Disaccharide

A disaccharide (also called a double sugar) is the sugar formed when two monosaccharides (simple sugars) are joined by **glycosidic linkage**. Like monosaccharides, disaccharides are soluble in water. The most common types of disaccharides (sucrose, lactose, and maltose) have twelve carbon atoms, with the general formula C12H22O11. The differences in these disaccharides are due to atomic arrangements within the molecule.

The joining of simple sugars into a double sugar happens by a condensation reaction, which involves the elimination of a water molecule from the functional groups only. Breaking apart a double sugar into its two simple sugars is accomplished by hydrolysis with the help of a type of enzyme called a disaccharidase (e.g. sucrase, lactase, and maltase). As building the larger sugar ejects water molecule, breaking it down consumes a water molecule (Figure 2.1).

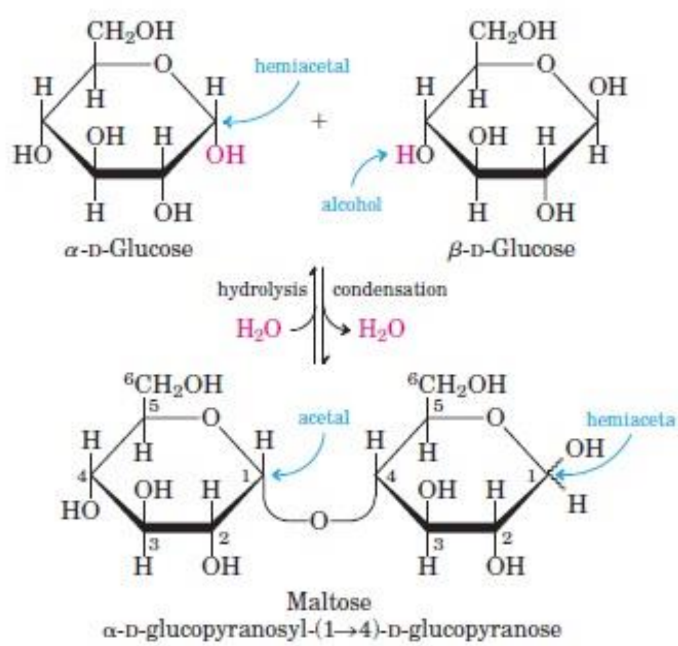

Figure 2.1: Formation of maltose. A disaccharide is formed from two monosaccharides (here, two molecules of D-glucose).

Common disaccharides

- **Sucrose:** a molecule composed of the two monosaccharides, **glucose** and **fructose**. Sucrose is produced naturally in plants, from which **table sugar** is refined. It has the formula C12H22O11. For human consumption, sucrose is extracted, and refined, from either **sugar cane** or **sugar beet**. The components glucose and fructose are linked via an ether bond between C1 on the glucosyl subunit and C2 on the fructosyl unit. The bond is called a glycosidic linkage (**α(1→2)β**) (Figure 2.2).

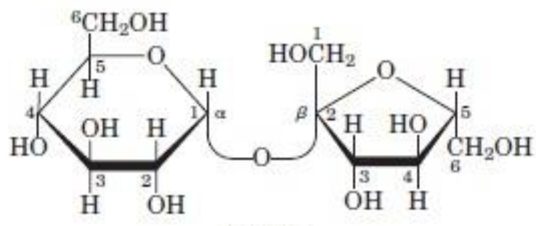

Figure 2.2: Sucrose.

Sucrose and human health

Tooth decay (dental caries) has associated with the consumption of sugars, especially sucrose; oral bacteria such as *Streptococcus mutans* live in dental plaque and metabolize any sugars (not just sucrose, but also glucose, lactose, fructose, and cooked starches) into lactic acid, the resultant lactic acid lowers the pH of the tooth's surface, stripping it of minerals in the process known as tooth decay.

Diabetes mellitus is metabolic disorders in which there are high blood sugar levels over a prolonged period.

Obesity may correlate better with sugar consumption than with fat consumption and that reducing fat consumption while increasing sugar consumption may increase the level of obesity.

