Biochemistry

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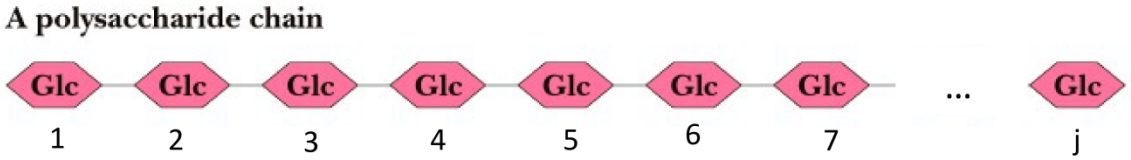
CARBOHYDRATES

$C_n (H_2O)_m$

Carbohydrates are defined chemically as aldehyde or ketone derivatives of the higher polyhydric alcohols, or compounds which yield these derivatives on hydrolysis.

CHAIN LENGTH

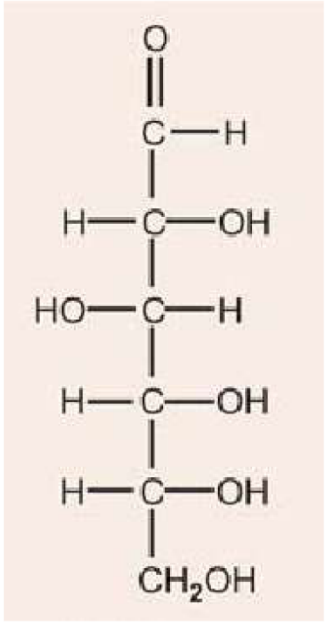
1. Monosaccharides (simple sugars) *(m=n, j=1)*
2. Disaccharides (hydrolysed into two monomers) *(m=n-1, j=2)*
3. Oligosaccharides (hydrolysed into "few" monomers) (oligo = few, 2<j<11)
4. Polysaccharides



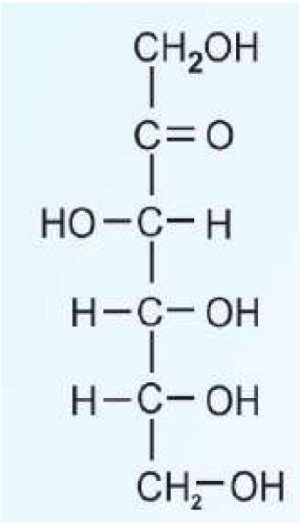
CARBOHYDRATES (monosaccharides)

Group type

1. Ketoses
2. Aldoses



glucose



fructose

Number of n

n=3 – trioses

n=4 – tetroses

n=5 – pentoses

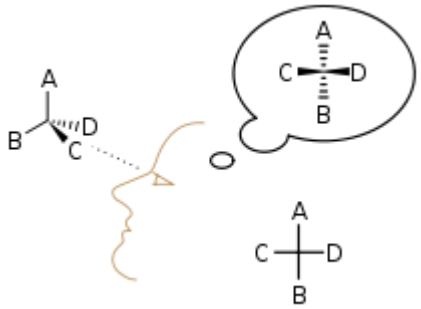
n=6

…

CARBOHYDRATES (monosaccharides)

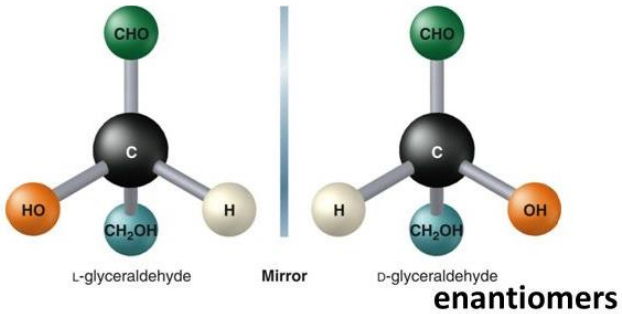
General formula	Aldosugars	Ketosugars
• **Trioses** ($C_3H_6O_3$)	Glyceraldehyde	Dihydroxyacetone
• **Tetroses** ($C_4H_8O_4$)	Erythrose	Erythrulose
• **Pentoses** ($C_5H_{10}O_5$)	Ribose	Ribulose
• **Hexoses** ($C_6H_{12}O_6$)	Glucose	Fructose

FISHCHER PROJECTIONS

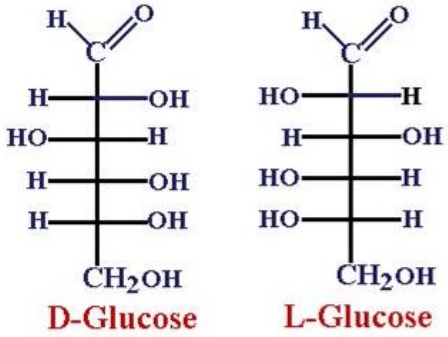


two-dimensional representation of a three-dimensional organic molecule by projection.

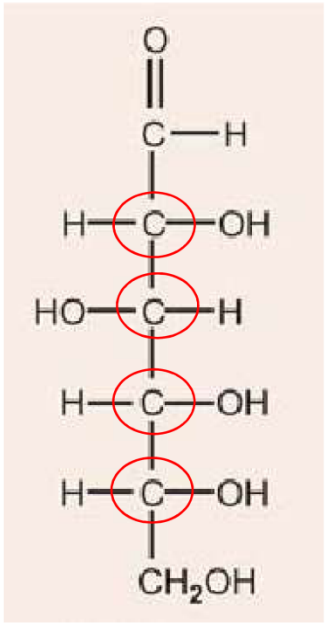
All nonterminal bonds are depicted as horizontal or vertical lines. The carbon chain is depicted vertically, with carbon atoms represented by the center of crossing lines. The orientation of the carbon chain is so that the C1 carbon is at the top. In an aldose, the carbon of the aldehyde group is C1; in a ketose the carbon of the ketone group has the lowest possible number (usually C2).



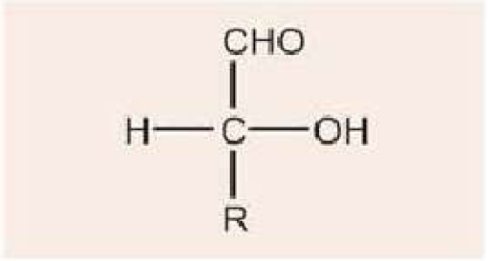
A Fischer projection is used to differentiate between L- and D- molecules. On a Fischer projection, the penultimate (next-to-last) carbon of D sugars are depicted with hydrogen on the left and hydroxyl on the right. L sugars will be shown with the hydrogen on the right and the hydroxyl on the left.



CARBOHYDRATES structure (stereoisometry)

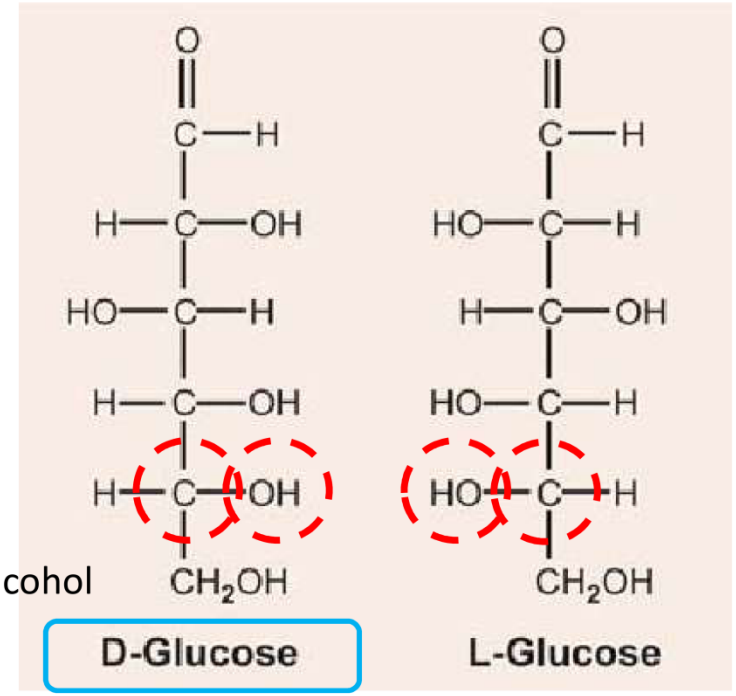


glucose



n

Asymmetric atom C
2 isomers (n – number of asymmetric atoms)

