Chapter 3: The Chemical Basis for Life
Lesson 2: Organic Compounds

We have already learned that water is the primary substance for life on Earth, but we will now explore the element found in most of the molecules from which living organisms are made. That element is carbon and it is found in all organic compounds. The picture above is a graphic depiction of the organic compounds: carbohydrates, proteins, lipids, and nucleic acids. These are all large complex molecules that have contributed to the great diversity of life on Earth.

Lesson Objectives

- Define and explain elements and compounds; the relationships from atom to molecule to macromolecule.
- Explain why carbon is essential to life on Earth and uniquely suited to form biological macromolecules.
- Describe and compare the structure and function of the four major types of organic compounds.

Vocabulary

- atom
- biochemical conversion
- biological macromolecule
- carbohydrate
- DNA (deoxyribonucleic acid)
- isomers
- lipids
- macromolecules
- molecule
- monomer
- nucleic acid
- organic molecule
- polymer
- protein

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 that cannot be broken down into other types of substances There are almost 120 known elements, **Figure 3.9** each with its own personality. The chemical and physical properties of one element differ from any other. Elements are arranged according to their properties in the Periodic Table.

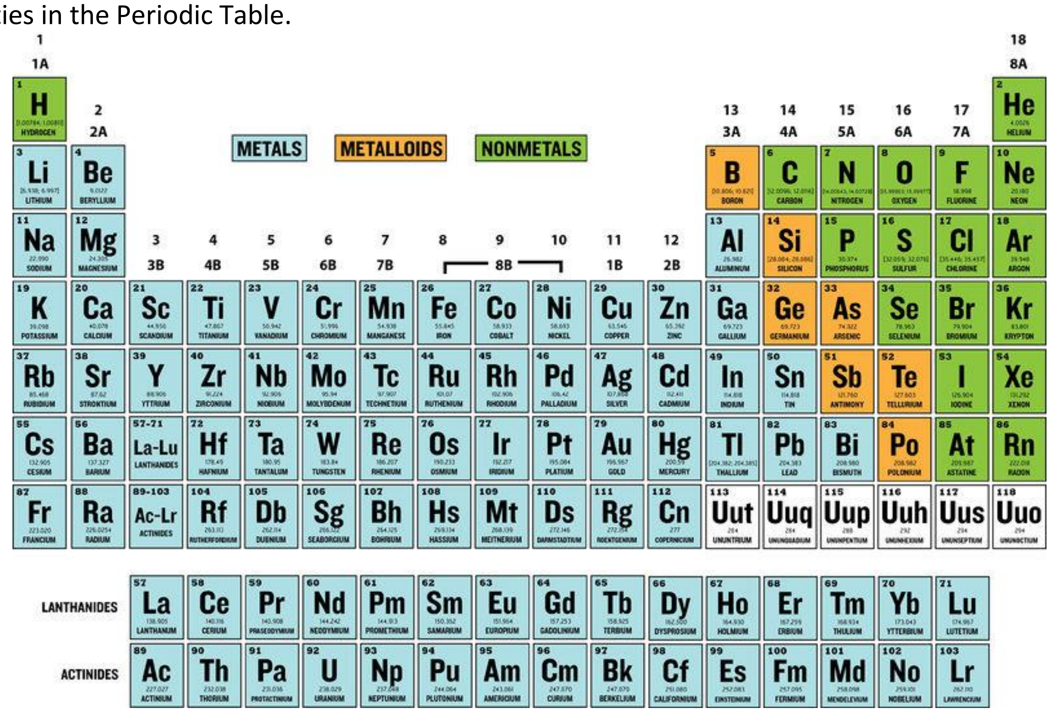


Figure 3.9: Periodic Table of the Elements. The Periodic Table of the Elements arranges elements in groups based on their properties. The element most important to life is carbon (C). Find carbon in the table. What type of element is it, metal or nonmetal?

Examples of elements include carbon, oxygen, hydrogen, gold, silver and iron. Each element is made up of just one type of atom. An atom is the smallest particle of an element that still characterizes the element. As shown in **Figure 3.10**, at the center of an atom is a nucleus. The nucleus contains positively charged particles called protons and electrically neutral particles called neutrons. Surrounding the nucleus is a much larger electron cloud consisting of negatively charged electrons. Electrons are arranged into distinct energy levels, at various distances from the nucleus. An atom is electrically neutral if it has the same number of protons as electrons. Each element has atoms with a characteristic number of protons, which defines the atomic number of the element. For example, all carbon atoms have six protons, and all oxygen atoms have eight protons. A combination of the number of protons and neutrons in the nucleus gives the approximate atomic mass of the atom, measured in an amu, or atomic mass unit.

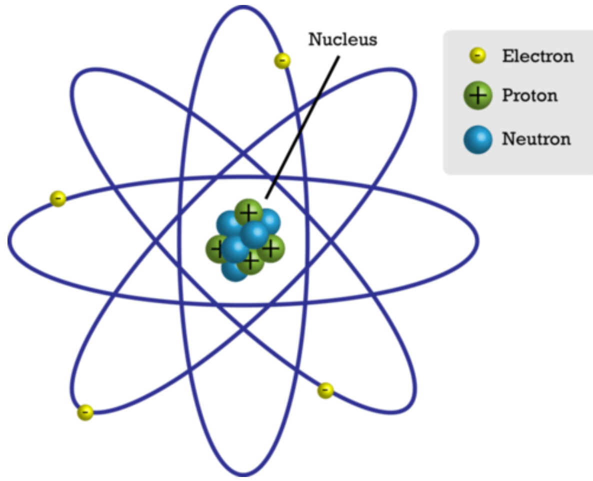


Figure 3.10 Model of an atom; protons and neutrons make up its nucleus and electrons surround the nucleus.

Chemical Compounds

A chemical compound is a new substance that forms when atoms of two or more elements react with each other. A chemical reaction is a process that changes some chemical substances into other chemical substances. A compound that results from a chemical reaction always has a unique and fixed chemical composition. The substances in a compound can be separated from one another only by another chemical reaction. An example of a chemical compound is water. An individual water molecule forms when one oxygen (O) and two hydrogen (H) atoms react and are bond. A molecule is the smallest particle of a substance that retains the chemical and physical properties of the substance and is composed of two or more atoms held together by chemical forces. Water molecules are held together by covalent bonds. Covalent bonds form between atoms that have little if any difference in electronegativity, and result when atoms share electrons. Electronegativity is the power of an atom to attract electrons toward itself**.** Like other compounds, water always has the same chemical composition: a 2:1 ratio of hydrogen atoms to oxygen atoms. This is expressed in the chemical formula H_2O. A model of a water molecule is shown in **Figure 3.11.**

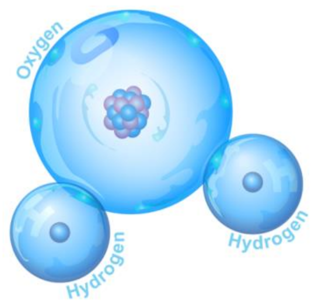


Figure 3.11 A water molecule always has this composition, one atom of oxygen and two atoms of hydrogen.

Compounds that contain mainly the elements carbon and hydrogen are called organic compounds. Organic compounds are composed of organic molecules**,** molecules containing carbon that are part of or produced by living systems. This is because they are found mainly in living organisms. Most organic compounds are held together by covalent bonds. An example of an organic compound is glucose ($C_6H_{12}O_6$), which is shown in **Figure 3.12**. Glucose is a simple sugar that living cells use for energy. All other compounds are called inorganic compounds. Water is an example of an inorganic compound.

