• Chemistry of Carbohydrates

Mrs. Nutan Y.Chaudhari
Assistant Professor
Department of Biochemistry

Competencies

1) Define carbohydrates
2) Classify carbohydrates with examples of each class
3) Describe monosaccharides, disaccharides and polysaccharides as an energy source
4) Describe the biological importance of disaccharides with examples
5) Describe polysaccharides like glycogen as a storage form in human body with examples
6) Describe polysaccharides like glycosaminoglycans as structural elements in the human body
7) Differentiate monosaccharides, disaccharides and polysaccharides as an energy source in the human body, with examples

9) Explain the importance of resistant starch in diet

10) Identify food items with high and low glycemic index

11) explain the importance of food items in the diet with high and low glycemic index

12) Explain the clinical importance of dextrans

- **Biomolecule** – a general term referring to organic compounds essential to life

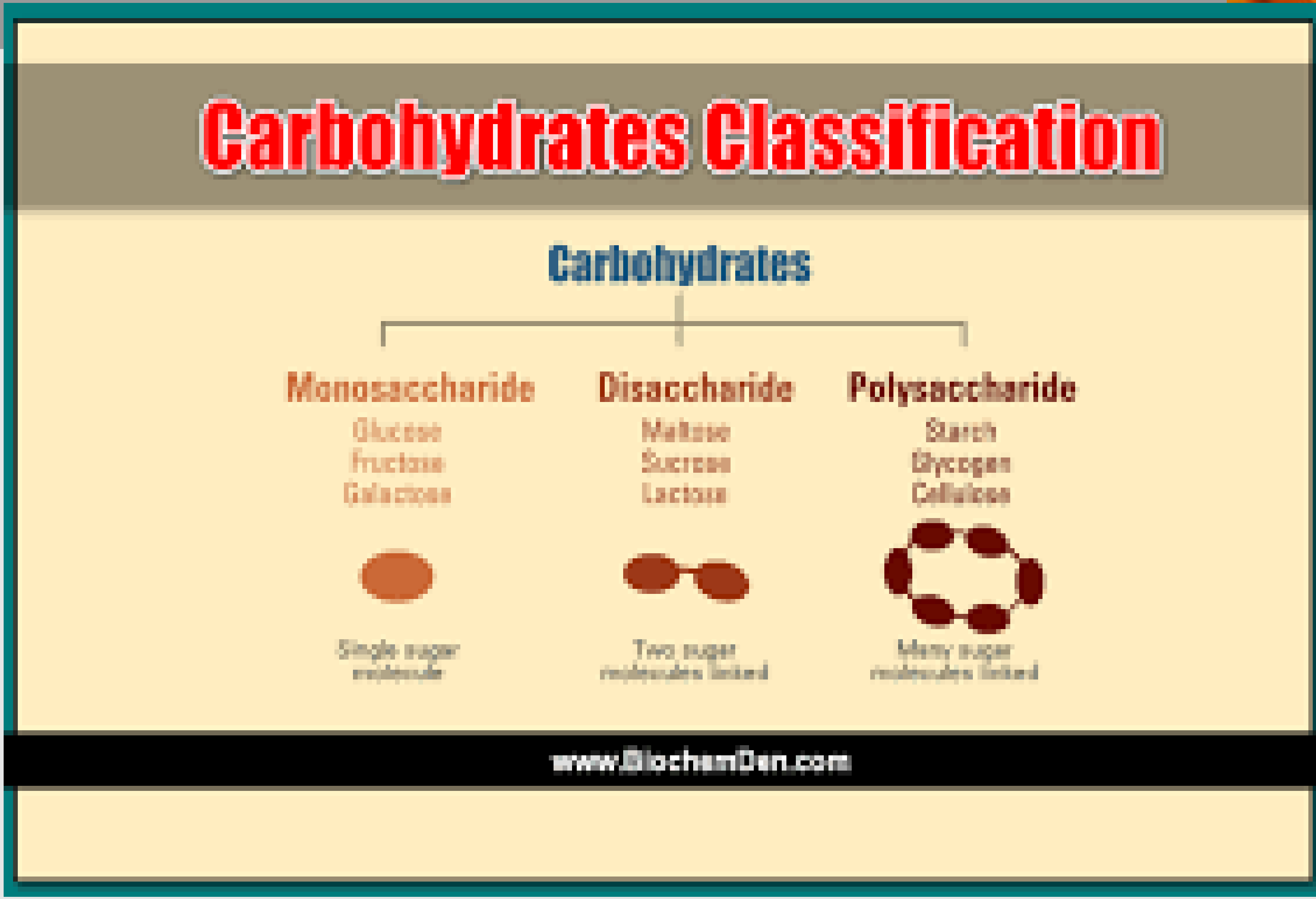
- **Biochemistry** – a study of the compounds and processes associated with living organisms

Definition

- The general molecular formula of carbohydrates is $Cn(H_2O)n$.
- For example, glucose has the molecular formula $C_6H_{12}O_6$.
- **CARBOHYDRATES IN GENERAL ARE POLYHYDROXY ALDEHYDES OR KETONES OR COMPOUNDS WHICH YIELD THESE ON HYDROLYSIS.**


C + H + O =
Carbohydrates


Simple carbohydrates
Simple carbohydrates are found in foods such as fruits, milk, and vegetables
Cake, candy, and other refined sugar products are simple sugars which also provide energy but lack vitamins, minerals, and fiber
ADAM


Carbohydrates Classification
Carbohydrates
Monosaccharide
Glucose
Fructose
Galactose
Disaccharide
Maltose
Sucrose
Lactose
Polysaccharide
Starch
Glycogen
Cellulose
Single sugar molecule
Two sugar molecules linked
Many sugar molecules linked
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Carbohydrates: Definition, Classification, Functions

Monosaccharides

Simple sugar

Aldoses	Ketoses
Glyceraldehyde	Dihydroxyacetone
Erythrose	Erythrulose
Ribose	Ribulose
Glucose	Fructose
Glucoheptose	Sedoheptulose

Disaccharides

2 monosaccharide units

Reducing

- Maltose
- Lactose

Non-Reducing

- Sucrose

Oligosaccharides

3-10 monosaccharide units

- Raffinose
- Stachyose
- Verbascose

Polysaccharides

>10 monosaccharide units

Homopolysaccharides	Heteropolysaccharides
Starch	Agar, Agarose
Dextrin	Gum & Pectin
Glycogen	Hyaluronic acid
Cellulose	Chondroitin sulfate
Inulin	Keratan Sulfate
Dextran	Dermatan Sulfate
Chitin	Heparan Sulfate

IMPORTANT FUNCTIONS OF **CARBOHYDRATES**

- Carbohydrates are the main sources of **energy** in the body.
- **Brain cells** and **RBCs** are almost wholly dependent on carbohydrates as the energy source.
- Energy production from carbohydrates will be

  4 kcal / g.
- Storage from of energy (**starch** and **glycogen**)
- Excess carbohydrate is converted as **fat**.
- Riboses and D-oxyriboses are components of **nucleic acids and co-enzymes.**

- **Glycoproteins** and **glycolipids** are components of cell membranes and receptors. They participate in biological transport, cell-cell recognition during developement, activation of growth factors, modulation of the immune system
- **Structural basis** of many organisms

✓ Cellulose of plants

✓ exoskeleton of insects

✓ cell wall of micro-organisms

✓ mucopolysaccharides as ground substance in higher organisms.

- Non digestible carbohydrate like **cellulose, agar, gum** and **pectins** serve as dietary fibres.

- Acts as **intermediates** in the biosynthesis of other basic biochemical entities (fats and proteins)

- Carbohydrates are also involved in detoxification e,g, **glucuronic acid**

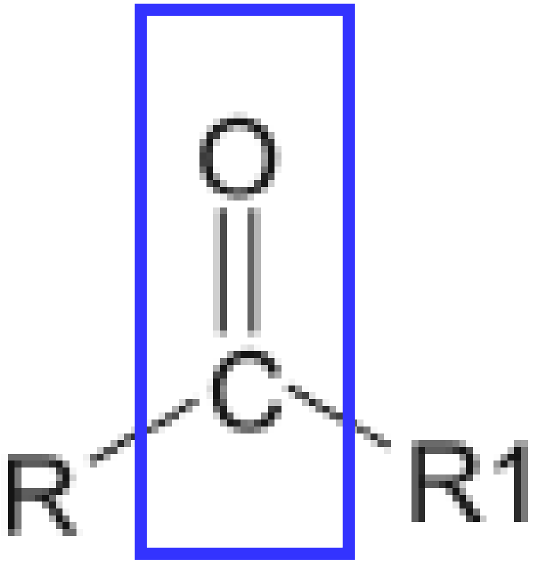
- Carbohydrates are utilised as **raw material** for several industries e.g. paper, plastis, textile, alcohol,etc.

But this is not true due to

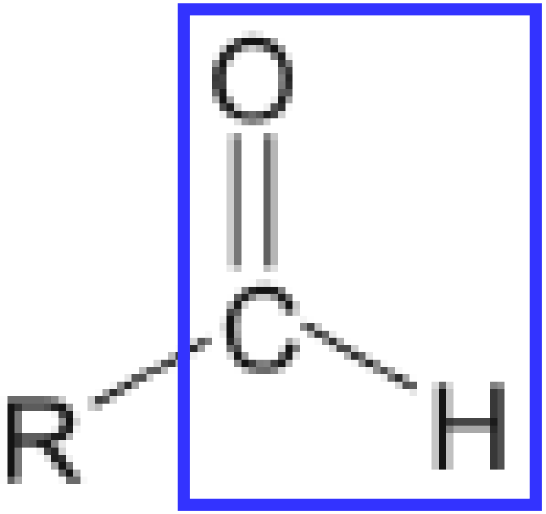
1. All sugars cannot be represented by this general formula.
   E.g. Deoxy Ribose – $C_5H_{10}O_4$.

2. All compounds having H and O in ratio of 2:1 are not carbohydrates
   E.g. Acetic acid – $C_2(H_2O)_2$
   Lactic acid – $C_3\ (H_2O)_3$

