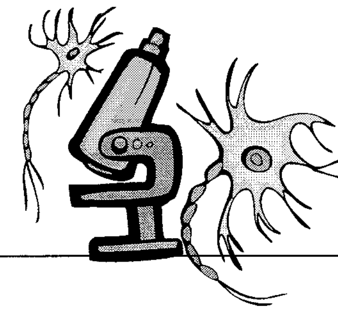
The Components of Life

Section 5.1
Organic Chemistry



Pre-View 5.1

- **Organic compounds** – chemical compounds that contain carbon and that make up living organisms
- **Valence electrons** – electrons that can be gained, lost, or shared in a chemical reaction
- **Macromolecules** (or **macronutrients**) – the large molecules that make up living organisms, such as proteins, carbohydrates, lipids, and nucleic acids
- **Monomer** – a small molecule that may be chemically bonded to other like molecules to form a polymer
- **Polymerization** – chemical process of combining monomers to form a polymer
- **Polymer** – long chain of monomers (small, repeating molecules)

The compounds created by living organisms are called **organic compounds**, and the study of these compounds is **organic chemistry**. Organic chemistry studies all of the compounds that have bonds between carbon atoms. There are two main reasons that carbon is so important:

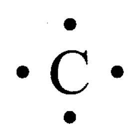


Fig. 5-1 Carbon's Four Valence Electrons

1. Carbon has four **valence electrons** (electrons that can be part of a chemical reaction). Each electron can form a covalent bond with many other elements such as hydrogen, nitrogen, oxygen, phosphorus, and sulfur. Figure 5-1 shows an electron dot diagram of carbon with its four valence electrons. Each of these electrons would like to form a covalent bond by sharing an electron with another atom. One of the simplest organic molecules is methane where four valence electrons in one carbon atom share electrons with four different hydrogen atoms (figure 5-2).

2. Carbon atoms can also bond with other carbon atoms to form single, double, and triple covalent bonds. These bonds allow carbon to form long chains that can be almost any length, and the chains can loop back to form ring structures. In this way, carbon can form thousands of different structures, including some that are very large and complex. Figure 5-3 shows carbon forming some of the simple organic molecules.

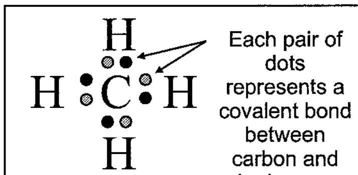
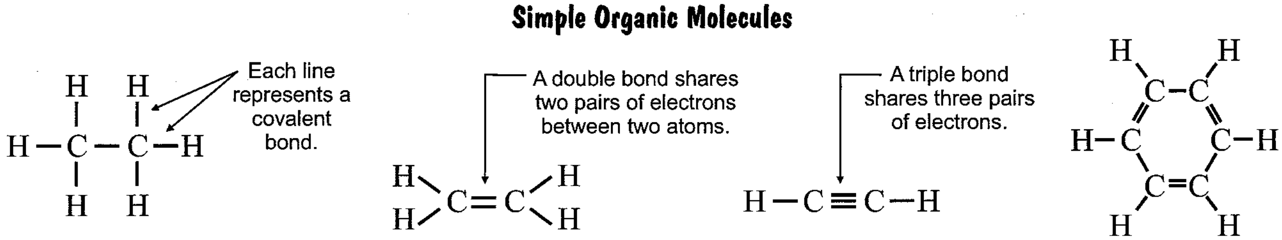


Fig. 5-2 Methane, CH_4

Simple Organic Molecules



Ethane, C_2H_6 — Ethene, C_2H_4 — Ethyne, C_2H_2 — Benzene, C_6H_6

Fig. 5-3

Organic Chemistry

Macromolecules

- carbohydrates
- proteins
- lipids
- nucleic acids

Not all molecules in living organisms are organic. Water is not an organic molecule, and neither are the various salts that are found in your body. But the large molecules called **macromolecules** are organic molecules. There are four main categories of macromolecules: carbohydrates, proteins, lipids, and nucleic acids. These macromolecules are sometimes called **macronutrients**.

