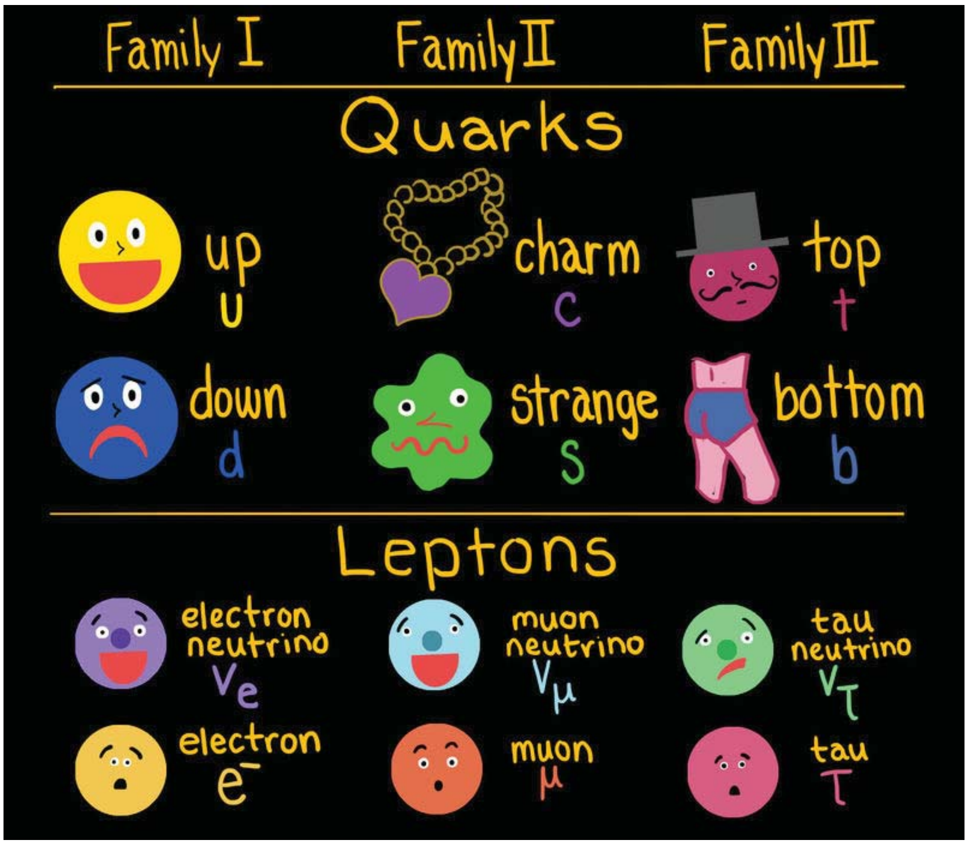
CHAPTER 11 Atoms

Chapter Outline



For many decades, scientists have known that atoms consist of electrons and other particles called protons and neutrons. Recently they found that there are even smaller particles in atoms. Scientists call these extremely tiny particles by the funny name of quarks. As you can see in this diagram, there are several different kinds of quarks, called up quarks, down quarks, top quarks, bottom quarks, charm quarks, and strange quarks. In this chapter you'll learn about these unusual particles and also other particles inside the atom.

11.1 Inside the Atom

Lesson Objectives

- Compare and contrast protons, neutrons, and electrons.
- Describe the forces that hold the particles of atoms together.
- Define atomic number and mass number.
- Describe ions and isotopes
- Identify the particles called quarks.

Vocabulary

- atomic mass unit (amu)
- atomic number
- electron
- ion
- isotope
- mass number
- neutron
- nucleus
- proton
- quark

Introduction

Atoms are the smallest particles of an element that still have the element's properties. They are the building blocks of all matter. Individual atoms are extremely small. In fact, they are so small that trillions of them would fit inside the period at the end of this sentence. Yet atoms, in turn, consist of even smaller particles.

Parts of the Atom

Figure 11.1 represents a simple model of an atom. You will learn about more complex models in later lessons, but this model is a good place to start. You can see similar, animated models of atoms at this URL: http://web.jjay.cuny.edu/~acarpi/NSC/3-atoms.htm .

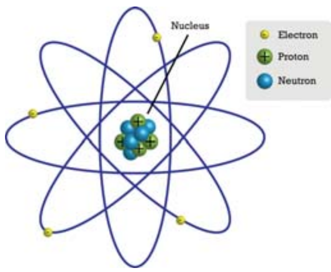


FIGURE 11.1
This simple atomic model shows the particles inside the atom.

The Nucleus

At the center of an atom is the **nucleus** (plural, nuclei). The nucleus contains most of the atom's mass. However, in size, it's just a tiny part of the atom. The model in **Figure** 11.1 is not to scale. If an atom were the size of a football stadium, the nucleus would be only about the size of a pea.

The nucleus, in turn, consists of two types of particles, called protons and neutrons. These particles are tightly packed inside the nucleus. Constantly moving about the nucleus are other particles called electrons. You can see a video about all three types of atomic particles at this URL: http://www.youtube.com/watch?v=lP57gEWcisY (1:57).

Protons

A **proton** is a particle in the nucleus of an atom that has a positive electric charge. All protons are identical. It is the number of protons that gives atoms of different elements their unique properties. Atoms of each type of element have a characteristic number of protons. For example, each atom of carbon has six protons, as you can see in **Figure** 11.2. No two elements have atoms with the same number of protons.

Neutrons

A **neutron** is a particle in the nucleus of an atom that has no electric charge. Atoms of an element often have the same number of neutrons as protons. For example, most carbon atoms have six neutrons as well as six protons. This is also shown in **Figure** 11.2.

Electrons

An **electron** is a particle outside the nucleus of an atom that has a negative electric charge. The charge of an electron is opposite but equal to the charge of a proton. Atoms have the same number of electrons as protons. As a result, the negative and positive charges "cancel out." This makes atoms electrically neutral. For example, a carbon atom has six electrons that "cancel out" its six protons.

Atomic Forces

When it comes to atomic particles, opposites attract. Negative electrons are attracted to positive protons. This force of attraction keeps the electrons moving about the nucleus. An analogy is the way planets orbit the sun.

What about particles with the same charge, such as protons in the nucleus? They push apart, or repel, each other. So why doesn't the nucleus fly apart? The reason is a force of attraction between protons and neutrons called the strong force. The name of the strong force suits it. It is stronger than the electric force pushing protons apart. However,

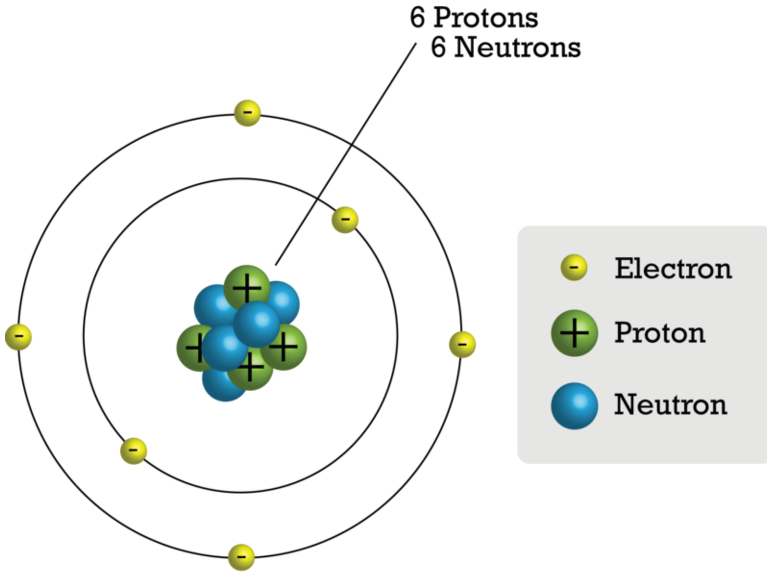


FIGURE 11.2
This model shows the particles that make up a carbon atom.

the strong force affects only nearby particles (see **Figure** 11.3). It is not effective if the nucleus gets too big. This puts an upper limit on the number of protons an atom can have and remain stable. You can learn more about atomic forces in the colorful tutorial at this URL: http://www.ric.edu/faculty/ptiskus/Atomic_Force/ .

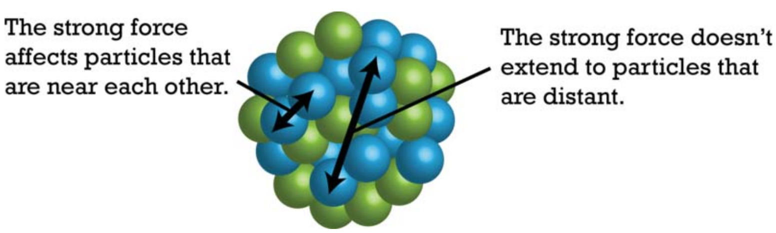


FIGURE 11.3
The strong force is effective only between particles that are very close together in the nucleus.

Atomic Number and Mass Number

Electrons have almost no mass. Instead, almost all the mass of an atom is in its protons and neutrons in the nucleus. The nucleus is very small, but it is densely packed with matter. The SI unit for the mass of an atom is the **atomic mass unit (amu)**. One atomic mass unit equals the mass of a proton, which is about 1.7×10^{-24} g. Each neutron also has a mass of 1 amu. Therefore, the sum of the protons and neutrons in an atom is about equal to the atom's total mass in atomic mass units.

Two numbers are commonly used to distinguish atoms: atomic number and mass number. **Figure** 11.4 shows how these numbers are usually written.

- The **atomic number** is the number of protons in an atom. This number is unique for atoms of each kind of element. For example, the atomic number of all helium atoms is 2.
- The **mass number** is the number of protons plus the number of neutrons in an atom. For example, most atoms of helium have 2 neutrons, so their mass number is 2 + 2 = 4. This mass number means that an atom of helium has a mass of about 4 amu.

FIGURE 11.4
The symbol He stands for the element helium. Can you infer how many electrons a helium atom has?

Problem Solving

Problem: An atom has an atomic number of 12 and a mass number of 24. How many protons and neutrons does the atom have?

Solution: The number of protons is the same as the atomic number, or 12. The number of neutrons is equal to the mass number minus the atomic number, or 24 –12 = 12.

You Try It!

Problem: An atom has an atomic number of 8 and a mass number of 16. How many neutrons does it have? What is the atom's mass in atomic mass units?

Ions and Isotopes

The number of protons per atom is always the same for a given element. However, the number of neutrons may vary, and the number of electrons can change.

Ions

Sometimes atoms lose or gain electrons. Then they become **ions**. Ions have a positive or negative charge. That's because they do not have the same number of electrons as protons. If atoms lose electrons, they become positive ions, or cations. If atoms gain electrons, they become negative ions, or anions.

Consider the example of fluorine in **Figure** 11.5. A fluorine atom has nine protons and nine electrons, so it is electrically neutral. If a fluorine atom gains an electron, it becomes a fluoride ion with a negative charge of minus one.

Isotopes of Atoms

Some atoms of the same element may have different numbers of neutrons. For example, some carbon atoms have seven or eight neutrons instead of the usual six. Atoms of the same element that differ in number of neutrons are called **isotopes**. Many isotopes occur naturally. Usually one or two isotopes of an element are the most stable and common. Different isotopes of an element generally have the same chemical properties. That's because they have the same numbers of protons and electrons. For a video explanation of isotopes, go to this URL: http://www.youtube.com/watch?v=6w7raarHNA8 (5:23).