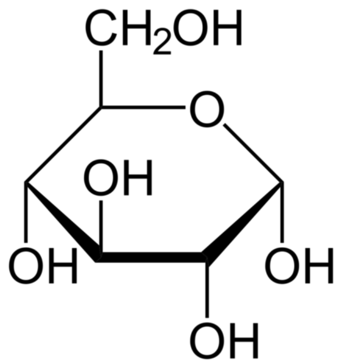
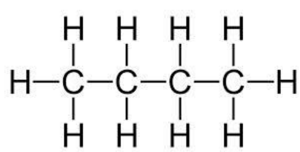


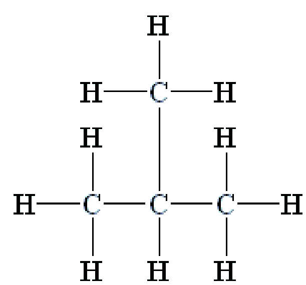
Figure 3.12 This model represents a molecule of glucose, an organic compound composed of carbon, hydrogen, and oxygen. The chemical formula for glucose is $C_6H_{12}O_6$. This means that each molecule of glucose contains six carbon atoms, twelve hydrogen atoms, and six oxygen atoms. NOTE: Each unlabeled point where lines intersect represents another carbon atom. Some of these carbons and the oxygen atom are bonded to another hydrogen atom, not shown here.

THE SIGNIFICANCE OF CARBON

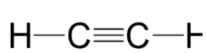
Why is carbon so important to organisms? Carbon is found in organic compounds which are found mainly in living things. Organic compounds make up the cells and other structures of organisms and carry out life processes. Carbon is the main element in organic compounds, so carbon is essential to life on Earth. Furthermore, the answer lies with carbon's unique properties. Carbon has an exceptional ability to bind with a wide variety of other elements. Carbon makes four electrons available to form covalent chemical bonds, allowing carbon atoms to form multiple stable bonds with other small atoms, including hydrogen, oxygen, and nitrogen. Carbon atoms can also form stable bonds with other carbon atoms. In fact, a carbon atom may form single, double, or even triple bonds with other carbon atoms. Carbon can also bond in a number of ways to produce molecules of different shapes, including straight chains, branched chains, and rings. The different types of carbon bonds and shapes are shown in **Figure 3. 13.** This allows carbon atoms to form a tremendous variety of very large and complex molecules.



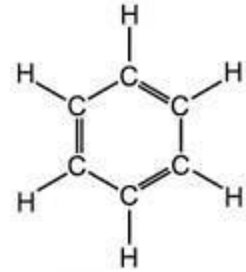
(a) Straight carbon chain, single bonds



(b) Branched carbon chain, single bonds



(c) Straight carbon chain, triple bonds



(d) Carbon ring

Figure 3.13 Carbon bonding: these structures form the backbone of many different types of organic molecules.

Organic Compounds

Carbon has the ability to form very long chains of interconnecting C-C bonds. This property allows carbon to form the backbone of organic compounds, carbon-containing compounds, which are the basis of all known organic life. Nearly 10 million carbon-containing organic compounds are known. Types of carbon compounds in organisms include carbohydrates, lipids, proteins, and nucleic acids. The elements found in each type are listed in the table below. Elements other than carbon and hydrogen usually occur within organic compounds in smaller groups of elements called functional groups. When organic compounds react with other compounds, generally just the functional groups are involved. Therefore, functional groups generally determine the nature and functions of organic compounds. You can compare these four types in **Table 3.1,** which lists the elements they contain, examples of each type, and their biological functions.

The organic molecules of carbohydrates, proteins and nucleic acids are biological macromolecules**,** as they are very large polymers made of individual monomers. A polymer is a molecule made up of repeated, linked units and a monomer is a smaller, simpler unit that makes up a polymer. Carbohydrates, lipids, proteins, and nucleic acids are all known as biological macromolecules because they are a group of biomacromolecules that interact with biological systems and their environments. The properties of all these organic molecules is related to the composition of the elements that compose the molecule. When combined with oxygen and hydrogen, carbon forms carbohydrates (sugars) and lipids (triglycerides). With nitrogen it forms alkaloids, and with the addition of sulfur in addition to the nitrogen, it forms amino acids which bind together to form proteins. With the addition of phosphorus to these other elements, carbon forms nucleotides which bond into nucleic acids (DNA and RNA).

Table 3.1 The four organic compounds, the elements they contain, examples of each type, and functions for each type of compound.

Type of Compound	**Elements It Contains**	**Examples**	**Functions**
Carbohydrates	carbon, hydrogen, oxygen	Glucose, Starch, Glycogen	provides energy to cells, stores energy, forms body structures
Lipids	carbon, hydrogen, oxygen	Cholesterol, Triglycerides (fats), Phospholipids	stores energy, forms cell membranes, carries messages
Proteins	carbon, hydrogen, oxygen, nitrogen, sulfur	Enzymes, Antibodies	helps cells keep their shape/structure, makes up muscles, catalyzes chemical reactions, carries messages and materials
Nucleic Acids	carbon, hydrogen, oxygen, nitrogen, phosphorus	Deoxyribonucleic acid (DNA), Ribonucleic acid (RNA), Adenosine Triphosphate (ATP)	contains instructions for proteins, passes instructions from parents to offspring, helps make proteins

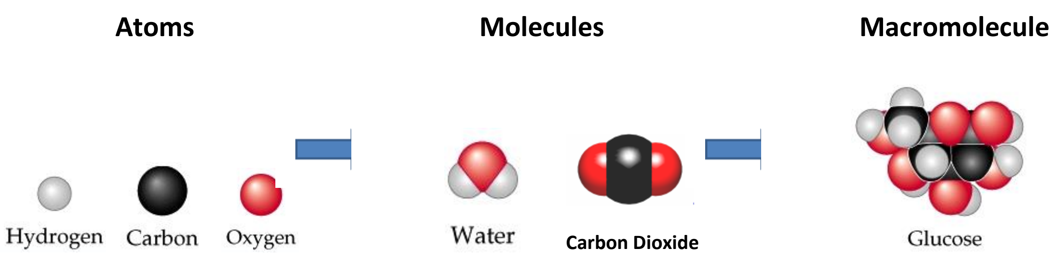
LET'S REVIEW

Atoms to Molecules to Macromolecules

Atoms are the smallest unit of an element that retains the chemical and physical properties of that element.

1. Molecules are a group of atoms that are held together by chemical forces; a molecule is the smallest unit of matter that can exist by itself and retain all of a substance's chemical properties
2. Macromolecules are polymers with a high molecular mass. Within organisms there are four main groups: carbohydrates, lipids, proteins, and nucleic acids.
3. Biological macromolecules are a group of biomacromolecules that interact with biological systems and their environments.

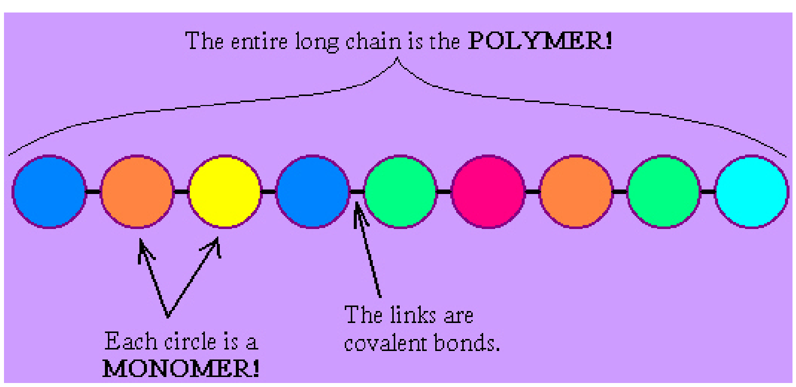
The picture below shows hydrogen, carbon, and oxygen atoms. Two hydrogen and one oxygen atom covalently bond to form a water molecule and one carbon and two oxygen atoms covalently bond to form a carbon dioxide molecule. Water molecules and carbon dioxide molecules chemically react doing photosynthesis to form a glucose macromolecule.