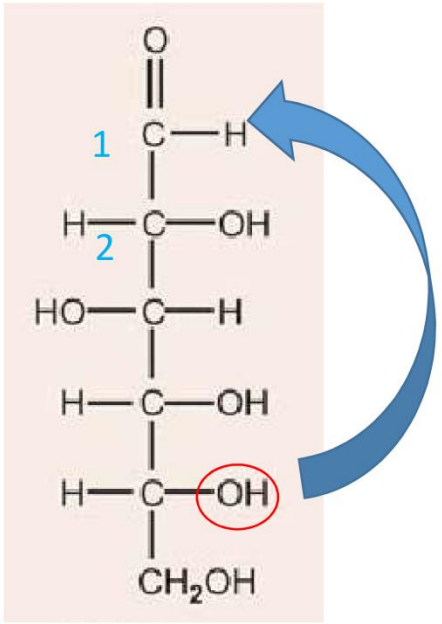


Primary alcohol

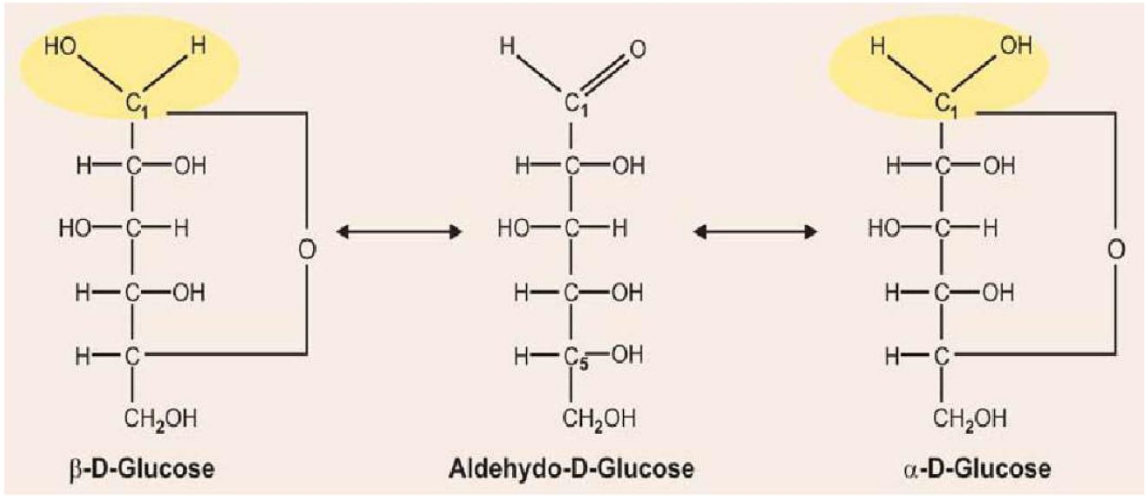
Most of enzymes are stereospecific!

Sterteoisomery implies optical activity and rotation of polarized light (+/- enantiomers)

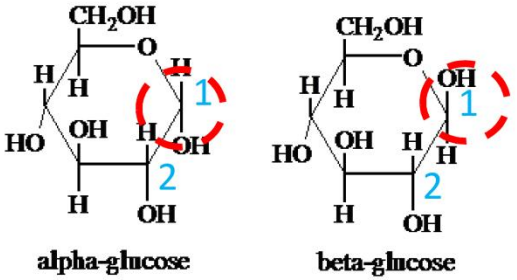
CARBOHYDRATES structure (cyclization and isomers)



D- glucose



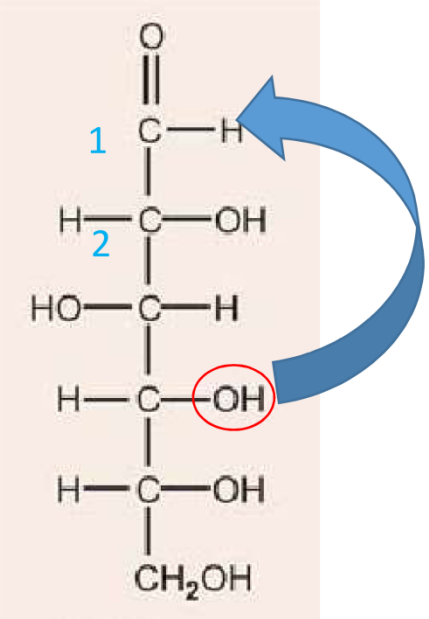
Pyranose ring



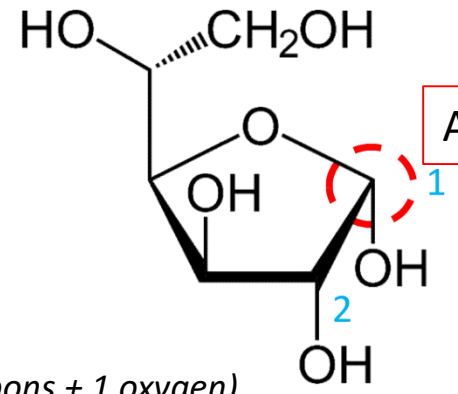
Alpha- and beta- cyclic isomers (anomers)

Mutarotation – change of optical activity of anomer after dissolution (equilibrium mixture of anomers)

CARBOHYDRATES structure (cyclization and isomers)

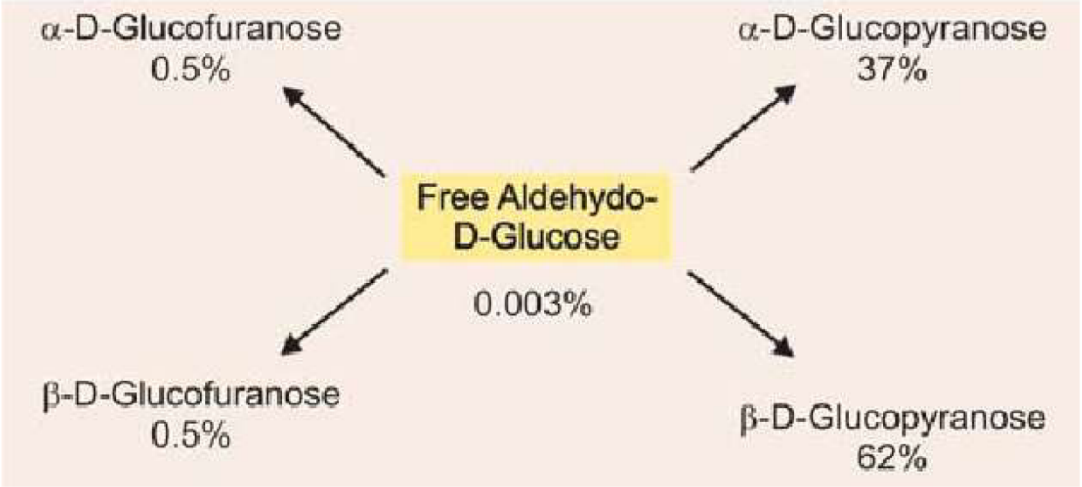


D- glucose



Alpha-D-glucofuranose

Furanose ring
(Cycle of 4 carbons + 1 oxygen)



CARBOHYDRATES (monosaccharides)

General formula	Aldosugars	Ketosugars
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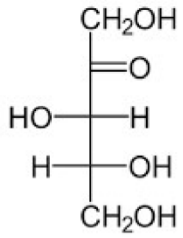
• **Hexoses** ($C_6H_{12}O_6$)	Glucose	Fructose

3C

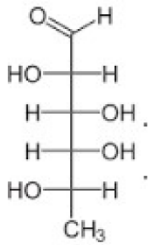
Trioses: involved in glycolysis
(as phosphor-esters)
Glycerol precursors

4C

Erythrose-4-P - intermediate in hexosemonophosphate shunt which is an alternative pathway for ***glucose*** oxidation.



