2.1 Matter and Organic Compounds

Lesson Objectives

- Define elements and compounds.
- Explain why carbon is essential to life on Earth.
- Describe the structure and function of the four major types of organic compounds.

Vocabulary

amino acid small molecule that is a building block of proteins

carbohydrate organic compound such as sugar or starch

chemical bond force that holds molecules together

chemical reaction process that changes some chemical substances into others

complementary base pair pair of nucleotide bases that bond together—either adenine and thymine (or uracil) or cytosine and guanine

compound substance with a unique, fixed composition that consists of two or more elements

DNA double-stranded nucleic acid that makes up genes and chromosomes

double helix double spiral shape of the DNA molecule

element pure substance that cannot be broken down into other types of substances

lipid organic compound such as fat or oil

matter anything that takes up space and has mass

monosaccharide simple sugar such as glucose that is a building block of carbohydrates

nucleic acid organic compound such as DNA or RNA

nucleotide small molecule containing a sugar, phosphate group, and base that is a building block of nucleic acids

organic compound compound found in living things that contains mainly carbon

polynucleotide chain of nucleotides that alone or with another such chain makes up a nucleic acid

polypeptide chain of amino acids that alone or with other such chains makes up a protein

polysaccharide chain of monosaccharides that makes up a complex carbohydrate such as starch

protein organic compound made up of amino acids

RNA single-stranded nucleic acid that helps make proteins

saturated fatty acid molecule in lipids in which carbon atoms are bonded to as many hydrogen atoms as possible

unsaturated fatty acid molecule in lipids in which some carbon atoms are bonded to other groups of atoms rather than to hydrogen atoms

Introduction

If you look at your hand, what do you see? Of course, you see skin, which consists of cells. But what are skin cells made of? Like all living cells, they are made of matter. In fact, all things are made of matter. **Matter** is anything that takes up space and has mass. Matter, in turn, is made up of chemical substances. In this lesson you will learn about the chemical substances that make up living things.

Chemical Substances

A chemical substance is matter that has a definite composition. It also has the same composition throughout. A chemical substance may be either an element or a compound.

Elements

An **element** is a pure substance. It cannot be broken down into other types of substances. Each element is made up of just one type of atom. An atom is the smallest particle of an element that still has the properties of that element.

There are almost 120 known elements. As you can see from **Figure** 2.1, the majority of elements are metals. Examples of metals are iron (Fe) and copper (Cu). Metals are shiny and good conductors of electricity and heat. Nonmetal elements are far fewer in number. They include hydrogen (H) and oxygen (O). They lack the properties of metals.

Compounds

A **compound** is a substance that consists of two or more elements. A compound has a unique composition that is always the same. The smallest particle of a compound is called a molecule. Consider water as an example. A molecule of water always contains one atom of oxygen and two atoms of hydrogen. The composition of water is expressed by the chemical formula H_2O. A model of a water molecule is shown in **Figure** 2.2.

What causes the atoms of a water molecule to "stick" together? The answer is chemical bonds. A **chemical bond** is a force that holds molecules together. Chemical bonds form when substances react with one another. A **chemical reaction** is a process that changes some chemical substances into others. A chemical reaction is needed to form a compound. Another chemical reaction is needed to separate the substances in a compound.

