Carbohydrates

Index to this page

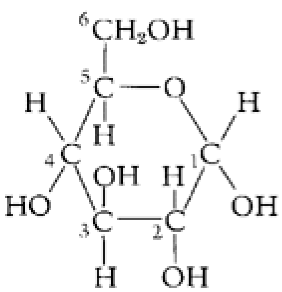
Carbohydrates have the general molecular formula CH_2O, and thus were once thought to represent "hydrated carbon". However, the arrangement of atoms in carbohydrates has little to do with water molecules.

Starch and cellulose are two common carbohydrates. Both are macromolecules with molecular weights in the hundreds of thousands. Both are polymers (hence "**polysaccharides**"); that is, each is built from repeating units, monomers, much as a chain is built from its links.

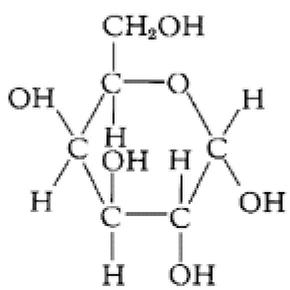
The monomers of both starch and cellulose are the same: units of the sugar **glucose**.

Sugars

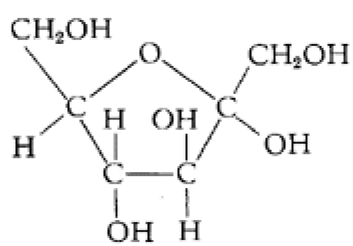
Monosaccharides



GLUCOSE



GALACTOSE



FRUCTOSE

Three common sugars share the same molecular formula: $C_6H_{12}O_6$. Because of their six carbon atoms, each is a **hexose**.

They are:

- **glucose**, "blood sugar", the immediate source of energy for cellular respiration
- **galactose**, a sugar in milk (and yogurt), and
- **fructose**, a sugar found in honey.

Although all three share the same molecular formula ($C_6H_{12}O_6$), the arrangement of atoms differs in each case. Substances such as these three, which have identical molecular formulas but different structural formulas, are known as **structural isomers**.

Glucose, galactose, and fructose are "single" sugars or **monosaccharides**. Two monosaccharides can be linked together to form a "double" sugar or **disaccharide**.

Disaccharides

Three common disaccharides:

- **sucrose** — common table sugar = glucose + fructose
- **lactose** — major sugar in milk = glucose + galactose
- **maltose** — product of starch digestion = glucose + glucose

Although the process of linking the two monomers is rather complex, the end result in each case is the loss of a hydrogen atom (H) from one of the monosaccharides and a hydroxyl group (OH) from the other. The resulting linkage between the sugars is called a **glycosidic bond**. The molecular formula of each of these disaccharides is

$$C_{12}H_{22}O_{11} = 2\ C_6H_{12}O_6 - H_2O$$

All sugars are very soluble in water because of their many hydroxyl groups. Although not as concentrated a fuel as fats, sugars are the most important source of energy for many cells.

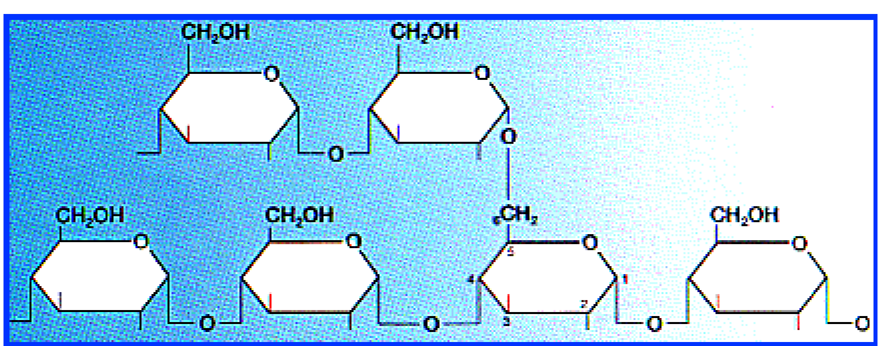
Carbohydrates provide the bulk of the calories (4 kcal/gram) in most diets, and starches provide the bulk of that. Starches are polysaccharides.

Polysaccharides

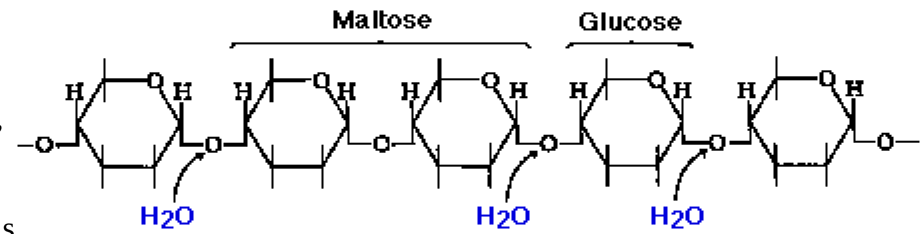
Starches

Starches are polymers of glucose. Two types are found:

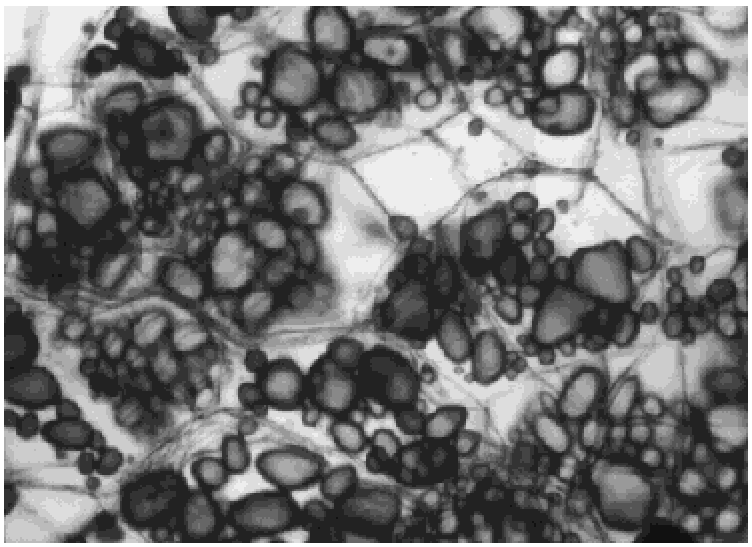
- **amylose** consists of linear, unbranched chains of several hundred glucose residues (units). The glucose residues are linked by a glycosidic bond between their #1 and #4 carbon atoms.
- **amylopectin** differs from amylose in being highly branched. At approximately every thirtieth residue along the chain, a short side chain is attached by a glycosidic bond to the #6 carbon atom (the carbon above the ring). The total number of glucose residues in a molecule of amylopectin is several thousand.



Starches are insoluble in water and thus can serve as storage depots of glucose. Plants convert excess glucose into starch for storage. The image shows starch grains (lightly stained with iodine) in the cells of the white potato. Rice, wheat, and corn are also major sources of starch in the human diet.



Before starches can enter (or leave) cells, they must be digested. The hydrolysis of starch is done by amylases. With the aid of an **amylase** (such as pancreatic amylase), water molecules enter at the 1 -> 4 linkages, breaking the chain and eventually producing a mixture of **glucose** and **maltose**. A different amylase is needed to break the 1 -> 6 bonds of amylopectin.



Glycogen

Animals store excess glucose by polymerizing it to form **glycogen**. The structure of glycogen is similar to that of amylopectin, although the branches in glycogen tend to be shorter and more frequent.

Glycogen is broken back down into glucose when energy is needed (a process called glycogenolysis).

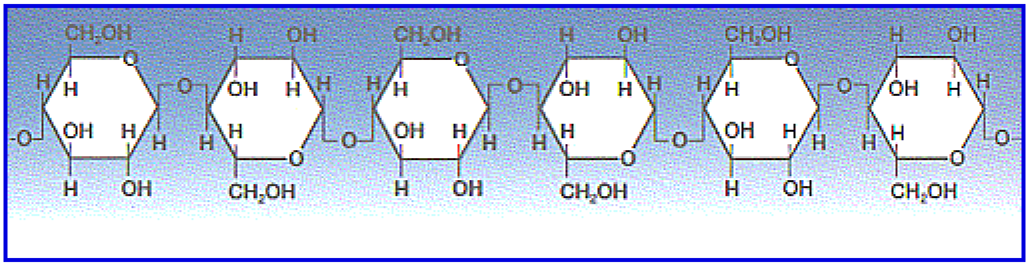
In **glycogenolysis**,

- phosphate groups — not water — break the 1 -> 4 linkages
- the phosphate group must then be removed so that glucose can leave the cell.

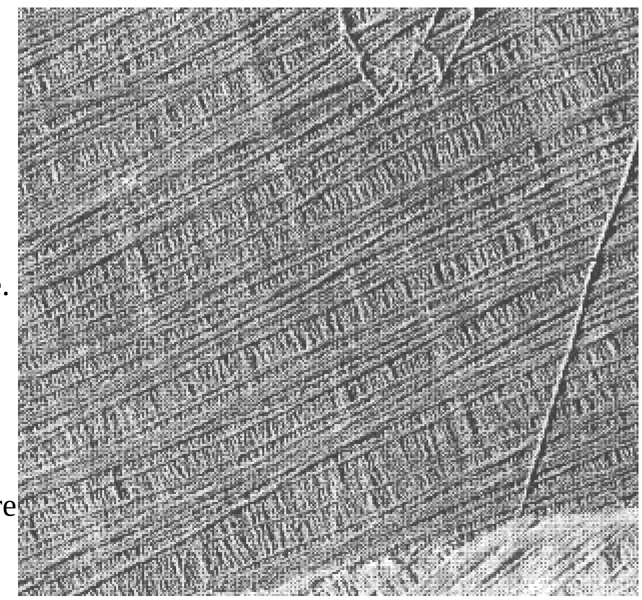
The liver and skeletal muscle are major depots of glycogen.

There is some evidence that intense exercise and a high-carbohydrate diet ("carbo-loading") can increase the reserves of glycogen in the muscles and thus may help marathoners work their muscles somewhat longer and harder than otherwise. But for most of us, carbo loading leads to increased deposits of fat.

Cellulose



Cellulose is probably the single most abundant organic molecule in the biosphere. It is the major structural material of which plants are made. Wood is largely cellulose while cotton and paper are almost pure cellulose.



Like starch, cellulose is a polysaccharide with glucose as its monomer. However, cellulose differs profoundly from starch in its properties.

- Because of the orientation of the glycosidic bonds linking the glucose residues, the rings of glucose are arranged in a flip-flop manner. This produces a long, straight, rigid molecule.
- There are no side chains in cellulose as there are in starch. The absence of side chains allows these linear molecules to lie close together.
- Because of the many -OH groups, as well as the oxygen atom in the ring, there are many opportunities for hydrogen bonds to form between adjacent chains.

The result is a series of stiff, elongated fibrils — the perfect material for building the cell walls of plants.

This electron micrograph (courtesy of R. D. Preston) shows the cellulose fibrils in the cell wall of a green alga. These long, rigid fibrils are a clear reflection of the nature of the cellulose molecules of which they are composed.

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