Gout is connected with an excess production of uric acid, a diet rich in sucrose may lead to gout as it raises the level of insulin, which prevents excretion of uric acid from the body.

Sucrose intolerance, also called **sucrase-isomaltase deficiency**, **congenital sucrase-isomaltase deficiency** (**CSID**), or **genetic sucrase-isomaltase deficiency** (**GSID**), is the condition in which sucrase-isomaltase, an enzyme needed for proper metabolism of sucrose (sugar) and starch (e.g., grains and rice), is not produced or the enzyme produced is either partially functional or non-functional in the small intestine.

- **Lactose**: a sugar composed of **galactose** and **glucose** that is found in **milk**. It has a formula of C12H22O11. Bond is **β(1→4)**. (Figure 2.3).

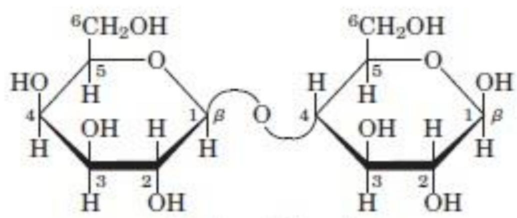

Figure 2.3: Lactose.

Lactose is not added directly to many foods, because its solubility is less than that of other sugars commonly used in food, infant formula is a notable exception, where the addition of lactose is necessary to match the composition of human milk. Lactose is added to tablet and capsule drug products as an ingredient because of its physical and functional properties, e.g., compressibility and cost effective use.

- **Maltose:** also known as **malt sugar**, is formed from two units of **glucose** joined with a **α(1→4)** bond. The two glucose units are in the pyranose form and are joined by a glycosidic bond, with the first carbon (C1) of the first glucose linked to the fourth carbon (C4) of the second glucose, indicated as (1→4). The link is characterized as α because the glycosidic bond to the anomeric carbon (C1) is in the opposite plane from the CH2OH substituent in the same ring (C6 of the first glucose). If the glycosidic bond to the anomeric carbon (C1) were in the same plane as the CH2OH substituent, it would be classified as a β(1→4) bond, and the resulting molecule would be cellobiose (Figure 2.1).

Oligosaccharide

An oligosaccharide (from the Greek *olígos* "a few") is a saccharide polymer containing a small number (typically 3 to 10) of monosaccharides. They are normally present as glycans (oligosaccharide chains linked to lipids or to proteins, by glycosidic bonds). **Glycosylation** is the process by which a carbohydrate is covalently attached to an organic molecule, creating structures such as glycoproteins and glycolipids. **N-linked oligosaccharides,** N-linked glycosylation involves oligosaccharide attachment to asparagine via a beta linkage to the amine nitrogen of the side chain. **O-linked oligosaccharides,** oligosaccharides are attached to threonine or serine on the hydroxyl group of the side chain. Not all natural oligosaccharides occur as components of glycoproteins or glycolipids. Some, such as the raffinose (trisaccharide composed of galactose, glucose, and fructose. It can be found in beans, cabbage, and broccoli) occur as storage or transport carbohydrates in plants. Others, such as maltodextrins or cellodextrins, result from the microbial breakdown of larger polysaccharides such as starch or cellulose.

Functions of oligosaccharide

- **Cell recognition:** All cells are coated in either glycoproteins or glycolipids, both of which help determine cell types. An important example of oligosaccharide cell recognition is the role of glycolipids in determining blood types.
- **Cell adhesion:** Many cells produce specific carbohydrate-binding proteins known as lectins, which mediate cell adhesion with oligosaccharides. Protein-Carbohydrate bonding is often mediated by hydrogen bonding and van der Waals forces.
- **Role in mother-to-child transmission of HIV-1:** Mixed feeding of breast milk and non-human milk increases the risk of postnatal transmission of HIV-1. The specific glycans that are present in human breast milk can inhibit HIV-1 transfer.