Macromolecules are formed when smaller molecules called **monomers** are joined together in a process known as **polymerization** (figure 5-4). Polymerization forms **polymers**, which may be made from hundreds or thousands of monomers.

Example of Polymerization

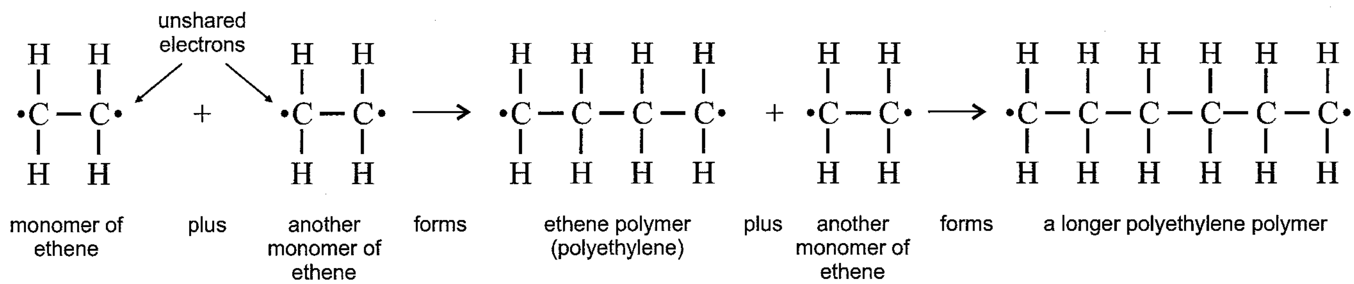


Fig. 5-4

Examples of Organic Compounds versus Non-Organic Compounds

Organic	Non-Organic
carbohydrates	salts
protein	minerals and simple elements
lipids/fats	water
enzymes	ionic compounds
carbon-based polymers	compounds without carbon

The Components of Life

Section 5.2
Carbohydrates

Pre-View 5.2

- **Carbohydrate** – an organic molecule made up of carbon, hydrogen, and oxygen; used as a source of energy and gives structure to some types of cells
- **Monosaccharides** – simple sugar
- **Polysaccharides** – a polymer of sugar, meaning a long chain of sugar molecules chemically linked together
- **Starch** – a polysaccharide made by plants to store energy
- **Cellulose** – a polysaccharide used in the cell walls of plants to give cells structural support
- **Glycogen** – a polysaccharide made by animal cells to store energy short term

One type of macromolecule is a **carbohydrate**. Carbohydrates are made of carbon, hydrogen, and oxygen, and these atoms are usually in a ratio of 1:2:1.

Functions and Importance of Carbohydrates

Carbohydrates have several purposes:

- They are used by living organisms as the primary source of energy. Sugars, the main component of complex carbohydrates, are broken down by cells to supply the energy needed for cellular activities.
- They are found in cell structures such as the cell membranes and the cytoplasm. They also have structural purposes for plants and some animals.
- They form parts of other macromolecules, such as nucleic acid.
- They are broken down in cells to provide the carbon to make other macromolecules.
- In animal and human diets, plant carbohydrates provide fiber that aids in digestion and elimination.

Simple Carbohydrates

The simplest carbohydrates are called **monosaccharides**, which means "simple sugar." Some examples of monosaccharides are glucose (figure 5-5), fructose (found in many fruits), and galactose (found in milk). These simple sugars can be used by cells to produce immediate energy, or they can be converted to a polysaccharide for later use.

During photosynthesis, plants produce **glucose**, a monosaccharide. Glucose is likely the most important carbohydrate in biology. It is the main energy source for cells. (You'll see how glucose is used for cellular energy later in Section 8.)

The Chemical Structure of Glucose

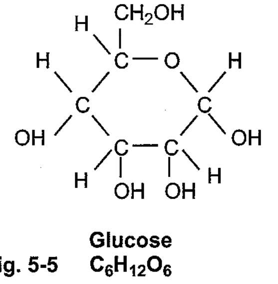
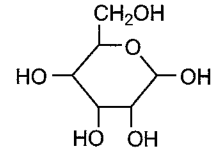


Fig. 5-5 **Glucose $C_6H_{12}O_6$**



Glucose (shorthand)

Since organic molecules can be large and complex, scientists often use a type of "shorthand" when showing their chemical structure. The C's for the carbons are left off at the intersections of bonds. Also, since each carbon in an organic molecule must have 4 bonds, the hydrogens are also left off but understood to be there.