3. Apart from C, H & O, many sugars contain N, S, P etc.
   E.g. Aminosugars, Phosphosugars etc

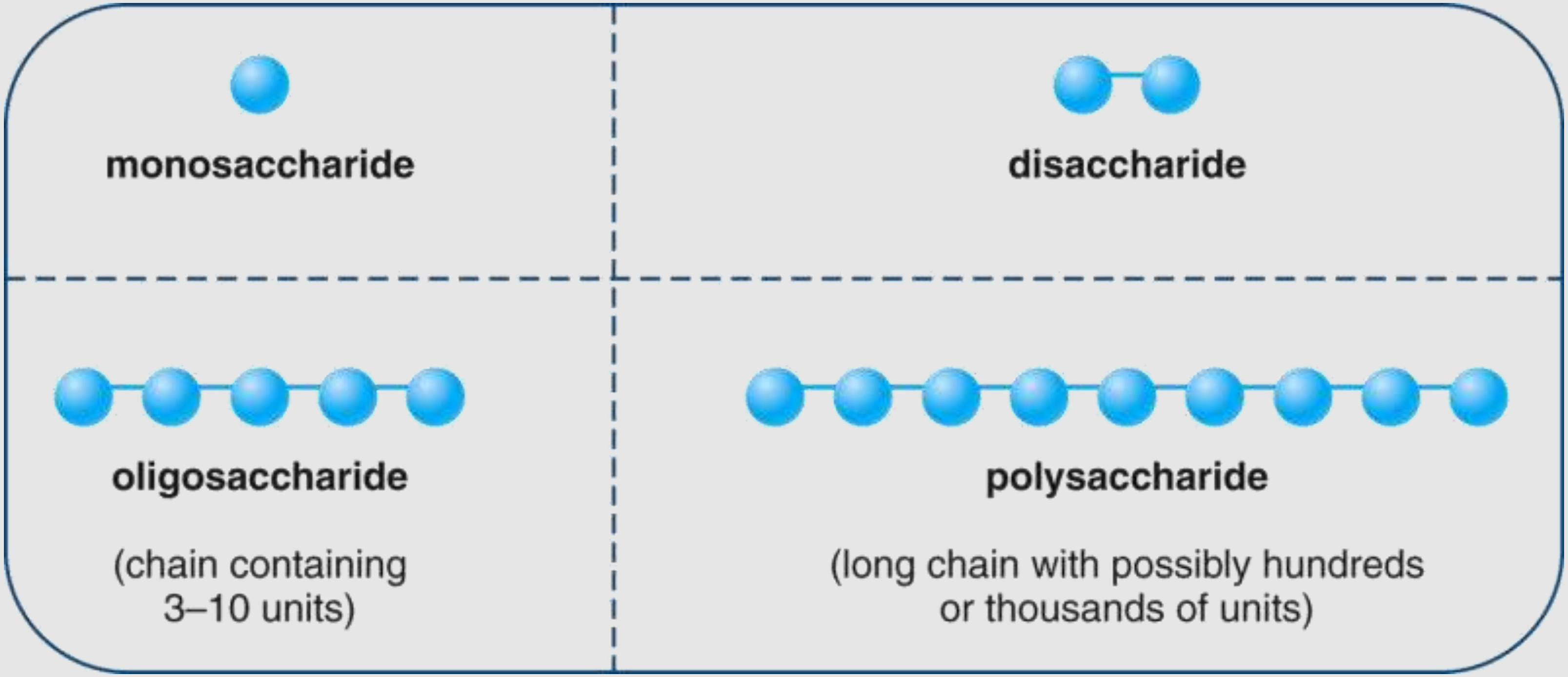


Keto group



Aldehyde group

- **Carbohydrates** are classified according to size:
  - **Monosaccharide** – a single polyhydroxy aldehyde or ketone unit
  - **Disaccharide** – composed of two **monosaccharide** units
  - **Polysaccharide** – very long chains of linked **monosaccharide** units



Disaccharides

- Sugars which yield 2 sugar units on hydrolysis. Monosaccharide unit may be the same or different.

- **Biologically important disaccharides** are
  Sucrose → Glucose + Fructose
  Maltose → Glucose + Glucose
  Lactose → Glucose + Galactose

Depending on whether a disaccharide contains a free functional group or not, classified to

- Reducing disaccharides – **Lactose, Maltose**
- Non-reducing disaccharides – **Sucrose, Trehalose**

Oligosacchrides

- Sugars on hydrolysis yield 3- 10 sugar units

- **Rhamnose, Raffinose**
- Carbohydrate moiety of glycoproteins
- Carbohydrate moiety of Proteoglycans

What are Isomers ?

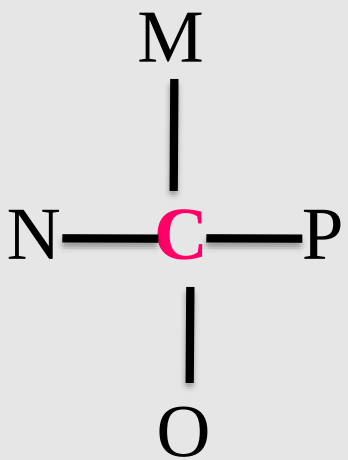
- Definition: Compounds having the same molecular formula, but differ in chemical and physical properties.
- Phenomenon is called Isomerism.
- 2 Types of Isomerism :
- Structural (Positional)
- Stereo

- Structural Isomers – Same molecular formula but differ in structure
- Eg. C_5H_{12}
- nPentane $CH_3CH_2CH_2CH_2CH_3$
- IsoPentane CH_3

$CH\ CH_2CH_3$

CH_3

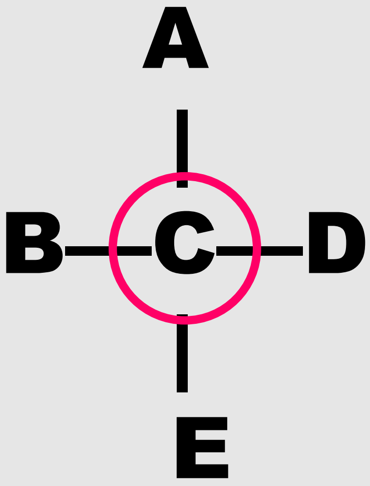
- Optical isomers - (Configurational) differ from disposition of various atoms or groups in space around an asymmetric Carbon atom (Chiral center)
- An asymmetric Carbon atom is a Carbon atom the four valences of which is attached to four different atoms or groups of atoms.



Stereoisomers

Compounds having same structural formula, but differ in spatial configuration are known as stereoisomers.

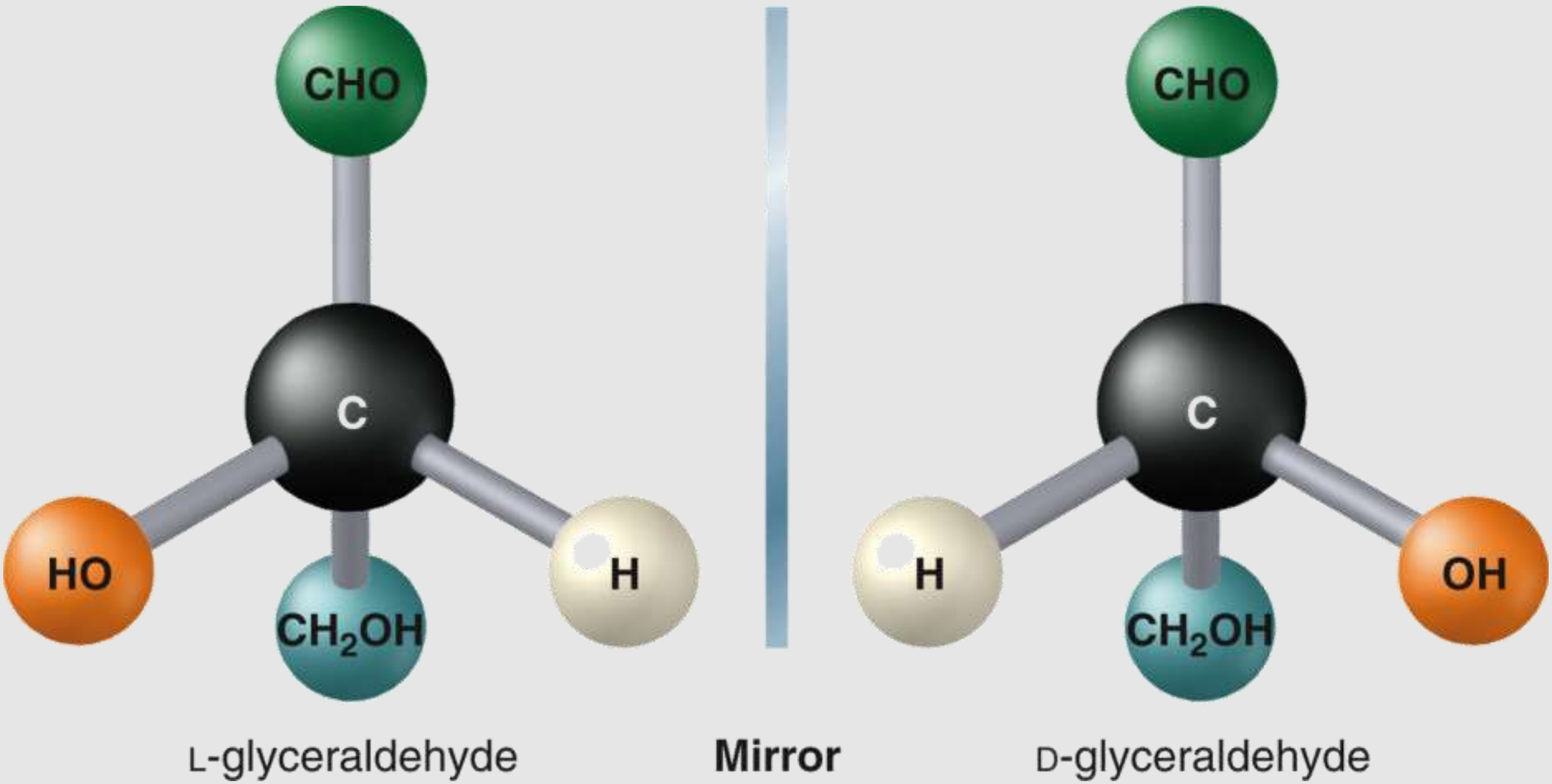
Asymmetric carbon means that four different groups are attached to the same carbon.



- **H—C = O   1   H—C = O**
- **| |**
- **H—C—OH   2   HO—C—H**
- **| |**
- **CH2—OH   3   CH2—OH**
- **D-glyceraldehyde   L-glyceraldehyde**
- The reference molecule is glyceraldehyde which has a single asymmetric carbon atom.

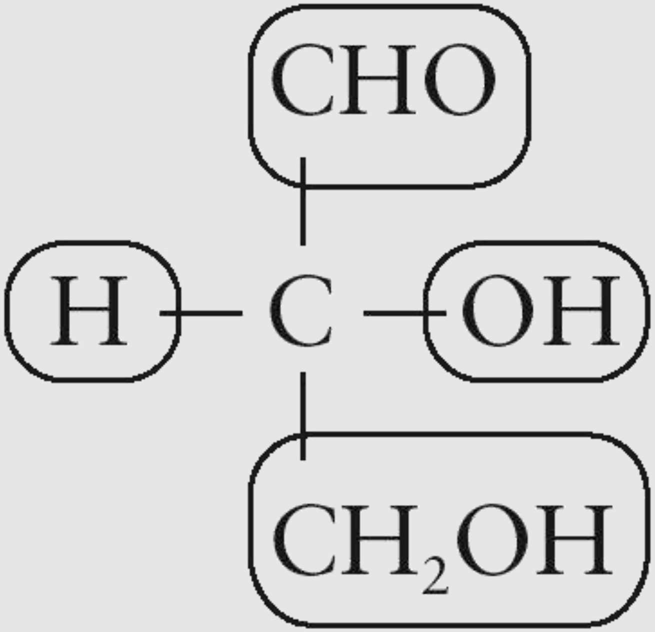
STEREOCHEMISTRY

- Many **carbohydrates** exist as **enantiomers** (stereoisomers that are mirror images).



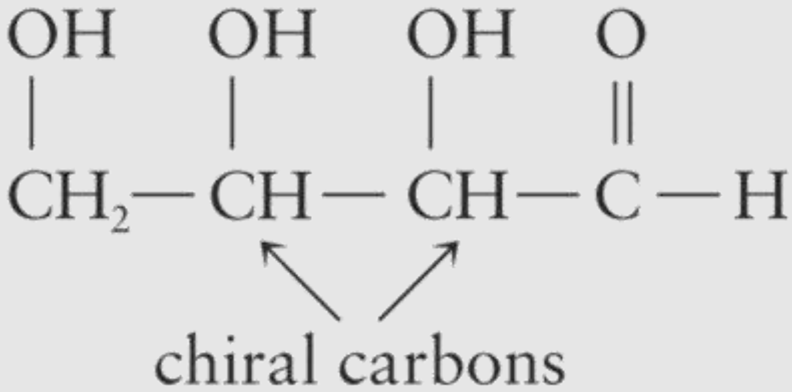
STEREOCHEMISTRY (continued)

- A **chiral** object cannot be superimposed on its mirror image.
- A **chiral carbon** is one that has four different groups attached to it.



