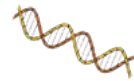




Chapter 13

Nutrients of Life

THE MAIN IDEA



There are four main classes of biomolecules.

13.1 Biomolecules

13.2 Carbohydrates

13.3 Lipids

13.4 Proteins

13.5 Nucleic Acids

13.6 Vitamins and Minerals

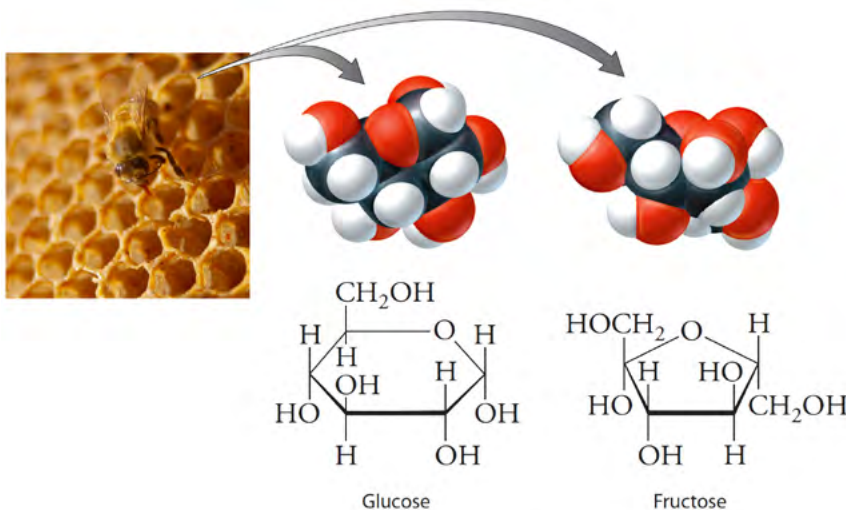
13.7 Metabolism

13.8 A Healthy Diet



13.2 Carbohydrates

Carbohydrates are organic molecules produced by photosynthetic plants, containing carbon, hydrogen, and oxygen. The term *carbohydrate* is derived from the fact that plants make these molecules from carbon (from atmospheric carbon dioxide) and water. The term **saccharide** is a synonym for carbohydrate, and a *monosaccharide* (“one saccharide”) is the fundamental carbohydrate unit. In most monosaccharides, each carbon atom is bonded to at least one oxygen atom, most often within a hydroxyl group. There are many kinds of monosaccharides. The structures of the two most common monosaccharides, glucose and fructose, are shown in **Figure 13.2**.



< **Figure 13.2**

Honey is a mixture of the monosaccharides glucose and fructose. Glucose has a six-membered ring, and fructose has a five-membered ring. The stick structures introduced in Chapter 12 are shown below each molecular model.

Figure 13.3 >

Disaccharides, such as sucrose, consist of two chemically bonded monosaccharide units, which are cleaved during digestion.



Monosaccharides are the building blocks of *disaccharides*, which are carbohydrate molecules containing two monosaccharide units linked together. **Figure 13.3** shows table sugar—*sucrose*—the best-known disaccharide. In the digestive tract, sucrose is readily cleaved, or separated, into its monosaccharide units, glucose and fructose.

Lactose, shown in **Figure 13.4**, is another important disaccharide. Lactose is the main carbohydrate in milk. In the digestive tract, it is cleaved into the monosaccharides galactose and glucose by the enzyme lactase, which most children produce in abundance up to about the age of 6. Thereafter, the production of this enzyme decreases, with the result that some adults

