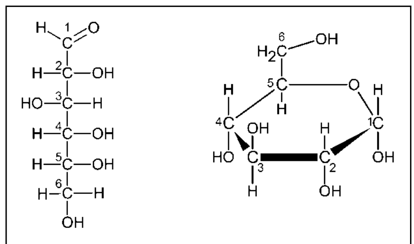
43. Glucose

CHEMICAL NAME = 6-(hydroxymethyl)oxane-2,3,4,5-tetrol
CAS NUMBER = 50–99–7 (D-glucose)
MOLECULAR FORMULA = $C_6H_{12}O_6$
MOLAR MASS = 180.2 g/mol
COMPOSITION = C(40.0%) H(6.7%) O(53.3%)
MELTING POINT = 146°C
BOILING POINT = decomposes
DENSITY = 1.54 g/cm^3



Glucose is one of the most important biological compounds found in nature. It is a main product in photosynthesis and is oxidized in cellular respiration. Glucose polymerizes to form several important classes of biomolecules including cellulose, starch, and glycogen. It also combines with other compounds to produce common sugars such as sucrose and lactose. The form of glucose displayed above is D-glucose. The "D" designation indicates the configuration of the molecule. The "D" configuration specifies that the hydroxyl group on the number 5 carbon is on the right side of the molecule (Figure 43.1). The mirror image of D-glucose produces another form of glucose called L-glucose.

In L-glucose, the hydroxyl group on the number 5 carbon is on the left hand side. The designations "D" and "L" are based on the configuration at the highest chiral center, which is carbon number 5. D-glucose is the common form found in nature. Glucose's biochemical abbreviation is Glc.

Glucose is the most common form of a large class of molecules called carbohydrates. Carbohydrates are the predominant type of organic compounds found in organisms and include sugar, starches, and fats. Carbohydrates, as the name implies, derive their name from glucose, $C_6H_{12}O_6$, which was considered a hydrate of carbon with the general formula of $C_n(H_2O)_n$, where n is a positive integer. Although the idea of water bonded to carbon to form a hydrate of carbon was wrong, the term *carbohydrate* persisted. Carbohydrates consist

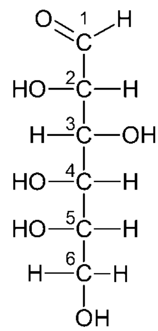


Figure 43.1 Numbering system for carbons in glucose.

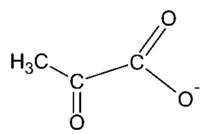
of carbon, hydrogen, and oxygen atoms, with the carbon atoms generally forming long unbranched chains. Carbohydrates are also known as saccharides derived from the Latin word for sugar, *saccharon.*

Carbohydrates contain either an aldehyde or a ketone group and may be either simple or complex. Simple carbohydrates, known as monosaccharides, contain a single aldehyde or ketone group and cannot be broken down by hydrolysis reactions. Glucose is a simple carbohydrate containing an aldehyde group. Disaccharides consist of two monosaccharides units bonded together. Maltose and cellobiose are disaccharides formed from two glucose units. They differ in one of the glucose units having an α rather than a β configuration as discussed in the next paragraph. Sucrose and lactose are examples of disaccharides, where glucose is combined with another sugar. Sucrose is a combination of glucose and fructose; lactose is formed from glucose and galactose.

Although often displayed as an open chain structure, glucose and most common sugars exist as ring structures. The ring structure displayed is the alpha (α) form. In the α form, the hydroxyl group attached to carbon 1 and the CH_2OH attached to carbon 5 are located on opposite sides of the ring; β-glucose has these two groups on the same side of the ring. Also, glucose may exist as l and d forms. The "l" and "d" labels come from the Latin *laevus* and *dexter* meaning left and right, respectively, and refers to the ability of solutions of glucose to rotate plane-polarized light to the left or right. Rotation to the left is generally specified by using a negative sign (–) prefix and positive rotation is given by a positive (+) sign. The rotation of light in glucose is due to the existence of mirror image forms of each molecule called stereoisomers. The D and L forms are mirror images and will rotate polarized in opposite direction. The capital letters L and D that designate configuration at the highest numbered chiral center should not be confused with the small letters l and d, which refer to the direction that plane polarized light rotates.

D-Glucose is the most important and predominant monosaccharide found in nature. It was isolated from raisins by Andreas Sigismund Marggraf (1709–1782) in 1747, and in 1838, Jean-Baptiste-André Dumas (1800–1884) adopted the name glucose from the Greek word *glycos* meaning sweet. Emil Fischer (1852–1919) determined the structure of glucose in the late 19th century. Glucose also goes by the names dextrose (from its ability to rotate polarized light to the right), grape sugar, and blood sugar. The term *blood sugar* indicates that glucose is the primary sugar dissolved in blood. Glucose's abundant hydroxyl groups enable extensive hydrogen bonding, and so glucose is highly soluble in water.