STEREOCHEMISTRY (continued)

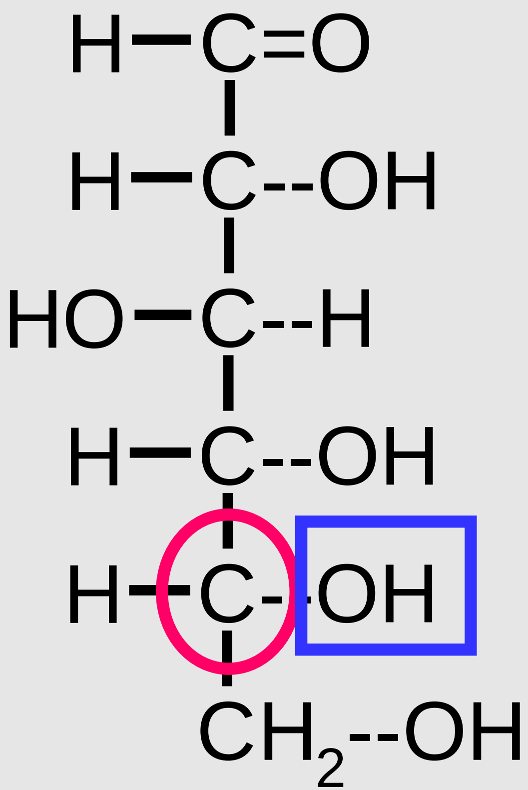
- Compounds can have more than one **chiral carbon**:



- The maximum number of stereoisomers is 2^n where n= number of **chiral carbon** atoms.

- Therefore, this compound with two **chiral carbon** atoms has 2^2 or 4 stereoisomers.

- The compound on the previous slide with four **chiral carbon** atoms has 2^4 or 16 stereoisomers.



1

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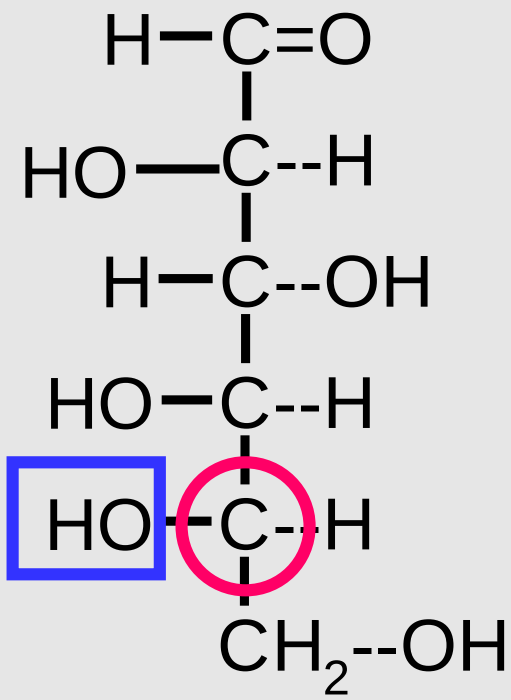
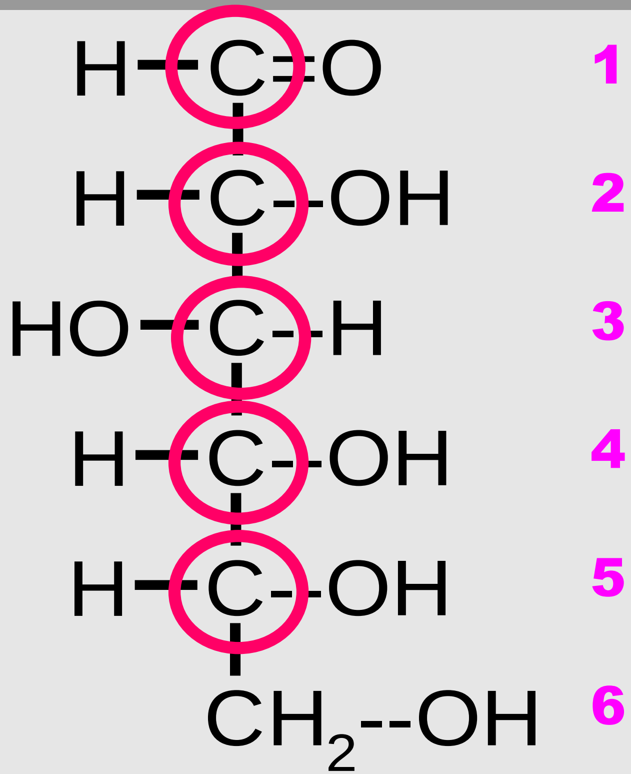
6

D-glucose (natural)



L-glucose

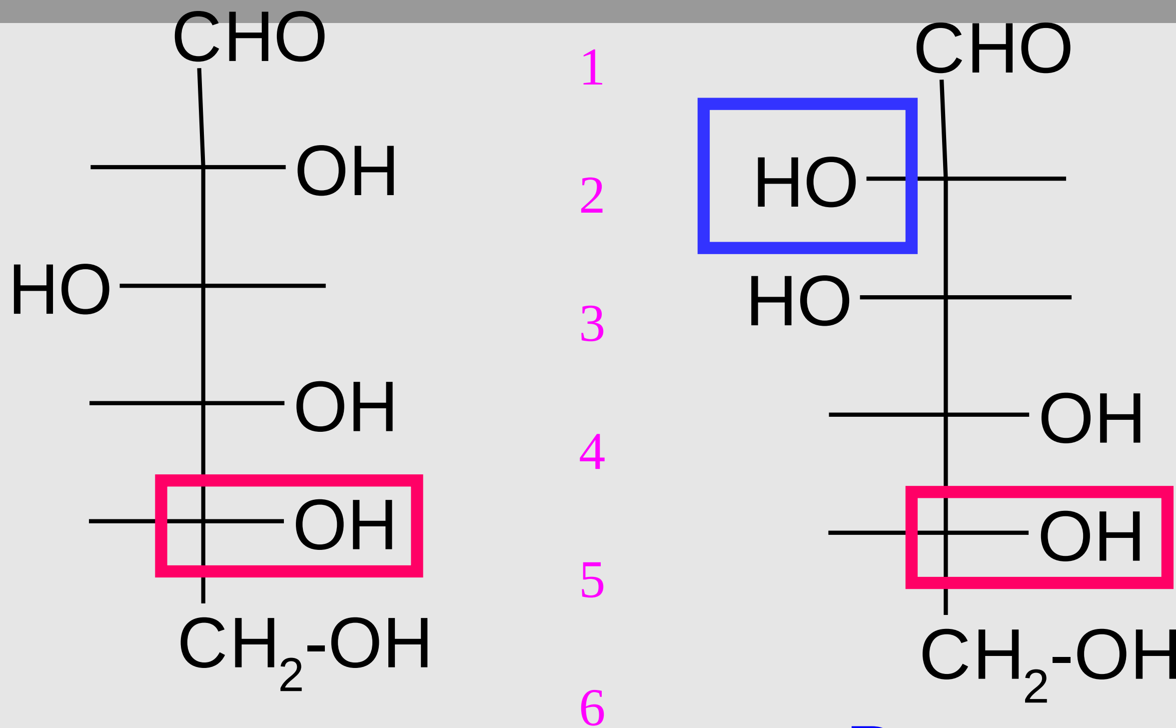
Penultimate (reference) carbon atom



number of possible stereoisomers

formula 2^n where n is the number of asymmetric carbon atoms.

