Carbohydrates

Carbohydrates are widely distributed in plants and animals; they have important structural and metabolic roles, in plants, glucose is synthesized from carbon dioxide and water by photosynthesis and stored as starch or used to synthesize cellulose of the plant framework, animals can synthesize carbohydrate from glycerol, fatty acids and amino acids.

Glucose is the most important carbohydrate; most dietary carbohydrate is absorbed into the bloodstream as glucose, and other sugars are converted into glucose in the liver, glucose is the major metabolic fuel of mammals (except ruminants) and a universal fuel of the fetus.

Diseases associated with carbohydrate metabolism include diabetes mellitus, galactosemia, glycogen storage diseases, and lactose intolerance. Carbohydrates have a wide range of functions, the following are few of them:

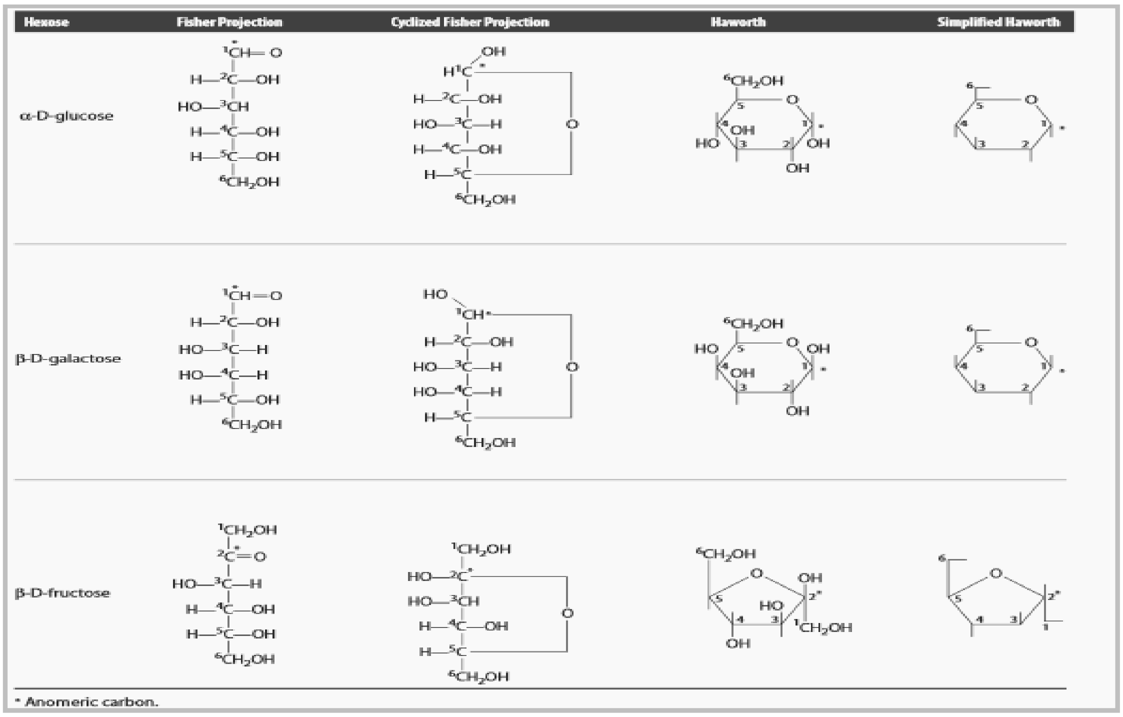
- Source of energy for living like glucose
- Storage form of energy like glycogen in animal tissue and starch in plants
- Serve as structural component like glycosaminoglycans in humans, cellulose in plants and chitin in insects
- Non-digestible carbohydrates like cellulose serve as dietary fibers
- Constituent of nucleic acids RNA and DNA like ribose and deoxyribose sugar
- Carbohydrates are also involved in detoxification like glucuronic acid.

Carbohydrates classified as:

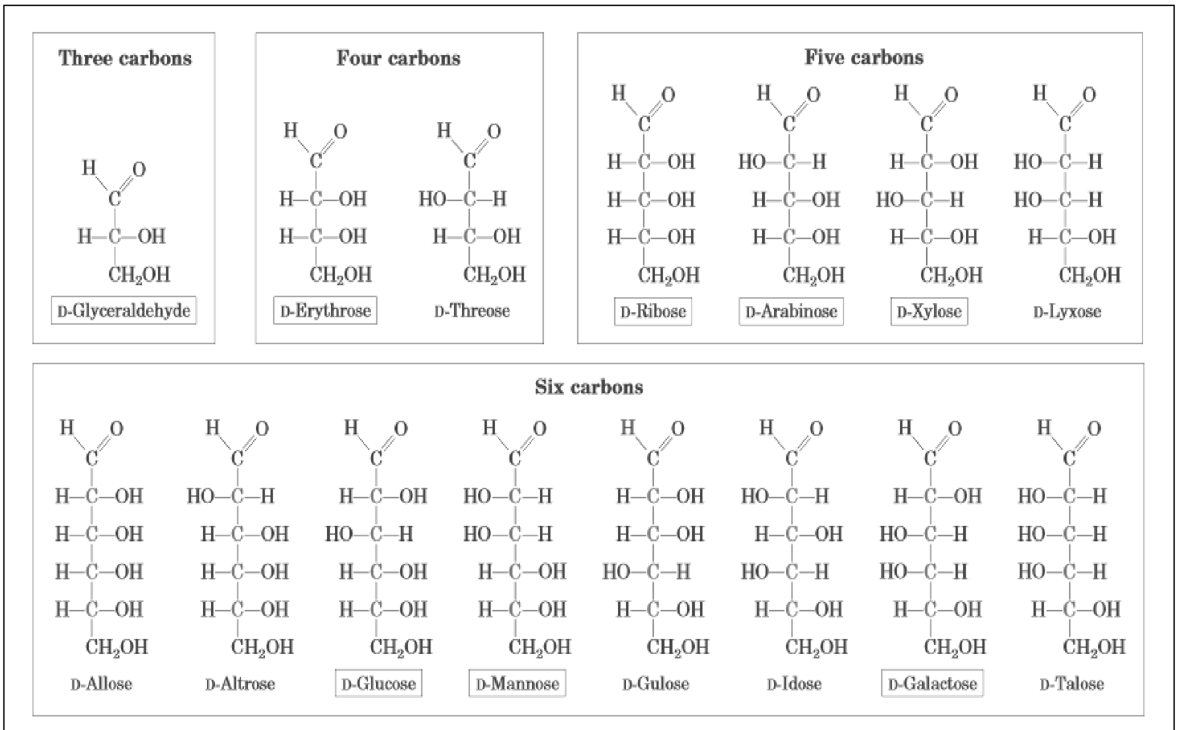
1-Monosaccharides

Most of carbohydrates are present with a cyclic structure in nature, as a consequence of internal linkages between the carbonyl carbone (of the aldehyde or ketone group) with one of the hydroxyl groups in the same molecule. carbohydrates cannot hydrolyzed into simpler carbohydrates, they classified as trioses, tetroses, pentoses, hexoses, or heptoses, depending upon the number of carbon atoms; and as aldoses or ketoses depending upon whether they have an aldehyde or ketone group as shown in figure :

Linear and cyclic structure of carbohydrate

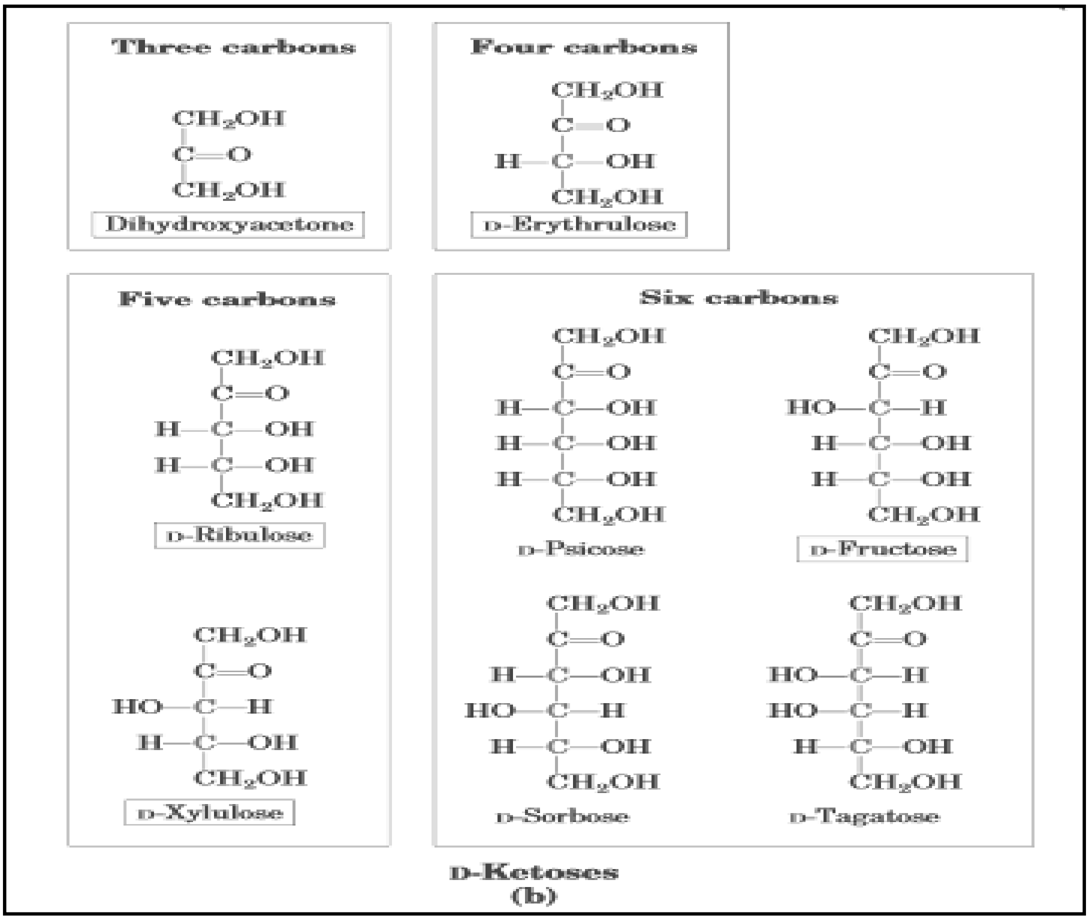


Classification of carbohydrate (aldosis)



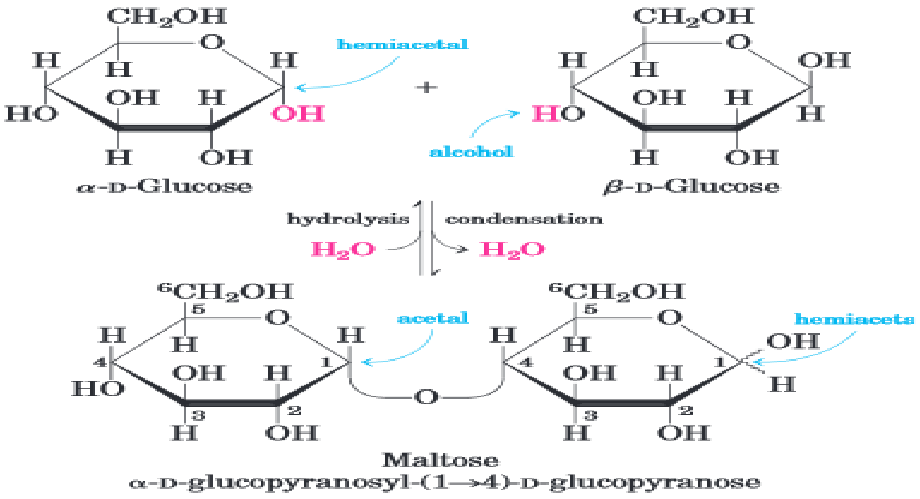
D-Aldoses
(a)

Classification of carbohydrate (ketosis)