Complex Carbohydrates

Complex carbohydrates are formed when two or more simple sugars link together. A **disaccharide** is formed with two simple sugars. For example, sucrose, also known as table sugar, is a disaccharide made up of a glucose molecule bonded to a fructose molecule.

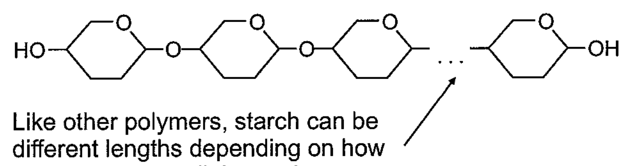
The larger carbohydrates are called **polysaccharides**. The prefix "poly-" is used a lot in science, and it means "many." What do you think polysaccharide means? If you guessed that it means "many sugars," you would be correct. Polysaccharides are polymers of sugar molecules linked together with covalent bonds.

Both plants and animals break down carbohydrates for energy, but they also store carbohydrates to use later for energy. The carbohydrates that organisms store are polysaccharides. When a plant or animal cell needs energy, it can then break down the polysaccharide into glucose, a monosaccharide, for energy. In plants, polysaccharides also provide structural support.

Starch

As mentioned earlier, plants produce glucose during photosynthesis. Plants can then store glucose as starch. **Starch** is a polysaccharide produced when sugar molecules form a chain (figure 5-6). Starch is one of the most important polysaccharides because it is a major source of the energy that we get from our food.

The Chemical Structure of Starch



Like other polymers, starch can be different lengths depending on how many monomers link together.

Fig. 5-6

Cellulose

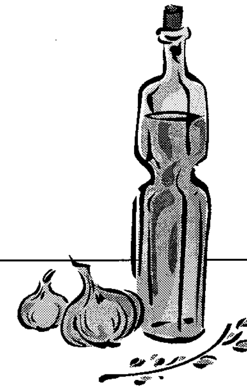
Plants also use a different polysaccharide, **cellulose**, in their cell walls. Cellulose is a structural polysaccharide instead of one used to store energy. It gives the cell wall strength. For example, cellulose is a major component of wood and cotton. It is also found in the cells of the fruits and vegetables that we eat. Even though we cannot break down cellulose into glucose, it is still a very important part of the human diet. It aids in digestion by slowing down the absorption of nutrients in the stomach and small intestines. Cellulose also aids elimination by absorbing water and speeding the passage of unused food through the large intestine.

Glycogen

Whenever we eat, the carbohydrates in the food are broken down into glucose or other simple sugars. Those simple sugars can then be used immediately by the body for energy. Many animals can also store excess sugar for a short-term by forming a polysaccharide called **glycogen**. Glycogen is stored in the cells and can release energy when needed.

The Components of Life

Section 5.3
Lipids



Pre-View 5.3

- **Lipids** – organic molecules made up of carbon, hydrogen, and oxygen, but unlike carbohydrates, they will not dissolve in water
- **Fat** – a type of lipid used to store energy and as a source of fatty acids
- **Saturated fat** – a fat that has all single carbon-to-carbon bonds and the maximum number of hydrogens attached to each carbon
- **Monounsaturated fat** – a fat that has one double carbon-to-carbon bond
- **Polyunsaturated fat** – a fat that has more than one double carbon-to-carbon bond
- **Essential fatty acids** – fatty acids that cannot be produced by the body but must be eaten; omega 3 and omega 6 fatty acids are essential fatty acids for humans
- **Phospholipid** – a type of lipid that helps to make up cell membranes
- **Steroid** – a type of lipid that can be present in cell membranes or can make up certain hormones
- **Cholesterol** – a type of steroid used in cell membranes and also used to make steroid hormones
- **Wax** – a type of lipid that is used to waterproof leaves, skin, feathers, etc.