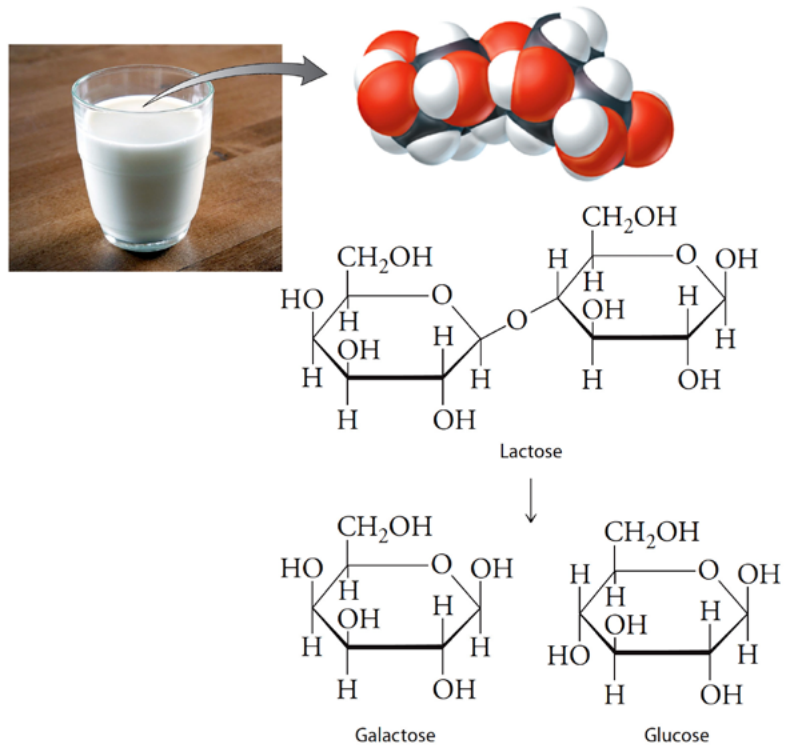


Figure 13.4 >

Milk and milk products contain the disaccharide lactose, which is digested to galactose and glucose.

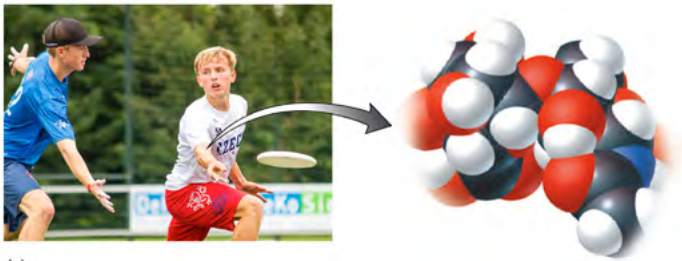
produce little or none. This leads to *lactose intolerance*, a condition in which ingestion of milk or milk products leads to bloating, flatulence, and painful cramps. These symptoms result as certain intestinal bacteria vigorously digest the lactose. In doing so, they generate large amounts of gases, such as hydrogen, H₂. To relieve these symptoms, some milk products are treated with *Acidophilus bifidus*, a strain of bacteria that destroy gas-causing bacteria in the digestive tract. Some lactose-intolerant individuals add commercially available lactase enzyme to milk or milk products before consuming them.

Monosaccharides and disaccharides are classified as *simple carbohydrates*. The word *simple* is used because these food molecules consist of only one or two monosaccharide units. Most simple carbohydrates have some degree of sweetness and are also known as *sugars*.

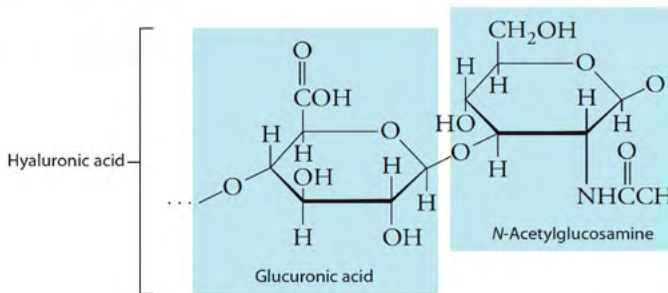
Carbohydrates	
Simple	Complex
<i>Monosaccharides</i>	<i>Polysaccharides</i>
Glucose	Hyaluronic acid
Fructose	Chitin
<i>Disaccharides</i>	Starch
Sucrose	Glycogen
Lactose	Cellulose

Polysaccharides are Complex Carbohydrates

Recall from Chapter 12 that polymers are large molecules made of repeating monomer units. Monosaccharides are the monomers that link to form the biomolecular polymers called *polysaccharides*, which contain hundreds to thousands of monosaccharide units. Polysaccharides can be built from any type of monosaccharide units. Our bone joints are lubricated by the polysaccharide hyaluronic acid, for example, which consists of alternating glucuronic acid and *N*-acetylglucosamine, as shown in **Figure 13.5a**.