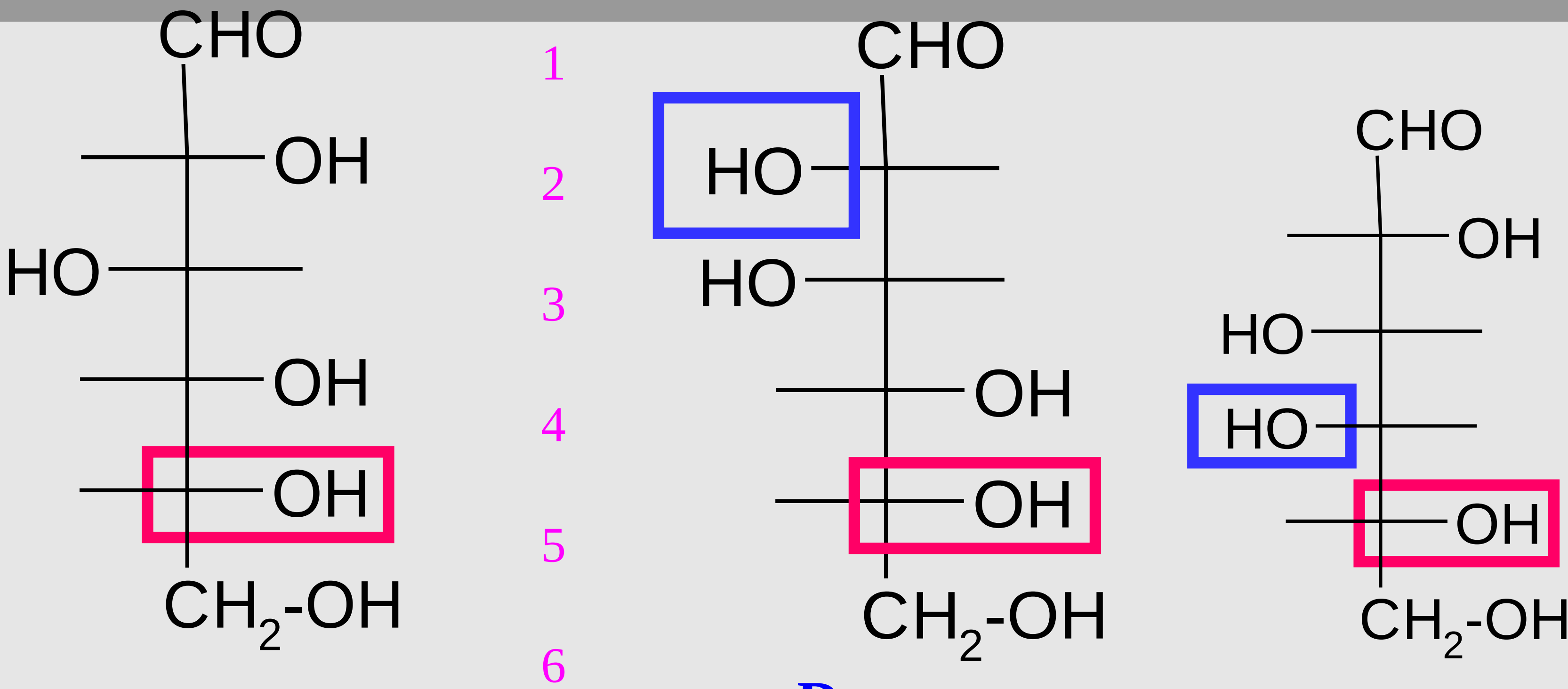
$$2^4 = 16$$



D-glucose

D-mannose,
2^{nd} epimer

<u>Epimers</u> of D-glucose



D-glucose

D-mannose,
2nd epimer

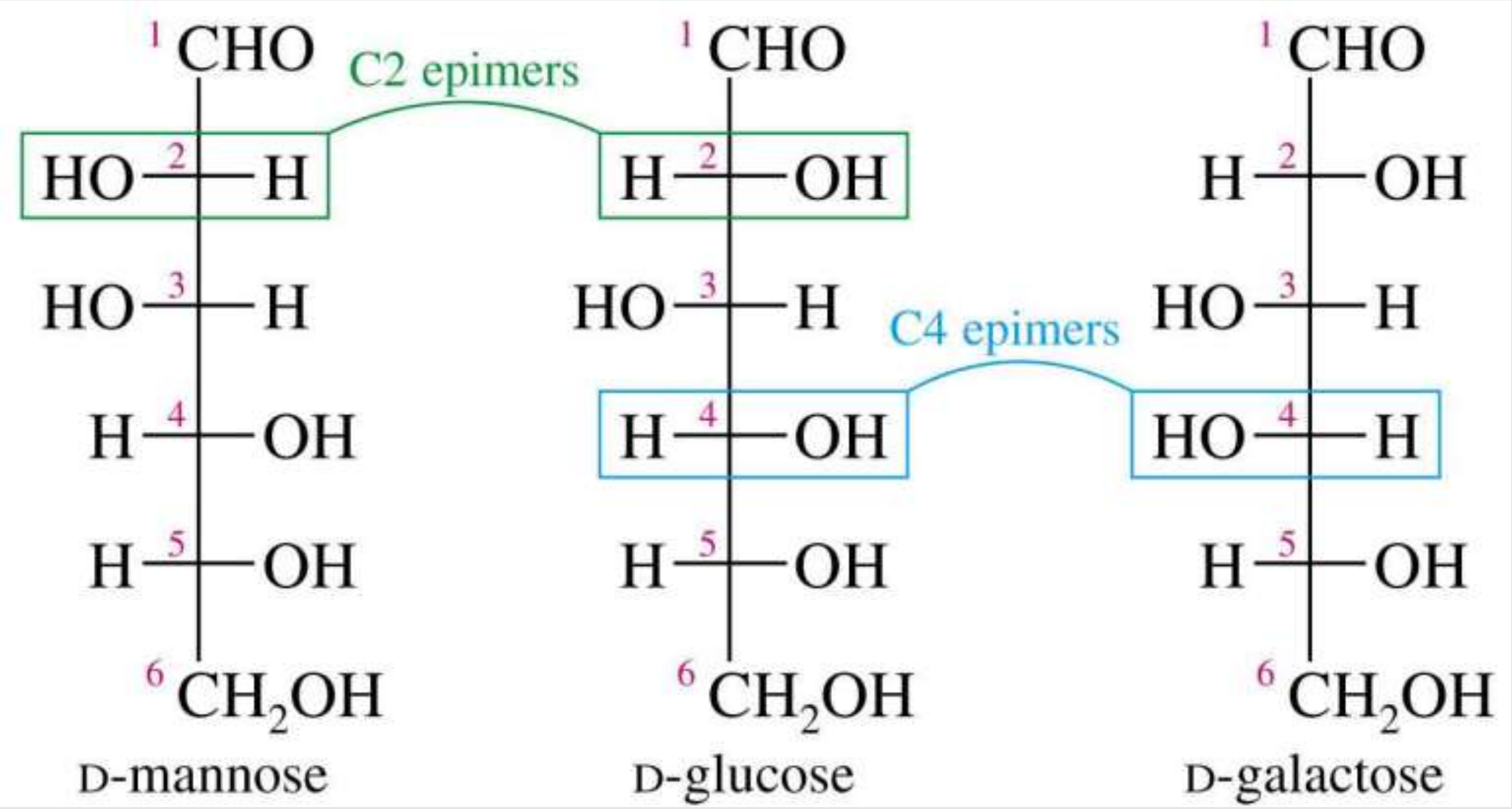
D-galactose
4th epimer

Epimers of D-glucose

Galactose and mannose are not epimers but diastereo-isomers

Epimers

Sugars that differ only in their stereochemistry at a single carbon.



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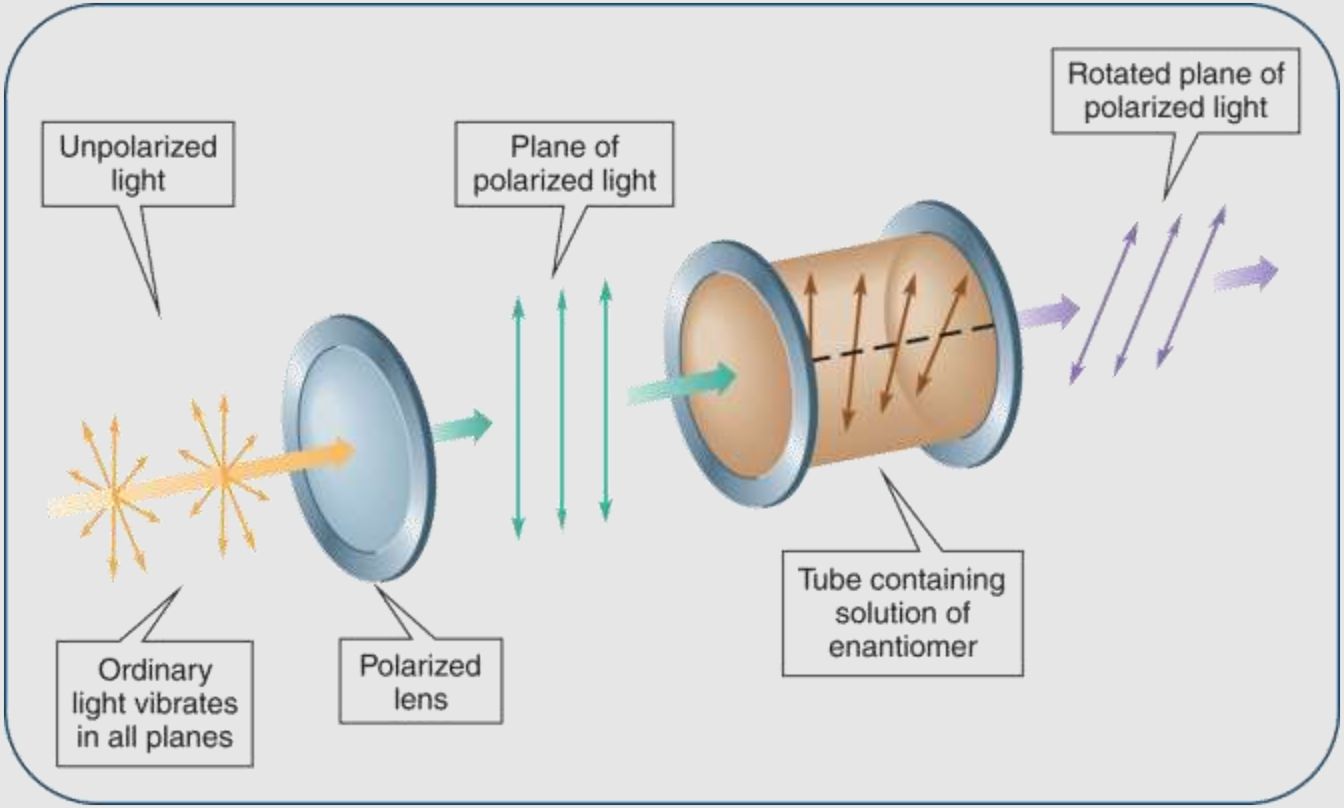
ENANTIOMER PROPERTIES

- The physical properties of D and L **enantiomers** are generally the same.
- D and L **enantiomers** rotate polarized light in equal, but opposite directions.



ENANTIOMER PROPERTIES (continued)

- The **enantiomer** that rotates polarized light to the left is the **levorotatory** or (-) **enantiomer**.
- The **enantiomer** that rotates it to the right is the **dextrorotatory** or (+) **enantiomer**.
- The D and L designations do not represent **dextrorotatory** and **levorotatory**.
- The property of rotating the plane of polarized light is called optical activity, and the molecules with this property are said to be **optically active**.
- Measurements of optical activity are useful for differentiating between **enantiomers**.

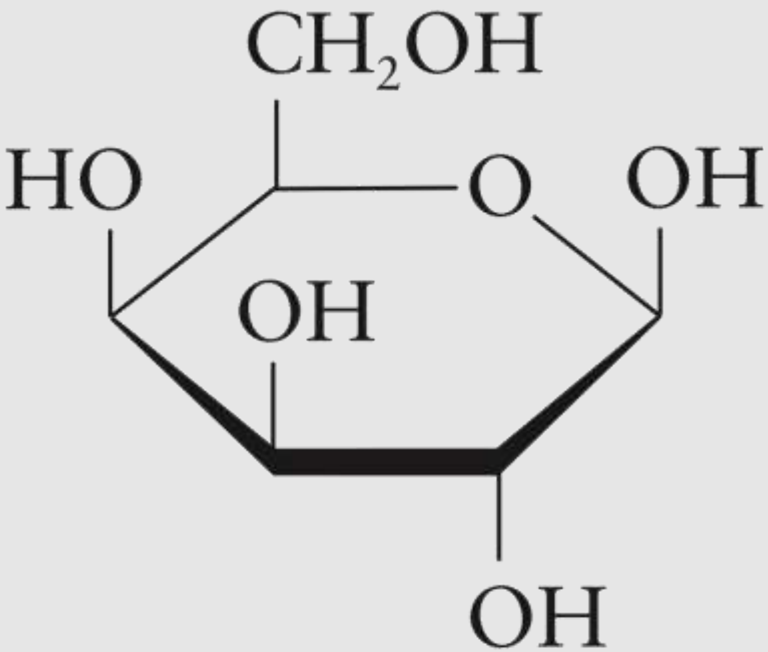
ENANTIOMER PROPERTIES (continued)

- In some instances, only the D or L **enantiomers** are found in nature.
- If both D and L forms are found in nature, they are rarely found together in the same biological system.

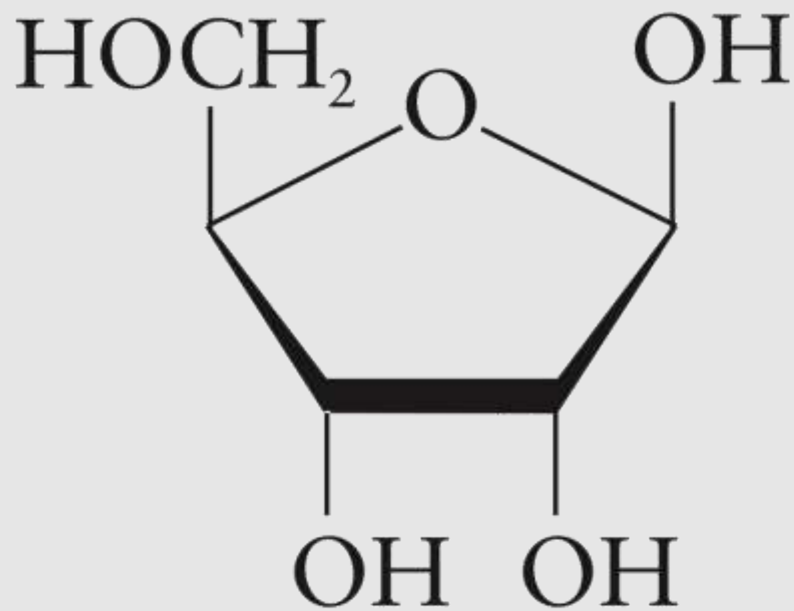
- For example:
  - **Carbohydrates** and amino acids are **chiral**.
  - Humans can only metabolize the D-isomers of **monosaccharides**.
  - Most animals are only able to utilize the L-isomers of amino acids to synthesize proteins.

MONOSACCHARIDE REACTIONS

- All **monosaccharides** with at least five carbon atoms exist predominantly as cyclic hemiacetals and hemiketals.
- A **Haworth structure** can be used to depict the three-dimensional cyclic **carbohydrate** structures.



β-D-galactose



D-ribose

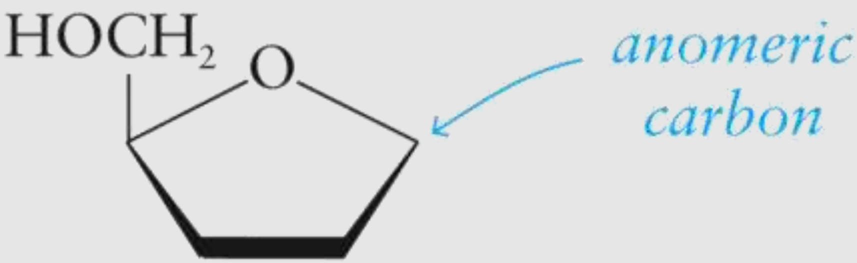
CYCLIZATION OF **MONOSACCHARIDES**

- The open-chain structure is numbered starting at the end closest to the carbonyl carbon atom.
- The alcohol group on the next to the last carbon atom adds to the carbonyl group.

