CONCEPT 1

Atoms bond together to form ionic and covalent compounds.

Activity

Finding Compounds

Your teacher will provide your group with cards that have a chemical name or formula of an ionic or covalent compound and its properties. Look around the classroom, and identify where each compound is. The compound may be part of a material or exist on its own. State which compounds are ionic and which are covalent. Explain how you decided.

Chemical reactions involve one or more pure substances interacting to form a different substance or substances. These pure substances can be elements or compounds. Compounds are made of atoms of different elements that chemically combine in specific proportions. They are classified into one of two categories, ionic or covalent, based on the type of chemical bond that forms between the atoms.

Ionic Compounds

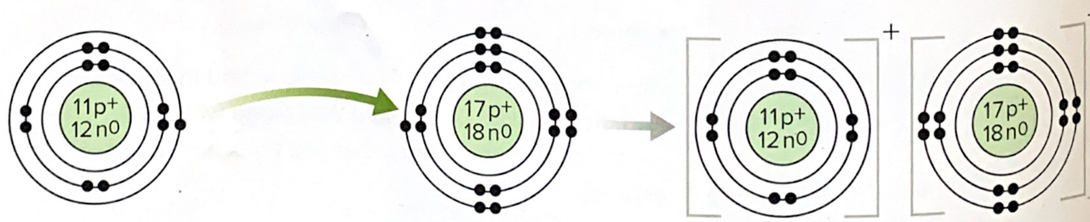
Ionic compounds consist of positively charged ions, called *cations*, and negatively charged ions, called *anions*. These ions are held together by **ionic bonds**. In binary ionic compounds, atoms of a metal element lose one or more electrons to atoms of a non-metal element (**Figure 2.4**). There is an *electrostatic attraction* between the cations and anions, resulting in the ionic bond. The strength of that attraction, and the resulting ionic bond, depend on the types of ions involved.

In the formation of ionic compounds, the electron transfer results in ions that have full valence shells and, therefore, greater stability.

ionic compound a compound made of oppositely charged ions

ionic bond a strong attraction that forms between oppositely charged ions

Figure 2.4 In binary ionic compounds such as sodium chloride, the transfer of electrons from metal atoms to non-metal atoms produces ions that are strongly attracted to each other. **Processing: What is the chemical formula for sodium chloride? Explain why sodium ions and chloride ions have the charges that they do.**



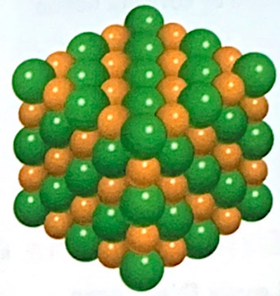
Na atom Cl atom Na^+ cation Cl^- anion

Activity

Predicting and Visualizing Ionic Compounds

1. Sodium chloride exists as a cubic crystal lattice.

   Describe how ions in sodium chloride are arranged in the crystal lattice. The chemical formula for an ionic compound represents the *formula unit*, which is the smallest whole number ratio of positive and negative ions to form a neutral compound. What is the formula unit of sodium chloride?



2. Give the names and chemical formulas for the ionic compounds that will form from the following pairs of elements. Why does each element form the ion it does? How many bonds form in each formula unit?

   a) calcium and oxygen
   b) sodium and fluorine
   c) aluminum and sulfur
   d) potassium and bromine

3. Choose one of the above compounds. Find out how its ions are arranged in a crystal lattice, and build a three-dimensional model using materials supplied by your teacher. Work with other students to evaluate the models.

Covalent Compounds

Covalent compounds consist of atoms of two or more non-metal elements joined together by **covalent bonds**. A covalent bond is a strong attraction between atoms that forms when the two atoms share electrons. The sharing of electrons results in electrostatic attractions between the positive nucleus of each atom and the negative electrons of the atoms.

As with ionic compounds, the formation of a covalent compound results in an increase in stability of the atoms due to the filling of valance shells. However, non-metals in covalent compounds achieve a full valence shell by sharing electrons.