(a)



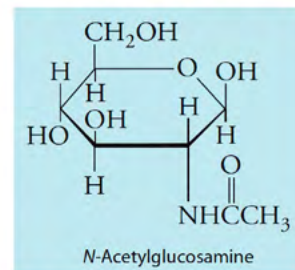
< **Figure 13.5**

(a) Hyaluronic acid, a lubricant in bone joints, is a polysaccharide consisting of the monosaccharides glucuronic acid and *N*-acetylglucosamine.

(b) The exoskeletons of insects, crabs, shrimp, and lobsters are made of chitin, a polysaccharide containing only *N*-acetylglucosamine units.



(b)



The exoskeletons (protective shells) of insects and some marine organisms, such as crabs and shrimp, are made of *chitin* (pronounced kite'-in), a hard, resilient polysaccharide made of the monosaccharide *N*-acetylglucosamine, shown in **Figure 13.5b**. The wood varnish known as shellac contains the chitin from the exoskeletons of insects. In powdered form, chitin is now finding use as a dietary fiber supplement.

Although a polysaccharide can be made of any type of monosaccharide unit, the polysaccharides in the human diet are made only of glucose. These polysaccharides include *starch*, *glycogen*, and *cellulose*, which differ from one another only in the way the glucose units are connected together. All polysaccharides, but especially the ones in our diet, are known as *complex carbohydrates*. *Complex* refers to the multitude of monosaccharide units linked together.

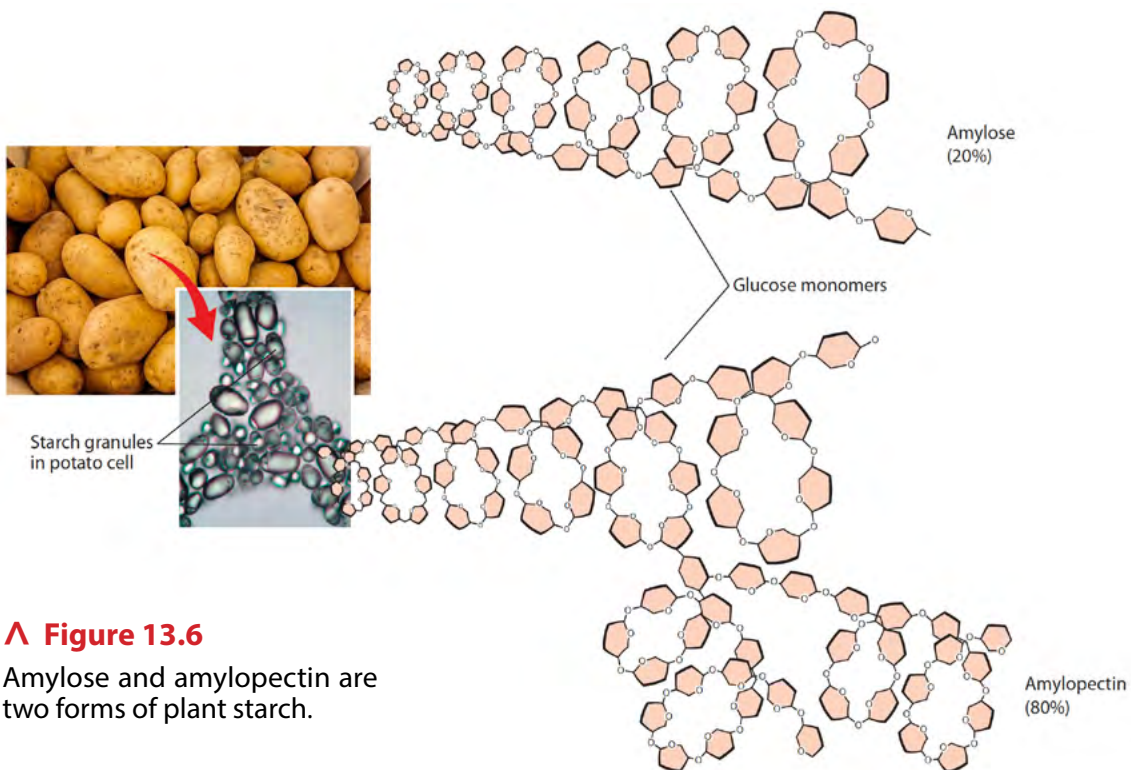
Starch is a polysaccharide produced by plants to store the abundance of glucose formed during photosynthesis, the process by which plants convert solar energy to the chemical energy of sugar molecules. (We shall return to a discussion of photosynthesis in Chapter 15.) On cloudy days or at night, the breakdown of starch polymers to glucose gives the plant a constant energy supply. Animals can also obtain glucose from plant starch, which makes plant starch an all-important food source. Most plants store the starch they produce either in their seeds or in their roots.