Monomers and Polymers

Look at the term: *monomer*
Mono- means "one."
So what does *monomer* mean?

Look at the term: *polymer*
Poly- means "many."
So what does *polymer* mean?



A *monomer* is a molecule that is able to bond in long chains.
Polymer means many *monomers*. Sometimes polymers are also known as macromolecules or large-sized molecules. Usually, polymers are organic (but not necessarily).
A polymer can be made up of thousands of monomer. This linking up of monomers is called *polymerization*.

DEHYDRATION SYNTHESIS AND HYDROLYSIS REACTIONS

Let's discuss the chemical processes by which macromolecules form polymers from their monomers and are broken down chemically from polymers to monomers. **Table 3.2** below lists the four organic compounds (polymers), their monomers, and the major type of bonds that hold them together. Two types of reactions that occur in organisms and involve water called dehydration synthesis reaction and hydrolysis reactions help to create and break down macromolecules. Dehydration synthesis reaction occurs when molecules combine to form a single, larger molecule and also a molecule of water (if some other small molecule is formed instead of water, the reaction is called by the more general term, condensation reaction). An example of a dehydration synthesis reaction is the formation of peptide bonds between amino acids in a polypeptide chain. When two amino acids bond together, a molecule of water is lost. This is shown in **Figure 3.14**

Table 3.2 The four biological macromolecules, their monomers, and the major type of bond found in each.

Polymer	Monomer	Bond
carbohydrates	monosaccharides	glycosidic
lipids	fatty acid	ester*
proteins	amino acids	peptide
nucleic acids	nucleotides	phosphodiester**

***** The ester linkage is between a glycerol molecule and fatty acid chain.
** The phosphodiester linkage is between a phosphate group and a 5-carbon sugar molecule.

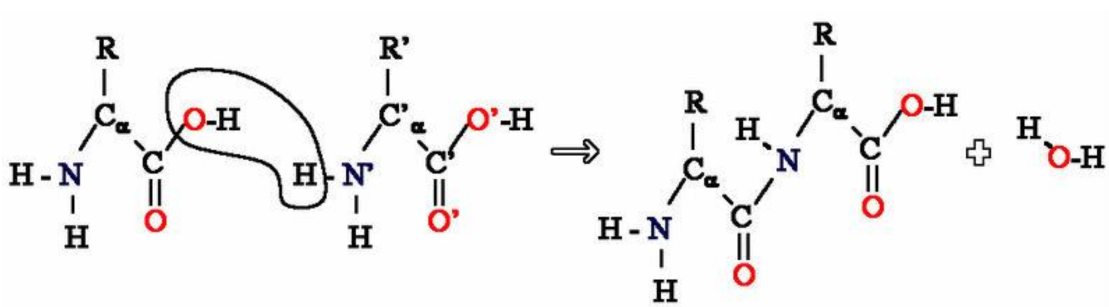


Figure 3.14 In this dehydration synthesis reaction, two amino acids form a peptide bond. A water molecule also forms.

A hydrolysis reaction is the opposite of a dehydration synthesis reaction. A hydrolysis reaction adds water to an organic molecule and breaks the large molecule into two smaller molecules, a hydration reaction. Hydrolysis reactions occur in an acidic water solution. An example of hydrolysis reaction is the breaking of peptide bonds in polypeptides, like amino acids. A hydroxide ion (OH^-) and a hydrogen ion (H^+) (both from a water molecule) bond to the carbon atoms that formed the peptide bond. This breaks the peptide bond and results in two amino acids. This is shown in **Figure 3.15**.

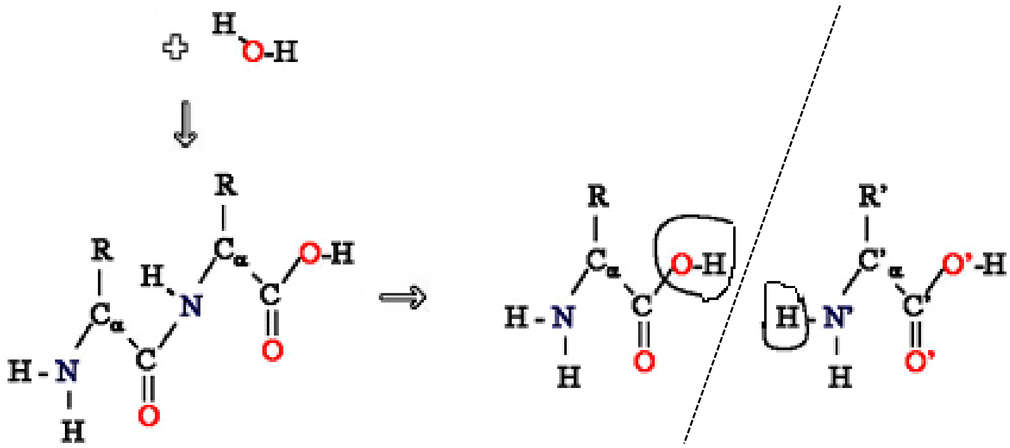
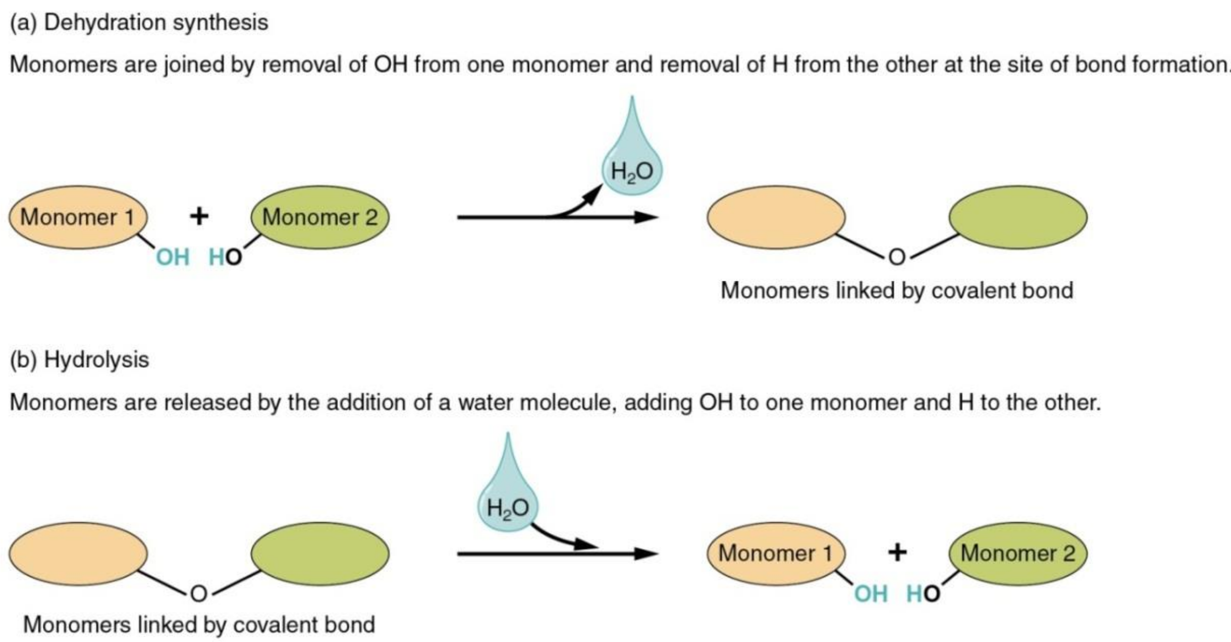


Figure 3.15 In this hydrolysis reaction, water is added breaking the peptide bond forming two amino acids.