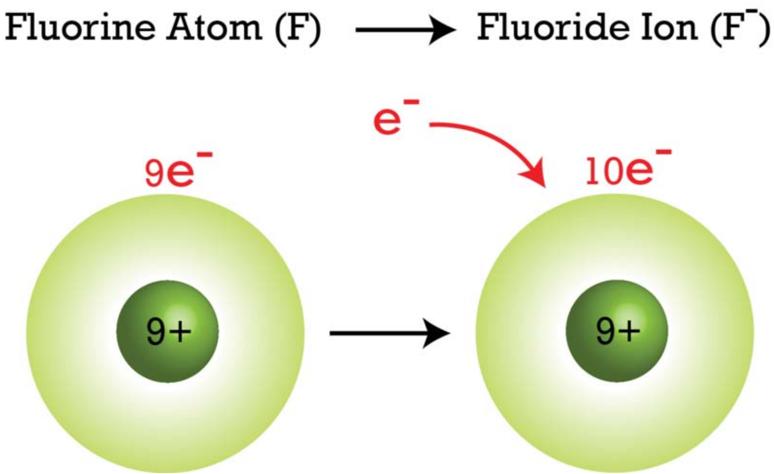
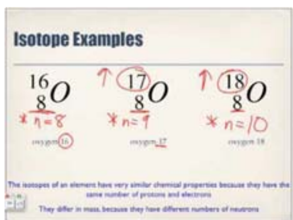


FIGURE 11.5
When a fluorine atom gains an electron, it becomes a negative fluoride ion.



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An Example: Hydrogen Isotopes

Hydrogen is a good example of isotopes because it has the simplest atoms. Three isotopes of hydrogen are modeled in **Figure** 11.6. Most hydrogen atoms have just one proton and one electron and lack a neutron. They are just called hydrogen. Some hydrogen atoms have one neutron. These atoms are the isotope named deuterium. Other hydrogen atoms have two neutrons. These atoms are the isotope named tritium.

Naming Isotopes

For most other elements, isotopes are named for their mass number. For example, carbon atoms with the usual 6 neutrons have a mass number of 12 (6 protons + 6 neutrons = 12), so they are called carbon-12. Carbon atoms with 7 neutrons have an atomic mass of 13 (6 protons + 7 neutrons = 13). These atoms are the isotope called carbon-13. Some carbon atoms have 8 neutrons. What is the name of this isotope of carbon? You can learn more about this isotope at the URL below. It is used by scientists to estimate the ages of rocks and fossils.

http://www.khanacademy.org/video/carbon-14-dating-1?playlist=Chemistry

Back to Quarks

Remember the quarks from the first page of this chapter? **Quarks** are even tinier particles of matter that make up protons and neutrons. There are three quarks in each proton and three quarks in each neutron. The charges of quarks are balanced exactly right to give a positive charge to a proton and a neutral charge to a neutron. It might seem strange that quarks are never found alone but only as components of other particles. This is because the quarks are held together by very strange particles called gluons.

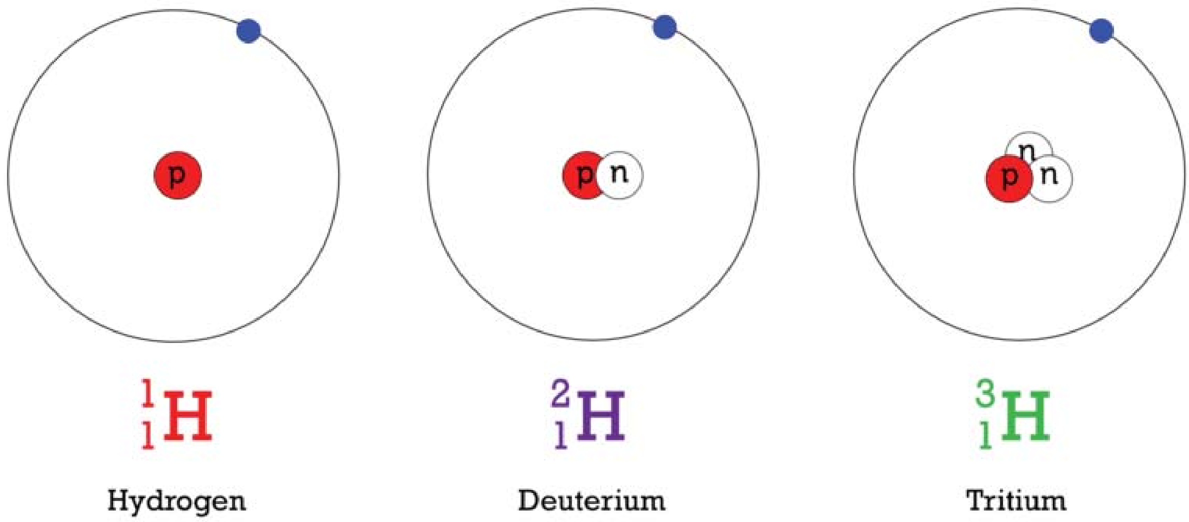


FIGURE 11.6
All isotopes of a given element have the same number of protons (P), but they differ in the number of neutrons (N). What is the mass number of each isotope shown here?

Gluons

Gluons make quarks attract each other more strongly the farther apart the quarks get. To understand how gluons work, imagine holding a rubber band between your fingers. If you try to move your hands apart, they will be pulled back together by the rubber band. The farther apart you move your hands, the stronger the force of the rubber band pulling your hands together. Gluons work the same way on quarks inside protons and neutrons (and other, really rare particles too).

If you were to move your hands apart with enough force, the rubber band holding them together would break. The same is true of quarks. If they are given enough energy, they pull apart with enough force to "break" the binding from the gluons. However, all the energy that is put into a particle to make this possible is then used to create a new set of quarks and gluons. And so a new proton or neutron appears.

Finding Quarks

The existence of quarks was first proposed in the 1960s. Since then, scientists have done experiments to show that quarks really do exist. In fact, they have identified six different types of quarks. However, much remains to be learned about these tiny, fundamental particles of matter. They are very difficult and expensive to study. If you want to learn more about them, including how they are studied, the URL below is a good place to start.

http://www.particleadventure.org/index.html

Lesson Summary

- The nucleus is at the center of the atom. It contains positive protons and neutral neutrons. Negative electrons constantly move about the nucleus.
- Atomic number is the number of protons in an atom. It is unique for the atoms of each element. Mass number is the number of protons plus neutrons in an atom. It is about equal to the mass of the atom in atomic mass units (amu).
- Negative electrons are attracted to positive protons, and this electric force keeps electrons moving about the nucleus. The force of attraction between protons and neutrons, called the strong force, holds the nucleus together.
- If atoms lose or gain electrons, they become positive or negative ions. Atoms of the same element that have different numbers of neutrons are called isotopes.
- Quarks are even tinier particles of matter that make up protons and neutrons. Scientists have identified six different types of quarks.

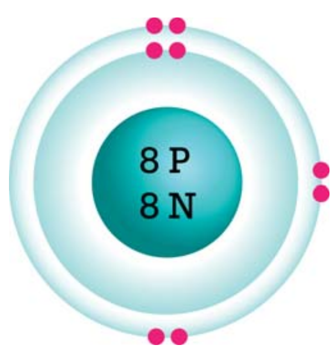
Lesson Review Questions

Recall

1. Describe the nucleus of an atom.
2. Outline the forces that hold particles together in an atom.
3. What does the atomic number of an atom represent?
4. Define isotope. Give an example.
5. What are quarks?

Apply Concepts

6. If an atom gains electrons, it becomes an ion. Is the ion positively or negatively charged? Explain your answer.
7. What is the atomic mass (in atomic mass units) of the atom represented by the model below?



Think Critically

8. Make a table comparing and contrasting protons, neutrons, and electrons. Include their location, mass, and electric charge.
9. Explain why atoms are neutral in electric charge.

Points to Consider

In this lesson, you saw several simple models of atoms. Models are useful for representing things that are very small. Scientists have used models to represent atoms for more than 200 years. In the next lesson, "History of the Atom," you'll read about some of the earlier models.

- How might scientists have modeled atoms before the particles inside atoms were discovered?
- How do you think earlier models might have differed from the models in this lesson?

11.2 References

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CHAPTER 12 Chemical Bonding

Chapter Outline

What do this lump of coal, diamond, and pencil "lead" all have in common? All three substances are forms of carbon. Are you surprised that one element can exist in forms that have such different properties? Do you know what explains it? The answer is chemical bonds. Carbon atoms chemically bond together in different ways to form these three substances. What are chemical bonds and how do they form? Read on to find out.

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12.1 Introduction to Chemical Bonds

Lesson Objectives

- Define chemical bond.
- List general properties of compounds.

Lesson Vocabulary

- chemical bond
- chemical formula

Introduction

There is an amazing diversity of matter in the universe, but there are only about 100 elements. How can this relatively small number of pure substances make up all kinds of matter? Elements can combine in many different ways. When they do, they form new substances called compounds. For a video introduction to compounds, go this URL: http://www.youtube.com/watch?v=-HjMoTthEZ0&feature=related (3:53).

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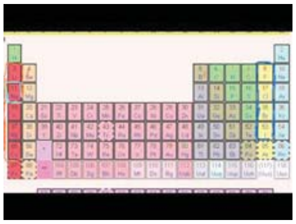
Chemical Bonding

Elements form compounds when they combine chemically. Their atoms join together to form molecules, crystals, or other structures. The atoms are held together by chemical bonds. A **chemical bond** is a force of attraction between atoms or ions. It occurs when atoms share or transfer valence electrons. Valence electrons are the electrons in the outer energy level of an atom. You can learn more about chemical bonds in this video: http://www.youtube.com/watch?v=CGA8sRwqIFg&NR=1 (13:21).



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Look at the example of water in **Figure** 12.1. A water molecule consists of two atoms of hydrogen and one atom of oxygen. Each hydrogen atom has just one electron. The oxygen atom has six valence electrons. In a water molecule, two hydrogen atoms share their two electrons with the six valence electrons of one oxygen atom. By sharing electrons, each atom has electrons available to fill its sole or outer energy level. This gives it a more stable arrangement of electrons that takes less energy to maintain.

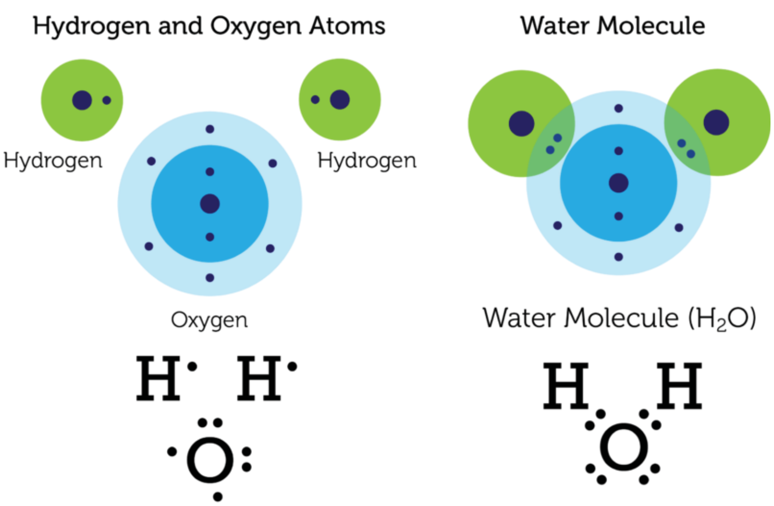


FIGURE 12.1

These diagrams show the valence electrons of hydrogen and water atoms and a water molecule. The diagrams represent electrons with dots, so they are called electron dot diagrams.

Chemical Compounds

Water (H_2O) is an example of a chemical compound. Water molecules always consist of two atoms of hydrogen and one atom of oxygen. Like water, all other chemical compounds consist of a fixed ratio of elements. It doesn't matter how much or how little of a compound there is. It always has the same composition.

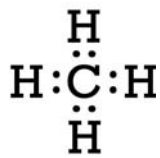
Chemical Formulas

Elements are represented by chemical symbols. Examples are H for hydrogen and O for oxygen. Compounds are represented by **chemical formulas**. You've already seen the chemical formula for water. It's H_2O. The subscript 2 after the H shows that there are two atoms of hydrogen in a molecule of water. The O for oxygen has no subscript. When there is just one atom of an element in a molecule, no subscript is used. **Table** 12.1 shows some other examples of compounds and their chemical formulas.

