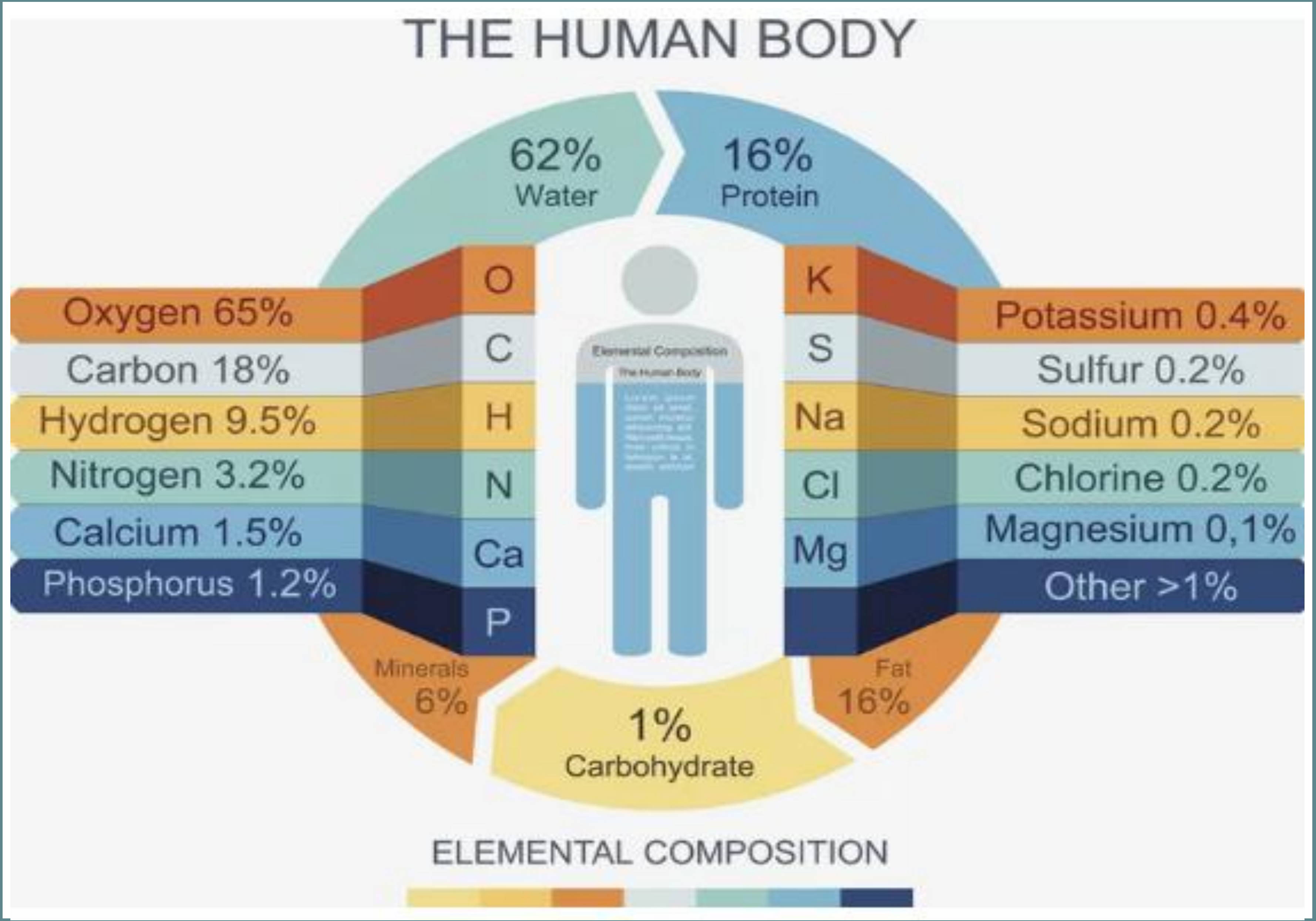
BIOMOLECULES

What molecules keep us alive, and how do they do so?

- All living organisms require several compounds to continue to live.
- We call these compounds **biomolecules.** All of these biomolecules are **organic**, which means that they contain carbon.
  - Carbon has four valence electrons, which means this element forms strong covalent bonds with many other elements.

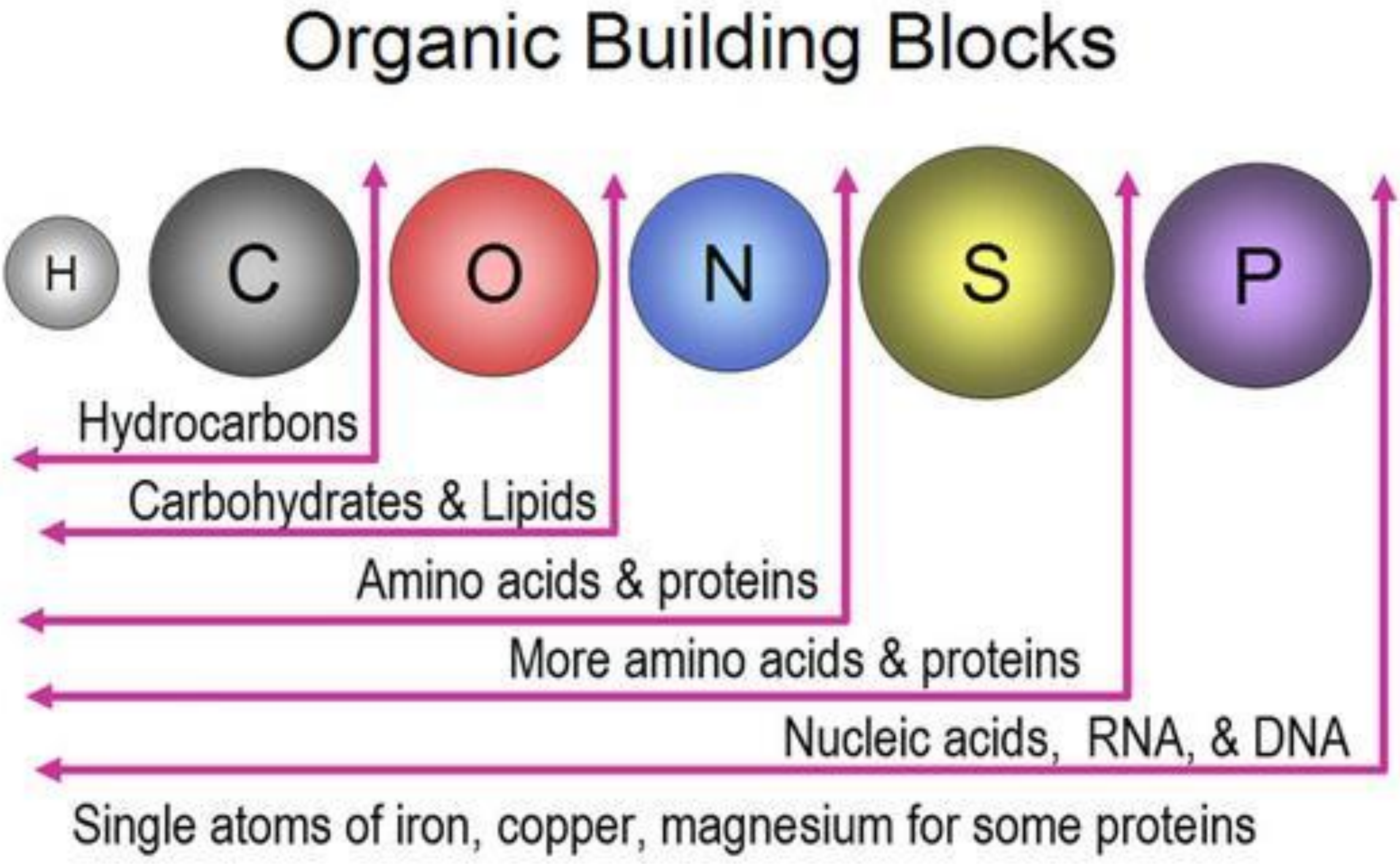

THE HUMAN BODY
62%
Water
16%
Protein
O
C
H
N
Ca
P
K
S
Na
Cl
Mg
Oxygen 65%
Carbon 18%
Hydrogen 9.5%
Nitrogen 3.2%
Calcium 1.5%
Phosphorus 1.2%
Potassium 0.4%
Sulfur 0.2%
Sodium 0.2%
Chlorine 0.2%
Magnesium 0,1%
Other >1%
Elemental Composition
The Human Body
Minerals
6%
1%
Carbohydrate
Fat
16%
ELEMENTAL COMPOSITION

What are BIOMOLECULES?

- **Organic compounds made by living things**
- Compounds essential to life
- Also called **biochemicals**
- Some are very large - **polymers**
- There are thousands of different biomolecules, but are **separated into 4 categories**

Carbohydrates	Lipids
Proteins	Nucleic Acids

Biomolecules of life consists of six basic elements



Biomolecules

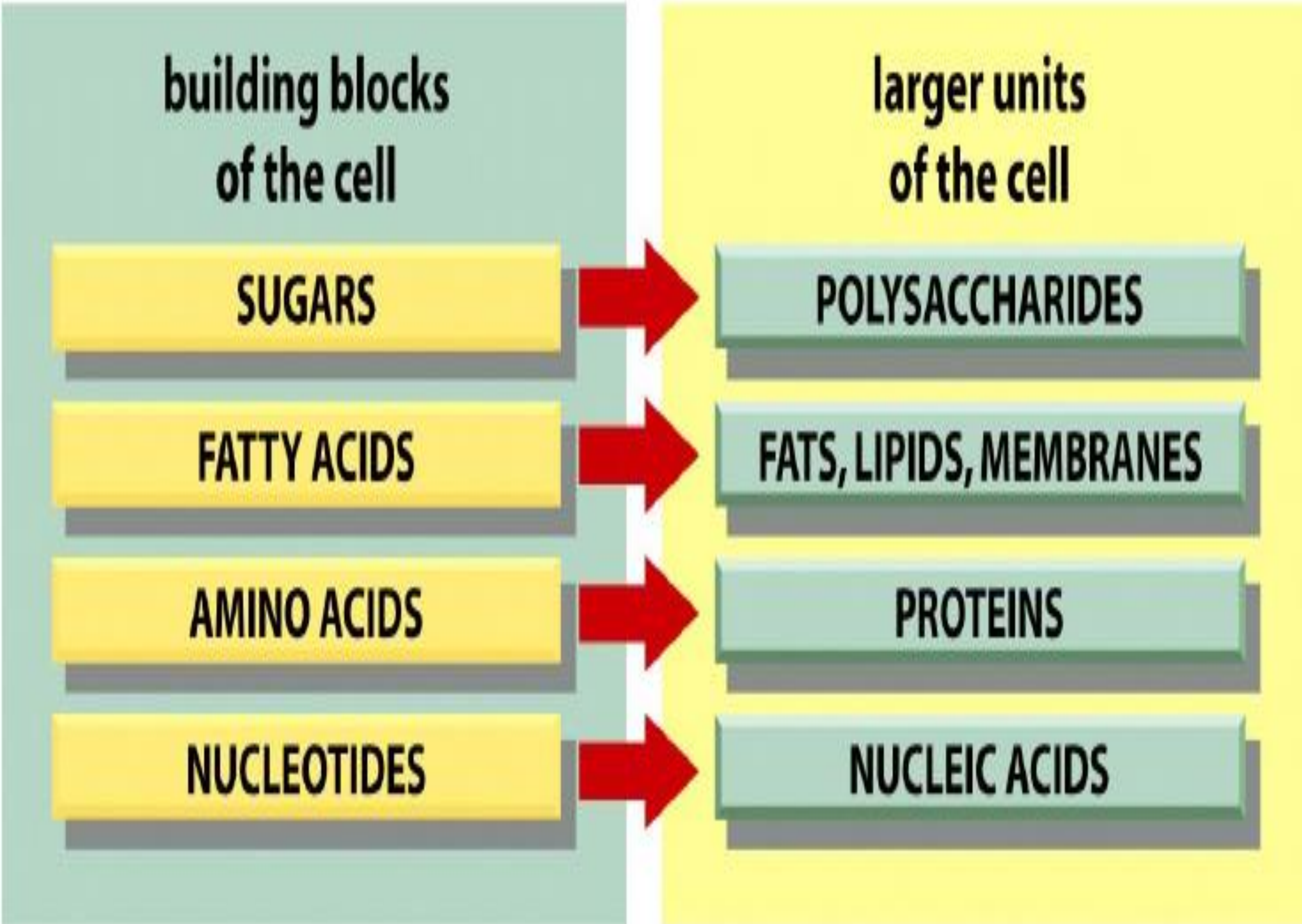
Macromolecules (Biomolecules)

made through POLYMERIZATION

MONOMER – building block

POLYMER – large compound made of monomers

1. Carbohydrates
2. Lipids
3. Proteins
4. Nucleic Acids


building blocks of the cell
larger units of the cell
SUGARS
POLYSACCHARIDES
FATTY ACIDS
FATS, LIPIDS, MEMBRANES
AMINO ACIDS
PROTEINS
NUCLEOTIDES
NUCLEIC ACIDS