D-Xylulose



L-Fucose

5C

D-ribose is a constituent of RNA;
constituent of certain coenzymes, e.g. FAD, NAD, coenzyme A.
D-2-deoxyribose is a constituent of DNA.

D-ribulose and D-xylulose as phosphates - intermediates in HMP shunt

L-fucose (methyl pentose): occurs in glycoproteins.

CARBOHYDRATES (monosaccharides)

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6C

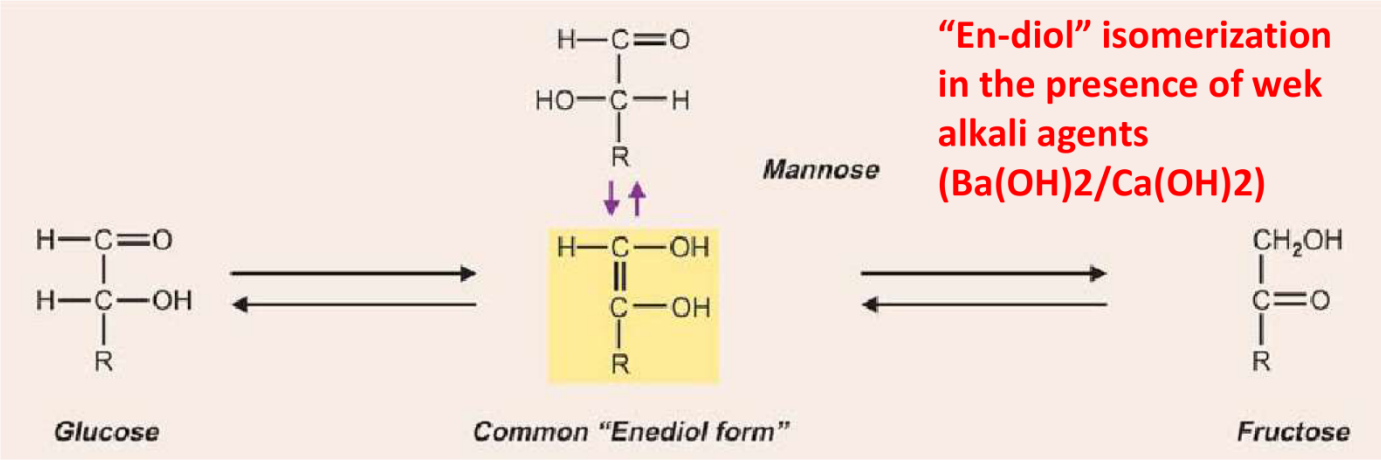
D-galactose: Seldom found free in nature. In combination it occurs both in plants and animals. Constituent of milk sugar (***lactose***) and also in tissues as a constituent of galactolipid and glycoproteins. • It is less sweet than ***glucose*** and less soluble in water.
6-deoxy-L-Galactose - constituent of glycoproteins, blood group substances and bacterial polysaccharides.

D-Glucose (Dextrose, Grape Sugar) • It is the chief physiological sugar present in normal blood continually and at fairly constant level, i.e. about 0.1 per cent.
• All tissues utilise glucose for energy. Erythrocytes and Brain cells utilise glucose ***solely*** for energy purposes. • Occurs as a constituent of disaccharide and polysaccharides.
• Stored as ***glycogen*** in liver and muscles mainly.

D-fructose (Laevulose, Fruit sugar) * occurs free in fruits. • It is very sweet sugar, much sweeter than ***sucrose*** and more reactive than ***glucose***. • It occurs as a constituent of ***sucrose*** and also of the polysaccharide ***inulin***. • Seminal fluid is rich in fructose and sperms utilize fructose for energy. Fructose is formed in the seminiferous tubular epithelial cells from glucose.

D-mannose: It does not occur free in nature but is widely distributed in combination as the polysaccharide ***mannan***. In the body, it is found as a constituent of glycoproteins.

CARBOHYDRATES (monosaccharides) reactivity



Sugars (monosaccharides) undergo interconversion

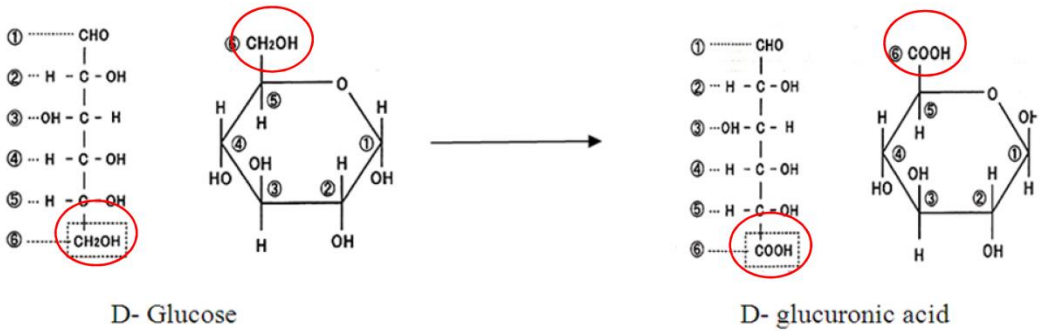
In general – monosaccharides in solution:
Alkali solution – "endiol isomerization" becoming unstable and easily oxidized by O2 and metals
Weak alkali solution – cyclisation of linear monosaccharides
Strong alkali solution - caramelizes

CARBOHYDRATES (monosaccharides) reactivity

Biologically relevant selective oxidation of aldoses primary hydroxyl group (-OH)

D-Glucose → D-Glucuronic acid

D-Galactose → D-Galacturonic acid



Aldose oxidation into ***uronic*** acid

Biomedical importance of D-Glucuronic acid:

In the body D-Glucuronic acid is formed from Glucose in liver by uronic acid pathway, an alternative pathway for glucose oxidation. It occurs as a constituent of certain mucopolysaccharides.

In addition, it is of importance in that it conjugates toxic substances, drugs, hormones and even bilirubin (a break down product of Hb) and converts them to a soluble nontoxic substance, a glucuronide, which is excreted in urine.

CARBOHYDRATES (monosaccharide derivatives)

1. ***Deoxy sugars***: 2-deoxy-D-Ribose is found in nucleic acid (DNA).
2. ***Amino sugars*** (hexosamines):

Glycosylamine: Anomeric –OH -> –NH2 group.