In water, the single valence electron of each hydrogen atom is paired with one of the valence electrons of oxygen. The sharing of this electron pair forms a single covalent bond. Covalent compounds can also contain double bonds, which form when atoms share two pairs of electrons, and triple bonds, which form when atoms share three pairs of electrons (**Figure 2.5**).

covalent compound a compound that results when atoms of two or more elements bond covalently

covalent bond a strong attraction between atoms that forms when atoms share valence electrons

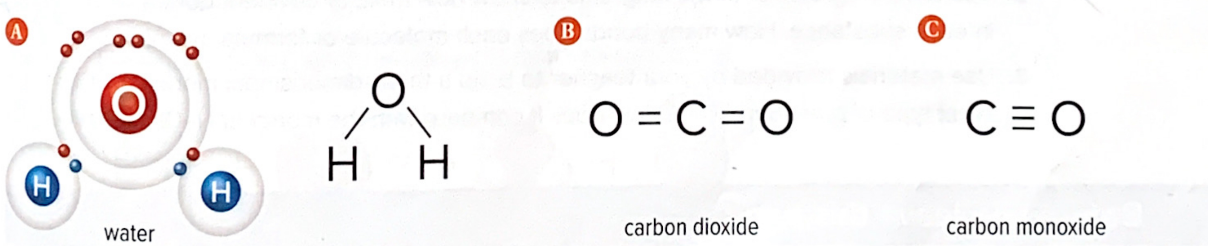


Figure 2.5 (A) In water, oxygen forms a covalent bond with each hydrogen atom. Single bonds may be represented with a single line. (B) Double bonds are shown using two parallel lines. (C) Triple bonds are shown using three parallel lines.

molecule a particle made up of two or more atoms bonded by covalent bonds

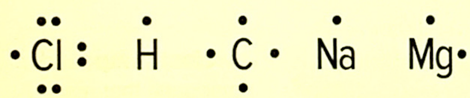
Most covalent compounds exist as molecules. A **molecule** is the smallest independent unit of a covalent compound. In a glass of water, individual molecules of water exist. In contrast, sodium chloride exists as a continuous arrangement of ions, not as separate molecules.

Two or more atoms of the same element that are joined by a covalent bond are also molecules. These elements include H_2, N_2, O_2, Cl_2, Br_2, I_2, F_2, S_8, and P_4. However, these molecules are not compounds, because they contain only one element.

Extending the Connections

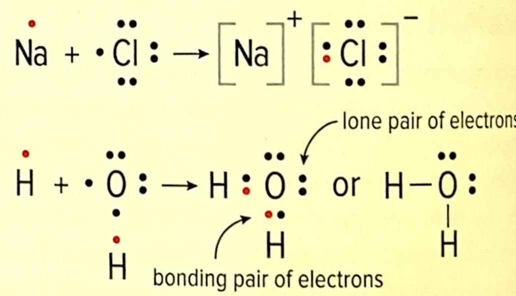
Lewis Diagrams

A common way to model electrons in an atom and the arrangement of atoms in a molecule or formula unit is with Lewis diagrams. They show only the valence electrons. Lewis diagrams consist of an element's chemical symbol surrounded by dots that represent its valence electrons. For helium, the dots are paired. Starting with second-period elements, dots are placed singly around the symbol at the points of a compass until the fifth one.



Then they are paired. In Lewis diagrams for molecules, each bonding pair of electrons is represented with a single line. Lewis diagrams that represent bonding in sodium chloride and water are shown below.

Draw the Lewis diagram for Cl_2. What is an advantage to using Lewis diagrams instead of Bohr diagrams? What is a limitation?



Activity

Showing the Bonds

1. Name each of the following substances. Which is different from the others? Which should be classified as molecules? Which should not?
   $MgBr_2$, CCl_4, KI, F_2
2. Use Bohr diagrams or Lewis diagrams to show how ionic or covalent bonds form in each substance. How many bonds does each molecule or formula unit have?
3. Use materials provided by your teacher to build a three-dimensional model of CCl_4. What type of compound is it? How does it compare with the model of NaCl you made?