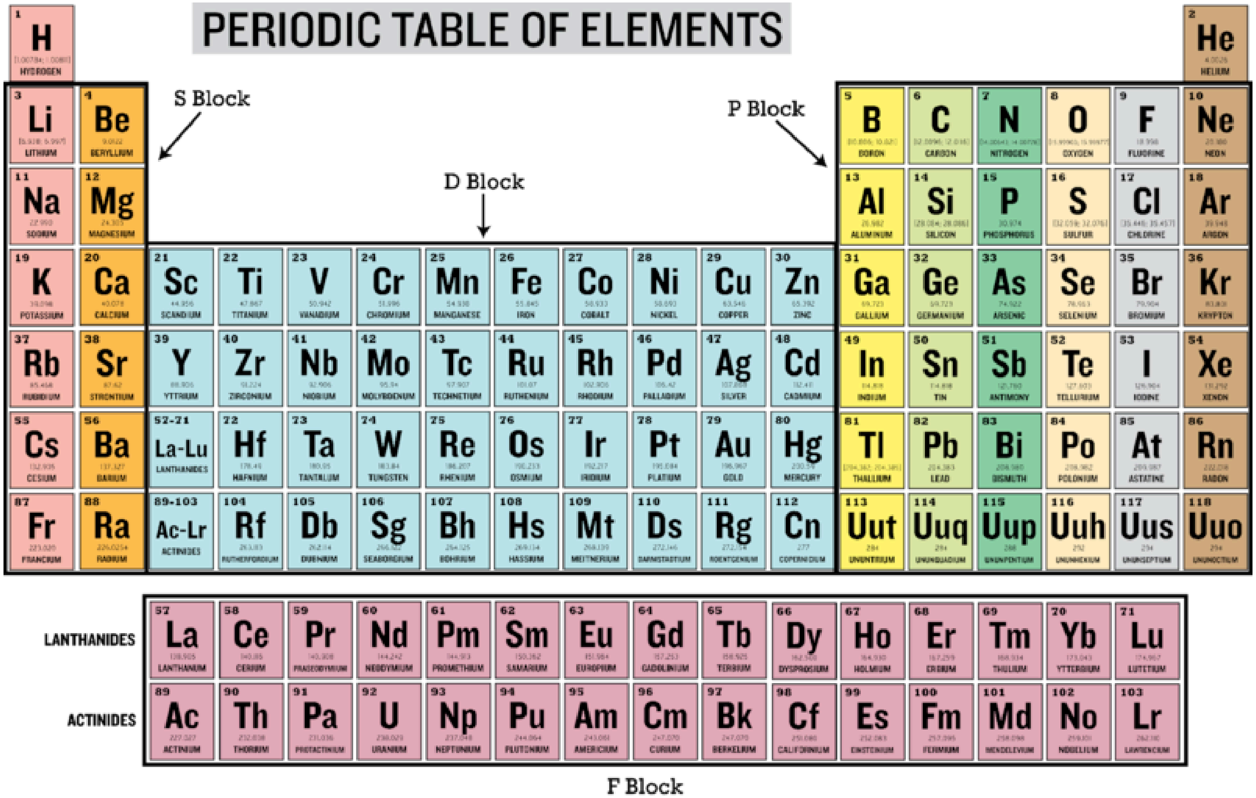


FIGURE 2.1

Periodic Table of the Elements. The Periodic Table of the Elements arranges elements in groups based on their properties. The element most important to life is carbon (C). Find carbon in the table. What type of element is it, metal or nonmetal?

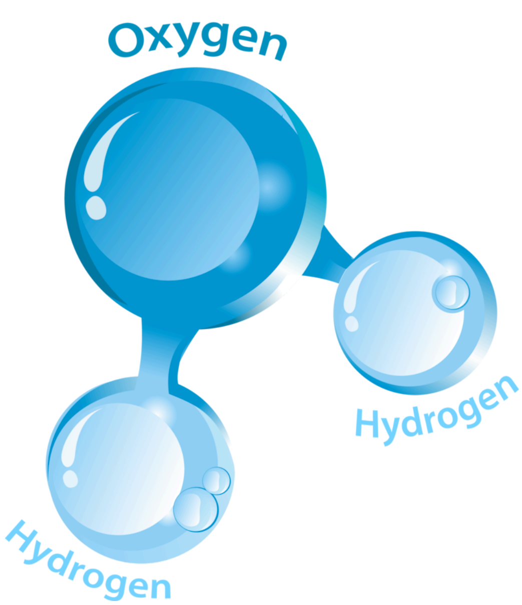


FIGURE 2.2

Water Molecule. A water molecule always has this composition, one atom of oxygen and two atoms of hydrogen.