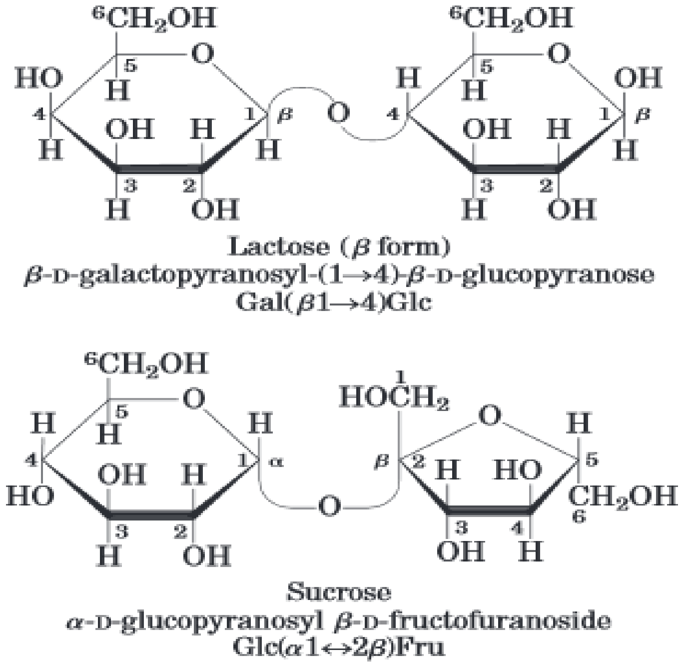


2-Disaccharides

Disaccharides are condensation products of two monosaccharide units. Examples are maltose (glucose+ glucose) and sucrose (glucose+ fructose) and lactose (glucose+ galactose):



Maltose



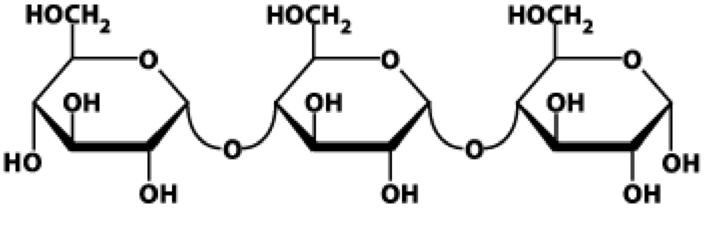
Lactose (β form)
β-D-galactopyranosyl-(1→4)-β-D-glucopyranose
Gal(β1→4)Glc

Sucrose
α-D-glucopyranosyl β-D-fructofuranoside
Glc(α1↔2β)Fru

Lactose and sucrose

3-Oligosaccharides

Oligosaccharides consist of a short chain of monosaccharide units (3 to 10 units), joined together by a characteristic bond called glycosidic bond which, on hydrolysis, gives three to ten molecules of simple sugar maltotriose is an example.



Maltotriose

4-Polysaccharides

Polysaccharides are condensation products of more than ten monosaccharide units; include Homopolysaccharides (Homoglycans) when a polysaccharide is made up of several units of one and the same type of monosaccharide, the most common homoglycans are starch, dextrin, glycogen, Inulin, cellulose.

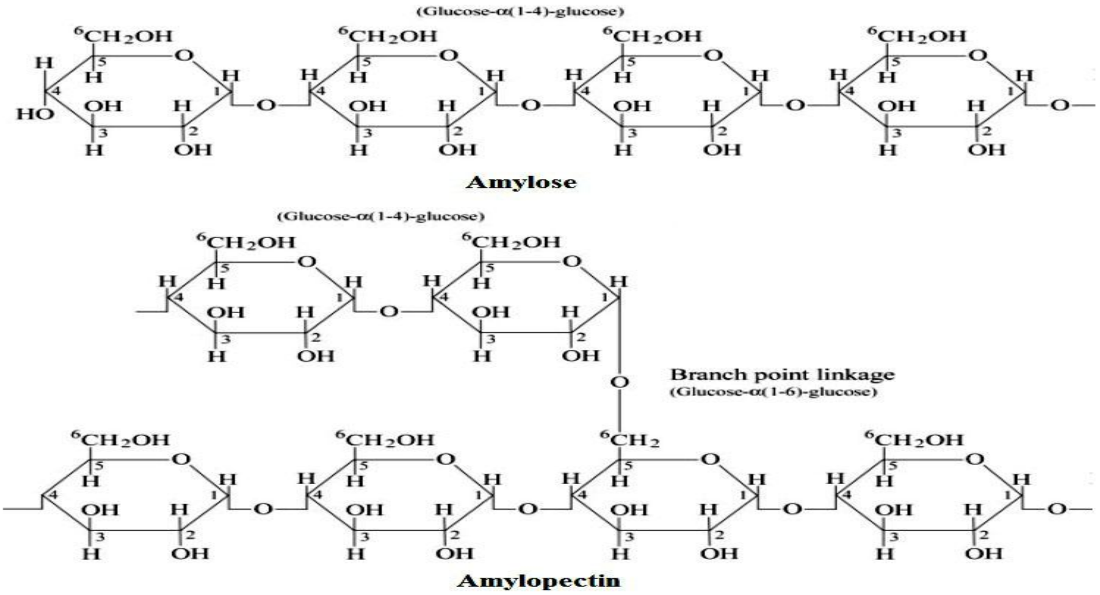
Some homopolysaccharides serve as a storage form of monosaccharides used as fuel, e.g. starch and glycogen, while others serve as structural elements in plants, e.g. cellulose.