TABLE 12.1: Examples of Chemical Compounds

Name of Compound	Electron Dot Diagram	Numbers of Atoms	Chemical Formula

TABLE 12.1: (continued)

Name of Compound	Electron Dot Diagram	Numbers of Atoms	Chemical Formula
Hydrogen chloride		H = 1 Cl = 1	HCl
Methane		C = 1 H = 4	CH_4
Hydrogen peroxide		H = 2 O = 2	H_2O_2
Carbon dioxide		C = 1 O = 2	CO_2

Problem Solving

Problem: A molecule of ammonia consists of one atom of nitrogen (N) and three atoms of hydrogen (H). What is its chemical formula?

Solution: The chemical formula is NH_3.

You Try It!

Problem: A molecule of nitrogen dioxide consists of one atom of nitrogen (N) and two atoms of oxygen (O). What is its chemical formula?

Same Elements, Different Compounds

The same elements may combine in different ratios. If they do, they form different compounds. **Figure** 12.2 shows some examples. Both water (H_2O) and hydrogen peroxide (H_2O_2) consist of hydrogen and oxygen. However, they have different ratios of the two elements. As a result, water and hydrogen peroxide are different compounds with different properties. If you've ever used hydrogen peroxide to disinfect a cut, then you know that it is very different from water! Both carbon dioxide (CO_2) and carbon monoxide (CO) consist of carbon and oxygen, but in different ratios. How do their properties differ?

Types of Compounds

There are different types of compounds. They differ in the nature of the bonds that hold their atoms together. The type of bonds in a compound determines many of its properties. Three types of bonds are ionic, covalent, and metallic bonds. You will read about these three types in later lessons. You can also learn more about them by watching this video: http://www.youtube.com/watch?v=hEFeLYWTKX0 (7:18).

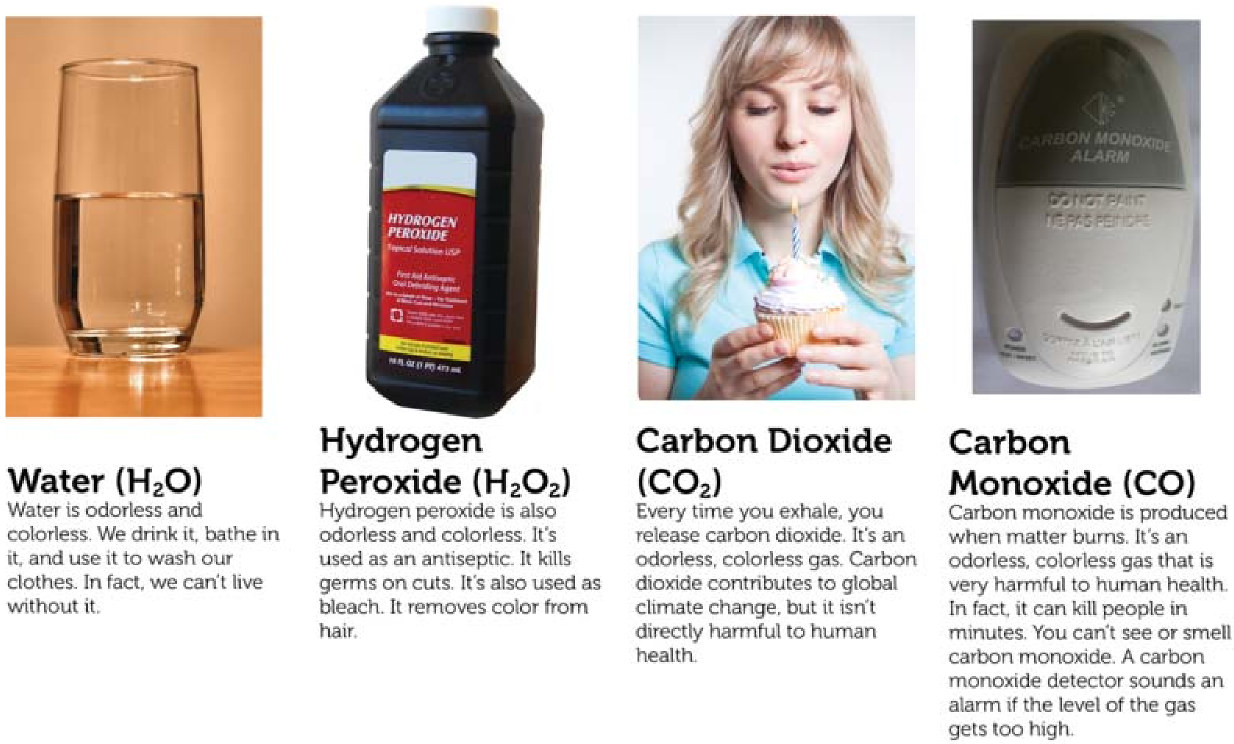


FIGURE 12.2

Different compounds may contain the same elements in different ratios. How does this affect their properties?

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Lesson Summary

- A chemical bond is a force of attraction between atoms. It occurs when atoms share or transfer electrons.
- A chemical compound is a new substance that forms when atoms of different elements form chemical bonds. A compound always consists of a fixed ratio of elements.

Lesson Review Questions

Recall

1. What is a chemical bond?
2. Define chemical compound.

Apply Concepts

3. Which atoms and how many of each make up a molecule of sulfur dioxide? Write the chemical formula for this compound.

Think Critically

4. Why does a molecule of water have a more stable arrangement of electrons than do individual hydrogen and oxygen atoms?
5. Explain how the ratio of elements in a compound is related to the compound's properties.

Points to Consider

In this lesson, you learned about chemical bonds in a water molecule. The bonds form between atoms of hydrogen and oxygen when they share electrons. This type of bond is an example of a covalent bond.

- What might be other ways that atoms can bond together?
- How might ions form bonds?

12.2 Ionic Bonds

Lesson Objectives

- Describe how ionic bonds form.
- List properties of ionic compounds.

Lesson Vocabulary

- ionic bond
- ionic compound

Introduction

All compounds form when atoms of different elements share or transfer electrons. In water, the atoms share electrons. In some other compounds, called **ionic compounds**, atoms transfer electrons. The electrons actually move from one atom to another. When atoms transfer electrons in this way, they become charged particles called ions. The ions are held together by ionic bonds.

Formation of Ionic Bonds

An **ionic bond** is the force of attraction that holds together positive and negative ions. It forms when atoms of a metallic element give up electrons to atoms of a nonmetallic element. **Figure** 12.3 shows how this happens.

In row 1 of **Figure** 12.3, an atom of sodium donates an electron to an atom of chlorine (Cl).

- By losing an electron, the sodium atom becomes a sodium ion. It now has one less electron than protons, giving it a charge of +1. Positive ions such as sodium are given the same name as the element. The chemical symbol has a plus sign to distinguish the ion from an atom of the element. The symbol for a sodium ion is Na^+.
- By gaining an electron, the chlorine atom becomes a chloride ion. It now has one more electron than protons, giving it a charge of -1. Negative ions are named by adding the suffix *–ide* to the first part of the element name. The symbol for chloride is Cl^-.

Sodium and chloride ions have equal but opposite charges. Opposites attract, so sodium and chloride ions attract each other. They cling together in a strong ionic bond. You can see this in row 2 of **Figure** 12.3. Brackets separate the ions in the diagram to show that the ions in the compound do not share electrons. You can see animations of sodium chloride forming at these URLs:

- http://web.jjay.cuny.edu/~acarpi/NSC/salt.htm

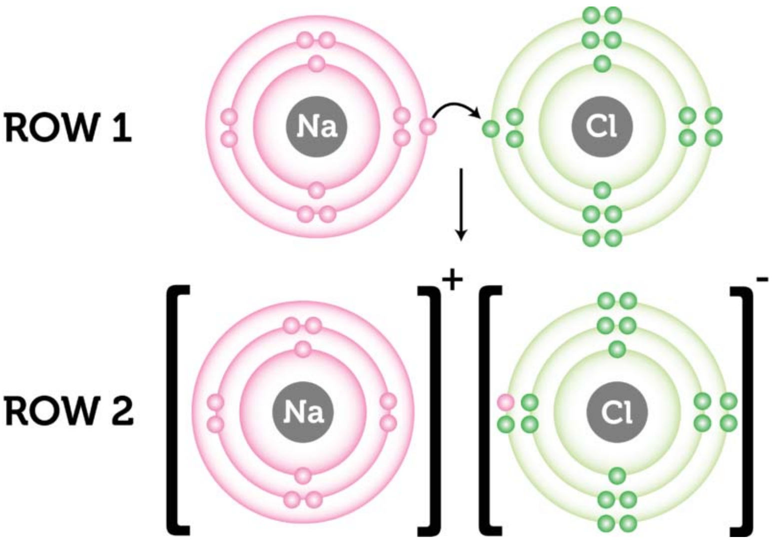

FIGURE 12.3
An ionic bond forms when the metal sodium gives up an electron to the non-metal chlorine.

- http://www.visionlearning.com/library/module_viewer.php?mid=55

Why Ionic Bonds Form

Ionic bonds form only between metals and nonmetals. Metals "want" to give up electrons, and nonmetals "want" to gain electrons. Find sodium (Na) in **Figure** 12.4. Sodium is an alkali metal in group 1. Like other group 1 elements, it has just one valence electron. If sodium loses that one electron, it will have a full outer energy level. Now find fluorine (F) in **Figure** 12.4. Fluorine is a halogen in group 17. It has seven valence electrons. If fluorine gains one electron, it will have a full outer energy level. After sodium gives up its valence electron to fluorine, both atoms have a more stable arrangement of electrons.

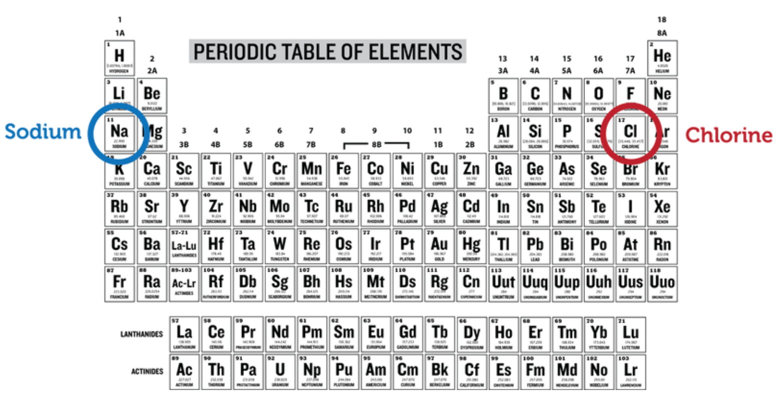

FIGURE 12.4
Sodium and chlorine are on opposite sides of the periodic table. How is this related to their numbers of valence electrons?

Energy and Ionic Bonds

It takes energy to remove valence electrons from an atom. The force of attraction between the negative electrons and positive nucleus must be overcome. The amount of energy needed depends on the element. Less energy is needed to remove just one or a few electrons than many. This explains why sodium and other alkali metals form positive ions so easily. Less energy is also needed to remove electrons from larger atoms in the same group. For example, in group 1, it takes less energy to remove an electron from francium (Fr) at the bottom of the group than from lithium (Li) at the top of the group (see **Figure** 12.4). In bigger atoms, valence electrons are farther from the nucleus. As a result, the force of attraction between the electrons and nucleus is weaker.

What happens when an atom gains an electron and becomes a negative ion? Energy is released. Halogens release the most energy when they form ions. As a result, they are very reactive.