Plants produce two forms of starch, *amylose* and *amylopectin*, as illustrated in **Figure 13.6**. In amylose, the glucose units are linked together in unbranched chains that coil. In amylopectin, the glucose units are linked together in coiling chains that branch periodically. The starch of most starchy foods, such as bread and potatoes, is about 20 percent amylose and 80 percent amylopectin. As these foods are digested, glucose units are broken off the ends of the chains. In Figure 13.6, you can see that because of its branching, amylopectin has more ends than amylose does. Therefore, amylopectin releases glucose units at a faster rate than amylose does.



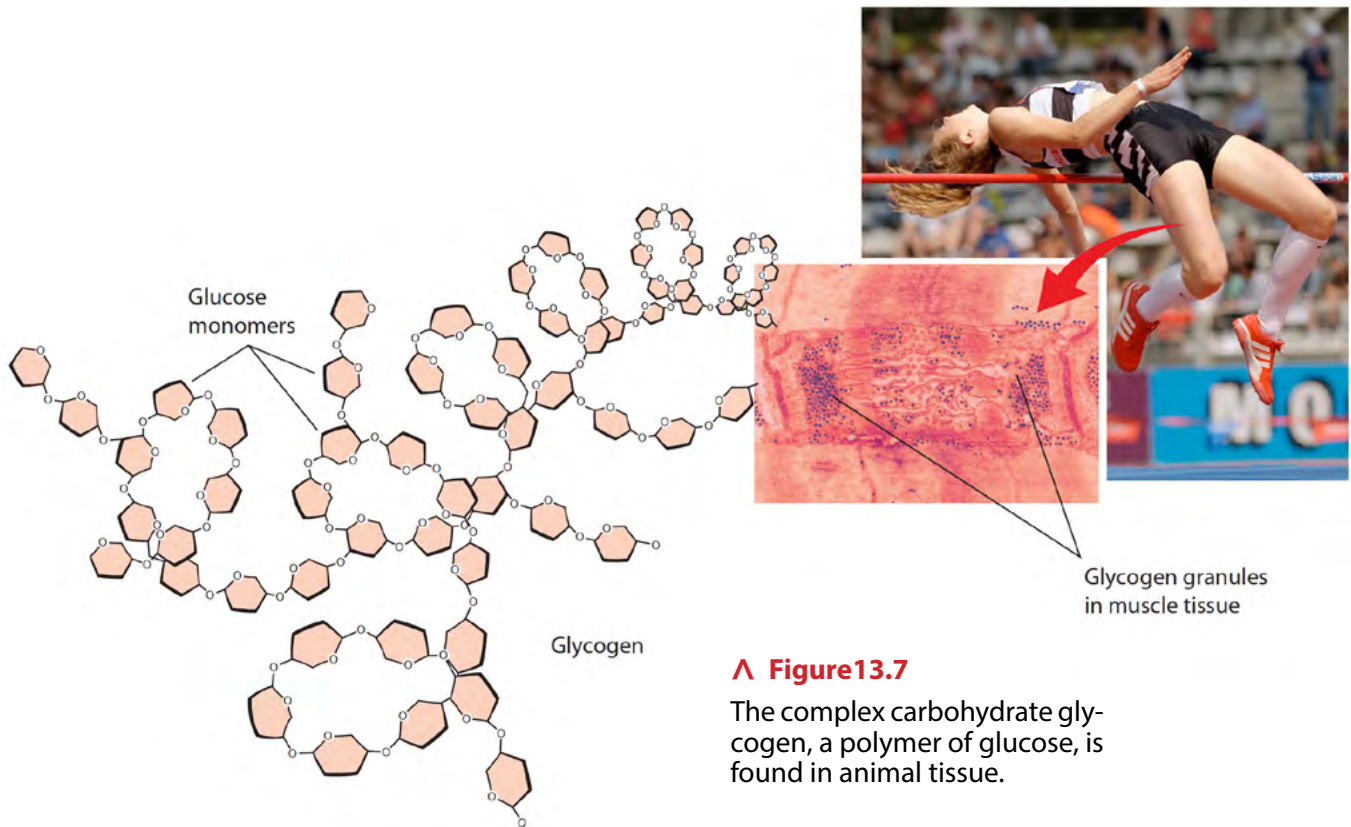
READING CHECK

What is starch?



^ Figure 13.6

Amylose and amylopectin are two forms of plant starch.



▲ Figure 13.7

The complex carbohydrate glycogen, a polymer of glucose, is found in animal tissue.

Animals store their excess glucose by converting it to **glycogen**, a polymer made of hundreds of glucose monomers and sometimes referred to as *animal starch*. Glycogen has a structure much like that of amylopectin but with a greater extent of branching, as shown in **Figure 13.7**. Between meals, when glucose levels drop, the body metabolizes glycogen to glucose. Glycogen therefore serves as our glucose reserve. Most of this glycogen is stored in our livers and muscle tissue.