The Significance of Carbon

A compound found mainly in living things is known as an **organic compound**. Organic compounds make up the cells and other structures of organisms and carry out life processes. Carbon is the main element in organic compounds, so carbon is essential to life on Earth. Without carbon, life as we know it could not exist. Why is carbon so basic to life? The reason is carbon's ability to form stable bonds with many elements, including itself. This property allows carbon to form a huge variety of very large and complex molecules. In fact, there are nearly 10 million carbon-based compounds in living things! However, the millions of organic compounds can be grouped into just four major types: carbohydrates, lipids, proteins, and nucleic acids. You can compare the four types in **Table** 2.1. Each type is also described below.

TABLE 2.1: Types of Organic Compounds

Type of Compound	Examples	Elements	Functions
Carbohydrates	sugars, starches	carbon, hydrogen, oxygen	provides energy to cells, stores energy, forms body structures
Lipids	fats, oils	carbon, hydrogen, oxygen	stores energy, forms cell membranes, carries messages
Proteins	enzymes, antibodies	carbon, hydrogen, oxygen, nitrogen, sulfur	helps cells keep their shape, makes up muscles, speeds up chemical reactions, carries messages and materials
Nucleic Acids	DNA, RNA	carbon, hydrogen, oxygen, nitrogen, phosphorus	contains instructions for proteins, passes instructions from parents to offspring, helps make proteins

The Miracle of Life: Carbohydrates, Proteins, Lipids & Nucleic Acids video can be viewed at http://www.youtube.com/watch?v=nMevuu0Hxuc (3:28).

KQED: Energy From Carbon?

It may look like waste, but to some people it's green power. Find out how California dairy farms and white tablecloth restaurants are taking their leftover waste and transforming it into clean energy. See *From Waste To Watts: Biofuel Bonanza* at http://www.kqed.org/quest/television/from-waste-to-watts-biofuel-bonanza for further information.

Carbohydrates

Carbohydrates are the most common type of organic compound. A **carbohydrate** is an organic compound such as sugar or starch, and is used to store energy. Like most organic compounds, carbohydrates are built of small, repeating units that form bonds with each other to make a larger molecule. In the case of carbohydrates, the small repeating units are called monosaccharides.

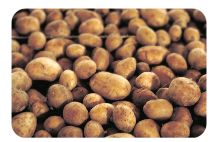
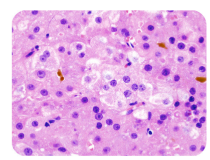
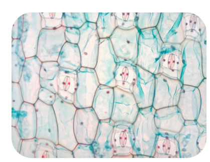
Monosaccharides

A **monosaccharide** is a simple sugar such as fructose or glucose. Fructose is found in fruits, whereas glucose generally results from the digestion of other carbohydrates. Glucose is used for energy by the cells of most organisms.

Polysaccharides

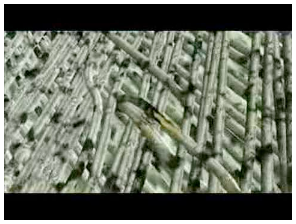
A **polysaccharide** is a complex carbohydrate that forms when simple sugars bind together in a chain. Polysaccharides may contain just a few simple sugars or thousands of them. Complex carbohydrates have two main functions: storing energy and forming structures of living things. Some examples of complex carbohydrates and their functions are shown in **Table** 2.2. Which type of complex carbohydrate does your own body use to store energy?

TABLE 2.2: Complex Carbohydrates

Name	Function	Example
Starch	Used by plants to store energy.	A potato stores starch in underground tubers. 
Glycogen	Used by animals to store energy.	A human being stores glycogen in liver cells. 
Cellulose	Used by plants to form rigid walls around cells.	Plants use cellulose for their cell walls. 
Chitin	Used by some animals to form an external skeleton.	A housefly uses chitin for its exoskeleton. 

KQED: Biofuels: From Sugar to Energy

For years there's been buzz – both positive and negative – about generating ethanol fuel from corn. But thanks to recent developments, the Bay Area of California is rapidly becoming a world center for the next generation of green fuel alternatives. The Joint BioEnergy Institute is developing methods to isolate biofeuls from the sugars in cellulose. See *Biofuels: Beyond Ethanol* at http://www.kqed.org/quest/television/biofuels-beyond-ethanol for further information.