In Summary



BIOLOGICAL MACROMOLECULES

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 (monomers) are called monosaccharides. Carbohydrates contain only carbon (C), hydrogen (H), and oxygen (O).

Monosaccharides and Disaccharides

A monosaccharide or simple sugar, contains carbon, hydrogen, and oxygen in a ratio of 1:2:1. The general formula for a monosaccharide is: $(CH_2O)_n$, where *n* can be any number greater than two. For example, if *n* is 6, then the formula can be written: $C_6H_{12}O_6$. This is the formula for the monosaccharide glucose. Another monosaccharide, fructose, has the same chemical formula as glucose, but the atoms are arranged differently. Molecules with the same chemical formula but with atoms in a different arrangement are called isomers. Compare the glucose and fructose molecules in **Figure 3.16**. Can you identify their differences? The only differences are the positions of some of the atoms. These differences affect the properties of the two monosaccharides. 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.

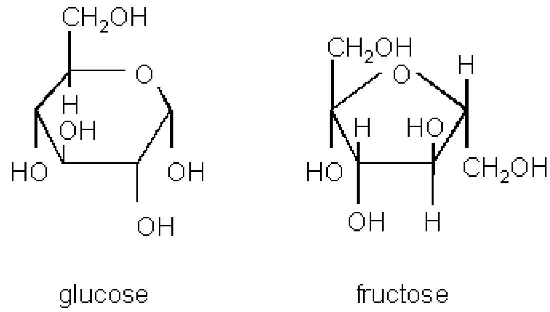


Figure 3.16 Glucose and fructose both have the same chemical formula but are isomer because their atoms are arranged differently.

Monosaccharides can be classified by the number of carbon atoms they contain: diose (2), triose (3), tetrose (4), pentose (5), hexose (6), heptose (7), and so on. In addition to glucose, other common monosaccharides include fructose ("fruit sugar"), galactose, xylose ("wood sugar") and ribose (in RNA) and deoxyribose (in DNA).

If two monosaccharides bond together, they form a carbohydrate called a disaccharide. Two monosaccharides will bond together through a dehydration synthesis reaction, in which a water molecule is lost. A dehydration synthesis reaction is a condensation reaction, a chemical reaction in which two molecules combine to form one single molecule, losing a small molecule in the process. In the dehydration reaction, this small molecule is water.

An example of a disaccharide is sucrose (table sugar), which consists of the monosaccharides glucose and fructose (**Figure 3.17**). Other common disaccharides include lactose ("milk sugar") and maltose. Monosaccharides and disaccharides are also called *simple sugars*. They provide the major source of energy to living cells.

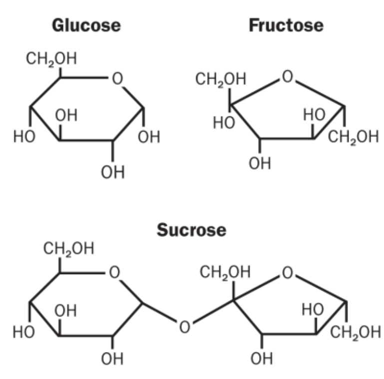


Figure 3.17 Sucrose is a disaccharide made up of the two monosaccharides, glucose and fructose through dehydration synthesis reaction. glucose ($C_6H_{12}O_6$) + fructose ($C_6H_{12}O_6$) → sucrose ($C_{12}H_{22}O_{11}$).

Oligosaccharides

An oligosaccharide is a saccharide polymer containing a small number (typically two to ten) of monosaccharides. Oligosaccharides can have many functions; for example, they are commonly found on

the plasma membrane of animal cells where they can play a role in cell–cell recognition. In general, they are found attached to compatible amino acid side-chains in proteins or to lipids.
Oligosaccharides are often found as a component of glycoproteins or glycolipids**.** They are often used as chemical markers on the outside of cells, often for cell recognition. An example is ABO blood type specificity. A and B blood types have two different oligosaccharide glycolipids embedded in the cell membranes of the red blood cells, AB-type blood has both, while O blood type has neither.

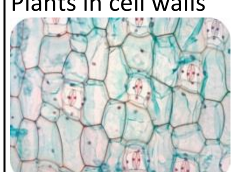
Polysaccharides

A polysaccharide is a complex carbohydrate that forms when simple sugars (monosaccahrides) bind together in a chain by glycosidic bonds. Polysaccharides may contain just a few simple sugars or thousands of them. Polysaccharides are also called complex carbohydrates. Polysaccharides have a general formula of $C_x(H_2O)_y$, where x is usually a large number between 200 and 2500. Considering that the repeating units in the polymer backbone are often six-carbon monosaccharides, the general formula can also be represented as $(C_6H_{10}O_5)_n$, where $40 \le n \le 3000$.

Starches are one of the most common polysaccharides. The formation of starches are the ways that plants store glucose. Glycogen is sometimes referred to as animal starch. Glycogen is used for long-term energy storage in animal cells. Glycogen is made primarily by the liver and the muscles.

Complex carbohydrates have two main functions: storing energy and forming structural tissues. Some examples of complex carbohydrates and their functions are shown in **Table 3.3**. Which type of complex carbohydrate does your own body use to store energy?

Table 3.3 Examples of complex carbohydrates and their general functions in living organisms.

Complex Carbohydrate	Function	Organism Examples
Starch	Used by plants to store energy	Plants in potato tubers 
Glycogen	Used by animals to store energy	Humans in liver cells 
Cellulose	Used by plants to form rigid cell walls	Plants in cell walls 
Chitin	Used by some animal to forms an exoskeleton	Housefly used for exoskeleton 

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 biofuels from the sugars in cellulose. This isolation of biofuels from the sugars in cellulose is just one example of biochemical conversions that are being explored today. Biochemical conversions change organic matter into other chemical forms such as fuels. See *Biofuels: Beyond Ethanol* at http://www.kqed.org/quest/television/biofuels-beyond-ethanol for further information.

Lipids

Lipids are organic compounds that contain carbon, hydrogen, and oxygen. They include substances such as fats or oils, as well as waxes, sterols, some vitamins (A, D, E, and K) and phospholipids (the main component of the outer membrane of all cells). Lipid molecules consist of fatty acids, with or without additional molecules. Fatty acids are organic molecules that have the general formula $CH_3(CH_2)_nCOOH$, where *n* usually ranges from 2 to 28 and is always an even number. There are two types of fatty acids: saturated fatty acids and unsaturated fatty acids.

A distinguishing feature of lipids is that they are insoluble in water. The main biological functions of lipids include energy storage, as the major structural component of cell membranes, and as important signaling molecules.

Saturated and Unsaturated Fatty Acids

Fatty acids can be saturated or unsaturated. The term saturated refers to the placement of hydrogen atoms around the carbon atoms. In a saturated fatty acid, all the carbon atoms (other than the carbon in the -COOH group) are bonded to as many hydrogen atoms as possible (usually two hydrogens). Saturated fatty acids do not contain any other groups except the -COOH. This is why they form straight chains, as shown in **Figure 3.18**. Because of this structure, saturated fatty acids 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. The fatty tissues of animals contain mainly saturated fatty acids.