Biomolecule	Building block	Major functions
Protein	Amino acid	Basic structure and function of cell
DNA	Deoxyribonucleotide	Hereditary information
RNA	Ribonucleotide	Protein synthesis
Polysaccharide	Monosaccharide	Storage form of energy
Lipids	Fatty acids & glycerol	Storage form of energy to meet long term demands

CARBOHYDRATES

- Carbohydrate is an organic compound, it comprises of only oxygen, carbon and hydrogen. Carbohydrates are good source of energy.
- The empirical formula being $\mathbf{C_n(H_2O)_n}$; **where n ≤ 3.**
- Ratio of C:H:O will be mostly 1:2:1.
- **Definitions-**Carbohydrates are hydrates of carbons. Carbohydrates are polyhydroxy aldehydes or polyhydroxy ketones or which produce them on hydrolysis.
- Carbohydrates are also known as saccharides, the word saccharide comes from Greek word **sakkron** which means sugar.

What are Carbohydrates?

- Most common organic molecule
- **<u>Function</u>:** Primary energy source our body needs
- **<u>Elements present</u>**: C, H, O (1:2:1 ratio) IMPORTANT!
- **<u>Monomer (building block):</u>** Monosaccharides (Glucose is most common)
- **<u>Polymer:</u>** Polysaccharides (starch, Glycogen, Cellulose, Chitin)
- **<u>Examples</u>**: Chocolate, Bread, Pasta, Fruits, Vegetables (ALL FROM PLANTS!!!)

Biological Importance of CARBOHYDRATES

- Carbohydrates are chief energy source, in many animals; they are instant source of energy. Glucose is broken down by glycolysis/ kreb's cycle to yield ATP.
- Glucose is the source of storage of energy. It is stored as glycogen in animals and starch in plants.
- Stored carbohydrates act as energy source instead of proteins.

4 calories/gm

- Carbohydrates are intermediates in biosynthesis of fats and proteins.
- Carbohydrates aid in regulation of nerve tissue and are the energy source for brain.
- Carbohydrates get associated with lipids and proteins to form surface antigens, receptor molecules, vitamins and antibiotics.
- They form structural and protective components, like in cell wall of plants and microorganisms.
- In animals they are important constituent of connective tissues.
- They participate in biological transport, cell-cell communication and activation of growth factors.

CLASSIFICATION OF CARBOHYDRATES

CARBOHYDRATES

	Saccharides (Sugars)		Polysaccharides (Complex sugars)
Physical Properties	* Low molecular weight * Soluble in water * Sweet to taste		* High molecular weight * Insoluble in water * Tasteless
Composition	Monosaccharides Simple sugars	Disaccharides Double sugars	Multiple sugars
Diagrammatic representation	See diagram below	See diagram below	See diagram below
General fromula	$(CH_2O)_n$ When n=3 to7	$C_{12}H_{22}O_{11}$	$C_x(H_2O)_n$
Common examples	Glyceraldehyde, Glucose Fructose, Galactose, Ribose sugar	Maltose,Sucrose Lactose	Starch, Glycogen Cellulose, Lignin, Chitin

Classification of Carbohydrates

Carbohydrates

Monosaccharides
1 sugar unit

e.g.Glucose,
fructose etc

Disaccharides
2 sugar units

e.g.Sucrose

Oligosaccharides
3-10 units

e.g. Maltotriose

Polysaccharides
>10

Homoglycans

e.g. starch,
glycogen

Heteroglycans

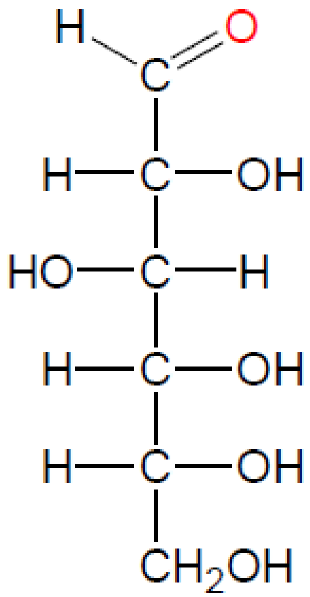
e.g. GAGs or
glycosaminoglycans

Different between Monosaccharaides, Oligosaccharides and Polysaccharides

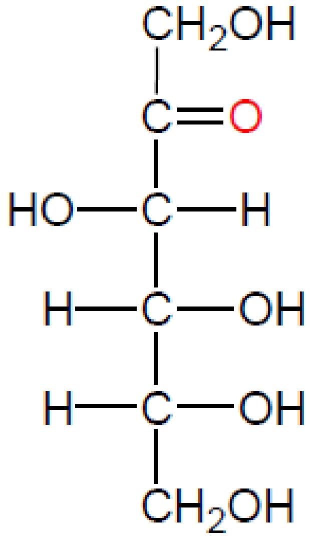
Character	Monosaccharaides	Oligosaccharides	Polysaccharides
No. of sugar molecules	1	2-9	More than 9
Glycoside bond	Absent	Present	Present
Molecular Weight	Low	Moderate	High
Taste	Sweet	Minimally sweet taste	No taste
Solubility	Soluble	Soluble	Insoluble
Nature	Always reducing sugar	May or may not be	Always non reducing sugar
Example	Glucose, fructose, Galactose	Sucrose, Maltose	Starch, Glycogen, Dextrin, Cellulose

Monosaccharides:

They are the simplest carbohydrates that cannot be broken into smaller units on hydrolysis.



D-glucose



D-fructose

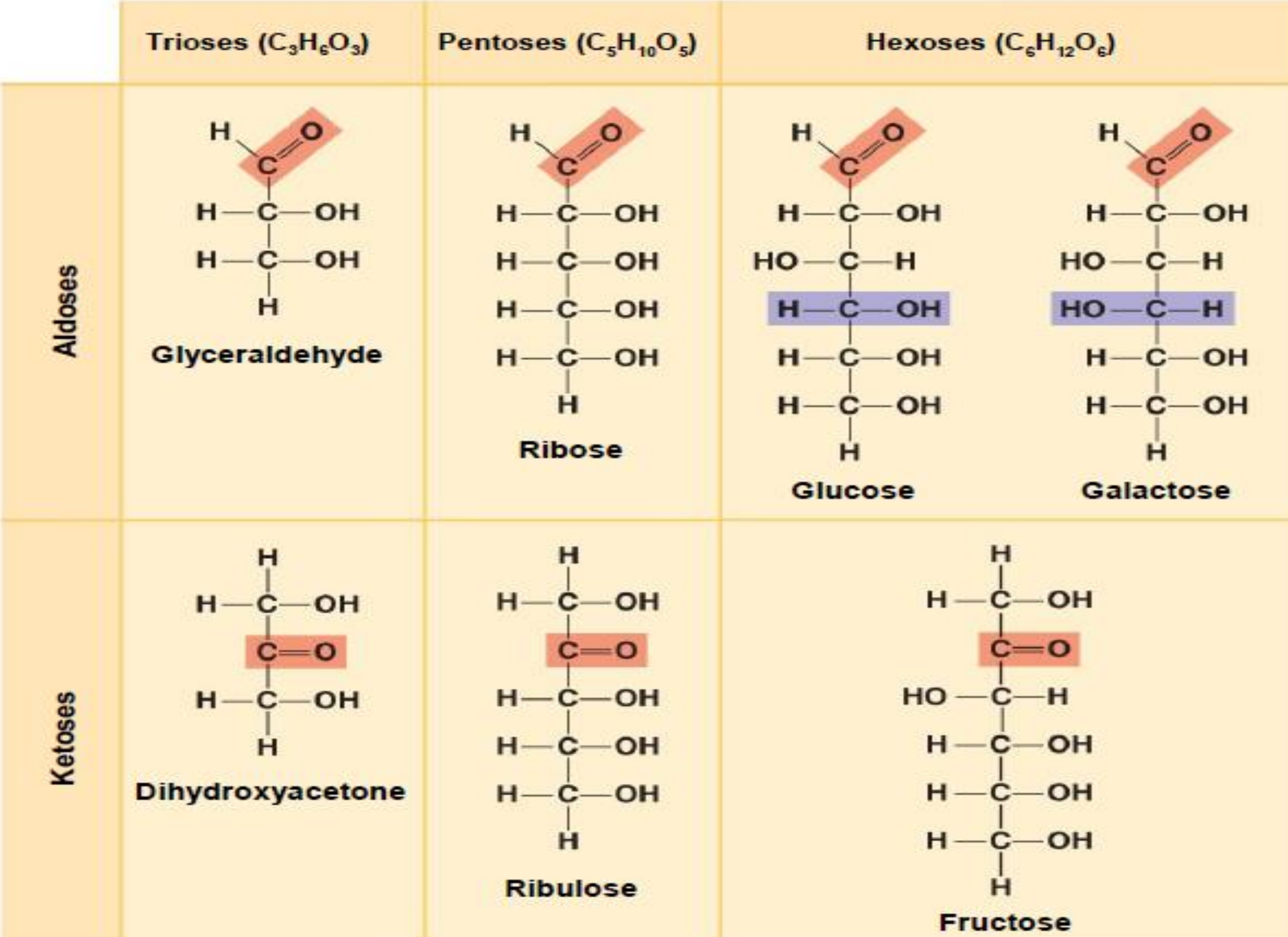
- Aldoses (e.g., glucose) have an aldehyde group at one end
- Ketoses (e.g., fructose) have a keto group, usually at C2.