Ionic Compounds

Ionic compounds contain ions of metals and nonmetals held together by ionic bonds. Ionic compounds do not form molecules. Instead, many positive and negative ions bond together to form a structure called a crystal. You can see an example of a crystal in **Figure** 12.5. It shows the ionic compound sodium chloride. Positive sodium ions (Na^+) alternate with negative chloride ions (Cl^-). The oppositely charged ions are strongly attracted to each other.

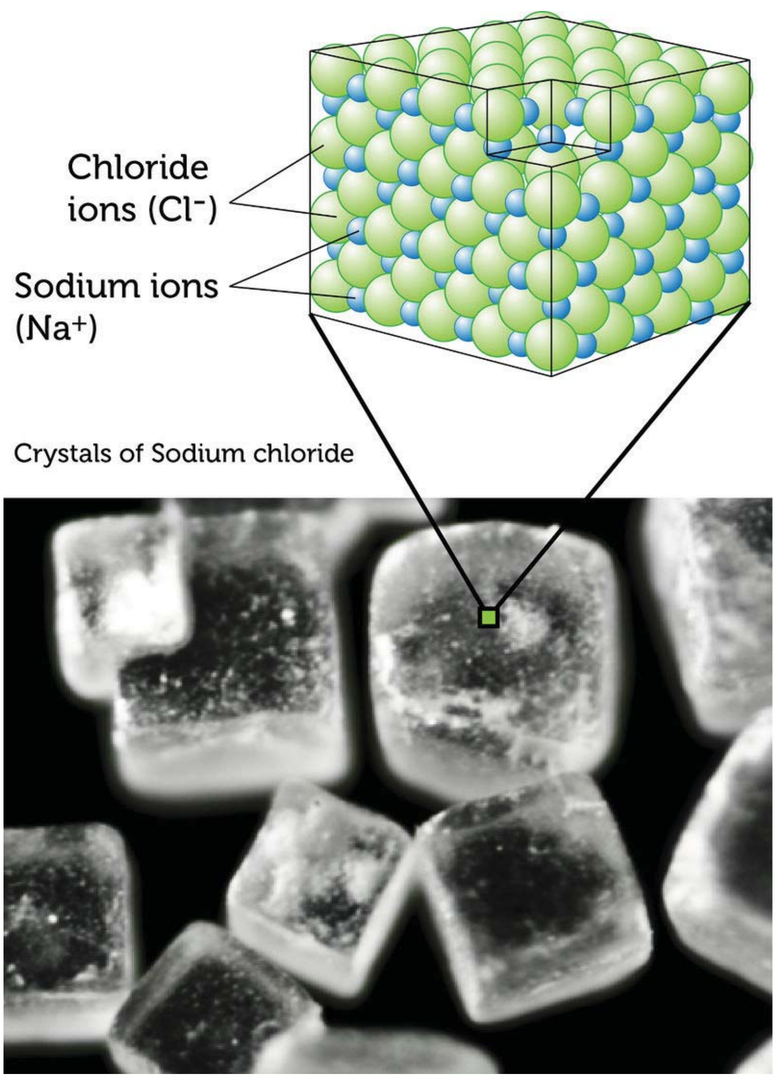

FIGURE 12.5
Sodium chloride crystals are cubic in shape. Other ionic compounds may have crystals with different shapes.

Helpful Hints

Naming Ionic Compounds Ionic compounds are named for their positive and negative ions. The name of the positive ion always comes first. For example, sodium and chloride ions form the compound named sodium chloride.

You Try It!

Problem: What is the name of the ionic compound composed of positive barium ions and negative iodide ions?

Properties of Ionic Compounds

The crystal structure of ionic compounds is strong and rigid. It takes a lot of energy to break all those strong ionic bonds. As a result, ionic compounds are solids with high melting and boiling points (see **Table** 12.2). The rigid crystals are brittle and more likely to break than bend when struck. As a result, ionic crystals tend to shatter. You can learn more about the properties of ionic compounds by watching the video at this URL: http://www.youtube.com/watch?v=buWrSgs_ZHk&feature=related (3:34).

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Compare the melting and boiling points of these ionic compounds with those of water (0°C and 100°C), which is *not* an ionic compound.

TABLE 12.2: Melting and Boiling Points of Select Ionic Compounds

Ionic Compound	**Melting Point** (°C)	**Boiling Point** (°C)
Sodium chloride ($NaCl$)	801	1413
Calcium chloride ($CaCl_2$)	772	1935
Barium oxide (BaO)	1923	2000
Iron bromide ($FeBr_3$)	684	934

Solid ionic compounds are poor conductors of electricity. The strong bonds between ions lock them into place in the crystal. However, in the liquid state, ionic compounds are good conductors of electricity. Most ionic compounds dissolve easily in water. When they dissolve, they separate into individual ions. The ions can move freely, so they are good conductors of electricity. Dissolved ionic compounds are called electrolytes.

Uses of Ionic Compounds

Ionic compounds have many uses. Some are shown in **Figure** 12.6. Many ionic compounds are used in industry. The human body also needs several ions for good health. Having low levels of the ions can endanger important functions such as heartbeat. Solutions of ionic compounds can be used to restore the ions.

Lesson Summary

- An ionic bond is the force of attraction that holds together oppositely charged ions. It forms when atoms of a metal transfer electrons to atoms of a nonmetal. When this happens, the atoms become oppositely charged ions.

FIGURE 12.6
Have you ever used any of these ionic compounds?

- Ionic compounds form crystals instead of molecules. Ionic bonds are strong and the crystals are rigid. As a result, ionic compounds are brittle solids with high melting and boiling points. In the liquid state or dissolved in water, ionic compounds are good conductors of electricity.

Lesson Review Questions

Recall

1. What is an ionic bond?
2. Outline the role of energy in the formation of an ionic bond.
3. List properties of ionic compounds.

Apply Concepts

4. Create a model to represent the ionic bonds in a crystal of the salt lithium iodide (LiI).
5. A mystery compound is a liquid with a boiling point of 50°C. Is it likely to be an ionic compound? Why or why not?

Think Critically

6. Explain why ionic bonds form only between atoms of metals and nonmetals.

Points to Consider

Bonds form not only between atoms of metals and nonmetals. Nonmetals may also bond with nonmetals.

- How do you think bonds form between atoms of nonmetals?
- Can you think of examples of compounds that consist only of nonmetals?

12.3 Covalent Bonds

Lesson Objectives

- Describe how covalent bonds form.
- Compare properties of polar and nonpolar covalent compounds.

Lesson Vocabulary

- covalent bond
- covalent compound
- hydrogen bond
- nonpolar
- polar

Introduction

Covalent bonds are bonds in which atoms share rather than transfer electrons. Compounds with covalent bonds are called covalent compounds.

Formation of Covalent Bonds

A **covalent bond** is the force of attraction that holds together two atoms that share a pair of electrons. The shared electrons are attracted to the nuclei of both atoms. Covalent bonds form only between atoms of nonmetals. The two atoms may be the same or different elements. If the bonds form between atoms of different elements, a covalent compound forms. Covalent compounds are described in detail later in the lesson. To see a video about covalent bonding, go to this URL: http://www.youtube.com/watch?v=-Eh_0Dseg3E (6:20).

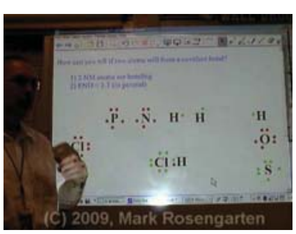

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Figure 12.7 shows an example of a covalent bond forming between two atoms of the same element, in this case two atoms of hydrogen. The two atoms share a pair of electrons. Hydrogen normally occurs in two-atom, or diatomic, molecules like this (*di-* means "two"). Several other elements also normally occur as diatomic molecules: nitrogen, oxygen, and all but one of the halogens (fluorine, chlorine, bromine, and iodine).

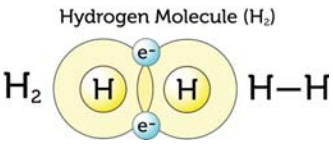

FIGURE 12.7

This figure shows three ways of representing a covalent bond. A dash (-) between two atoms represents one pair of shared electrons.

Why Covalent Bonds Form

Covalent bonds form because they give atoms a more stable arrangement of electrons. Look at the hydrogen atoms in **Figure** 12.7. Alone, each hydrogen atom has just one electron. By sharing electrons with another hydrogen atom, it has two electrons: its own and the one in the other hydrogen atom. The shared electrons are attracted to both hydrogen nuclei. This force of attraction holds the two atoms together as a molecule of hydrogen.

Some atoms need to share more than one pair of electrons to have a full outer energy level. For example, an oxygen atom has six valence electrons. It needs two more electrons to fill its outer energy level. Therefore, it must form two covalent bonds. This can happen in many different ways. One way is shown in **Figure** 12.8. The oxygen atom in the figure has covalent bonds with two hydrogen atoms. This forms the covalent compound water.

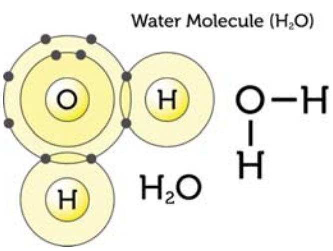

FIGURE 12.8

An oxygen atom has a more stable arrangement of electrons when it forms covalent bonds with two hydrogen atoms.

Polar and Nonpolar Covalent Bonds

In some covalent bonds, electrons are not shared equally between the two atoms. These are called **polar** bonds. **Figure** 12.9 shows this for water. The oxygen atom attracts the shared electrons more strongly because its nucleus has more positively charged protons. As a result, the oxygen atom becomes slightly negative in charge. The hydrogen atoms attract the electrons less strongly. They become slightly positive in charge. For another example of polar bonds, see the video at this URL: http://www.youtube.com/watch?v=1lnjg81daBs (0:52).

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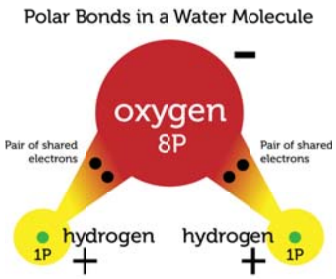


FIGURE 12.9
A water molecule has two polar bonds.

In other covalent bonds, electrons are shared equally. These bonds are called **nonpolar** bonds. Neither atom attracts the shared electrons more strongly. As a result, the atoms remain neutral. **Figure** 12.10 shows an example of nonpolar bonds.

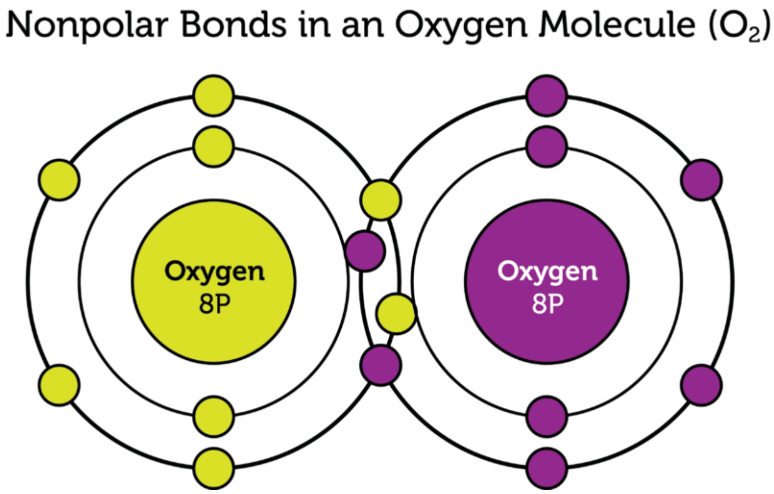


FIGURE 12.10
An oxygen molecule has two nonpolar bonds. This is called a double bond. The two oxygen atoms attract equally the four shared electrons.