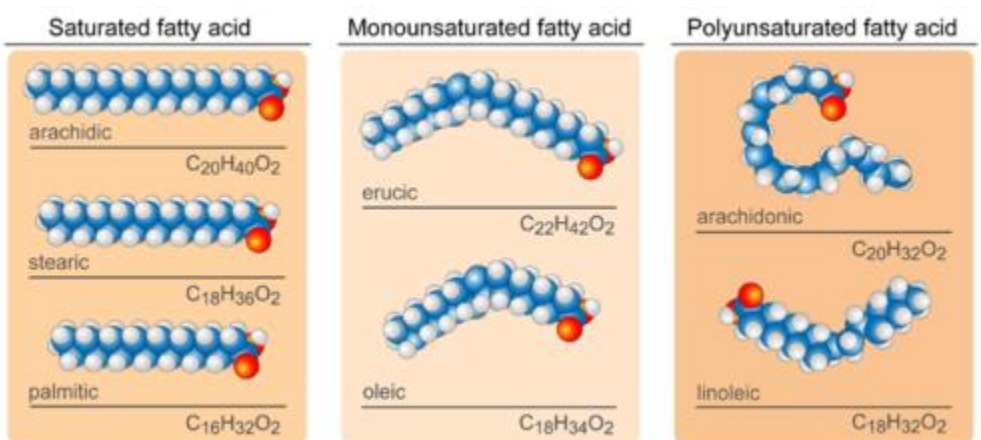


Figure 3.18: Fatty Acids. Saturated fatty acids have straight chains, like the three fatty acids shown on the left. Unsaturated fatty acids have bent chains, like all the other fatty acids in the figure.

In an unsaturated fatty acid, some carbon atoms are not bonded to the maximum number of hydrogen atoms. This is because they are bonded to one or more additional groups, including double and triple bonds between carbons. Wherever these other groups bind with carbon, they cause the chain to bend - they do not form straight chains (**Figure 3.18**). This gives unsaturated fatty acids different properties than saturated fatty acids. For example, unsaturated fatty acids are liquids at room temperature. Unsaturated fatty acids are found mainly in plants, especially in fatty tissues such as nuts and seeds and are used to store energy, see **Figure 3.19.**

Unsaturated fatty acids occur naturally in the bent shapes, however, unsaturated fatty acids can be artificially manufactured to have straight chains like saturated fatty acids and are called trans fatty acids, these synthetic lipids were commonly added to foods, until it was found that they increased the risk for certain health problems. Many food manufacturers no longer use trans fatty acids for this reason.

Figure 3.19: These plant products all contain unsaturated fatty acids.

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:

1. triglycerides: composed of three molecules of fatty acid joined to one molecule of the alcohol glycerol and are the main form of stored energy in animals. An example is shown in **Figure 3.20**. In humans, triglycerides are a mechanism for storing unused calories, and their high concentration in blood correlates with the consumption of excess starches and other carbohydrate-rich foods.

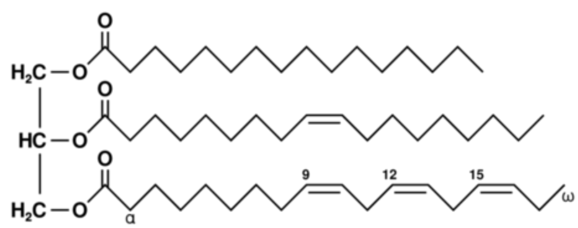


Figure 3.20 The left part of this triglyceride molecule represents glycerol. Each of the three long chains on the right represents a different fatty acid.
The chemical formula for this triglyceride is $C_{55}H_{98}O_6$.

2. phospholipids: composed of two fatty acids attached to a molecule of glycerol and are the major components of cell membranes surrounding the cells of all organisms, as they have the ability to form bilayers. An example is shown in **Figure 3.21.**

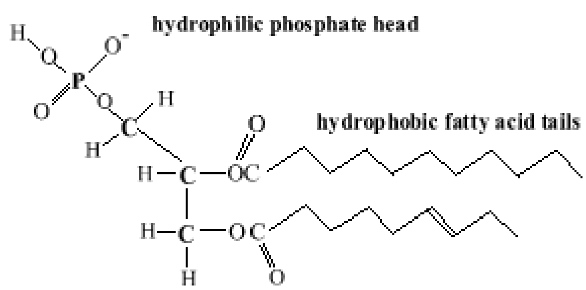


Figure 3.21 The structure of the phospholipid molecule consists of two hydrophobic tails (a diglyceride made of two fatty acid chains) and a hydrophilic head (a phosphate group, PO_4^{3-}).

3. steroids: composed of four fused carbon rings with various functional groups attached to them, unlike other lipids they are not composed of fatty acids. An example is shown in **Figure 3.22.** Steroids (or sterols) have several functions. Sterols are a subgroup of steroids. The sterol cholesterol is an important part of cell membranes and plays other vital roles in the body. Cholesterol is a precursor to fat-soluble vitamins and steroid hormones. Steroid hormones include the male and female sex hormones. Sterols also have roles as second messengers (or chemical messengers) in signaling pathways.

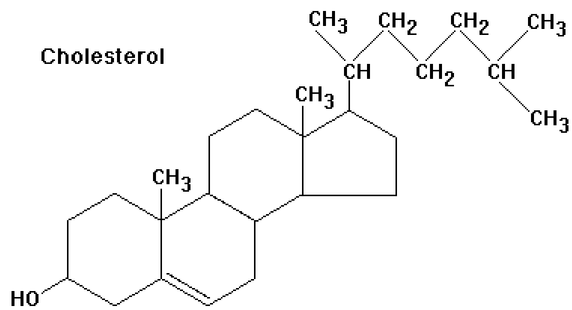


Figure 3.22 A cholesterol molecule composed of four fused carbon rings on the left hand side and a functional group attached on the right hand side.

4. Waxes: consists of a long fatty acid chain joined to a long alcohol chain and offer waterproofing. Examples are shown in **Figure 3.23.** Plants use them to waterproof their outer surfaces. Waxes also form protective layers in animals. For example, earwax helps prevent microorganisms from entering the ear canal.

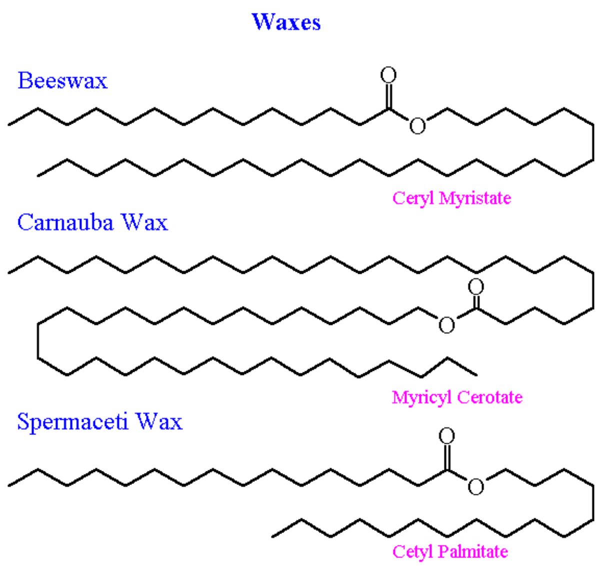


Figure 3.23 Beeswax is used mostly to make candles. Carnauba wax is an ingredient in many foods and household products, for example it is used to coat candles to prevent them from melting. Spermaceti wax is most often found in the head cavities of the sperm whale. Two theories for the spermaceti organ's biological function suggest it either controls buoyancy, or acts as a focusing apparatus for the whale's sense of echolocation.

