LESSON 2

# Organic Molecules: Lipids and Carbohydrates

BIO.A.2.2.1, BIO.A.2.2.2, BIO.A.2.2.3

You may have heard the phrase "carbon based life form." Actually, all life on Earth is carbon based because this element forms the compounds that make up cells and organisms. **Organic compounds** contain carbon and hydrogen, often along with oxygen, nitrogen, phosphorus, or other elements.

*Organic compounds contain carbon atoms bonded to hydrogen atoms.*

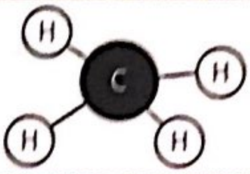
## The Uniqueness of Carbon

When atoms share electrons, they form covalent bonds. Elements differ in the number of covalent bonds they can form. Think of drink cup holders with different numbers of slots for cups. A hydrogen atom is a single cup holder—it can form just a single covalent bond with another atom. An atom of oxygen can form up to two bonds; it is a two-cup holder. A carbon atom is a deluxe cup holder with four slots—the most of any element!

*Covalent bonds may be single, double, or triple bonds. In a single bond, one pair of electrons is shared between the atoms. In a double bond, two pairs are shared, and three pairs are shared in a triple bond.*

A carbon atom is most stable when all four of its slots are filled. The simplest organic molecule, methane, is a carbon atom singly bonded to four hydrogen atoms. Single bonds fill all four slots. But carbon can also form double or triple bonds. A carbon atom doubly bonded to two oxygen atoms forms carbon dioxide. Carbon can even form a triple bond, as in the acetylene molecule. Notice that the hydrogen atoms in acetylene fill the remaining slots for each carbon atom.

**BONDS IN CARBON MOLECULES**

| Compound | Formula | Molecule |
|---|---|---|
| Methane | $CH_4$ |  |
| Carbon dioxide | $CO_2$ |  |
| Acetylene | $C_2H_2$ |  |

Carbon is unique in that a single atom can form up to four covalent bonds.

The diagram shows part of a carbon compound. Its hydrogen atoms are not shown. How many hydrogen atoms are needed to make up one molecule of the compound?

A 5

B 6

C 7

D 8

The left-hand carbon forms one double bond. It can therefore form two single bonds with hydrogen atoms. The central carbon forms a double and a single bond. It is able to form one more single bond to a hydrogen atom. The right-hand carbon atom forms a single bond with the central carbon and has the capacity for three more single bonds. The total number of hydrogen atoms is 2 + 1 + 3 = 6, choice B.

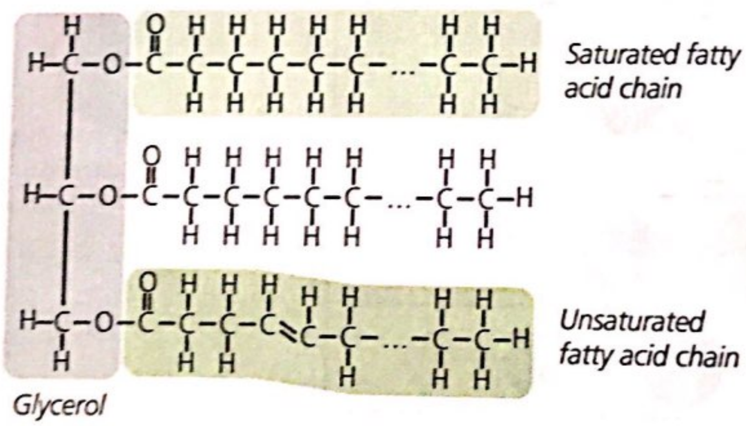
Carbon's unique structure allows the formation of **macromolecules,** large, complex molecules such as lipids, carbohydrates, proteins, and nucleic acids.