Ribosylamine – synthesis of purines

Glycosamine (Glycamine): Alcohol –OH -> –NH2 group

*Glucosamine (@C2) (chitosamine) *(acetylated)*

constituent of certain mucopolysaccharides (MPS)

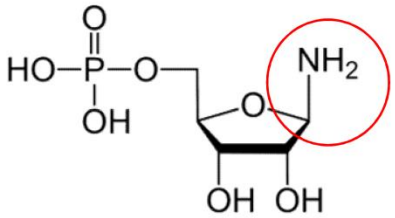
organic constituent of fungi cell wall

composes Chitin - shells of crabs, Lobsters, etc

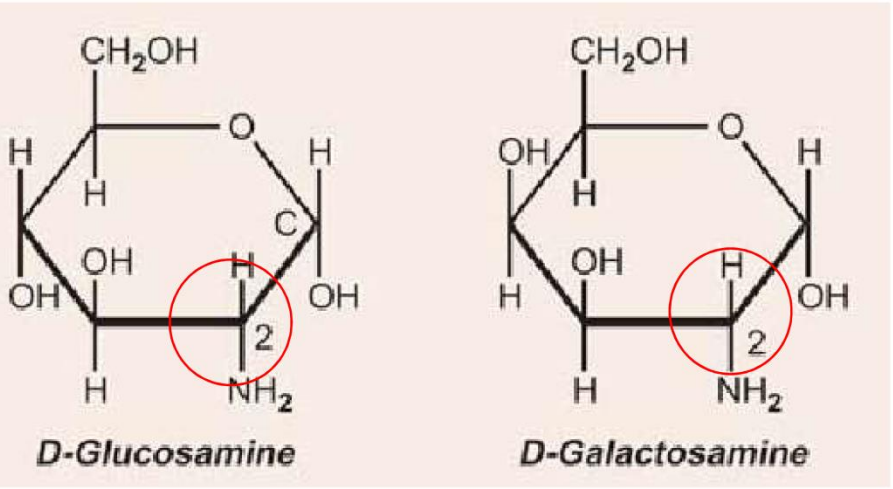
*Galactosamine (@C2)(chondrosamine) *(acetylated)*

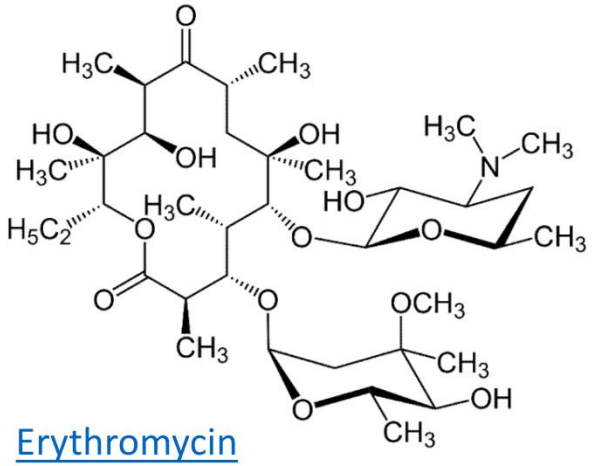
component of chondroitin sulphates (cartilages, bones, tendons)

Antibiotics *(Erythromycin, Carbomycin)*



P-ribosylamine





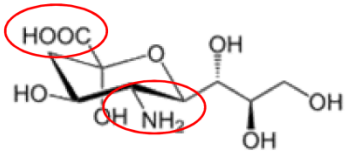
Erythromycin

CARBOHYDRATES (monosaccharide derivatives)

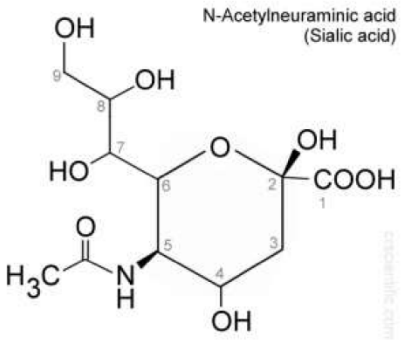
3. ***Amino Sugar Acids***

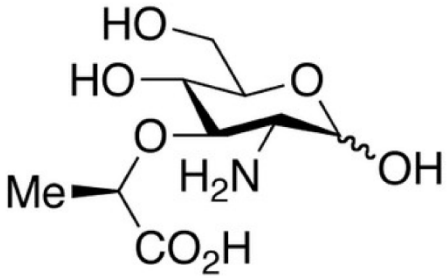
• *Neuraminic acid*: Neuraminic acid is unstable and found in nature in the form of acylated derivatives known as *Sialic acids* (N-acetyl Neuraminic acid —NANA). * both NA and NANA are found in mucopolysaccharides and in glycolipids like gangliosides

• *Muramic acid*: is found in some bacterial cell walls



Neuraminic acid





Muramic acid

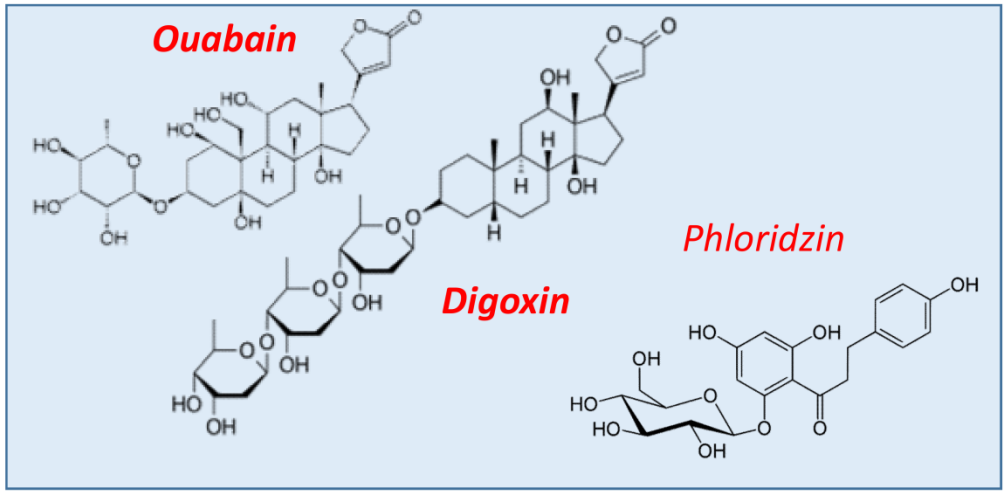
CARBOHYDRATES (monosaccharide derivatives)

4. ***Glycosides (****compounds containing a carbohydrate and a noncarbohydrate residue, attached by an acetal linkage to C1 of carbohydrate****)*** * widely distributed in plant kingdom.

*CH – glucose (in **glucoside**), galactose (in **galactoside**), etc*
NCH - methyl alcohol, glycerol, phenol, adenine, sterols (!), hydroquinones (!)

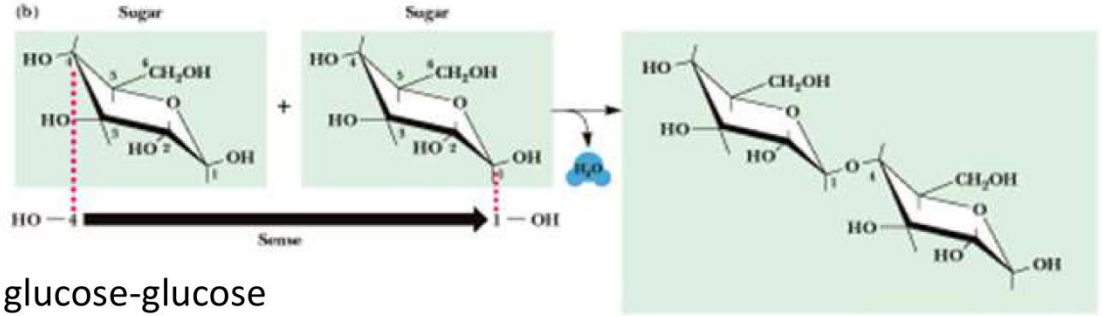
Cardiac glycosides (medicine) – treatments for cardiac insufficiency (***Digoxin, Ouabain)***: inhibits active transport of Na+ in cardiac muscle.