Covalent Compounds

Covalent bonds between atoms of different elements form **covalent compounds**. The smallest, simplest covalent compounds have molecules with just two atoms. An example is hydrogen chloride (HCl). It consists of one hydrogen atom and one chlorine atom. The largest, most complex covalent molecules have thousands of atoms. Examples include proteins and carbohydrates. These are compounds in living things.

Helpful Hints

Naming Covalent Compounds Follow these rules in naming simple covalent compounds:

- The element closer to the left of the periodic table is named first.
- The second element gets the suffix *–ide*.
- Prefixes such as *di-* (2) and *tri-* (3) show the number of each atom in the compound. These are written with subscripts in the chemical formula.

Example: The gas that consists of one carbon atom and two oxygen atoms is named carbon dioxide. Its chemical formula is CO_2.

You Try It!

Problem: What is the name of the compound that contains three oxygen atoms and two nitrogen atoms? What is its chemical formula?

Properties of Covalent Compounds

Covalent compounds have different properties than ionic compounds because of their bonds. Covalent compounds exist as individual molecules rather than crystals. It takes less energy for individual molecules than ions in a crystal to pull apart. As a result, covalent compounds have lower melting and boiling points than ionic compounds. Many are gases or liquids at room temperature. Covalent compounds have shared electrons. These are not free to move like the transferred electrons of ionic compounds. This makes covalent compounds poor conductors of electricity. Many covalent compounds also do not dissolve in water as all ionic compounds do.

Polar and Nonpolar Covalent Compounds

Having polar bonds may make a covalent compound polar. A polar compound is one in which there is a slight difference in charge between opposite ends of the molecule. All polar compounds contain polar bonds. But having polar bonds does not necessarily result in a polar compound. It depends on how the atoms are arranged. This is illustrated in **Figure** 12.11. Both molecules in the figure contain polar bonds, but only formaldehyde is a polar compound. Why is carbon dioxide nonpolar?

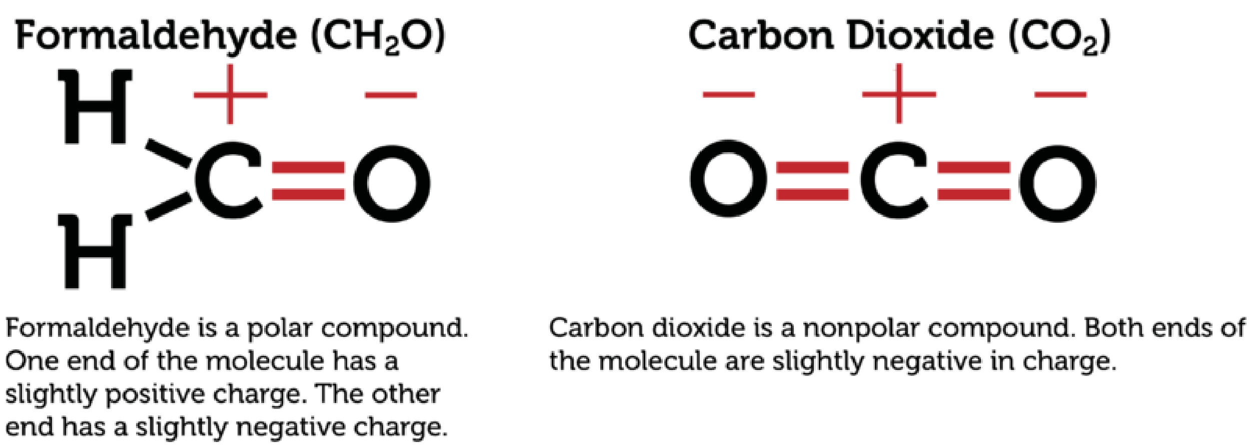
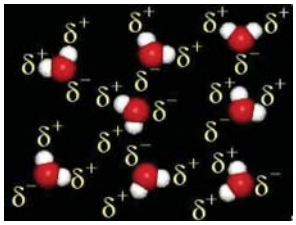


FIGURE 12.11

Covalent compounds may be polar or nonpolar, as these two examples show. In both molecules, the oxygen atoms attract electrons more strongly than the carbon or hydrogen atoms do.

The molecules of polar compounds are attracted to each other. You can see this in **Figure** 12.27 for water. A bond forms between the positive hydrogen end of one water molecule and the negative oxygen end of another water molecule. This type of bond is called a **hydrogen bond**. Hydrogen bonds are weak, but they still must be overcome when a polar substance changes from a solid to a liquid or from a liquid to a gas. As a result, polar covalent compounds may have higher melting and boiling points than nonpolar covalent compounds. To learn more about hydrogen bonding and when it occurs, see the video at this URL: http://www.youtube.com/watch?v=lkl5cbfqFRM&feature=related (0:58).



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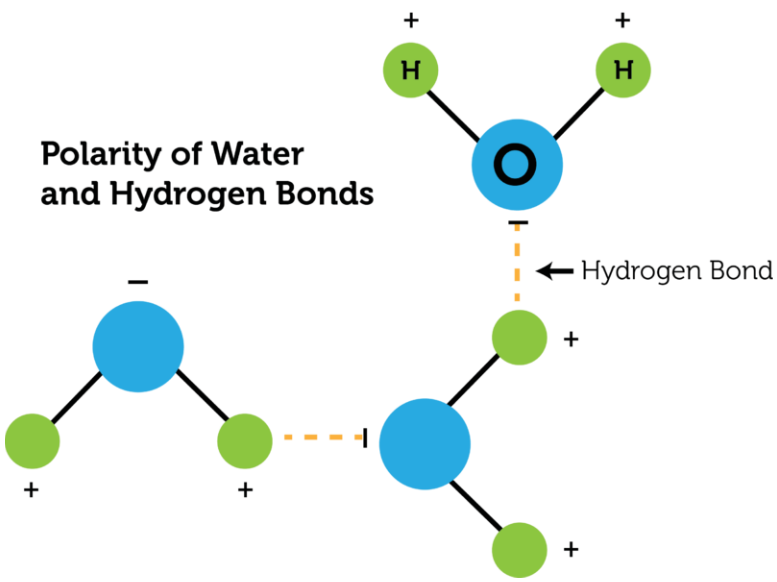


FIGURE 12.12
Water is a polar compound, so its molecules are attracted to each other and form hydrogen bonds.

Lesson Summary

- A covalent bond is the force of attraction that holds together two atoms that share a pair of electrons. It forms between atoms of the same or different nonmetals. In polar covalent bonds, one atom attracts the shared electrons more strongly and becomes slightly negative. The other atom becomes slightly positive.
- Covalent compounds form individual molecules rather than crystals. Compared with ionic compounds, they have low melting and boiling points. They are also poor conductors of electricity. In polar covalent compounds, oppositely charged ends of different molecules attract each other. This affects the properties of polar compounds.

Lesson Review Questions

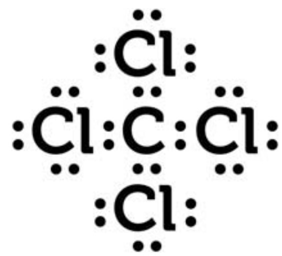
Recall

1. What is a covalent bond?
2. What is the difference between a polar and nonpolar covalent bond?

3. List general properties of covalent compounds.

Apply Concepts

4. The electron dot diagram below represents a covalent compound. Do you think it is a polar or nonpolar compound? Explain.



Think Critically

5. Explain why covalent bonds form.

Points to Consider

You read in this lesson that covalent bonds may form between atoms of the same nonmetal element. For example, hydrogen atoms (H) commonly form covalent bonds to form hydrogen molecules (H_2).

- Do you think bonds may also form between atoms of the same metallic element?
- Predict what these metallic bonds might be like.

12.4 Properties of Carbon

Lesson Objectives

- Explain how carbon forms bonds.
- Define monomer and polymer.
- Describe forms of carbon.

Lesson Vocabulary

- monomer
- polymer

Introduction

Carbon is a very common "ingredient" of matter. The reason? Carbon can combine with itself and with many other elements to form a great diversity of compounds. The compounds can also range in size from just a few atoms to thousands. There are millions of known carbon compounds. Carbon is the only element that can form so many different compounds. You can find a good introduction to carbon and its chemistry at these URLs:

- http://www.youtube.com/watch?v=HJnlNpMStbs
- http://www.youtube.com/watch?v=Kjn5Ht0Vn30&feature=related (9:27)

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Valence Electrons and Bonding in Carbon

Carbon is a nonmetal in group 14 of the periodic table. Like other group 14 compounds, carbon has four valence electrons. Valence electrons are the electrons in the outer energy level of an atom that are involved in chemical bonds. The valence electrons of carbon are shown in **Figure** 12.13.

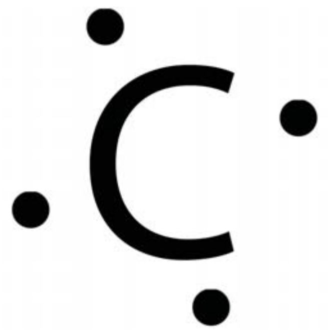

FIGURE 12.13
The dots in this diagram represent the four valence electrons of carbon.

Carbon Bonding

Because it has four valence electrons, carbon needs four more electrons to fill its outer energy level. It can achieve this by forming four covalent bonds. Covalent bonds are chemical bonds that form between nonmetals. In a covalent bond, two atoms share a pair of electrons. By forming four covalent bonds, carbon shares four pairs of electrons, thus filling its outer energy level.

A carbon atom can form bonds with other carbon atoms or with the atoms of other elements. Carbon often forms bonds with hydrogen. You can see an example in **Figure** 12.14. The compound represented in the figure is methane (CH_4). The carbon atom in a methane molecule forms bonds with four hydrogen atoms. The diagram on the left shows all the shared electrons. The diagram on the right represents each pair of shared electrons with a dash (–). This type of diagram is called a structural formula.

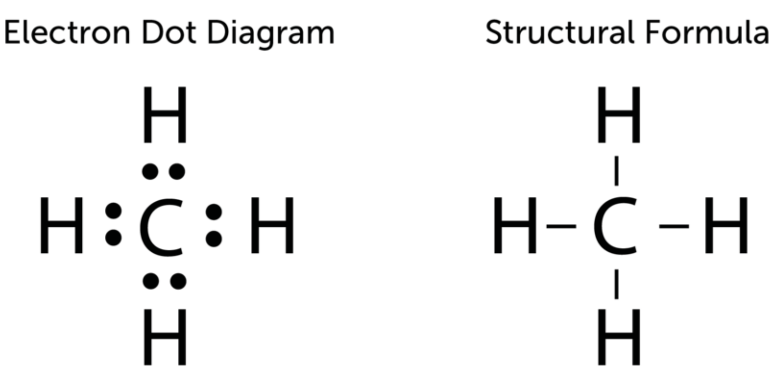

FIGURE 12.14
Methane is one of the simplest carbon compounds. At room temperature, it exists as a gas. It is a component of natural gas. These diagrams show two ways of representing the covalent bonds in methane.

How Many Bonds?

Carbon can form single, double, or even triple bonds with other carbon atoms. In a single bond, two carbon atoms share one pair of electrons. In a double bond, they share two pairs of electrons, and in a triple bond they share three pairs of electrons. Examples of compounds with these types of bonds are shown in **Figure** 12.15.

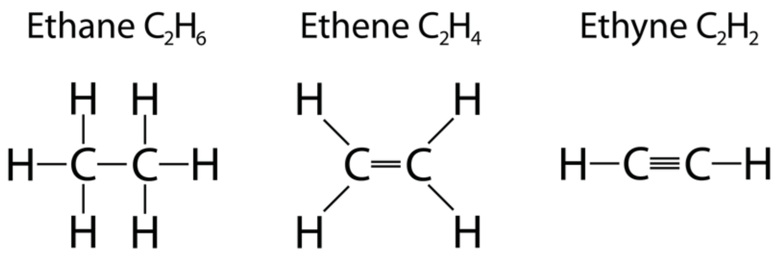

FIGURE 12.15
Carbon atoms can form single, double, or triple bonds with each other. How many bonds do the carbon atoms share in each compound shown here?