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Lipids

A **lipid** is an organic compound such as fat or oil. Organisms use lipids to store energy, but lipids have other important roles as well. Lipids consist of repeating units called fatty acids. There are two types of fatty acids: saturated fatty acids and unsaturated fatty acids.

Saturated Fatty Acids

In **saturated fatty acids**, carbon atoms are bonded to as many hydrogen atoms as possible. This causes the molecules to form straight chains, as shown in **Figure** 2.3. The straight chains can be packed together very tightly, allowing them to store energy in a compact form. This explains why saturated fatty acids are solids at room temperature. Animals use saturated fatty acids to store energy.

Unsaturated Fatty Acids

In **unsaturated fatty acids**, some carbon atoms are not bonded to as many hydrogen atoms as possible. Instead, they are bonded to other groups of atoms. Wherever carbon binds with these other groups of atoms, it causes chains to bend (see **Figure** 2.3). The bent chains cannot be packed together very tightly, so unsaturated fatty acids are liquids at room temperature. Plants use unsaturated fatty acids to store energy. Some examples are shown in **Figure** 2.4.

Types of Lipids

Lipids may consist of fatty acids alone, or they may contain other molecules as well. For example, some lipids contain alcohol or phosphate groups. They include

a. triglycerides: the main form of stored energy in animals
b. phospholipids: the major components of cell membranes
c. steroids: serve as chemical messengers and have other roles

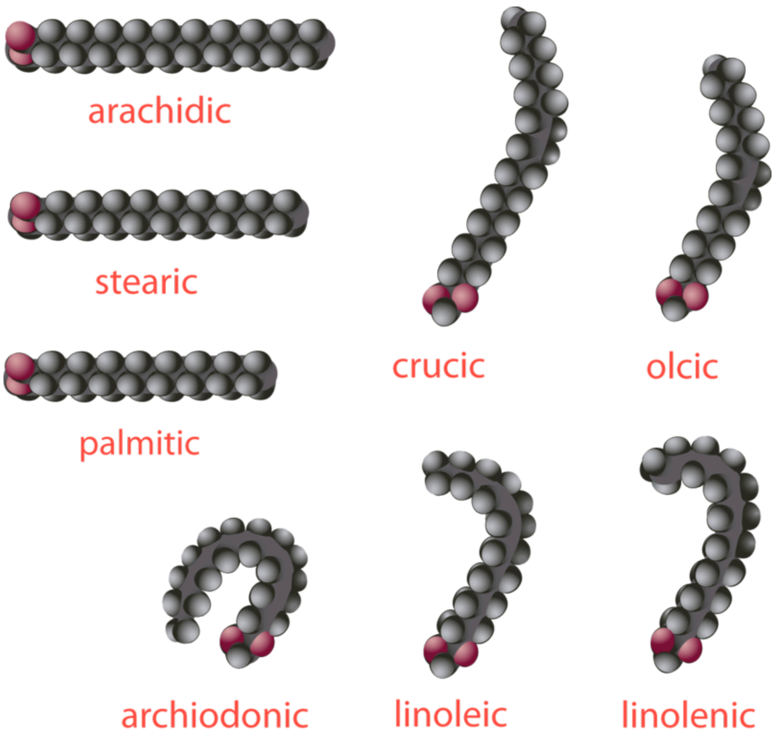

FIGURE 2.3
Fatty Acids. Saturated fatty acids have straight chains, like the three fatty acids shown on the left. Unsaturated fatty acids have bent chains, like all the other fatty acids in the figure.

FIGURE 2.4
These plant products all contain unsaturated fatty acids.

Proteins

A **protein** is an organic compound made up of small molecules called **amino acids**. There are 20 different amino acids commonly found in the proteins of living things. Small proteins may contain just a few hundred amino acids, whereas large proteins may contain thousands of amino acids.