- ***Phloridzin*** - blocks the transport of sugar across the mucosal cells of small intestine and also renal tubular epithelium
- Antibiotics (***streptomycin***)



CARBOHYDRATES (disaccharides m=n-1)

Two monosaccharides are joined by glycosidic linkage



Maltose = glucose-glucose
Lactose = glucose-galactose
Sucrose = glucose-fructose
Lactulose = keto(glucose-galactose)

(galactose = one of aldohexose)

CARBOHYDRATES (oligosaccharides m=n-1, 2<j<11)

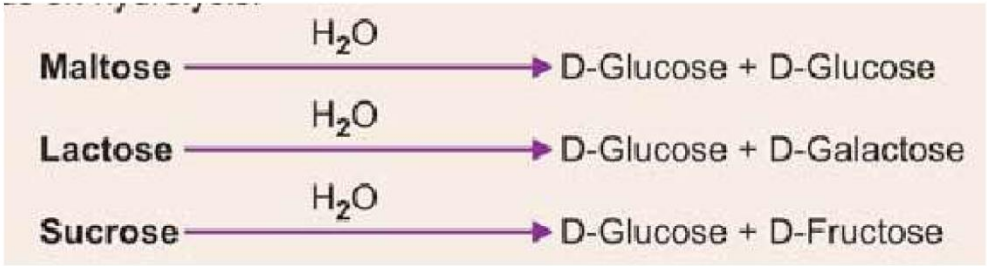
Maltotriose = glucose-glucose-glucose

several monosaccharides are joined by glycosidic linkage

CARBOHYDRATES (polysaccharides m=n-1, j>10)

Glycans (homo-, heteroglycans=different units or derivatives)

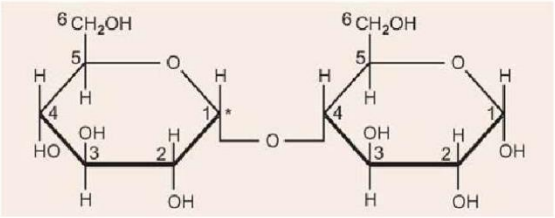
CARBOHYDRATES (disaccharides m=n-1)

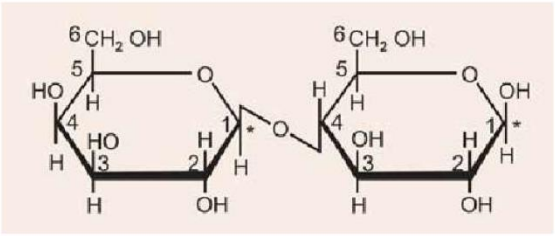


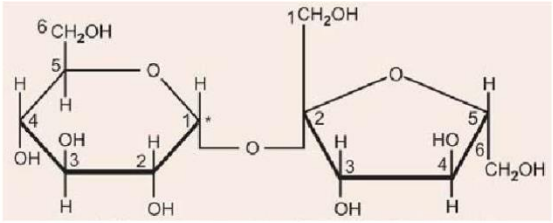
Maltose (malt sugar) can be obtained from starch by amylase digestion (in the gut) * rather sweet sugar and is very soluble in water * digested by maltase

Lactose (milk sugar) found in in milk to the extent of about 5% * not very soluble and is not so sweet * Digested by lactase (intestinal juice).

Sucrose (table sugar, Cane sugar) Can be found in sugar beet, most fruits and vegetables (pineapples, carrots) * very soluble and very sweet * Digested by sucrase (intestinal juice) * As both anomeric carbons are involved in 'linkage', it does not exhibit mutarotation.







CARBOHYDRATES (disaccharides m=n-1)

* Baby and invalid foods are produced by hydrolysis of grains – large amount of maltose. Easily digestible!

• In lactating mammary gland, the lactose is synthesized from glucose by the duct epithelium.

• 'Souring' of milk: Many organisms that are found in milk, e.g. E. coli, A. aerogenes, and Str. lactis convert lactose of milk to lactic acid (LA) thus causing souring of milk.

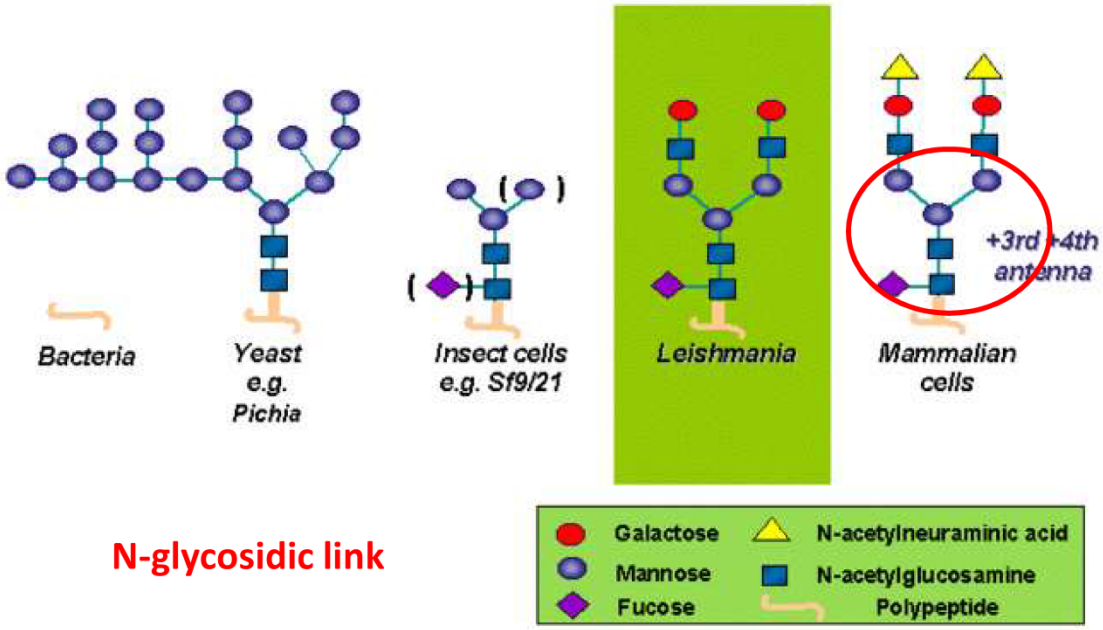
• Sucrose if introduced parenterally cannot be utilised, but it can change the osmotic condition of the blood and causes a flow of water from the tissues into the blood. Thus clinicians use it in oedema like cerebral oedema. If sucrose or some other disaccharides are not hydrolysed in the gut, due to deficiency of the appropriate enzyme, diarrhoea is likely to occur.

CARBOHYDRATES (oligosaccharides m=n-1, 2<j<11)

Major biological function – glycosylated proteins at the cell surface, glycosylated secreted proteins (antibodies, coagulation factors)/

1. Information and signaling! (cell-cell recognition and targeting)
2. Protection from proteases

Connection to Ser/Thr (by O-glycosidic linkage) or Asp (N-glycosidic link)



N-glycosidic link

CARBOHYDRATES (polysaccharides m=n-1, j>10)

Glycans (homo-, heteroglycans=different units or derivatives)

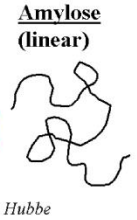
Starch - polymer of glucose, and occurs in many plants as storage foods.

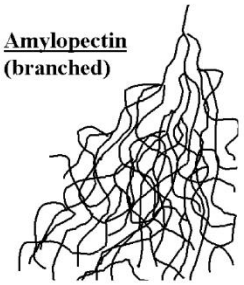
Course of Hydrolysis	*Reaction with Iodine*
Starch	Blue
↓	
Soluble starch	Blue
↓	
Amylodextrin	Purple
↓	
Erythrodextrin	Red
↓	
Achroodextrin	Colourless
↓	
Maltose	

starch consists of two polymeric units of glucose called (i) Amylose (20%) and (ii) Amylopectin(80%)

