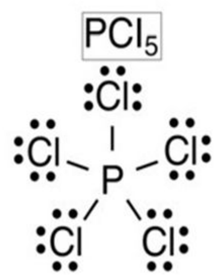


Look Out!

Molecules containing atoms of carbon and oxygen almost always have complete valence shells of electrons. Sometimes, however, covalent compounds form with incomplete valence shells. For example, an atom of boron (B) typically contains three valence electrons. In the molecule boron trifluoride (BF_3), the boron atom shares an electron pair with each of three fluorine atoms. Each fluorine atom ends up with eight valence electrons, but the boron atom ends up with only six.



Some atoms can have more than eight valence electrons. For example, in a molecule of phosphorus pentachloride (PCl_5), the central phosphorus atom (P) has five valence electrons.



Each chloride atom has seven valence electrons and forms a single bond with the phosphorus atom, which ends up with ten valence electrons.

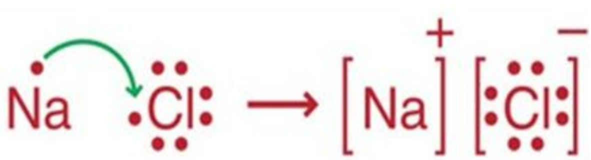
These diagrams show the electron dot structures for each of these unusual covalent compounds

Polar versus Non Polar Covalent Bonds

Covalent boding is when valence electrons are shared between atoms, causing them to form a relatively *weak* bond. Not all electrons are shared equally in covalent bonds.

In non-polar covalent bonding, the electrons split their time orbiting the different atoms. This true sharing of valence electrons leaves the newly formed molecule as non-polar, or with no net charge.

Sometimes though, electrons spend more time orbiting a particular atom in the molecule. This will cause the atom to have a slightly negative charge, thus creating a polar molecule.



Water is an example of a polar covalent bond. The electrons are unevenly distributed, giving the molecule an overall charge.

Try Now

Application
Draw the Lewis Dot structure and determine the type of bond in the following compounds.

H2S

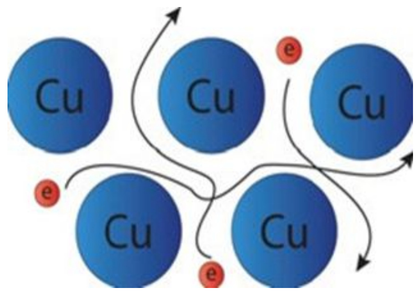
CH2O

NaCl

MgO

Look Out!

Metallic Bonding
In addition to ionic and covalent bonds, there is a third type of chemical bond: *metallic bonds*. The strongest type of chemical bonds, these are formed between closely grouped atoms of metals. Examples of substances that contain metallic bonds are gold bars, sheets of aluminum foil, cooking pans, and copper wires.



This diagram shows metallic bonds in a sample of copper (Cu). Freely moving valence electrons (red) form an electron sea around the positively charged copper ions (blue).

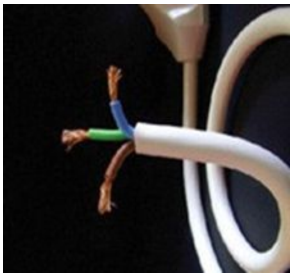
In metallic bonds, atoms do not share electrons, nor does one atom give up its electrons to another atom. Instead, electrons travel from one nucleus to another within the metallic structure. Because they do not hold on to their valence electrons, the metal atoms are actually positively charged ions (cations). Together, the electrons make up an *electron sea*. Metallic bonds form because metal cations are attracted to electrons in the electron sea.

The structure of the electron sea in a metallic bond provides many of the properties observed in metals. The abilities of the electrons to move throughout the electron sea and of the cations to slide past each other make metallic bonds more flexible than ionic or covalent bonds. This flexibility makes metals *malleable*, meaning able to be stretched and bent into shapes, and *ductile*, or able to be shaped into long, thin wires.

Metals like copper are commonly used to make wires that provide power to electrical appliances such as televisions and computers. In addition to their ductility, most metals are good conductors of electricity and heat. When an electric current is applied to a metal, the electrons in the electron sea begin to flow in the direction of the current. When heat is applied to a metal, the electrons in the electron sea vibrate and collide with each other. As a result, energy—whether electrical or thermal—transfers easily through the metal.

What Do You Think?

Take a look at these photographs. The picture on the left shows an egg in a metal frying pan. The picture on the right shows metal wires in a power cable. Why are metals good materials from which to make frying pans and electrical wires?



Connecting With Your Child

Molecular Modeling

To help your child learn more about molecular bonding and take a look at molecular geometry, create three-dimensional structures of molecules using household items. Here is a typical materials list:

- 15–20 toothpicks
- 15–20 marshmallows (or another small, soft food)

The marshmallows represent atoms and the toothpicks are the chemical bonds between them. Have your child create models of the following molecules, using toothpicks to join marshmallows. Each toothpick represents two valence electrons. (On each marshmallow, write the chemical symbol for the element represented by the marshmallow.

Alternatively, you may use a different- colored item to represent the different atoms of each element.)

- **Carbon monoxide (CO):** A linear molecule with a carbon atom that is triple bonded to an oxygen atom. Use three toothpicks to connect a carbon atom to an oxygen atom.
- **Borane (BH_3):** A planar molecule with a central boron atom bonded to three hydrogen atoms through single bonds.

Each hydrogen atom should lie in the same plane at 120˚ angles from each other.

- **Methane (CH_4):** A tetrahedral molecule with a central carbon atom bonded to four hydrogen atoms through single bonds. Each hydrogen atom should be at an angle of approximately 109.5˚ from the others.
- **Water (H_2O):** A bent molecule with a central oxygen atom bonded to two hydrogen atoms through single bonds. The two hydrogen atoms should be at an angle of about 104˚ from each other.
- **Ammonia (NH_3):** A trigonal pyramidal molecule with a central nitrogen atom bonded to three hydrogen atoms through single bonds. Each hydrogen atom should be at an angle of approximately 107˚ from the others.

Here are some questions to discuss with your child:

1. What is the electron dot structure for each molecule?
2. What information can you get from a molecular structure that cannot be obtained from the electron dot structure of a molecule?
3. Why are molecular models valuable tools for understanding molecules?
4. What is the difference between ionic and covalent bonds? Between metallic and covalent bonds?