Heteropolysaccharides (Heteroglycans). they contain two or more different types of monosaccharide units or their derivatives. Heteropolysaccharide present in human beings is glycosaminoglycans (mucopolysaccharides), e.g. Heparin, chondritin sulfate, hyaluronic acid, dermatan sulfate, keratan sulfate.

polysaccharides are classified as:

a-Starch

Starch contains two types of glucose polymer, amylose and amylopectin. The former consists of long, unbranched chains of D-glucose residues connected by (α 1-4) linkages, such chains vary in molecular weight from a few thousand to more than a million, amylopectin also has a high molecular weight (up to 100 million) but unlike amylose is highly branched, the glycosidic linkages joining successive glucose residues in amylopectin chains are (α 1-4); the branch points (occurring every 24 to 30 residues) are (α 1-6) linkages that amylase consist of (15–20 %) of starch where amylopectin consist of (80–85%),

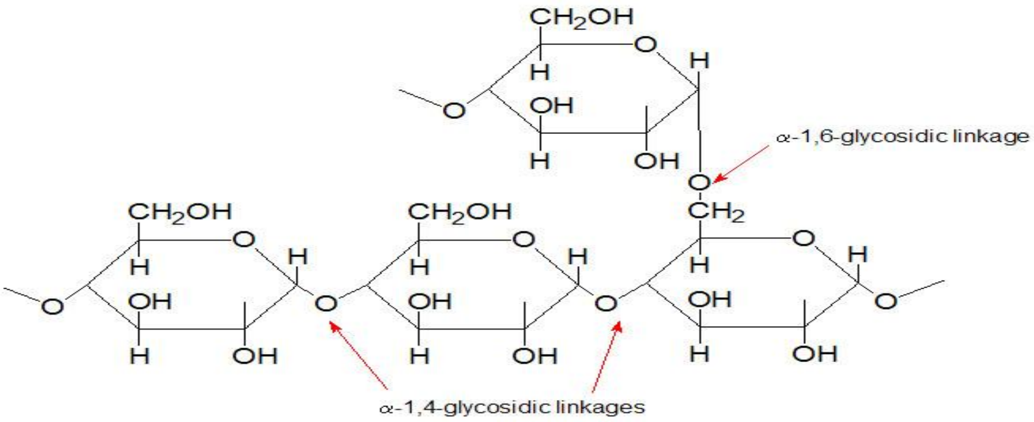


Starch

b-Glycogen

Glycogen is the main storage polysaccharide of animal cells. Like amylopectin, glycogen is a polymer of (α1-4)-linked subunits of glucose, with (α1-6)-linked branches, but glycogen is more extensively branched (on average, every 8 to 12 residues) and more compact than starch. Glycogen is especially abundant in the liver where it may constitute as much as 7% of the wet weight; it is also present in skeletal muscle. In hepatocytes glycogen is found in large granules.

Such glycogen granules tightly bound form which enzymes responsible of synthesis and degradation of glycogen, each branch in glycogen ends with a non-reducing sugar unit, a glycogen molecule has as many non-reducing ends as it has branches, but only one reducing end, when glycogen is used as an energy source, glucose units are removed one at a time from the nonreducing ends, degradative enzymes that act only at nonreducing ends can work simultaneously on the many branches, speeding the conversion of the polymer to monosaccharides.



Glycogen

c-Inulin

Inulin is a polysaccharide of fructose β (2-1) found in tubers and roots of dahlias, artichokes, and dandelions, it is readily soluble in water and used to help measure kidney function by determining the glomerular filtration rate (GFR), in general, plant inulins contain between 20 and several thousand fructose units.

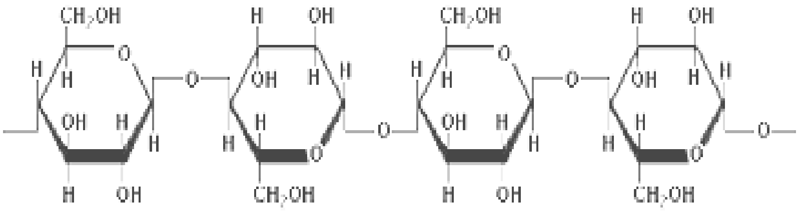
d-Dextrins

Dextrins are bacterial and yeast polysaccharides made up of (α 1- 6)-linked poly- D-glucose; all have (α 1-3) (α 1-2) or (α1-4) branches, dextrins are white, yellow, or brown powders that are partially or fully water-soluble.

e-Cellulose

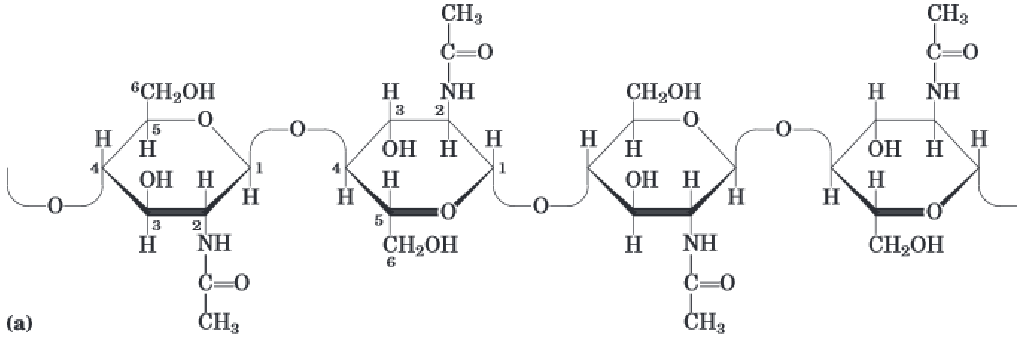
Organic compound consisting of a linear chain of several hundred to many thousands of β (1→4) linked D-glucose units, cellulose is an important structural component of the primary cell wall of green plants.

Cellulose cannot be digested by mammals because of the absence of an enzyme that hydrolyzes the linkage, it is an important source of "bulk" in the diet, there is limited bacterial metabolism of cellulose in the human colon while microorganisms in the gut of ruminants and other herbivores can hydrolyze the linkage and ferment the products to short-chain fatty acids as a major energy source,



f-Chitin

It consists of *N*-acetyl-D-glucosamine units joined by (1 →4)-glycosidic linkages, the only chemical difference from cellulose is the replacement of the hydroxyl group at C-2 with an acetylated amino group responsible for hard structure, chitin forms extended fibers similar to those of cellulose, and like cellulose cannot be digested by vertebrates, chitin is the principal component of the hard exoskeletons of nearly a million species of arthropods insects, lobsters, and crabs, for example and is probably the second most abundant polysaccharide, next to cellulose, in nature.