Monomers and Polymers of Carbon

Because of carbon's ability to form so many covalent bonds, it often forms polymers. A **polymer** is a large molecule that consists of many smaller molecules joined together by covalent bonds. The smaller molecules are called **monomers**. (The prefix *mono*means "one," and the prefix *poly* means "many.") Polymers may consist of just one type of monomer or of more than one type. Polymers are a little like the strings of beads in **Figure** 12.16. What do the individual beads represent?

FIGURE 12.16
A string of beads serves as a simple model of a polymer. Like monomers making up a polymer, the beads in a string may be all the same or different from one another.

Many polymers occur naturally. You will read about natural polymers in this chapter's "Hydrocarbons" and "Carbon and Living Things" lessons. Other polymers are synthetic. This means that they are produced in labs or factories. Synthetic polymers are created in synthesis reactions in which monomers bond together to form much larger compounds. Plastics are examples of synthetic polymers. The plastic items in **Figure** 12.17 are all made of polythene (also called polyethylene). It consists of repeating monomers of ethene (C_2H_4). To learn more about polymers and how they form, go to this URL: http://www.youtube.com/watch?v=7nCfbZwGWK8 (2:13).

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FIGURE 12.17

Many common products are made of the plastic known as polyethylene.

Forms of Carbon

Pure carbon can exist in different forms, depending on how its atoms are arranged. The forms include diamond, graphite, and fullerenes. All three forms exist as crystals, but they have different structures. Their different structures, in turn, give them different properties. You can learn more about them in **Table** 12.3.

TABLE 12.3: Carbon atoms can be arranged in any of these three ways. How does the arrangement of atoms affect the properties of the substances formed?

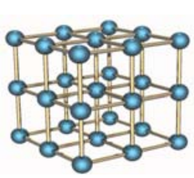
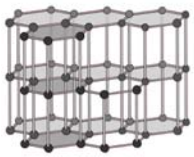
Structure	Description	
 Diamond crystal	**Diamond** Diamond is a form of carbon in which each carbon atom is bonded to four other carbon atoms. This forms a strong, rigid, three-dimensional structure. Diamond is the hardest natural substance. It is used for cutting and grinding tools as well as for rings and other pieces of jewelry.	 This metal cutter has a diamond blade.

TABLE 12.3: (continued)

Structure	Description	
	**Graphite** Graphite is a form of carbon in which carbon atoms are arranged in layers. Bonds are strong between carbon atoms within each layer but relatively weak between atoms in different layers. The weak bonds between layers allow the layers to slide over one another. This makes graphite relatively soft and slippery. It is used as a lubricant. It also makes up the "lead" in pencils.	
	**Fullerene** A fullerene (also called a bucky-ball) is a form of carbon in which carbon atoms are arranged in hollow spheres. Each carbon atom is bonded to three others by single covalent bonds. The pattern of atoms resembles the pattern on the surface of a soccer ball. Fullerenes were first discovered in 1985. They have been found in soot and meteorites. Possible commercial uses of fullerenes are under investigation. To learn how this form of carbon got its funny names, go to this URL: http://www.universetoday.com/83106/fullerene/ .	

Lesson Summary

- Carbon is a nonmetal with four valence electrons. Each carbon atom forms four covalent bonds. Atoms of carbon can bond with each other or with atoms of other elements. The bonds may be single, double, or triple bonds.
- Because of carbon's ability to form so many covalent bonds, it often forms polymers. A polymer is a large molecule that consists of many smaller molecules, called monomers.
- Pure carbon can form different types of crystals. Crystalline forms of carbon include diamond, graphite, and fullerenes.

Lesson Review Questions

Recall

1. Describe the type of bonds that carbon forms.
2. How many bonds does a single carbon atom form?
3. What are polymers and monomers?
4. Name three forms of pure carbon. How do they differ?

Apply Concepts

5. A certain compound consists of two carbon atoms and two hydrogen atoms. Each carbon atom is bonded with one hydrogen atom and also with the other carbon atom. How many bonds do the two carbon atoms share? Draw the structural formula for this compound.

Think Critically

6. Explain why carbon is a component of most compounds.
7. Relate the properties of graphite and diamond to the arrangement of their atoms.

Points to Consider

The carbon compounds represented in **Figure** 12.14 and **Figure** 12.15 contain only carbon and hydrogen. You will read more about this type of carbon compound in the next lesson, "Hydrocarbons."

- What might be some general properties of compounds that consist only of carbon and hydrogen? (*Hint*: What is methane used for?)
- Do you know other examples of this type of compound?

12.5 Carbon and Living Things

Lesson Objectives

- Give an overview of biochemical compounds.
- Identify the structure and functions of carbohydrates.
- Describe protein structure, and list functions of proteins.
- Outline the structure and functions of lipids.
- Identify the structure of nucleic acids and their functions.

Lesson Vocabulary

- biochemical compound
- carbohydrate
- lipid
- nucleic acid
- protein

Introduction

Carbon is the most important element in living things. Carbon-based compounds in living things are generally called biochemical compounds. The prefix *bio* comes from the Greek word that means "life." Many of the same biochemical compounds are found in all forms of life, despite life's great diversity.

Biochemical Compounds

A **biochemical compound** is any carbon-based compound found in living things. Like hydrocarbons, all biochemical compounds contain hydrogen as well as carbon. However, biochemical compounds also contain other elements, such as oxygen and nitrogen. Almost all biochemical compounds are polymers. They consist of many, smaller monomer molecules. Biochemical polymers are referred to as macromolecules. The prefix *macro* means "large," and many biochemical molecules are very large indeed. They may contain thousands of monomer molecules.

Biochemical compounds make up the cells and tissues of organisms. They are also involved in life processes, such as making and using food for energy. Given their diversity of functions, it's not surprising that there are millions of different biochemical compounds. However, they can be grouped into just four main classes: carbohydrates, proteins, lipids, and nucleic acids. The classes are summarized in **Table** 12.4 and described in the rest of this lesson.

TABLE 12.4:

Class	Elements	Examples	Functions
Carbohydrates	carbon hydrogen oxygen	sugars starches cellulose	provide energy to cells store energy in plants makes up the cell walls of plants
Proteins	carbon hydrogen oxygen nitrogen sulfur	enzymes hormones	speed up biochemical reactions regulate life processes
Lipids	carbon hydrogen oxygen	fats oils	store energy in animals store energy in plants
Nucleic acids	carbon hydrogen oxygen nitrogen phosphorus	DNA RNA	stores genetic information in cells helps cells make proteins

Carbohydrates

Carbohydrates are biochemical compounds that include sugars, starches, and cellulose. They contain oxygen in addition to carbon and hydrogen. Organisms use carbohydrates mainly for energy.

Sugars

Sugars are simple carbohydrates. Molecules of sugar have just a few carbon atoms. The simplest sugar is glucose ($C_6H_{12}O_6$). Glucose is the sugar that the cells of living things use for energy. Plants and some other organisms make glucose in the process of photosynthesis. Living things that cannot make glucose obtain it by consuming plants or these other organisms.

You can see the structural formula of glucose and two other sugars in **Figure** 12.18. The other sugars in the figure are fructose and sucrose. Fructose is an isomer of glucose. It is found in fruits. It has the same atoms as glucose, but they are arranged differently. Sucrose is table sugar. It consists of one molecule of glucose and one molecule of fructose.

Starches

Starches are complex carbohydrates. They are polymers of glucose. They consist of hundreds of glucose monomers bonded together. Plants make starch to store extra sugars. Consumers get starch from plants. Common sources of starch in the human diet are pictured in **Figure** 12.19. Our digestive system breaks down starch to simple sugars, which our cells use for energy.

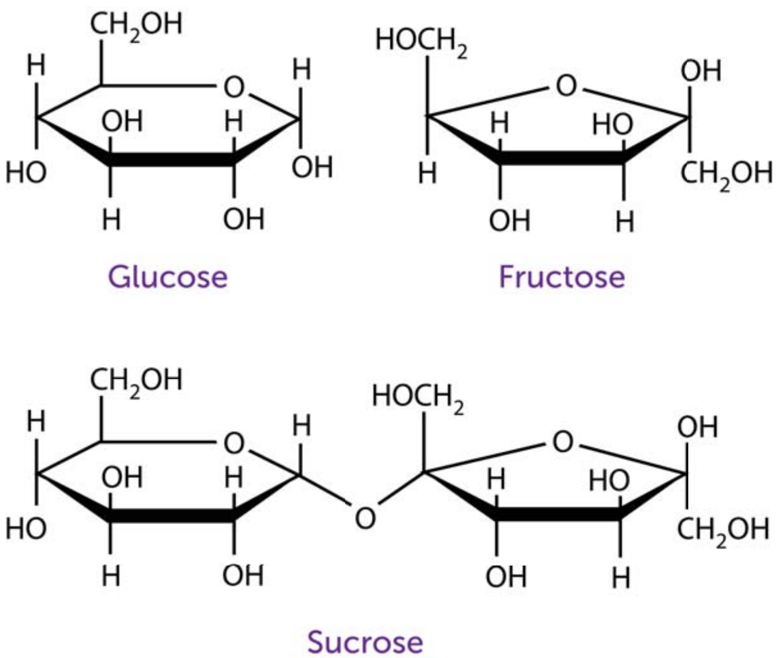


FIGURE 12.18
Glucose and fructose are isomers. Sucrose contains a molecule of each.

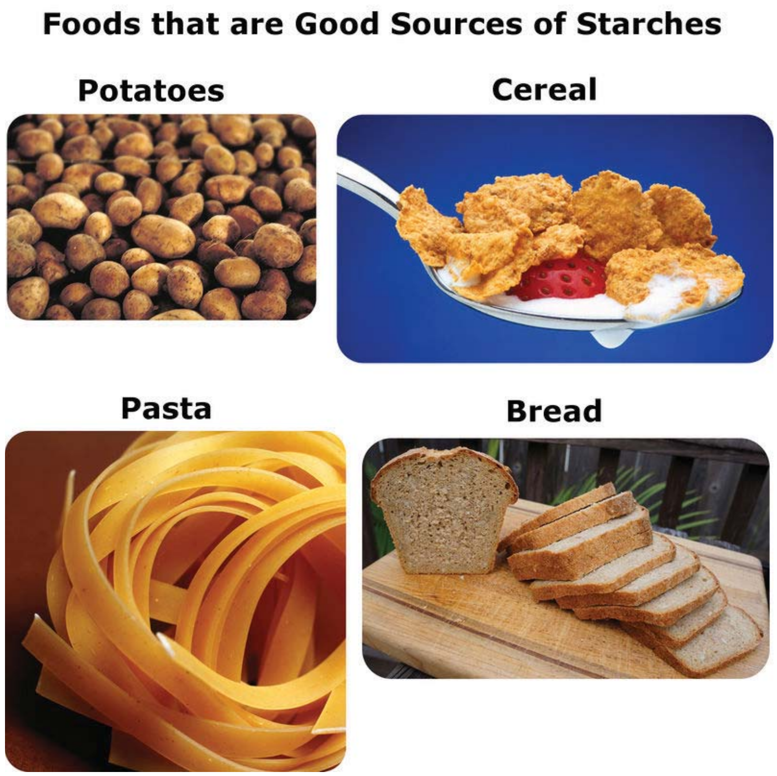


FIGURE 12.19
These foods are all good sources of starch.

Cellulose

Cellulose is another complex carbohydrate that is a polymer of glucose. However, the glucose molecules are bonded together differently in cellulose than they are in starches. Cellulose molecules bundle together to form long, tough fibers (see **Figure** 12.20). Have you ever eaten raw celery? If you have, then you probably noticed that the stalks contain long, stringy fibers. The fibers are mostly cellulose.