Lipids and Diet

Humans need lipids for many vital functions, such as storing energy and forming cell membranes. Lipids can also supply cells with energy. In fact, a gram of lipids supplies more than twice as much energy as a gram of carbohydrates or proteins. Lipids are necessary in the diet for most of these functions. Although the human body can manufacture most of the lipids it needs, there are others, called essential fatty acids that must be consumed in food. Essential fatty acids include omega-3 and omega-6 fatty acids. Both of these fatty acids are needed for important biological processes, not just for energy.

Although some lipids in the diet are essential, excess dietary lipids can be harmful. Because lipids are very high in energy, eating too many may lead to unhealthy weight gain. A high-fat diet may also increase lipid levels in the blood. This, in turn, can increase the risk for health problems such as cardiovascular disease. The dietary lipids of most concern are saturated fatty acids, trans fats, and cholesterol. For example, cholesterol is the lipid mainly responsible for narrowing arteries and causing the disease atherosclerosis.

Proteins

A protein is an organic compound that contain carbon, hydrogen, oxygen, nitrogen, and in some cases sulfur and are made up of small molecules called amino acids. There are 20 different amino acids commonly found in the proteins of living things. All amino acids have the same basic structure, which is shown in **Figure 3.24.** Only the side chain (labeled R in the figure) differs from one amino acid to another. All amino acids also contain an amine group (NH_2) and a carboxyl group (COOH).

Proteins can differ from one another in the number and sequence (order) of amino acids. It is because of the side chains of the amino acids that proteins with different amino acid sequences have different shapes and different chemical properties. Small proteins can contain just a few hundred amino acids. Yeast proteins average 466 amino acids. The largest known proteins are the titins, found in muscle, which are composed from almost 27,000 amino acids.

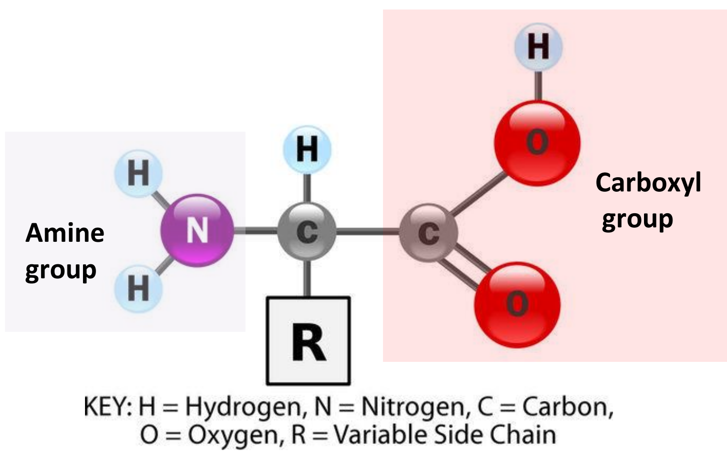


Figure 3.24 This model shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. Variable side chains give amino acids different chemical properties.

Protein Structure

When amino acids bind together through peptide bonds, they form a long chain called a polypeptide, see **Figure 3.25**. a peptide bond is a covalent bond formed from a condensation reaction between two molecules, causing the release of water. Polypeptides may have as few as 40 amino acids or as many as several thousand.

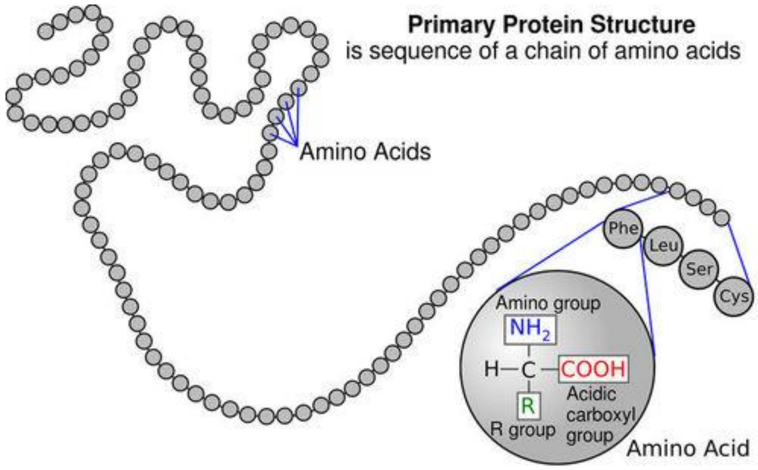


Figure 3.25 This polypeptide is a chain made up of many linked amino acids.

The sequence of amino acids in a protein's polypeptide chain(s) determines the overall structure and chemical properties of the protein. 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 3.26.** 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 how protein structures are folded by watching the animation at the link below. http://www.stolaf.edu/people/giannini/flashanimat/proteins/protein%20structure.swf.

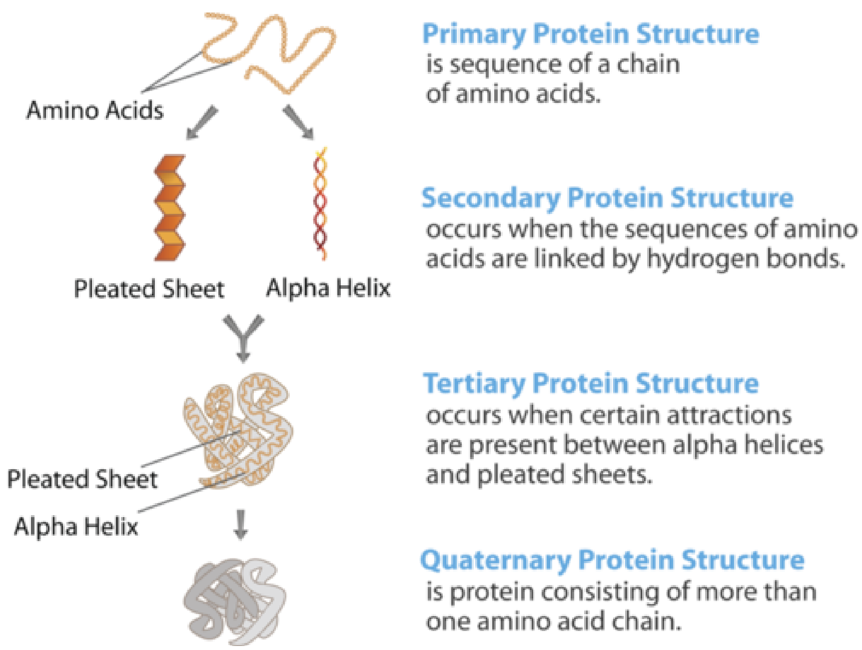


Figure 3.26 Primary protein structure is the sequence of amino acids in a single polypeptide. Secondary protein structure refers to internal shapes, such as alpha helices and beta pleated sheets that a single polypeptide takes on due to bonds between atoms in different parts of the polypeptide. Tertiary protein structure is the overall three-dimensional shape of a protein consisting of one polypeptide. Quaternary protein structure is the shape of a protein consisting of two or more polypeptides.

Functions of Proteins

Proteins play many important roles in living things. Some proteins (structural proteins) help cells keep their shape, and some make up muscle tissues. Many proteins (enzymes) 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 in and out of cells (transport proteins) or around the body. 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 3.27**.

