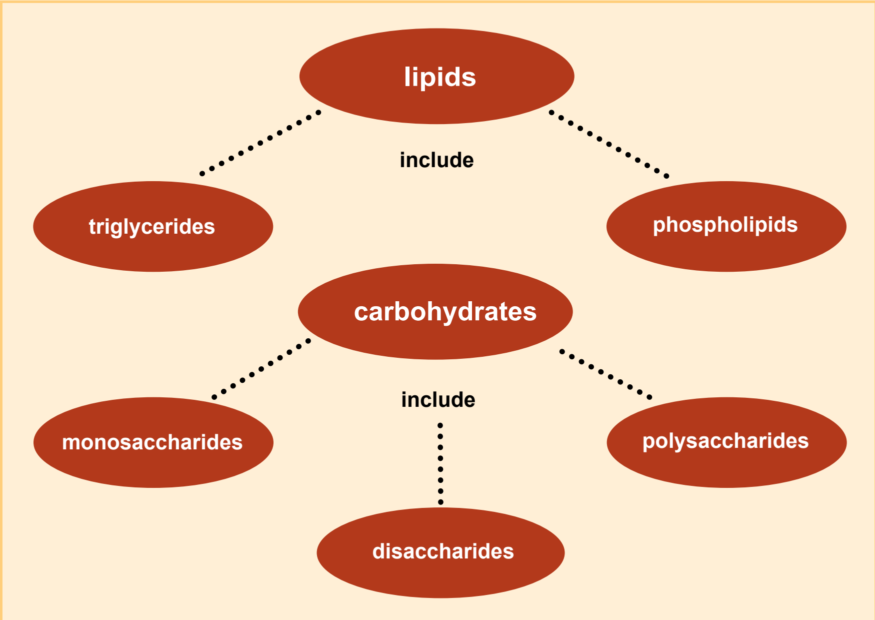
# Lipids and Carbohydrates




## Essential Questions

- What are the solubility characteristics and functions of fats and phospholipids?
- How do the structures of starch, glycogen, and cellulose differ?
- What are the consequences of base additions, deletions, and substitutions on a molecule of DNA?

## Keywords

carbohydrate
cellulose
chitin
disaccharide
glucose
glycerol
glycogen
isomers
lipid
phospholipid
polysaccharide
saturated fatty acid
starch
triglyceride
unsaturated fatty acid

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## *Set the Stage*

Different types of lipids have different impacts on human health. Saturated fats, including artificially saturated trans fats, have the ability to raise "bad" cholesterol (LDL or low-density lipoprotein) levels and lower "good" cholesterol (HDL or high-density lipoprotein) levels, building up fatty material in arteries. Over time, plaque ruptures and blood clots can occur, at times clogging arteries. Plaque ruptures and blood clots in arteries feeding the heart or brain often cause a heart attack or stroke. Since heart disease and stroke are among the leading killers of adults in the United States today, people are giving much attention to contributing factors in this disease.

On the flip side, unsaturated fats, in particular monounsaturated and polyunsaturated fats, have the opposite effect on blood cholesterol levels. When eaten in moderation, these fats help lower LDL levels, thus reducing risk of heart disease. Polyunsaturated fats include omega-3 fatty acid. It is a type of essential fatty acid, meaning that our bodies cannot produce it, so it must be ingested. Omega-3 fatty acids play a role in healthy brain function, growth, and development.

Generally, it is the quantity and type of fats eaten that affects health. The right kinds of fats are essential to life. As our knowledge about fats continues to grow, especially at the molecular level, so will our basic understanding of correlations between diet and health, and many lives can be saved.

## Lipid macromolecules are made of glycerol and fatty acids.

**Lipids** are a class of macromolecules that includes fats, phospholipids, and steroids. Lipids are central to several major biological functions, including energy storage, cell membrane structure, and hormone messaging.

As in other macromolecules, the molecular components of a basic lipid are responsible for the unique functions of lipid macromolecules. Lipids are made up of several smaller molecular structures such as glycerol and fatty acids.

**Glycerol** is an alcohol with three carbons, each attached to an –OH. A fatty acid is a long chain of carbons, typically 16 or 18 in length, with hydrogen atoms attached to each carbon and a carboxyl functional group at one end. The carboxyl group on the fatty acid is the portion of the fatty acid that undergoes the dehydration synthesis reaction with glycerol.