CONCEPT CHECK

What makes a simple carbohydrate simple and a complex carbohydrate complex?

CHECK YOUR ANSWER We refer to a carbohydrate as simple when it consists of only one or two monosaccharide units per molecule. Complex carbohydrates consist of large numbers of monosaccharide units per molecule.

Cellulose, a structural component of plant cell walls, is also a polysaccharide of glucose. The glucose in cellulose, however, is slightly different from the glucose in starch and glycogen. As highlighted in **Figure 13.8**, the glucose in cellulose is identical to the glucose in starch except for the orientation of one hydroxyl group. Because this particular hydroxyl group is involved in the joining of glucose monomers, the way in which the glucose units join together is affected. The glucose units of starch and glycogen are connected by what is called an alpha (α) linkage, which results in a coiling of the polysaccharide strand. The glucose units of cellulose are connected by a beta (β) linkage, which results in straight uncoiled, unbranched chains. These two attributes of cellulose molecules allow the polysaccharide strands to align much like strands of uncooked spaghetti. This alignment maximizes

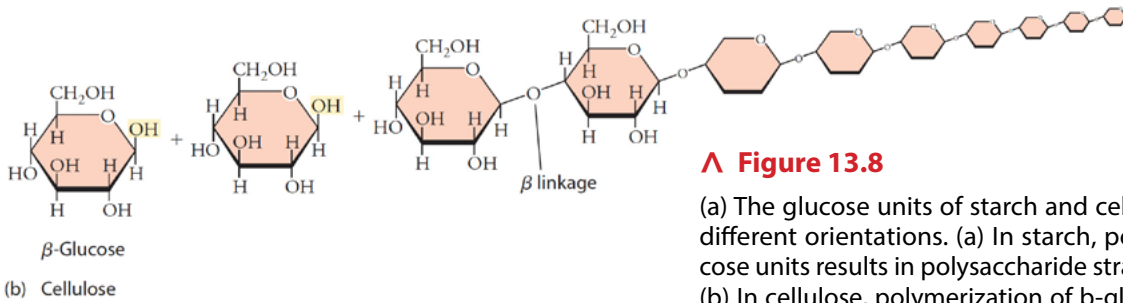
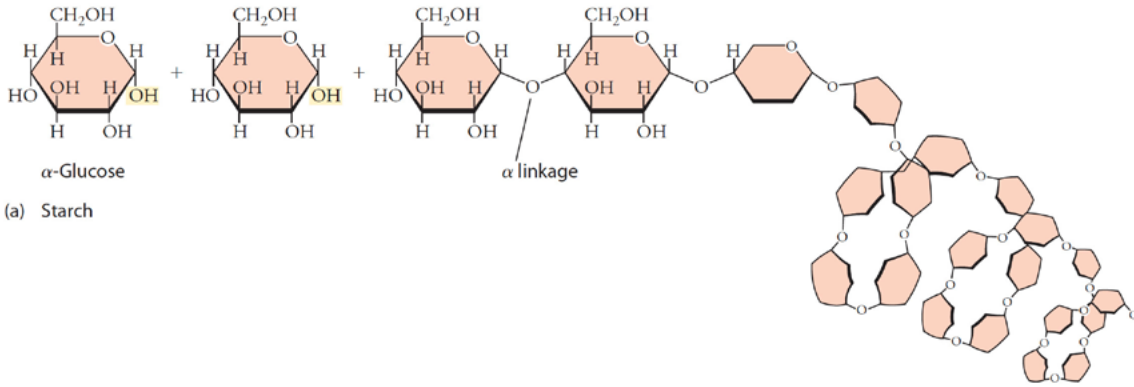
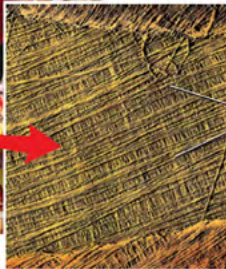