**Macromolecules** are large, complex molecules made of chains of smaller molecules.

## Lipids: Fats and Oils

**Lipids** include fats, oils, waxes, and sterols (such as cholesterol). Fats and oils share the same basic structure: *fatty acid* "tails" connected to a single *glycerol* molecule. A fatty acid is a long chain of carbon atoms connected to each other by single or double bonds. Lipids consist almost entirely of carbon and hydrogen atoms, with very few oxygen atoms.

Because lipids are nonpolar molecules, they are not soluble in water.




**This lipid molecule consists of glycerol attached to three fatty acid chains. Note the difference between the saturated and the unsaturated fatty acids.**

In fats and oils, a single *glycerol* molecule is attached to three long *fatty acid* chains. Because they are not made up of repeating subunits, lipids are not considered polymers.

Fatty acids may be saturated or unsaturated. In a saturated fatty acid, the carbon atoms have the maximum number of single bonds (and hydrogen atoms). An unsaturated fatty acid has fewer than the maximum number of bonds. That is, it has one or more double bonds.

Lipids have the following important functions:

- **Energy storage—**Organisms may convert other organic molecules to lipids for long-term storage. For example, your body's *adipose* tissue is made up of cells with special compartments that store lipids.
- **Cell membranes—**Phospholipids help to form the plasma and organelle membranes of the cell. A phospholipid contains a polar phosphate group attached to glycerol.
- **Insulation and protection—**Fats help to insulate the body and provide vital cushioning to major organs. Waxes coat and protect some organisms.
- **Chemical messengers—**Another class of lipids, the *sterols*, act as chemical messengers or hormones. Cholesterol is the basic molecule from which estrogen, progesterone, and testosterone are made.

Fats and oils provide 9 Calories of energy per gram. Unsaturated fats are thought to be healthier than saturated fats.

*Adipose* tissue is the tissue found in your body that helps to store "fat."

Some insects have a waxy coating to keep them from getting wet in rainy weather. Plant leaves have a waxy cuticle to prevent water loss.

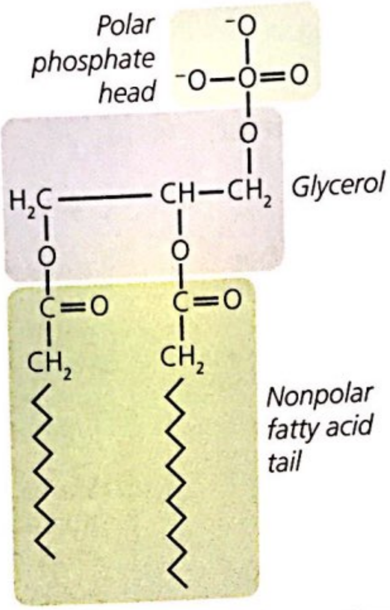
*Sterols* are lipid molecules that act as chemical messengers within your body.

A double bond causes a fatty acid chain to kink or bend. This makes the lipid more likely to melt at room temperature. Explain whether fats (solids at room temperature) or oils (liquid) are more likely to have saturated fatty acids.

While a saturated fatty acid chain is straight, an unsaturated fatty acid chain has a double bond, which causes it to bend. This makes it more difficult for the lipid to take on a rigid, tightly packed, solid form. Since fats tend to be solid at room temperature, they are more likely to have fully saturated fatty acids. Oils tend to have unsaturated fatty acids.

## Phospholipids

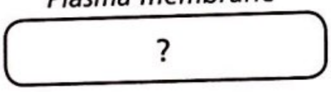
The plasma membrane is made up of *phospholipids*. Two fatty acid chains make up the nonpolar "tails" while the phosphate group is the polar "head." The lipids in cell membranes make them impermeable to water; water cannot cross the membrane directly, but must go through special protein channels.




**A phospholipid molecule consists of a polar "head" region and a nonpolar "tail."**

**Phospholipids** are the major component of cell membranes. Because the lipid portion is nonpolar, it is impermeable to water.