Lipids are also organic molecules and can be in the form of fats, waxes, phospholipids, or steroids. Similar to carbohydrates, lipids are made up of carbon, hydrogen, and oxygen, but they generally have fewer oxygen molecules than carbohydrates. Lipids also have one important characteristic that makes them very different from carbohydrates. They are generally not soluble in water, meaning that they will not dissolve in water.

Functions and Importance of Lipids

Each type of lipid has its own unique functions and importance. The table below summarizes their purposes.

Type of Lipid	Function or Importance
Fat	• long-term energy storage • source of fatty acids • insulation against cold • protection around organs
Wax	• waterproof covering
Phospholipid	• major component of cell membranes
Steroid	• component of cell membranes • forms hormones, which are chemical messengers

General Structure of a Fat

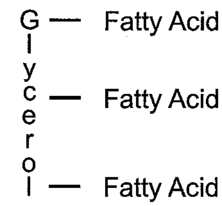


Fig. 5-7

Fats

Fats are made of a glycerol molecule bonded to three fatty acid molecules (figure 5-7). Fats can be classified as saturated, monounsaturated, or polyunsaturated. The classification of the fat depends on the types of fatty acids. Look at the examples of fatty acids below in figure 5-8.

Examples of Fatty Acids

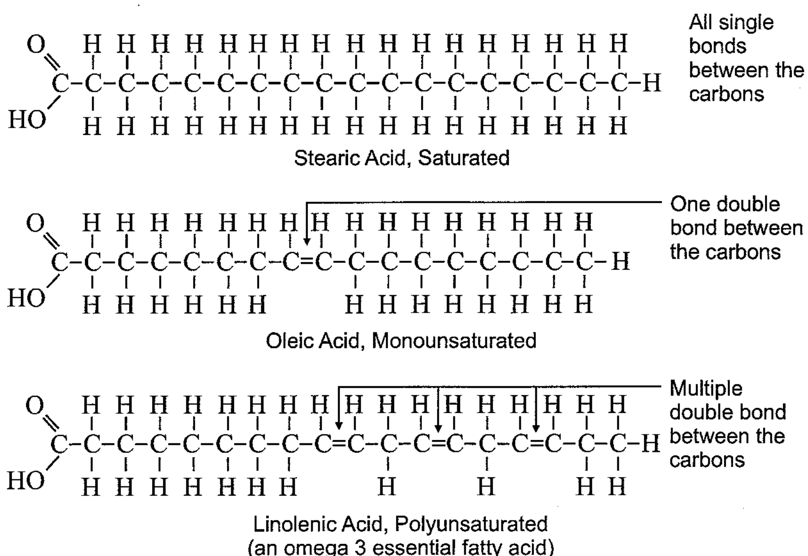


Fig. 5-8

When every carbon atom in the fatty acid chains has a single bond with another carbon atom, the fat is **saturated.** Being saturated means that it has the maximum number of hydrogen atoms possible. Solid fats such as butter, shortening, and lard are usually saturated.

Monounsaturated fats have one double carbon to carbon bond, and **polyunsaturated** means that the fatty acid part has more than one double bond. Unsaturated fats are usually liquid at room temperature. Nuts, seeds, avocados, olive oil, and peanut oil contain monounsaturated fats. Vegetable oils, nuts, seeds, and cold-water fish contain polyunsaturated fats. You may have seen these terms on food labels.

Humans need to eat some fat to live. It is especially important that we eat foods that contain two types of fatty acids called omega 3 and omega 6 fatty acids. Our bodies cannot produce these two fatty acids, so they are called **essential fatty acids**. It is essential to eat them so that the body can make the other fats that it needs. Omega 3 and omega 6 fatty acids are found in cold-water fish, nuts, and seeds. Small amounts are also found in fresh vegetables. Omega 3 and omega 6 fatty acids both come from polyunsaturated fats, which means these fatty acids have more than one double bond between carbon atoms. Linolenic acid shown in figure 5-8 is an example of an omega 3 essential fatty acid.