Fatty acids are nonpolar: they have no negative or positive end. Carbon and hydrogen atoms in fatty acids have approximately the same electronegativity, meaning that they share electrons equally between each other. Water molecules, by contrast, are polar: they have positive and negative sides. Polar molecules do not mix with nonpolar molecules. Therefore, lipids separate into a separate layer when mixed with water.

**lipid** a macromolecule composed of fats, oils, phospholipids, steroids, and waxes

**glycerol** an alcohol with three carbons each attached to a different hydroxyl group

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## Triglycerides are a commonly occurring lipid.

When one glycerol molecule bonds covalently to three fatty acids through dehydration synthesis, the product is a **triglyceride** (**Figure 1**), a lipid commonly referred to as fat. Depending on the particular structure of the fatty acids forming a triglyceride, different triglycerides have different properties.

Fats that are solid at room temperature, such as butter, lard, and other animal fats, are called **saturated fatty acids**. In these fatty acids, all carbons that can possibly bond to hydrogen are bonded, so the molecule is saturated with hydrogen molecules. Saturated fat molecules can stack tightly together, which means that they require higher temperatures to melt and are typically solid at room temperature.

Fatty acids also commonly contain double bonds between carbons. When a fatty acid contains one or more double bond and thus cannot be saturated with many hydrogen molecules, it is called an **unsaturated fatty acid**. Unsaturated fatty acids are typically liquid at room temperature because double bonds form large kinks in the fatty acid tails and prevent unsaturated fatty acid molecules from stacking tightly together. When the molecules are farther apart, unsaturated fats reach a liquid state at lower temperatures, compared to their well-compacted saturated fat counterparts. Unsaturated fats are typically oils. They are considered healthier to eat than saturated fats and are naturally found in plants and fish. Omega-3 is a fatty acid.