The plasma membrane is made up of a phospholipid bilayer, or two sheets of phospholipids. Given the structure of a phospholipid, how are these sheets arranged in the plasma membrane?




**A** head•tail—head•tail

**B** head•tail—tail•head

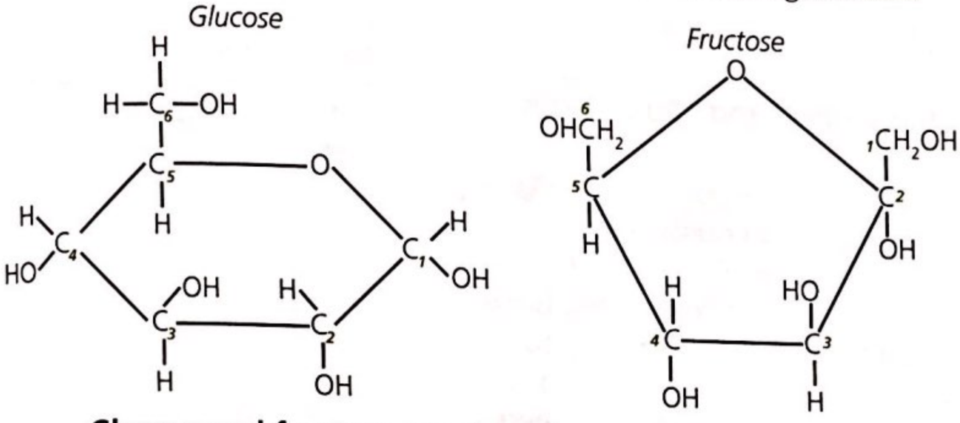
**C** tail•head—tail•head

**D** tail•head—head•tail

Both the exterior of the cell and the cytoplasm are water solutions. Therefore, the polar phosphate "heads" will be oriented toward the outer sides of the membrane. The nonpolar, hydrophobic fatty acid "tails" will be on the inside of the membrane, away from water. Choice B is correct.

## Carbohydrates

**Carbohydrates** consist of carbon, hydrogen, and oxygen, in a 1:2:1 ratio. Glucose, the compound used by cells for energy, is the simplest type of carbohydrate, a *monosaccharide*. Monosaccharides with six carbon atoms all have the molecular formula $C_6H_{12}O_6$. The carbon and oxygen atoms often form the basic structure, a ring. Monosaccharides also include the *isomers* fructose and galactose.




**Glucose and fructose are six-carbon monosaccharides.**

The table sugar you're familiar with is a *disaccharide* called sucrose. Disaccharides consist of two monosaccharides joined in a double-ring structure. In the case of sucrose, the monosaccharides are glucose and fructose.

## Polysaccharides

Small organic molecules such as monosaccharides may be linked up in chains of many hundreds to create much larger macromolecules. These basic building block units are **monomers,** and they join together to form large *polymers*. Glucose is an important monomer. Many glucose molecules link together to form *polysaccharides*, such as starch, glycogen, and cellulose.

Starch is a complex carbohydrate produced by plants to store energy. Starch molecules may be extremely long, straight chains of glucose, or chains with multiple branches. Sources of starch include wheat, rice, and potatoes.

Glycogen is the human body's equivalent of starch, found in the liver and muscles. Glycogen is broken down into glucose when energy is required. It is more highly branching than plant starch, and forms around a central kernel of protein.

Cellulose is a structural carbohydrate that makes up plant cell walls. It functions to strengthen and support the plant cell. This polysaccharide can be broken down by very few organisms.

A **carbohydrate** is a macromolecule made of carbon, hydrogen, and oxygen, that cells use for energy.

A gram of carbohydrate provides 4 Calories of energy.

Carbohydrates contain proportionally more oxygen than lipids do. The generic formula for a monosaccharide is $C_nH_{2n}O_n$.

*Isomers* have the same molecular formula but different arrangements of atoms.