Protein Structure

When amino acids bind together, they form a long chain called a **polypeptide**. A protein consists of one or more polypeptide chains. A protein may have up to four levels of structure. The lowest level, a protein's primary structure, is its sequence of amino acids. Higher levels of protein structure are described in **Figure** 2.5. The complex structures of different proteins give them unique properties, which they need to carry out their various jobs in living organisms. You can learn more about protein structure by watching the animation at the link below. http://www.stolaf.edu/people/giannini/flashanimat/proteins/protein%20structure.swf

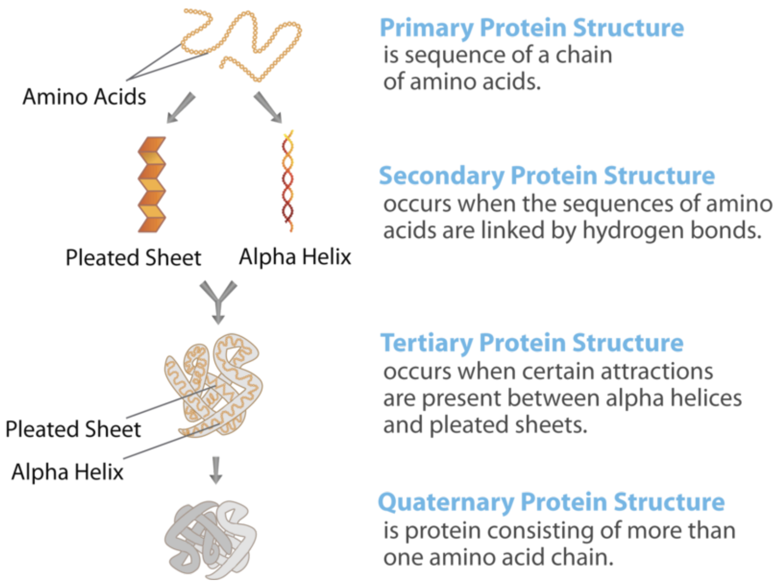

FIGURE 2.5

Protein Structure. The structure of a protein starts with its sequence of amino acids. What determines the secondary structure of a protein? What are two types of secondary protein structure?

Functions of Proteins

Proteins play many important roles in living things. Some proteins help cells keep their shape, and some make up muscle tissues. Many proteins speed up chemical reactions in cells. Other proteins are antibodies, which bind to foreign substances such as bacteria and target them for destruction. Still other proteins carry messages or materials. For example, human red blood cells contain a protein called hemoglobin, which binds with oxygen. Hemoglobin allows the blood to carry oxygen from the lungs to cells throughout the body. A model of the hemoglobin molecule is shown in **Figure** 2.6.

A short video describing protein function can be viewed at http://www.youtube.com/watch?v=T500B5yTy58#38;feature=related (4:02).

Nucleic Acids

A **nucleic acid** is an organic compound, such as DNA or RNA, that is built of small units called **nucleotides**. Many nucleotides bind together to form a chain called a **polynucleotide**. The nucleic acid **DNA** (deoxyribonucleic acid) consists of two polynucleotide chains. The nucleic acid **RNA** (ribonucleic acid) consists of just one polynucleotide chain.

An overview of DNA can be seen at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/4/_-vZ_

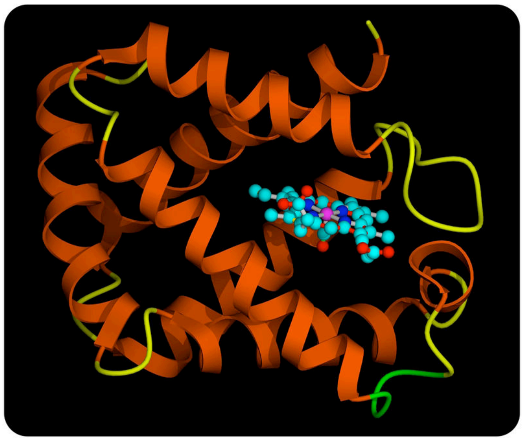

FIGURE 2.6
Hemoglobin Molecule. This model represents the protein hemoglobin. The red parts of the molecule contain iron. The iron binds with oxygen molecules.