Monosaccharide further classified on the basis of functional group and number of carbon atoms present in their structure

On the basis of no. of carbon atom

On the basis of functional group

No. of carbon atom	Generic name	ALDOSE	KETOSE
3	Trioses	Aldotriose e.g. glyceraldehyde	Ketotriose e.g. Dihydroxyacetone
4	Tetroses	Aldotetrose e.g. Erythrose	Ketotetrose e.g. Erythrulose
5	Pentoses	Aldopentoses e.g Arabinose, Xylose, Ribose	Ketopentoses e.g. Xylulose, Ribulose
6	Hexoses	Aldohexose e.g. Glucose, Galactose, Mannose	Ketohexose e.g. Fructose
7	Heptoses	Aldoheptose: Glucoheptose	Ketoheptose e.g Sedoheptulose

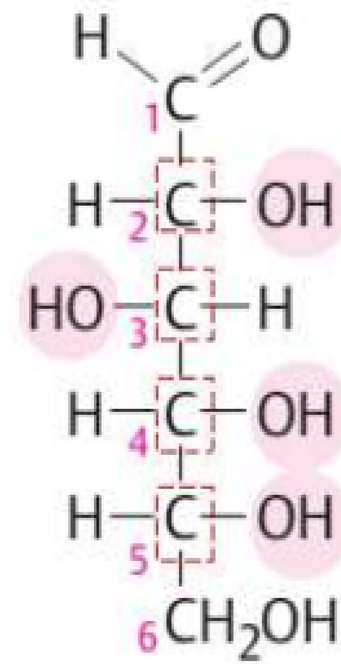

Trioses ($C_3H_6O_3$)
Pentoses ($C_5H_{10}O_5$)
Hexoses ($C_6H_{12}O_6$)
Aldoses
Glyceraldehyde
Ribose
Glucose
Galactose
Ketoses
Dihydroxyacetone
Ribulose
Fructose

Isomerism in monosaccharides

- **Stereoisomerism** - Compound shaving same structural formula but they differ in spatial configuration. Example: Glucose has two isomers with respect to penultimate carbon atom. They are D-glucose and L-glucose.
- **Optical Activity** - It is the rotation of plane polarized light forming (+) glucose and (-) glucose.
- **Distereo isomers** - It the configurational changes with regard to C2, C3, or C4 in glucose. Example: Mannose, galactose.
- **Annomerism** - It is the spatial configuration with respect to the first carbon atom in aldoses and second carbon atom in ketoses.

Stereoisomerism

- Important characteristics of monosaccharide.
- Same structural formulae but differs in their spatial arrangement.
- A carbon is said to **assymetric or chiral** when its is attached to different atoms or groups.
- Possible number of isomers – **2^n** where *n = number of chiral carbon atoms*.



Open-chained form of glucose

Chiral center

Enantiomers

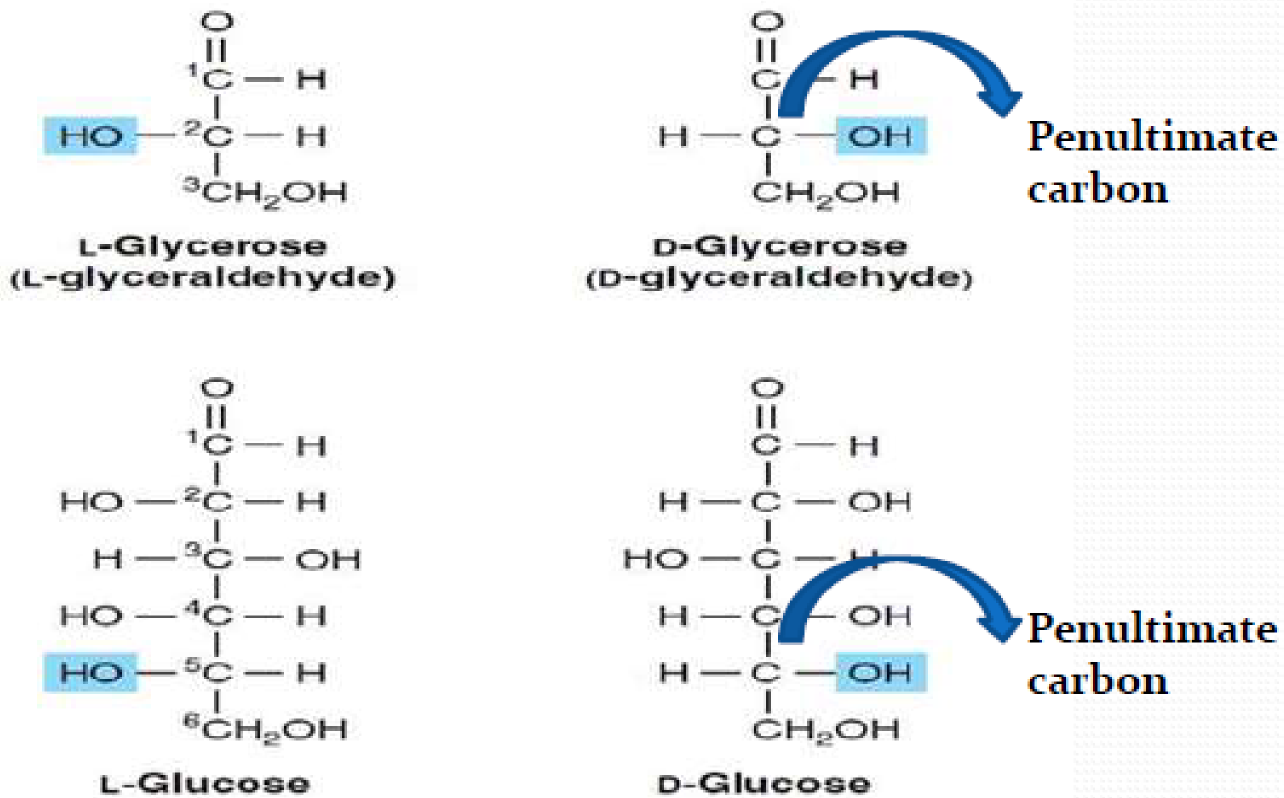
- Non-superimposable *COMPLETE* mirror image
- A special type of isomerism.
- The two members of the pair are designated as **D** and **L** forms.
- Majority of the sugars in humans are D-sugars.

D- and L- isomers

D and L Isomers are mirror images of each other.

The *spatial orientation of H & OH groups on the C- atom (C5 for glucose), adjacent to the terminal primary alcohol carbon determines whether the sugar is D or L Isomer.*

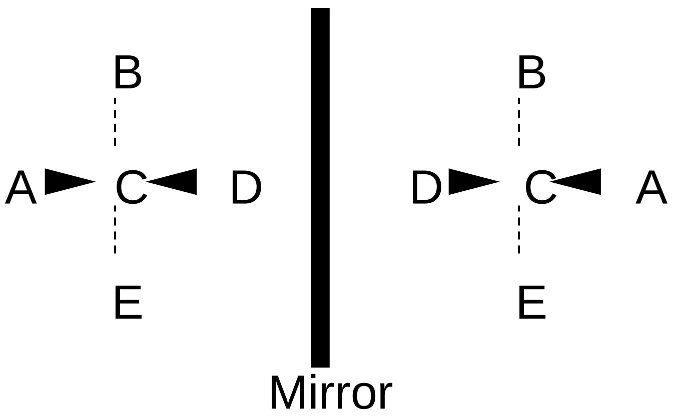
If the OH group is on the right side, the sugar is of D- Isomer. If the OH group is on the Left side, the sugar is of L- Isomer. Mammalian tissues have D- sugars.

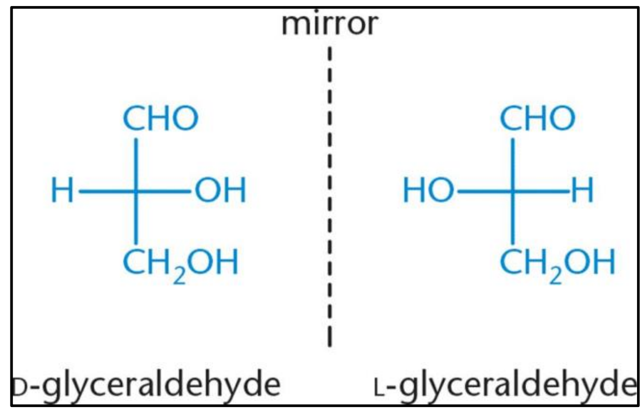


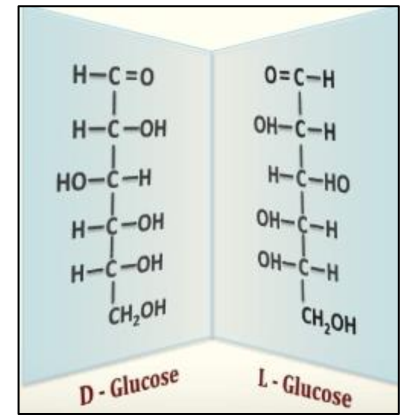
Optical Isomerism

- Optical activity is characteristic principle of asymetric carbon atom.
- Polarized light when passed through solution
  - turns to left – **Levorotatory (–)**
  - and if it turns to right – **Dextrorotatory (+).**
- So carbohydrate can be either D(+), D(–), L(+), L(–).
- **Racemic mixture** : when D and L isomers are present in equal concentration which doesn't shows any optical activity.

Enantiomers- Mirror images and non superimposable on each other







Ex: D-Glucose and L-Glucose

Distereoisomers

- **Non mirror images and non superimposable**

Ex: Glucose and Mannose

- **Dextrorotatory (d)** which is labelled (+) rotate a plane of polarized light in a clockwise direction.
- **Levorotatory (l)** which is labelled (-) rotate the light in a counterclockwise direction.

Epimers

- Epimers are sugars that differ in configuration at ONLY one specific carbon atom.
- With the exception of the carbonyl carbon
- Examples of epimers :
  - glucose & galactose (epimeric at C4)
  - glucose & mannose (epimeric at C2)

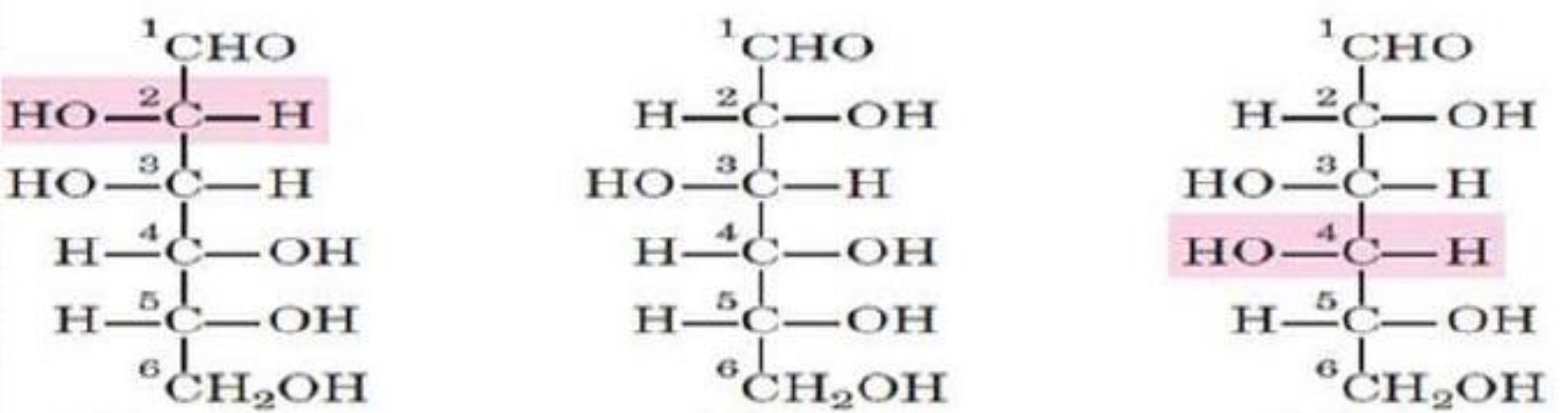
Epimers

If two monosaccharides differ from each other in their configuration around a single specific carbon atom, they are referred as epimers to each other.