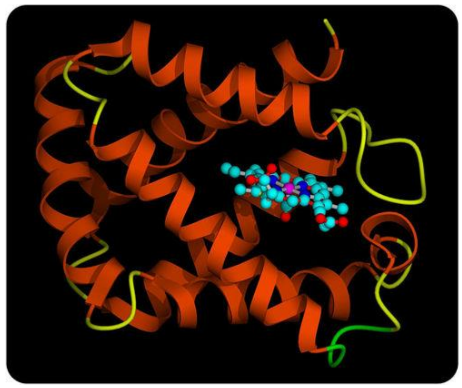


Figure 3.27 Hemoglobin Molecule. This model represents the protein hemoglobin. The red parts of the molecule contain iron. The iron binds with oxygen molecules.

One of the most important traits of proteins, allowing them to carry out these functions, is their ability to bond with other molecules. They can bond with other molecules very specifically and tightly. This ability, in turn, is due to the complex and highly specific structure of protein molecules. The structure-function relationship of proteins is an important principle of biology. A slight difference in the structure of a protein can lead to a difference in the function of that protein, and this can have devastating effects on the cell or organism.

Proteins and Diet

Proteins in the diet are necessary for life. Dietary proteins are broken down into their component amino acids when food is digested. Cells can then use the components to build new proteins. Humans are able to synthesize all but nine of the twenty common amino acids. These nine amino acids, called essential amino acids, must be consumed in foods. Like dietary carbohydrates and lipids, dietary proteins can also be broken down to provide cells with energy. The amino acids regarded as essential for humans are phenylalanine, valine, threonine, tryptophan, isoleucine, methionine, leucine, lysine, and histidine. Additionally, cysteine, tyrosine and arginine are required by infants and growing children.

In addition, certain amino acids (arginine, cysteine, glycine, glutamine, histidine, proline, serine and tyrosine) are considered conditionally essential, meaning they are not normally required in the diet, but must be supplied to specific populations that do not synthesize them in adequate amounts. An example would be with the disease phenylketonuria (PKU). Individuals with PKU must keep their intake of phenylalanine extremely low to prevent mental retardation and other metabolic complications. However, they cannot synthesize tyrosine from phenylalanine, so tyrosine becomes essential in the diet of PKU patients. PKU can be easily detected with a simple blood test. All states in the US require a PKU screening test for all newborns as part of the newborn screening panel. These individuals are placed on a special diet as soon as the disease is detected, a diet that is extremely low in phenylalanine, particularly when the child is growing. The diet must be strictly followed. Those who continue the diet into adulthood have better physical and mental health. Maintaining the diet for life has become the standard recommended by most experts.

Nucleic Acids

Nucleic acids are organic compounds that contain carbon, hydrogen, oxygen, nitrogen, and phosphorus. They are made up of smaller units called nucleotides. Nucleic acids are named for the nucleus of the cell, where some of them are found. Nucleic acids are found not only in all living cells but also in viruses. Types of nucleic acids include deoxyribonucleic acid (DNA)and ribonucleic acid (RNA)**.** The nucleic acids, DNA is considered to essential be the "instructions" or "blueprints" of life because it contains the code for the proteins that give you your traits.

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. A KhanAcademy overview of DNA can be seen at http://www.youtube.com/watch?v=_-vZ_g7K6P0.

Structure of Nucleic Acids

A nucleic acid consists of one chain (in RNA) or two chains (in DNA) of nucleotides held together by chemical bonds. Each nucleotide consists of three smaller molecules:

1. sugar(ribose in RNA, deoxyribose in DNA)
2. phosphate group
3. nitrogen base

If you look at **Figure 3.28**, 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.

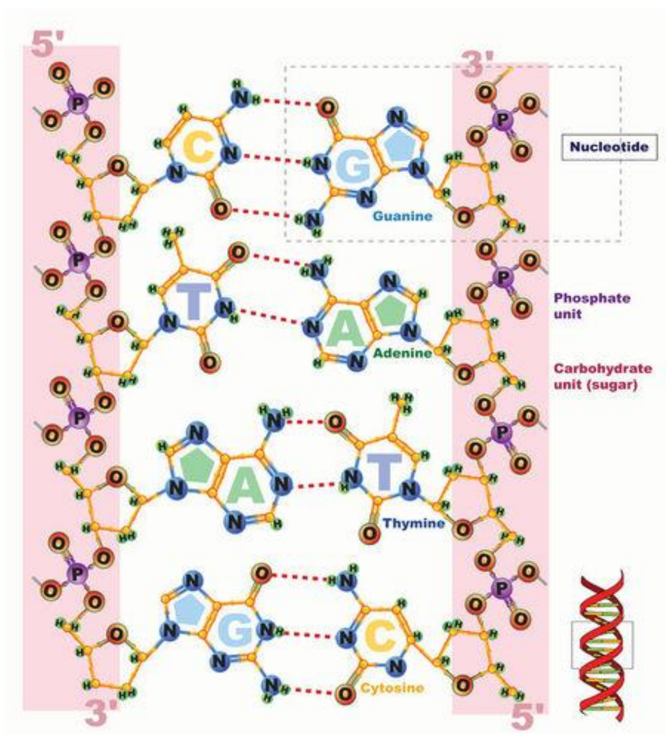


Figure 3.28 Nucleic Acid. Sugars and phosphate groups form the backbone of a polynucleotide chain. Hydrogen bonds between complementary bases hold two polynucleotide chains together.

RNA consists of a single chain of polynucleotides, and DNA consists of two chains of polynucleotides. Bonds form between the bases on the two chains of DNA and hold the chains together (**Figure 3.28**). There are four different types of bases in a nucleic acid molecule: cytosine (C), adenine

(A), guanine (G), and either thymine (T) (in DNA) or uracil (U) (in RNA). Each type of base bonds with just one other type of base. Cytosine and guanine always bond together, and adenine and thymine (or uracil) always bond with one another. The pairs of bases that bond together are called complementary bases. A brief overview of DNA, stressing the base-pairing rules, can be seen in the following animation: http://www.youtube.com/watch?v=cwfO6SzGaEg.

The binding of complementary bases allows DNA molecules to take their well-known shape, called a double helix. **Figure 3.29** shows how two chains of polynucleotides form a DNA double helix. It shows more clearly how the two chains are intertwined. The double helix shape forms naturally and is very strong. Being intertwined, the two chains are difficult to break apart. This is important given the fundamental role of DNA in all living organisms.

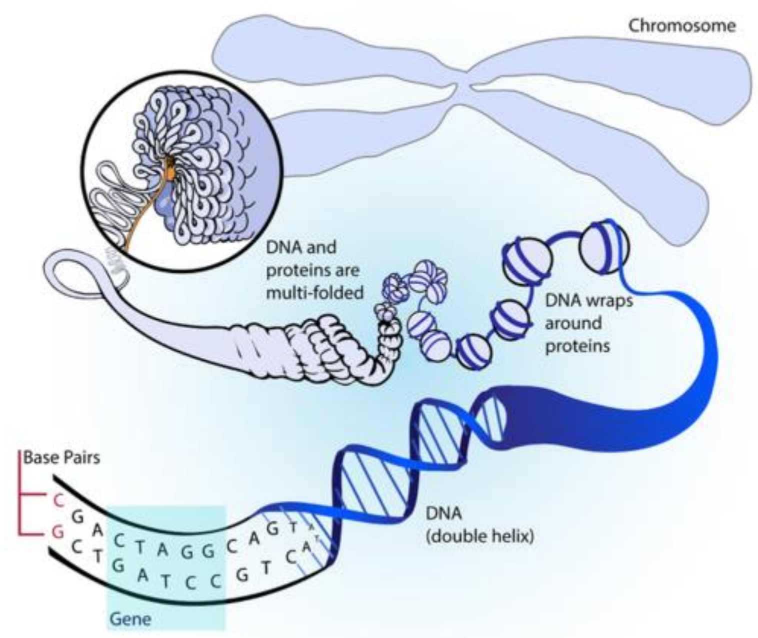


Figure 3.29 DNA Molecule. Bonds between complementary bases help form the double helix of a DNA molecule. The letters A, T, G, and C stand for the bases adenine, thymine, guanine, and cytosine. The sequence of these four bases in DNA is a code that carries instructions for making proteins.