Before you leave this page . . .

1. What type of bond is formed between two non-metal atoms? Describe how it forms.
2. Describe how a binary compound composed of sodium and bromine forms.

CONCEPT 2

Bonds are broken, atoms are rearranged, and new bonds are formed.

Activity

Rearranging the Atoms

CAUTION: Avoid touching the burner directly while hot. Following your teacher's instructions, light a Bunsen burner. Methane, CH_4, is the covalent compound in natural gas that burns in the presence of oxygen, O_2, to produce the flame that you see. In this reaction, carbon dioxide gas and water vapour form.

1. Where does the oxygen come from? Where are the products that form?
2. Using the materials provided by your teacher, build models of the four chemicals that show individual atoms and bonds between the atoms.
3. Describe how the atoms in molecules of methane and oxygen are rearranged to form the products. (Keep your models to use in other activities.)

When thinking about chemical reactions, imagine the atoms of each substance and how they might need to move for the reaction to take place. Some examples are shown in **Figure 2.6**.

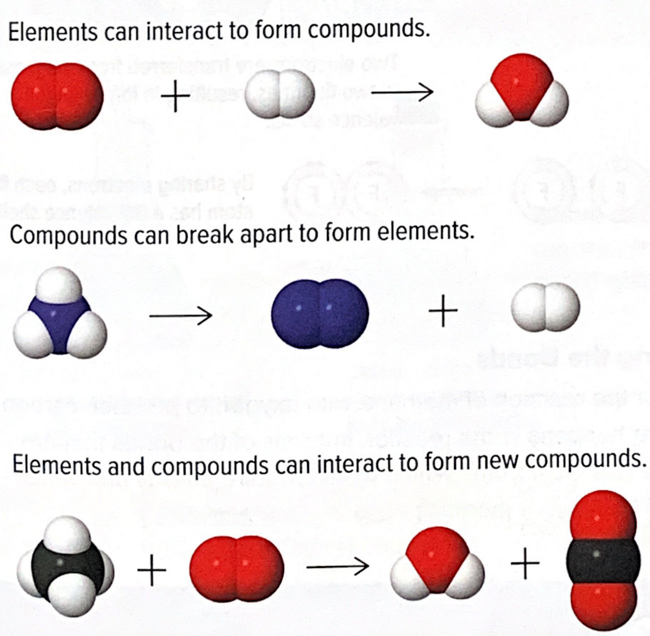


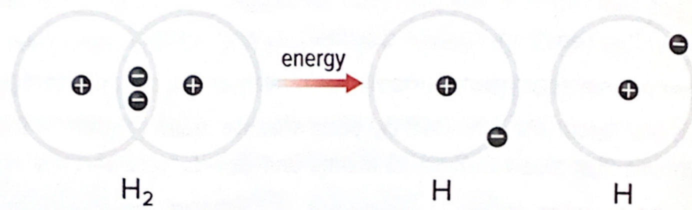
Figure 2.6 Examples of ways that elements and compounds can form new substances in chemical reactions. **Analyzing: What is happening to the atoms and bonds?**

Chemical Bonds and Energy

In order for atoms to be rearranged in a chemical reaction, the chemical bonds that hold them together must first be broken. Then new bonds can form between different atoms to produce different substances. For all chemical reactions, changes in energy are involved in these processes.