**triglyceride** a glycerol attached to three fatty acids; also called a fat

**saturated fatty acid** a triglyceride with no double bonds

**unsaturated fatty acid** a triglyceride that contains double bonds

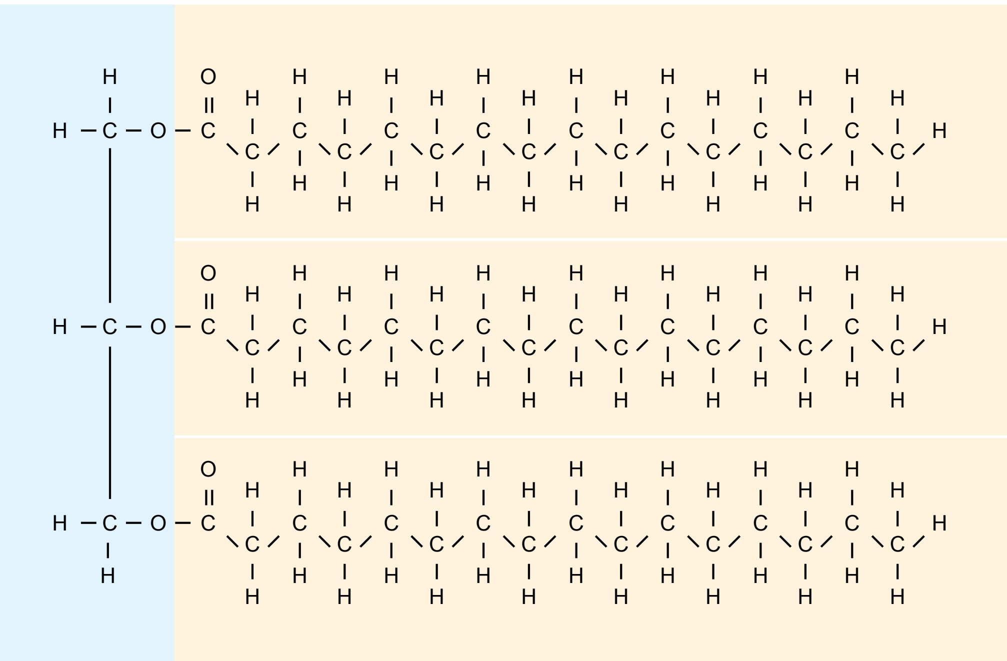

**Figure 1.** A triglyceride consists of one glycerol molecule covalently bonded to three fatty acids.

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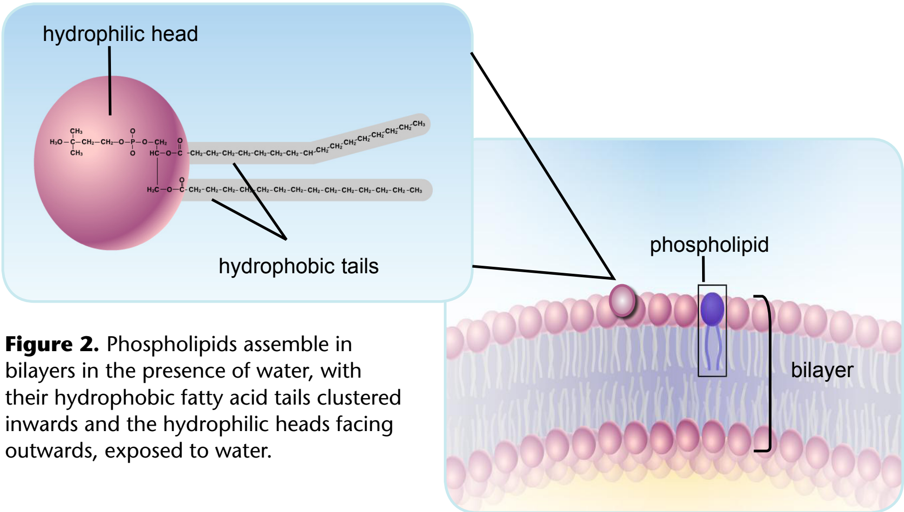


**Figure 2.** Phospholipids assemble in bilayers in the presence of water, with their hydrophobic fatty acid tails clustered inwards and the hydrophilic heads facing outwards, exposed to water.

### Phospholipids are another commonly occurring lipid.

Another type of lipid is a **phospholipid**, made up of a glycerol molecule bonded to only two fatty acids instead of three, like triglyceride. Instead of a third fatty acid, a phospholipid contains a phosphate molecule that is covalently bonded to the third hydroxyl functional group on the glycerol. This phosphate group, unlike the fatty acids, does not share electrons equally with its various atoms and is therefore slightly electronegative and capable of forming polar covalent bonds with other molecules. These polar covalent bonds result in areas of the phospholipid that are partially charged and hydrophilic. They interact with water molecules. Therefore, the fatty acid part of the phospholipid macromolecule is hydrophobic while the other part, the phosphate group, is hydrophilic.

The unique combination of hydrophobic and hydrophilic chemical properties makes the phospholipid molecule the ideal component for cellular membranes. When placed in water, phospholipids assemble themselves into two layers, or bilayers, with the fatty acid tails clustered inward away from water and the phosphate groups outward, where they are exposed to water (**Figure 2**). This arrangement is ideal in cell membranes since both intracellular and extracellular fluids are aqueous.

**phospholipid** a glycerol bonded to two fatty acids and one phosphate

## Carbohydrates include monosaccharides and polysaccarides.

A **carbohydrate** is a molecule composed of carbon, hydrogen, and oxygen in the ratio of one carbon and oxygen atom for every two hydrogen atoms, or one carbon for every $H_2O$ molecule. The name *carbo*hydrate is therefore very appropriate.

Carbohydrates vary in complexity ranging from simple monomer sugars to complex polymers like starch, glycogen, and cellulose. Carbohydrates are ubiquitous in the plant and animal kingdoms, and, as with the other macromolecules, we are dependent on them for survival.

**carbohydrate** a macromolecule composed of large organic molecules made from carbon, oxygen, and hydrogen

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## Monosaccharides are carbohydrate monomers.

Carbohydrate monomers are called monosaccharides, or single sugars. The various types of monosaccharides are classified based on size, location of their characteristic carbonyl group (a carbon double bonded to oxygen), and the spatial arrangement of atoms around the carbons. Sugars naturally favor the form of carbon rings but are often portrayed in diagrams in the linear form for comparison.

The most common carbohydrate sugar is **glucose**, a molecule used for energy storage with the molecular formula $C_6H_{12}O_6$. A molecular formula indicates which atoms are present in a molecule and in what quantity, but it does not indicate how these atoms are connected. A structural formula shows how the atoms in a molecule are connected three-dimensionally. Two molecules can have the same molecular formula but different structural formulas, in which case the two molecules are called **isomers** of one another.