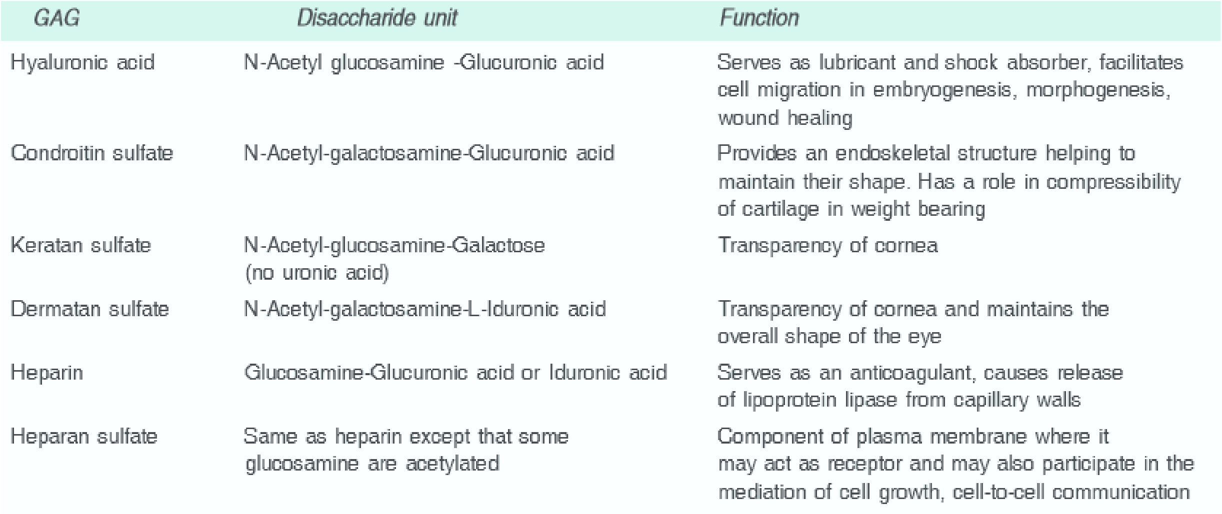


Chitin

Heteropolysaccharides or Heteroglycans

Glycoprotein (Mucoprotein)

Glycosaminoglycans (mucopolysaccharides) are complex carbohydrates containing amino sugars and uronic acids, they may be attached to a protein molecule to form a proteoglycan.

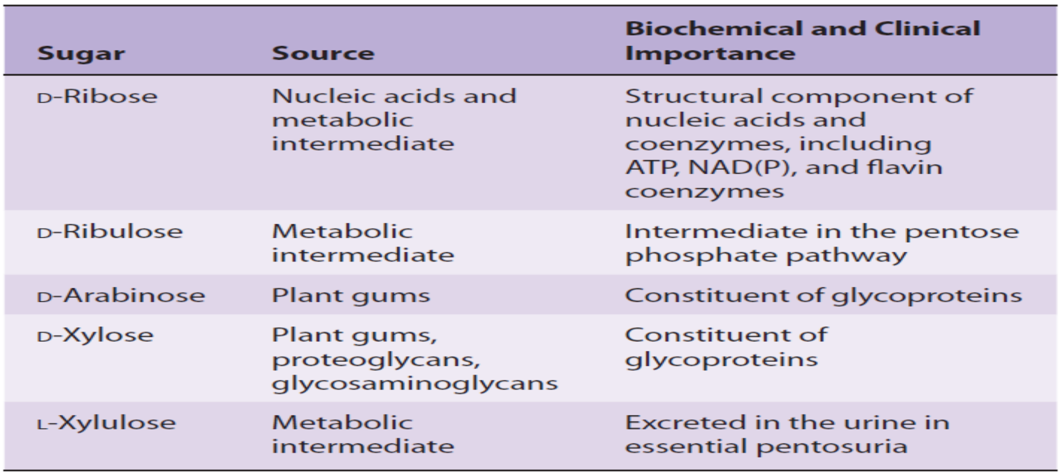


GAG	Disaccharide unit	Function
Hyaluronic acid	N-Acetyl glucosamine -Glucuronic acid	Serves as lubricant and shock absorber, facilitates cell migration in embryogenesis, morphogenesis, wound healing
Condroitin sulfate	N-Acetyl-galactosamine-Glucuronic acid	Provides an endoskeletal structure helping to maintain their shape. Has a role in compressibility of cartilage in weight bearing
Keratan sulfate	N-Acetyl-glucosamine-Galactose (no uronic acid)	Transparency of cornea
Dermatan sulfate	N-Acetyl-galactosamine-L-Iduronic acid	Transparency of cornea and maintains the overall shape of the eye
Heparin	Glucosamine-Glucuronic acid or Iduronic acid	Serves as an anticoagulant, causes release of lipoprotein lipase from capillary walls
Heparan sulfate	Same as heparin except that some glucosamine are acetylated	Component of plasma membrane where it may act as receptor and may also participate in the mediation of cell growth, cell-to-cell communication

Monosaccharides are Physiologically Important

Derivatives of trioses, tetroses, and pentoses and of the seven carbon sugar sedoheptulose, are formed as metabolic intermediates in glycolysis and the pentose phosphate pathway.

Physiologically important of Pentoses



Sugar	Source	Biochemical and Clinical Importance
D-Ribose	Nucleic acids and metabolic intermediate	Structural component of nucleic acids and coenzymes, including ATP, NAD(P), and flavin coenzymes
D-Ribulose	Metabolic intermediate	Intermediate in the pentose phosphate pathway
D-Arabinose	Plant gums	Constituent of glycoproteins
D-Xylose	Plant gums, proteoglycans, glycosaminoglycans	Constituent of glycoproteins
L-Xylulose	Metabolic intermediate	Excreted in the urine in essential pentosuria