Dietary oligosaccharides

Fructo-oligosaccharides (**FOS**), which are found in many vegetables, are short chains of fructose molecules, they differ from inulin, which has a much higher degree of polymerization than FOS and is therefore a polysaccharide, but like inulin, they are considered soluble dietary fiber. **Galactooligosaccharides** (**GOS**), consist of short chains of galactose molecules; promote the growth of *Bifidobacteria* in large intestine, which are beneficial to gut health. **Mannan oligosaccharides** (**MOS**) are widely used in animal feed to improve gastrointestinal health; they are normally obtained from the yeast cell walls of *Saccharomyces cerevisiae*.

Polysaccharide

Polysaccharides are polymeric carbohydrate molecules composed of long chains of monosaccharide units bound together by glycosidic linkages, and on hydrolysis give the constituent monosaccharides or oligosaccharides. They range in structure from linear to highly branch. Examples include **storage polysaccharides** such as starch and glycogen, and **structural polysaccharides** such as cellulose and chitin. When all the monosaccharides in a polysaccharide are the same type, the polysaccharide is called a **homopolysaccharide** or **homoglycan**, but when more than one type of monosaccharide is present they are called **heteropolysaccharides** or **heteroglycans**. Polysaccharides contain more than **ten** monosaccharide units.

Storage polysaccharides

- **Starch** or **amylum:** is a **glucose** polymer in which glucopyranose units are bonded by alpha-linkages. It is made up of a mixture of amylose (15–20%) and amylopectin (80–85%).
  Amylose consists of a linear chain of several hundred of α-D-glucose units, bonded to each other through α(1→4) glycosidic bonds.
  Amylopectin is a branched molecule made of several thousand glucose units, glucose units are linked in a linear way with α(1→4) glycosidic bonds, branching takes place with α(1→6) bonds occurring every 24 to 30 glucose units.
  Starches are insoluble in water. They can be digested by breaking the alpha-linkages (glycosidic bonds). Both humans and animals have amylases, so they can digest starches. Potato, rice, wheat, and maize are major sources of starch in the human diet. The formations of starches are the ways that plants store glucose.
- **Glycogen:** is composed of a branched chain of glucose, insoluble in water, stored in liver and muscles. It serves as the secondary long-term energy storage in

animal and fungal cells, with the primary energy stores being held in adipose tissue. Glycogen is analogous to starch, a glucose polymer in plants, and is sometimes referred to as animal starch, having a similar structure to amylopectin but more extensively branched and compact than starch. Glycogen is a polymer of α(1→4) glycosidic bonds linked, with α(1→6)-linked branches.

Structural polysaccharides

- **Cellulose:** the structural component of plants is formed primarily from cellulose. Wood is largely cellulose and lignin, while paper and cotton are nearly pure cellulose. Cellulose is a polymer made with repeated glucose units bonded together by beta-linkages. Humans and many animals lack an enzyme to break the beta-linkages, so they do not digest cellulose.
- **Chitin:** forms a structural component of many animals, such as exoskeletons. Chemically, chitin is closely related to chitosan (a more water-soluble derivative of chitin). It is also closely related to cellulose in that it is a long unbranched chain of glucose derivatives. Both materials contribute structure, strength, and protecting the organism.
- **Pectin:** is complex polysaccharides that contain 1,4-linked D-galacturonic acid (a sugar acid, an oxidized form of D-galactose). It is presents in most primary cell walls and in the non-woody parts of terrestrial plants.

Bacterial capsular polysaccharides

Pathogenic bacteria commonly produce a thick, mucous-like, layer of polysaccharide. They are linear and consist of regularly repeating subunits of one to six monosaccharides. Capsular polysaccharides are used as vaccines. Bacteria and many other microbes, including fungi and algae, often secrete polysaccharides to help them adhere to surfaces and to prevent them from drying out.

Carbohydrate metabolism

Carbohydrate metabolism denotes the various biochemical processes responsible for the formation, breakdown, and interconversion of carbohydrates in living organisms.

Carbohydrates are central to many essential metabolic pathways. Plants synthesize carbohydrates from carbon dioxide and water through photosynthesis, allowing them to store energy absorbed from sunlight internally. When animals and fungi consume plants, they use cellular respiration to break down these stored carbohydrates to make energy available to cells. Both animals and plants temporarily store the released energy in the form of high energy molecules, such as ATP, for use in various cellular processes.