Cellulose is the most abundant biochemical compound. It makes up the cell walls of plants and gives support to trunks and stems. Cellulose also provides needed fiber in the human diet. We can't digest cellulose, but it helps keep food wastes moving through the digestive tract.

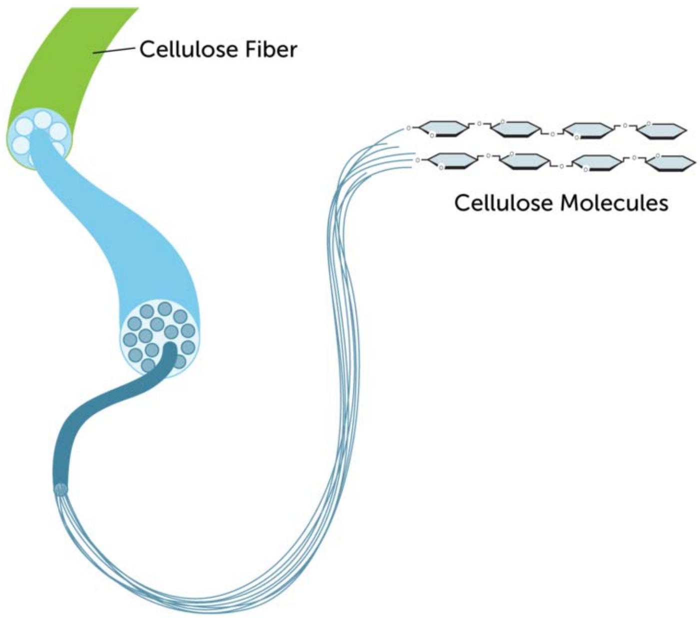


FIGURE 12.20
Cellulose molecules form large cellulose fibers.

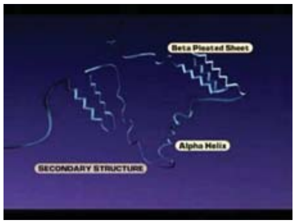
Proteins

Proteins are biochemical compounds that contain oxygen, nitrogen, and sulfur in addition to carbon and hydrogen. Protein molecules consist of one or more chains of small molecules called amino acids.

Protein Structure

Amino acids are the "building blocks" of proteins. There are 20 different common amino acids. The structural formula of the simplest amino acid, called glycine, is shown in **Figure** 12.21. Other amino acids have a similar structure. The sequence of amino acids and the number of amino acid chains in a protein determine the protein's shape. The shape of a protein, in turn, determines its function. Shapes may be very complex. You can learn more about the structure of proteins at the URL below.

http://www.youtube.com/watch?v=lijQ3a8yUYQ (0:52)



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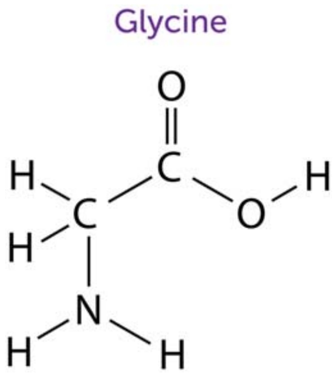


FIGURE 12.21

Glycine is one of 20 common amino acids that make up the proteins of living things.

Protein Functions

Proteins are the most common biochemicals. They have many different functions, including:

- making up tissues as components of muscle.
- speeding up biochemical reactions as enzymes.
- regulating life processes as hormones.
- helping defend against infections as antibodies.
- transporting materials as components of the blood (see the example in **Figure** 12.22).

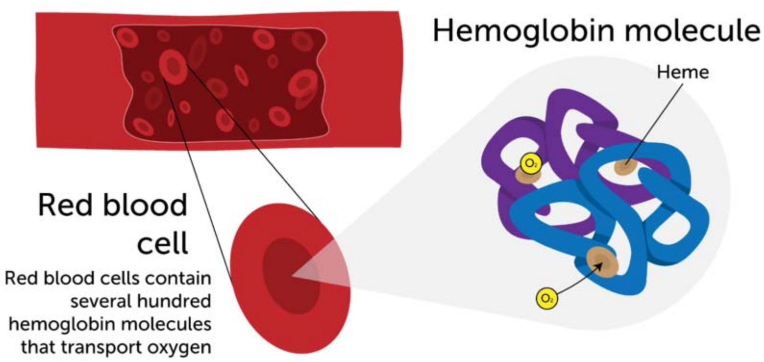


FIGURE 12.22

The blood protein hemoglobin binds with oxygen and carries it from the lungs to cells throughout the body. Heme is a small molecule containing iron that is part of the larger hemoglobin molecule. Oxygen binds to the iron in heme.

Lipids

Lipids are biochemical compounds such as fats and oils. Organisms use lipids to store energy. In addition to carbon and hydrogen, lipids contain oxygen.

Fatty Acids

Lipids are made up of long carbon chains called fatty acids. Like hydrocarbons, fatty acids may be saturated or unsaturated. **Figure** 12.23 shows structural formulas for two small fatty acids. One is saturated and one is unsaturated.

- In saturated fatty acids, there are only single bonds between carbon atoms. As a result, the carbons are saturated with hydrogen atoms. Saturated fatty acids are found in fats. Fats are solid lipids that animals use to store energy.
- In unsaturated fatty acids, there is at least one double bond between carbon atoms. As a result, some carbons are not bonded to as many hydrogen atoms as possible. Unsaturated fatty acids are found in oils. Oils are liquid lipids that plants use to store energy.

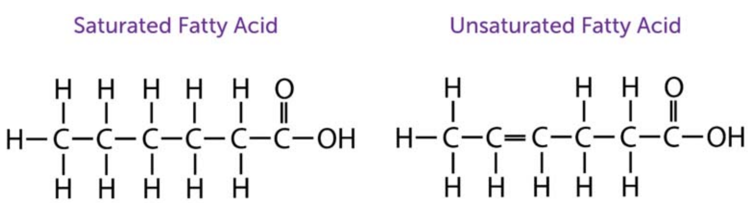


FIGURE 12.23
Both of these fatty acid molecules have six carbon atoms and two oxygen atoms. How many hydrogen atoms does each fatty acid have?

Phospholipids

Some lipids contain the element phosphorus as well as oxygen, carbon, and hydrogen. These lipids are called phospholipids. Two layers of phospholipid molecules make up most of the cell membrane in the cells of living things.

Figure 12.24 shows how phospholipid molecules are arranged in a cell membrane. One end (the head) of each phospholipid molecule is polar and attracts water. This end is called hydrophilic ("water loving"). The other end (the tail) is nonpolar and repels water. This end is called hydrophobic ("water hating"). The nonpolar tails are on the inside of the membrane. The polar heads are on the outside of the membrane. These differences in polarity allow some molecules to pass through the membrane while keeping others out. You can see how this works in the video at the URL below.

http://www.beyondbooks.com/lif71/4b.asp

Nucleic Acids

Nucleic acids are biochemical molecules that contain oxygen, nitrogen, and phosphorus in addition to carbon and hydrogen. There are two main types of nucleic acids. They are DNA (deoxyribonucleic acid) and RNA (ribonucleic acid).

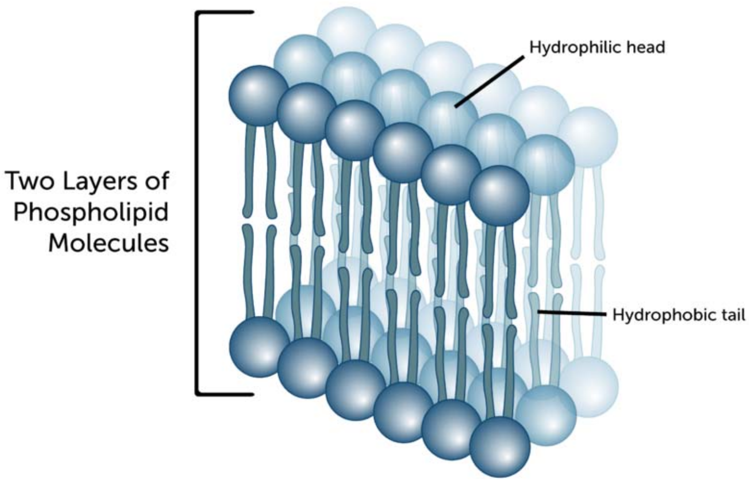


FIGURE 12.24
The arrangement of phospholipid molecules in a cell membrane allows the membrane to control what enters and leaves the cell.

Structure of Nucleic Acids

Nucleic acids consist of chains of small molecules called nucleotides. The structure of a nucleotide is shown in **Figure** 12.25. Each nucleotide contains a phosphate group (PO_4), a sugar ($C_5H_8O_4$) in DNA, and a nitrogen-containing base. (A base is a compound that is not neither acidic nor neutral.) There are four different nitrogenous bases in DNA. They are adenine, thymine, guanine, and cytosine. In RNA, the only difference is that thymine is replaced with a different base, uracil.

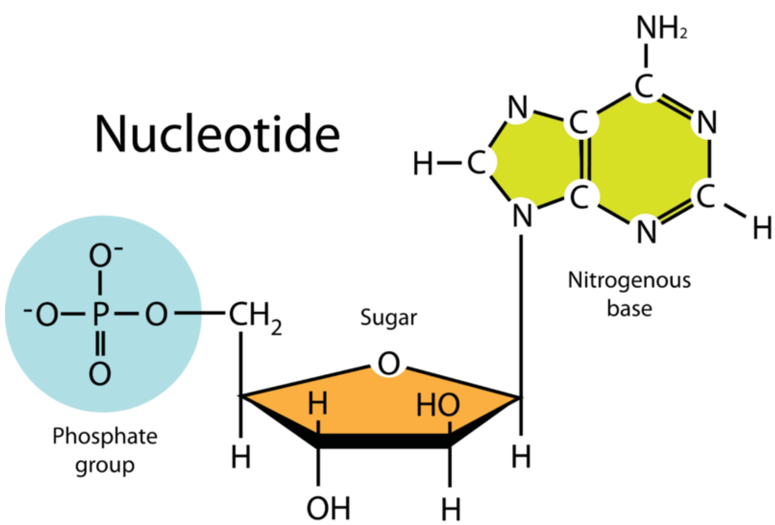


FIGURE 12.25
Each nucleotide contains these three components.

DNA consists of two long chains of nucleotides. Nitrogen bases on the two chains form hydrogen bonds with each other. Adenine always bonds with thymine, and guanine always bonds with cytosine. These bonds hold the two chains together and give DNA is characteristic double helix, or spiral, shape. You can see the shape of the DNA molecule in **Figure** 12.26. Sugars and phosphate groups form the "backbone" of each chain of DNA. The bonded bases are called base pairs. RNA, in contrast to DNA, consists of just one chain of nucleotides. Determining the structure of DNA was a big scientific breakthrough. You can read the interesting story of its discovery at the URL below.

http://nobelprize.org/educational/medicine/dna_double_helix/readmore.html

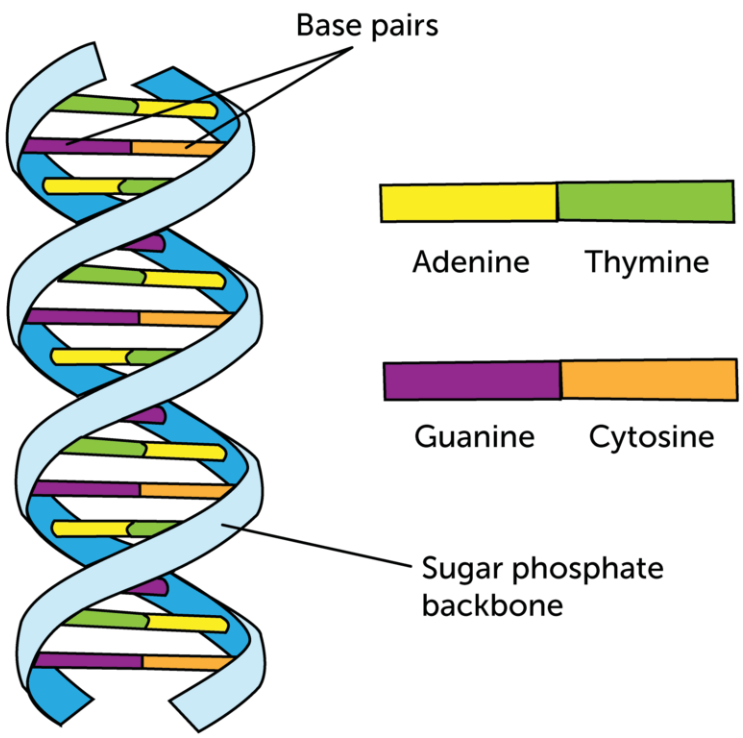


FIGURE 12.26
DNA has the shape of a double helix because of hydrogen bonds between nitrogen bases.