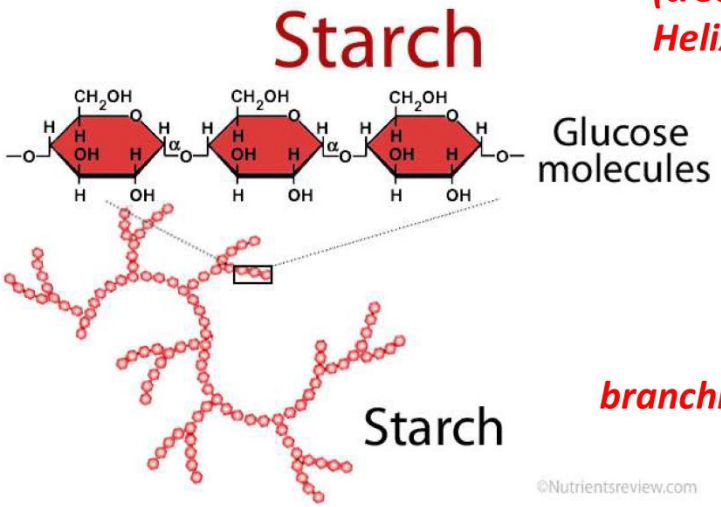
Native Starch Types

Small - 60 kDa
Soluble
Blue
(treated by I2)
Helix

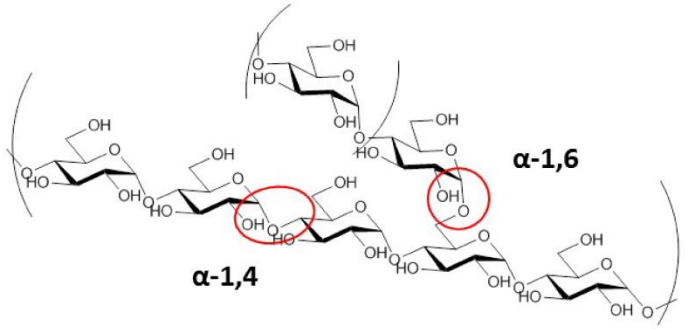


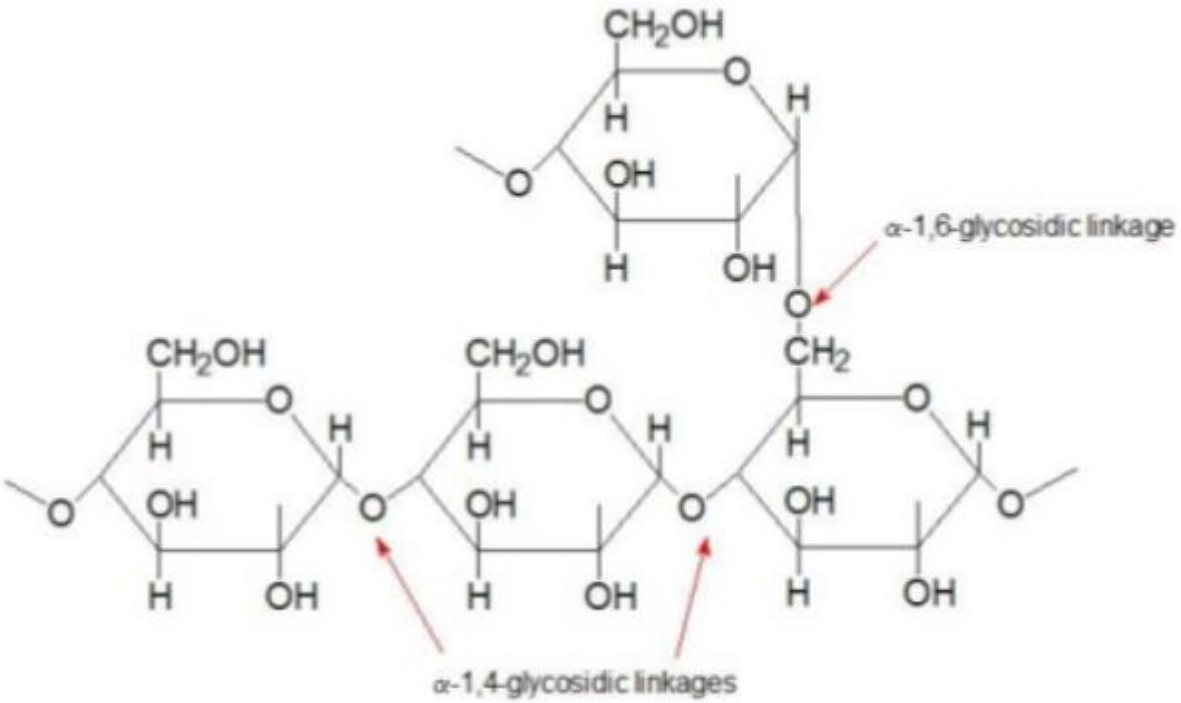


Big
Swells
Reddish-violet
(treated by I2)



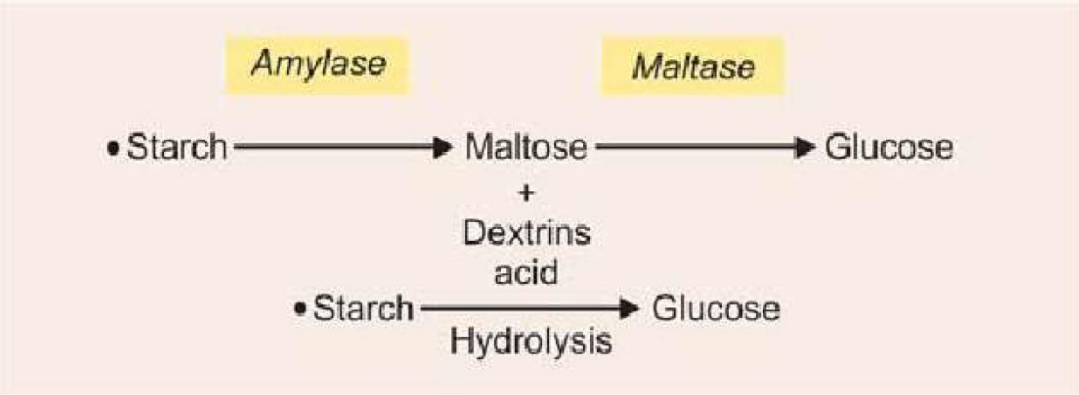
branching




α-1,6-glycosidic linkage
α-1,4-glycosidic linkages

CARBOHYDRATES (polysaccharides m=n-1, j>10)

Glycans (homo-, heteroglycans=different units or derivatives)

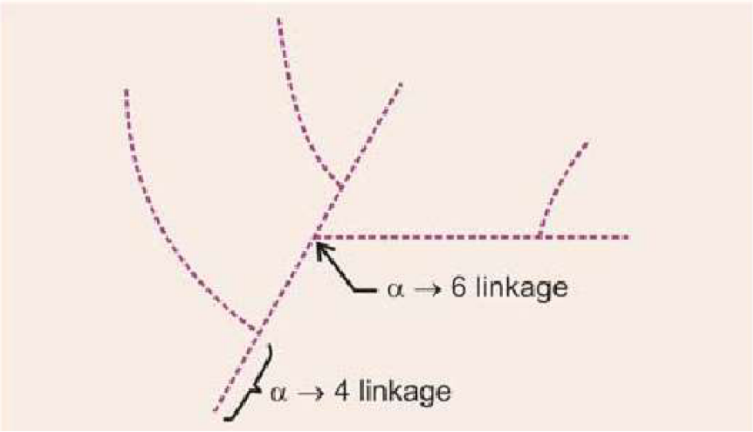


Alpha-Amylase in saliva + pancreatic juice - endo enzyme
Beta-Amylase in malts and sprouted grains - exo enzyme

CARBOHYDRATES (polysaccharides m=n-1, j>10)

Glycans (homo-, heteroglycans=different units or derivatives)

Glycogen - reserve carbohydrate of the animal // fungi // yeasts.
It is also found in large amounts in oysters and other shell fish.
In higher animals, it is deposited in the liver and muscle as storage material which are readily available as immediate source of energy.