Glucose & galactose are C4-epimers.

Glucose & mannose are C2-epimers

Inter-conversion of epimers is known as epimerization, epimerase catalyzes this reaction.



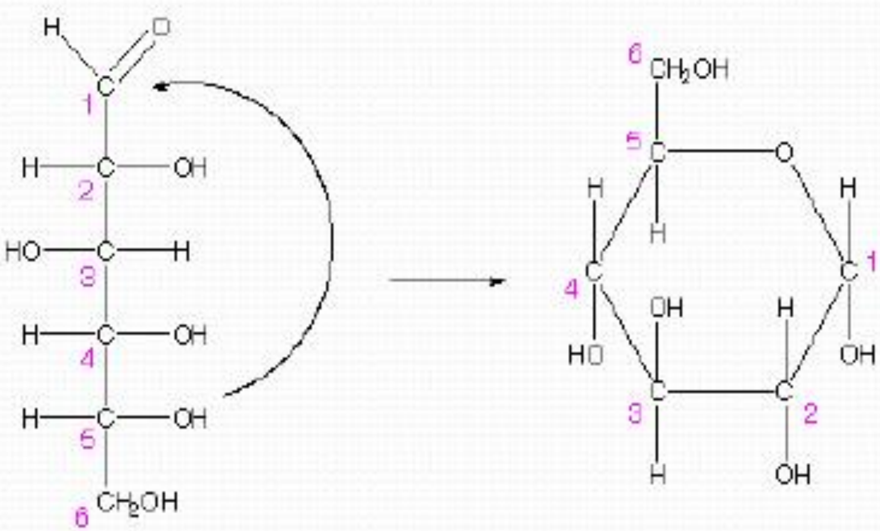
D-Mannose epimer at C-2) | D-Glucose | D-Galactose (epimer at C-4)

Cyclization of Monosaccharides

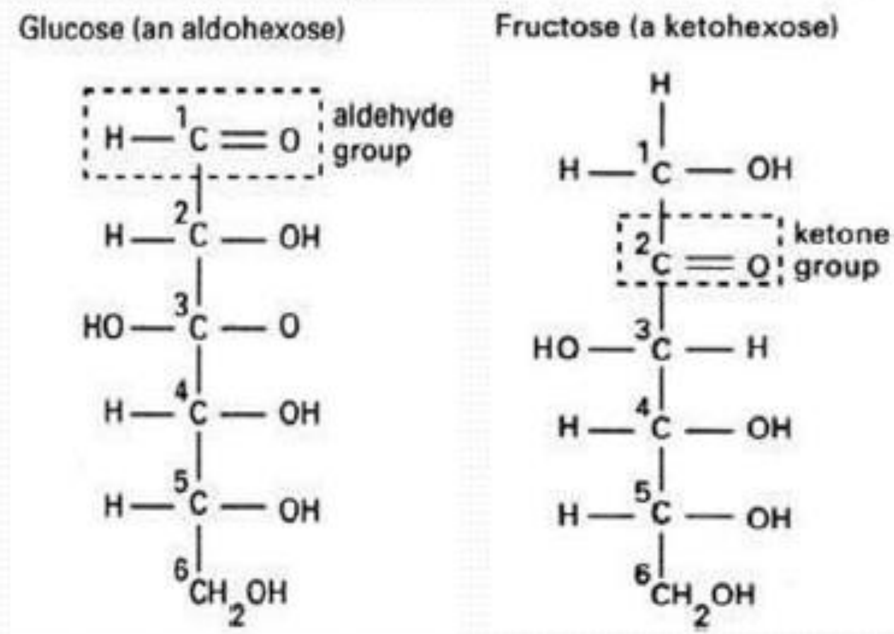
- Less than 1% of monosaccharides exist in the open chain form in solution.
- Predominantly found in ring form or cyclic structure.
- Involving reaction of C-5 OH group with the C-1 aldehyde group or C-2 of keto group.

Cyclization

- Less then 1% of CHO exist in an open chain form.
- Predominantly found in **ring form**.
- involving reaction of C-5 OH group with the C-1 aldehyde group or C-2 of keto group.
- Six membered ring structures are called **Pyranoses** .
- Five membered ring structures are called **Furanoses** .

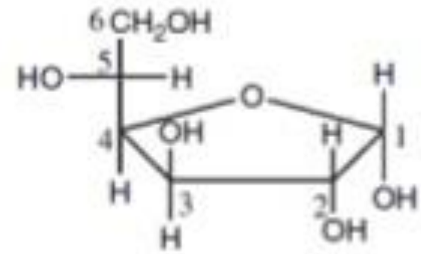


Straight chain form

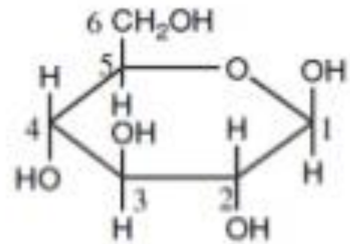


Haworth Projection (Cyclic Form)

W. N. Haworth (Nobel Prize, 1937)



42, α-D-glucofuranose



41, β-D-glucopyranose

- Cyclization via intramolecular hemiacetal (hemiketal) formation
- C-1 becomes chiral upon cyclization - anomeric carbon
- Anomeric C contains -OH group which may be **α** or **β** (mutarotation **α** ⇔ **β**)

Anomerism – Mutarotation

Anomers have same composition but differ in the orientation of groups around anomeric carbon atom.

Anomeric carbon is a hemiacetal or carbonyl carbon atom, e.g. 1st carbon atom in glucose is anomeric carbon atom.
Carbonyl carbon atom becomes asymmetric because of ring structures of monosaccharides in solution thus anomers are encountered in cyclic structures of monosaccaharides.

The alpha & beta cyclic forms of D-glucose are known as Anomers.
They differ from each other in the configuration only around C1 known as anomeric carbon.

In case of alpha anomer, the OH group held by anomeric carbon is on the opposite side of the group CH_2OH of sugar ring

Anomers are expressed as α and β forms.

In α form "OH" group is below the plane (OH group is oriented away from the oxygen atom)

In β form "OH" group is above the plane (OH group is oriented towards the oxygen atom)

Mutarotation:

When D-glucose is crystallized at room temperature and a fresh solution is prepared, its specific rotation of polarized light is 112°; but after 12- 18 hrs it changes to +52.5 °

Mutarotation is defined as the change in the specific optical rotation representing the interconversion of α and β forms of D-glucose to an equilibrium mixture.

- α-D- glucose is less stable as compared to β- D- glucose.
- If we will dissolve α-D- glucose in water then some part will convert into β- D- glucose and achieve the equilibrium I the solution and if we will take β- D- glucose then reverse condition will occur.

Specific rotation

- α-D- glucose $\rightleftharpoons$ Equilibrium mixture $\rightleftharpoons$ β- D- glucose

  +112.2° +52.4° +18.7°

- Due to more stability β- D- glucose will be present in higher percentage.

Glucose

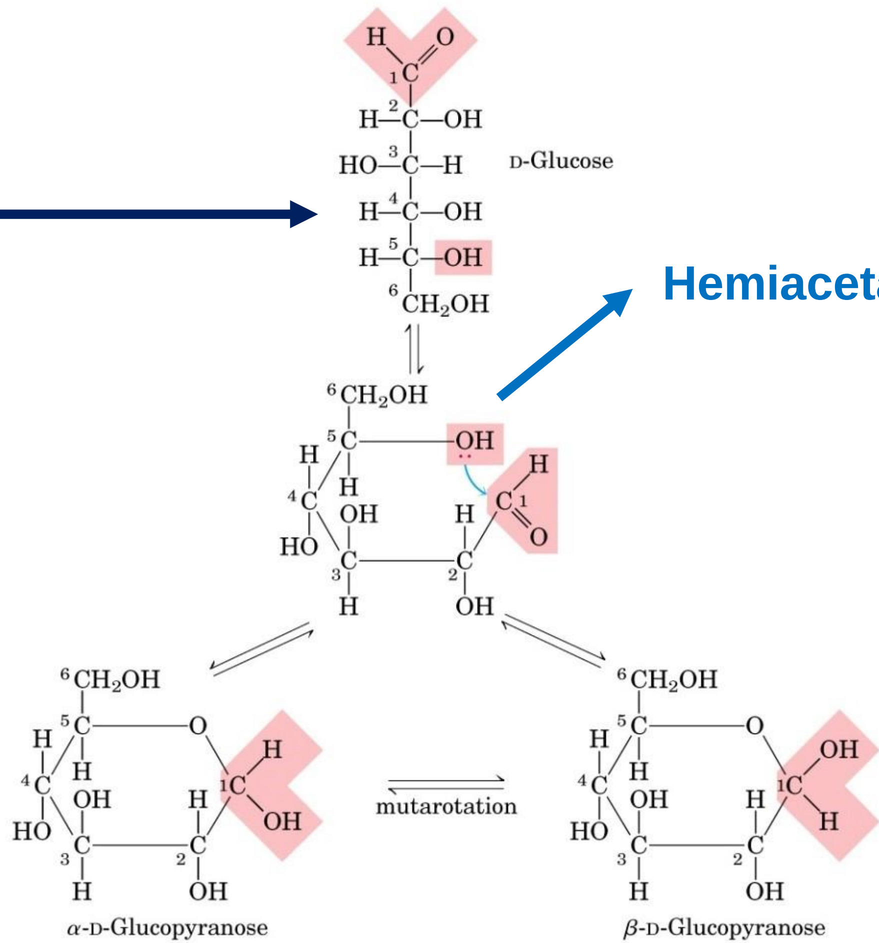
- **C-1 and C-5-intramolecular hemiacetal formation give rise to a pyranose ring**