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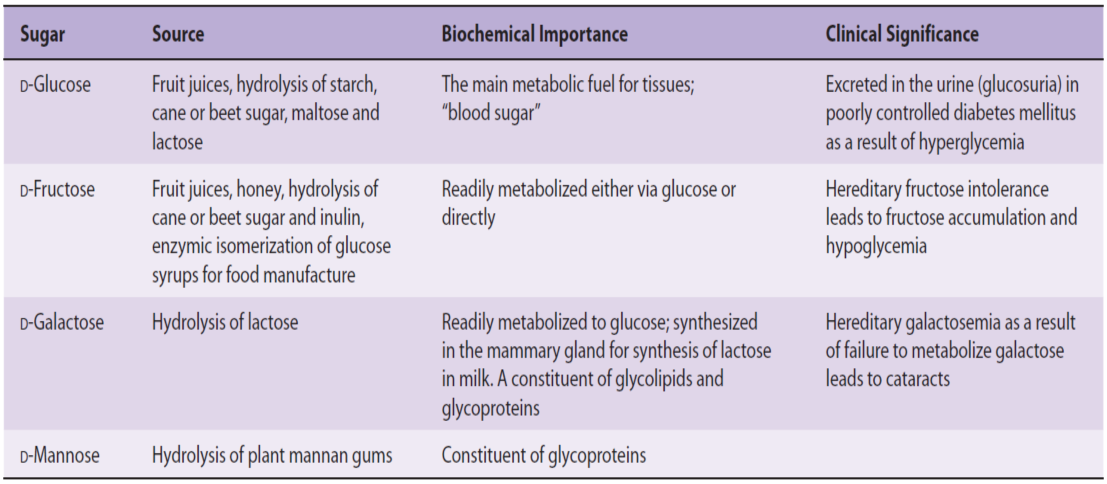
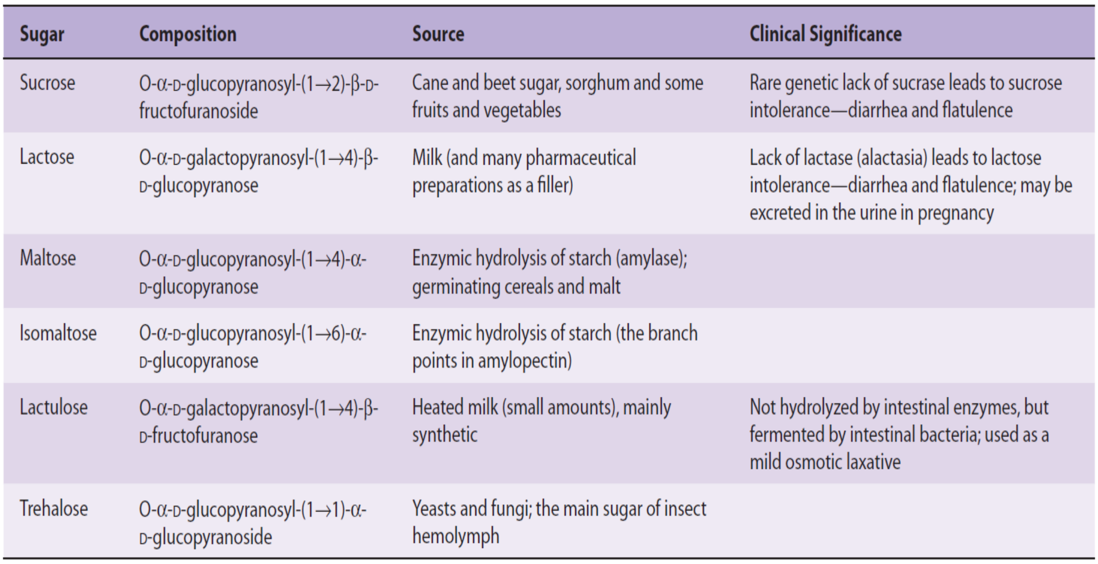
Physiologically important of Hexoses



Sugar	Source	Biochemical Importance	Clinical Significance
D-Glucose	Fruit juices, hydrolysis of starch, cane or beet sugar, maltose and lactose	The main metabolic fuel for tissues; "blood sugar"	Excreted in the urine (glucosuria) in poorly controlled diabetes mellitus as a result of hyperglycemia
D-Fructose	Fruit juices, honey, hydrolysis of cane or beet sugar and inulin, enzymic isomerization of glucose syrups for food manufacture	Readily metabolized either via glucose or directly	Hereditary fructose intolerance leads to fructose accumulation and hypoglycemia
D-Galactose	Hydrolysis of lactose	Readily metabolized to glucose; synthesized in the mammary gland for synthesis of lactose in milk. A constituent of glycolipids and glycoproteins	Hereditary galactosemia as a result of failure to metabolize galactose leads to cataracts
D-Mannose	Hydrolysis of plant mannan gums	Constituent of glycoproteins	