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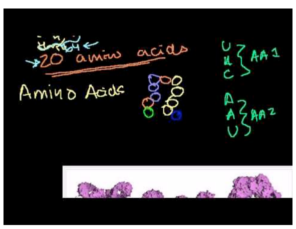

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Structure of Nucleic Acids

Each nucleotide consists of three smaller molecules:

a. sugar
b. phosphate group
c. nitrogen base

If you look at **Figure** 2.7, you will see that the sugar of one nucleotide binds to the phosphate group of the next nucleotide. These two molecules alternate to form the backbone of the nucleotide chain. The nitrogen bases in a nucleic acid stick out from the backbone. There are four different types of bases: cytosine, adenine, guanine, and either thymine (in DNA) or uracil (in RNA). In DNA, bonds form between bases on the two nucleotide chains and hold the chains together. Each type of base binds with just one other type of base: cytosine always binds with guanine, and adenine always binds with thymine. These pairs of bases are called **complementary base pairs**.

The binding of complementary bases allows DNA molecules to take their well-known shape, called a **double helix**, which is shown in **Figure** 2.8. A double helix is like a spiral staircase. The double helix shape forms naturally and is very strong, making the two polynucleotide chains difficult to break apart. The structure of DNA will be further discussed in the chapter *Molecular Genetics: From DNA to Proteins*.

An animation of DNA structure can be viewed at http://www.youtube.com/watch?v=qy8dk5iS1f0#38;feature=related.

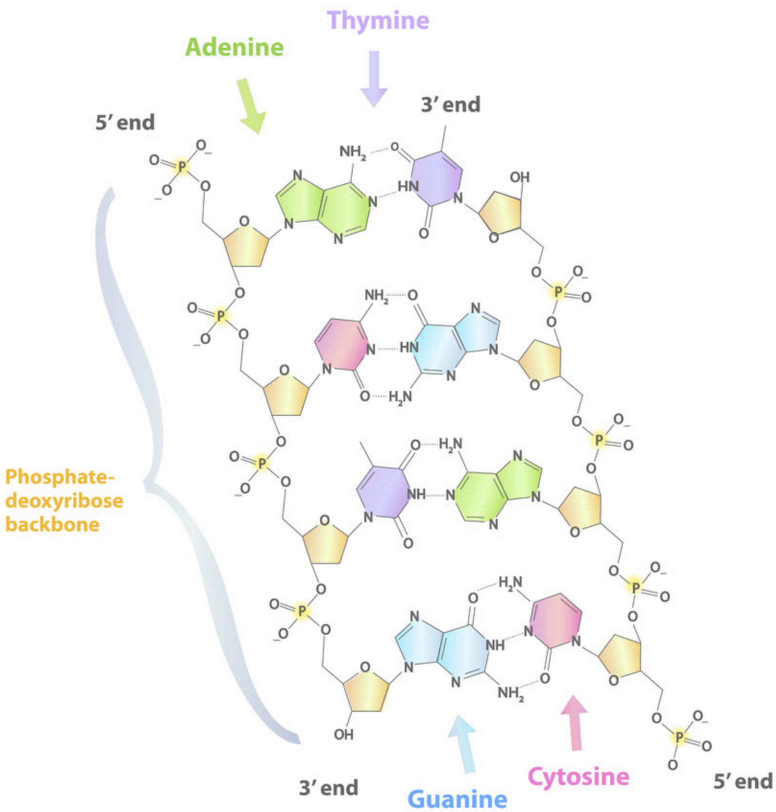

FIGURE 2.7
Nucleic Acid. Sugars and phosphate groups form the backbone of a polynucleotide chain. Hydrogen bonds between complementary bases hold two polynucleotide chains together.