Humans consume a variety of carbohydrates, digestion breaks down complex carbohydrates into a few simple monomers for metabolism: glucose, fructose, and galactose. Glucose constitutes about 80% of the products, and is the primary structure that is distributed to cells in the tissues, where it is broken down or stored as glycogen. In aerobic respiration, the main form of cellular respiration used by humans, glucose and oxygen are metabolized to release energy, with carbon dioxide and water as byproducts. Most of the fructose and galactose travel to the liver, where they can be converted to glucose.

Metabolic pathways (Figure 2.4)

1- Glycolysis: is the process of breaking down a glucose molecule into **two pyruvate** molecules which can be further oxidized to access more energy in later processes, while storing energy released during this process as **ATP** and **NADH**. Nearly all organisms that break down glucose utilize glycolysis. This pathway is **anaerobic**, because it doesn't require oxygen.

2- Gluconeogenesis: is the reverse process of glycolysis. It involves the conversion of non-carbohydrate molecules into glucose. The non-carbohydrate molecules that are converted in this pathway include pyruvate, lactate, glycerol, alanine, and glutamine. This process occurs when there are lowered amounts of glucose. The production of glucose by this pathway is important to tissues that cannot use any other fuels, such as the brain. The liver is the primary location of gluconeogenesis, but some also occurs in the kidney.

3- Glycogenolysis: refers to the breakdown of glycogen. In the liver, muscles, and the kidney, this process occurs to provide glucose when necessary. A single glucose molecule is cleaved from a branch of glycogen, and is transformed into glucose-1-phosphate during this process. This molecule can then be converted to glucose-6-phosphate, an intermediate in the glycolysis pathway. Glucose-6-phosphate can then progress through glycolysis. Alternatively, glucose-6-phosphate can be converted back into glucose in the liver and the kidneys, allowing it to raise blood glucose levels if necessary.

Glucagon (peptide hormone, produced by the pancreas, works to raise the concentration of glucose in the bloodstream) in the liver stimulates glycogenolysis when the blood glucose is lowered, known as hypoglycemia. The glycogen in the liver can function as a backup source of glucose between meals. Adrenaline stimulates the breakdown of glycogen in the skeletal muscle during exercise. In the muscles, glycogen ensures a rapidly accessible energy source for movement

4- Glycogenesis: refers to the process of synthesizing glycogen. In humans, excess glucose is converted to glycogen via this process. Glycogen is a highly branched structure, consisting of glucose, in the form of glucose-6-phosphate, linked together. The branching of glycogen increases its solubility, and allows for a higher number of glucose molecules to be accessible for breakdown. Glycogenesis occurs primarily in the liver, skeletal muscles, and kidney.

5- Pentose phosphate pathway: is an alternative method of oxidizing glucose. It occurs in the liver, adipose tissue, adrenal cortex, testis, milk glands, phagocyte cells, and red blood cells. It produces products that are used in other cell processes, while reducing NADP to NADPH. This pathway is regulated through changes in the activity of glucose-6-phosphate dehydrogenase.

6- Fructose metabolism: fructose must undergo certain extra steps in order to enter the glycolysis pathway. Enzymes located in certain tissues can add a phosphate group to fructose. This phosphorylation creates fructose-6-phosphate, an intermediate in the glycolysis pathway that can be broken down directly in those tissues. This pathway occurs in the muscles, adipose tissue, and kidney. In the liver, enzymes produce fructose-1-phosphate, which enters the glycolysis pathway and is later cleaved into glyceraldehyde and dihydroxyacetone phosphate.

7- Galactose metabolism: lactose, or milk sugar, consists of one molecule of glucose and one molecule of galactose. After separation from glucose, galactose travels to the liver for conversion to glucose. Galactokinase uses one molecule of ATP to phosphorylate galactose. The phosphorylated galactose is then converted to glucose-1-phosphate, and then eventually glucose-6-phosphate, which can be broken down in glycolysis.