Two monosaccharides join to form a *disaccharide*.

**Monomers** are smaller building block molecules that combine through chemical reactions to form large polymers.

*Polysaccharides* include glycogen, starch, and cellulose. Glycogen has chains that branch off in many directions, while starch is more linear.

Like lipids, carbohydrates also have many different functions:

- **Cellular respiration**—Carbohydrates are digested to glucose, which enter cells to be used in cellular respiration.
- **Energy storage**—Glycogen and starch store energy for animals and plants, respectively. Glycogen in the muscles and liver can be broken down into glucose. Plant starches, such as wheat, potatoes, and corn, can be ingested for energy.
- **Structure**—Cellulose strengthens the plant cell walls.

Because of how the glucose monomers are linked, cellulose is not digestible by most animals. It is therefore a good source of indigestible fiber in the diet.

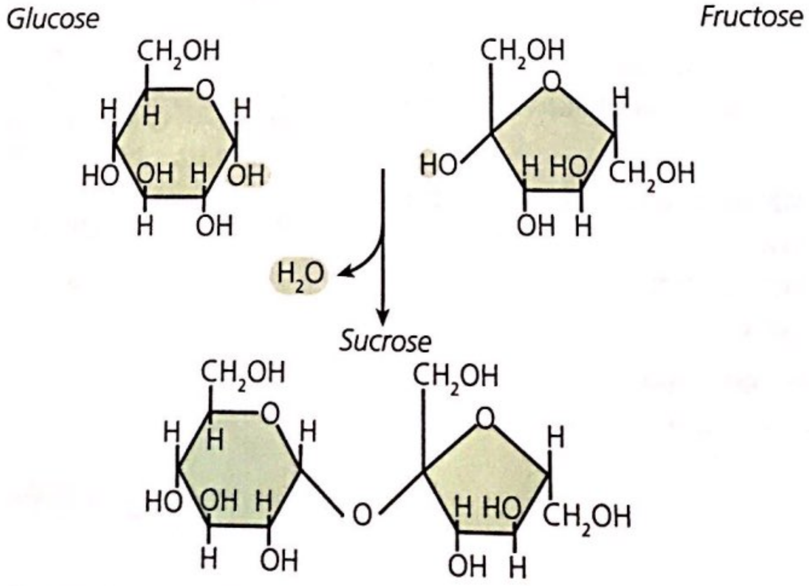
Compare 100 Calories' worth of table sugar and 100 Calories' worth of baked potato.

Table sugar is a disaccharide while potato consists of a polysaccharide, starch. Starch is a macromolecule. Both are similar in that they are composed of monosaccharides. Both contain glucose, although table sugar also contains fructose. Both are carbohydrates and provide 4 Calories per gram. Both consist of the elements carbon, hydrogen, and oxygen.

## Reactions That Make or Break Macromolecules

In organisms, specific chemical reactions join monomers together and break polymers apart. The first is called *dehydration synthesis,* and it occurs when two monomers join together. For monosaccharides, two –OH groups join together, losing two hydrogen atoms and one oxygen atom. The two monomers are now linked and one molecule of water ($H_2O$) is created. Multiple rounds of dehydration synthesis create large macromolecules from small monomers. This reaction also joins fatty acids to a glycerol molecule, which has three –OH groups.

*Dehydration synthesis* joins monomers together to form large polymers. Water is produced as a by-product of the reaction. Some textbooks call this a *condensation reaction.*