Glucose has several isomers, including fructose and galactose, each of which shares the molecular formula $C_6H_{12}O_6$. Because they are each arranged differently and have unique structural formulas, however, the molecules have very different chemical properties (**Figure 3**). Fructose, for example, tastes much sweeter than glucose. It is therefore necessary to consider both molecular and structural formulas in carbohydrates.

**glucose** a monosaccharide with the chemical formula $C_6H_{12}O_6$

**isomers** chemicals that have the same numbers and types of atoms but that differ in their structural arrangement

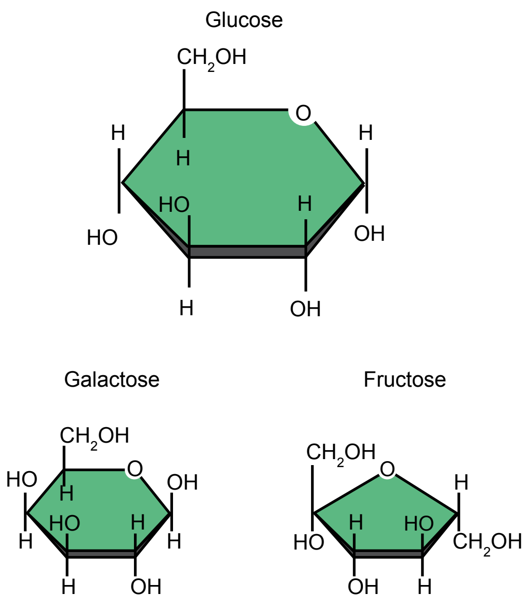


**Figure 3.** The molecular formulas of glucose, fructose, and galactose are the same, but their structural formulas differ, making these three monosaccharides isomers of one another.

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## Monosaccharides pair to form disaccharides.

Two monosaccharides can join to form a **disaccharide** (diy-SA-kuh-riyd) through an enzyme-catalyzed dehydration synthesis reaction. The two monomers are held together by a covalent bond called a glycosidic linkage. One of the products of this reaction is common table sugar, also known as sucrose, a disaccharide consisting of a glucose molecule and a fructose molecule. Maltose, another common disaccharide, consists of two joined glucose molecules. Lactose, the natural sugar found in milk, consists of glucose joined with a galactose molecule (**Figure 4**).

## Multiple monosaccharides join to form polysaccharides.

Carbohydrates become even more complex when more than two monomers are linked together and form long chains, hundreds to thousands of monomers long. The name **polysaccharide** (pah-lee-SA-kuh-riyd) reflects this characteristic, literally meaning "many sugars." With the most complex structures out of all the carbohydrates, polysaccharides provide the broadest range of functions, from energy storage to cellular building materials within organisms.

Plants store energy in the form of **starch**, a polysaccharide made up of many glucose molecules linked together in chains (**Figure 5**). Starches are helical in their structural arrangement and can be either branched or unbranched. Unbranched starch is called amylose, while the more complex branched starch is called amylopectin.