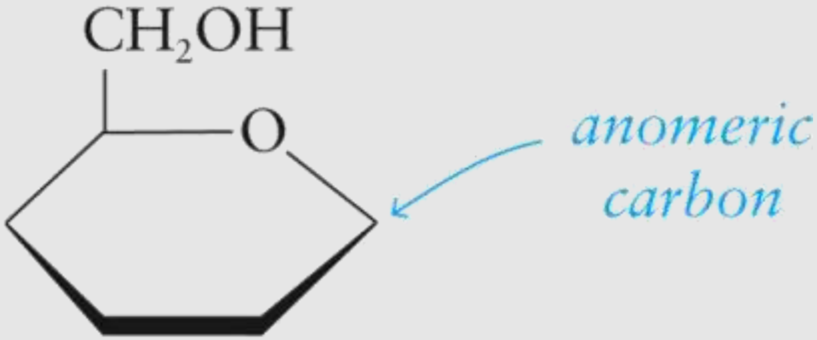
- In the case of glucose, the alcohol group on carbon 5 adds to the aldehyde group on carbon 1 and a **pyranose** (six-membered ring containing an oxygen atom) forms.
- In the case of fructose, the alcohol group on carbon 5 adds to the ketone group on carbon 2 and a **furanose** (five-membered ring containing an oxygen atom) forms.

- The former carbonyl carbon atom is now **chiral** and called the **anomeric carbon** atom.

CYCLIZATION OF **MONOSACCHARIDES** (continued)



furanose
ring



pyranose
ring

- Because the **anomeric carbon** atom is **chiral**, two possible stereoisomers can be formed during cyclization.
  - An α **anomer** (-OH on the **anomeric carbon** pointing down)
  - A β **anomer** (-OH on the **anomeric carbon** pointing up)
- **Anomers** are stereoisomers that differ in the 3-D arrangement of groups at the **anomeric carbon** of an acetal, ketal, hemiacetal, or hemiketal group.

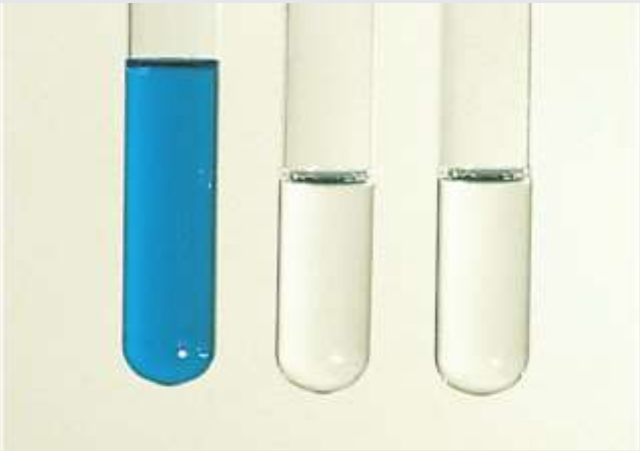
- **REACTIONS OF MONOSACCHARIDES**

MONOSACCHARIDE REACTIONS (continued)

- A **reducing sugar** can be easily oxidized.
- All **monosaccharides** are **reducing sugars**.
- Benedict's reagent tests for **reducing sugars**:

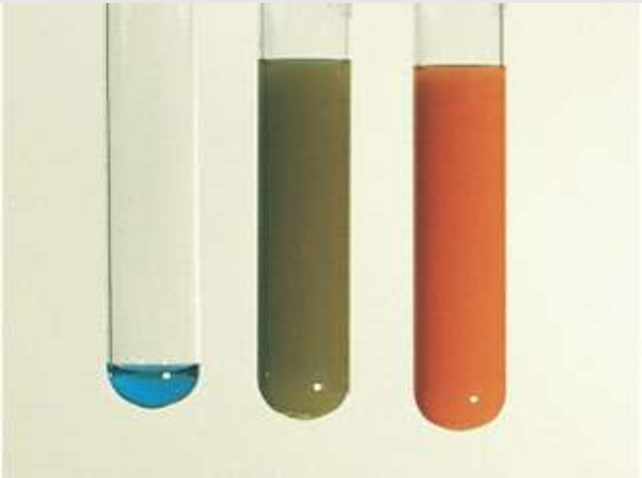
$$\text{Reducing sugar} + Cu^{2+} \rightarrow \text{oxidized compound} + Cu_2O$$

blue



From left to right, three test tubes containing Benedict's reagent, 0.5% glucose solution, and 2.0% glucose solution

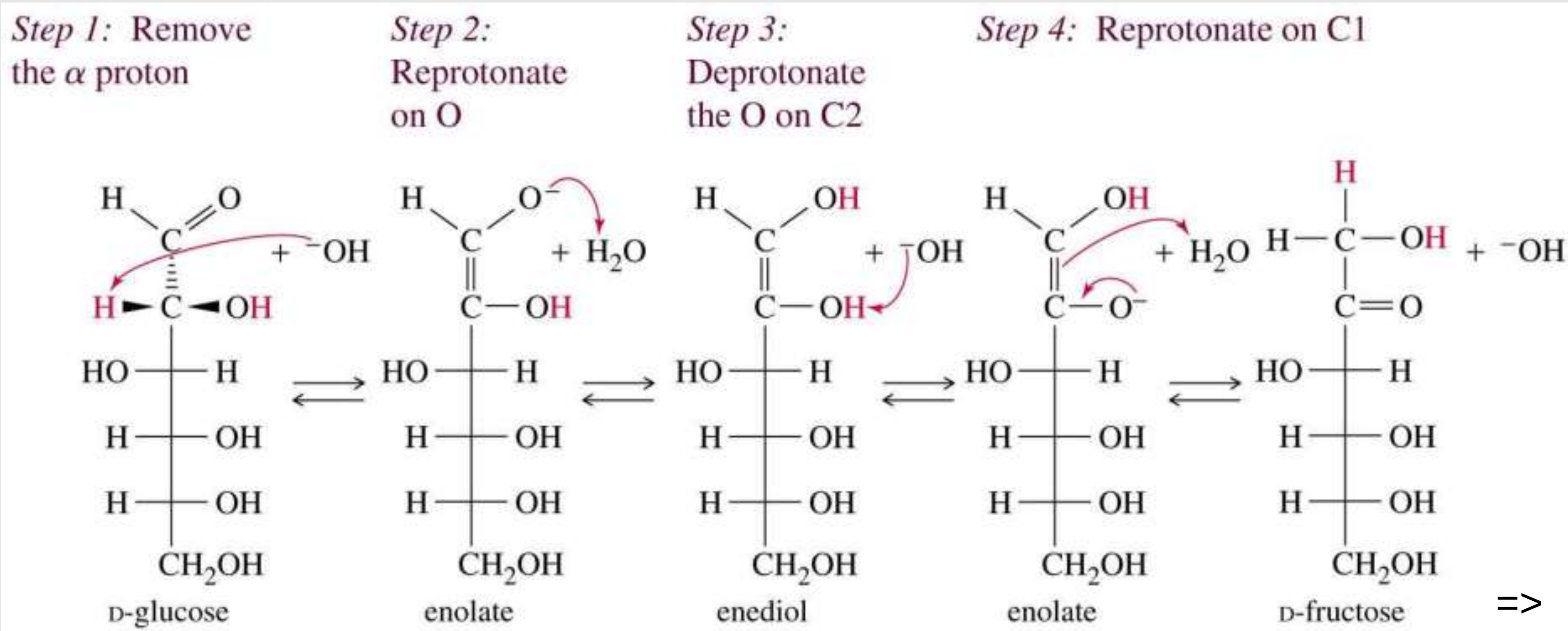
orange-red precipitate



The addition of Benedict's reagent produces colors (due to the red Cu_2O) that indicate the amount of glucose present.

Enediol Formation

In base, the position of the C=O can shift. Chemists use acidic or neutral solutions of sugars to preserve their identity.



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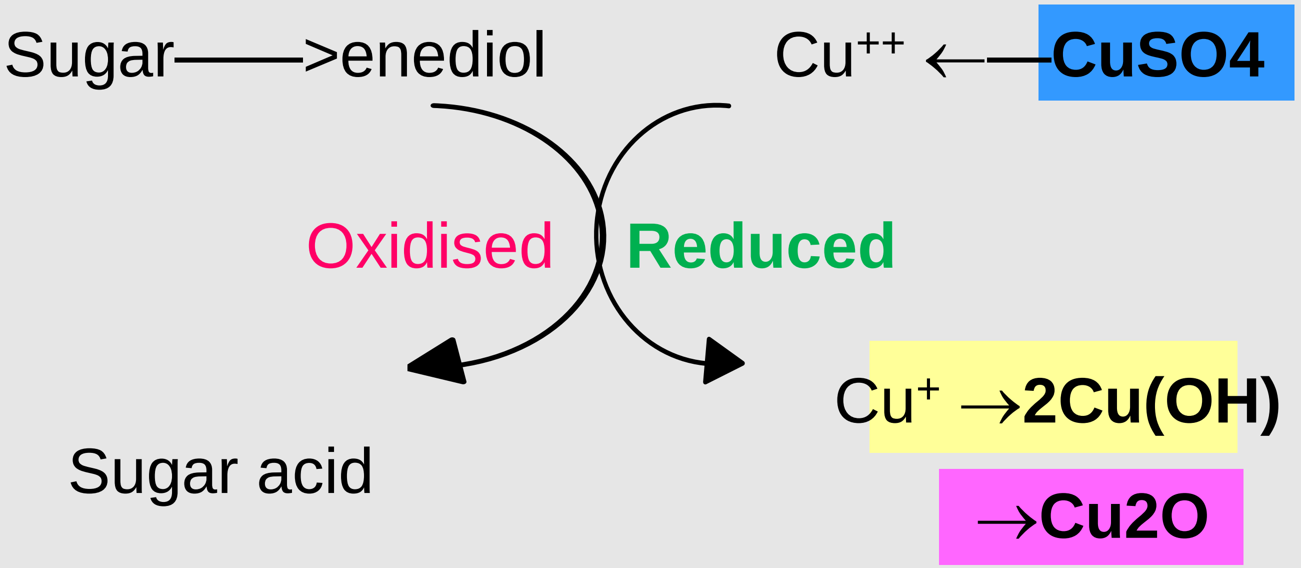
Benedict's Reaction



Glucose is a Reducing sugar

Semi-quantitative test

Action of Strong Alkali on Sugars

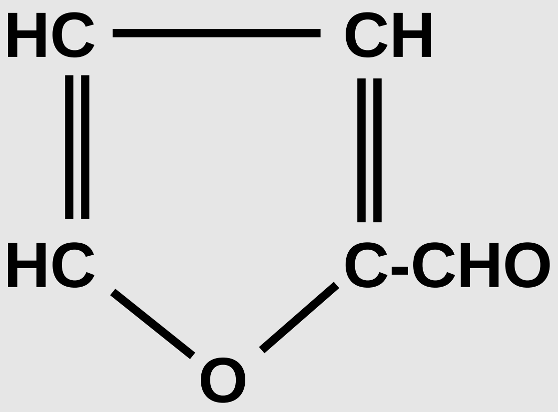
- When treated with strong alkali, sugars are enolised and the double bond will shift from 1:2 to 2:3, 3:4 or 4:5 to form the corresponding enediols and gets fragmented.

- The fragmented molecules will polymerize to form a yellow resinous material called Caramel.