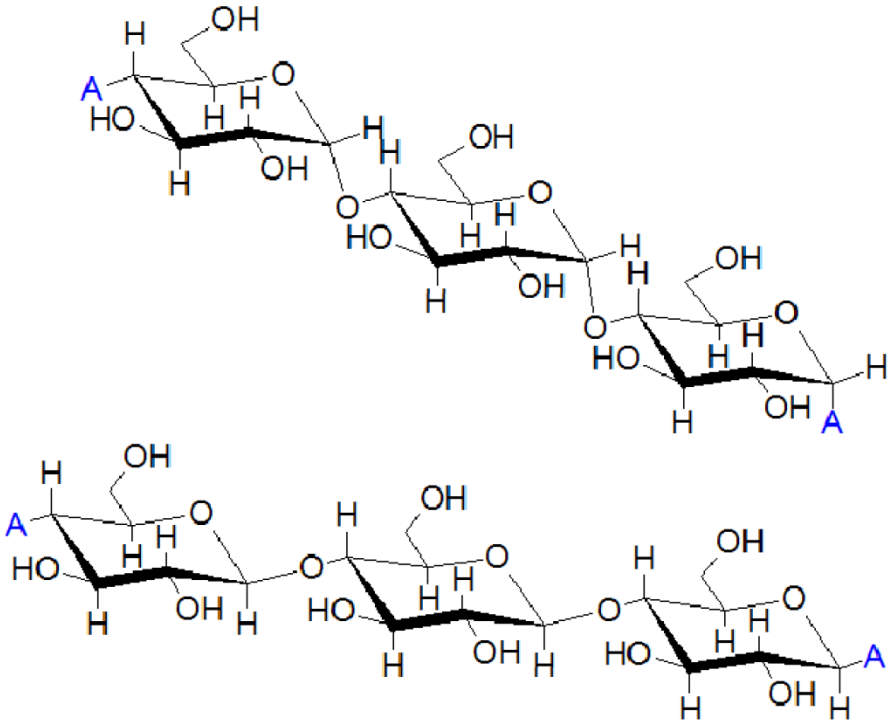


D-glucose
Mol. Size – approx. that of AP (5 000 000 Da)

Amylopectin and glycogen are both polysaccharides. Amylopectin is an insoluble form of starch while glycogen is a soluble form of starch.
The great sources of amylopectin come from plants which include: rice, corn, potatoes, and other starchy foods. On the other hand, glycogen is found in the meat, intestines, and livers of animals.

Amylopectin is less branched compared to glycogen.Glycogen is a highly branched molecule. Branches are larger in amylopectin compared to glycogen.

Cellulose - polymer of glucose. It is not hydrolyzed readily by dilute acids, but heating with fairly high concentrations of acids yields, the disaccharide Cellobiose and D-Glucose. Cellobiose is made up of two molecules of D-Glucose linked together by β-Glucosidic linkage between C1 and C4 of adjacent glucose units.

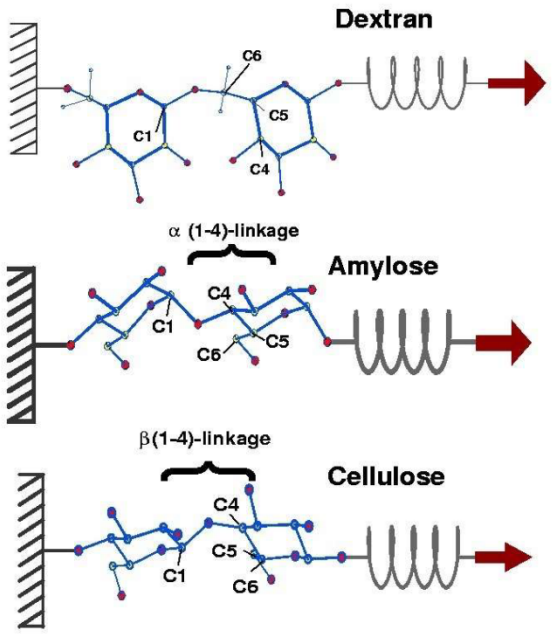


Inulin - polymer of D-fructose and has a low molecular weight (MW = 5000). It occurs in tubers of the Dehlia, in the roots of the Jerusalem artichoke, dandelion and in the bulbs of onion and garlic. It is a white, tasteless powder. It has no dietary importance in human beings as inulinase is absent in human.

Dextrins - When starch is partially hydrolysed by the action of acids or enzymes, it is broken down into a number of products of lower molecular weight known as dextrins. They resemble starch by being precipitable by alcohol, forming sticky, gummy masses.

Dextrans - It is a polymer of D-Glucose.
1-3, 1-4, 1-6 bonding
Branched!
Some fractions can be used as plasma extension upon blood loss (slow elimination)

Agar - It is a homopolysaccharide.
Made up of repeated units of galactose which is sulphated. Present in seaweed.
It is obtained from them.



CARBOHYDRATES (heteropolysaccharides)

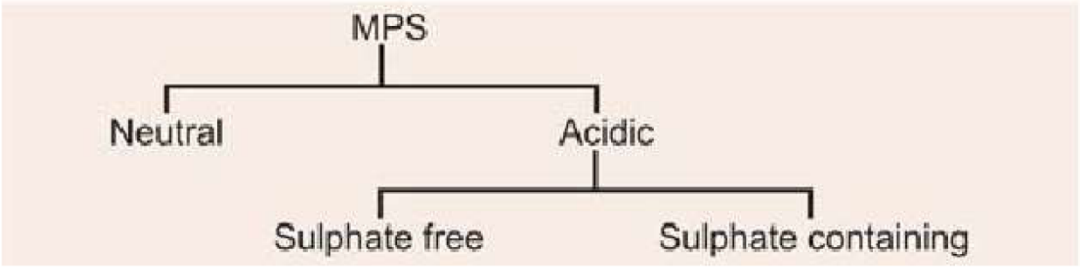
Heteroglycans (Mucopolysaccharides)

Carbohydrates that include AMINOSUGARS and URONIC ACID

Biological relevance – tissue construction, protein modifiers

Nomenclature: Glycoproteins <4% of Carbohydrate
Mucoproteins >4% of Carbohydrate

classification



CARBOHYDRATES (heteropolysaccharides)

Heteroglycans (Mucopolysaccharides)

Acidic Sulphate free MPS

Hyaluronic Acid - synovial fluid, skin, umbilical cord
structure - N-acetyl glucosamine and D-Glucuronic acid

Chondroitin – cornea of the eye, cranial cartilages
structure - N-acetyl galactoseamine and D-Glucuronic acid

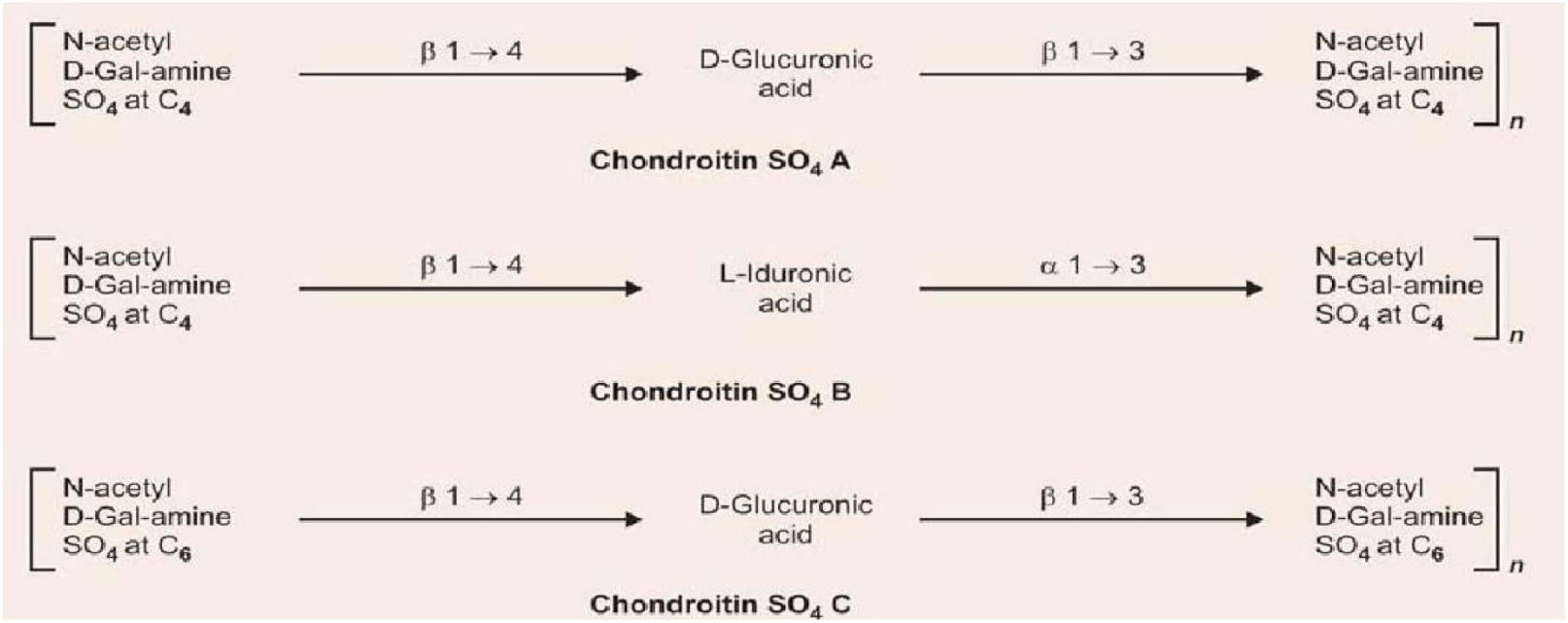
CARBOHYDRATES (heteropolysaccharides)