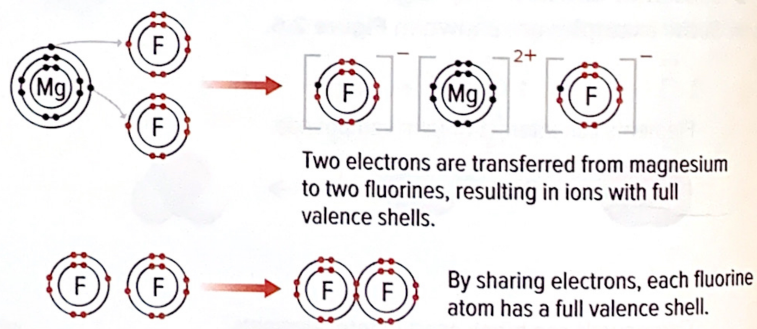
Chemical bonds are electrostatic attractions that hold atoms or ions together (**Figure 2.7**). In order to break those bonds (attractions), energy must be added until the atoms or ions are no longer held together. The amount of energy that is needed to break a chemical bond depends on the atoms or ions involved.

Figure 2.7 Energy must be added to break a chemical bond. **Applying: Is the bond shown here covalent or ionic? How do you know?**



When a chemical bond forms, energy is released. When chemical bonds form and the atoms achieve full valence shells of electrons, the atoms gain stability. Thus, atoms go from low stability (high energy state) to greater stability (lower energy state), and the "extra" energy is released (**Figure 2.8**).

Figure 2.8 When a bond forms, energy is released.



Activity

Making and Breaking the Bonds

Look at your models for the reaction of methane with oxygen to produce carbon dioxide and water. What happens in the reaction in terms of the bonds that are broken and new bonds that must form? Which would require energy and which would release energy? (Keep your models to use in other activities.)

Before you leave this page . . .

1. Is it possible for a chemical reaction to occur without new chemical bonds forming? Explain.
2. Describe how energy is involved in making and breaking chemical bonds.

CONCEPT 3

Mass cannot be created or destroyed in a chemical reaction.

In the late 1700s, a French chemist named Antoine Lavoisier, shown in Figure 2.9, greatly advanced the understanding of chemical reactions. He recognized that accurate inferences could be made about what happens to substances in a chemical reaction by studying the masses of those substances. Many experiments were performed that involved measuring the mass of the substances before the reaction, performing the reaction in a sealed container, called a *closed system* (Figure 2.10), and then carefully measuring the mass of the substances after the reaction.

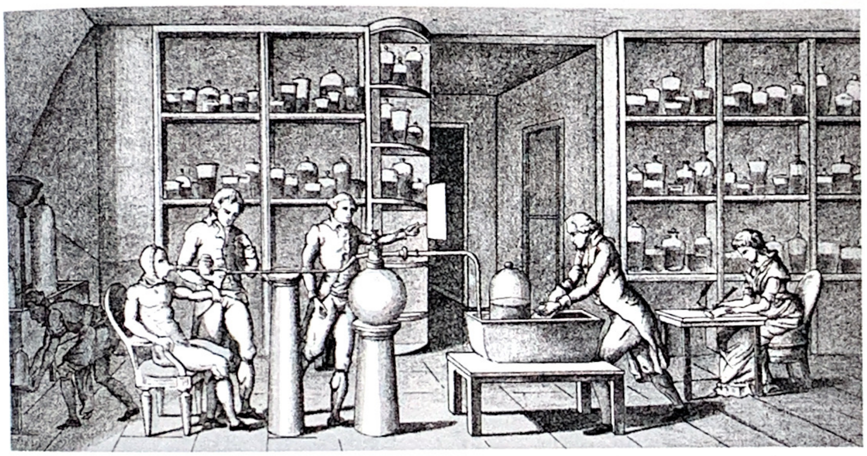


Figure 2.9 Antoine and Marie-Anne Lavoisier were a successful scientific team. Marie-Anne translated scientific papers from English into French for her husband and drew diagrams of the equipment he used for his experiments. **Analyzing: What is going on in this image? What equipment do you recognize? What kind of experiment do you think is taking place?**

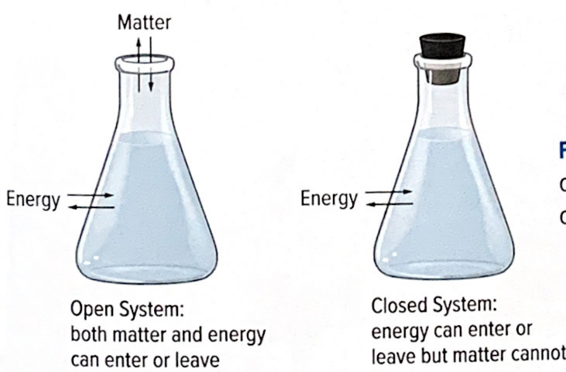


Figure 2.10 Reactions can occur in open or closed systems.