Physiologically important of Disaccharides

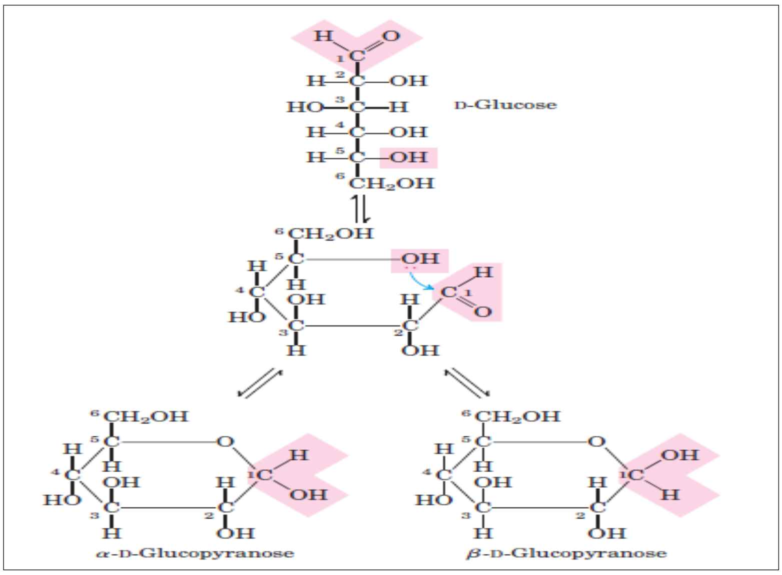


Sugar	Composition	Source	Clinical Significance
Sucrose	O-α-D-glucopyranosyl-(1→2)-β-D-fructofuranoside	Cane and beet sugar, sorghum and some fruits and vegetables	Rare genetic lack of sucrase leads to sucrose intolerance—diarrhea and flatulence
Lactose	O-α-D-galactopyranosyl-(1→4)-β-D-glucopyranose	Milk (and many pharmaceutical preparations as a filler)	Lack of lactase (alactasia) leads to lactose intolerance—diarrhea and flatulence; may be excreted in the urine in pregnancy
Maltose	O-α-D-glucopyranosyl-(1→4)-α-D-glucopyranose	Enzymic hydrolysis of starch (amylase); germinating cereals and malt	
Isomaltose	O-α-D-glucopyranosyl-(1→6)-α-D-glucopyranose	Enzymic hydrolysis of starch (the branch points in amylopectin)	
Lactulose	O-α-D-galactopyranosyl-(1→4)-β-D-fructofuranose	Heated milk (small amounts), mainly synthetic	Not hydrolyzed by intestinal enzymes, but fermented by intestinal bacteria; used as a mild osmotic laxative
Trehalose	O-α-D-glucopyranosyl-(1→1)-α-D-glucopyranoside	Yeasts and fungi; the main sugar of insect hemolymph	

Some characterization of sugar:

1-α and β anomers

Reaction between the aldehyde group or ketone groups at C-1 or C-2 and the OH of carbon in open chain forms a hemiacetal or hemiketal linkage, producing either of two stereoisomers, the α and β anomers, which differ only in the stereochemistry around the hemiacetal carbon, the interconversion of α and β anomers is called mutarotation, oxidation of the anomeric carbon of glucose and other sugars is the basis for Fehling's reaction called reducing sugar

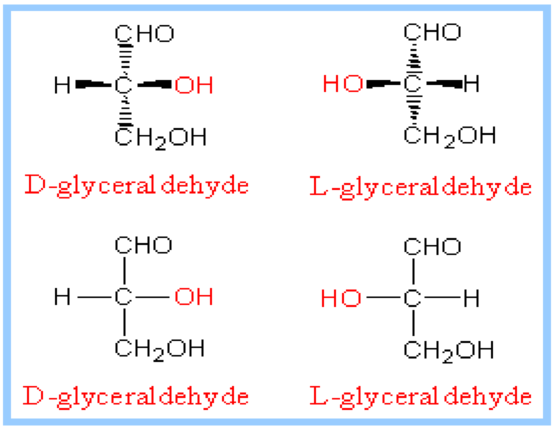


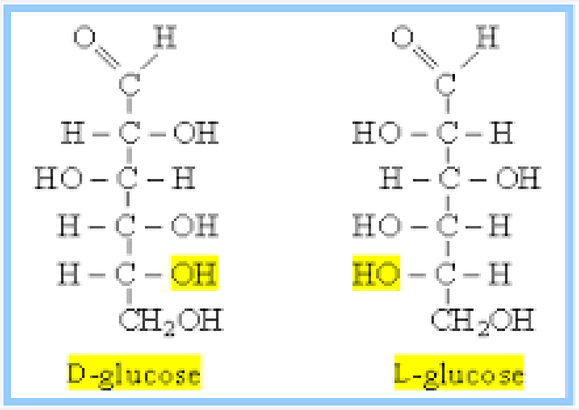
Formation of the two cyclic forms of D-glucose.

2-D and L isomerism:

D and L designations are based on the configuration the single asymmetric carbon (chiral carbon) which a carbon atom that is attached to four different types of atoms or four different groups of atoms) the farthest from the aldehyde or keto group.

The L and D forms of this sugar, and of glucose, the orientation of the H and OH groups around the carbon atom adjacent (carbon 5 in glucose) chiral carbon determines whether the sugar belongs to the D or L series, when the OH group on this carbon is on the right the sugar is the D-isomer; when it is on the left, it is the L-isomer.



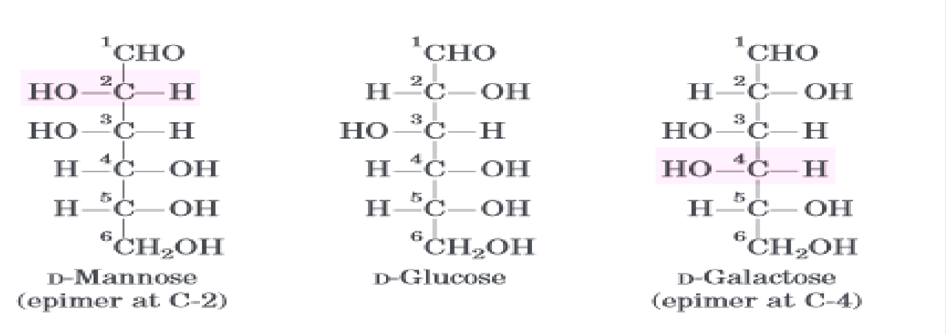


3-Optical activity

Most of the monosaccharides occurring in mammals are D-sugars and the enzymes responsible for their metabolism are specific for this configuration, in clinical practice that the presence of asymmetric carbon atoms also confers **optical activity** on the compound, when a beam of plane-polarized light is passed through a solution of an **optical isomer,** it will be rotated either to the right, dextrorotatory (+); or to the left, levorotatory (−).

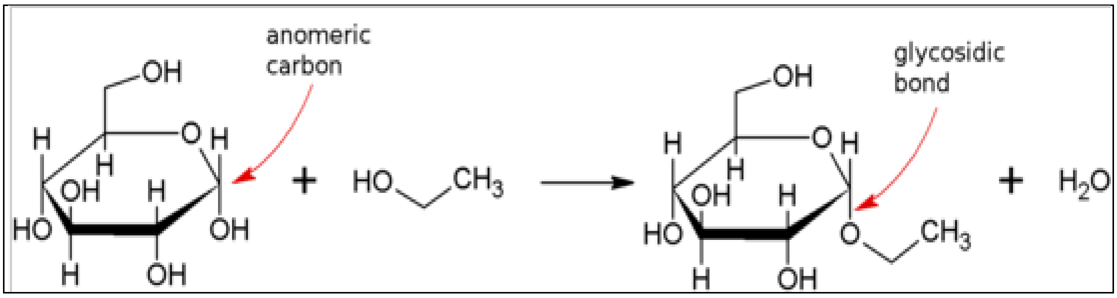
4-Epimers:

Isomers differing as a result of variations in configuration of the OH and H on carbon atoms 2, 3 and 4 of glucose are known as epimers, biologically, the most important epimers of glucose are mannose and galactose, formed by epimerization at carbons 2 and 4, respectively.