Figure 13.8

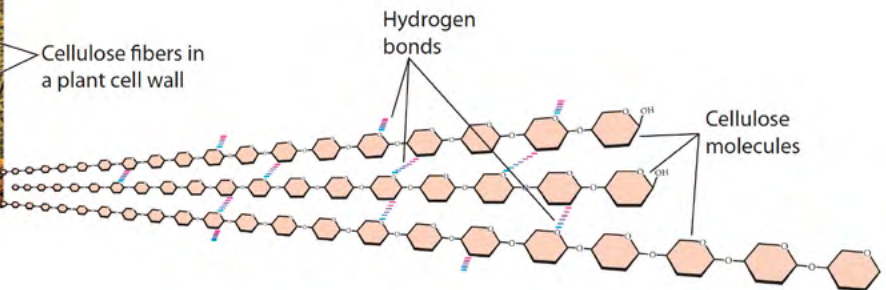
(a) The glucose units of starch and cellulose are bonded in different orientations. (a) In starch, polymerization of glucose units results in polysaccharide strands that tend to coil. (b) In cellulose, polymerization of β -glucose units results in polysaccharide strands that do not coil and so can align with one another.



Cellulose fibers in a plant cell wall

Figure 13.9

Strands of cellulose in a plant, including the leaves held by Maitreya, are joined by hydrogen bonds. These microscopic fibers are laid down in a crisscross pattern to give strength in many directions.



the number of hydrogen bonds between strands, which makes cellulose a tough material. Plants produce microscopic cellulose fibers in a crisscross fashion, as shown in **Figure 13.9**, increasing their structural strength.

Cellulose serves as the primary structural component of all plants. Cotton is nearly pure cellulose. Wood, made largely of cellulose, can support trees that are as much as 30 meters tall. Cellulose is by far the most abundant organic compound on the Earth.

Most animals, including humans, are not able to break down cellulose into its monomer units, glucose. Instead, the cellulose in the food we eat serves as dietary fiber that helps in regulating bowel movements. In the large intestine, cellulose-based fiber absorbs water and has a laxative effect. Waste products are therefore moved along faster and, with them, harmful bacteria and toxins, including carcinogens. Microorganisms that live in the digestive tracts of wood-eating termites and grass-eating ruminants, such as cattle, sheep, and goats, can break down cellulose to glucose. Strictly speaking, termites and ruminants do not digest cellulose. Rather, they digest the glucose produced by the cellulose-digesting microorganisms that live inside them, as shown in **Figure 13.10**.



^ Figure 13.10

A termite digests glucose produced by cellulose-digesting microorganisms living in the termite's digestive tract.

CONCEPT CHECK

When amylose and amylopectin are digested, which one supplies glucose at a faster rate?

CHECK YOUR ANSWER There is more branching in amylopectin and therefore a greater number of ends per molecule. The digestion of amylopectin produces more glucose molecules at a faster rate and therefore is a quicker and more immediate supply of glucose.