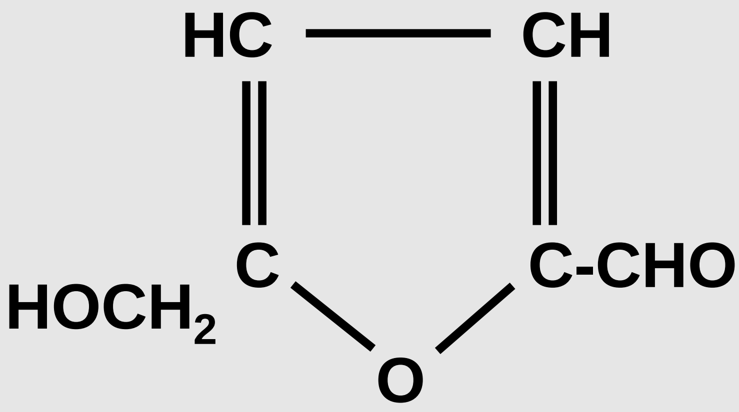
Action of Acids on Sugars

- Dilute acids –
  Aldoses in general are relatively stable.
  Ketoses degraded.
- Concentrated acids –
  Dehydrated to cyclical derivatives
  Pentoses: Furfural
  Hexoses : Hydroxy methyl furfural
- Ketoses are more susceptible to the action of acids

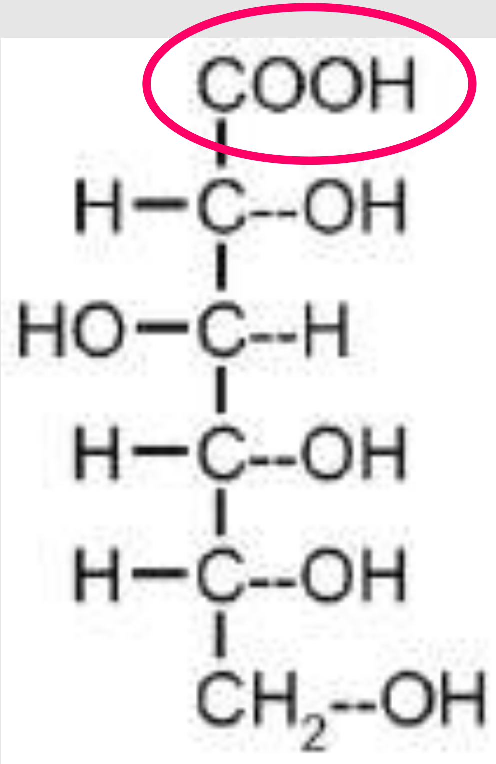
Action of Acids on Sugars



Furfural



Hydroxymethyl Furfural



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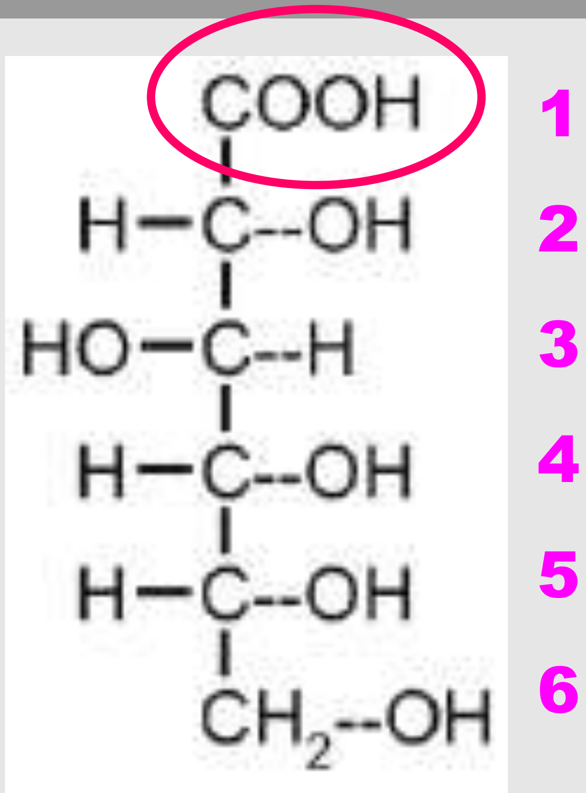
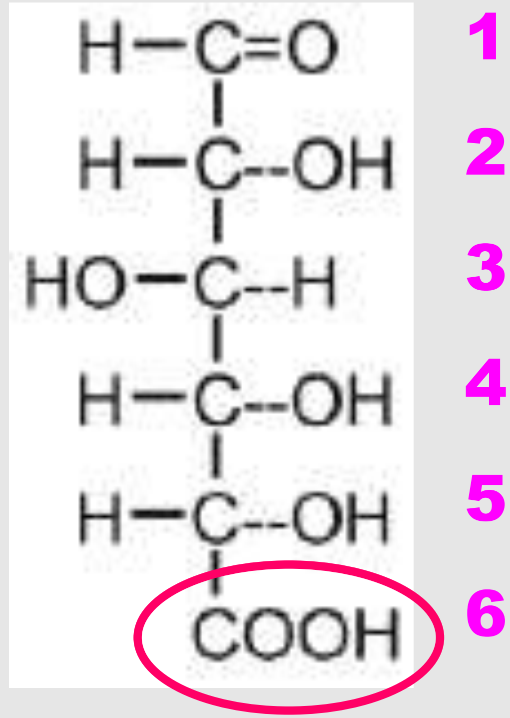
Gluconic acid

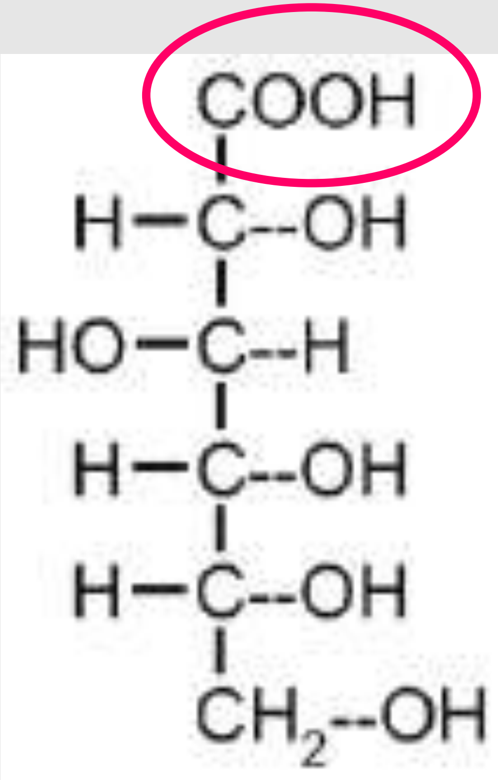
Oxidation



Gluconic acid



Glucuronic Acid Used for conjugation with insoluble molecules



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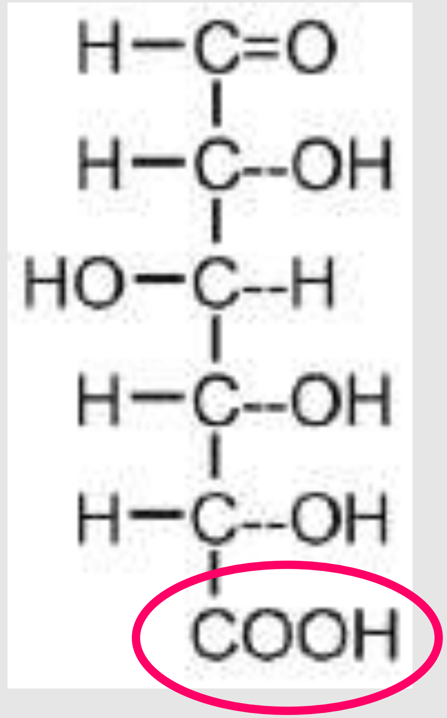

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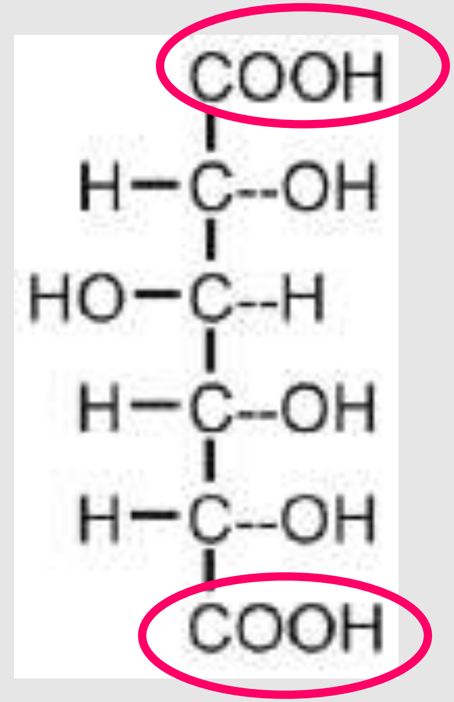
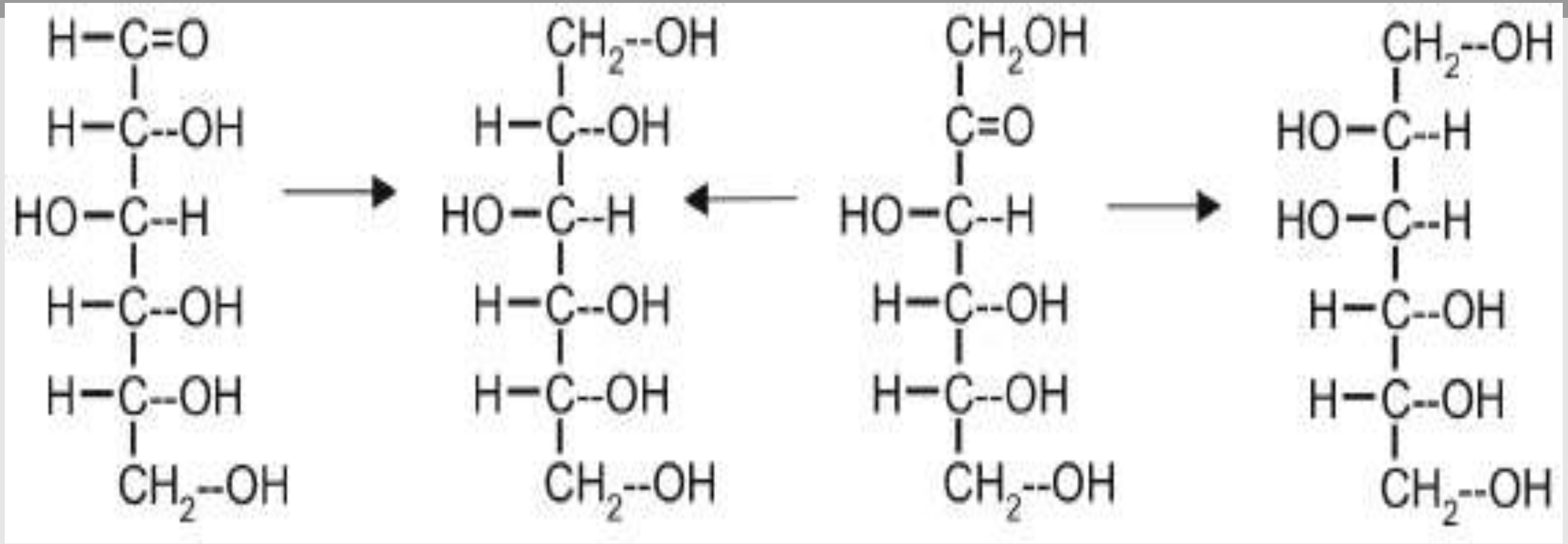


Gluconic acid

Glucuronic Acid

Gluco-saccharic acid



Glucose **Sorbitol** **Fructose** **Mannitol**

Reduction

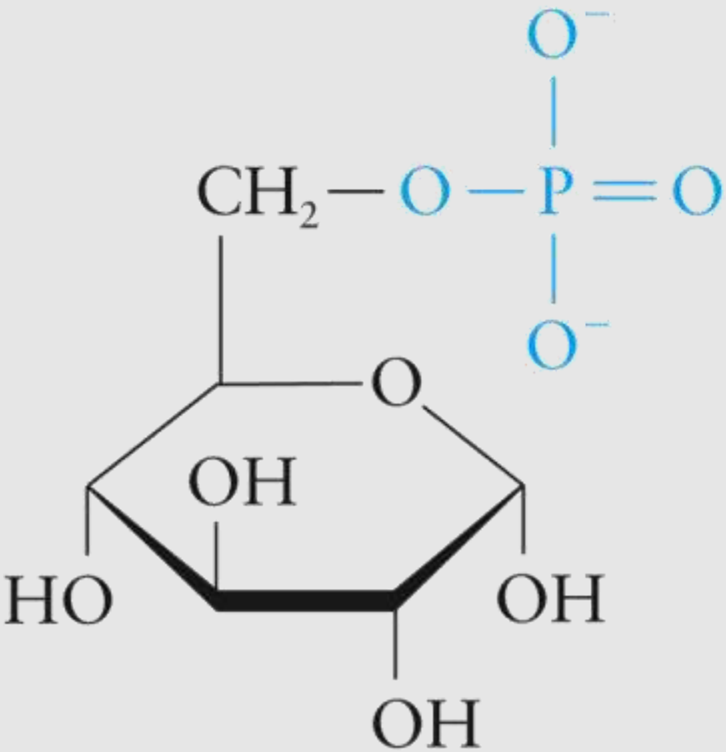
Glucose is reduced to sorbitol, Mannose to mannitol Fructose to sorbitol and mannitol. Galactose is reduced to dulcitol

Sorbitol, mannitol and dulcitol are used to identify bacterial colonies. Mannitol is also used to reduce intracranial tension by forced diuresis.