**disaccharide** a carbohydrate molecule composed of two monosaccharides bonded together

**polysaccharide** a complex carbohydrate, typically from a hundred to a thousand monomers in length

**starch** a polysaccharide made from glucose monomers, used for energy storage in plants

**1**
**SELF-CHECK**
What are the structural and functional differences between triglycerides and phospholipids?

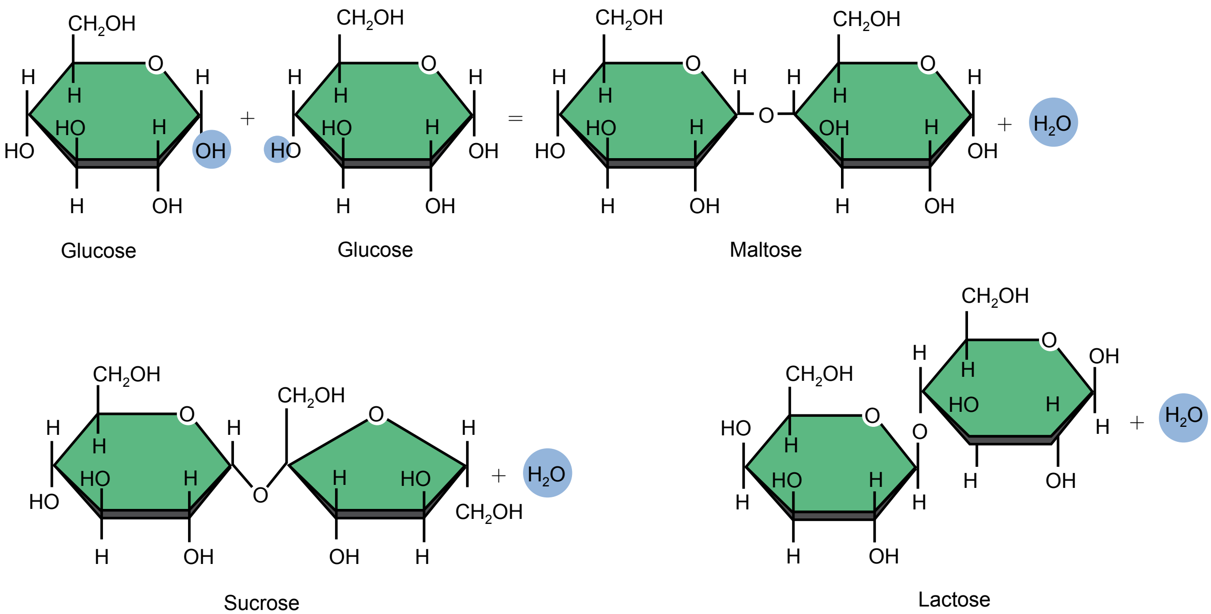


**Figure 4.** Maltose is a disaccharide formed by joining two glucose molecules with a glycosidic linkage. Sucrose is formed by joining glucose and fructose. Lactose is a combination of glucose and galactose molecules bonded together.

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Plants store starches in organelles called plastids when energy is abundantly available. When energy is no longer readily available to a plant, these starches are broken down through hydrolysis reactions to make glucose available to the plant to keep it alive temporarily. Humans use this adaptation in plants by harvesting and eating plants' starches. Corn, rice, potatoes, and wheat are only a few examples of energy stored in the form of starches that humans and other animals regularly take advantage of.

In animals, glucose is stored in the form of **glycogen**, a highly branched polysaccharide similar to the amylopectin found in plants. Glycogen provides quick energy in the form of glucose for cells when decreased food intake causes blood sugar levels to drop. When blood sugar is high, excess glucose is packaged into glycogen and stored in the liver and muscle cells until it is needed. Although it is useful in this sense, glycogen diminishes quickly if food intake does not increase within a day or two, at which point the body will resort to disassembling other macromolecules within the body for energy. Like starch, glycogen polysaccharides, through enzyme-aided hydrolysis reactions, make glucose available for cellular metabolic pathways.

In addition to energy storage, polysaccharides also play important structural roles within cells. The structural polysaccharide **cellulose** is the most abundant polysaccharide in the natural world. Cellulose, the main component of cell walls in plants, is a polymer of glucose, just like starch, but the glycosidic linkages holding the monomers together are located in different positions. In starch and glycogen, glucose rings exist in what is known as the alpha ($\alpha$) configuration with the hydroxyl group oriented downward from the rest of the molecule. In cellulose, the hydroxyl group at the 1 carbon position is oriented upward in the ($\beta$) configuration (**Figure 6**).

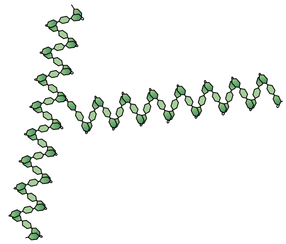

**Figure 5.** Starch is a polysaccharide made of many glucose molecules bonded together. Starches can form straight chains or complex branching structures.