Phospholipids

Phospholipids are lipids that form an important part of cell membranes. They are actually the primary component that makes up cell membranes. The chemical structure of phospholipids is similar to that of fats except that one of the three fatty acid groups is replaced by a phosphate (PO_4) group (figure 5-9). The fatty acid part of the phospholipid repels water, but the phosphate group attracts water. The cell membrane is made up of two layers of phospholipids arranged tail to tail. (You'll learn more about the phospholipids in the cell membrane in Section 7.)

General Structure of a Phospholipid

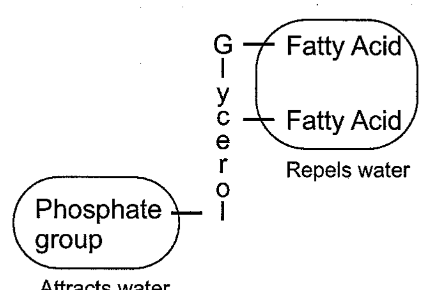


Fig. 5-9

Steroids

The lipids called **steroids** are used in cell membranes and are also used to make hormones that your body needs. Two main types of steroids are cholesterol and steroid hormones.

Cholesterol is a type of steroid that is used by the body to make steroid hormones. It is also important for many other body functions. Cholesterol, a major component of cell membranes, is also found in other structures and organelles within the cell.

General Structure of a Steroid

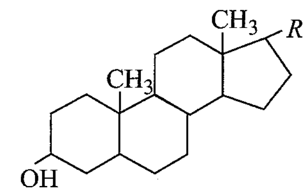
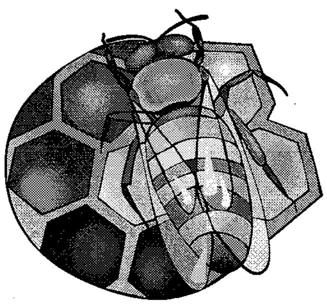


Fig. 5-10

Hormones are chemical messengers. Steroid hormones include the sex hormones like estrogens, progesterone, and testosterone as well as other hormones like cortisol. (Note: Not all hormones are steroid hormones.)

The chemical structure of steroids contains four carbon rings. Three of the rings have 6 carbons, and one of the rings has 5 carbons. The general structure of steroids is shown in figure 5-10. The "*R*" is a generic symbol that can represent any atom or chemical group.

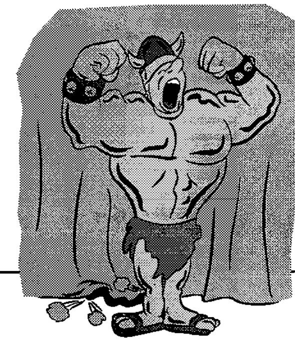


Waxes

Wax is another type of lipid. Waxes are usually made up of fatty acids combined with other organic molecules. They are used to form waterproof coverings on leaves, skin, or fur. To give a few examples, bees make beeswax, your ears make ear wax, and a certain type of palm tree makes carnauba wax that you may use to wax your car.

The Components of Life

Section 5.4
Proteins



Pre-View 5.4

- **Protein** – an organic molecule with many important functions; the main structural component of muscle, skin, bone, etc.
- **Amino acids** – organic molecules that are building blocks of protein
- **Nitrogen** – an element found in amino acids and proteins but is NOT found in carbohydrates or fats
- **Peptide bond** – the covalent bond between the amino acids in a protein

Protein is a third type of important macromolecule. There are many types of proteins, and they have a lot of different functions.

Functions and Importance of Proteins

- They form the main structural component of skeletal muscle, skin, cartilage, tendons, ligaments, horns, bone, hair, and feathers.
- They are receptors that detect chemical signals so that cells can respond to stimuli.
- They are important in the movement of muscles and for the movement of many cells.
- They serve as antibodies to protect against diseases.
- They may be highly specialized as enzymes. (More about enzymes later.)
- They help transport substances throughout the body.
- They provide storage for elements like iron.