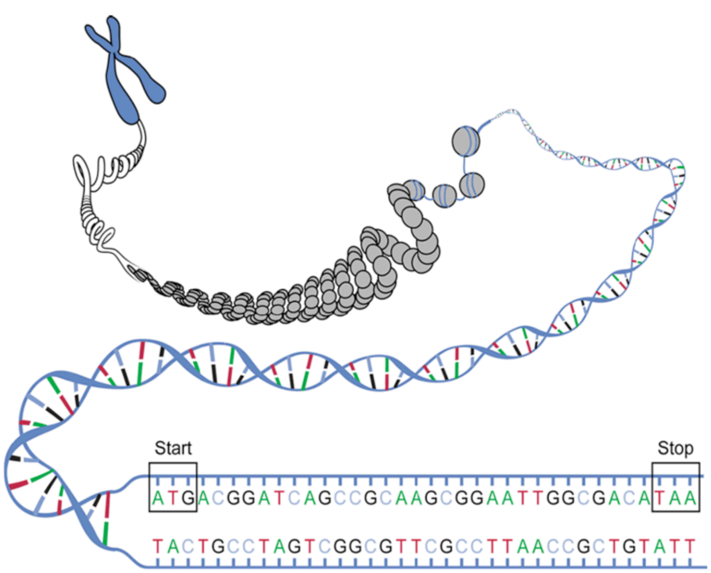

FIGURE 2.8
DNA Molecule. Bonds between complementary bases help form the double helix of a DNA molecule. The letters A, T, G, and C stand for the bases adenine, thymine, guanine, and cytosine. The sequence of these four bases in DNA is a code that carries instructions for making proteins. The start and stop codons are shown; these will be discussed in the Molecular Genetics: From DNA to Proteins chapter.

Roles of Nucleic Acids

DNA is found in genes, and its sequence of bases makes up a code. Between "starts" and "stops," the code carries instructions for the correct sequence of amino acids in a protein (see **Figure** 2.8). RNA uses the information in DNA to assemble the correct amino acids and help make the protein. The information in DNA is passed from parent cells to daughter cells whenever cells divide. The information in DNA is also passed from parents to offspring when organisms reproduce. This is how inherited characteristics are passed from one generation to the next.

Lesson Summary

- Living things consist of matter, which can be an element or a compound. A compound consists of two or more elements and forms as a result of a chemical reaction.
- Carbon's unique ability to form chemical bonds allows it to form millions of different large, organic compounds. These compounds make up living things and carry out life processes.
- Carbohydrates are organic compounds such as sugars and starches. They provide energy and form structures such as cell walls.
- Lipids are organic compounds such as fats and oils. They store energy and help form cell membranes in addition to having other functions in organisms.
- Proteins are organic compounds made up of amino acids. They form muscles, speed up chemical reactions, and perform many other cellular functions.
- Nucleic acids are organic compounds that include DNA and RNA. DNA contains genetic instructions for proteins, and RNA helps assemble the proteins.

Lesson Review Questions

Recall

1. What are elements and compounds? Give an example of each.

2. List the four major types of organic compounds.

3. What determines the primary structure of a protein?

4. State two functions of proteins.

5. Identify the three parts of a nucleotide.

Apply Concepts

6. Butter is a fat that is a solid at room temperature. What type of fatty acids does butter contain? How do you know?

7. Assume that you are trying to identify an unknown organic molecule. It contains only carbon, hydrogen, and oxygen and is found in the cell walls of a newly discovered plant species. What type of organic compound is it?

Think Critically

8. Explain why carbon is essential to all known life on Earth.

9. Compare and contrast the structures and functions of simple sugars and complex carbohydrates.

10. Explain why molecules of saturated and unsaturated fatty acids have different shapes.

Further Reading / Supplemental Links

- James D. Watson, *The Double Helix: A Personal Account of the Discovery of DNA*. Touchstone, 2001.
- The Chemistry of Biology http://www.infoplease.com/cig/biology/organic-chemistry.html

Points to Consider

Large organic compounds consist of many smaller units that are linked together in chains.

- How can the smaller units become linked together? What process do you think is involved?
- What do you think holds the smaller units together in a chain?