Functions of Nucleic Acids

DNA stores genetic information in the cells of all living things. It contains the genetic code. This is the code that instructs cells how to make proteins. The instructions are encoded in the sequence of nitrogen bases in the nucleotide chains of DNA. RNA "reads" the genetic code in DNA and is involved in the synthesis of proteins based on the code. This video shows how: http://www.youtube.com/watch?v=NJxobgkPEAo&feature=related (2:51).

MEDIA
Click image to the left for more content.

Lesson Summary

- A biochemical compound is any carbon-based compound found in living things. Most biochemical compounds are polymers that contain oxygen, nitrogen, or other elements in addition to carbon and hydrogen.

- Carbohydrates are biochemical compounds that include sugars, starches, and cellulose. Their functions include providing or storing energy and making up plant cell walls.
- Proteins are biochemical compounds that consist of one or more chains of amino acids. Proteins have many different functions. For example, some are enzymes, and some are hormones.
- Lipids are biochemical compounds such as fats and oils. They consist of fatty acids, which may saturated or unsaturated. Lipids are used to store energy. They also make up cell membranes.
- Nucleic acids are biochemical compounds that include DNA and RNA. They consist of chains of smaller molecules called nucleotides. DNA stores the genetic code for proteins. RNA helps make proteins.

Lesson Review Questions

Recall

1. Name the four classes of biochemical compounds.
2. What are sugars and starches? How are they used?
3. Describe the structure of proteins. List three functions of proteins.
4. Describe the structure of nucleic acids. What components are found in each nucleotide?

Apply Concepts

5. A mystery biochemical compound contains only carbon, hydrogen, and oxygen. It is made by both plants and animals. In which class of biochemical compounds should it be placed?

Think Critically

6. Use structural formulas to illustrate the difference between fatty acids in oils and fatty acids in fats.
7. Explain the relationship between DNA and RNA.

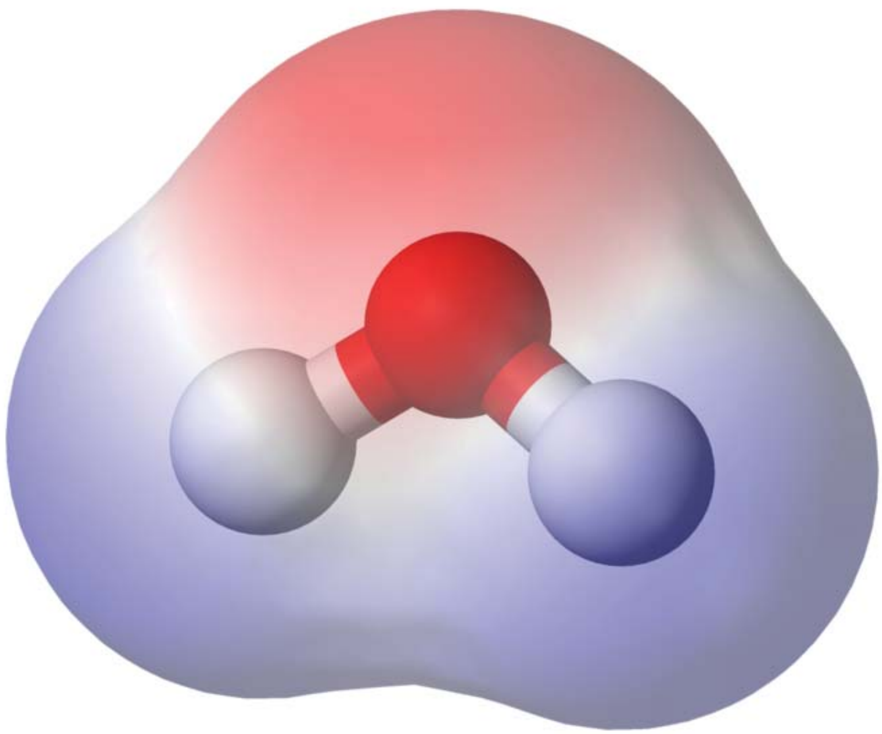
Points to Consider

Biochemical compounds are involved in almost all life processes. One of the most important life processes is photosynthesis.

- What is photosynthesis?
- Why is photosynthesis so important to living things?

12.6 Hydrogen Bonding

- Describe hydrogen bonds and explain why they form.
- Relate hydrogen bonding to melting and boiling points of compounds.



The colorful red and blue model in the opening image represents a water molecule. The molecule's one oxygen atom is colored red, and its two hydrogen atoms are colored blue. Can you guess why? The red color represents negative electric charge, and the blue color represents positive electric charge. The colors show that water is a polar compound.

What Are Polar Compounds?

Polar compounds, such as water, are compounds that have a partial negative charge on one side of each molecule and a partial positive charge on the other side. All polar compounds contain polar bonds (although not all compounds that contain polar bonds are polar.) In a polar bond, two atoms share electrons unequally. One atom attracts the shared electrons more strongly, so it has a partial negative charge. The other atom attracts the shared electrons less strongly, so it is has a partial positive charge. In a water molecule, the oxygen atom attracts the shared electrons more strongly than the hydrogen atoms do. This explains why the oxygen side of the water molecule has a partial negative charge and the hydrogen side of the molecule has a partial positive charge.

Q: If a molecule is polar, how might this affect its interactions with nearby molecules of the same compound?

A: Opposite charges on different molecules of the same compound might cause the molecules to be attracted to each other.

Hydrogen Bonding

Because of water's polarity, individual water molecules are attracted to one another. You can see this in the **Figure** 12.27. The positively charged hydrogen side of one water molecule is attracted to the negatively charged oxygen side of a nearby water molecule. This force of attraction is called a **hydrogen bond**. You can watch hydrogen bonds forming between water molecules in the animation at this URL: http://www.northland.cc.mn.us/biology/biology1111/animations/hydrogenbonds.html .

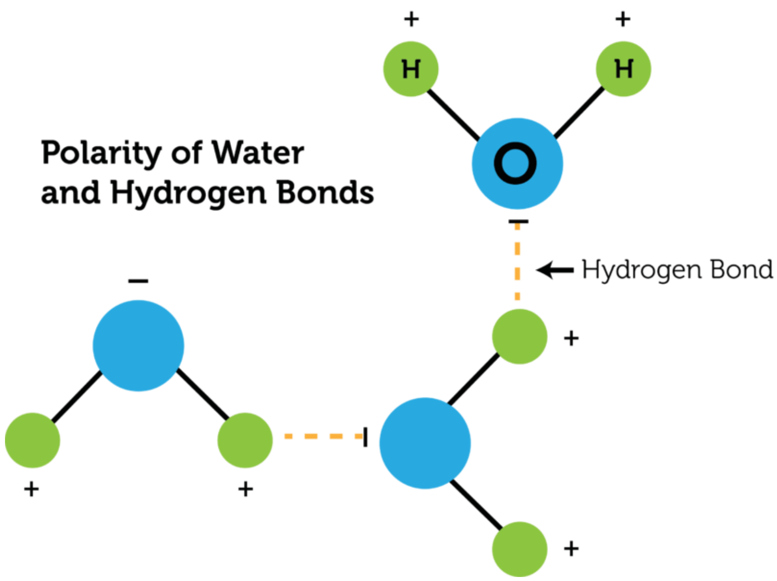
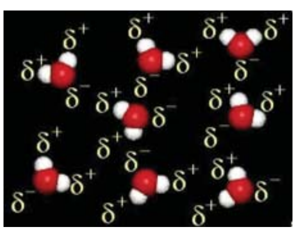


FIGURE 12.27

Hydrogen bonds are intermolecular ("between-molecule") bonds, rather than intramolecular ("within-molecule") bonds. They occur not only in water but in other polar molecules in which positive hydrogen atoms are attracted to negative atoms in nearby molecules. Hydrogen bonds are relatively weak as chemical bonds go. For example, they are much weaker than the bonds holding atoms together within molecules of covalent compounds. To learn more about hydrogen bonding and when it occurs, see the video at this URL:

http://www.youtube.com/watch?v=lkl5cbfqFRM&feature=related



MEDIA

Click image to the left for more content.

Hydrogen Bonds and Changes of State

Changes of state from solid to liquid and from liquid to gas occur when matter gains energy. The energy allows individual molecules to separate and move apart from one another. It takes more energy to bring about these changes of state for polar molecules. Although hydrogen bonds are weak, they add to the energy needed for molecules to move apart from one another, so it takes higher temperatures for these changes of state to occur in polar compounds. This explains why polar compounds have relatively high melting and boiling points. The **Table** 12.5 compares melting and boiling points for some polar and nonpolar covalent compounds.

TABLE 12.5: title

Name of Compound (Chemical Formula)	Polar or Nonpolar?	Melting Point(°C)	Boiling Point (°C)
Methane (CH_4)	nonpolar	-182	-162
Ethylene (C_2H_2)	nonpolar	-169	-104
Ammonia (NH_3)	polar	-78	-33
Water (H_2O)	polar	0	100

Q: Which compound in the table above do you think is more polar, ammonia or water?

A: Water is more polar than ammonia. Its strong polarity explains why its melting and boiling points are high even for a polar covalent compound.

Summary

- Polar covalent compounds have molecules with a partial negative charge on one side and a partial positive charge on the other side. This occurs because the compounds contain polar bonds. In a polar bond, one atom attracts the shared electrons more strongly than the other atom does.
- In some polar molecules that contain hydrogen atoms, the partial positive charge of the hydrogen atoms of one molecule are attracted to the partial negative charge of an atom of a nearby molecule. This force of attraction is called a hydrogen bond.
- Hydrogen bonds are relatively weak, but they add to the energy needed for molecules to move apart from each other when matter changes state from a solid to a liquid or from a liquid to a gas. This explains why polar covalent compounds have relatively high melting and boiling points.

Vocabulary

- **hydrogen bond**: Weak bond that forms between a slightly positive hydrogen atom in one molecule and a slightly negative atom in another molecule.

Practice

Watch the video about hydrogen bonds at the following URL, and then answer the questions below.

http://www.brightstorm.com/science/biology/chemical-basis-of-life/hydrogen-bonds/

1. What is electronegativity?
2. In water molecules, why do shared electrons spend more time orbiting the oxygen atom than the hydrogen atoms?
3. Hydrogen forms hydrogen bonds with oxygen. What is another element besides oxygen that may be involved in hydrogen bonds?
4. Water has the properties of cohesion and adhesion. Define these two properties, and explain why they occur in water.
5. Why are hydrogen bonds extremely important in biology?

Review

1. What are polar covalent compounds?
2. Define hydrogen bond.

3. Explain why hydrogen bonds increase melting and boiling points of polar covalent compounds such as water.

12.7 References

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