Structure of Proteins

Although there are so many different proteins, all proteins are made of building blocks called **amino acids**. Like the other organic molecules you have studied so far, amino acids contain carbon, hydrogen, and oxygen, but they also contain **nitrogen**. Each amino acid has a central carbon atom with an attached hydrogen atom, an amino group, a carboxyl group, and an *R* group (or variable group) put together as seen in figure 5-11. The *R* group can be any of 20 different atoms or groups of atoms, depending on the amino acid. The amino group is 1 nitrogen and 2 hydrogen atoms on one end of the molecule, and the carboxyl group is -COOH on the other end.

General Structure of an Amino Acid

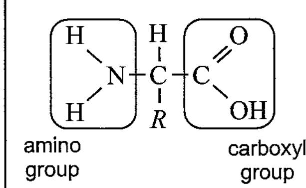


Fig. 5-11

The way that these amino acids are arranged to make different proteins depends on the instructions given in the DNA of each cell. The amino acids are joined together by a type of covalent bond called a **peptide bond**, and the chain is called a polypeptide. Proteins are longer polypeptide chains of up to 3000 amino acids. The arrangement, number, and type of the amino acids are important because any changes will cause a change in the protein's shape, and a protein's shape is directly related to its specific function.

Temperature and pH are two factors that can affect the shape, and therefore the function, of proteins. When a protein's shape is changed so that it no longer functions as intended, it is said to be *denatured*. Keeping the pH within a narrow range is important to living organisms so that their proteins function properly.

The Components of Life

Section 5.5
Nucleic Acids

Pre-View 5.5

- **Nucleic acid** – an organic molecule that contains carbon, hydrogen, oxygen, nitrogen, and phosphorus and makes up RNA and DNA
- **Nucleotide** – a molecule that contains a sugar, a phosphate group, and a nitrogen base and that links together to form RNA and DNA
- **Deoxyribonucleic acid (DNA)** – a nucleic acid molecule in the shape of a double helix that contains deoxyribose sugar and that stores genetic information
- **Ribonucleic acid (RNA)** – a nucleic acid molecule that contains ribose sugar
- **Double helix** – the shape, similar to a twisted ladder, of a DNA molecule

Nucleic acids are macromolecules that contain carbon, hydrogen, oxygen, nitrogen, and phosphorus. They are made of units called **nucleotides**. (Which other macromolecule that you've studied is made up of smaller units? That's right — proteins are made up of smaller units called amino acids.) Each nucleotide has three parts: a sugar, a phosphate group, and a nitrogen-containing base (figure 5-12).

There are two types of nucleic acids, DNA and RNA. Let's look at each of these and review their structures and functions.

General Structure of a Nucleotide

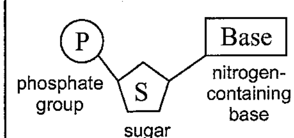


Fig. 5-12

Deoxyribonucleic Acid, DNA

Nucleic acids can have one of two different sugars, deoxyribose or ribose. **Deoxyribonucleic acid**, or **DNA**, is made of nucleotides that contain deoxyribose sugar. There are four different bases that make up the nucleotides for DNA. They are adenine (A), cytosine (C), guanine (G), and thymine (T).

How Nucleotides Link to Form DNA

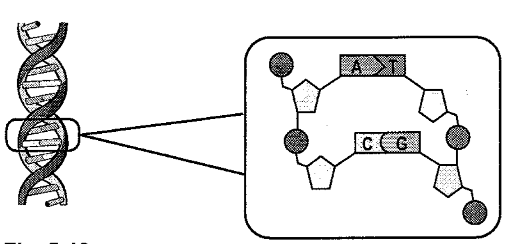


Fig. 5-13

You can think of a DNA molecule as being like a ladder. The nucleotides are connected between the sugars by the phosphate groups to form the sides of the ladder. The rungs of the ladder are formed by the bases, which are joined by hydrogen bonds in complementary base pairs. In DNA, adenine (A) and thymine (T) are always paired, and cytosine (C) and guanine (G) are always paired. The interactions between nucleotides cause the ladder to twist into a shape known as a **double helix**.