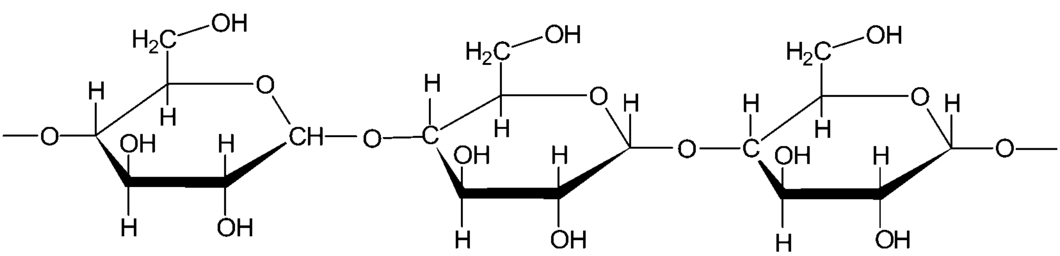
Glucose is the primary fuel for biological respiration. During digestion, complex sugars and starches are broken down into glucose (as well as fructose and galactose) in the small intestine. Glucose then moves into the bloodstream and is transported to the liver where glucose is metabolized through a series of biochemical reactions, collectively referred to as glycolysis. Glycolysis, the breakdown of glucose, occurs in most organisms. In glycolysis, the final product is pyruvate. The fate of pyruvate depends on the type of organism and cellular conditions. In animals, pyruvate is oxidized under aerobic conditions producing carbon dioxide. Under anaerobic conditions in animals, lactate is produced. This occurs in the muscle of humans and other animals. During strenuous conditions the accumulation of lactate causes muscle fatigue and soreness. Certain microorganisms, such as yeast, under anaerobic conditions convert pyruvate to carbonic dioxide and ethanol. This is the basis of the production of alcohol. Glycolysis also results in the production of various intermediates used in the synthesis of other



pyruvate

biomolecules. Depending on the organism, glycolysis takes various forms, with numerous products and intermediates possible.

Several common polysaccharides are derived from glucose including cellulose, starch, and glycogen. These polymeric forms of glucose differ in structure. Cellulose, the most abundant polysaccharide, forms the structural material of the cell walls of plants. Cellulose is a polymer



Cellulose

of glucose and consists of several thousand glucose molecules linked in an unbranched chain. Humans do not produce the enzymes, called cellulases, necessary to digest cellulose.

Bacteria possessing cellulase inhabit the digestive tracts of animals such as sheep, goats, and cows, giving these animals the ability to digest cellulose. Cellulase bacteria also exist in the digestive systems of certain insects, such as termites, allowing these insects to use wood as an energy source. Although humans cannot digest cellulose, this carbohydrate plays an important role in the human diet. Carbohydrates that humans cannot digest are called fiber or roughage. Fruit, vegetables, and nuts are primary sources of fiber. These foods have a cleansing effect on the large intestine, and such action is thought to speed the passage of cancer-causing materials through the intestine and therefore reduce the risk of colon cancer. Fiber helps retains water in the digestive system, aiding the overall digestion process. Another benefit of fiber is believed to be its ability to lower blood cholesterol, reducing heart and arterial disease.

Starch is a α-glucose polymer with the general formula $(C_6H_{12}O_5)_n$, where n can be a number from several hundred to several thousand. Plants store carbohydrate energy as starch. Grains, such as rice, corn, and wheat; potatoes; and seeds are rich in starch. Two principal forms of starch exist. One form is amylose and it accounts for approximately 20% of all starches. Amylose is a straight-chain form of starch containing several hundred glucose units. In the other form, called amylopectin, numerous glucose side branching is present. Starch is the primary food source for the human population, accounting for nearly 70% of all food consumed. Starch is broken down in the digestive system, starting in the mouth where the enzyme amylase breaks the bonds holding the glucose units together. This process ceases in the stomach because stomach acid creates a low pH environment, but it resumes in the small intestine. Glucose, maltose, and other small polysaccharides result from the digestion of starch.

In animals, most glucose is produced from starch and is not immediately needed for energy; therefore it is stored as glycogen. Because glycogen's function in animals is similar to that of starch in plants, it is sometimes referred to as animal starch. Glycogen is similar in structure to amylopectin, but it is larger and contains more glucose branching. When glucose blood levels drop, for instance during fasting or physical exertion, glycogen stored in the liver and muscles is converted into glucose and used by cells for energy. The process of conversion of glycogen to glucose is called glucogenesis. During periods of stress, the release of the hormone epinephrine (adrenaline) also causes glucose to be released from glycogen reserves (see Epinephrine). When blood glucose is high, such as immediately after a meal, glucose is converted into glycogen and stored in the liver and muscles in a process called glycogenesis. When glycogen stores are depleted and blood glucose levels are low, glucose can be synthesized from noncarbohydrate sources in a process called gluconeogenesis. Pyruvate, glycerol, lactate, and a number of amino acids are sources that can be converted to glucose.

The transformation of glucose to glycogen and glycogen back to glucose enables humans to regulate their energy demands throughout the day. This process is disrupted in individuals who have a form of diabetes known as diabetes mellitus. Diabetes mellitus occurs in individuals whose pancreas produces insufficient amounts of insulin or whose cells have the inability to use insulin (see Insulin). Insulin is a hormone responsible for signaling the liver and muscles to store glucose as glycogen. In Type 1 diabetes, called insulin-dependent diabetes mellitus, the body produces insufficient amounts of insulin. This type of diabetes occurs in youth under the age of 20 years and is the less prevalent form (about 10% of diabetics carry this form). Type 1 diabetes is controlled using insulin injections and regulating the diet. Type 2 diabetes, known as insulin-independent diabetes mellitus, is the most common form of diabetes and is associated with older individuals (generally over 50) who are overweight. In this form of diabetes, individuals produce adequate supplies of insulin, but the cells do not recognize the insulin's signal, and therefore do not capture glucose from the blood. This type of diabetes is regulated with drugs and a strictly controlled diet.