**glycogen** a highly heavily branched polysaccharide made from glucose monomers, used for energy storage in animal cells

**cellulose** a structural polysaccharide made from glucose molecules in the beta configuration

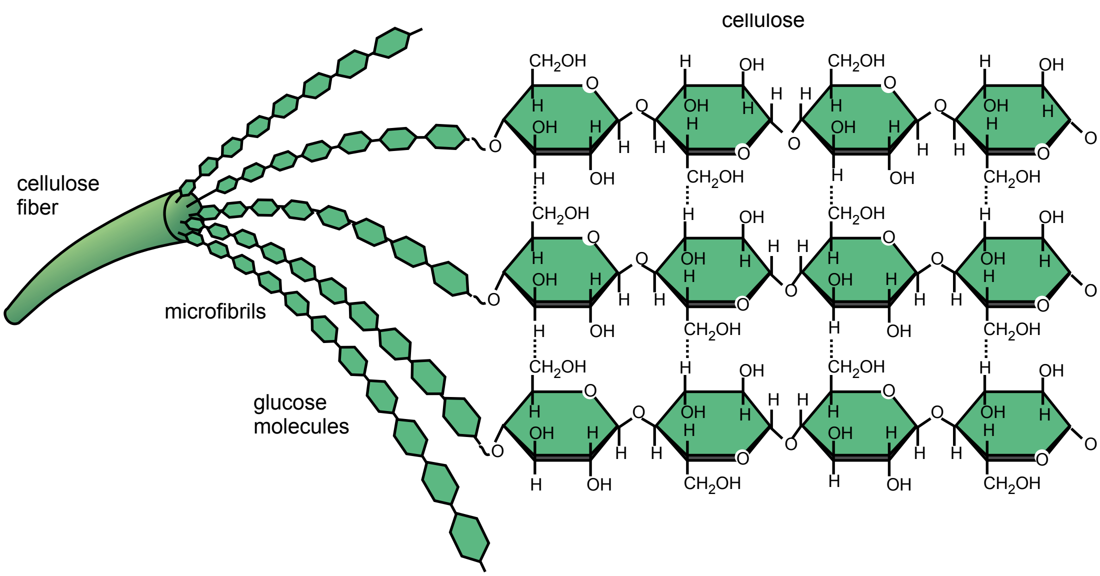


**Figure 6.** Cellulose is made of many glucose molecules joined in straight chains which connect to each other. The structure of cellulose differs from starch because of the upward ($\beta$) configuration of the hydroxyl group on the first carbon in the ring.

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This small difference in configuration is enough to prevent cellulose from being digested by humans and other non-ruminant animals because the shape does not allow cellulose to interact with digestive enzymes the way starch does. Cellulose from plants passes through our bodies undigested as insoluble fiber. Although we cannot use cellulose for energy, it is useful for cleaning out our digestive tracts and is considered a healthy, beneficial part of the human diet. Cows, horses, and other ruminant herbivores, on the other hand, can digest cellulose because cellulose-digesting bacteria located in the animals' digestive tracts. Another structural polysaccharide produces the diversity found in insects and fungi. Both utilize the polysaccharide **chitin** for various structural rolls. Arthropods use chitin to create the protective exoskeletons around their soft bodies. Mushrooms and other fungi use chitin instead of cellulose for structural support in their cell walls. Chitin, unlike the other polysaccharides, contains an additional nitrogen group attached to each glucose monomer, which allows for the functional differences between arthropods and fungi.

**chitin** a structural polysaccharide commonly found in arthropod exoskeletons and fungi cell walls

## Monomer substitution and elimination lead to changes in polymers.

Because macromolecule and organism function is so dependent on monomer structure and configuration, the effects on polymers of substituting, adding, or eliminating monomers can be profound. For example, a large focus of pathophysiology is devoted to genetic disorders resulting from seemingly simple changes made to proteins in transcription or translation error. These small changes make a huge difference in the functioning of organisms. As another example, small differences between polysaccharide glycosidic linkages are the differences between digestible glycogen and indigestible cellulose.

### Substitutions and eliminations can affect protein production.

Proteins are the workforce in cells and are often dependent on one another to carry out the functions necessary for life. One missing or incorrect nucleotide in DNA can wreak havoc in the human body. If a codon becomes improperly coded, an amino acid in the primary sequence will be eliminated, substituted, or added. A codon disruption that alters the correct sequence of an amino acid is called a point mutation. Just one missing amino acid can affect the folding and ultimately the function of the entire protein, and if one protein does not work, many systems in a body can malfunction as a result.

An example of the serious problems that point mutation can cause is sickle-cell disease in humans. Sickle-cell disease is a genetic blood disorder which produces abnormal, sickle-shaped red blood cells. Because of their shape, these cells have a tendency to get stuck together and form unwanted clots in the blood stream. This disease is the result of *one* monomer, glutamic acid, being substituted for the amino acid valine in the primary sequence of the protein hemoglobin. Sickle-cell anemia is only one example of the thousands of genetic disorders that can occur when only one monomer is out of place.