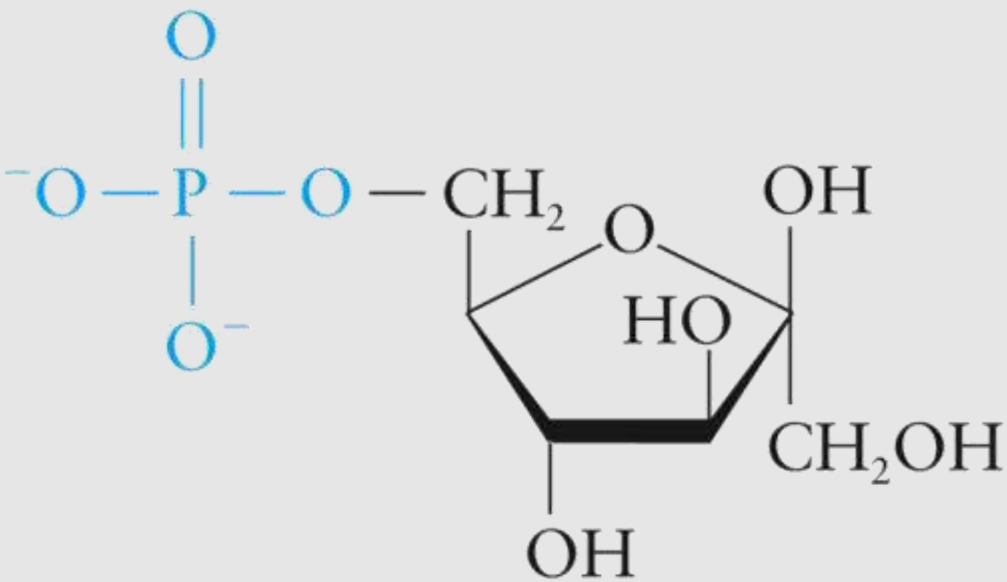
The osmotic effect of sorbitol and dulcitol produces changes in tissues when they accumulate in abnormal amounts, e.g. cataract of lens.

MONOSACCHARIDE REACTIONS (continued)

- The –OH groups of **monosaccharides** can behave as alcohols and react with acids (especially phosphoric acid) to form esters.



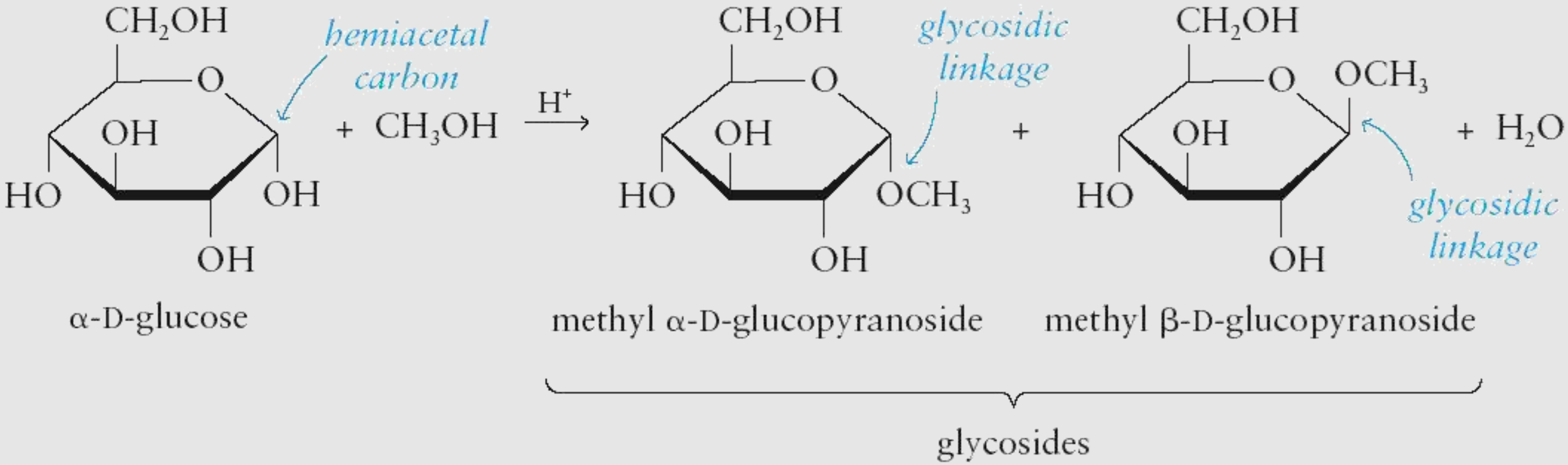
glucose 6-phosphate



fructose 6-phosphate

GLYCOSIDES

- Cyclic **monosaccharide** hemiacetals and hemiketals react with alcohols to form acetals and ketals, referred to as **glycosides**.



- The new carbon-oxygen-carbon linkage that joins the components of the **glycoside** is called a **glycosidic linkage**.
- **Glycosides** do not exhibit open-chain forms.
- **Glycosides** are not **reducing sugars**.

- Some glycosides have medical importance

  e.g. **Digitonin (leaves of foxglove)** is a cardiac stimulant.

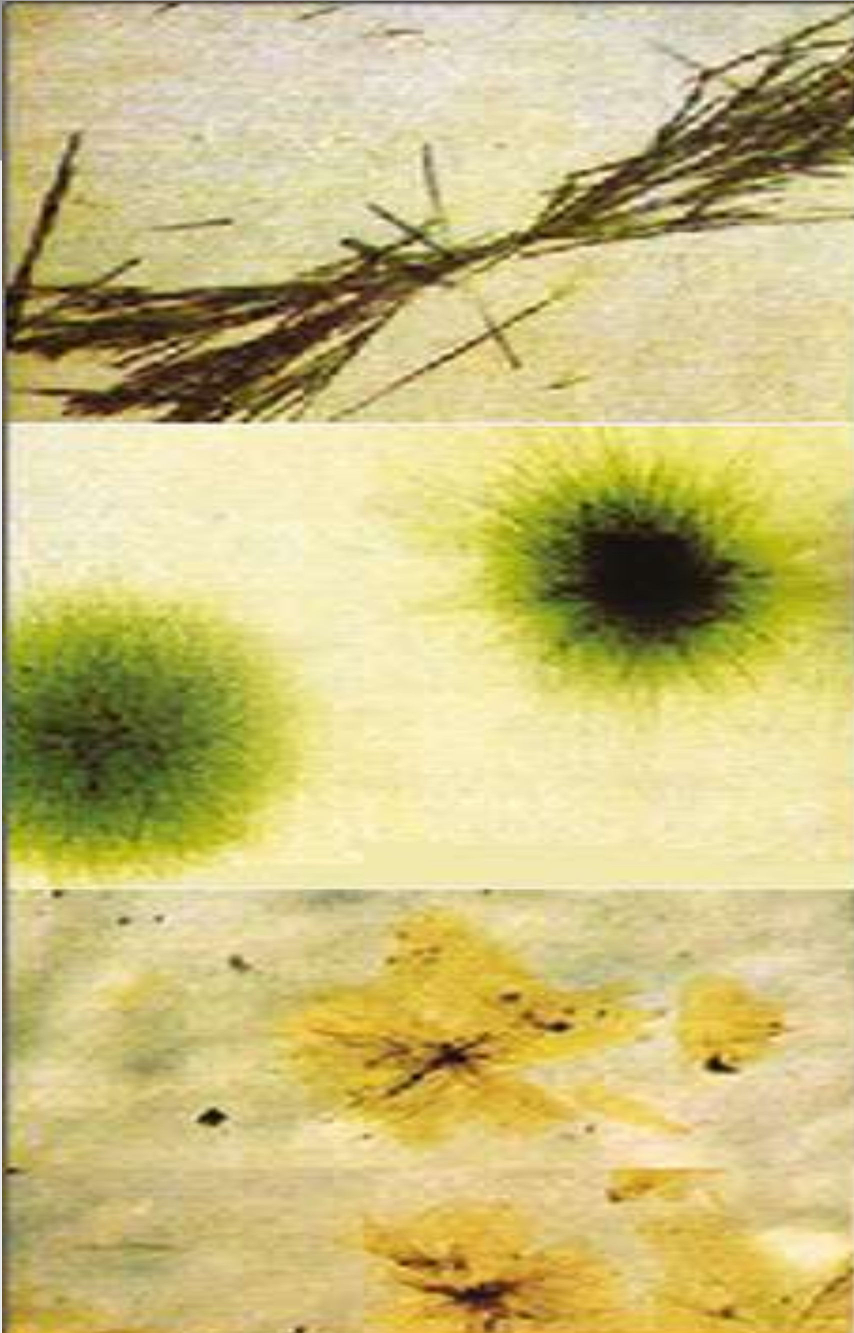
- **Phlorizin (rosebark)** is used to produce renal damage in experimental animals.
- **Plant indican** present in leaves of indigofera used as stain.

Osazone Formation

All reducing sugars will form osazones with excess of phenylhydrazine when kept at boiling temperature.

Osazones are insoluble.

Each sugar will have characteristic crystal form of osazones.