Open chain / Fischer projection

Hemiacetal formation

C-1 is called anomeric carbon

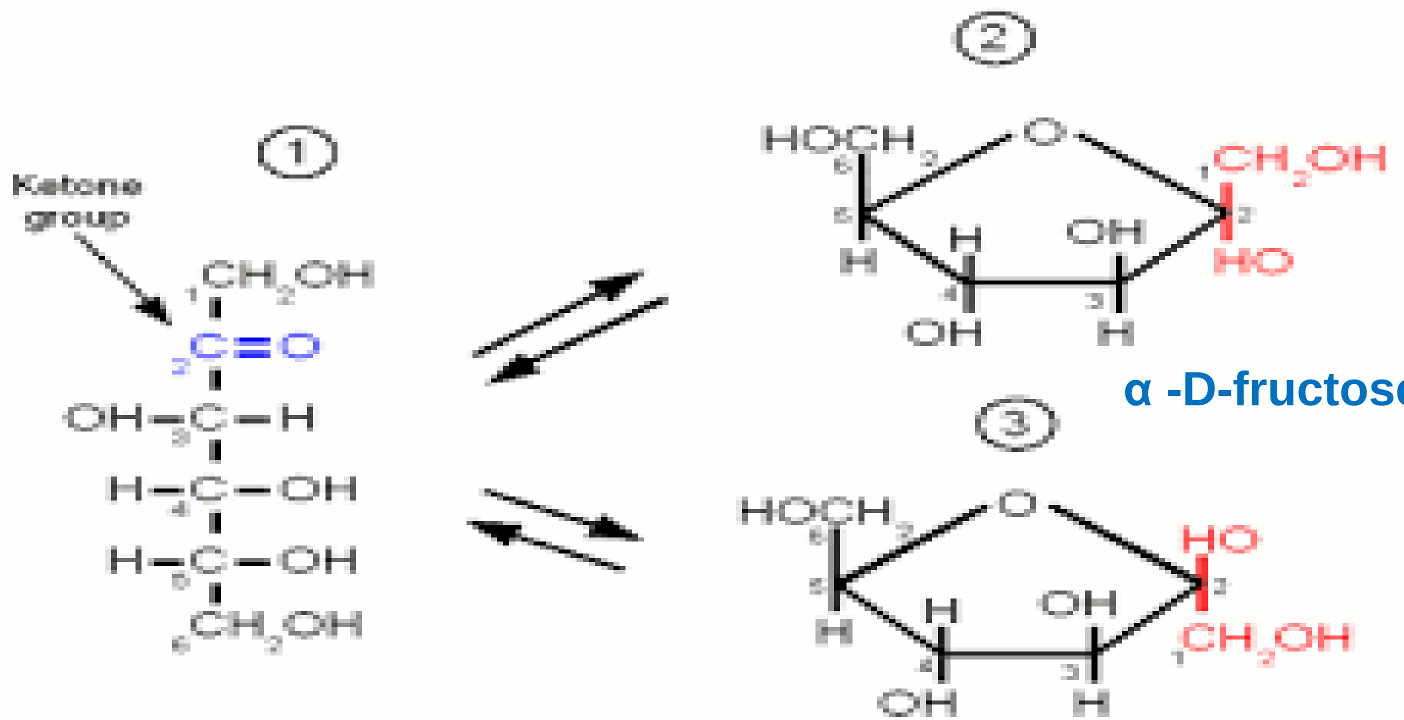
Ring form/ Haworth projection



Pyranose ring

Fructose

- **C-2 and C-5-intramolecular hemiketal formation in fructose forms furanose ring**

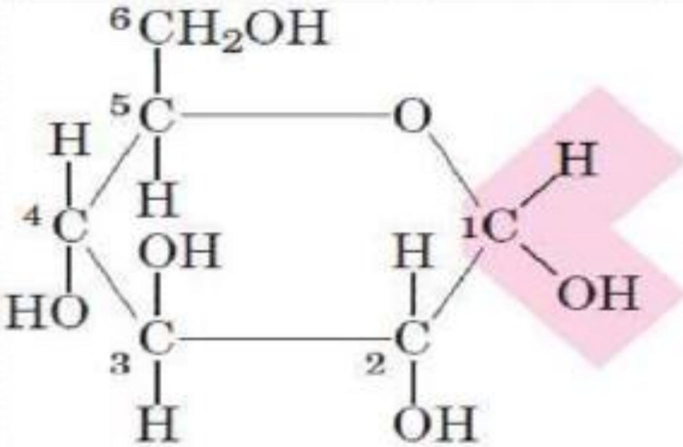


α -D-fructose

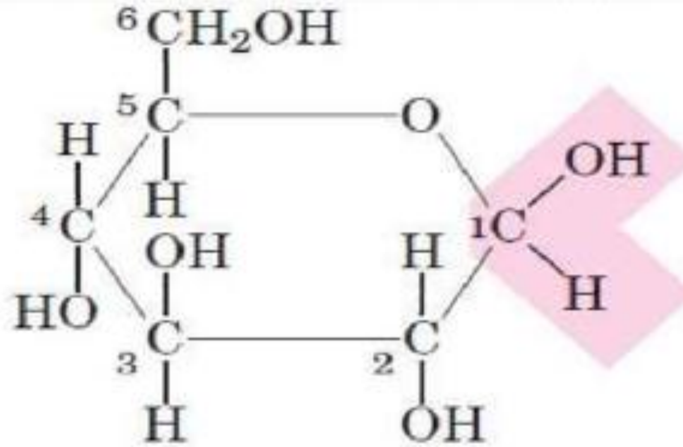
C-2 is called anomeric carbon

β -D-fructose

Furanose ring

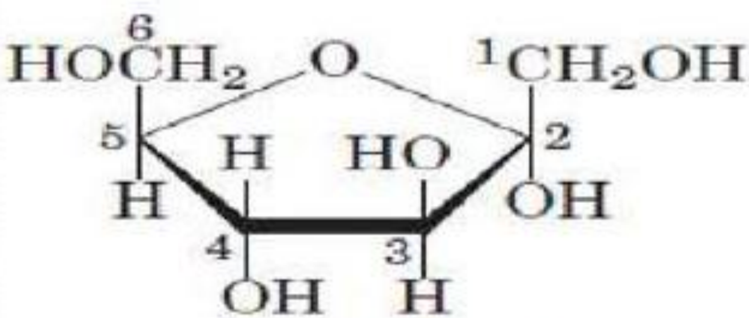


α-D-Glucopyranose

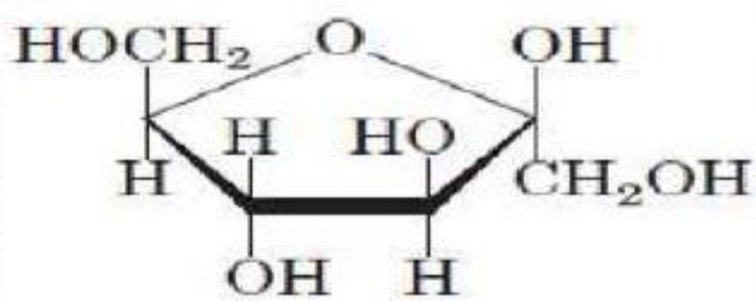


β-D-Glucopyranose

Glucose and Fructose has two anomers α and β



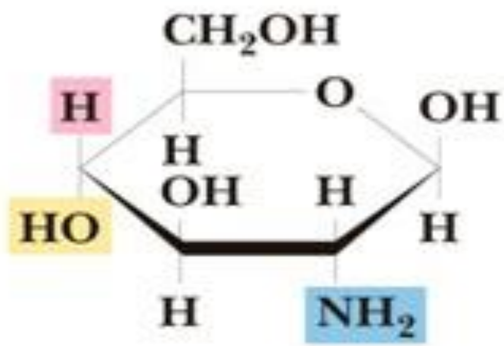
α-D-Fructofuranose



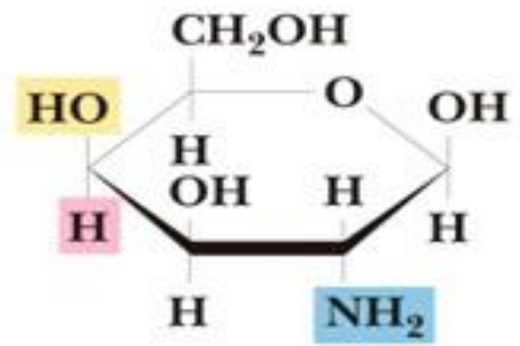
β-D-Fructofuranose

Other monosaccharide derivatives

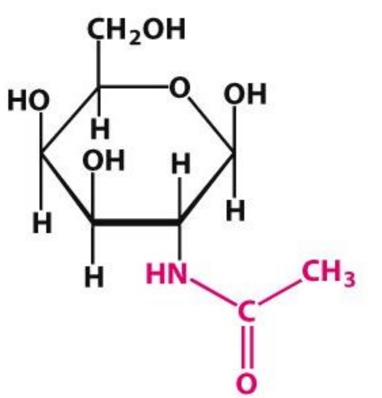
- **Amino sugars** found in animal cells



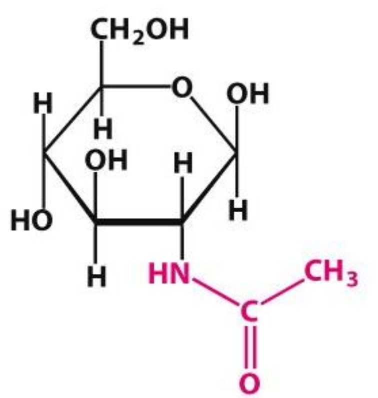
β-D-Glucosamine



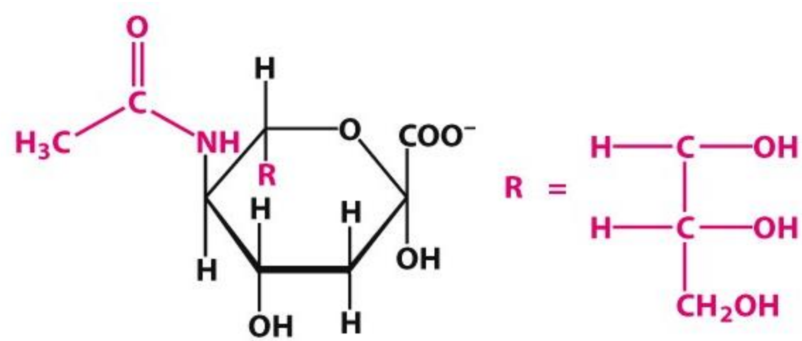
β-D-Galactosamine



β-D-Acetylgalactosamine
(GalNAc)



β-D-Acetylglucosamine
(GlcNAc)



Sialic acid (Sia)
(*N*-Acetylneuraminate)

PROPERTIES OF MONOSACCHARIDES

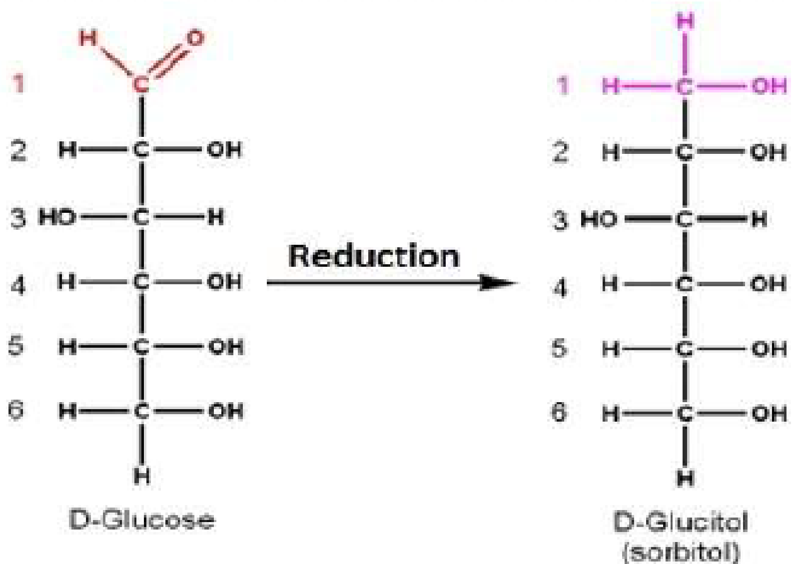
1. **Physical properties:**

   Monosaccharides are colourless, crystalline compounds, readily soluble in water and sweet in taste. Their solutions are optically active and exhibit mutarotation.