Heteroglycans (Mucopolysaccharides)

Acidic Sulphate containing MPS

Keratan Sulphate (Kerato Sulphate) - costal cartilage, cornea, aorta wall
structure - N-acetyl glucosamine and Galactose

Chondroitin Sulphates - ground substance of mammalian tissues and cartilage
(part of chondroproteins)

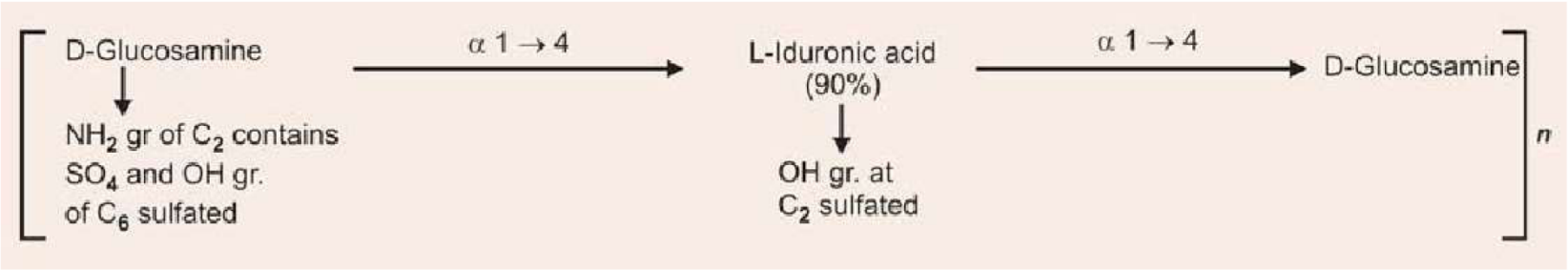


CARBOHYDRATES (heteropolysaccharides)

Heteroglycans (Mucopolysaccharides)

Acidic Sulphate containing MPS

Heparin - anticoagulant present in liver and it is produced mainly by mast cells of liver



Neutral MPS

pneumococci capsule (haptens)

Blood group substances: These contain peptides or amino acids as well as carbohydrates

Nitrogenous neutral MPS firmly bound proteins, e.g. ovalbumin

CARBOHYDRATES function (summary)

- Energy source
- Lipid component
- Glycoprotein/proteoglycan component
- Mucopolysacharides component

- Drugs (cardiac/antibiotics)

MPS-proteoglycans

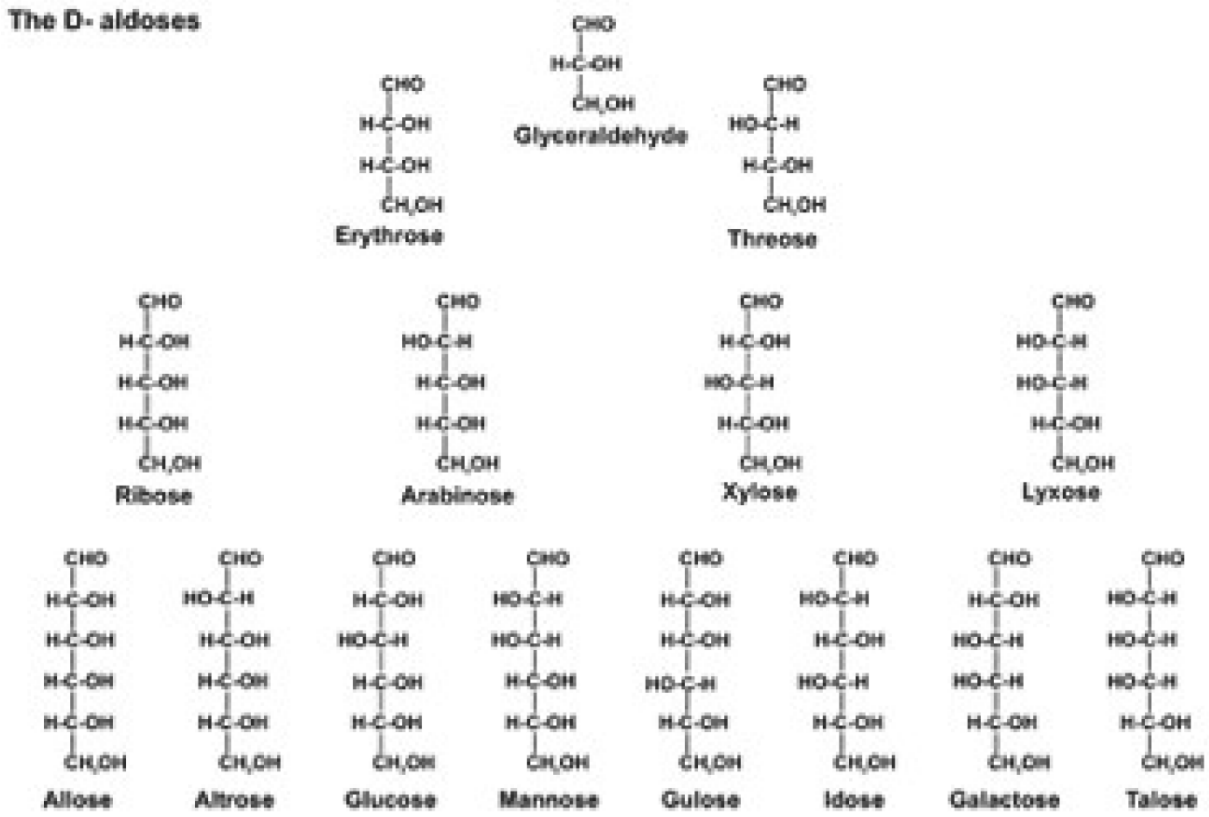
- extracellular matrix
- polyanions
- barrier (hyaluronic)
- lubricant/cell migration
- kidney filtration
- anticoagulants

- coenzymes
- cell receptors
- cornea/eye
  - structure/
  - transparency

Literature biochemistry

1. Lehninger Principles of Biochemistry (Nelson D.L., Cox M.M.)
2. Principles and Techiniques of Biochemistry and Molecular Biology (Wilson K., Walker J.)

Aldoses (aldo-group) of different carbon-chain length(trioses, tetroses, pentoses, hexoses) with their simple names.
Only D-isomers are shown.



Hexo-aldoses with their simple names.
The difference is in the position of –OH groups at different chiral C atoms.
Only D-isomers are shown.