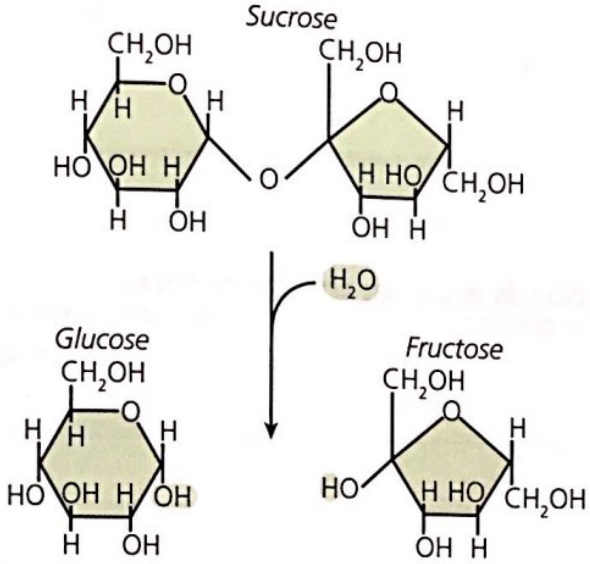



In these diagrams, the carbon atoms are not all labeled. They also occur at any unlabeled angles between straight lines.

**Dehydration synthesis produces sucrose from glucose and fructose. It also produces a water molecule.**

When organisms need to break down polymers into monomers, they use a chemical reaction called *hydrolysis*. A molecule of water is used to add back the –OH group and hydrogen atom to the monomers. As a result, the chemical bond between the monomers is broken. Hydrolysis is the reverse of dehydration synthesis.

*Hydrolysis* reactions break down polymers into smaller monomers. The root term *hydro* means "water" and *lysis* means "to loosen or release."




**Water is required for the hydrolysis of sucrose.**

In a cell, 132 glucose monomers are joined to form a straight chain of starch. Explain how the number of water molecules changes.

Dehydration synthesis joins monomers together to form polymers, producing water. If 132 monomers are joined, the dehydration synthesis reaction must occur 131 times. Therefore, 131 new water molecules form.

# IT'S YOUR TURN

**Please read each question carefully. For a multiple-choice question, circle the letter of the correct response. For a constructed-response question, write your answers on the lines.**

**1** A single atom of carbon is joined to a hydrogen atom. What is the maximum number of double bonds the carbon atom may yet form?

A 1
B 2
C 3
D 4

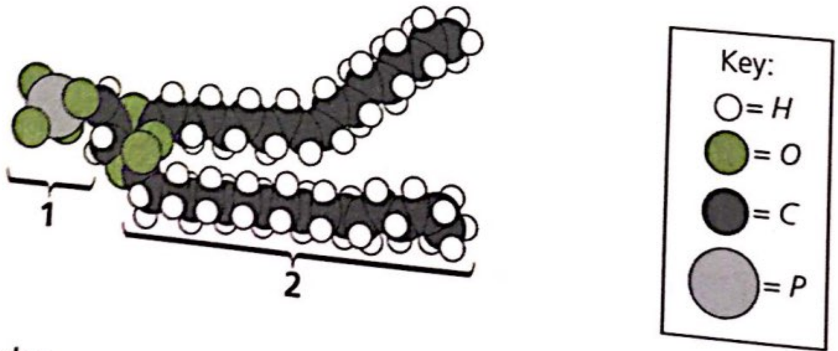
**2** Which of the following types of compounds is unlike the other three?

A wax
B saturated fat
C phospholipid
D polysaccharide

**3** Which of the following is **not** created as a result of dehydration synthesis?

A cellulose
B disaccharide
C glucose
D water

***Use the diagram below to answer question 4.***




**4** The diagram shows a molecule with regions numbered 1 and 2. Which statement correctly describes the molecule?

A Region 1 is composed of fatty acids and is polar.
B Region 1 is composed of phosphate and is nonpolar.
C Region 2 is composed of phosphate and is polar.
D Region 2 is composed of fatty acids and is nonpolar.

5 Lipids, such as fats and oils, play important roles in living organisms. Carbohydrates also carry out essential functions in living things.

A Describe the general structure of a fat or oil molecule.

B Describe how the structures of fats and oils differ from the structure of carbohydrates.

C Describe how a function of fats and oils is similar to a function of carbohydrates.