2. **Chemical properties:**

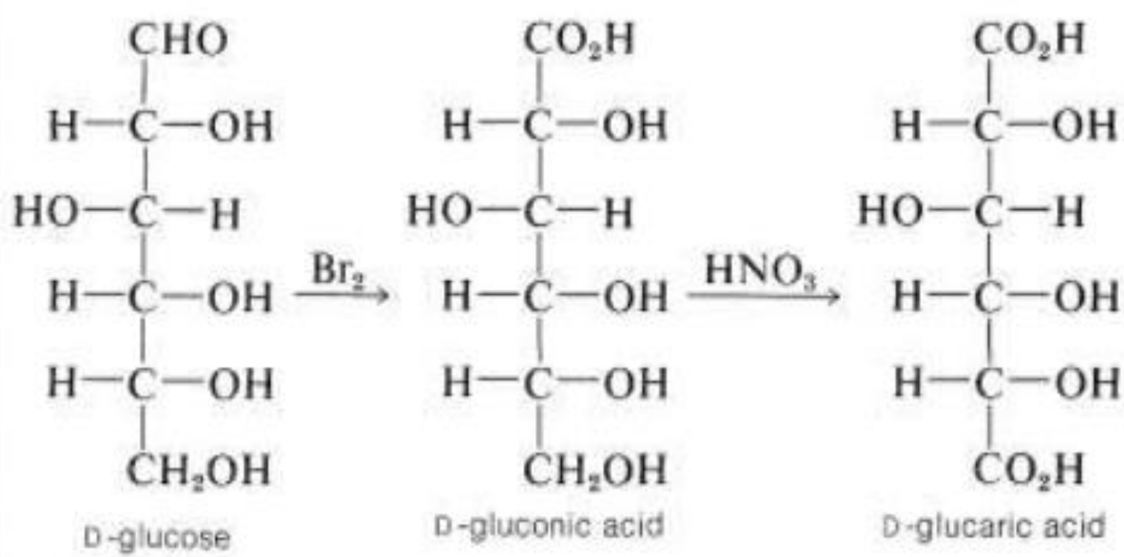
   a) **Reduction:** When treated with reducing agents such as sodium amalgam, hydrogen can reduce sugars. Aldose yields corresponding alcohol. Ketoses form two alcohols because of appearance of new asymmetric carbon in this process.

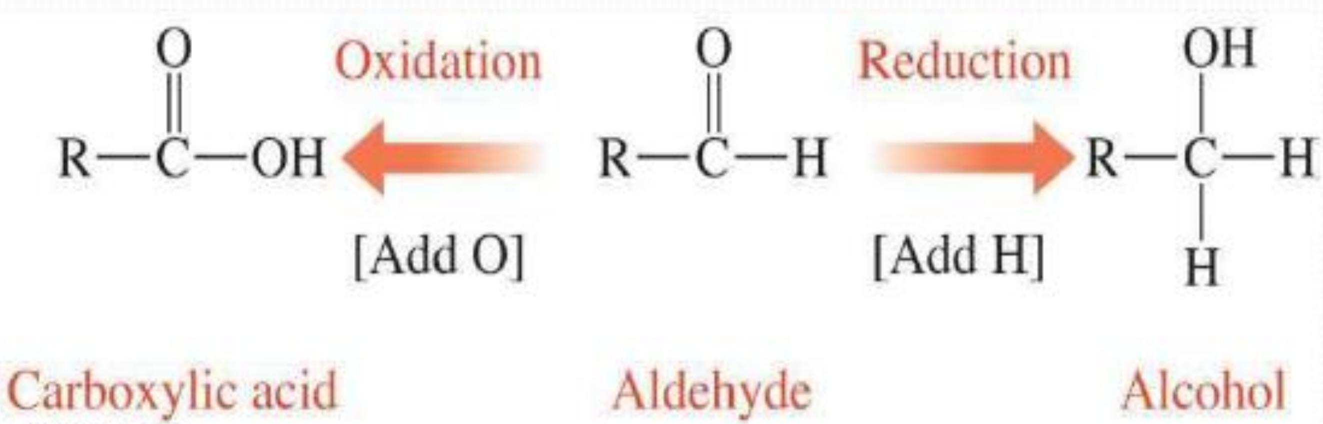
D-Glucose→ D-Sorbitol
D-Fructose →D-Sorbitol+D-Mannitol



b) Oxidation: upon oxidation aldose sugars like glucose yields carboxylic acid, *the aldehyde group is oxidized to carboxyl group to produce respective acids.*

Glucose → Gluconic acid
Mannose → Mannonic acid
Galactose → Galactonic acid

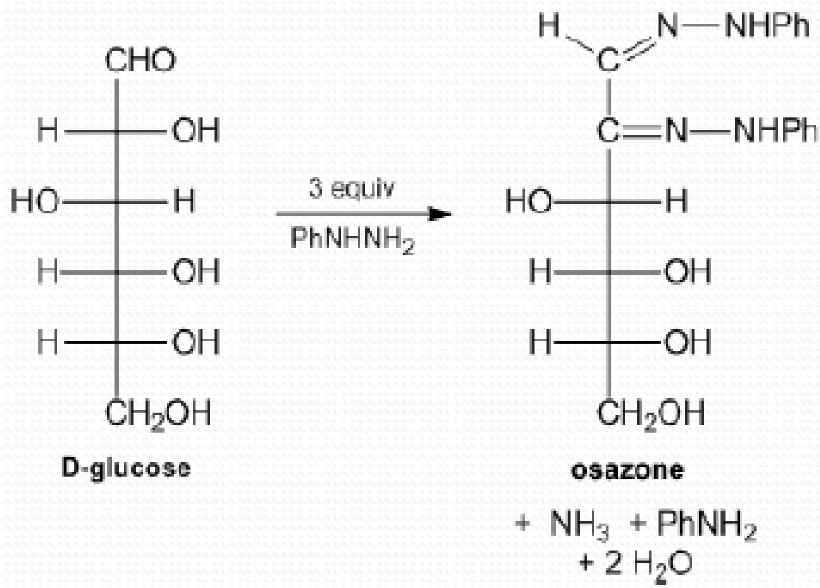




c) Formation of esters: Hydroxyl groups of sugars can be esterified to form acetates, propionates, benzoates, etc. Sugar phosphates are of great biological importance. Metabolism of sugars inside the body starts with phosphorylation.

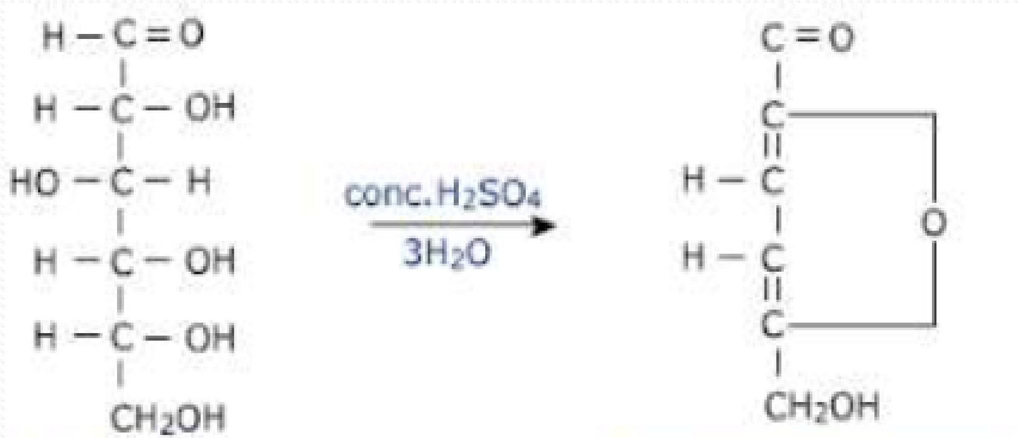
e.g Glucose 6-Po_4

d) Formation of osazone: this test is given by reducing sugar like, glucose, fructose, lactose and maltose. In this test phenyl hydrazine is reduced to phenyl hydrazone by sugar solution. Phenyl hydrazone when heated with more amount of phenyl hydrazine forms yellow crystals of osazone.



e) Furfural formation/Dehydration: Monosaccharides when treated with concentrated H_2SO_4 undergoes dehydration with the removal of 3 molecules of water. Hexoses give hydroxymethyl furfural and pentoses give furfural. Furfurals condense with phenolic compounds to give various colors.

E.g. Molisch's test: General test for carbohydrates (H_2SO_4 and α-naphthol). Rapid Furfural and Seliwanoff's test: Tests for presence of keto group



D - Glucose

Hydroxy methyl furfural

Hexoses of Physiological Importance

Sugar	Source	Importance	Clinical Significance
D-Glucose	Fruit juices. Hydrolysis of starch, cane sugar, maltose, and lactose.	The "sugar" of the body. The sugar carried by the blood, and the principal one used by the tissues.	Present in the urine (glycosuria) in diabetes mellitus owing to raised blood glucose (hyper-glycemia).
D-Fructose	Fruit juices. Honey. Hydrolysis of cane sugar and of inulin (from the Jerusalem artichoke).	Can be changed to glucose in the liver and so used in the body.	Hereditary fructose intolerance leads to fructose accumulation and hypoglycemia.
D-Galactose	Hydrolysis of lactose.	Can be changed to glucose in the liver and metabolized. Synthesized in the mammary gland to make the lactose of milk. A constituent of glycolipids and glycoproteins.	Failure to metabolize leads to galactosemia and cataract.
D-Mannose	Hydrolysis of plant mannans and gums.	A constituent of many glycoproteins.	

DISACCHARIDES

A disaccharide consists of 2 monosaccharide units (similar or dissimilar) held together by a glycosidic bond

They are crysatalline, water soluble and sweet to taste.

MALTOSE : - is also called as **malt sugar**.
- made up of **2 glucose molecules**

LACTOSE : - is also called **as milk sugar** as it is found naturally in milk
- made up of **glucose and galactose**
- souring of milk is due to conversion of lactose to lactic acid

SUCROSE : -is also called as **cane sugar.** It is the sugar found in sugar cane and sugar beet
- most abundant among naturally occuring sugars.
- Important source of Dietary carbohydrates
- made up of **glucose and fructose**

DISACCHARIDES

- **Disaccharides are composed of two sugar unit linked through glycosidic bond, that is formed by dehydration process with removal of one water molecule.**
- **Hydrolysis of disaccharide in the presence of water molecule releases its two units.**
- **Disaccharides consumed by us through foods,** is digested and hydrolyzed by enzymes called disaccharidases, and then individual units of disaccharide is absorbed by the cells of our body for various cellular functions. For example: sucrase hydrolyses sucrose; maltase hydrolyses maltose; lactase hydrolyses lactose

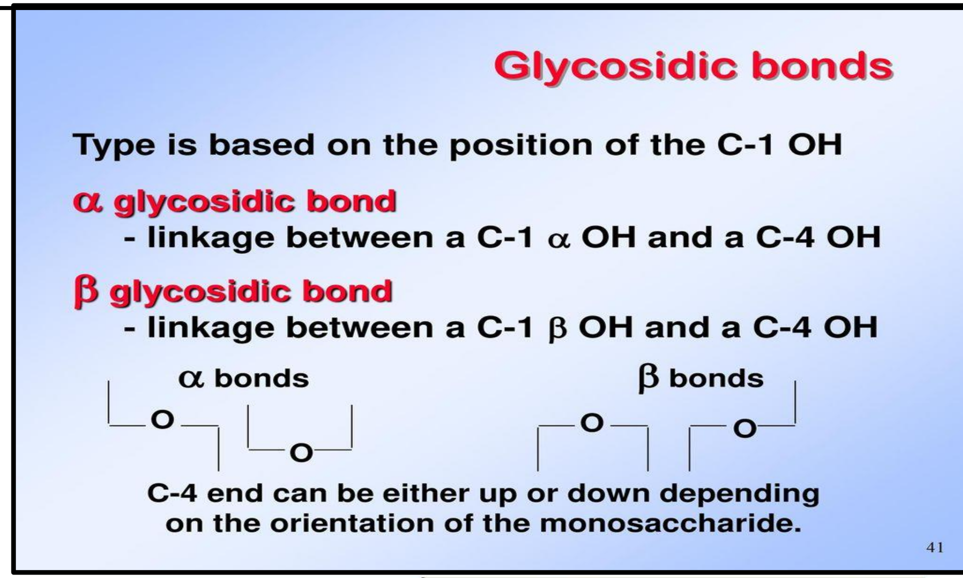
- The disaccharides of physiological importance are as follows-
  1)Maltose
  2)isomaltose
  3)Sucrose
  4)Lactose
  5)Lactulose
  6) Trehalose

Glycosidic bonds

Linkage formed between two-sugar units involving –OH groups or a sugar unit with –OH group and N-atom containing compound such as amino acid asparangine, and glutamine; purine and pyrimidine bases

O-glycosidic bond: formed between sugar units or monosaccharides to form disaccharides, oligosaccharides or polysaccharides. Also found between sugar unit and –OH containing amino acid

They are either alpha-glycosidic bond or Beta glycosidic bond in disaccharides



N-glycosidic bond: formed between a sugar unit with –OH group and N-atom containing compound **such as amino acid asparangine, and glutamine; purine and pyrimidine bases**.