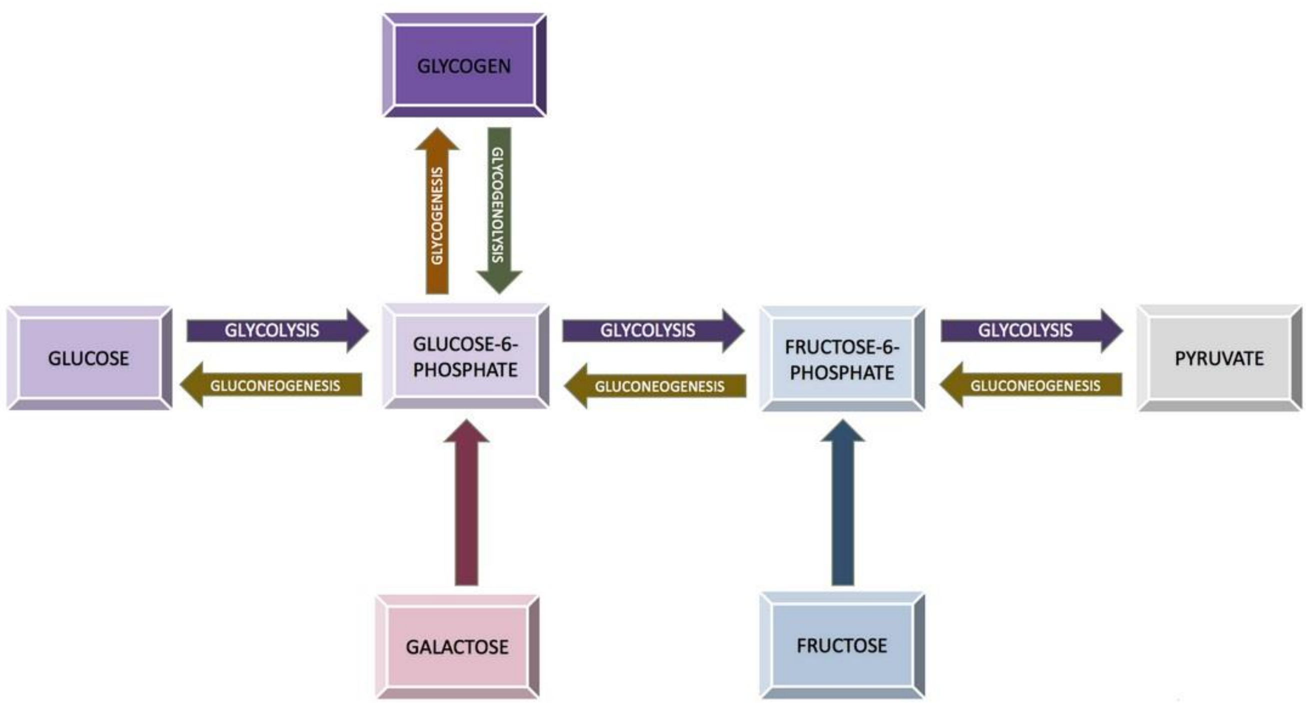

Figure 2.4: Overview of connections between metabolic processes.

Biomedical importance of carbohydrates

1- Carbohydrates are the major source of energy for man. For example, glucose is used in the human body for energy production.
2- Some carbohydrates serve as food material in human and in plants. For example, glycogen in animal tissue and starch in plants serves as reserve food materials.
3- Carbohydrates are components of several animal structure and plant structures. In animal, carbohydrates are components of skin, connective tissue, tendons, cartilage, and bone. In plants, cellulose is a component of wood and fiber.
4- Some carbohydrates are components of cell membrane and nervous tissue.
5- Carbohydrates are components of nucleic acids and blood group substances.
6- Carbohydrates are involved in cell-cell interaction.
7- Derivatives of carbohydrates are drugs. For example, a glycoside is used in clinical medicine. Streptomycin an antibiotic is a glycoside.
8- Aminosugars, derivatives of carbohydrates are components of antibiotics like erythromycin and carbomycin.
9- Ascorbic acid (vitamin C), a derivative of carbohydrate is a water-soluble vitamin.
10- Bacterial invasion involves hydrolysis of mucopolysaccharides.
11- Survival of Antarctic fish in icy environment is due to presence of anti-freeze glycoproteins in their blood.