Glycosidic bond

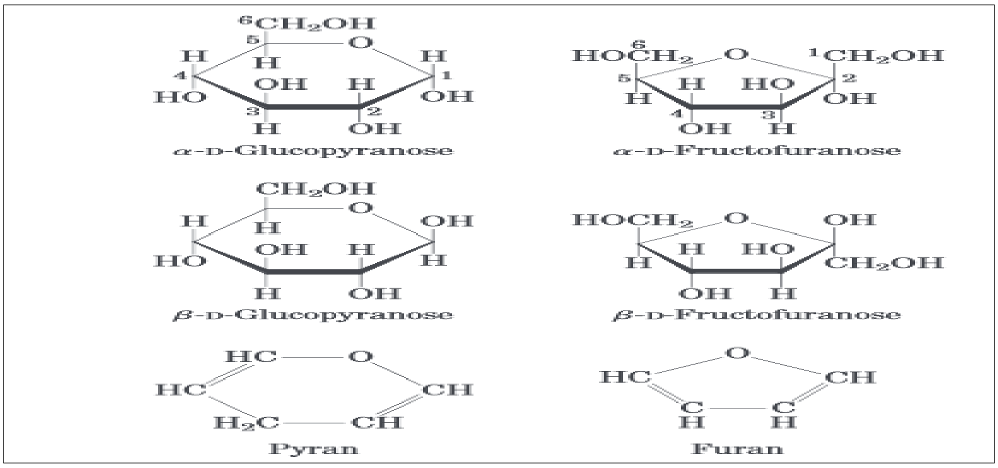
A glycosidic bond is formed between the hemiacetal or hemiketal group of saccharide (or a molecule derived from a saccharide) and the hydroxyl group of some compound such as an alcohol, glycosidic bonds of the form discussed above are known as O-glycosidic bonds, if the hemiacetal portion is glucose, the resulting compound is a **glucoside;** if galactose, a **galactoside;** and so on, if the second group is an amine, an *N*-glycosidic bond is formed, for example, between adenine and ribose in nucleotides such as ATP.



The glycosides that are important in medicine because of their action on the heart **(cardiac glycosides)**, these include derivatives of digitalis and strophanthus such as **ouabain,** an inhibitor of the Na+-K+ ATPase of cell membranes other glycosides include antibiotics such as **streptomycin.**

Pyranose and furanose ring structures:

The stable ring structures of monosaccharides are similar to the ring structures of either pyran (a six membered ring) or furan a five-membered ring, for glucose in solution, more than 99% is in the pyranose form, the pyranose forms of D-glucose and the furanose forms of D-fructose are shown here as Haworth perspective formulas.



α-D-Glucopyranose

α-D-Fructofuranose

β-D-Glucopyranose

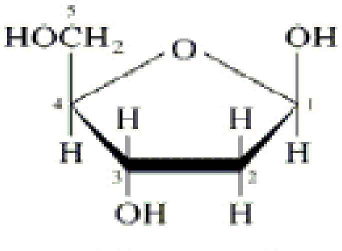
β-D-Fructofuranose

Pyran

Furan

Deoxy Sugars Lack an Oxygen Atom

Deoxy sugars are those in which a hydroxyl group has been replaced by hydrogen, an example is **deoxyribose** in DNA, deoxyribose are important in nucleotides

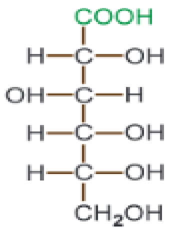


Deoxy-D-ribose

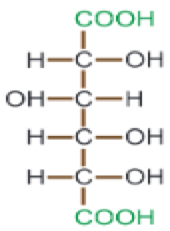
Oxidation (Sugar Acid Formation)

Aldoses oxidize under proper conditions they may form:
–Aldonic acid
–Saccharic acids
–Uronic acid.

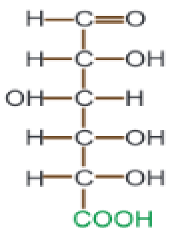
- Oxidation of an aldose with hypobromous acid (HOBr), which acts as an oxidizing agent gives aldonic acid, thus, glucose is oxidized to gluconic acid.
- oxidation of aldoses with nitric acid under proper conditions convert both aldehyde and terminal primary alcohol groups to carboxyl groups, forming saccharic acid.
- when an aldose is oxidized in such a way that the terminal primary alcohol group is converted to carboxyl without oxidation of the aldehyde group (usually by specific enzymes), a uronic acid is formed.



D-Gluconic acid



D-Glucosaccharic acid



D-Glucuronic acid

Reduction to Form Sugar Alcohol

Both aldoses and ketoses may be reduced by enzymes or non enzymatic to the corresponding polyhydroxy alcohols, the alcohols formed from glucose, mannose, fructose and galactose

•Manitol, the sugar alcohol derived from mannose, is frequently used medically as an osmotic diuretic to reduce cerebral edema.

• Sorbitol, the sugar alcohol derived from glucose, often accumulates in the lenses of diabetics and produces cataracts.

$$\text{D-Glucose} \xrightarrow{\text{Reduction}} \text{D-Sorbitol}$$

$$\text{D-Mannose} \xrightarrow{\text{Reduction}} \text{D-Mannitol}$$

$$\text{D-Fructose} \xrightarrow{\text{Reduction}} \text{D-Mannitol} + \text{D-Sorbitol}$$

$$\text{D-Galactose} \xrightarrow{\text{Reduction}} \text{D-Dulcitol}$$