The main function of DNA is forming genes. Genes are responsible for heredity, the storing and sending of genetic information from one generation to the next in living organisms. (You will see much more about DNA and genes in later sections.)

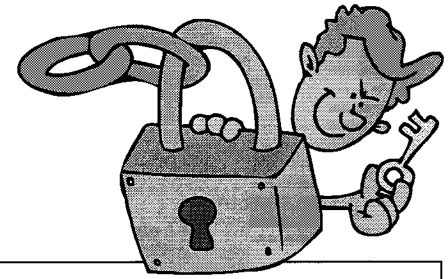
Ribonucleic Acid, RNA

Ribonucleic acids, or **RNA**, contain ribose sugar in their nucleotides instead of deoxyribose sugar. In RNA, the nucleotides form a single-stranded molecule. RNA nucleotides have the same bases of adenine (A), cytosine (C), and guanine (G), but uracil (U) is present instead of thymine (T).

The main function of RNA is protein synthesis (making protein) within the cells.

The Components of Life

Section 5.6
Enzymes



Pre-View 5.6

- **Enzyme** – a biological catalyst that enables chemical reactions to take place in the body
- **Substrate** – a substance that is changed by an enzyme
- **Active site** – the part of an enzyme that "attaches to" a substrate

Living organisms are dependent on certain chemical reactions that normally would occur too slowly or require too much energy to take place on their own. To make these reactions possible, special proteins called **enzymes** are used. Enzymes act as catalysts that lower the amount of energy needed for a chemical reaction to begin. The enzyme speeds up the reaction. (A catalyst is a substance that speeds up a chemical reaction without itself being affected by the reaction.)

Enzymes are very specific. They will work only on certain substances called **substrates**. Each type of enzyme has an area on it that is called the **active site**. The active site of the enzyme and the shape of the substrate fit together like the pieces of a puzzle. If the shape of the substrate doesn't fit the active site, then that enzyme will not work with that substrate. This specific fit is often called the lock and key model because the substrate (key) must fit precisely into the active site (lock) in order for the "key" to work. Once the substrate fits into the active site, it stays there until the reaction is finished. When the reaction is complete, the products are released, and the enzyme, which has not been changed during the reaction, can be used in another process.

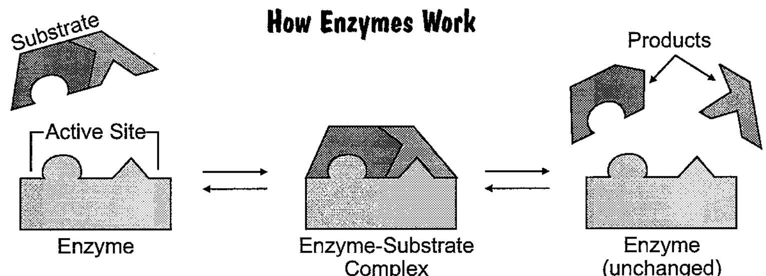


Fig. 5-14

Factors Affecting Enzyme Activity
• Concentration
• Temperature
• pH

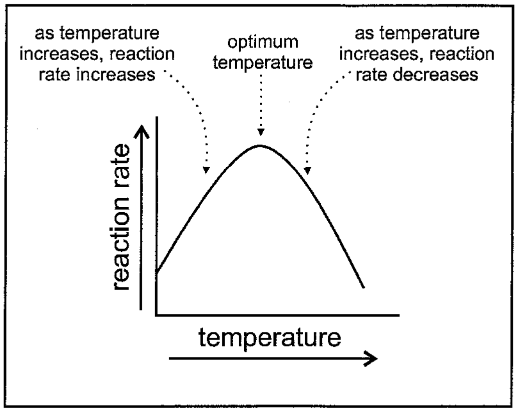
Anything affecting the chemical reaction can affect how well an enzyme works. There are three main factors that influence enzyme activity: concentration, temperature, and pH.