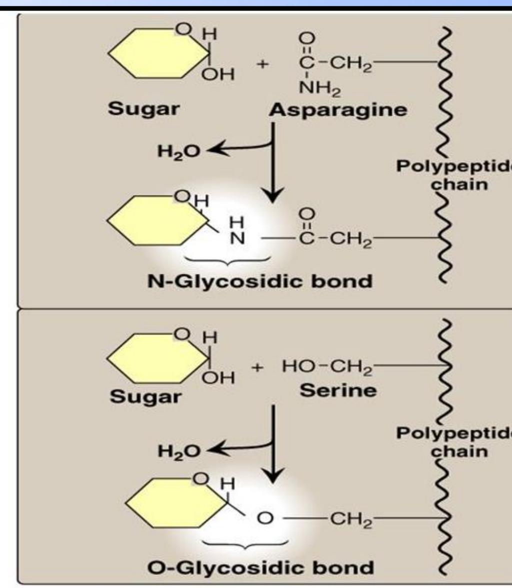
Found in heteropolysaccharide such as proteoglycans, glycoproteins, and nucleic acids (DNA and RNA that has purine and pyrimidine bases

N-Glycosidic

(C-N-C link)

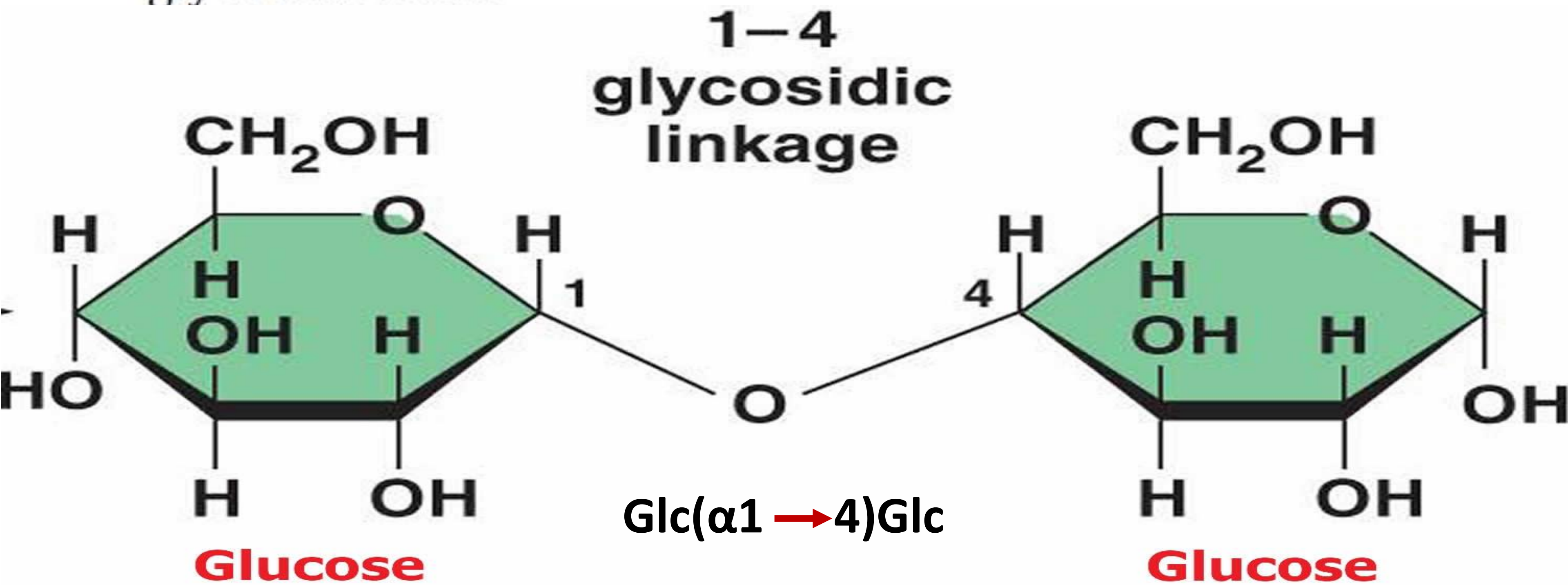
O-Glycosidic

(C-O-C link)



MALTOSE (Malt sugar)

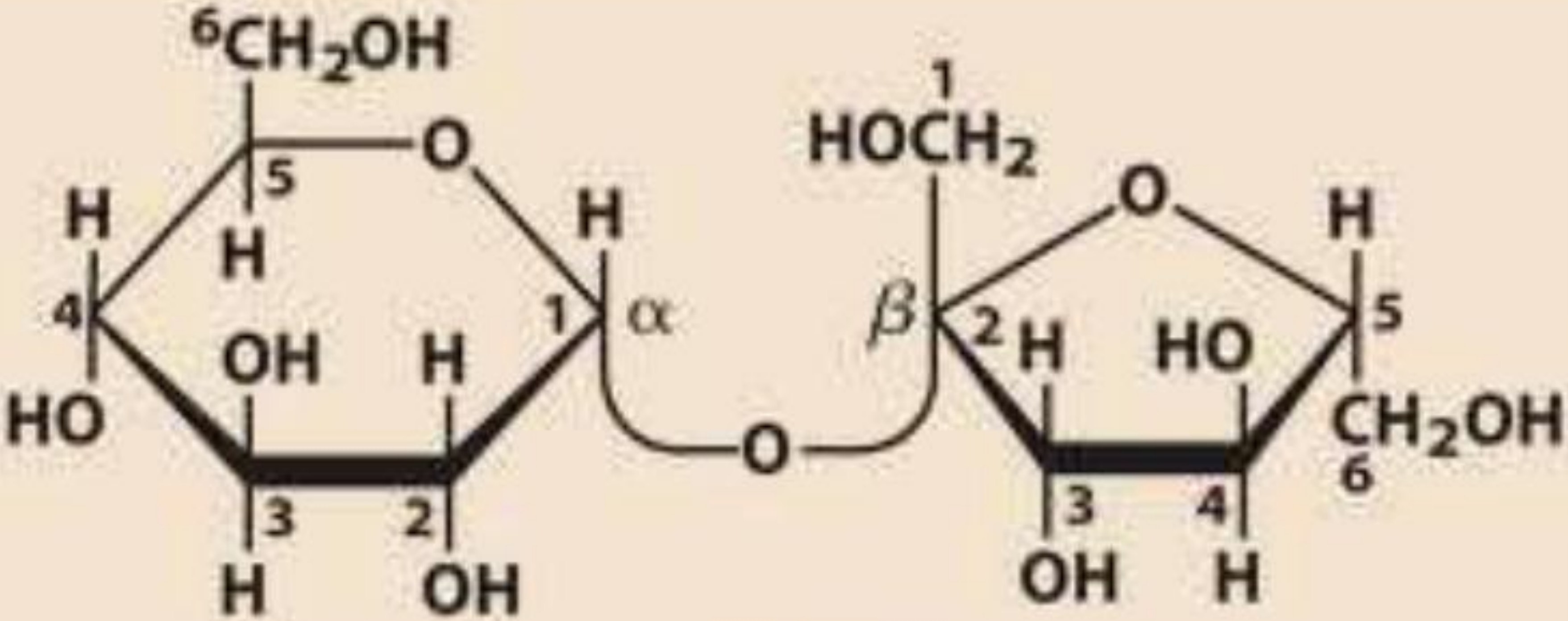
- Maltose is formed by joining of 2 glucose units by α-(1,4) glycosidic bond.



Maltose

α -D-glucopyranosyl- (1-4) -D -glucopyranose

SUCROSE (TABLE SUGAR)