Roles of Nucleic Acids

DNA is also known as the hereditary material or genetic information. It 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. DNA and RNA have different functions relating to the genetic code and proteins. Like a set of blueprints, DNA contains the genetic instructions for the correct sequence of amino acids in proteins. 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.

The order of bases in nucleic acids is highly significant. The bases are like the letters of a four-letter alphabet. These "letters" can be combined to form "words." Groups of three bases form words of the genetic code. Each code word, called a codon**,** stands for a different amino acid. A series of many codons spells out the sequence of amino acids in a polypeptide or protein (**Figure 3.30**). In short, nucleic acids contain the information needed for cells to make proteins. This information is passed from a body cell to its daughter cells when the cell divides and also to the sex cells when they divide. We will learn more about this process later in the chapter on *Cell Growth and Reproduction.*

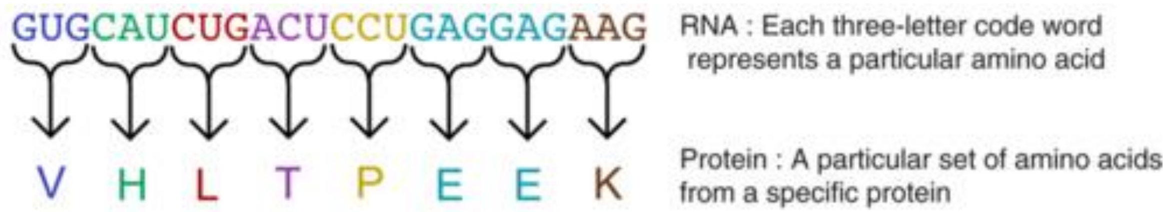


Figure 3.30 RNA coding for proteins: the letters G, U, C, and A stand for the bases in RNA, specifically mRNA or messenger RNA. Each group of three bases makes up a codon, and each codon represents one amino acid (represented here by a single letter, such as V (valine), H (histidine), or L (leucine)). A string of codons specifies the sequence of amino acids in a protein.

Adenosine Triphosphate (ATP)

One particular nucleotide all by itself (as a monomer, not a polymer) has a very important role in all cells. That nucleotide is ATP, adenosine triphosphate, the cellular form of energy often described as the "energy currency" of the cell or the "molecular unit of currency".. ATP is just like any other nucleotide except for the fact that ATP has three phosphate groups instead of just one. You have a detailed picture of ATP in **Figure 3.31**. The word "adenosine" just represents the sugar and nitrogenous base together (ribose + adenine = adenosine). ATP is produced in the mitochondria during cellular respiration and will be discussed further in the chapter on *Cells and Cell Processes.*

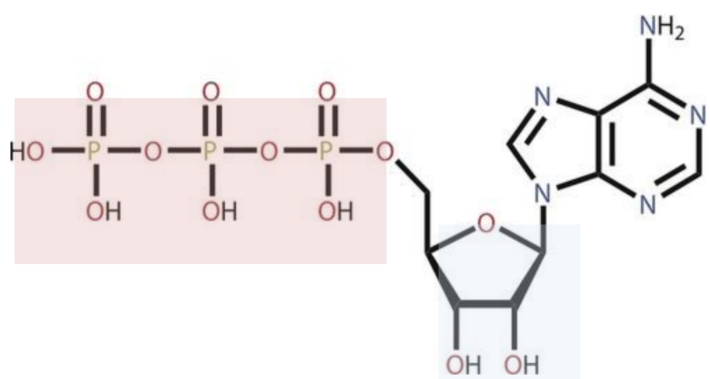


Figure 3.31 The ATP molecule clearly shows three phosphate groups on the left hand side highlighted in light purple, the sugar (ribose) is highlighted in light blue, and the adenine can be seen on the right had side.

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 with other elements and itself allows it to form millions of different large, organic molecules. These organic molecules make up organic compounds that make up living things and carry out life processes.
- The four major types of organic compounds are carbohydrates, lipids, proteins, and nucleic acids.
- Carbohydrates are organic molecules that consists of carbon, hydrogen, and oxygen. They are made up of repeating units called saccharides. They provide cells with energy, store energy, and form structural tissues.
- Lipids are organic compounds that consist of carbon, hydrogen, and oxygen. They are made up of fatty acids and other compounds. They provide cells with energy, store energy, and help form cell membranes.
- There are two types of fatty acids: saturated fatty acids and unsaturated fatty acids. Animals use saturated fatty acids to store energy. Plants use unsaturated fatty acids to store energy.

- Phospholipids are the major components of cell membranes.
- Excess dietary lipids can be harmful.
- Proteins are organic compounds that consist of carbon, hydrogen, oxygen, nitrogen, and, in some cases, sulfur. They are made up of repeating units called amino acids. They provide cells with energy, form tissues, speed up chemical reactions throughout the body, and perform many other cellular functions.
- A protein may have up to four levels of structure. The complex structures of different proteins give them unique properties. Enzymes are proteins that speed up biochemical reactions in cells. Antibodies are proteins that target pathogens for destruction.
- Nucleic acids are organic compounds that consist of carbon, hydrogen, oxygen, nitrogen, and phosphorus.
- DNA and RNA are made up of repeating units called nucleotides. They contain genetic instructions for proteins, help synthesize proteins, and pass genetic instructions on to daughter cells and offspring.
- DNA contains the genetic instructions for the correct sequence of amino acids in proteins. RNA uses the information in DNA to assemble the correct amino acids and help make the protein.

References/ Multimedia Resources

Opening image by Kylie Golden. “Organic Compounds”. Retrieved from http://www.glogster.com/stormyhusbands/organic-compounds/g-6l9ml6a9bnl5urnckjfoja0. 30 Jul. 2013.

"DNA: Key to Life (clip)." *YouTube*. YouTube, 11 Jan. 2008. Web. Summer 2013. <http://www.youtube.com/watch?v=cwfO6SzGaEg>

"DNA." *YouTube*. YouTube, 22 Sept. 2009. Web. 04 Aug. 2013. <http://www.youtube.com/watch?v=_-vZ_g7K6P0>

"Nucleic Acids." *Nucleic Acids*. N.p., n.d. Web. Summer 2013. <http://faculty.stcc.edu/AandP/AP/AP1pages/Units1to4/epitissmol/nucleic.htm>

Postlethwait, John H. "Biochemistry." *Modern Biology. Student Ed.* [S.l.]: Holt, Rinehart and Winston, 2009. 51-60. Print.

"QUEST." *QUEST RSS*. N.p., n.d. Web. Summer 2013. < http://www.kqed.org/quest/television/biofuels-beyond-ethanol>

St. Olaf Ed Center, “Protein Structure”.. N. p., n.d. Web. Summer 2013 <http://www.stolaf.edu/people/giannini/flashanimat/proteins/protein%20structure.swf>