Extending the Connections

Women in Chemistry and Other Sciences

Margaret Cavendish published ideas about atoms and energy in the late 1600s. Elizabeth Fulhame was a chemist reknowned for her meticulous experimental methods during the late 1700s. You likely have never heard of either. Why do we know so much less, and often so little, about women in science until more recent times? Who should we know more about?

Showing the Conservation of Mass

One experiment that Lavoisier studied extensively involved mercury(II) oxide, HgO. This compound is a red solid that breaks down to form silver-coloured liquid mercury, Hg, and colourless oxygen gas, O_2, when it is heated. Figure 2.11 shows the kind of apparatus Lavoisier used in his experiments with mercury(II) oxide.

He repeated this reaction many times, and each time the results were the same: the total mass of the mercury(II) oxide was the same as the total mass of the mercury and oxygen that were produced. Therefore, whatever atoms are present in the substances undergoing a chemical reaction must also be present in the new substances that form. This observation is summarized in the **law of conservation of mass**.

law of conservation of mass in a chemical reaction, the total mass of the substances used is equal to the total mass of the substances produced

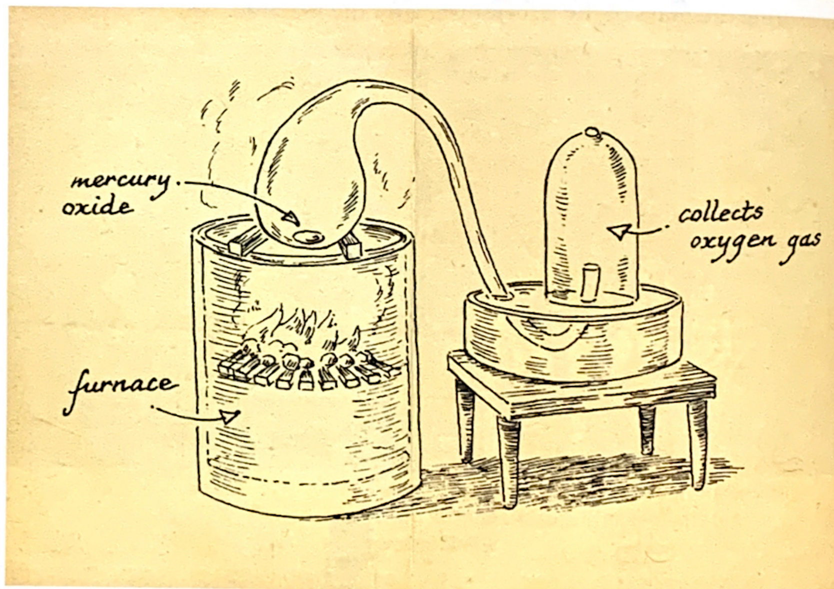


Figure 2.11 This sketch shows the apparatus that Lavoisier used for his experiment with HgO. **Communicating: Is this setup a closed or open system? How can you tell?**

Connect to Investigation 2-C on page 136

Activity

Modelling Conservation of Mass

Working with a partner, use your models of methane, oxygen, carbon dioxide, and water to show what must happen in order for the reaction to obey the law of conservation of mass. How many models of each type of molecule did you need to use in order to demonstrate the law of conservation of mass? Explain your answer.

Before you leave this page . . .

1. What is the law of conservation of mass?
2. What is the difference between an open and closed system?
3. What would you expect Lavoisier's results to be if he had used an open system? Explain your answer.