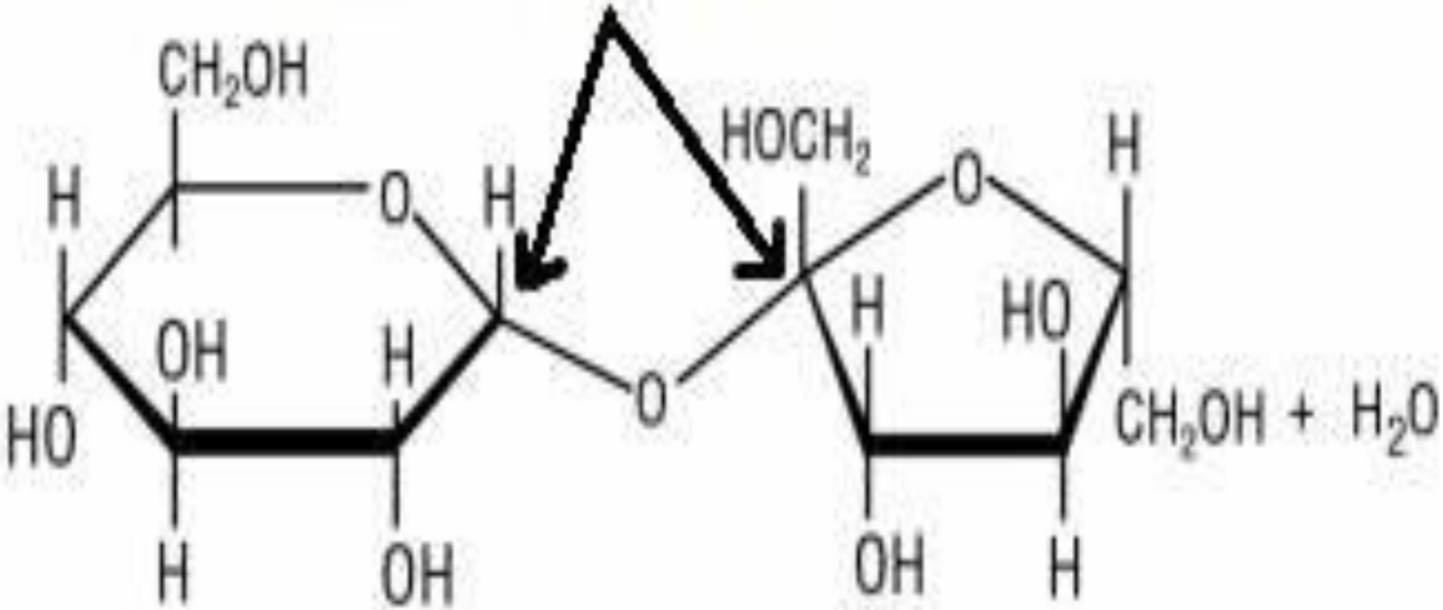


Sucrose

α-D-glucopyranosyl β-D-fructofuranoside

Glc(α1$\leftrightarrow$2β)Fru

Both anomeric carbons are involved in the O-glycosidic bond



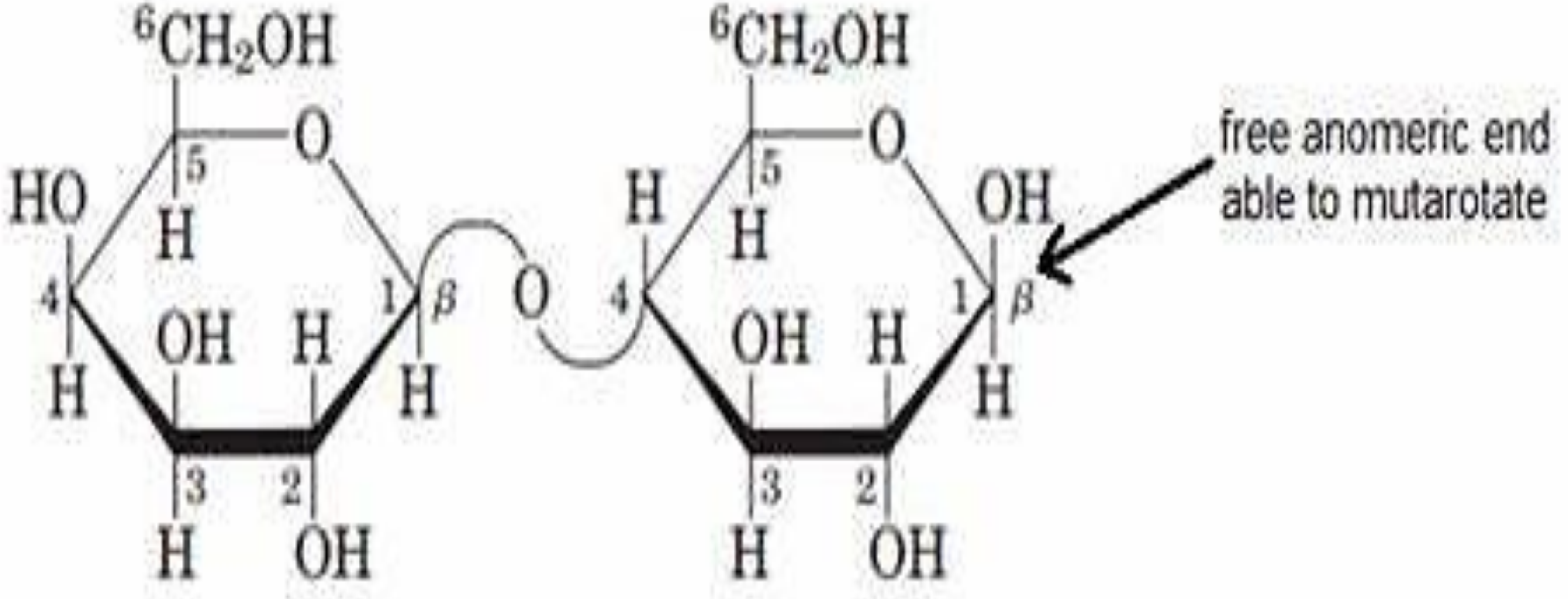
Sucrose

- Sucrose has no free reactive group because the anomeric carbons of both monosaccharides units are involved in the glycosidic bond.

- Thus, sucrose neither shows reducing properties nor mutarotation characters.

- Hydrolytic product of Sucrose is called invert sugar because the optical activity of sucrose (dextrorotatory) is inverted after hydrolysis [by an acid or an enzyme (invertase or sucrase)] into equimolar mixture of its two components glucose (+52.5) and fructose (-92.5) and the optical activity of the mixture becomes levorotatory.

LACTOSE (MILK SUGAR)



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

- Lactose is the only sugar of milk -

  Synthesized by mammary glands during lactation.

  Milk contains the α and β-anomers in a 2:3 ratio.

  β -lactose is sweeter and more soluble than ordinary α – lactose.

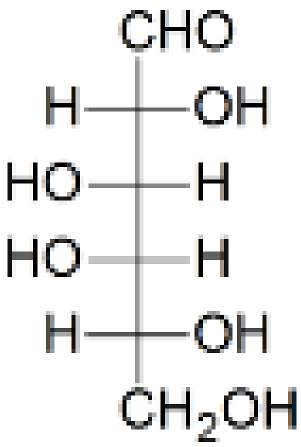
  used in infant formulations, medium for penicillin production and as a diluent in pharmaceuticals.

OLIGOSACCHARIDES

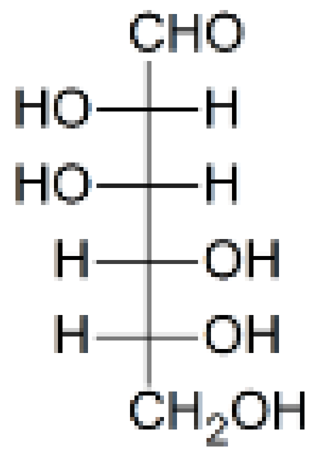
- Trisaccharide: Raffinose (glucose + galactose + fructose)
- Tetrasaccharide: Stachyose (2 galactose + glucose + fructose)
- Pentasaccharide: Verbascose (3 galactose + glucose + fructose)
- Hexasaccharide: Ajugose (4 galactose + glucose + fructose)

Sample questions

(01) Study the following Fischer projections to answer the questions below.



galactose



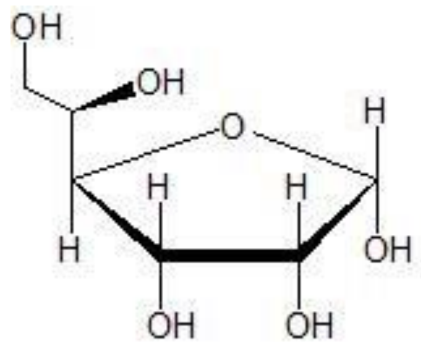
mannose

I. Is galactose a D-sugar or an L-sugar?
II. Is mannose a D-sugar or an L-sugar?
III. Choose either one and sketch it as it would appear if it was an L-sugar.
IV. Are these two carbohydrates enantiomers? If not, in how many places do they differ?
V. What is the term to describe the relationship between galactose and mannose?

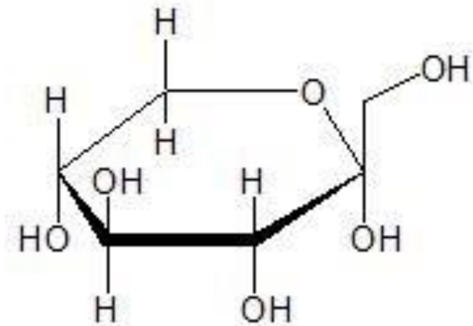
(02) Which carbon is considered the anomeric carbon? How do you distinguish between the alpha and beta types of anomers?

(03) Study these Haworth projections to answer the following for each of them.

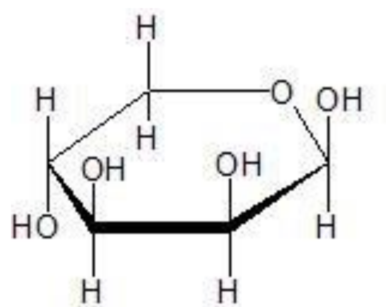
A)



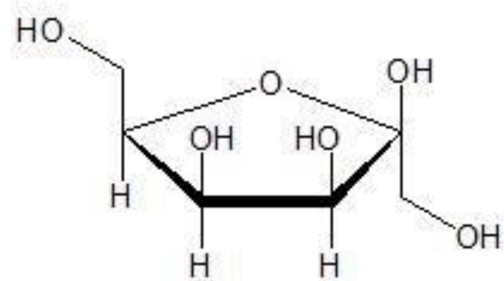
B)



C)

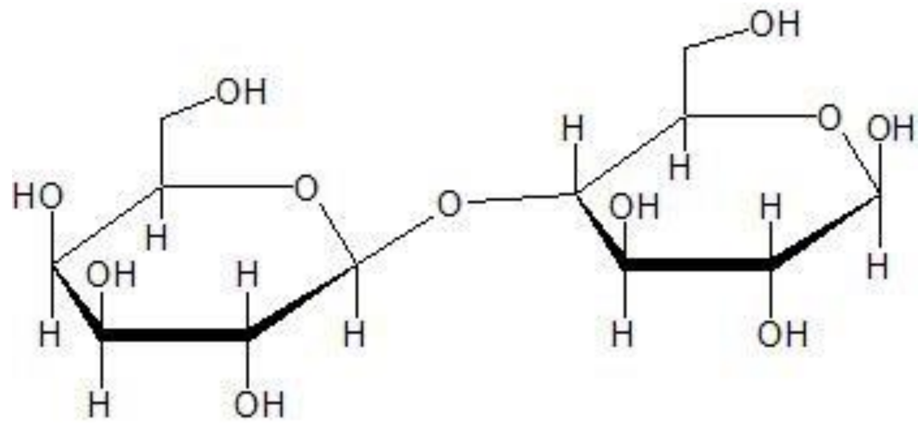


D)



i. Is it a furanose or a pyranose?
ii. Is it an alpha or beta anomer?
iii. Circle the anomeric carbon.

(04) Some people cannot digest the disaccharide lactose. The term for this is known as lactose intolerance. Lactose is shown below. Answer the following questions.



I. What is the name of the enzyme that would be required for someone to be able to digest lactose?
II. Classify lactose as a mono-, di-, oligo-, or polysaccharide.
III. Label anomeric carbons by circling them. Is lactose a reducing sugar?
IV. Draw an arrow pointing to the glycosidic bond. Is the glycosidic bond connected to both anomeric carbons?
V. Classify the glycosidic bonds using the alpha or beta-(#,#) format.
VI. If the glycosidic bond is hydrolyzed, what are the names of the monosaccharides produced. Remember to include the alpha or beta classification for the anomeric carbon.

CheckPOINT: Carbohydrates

1. What is the primary function of carbohydrates?
2. What are the elements that make up carbohydrates?
3. What are the building blocks of carbohydrates?
4. What simple sugar is present in fruits?
5. What carbohydrate is composed of two simple sugars (monosaccharides) linked by a glycosidic bond?
6. What disaccharide will form after the condensation reaction between glucose and galactose?

CheckPOINT: Carbohydrates

7. What way of representing carbohydrates is shown in figure 1?

For **items 8 – 10**, identify whether the following is monosaccharide, disaccharide, or polysaccharide.

8. Maltose

9. Starch

10. Galactose

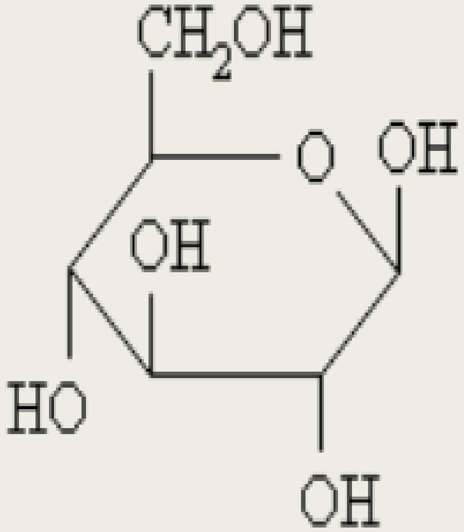


Figure 1

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