An elimination, substitution, or addition of a base within DNA or RNA does not automatically cause a point mutation. Frequently, the mistake occurs at a location that does not code for a specific amino acid. Sometimes, if a mistake does occur in

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a vital location within a gene, the proofreader enzymes such as DNA polymerase will trade out the incorrect base for the proper base before translation occurs, thus preventing the mistake from being passed on to the protein sequence.

## Different arrangements of polysaccharide monomers change the function of the polymers.

Whether polysaccharide carbohydrates are used for energy storage or structural integrity within cells, their function is determined by their more basic structure and how their sugar monomers are joined. Small changes in the molecular configuration of monosaccharides and their glycosidic linkages can lead to big differences in the ultimate function of the polysaccharide that these monomers form. The difference between a hydroxyl group oriented upward verses downward is the difference between digestible starch and indigestible cellulose. The presence of a nitrogen-containing group on some glucose molecules is the difference between exoskeleton-forming chitin and normal starch or glycogen.

Small structural differences result in much of the diversity that is observable in nature. Basic structure impacts the functioning of macromolecules and the world as we know it in pronounced ways, and as our understanding of these molecular differences grows, so does our understanding of the world.

**2**
**SELF-CHECK**
Which chemical reaction puts carbohydrate monomers together, and which reaction takes them apart?

**3**
**SELF-CHECK**
Which is more dangerous to the function of an organism: a substituted base or a substituted amino acid?

## *Extensions*

- Read the scientific paper entitled "Kinetics of Cellulose Digestion". What other possible avenues of research could be explored based on the findings of this paper?
- Explore the American Heart Association website about fats and oils. What effects do different fats and oils have on our health and what were some scientific findings that helped lead researchers to these conclusions?

## *Summary*

Macromolecules are the building blocks of all living things, and their molecular components determine their function. Lipids are macromolecules constructed out of glycerol, fatty acid, and steroid molecules. Triglycerides are the lipids known as fat and contain a glycerol unit attached to three fatty acids. Depending on the number of double bonds present in the fatty acids, triglycerides are considered either saturated or unsaturated. Phospholipids are similar to triglycerides, but one fatty acid is replaced by a polar phosphate group, making the molecule ideal for use in cell membranes. Carbohydrate macromolecules range from simple monosaccharide units to more complex disaccharide or polysaccharide units and function as energy storage or structural support in cells. Because structure determines function, eliminations, additions, and substitutions of monomers can prove detrimental to organism function.

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## *Connections*

What happens if a human body runs out of energy-storing glycogen? Since it only takes about a day for liver and skeletal muscles to be depleted of this resource, metabolic pathways exist to switch and use other backup sources of energy if glycogen stores fail before more food is consumed. When glycogen is present, glucose splits off from glycogen through the process of glycogenolysis. Cells switch over to the process of gluconeogenesis when glycogen stores become depleted. In gluconeogenesis, glucose is formed from noncarbohydrate materials including amino acids, glycerol, lactate, and pyruvate. Over time, lipolysis provides most energy for cells by breaking down adipose tissue. Once adipose tissue is used up, however, the dangerous process of proteolysis begins as the body breaks down its own protein for energy from muscles and visceral organs, including the heart, lungs, and kidneys. If these vital organs become too catabolized, body functions cease, and the body dies from starvation.

### SELF-CHECK ANSWERS

**1.** A triglyceride is a glycerol attached to three fatty acids, while a phospholipid is a glycerol attached to two fatty acids and a phosphate group. A triglyceride is a nonpolar hydrophobic molecule. The phosphate on the phospholipid produces a molecule with both polar and nonpolar portions, so a phospholipid is both hydrophobic and hydrophilic.

**2.** Dehydration synthesis reactions allow enzymes to join monosaccharides while hydrolysis reactions detach glucose monomers in cells, freeing them for use in metabolic pathways.

**3.** A substituted base may or may not cause the dangerous point mutation that disrupts the primary amino acid sequence. The substituted base could be considered less dangerous because disruption is only a possibility, whereas a substituted amino acid will always disrupt the protein.

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## Unit 7 Lesson 2

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