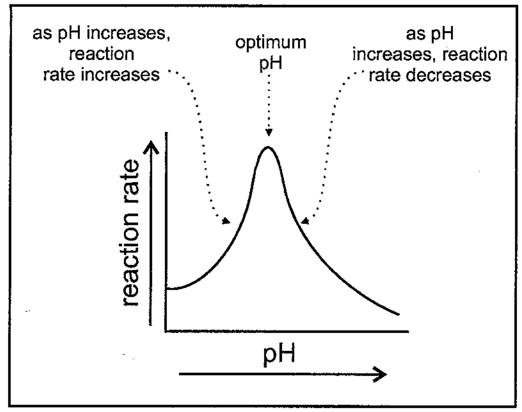
Concentration
In general, the greater the concentration of a substrate, the faster the rate of reaction. A higher concentration of substrate increases the chance that the substrate will fit into the active site, so the rate of the reaction increases.

Temperature
Temperature also affects enzyme activity. Enzymes work best within a certain temperature range. If the temperature is much higher or lower than optimum, then the enzyme changes shape. If the enzyme changes shape, the substrate won't fit, and the reaction slows down. Most enzymes in your body work best at around 37°C, which is the average internal temperature for humans.

pH
Most enzymes have a small pH range that allows them to work most efficiently. If the pH gets higher or lower, then the enzyme will change shape so the substrate doesn't fit, and again the reaction will slow down.

Both temperature and pH will change the shape of an enzyme. Since the shape of the enzyme affects how well it works on a substrate, enzymes work best at an optimum temperature and pH. Look at the graphs below that show how temperature and pH generally affect reaction rate.





Although the shapes of the curves are a little different, they both show the same trend. They simply show that as temperature or pH increases, reaction rate increases until it gets to an optimum temperature or pH. Then the reaction rate decreases when temperature or pH gets any higher. What point on the graphs represents the optimum temperature and optimum pH? The optimum is represented by the highest peak on the curve. Generally, enzymes work well in a narrower pH range than temperature range, so the "hill" of the curve is narrower and steeper on the pH graph.

Types of Enzymes

Humans produce two types of enzymes: metabolic enzymes and digestive enzymes. Humans also obtain and use a third kind of enzyme, food enzymes, from eating raw foods. Remember, enzymes are needed to speed up the rate of reaction. Reactions that could take days to complete can be completed in minutes or hours when enzymes are used.

Metabolic enzymes enable cells to perform cellular reactions. These reactions allow cells to make energy, repair tissues, and eliminate or neutralize wastes and toxic substances.

Digestive enzymes are ones that may be more familiar to you. The name of a digestive enzyme usually ends in *-ase*, and the first part of the name often indicates what it helps to digest (or break down into smaller components). Look at the chart on the right for common digestive enzymes and the substances they digest. For example, lactase is an enzyme that breaks down lactose, the sugar found in milk, into the monosaccharides of galactose and glucose. These are only a few of many. As you can see in the chart, digestive enzymes help to digest the different types of macronutrients. They allow the body to break down food in hours instead of days.

Common Digestive Enzymes

Enzyme	Breaks down —	Into products of —
amylase	carbohydrates	Disaccharides, monosaccharides
lactase	lactose (milk sugar)	galactose and glucose
sucrase	sucrose (table sugar)	glucose and fructose
protease	proteins	polypeptides, amino acids
lipase	fats	glycerol and fatty acids

Food enzymes also help to break down the foods we eat. Since food enzymes are destroyed at high temperatures, they are only found in uncooked (raw) foods or from supplements. Consuming food enzymes from raw foods helps the body to digest the foods without causing as much strain on the body to produce additional digestive enzymes.

The Components of Life

Section 5.7
Macronutrient Review

The chart below reviews the basics of each macronutrient.

Macronutrient	Chemical/Basic Structure	Function
carbohydrate	carbon, hydrogen, oxygen; monosaccharides	primary source of energy; structural component of plants
lipid	carbon, hydrogen, oxygen; glyceral chain and fatty acids	energy storage (long-term); major component of cell membrane
protein	carbon, hydrogen, oxygen, and nitrogen; amino acids	major component of muscle; enzymes
nucleic acid	carbon, hydrogen, oxygen, nitrogen, and phosphorous; base, sugar, and phosphate group	genetic information storage; protein synthesis