Needle shaped
crystals arranged
like a broom
Glucososazone

Hedgehog or
"pincushion with
pins" or flower of
"touch-me-not-plant"
Lactososazone

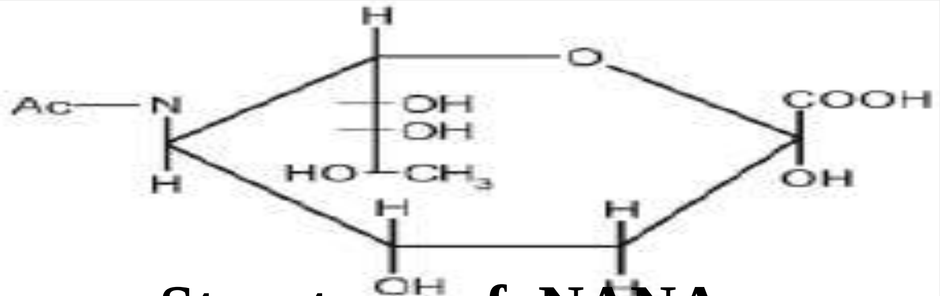
Sunflower
shaped or
petal shaped
crystals of
Maltosazone

Derivatives of Monosaccharide

Aminosugar : non reducing nature

- **Sialic acids:** Naturally occurring N-acetyl derivatives

  E.g. N acetyl Neuraminic acid – **NANA**
- **Glucosamine in** hyaluronic acid and blood group substances.
- **N-acetyl-galactoseamine** present in Glycoproteins, cell membrane antigen and Gangli



Structure of NANA

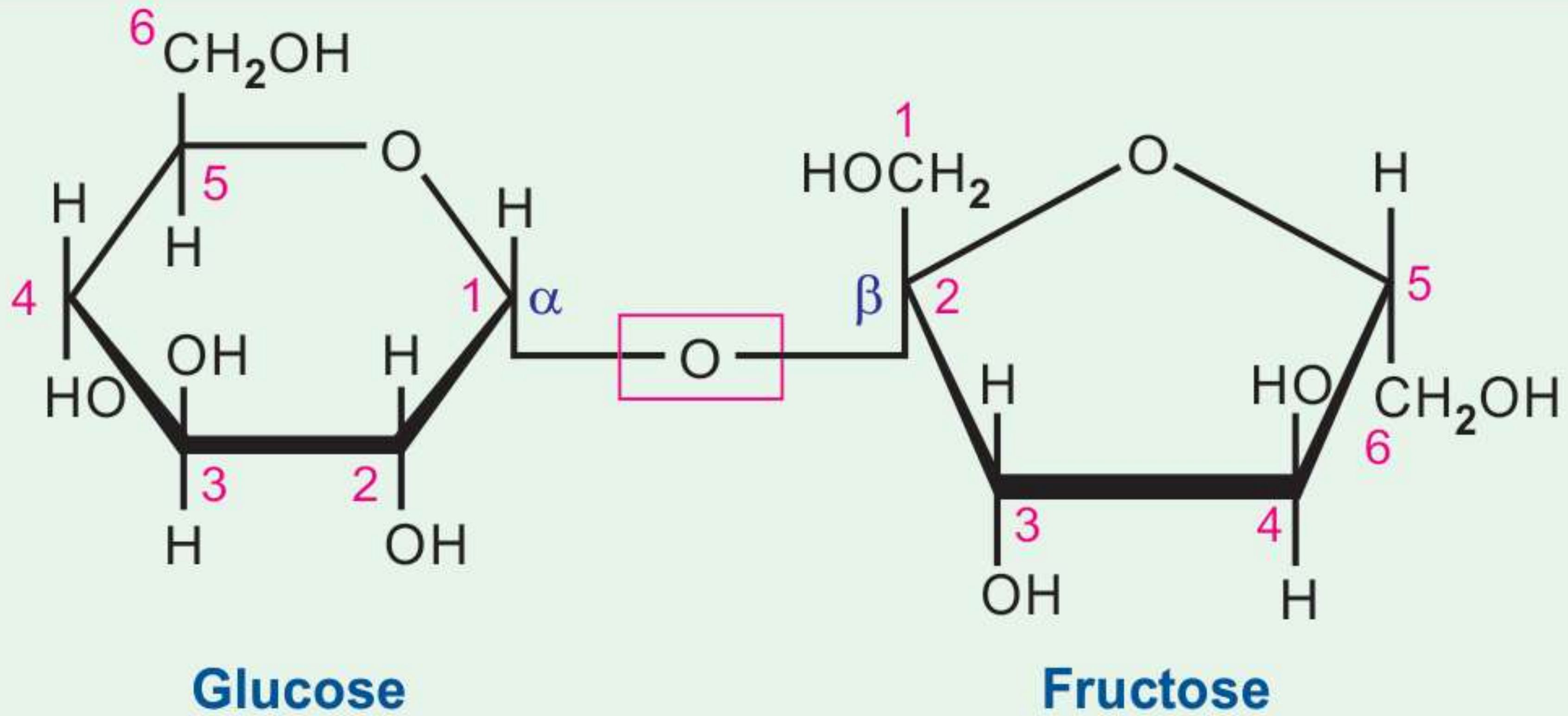
Disaccharides

When two monosaccharides are combined together by glycosidic linkage, a disaccharide is formed.

Important disaccharides

1. Sucrose
2. Maltose
3. Lactose

Sucrose



α-D-Glucosyl (1→2) β-D-fructose

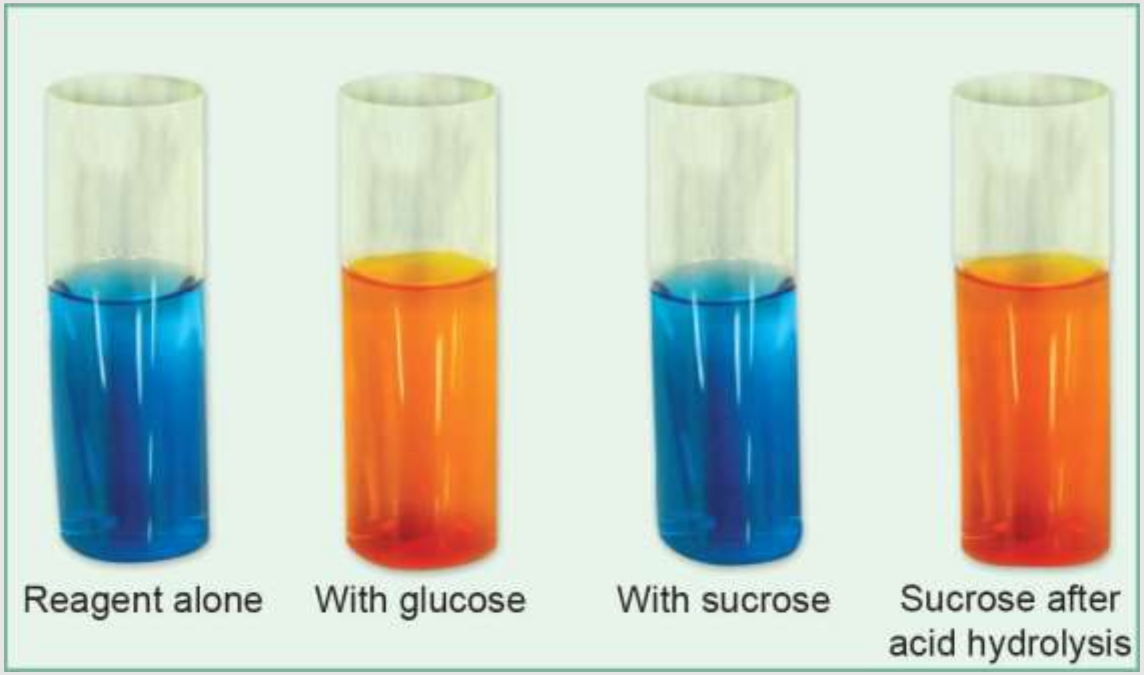
Sucrose is the **sweetening agent** known as cane sugar.
It is present in sugarcane and various fruits.

Sucrose is **not a reducing sugar**; and it will not form osazone.

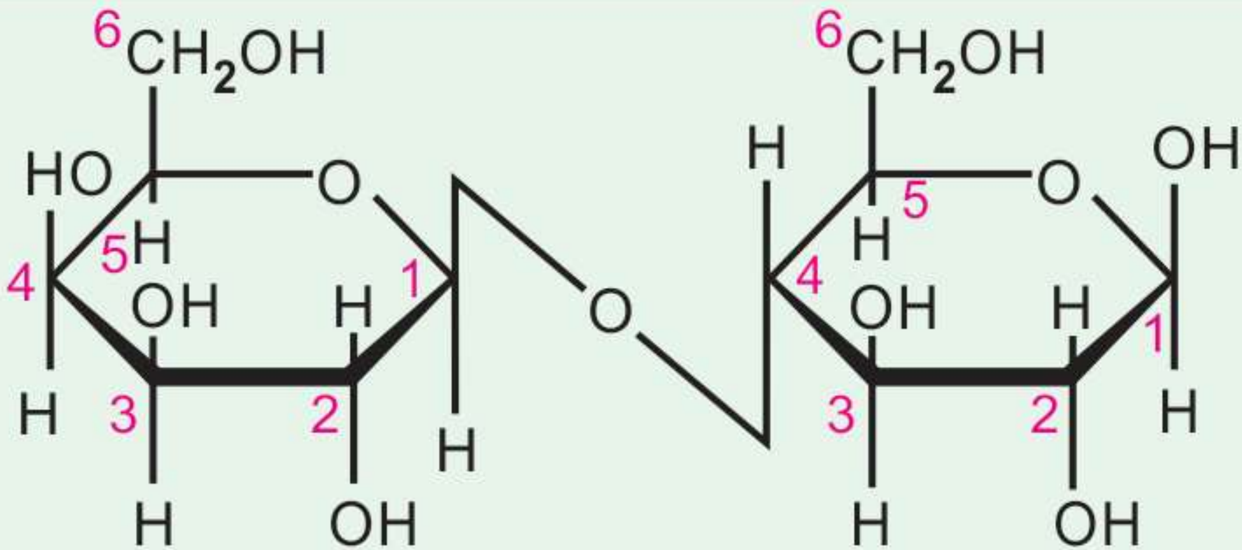
This is because the linkage involves first carbon of glucose and second carbon of fructose, and free sugar groups are not available.

When sucrose is hydrolysed, the products have reducing action.

A sugar solution which is originally nonreducing, but becomes reducing after hydrolysis, is inferred as sucrose (**specific sucrose test**).



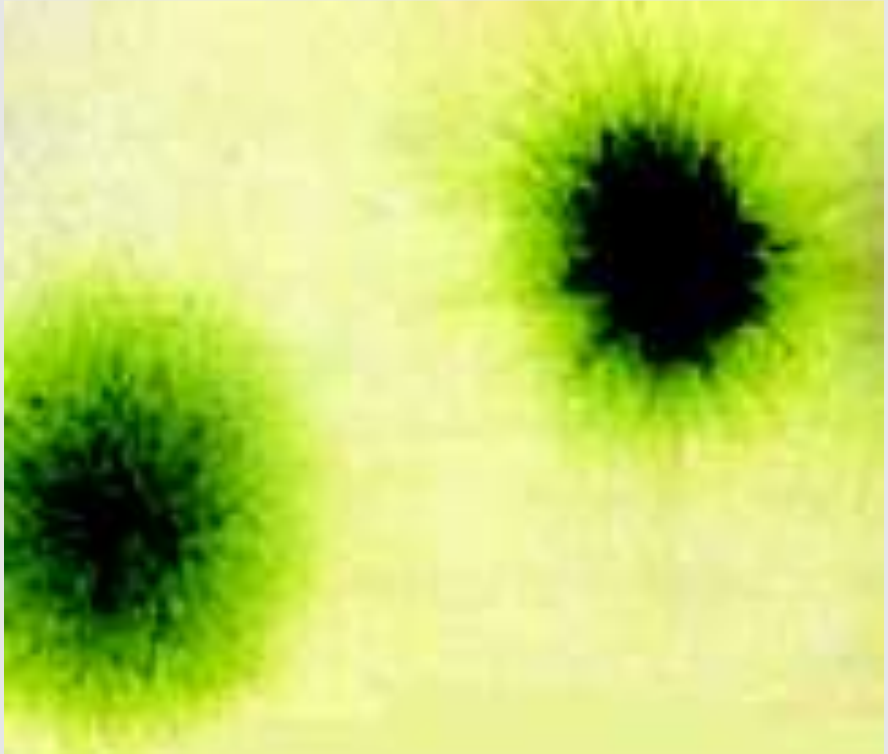
Lactose



Galactose **Glucose**

β-D-Galactosyl (1→4) β-D-Glucose

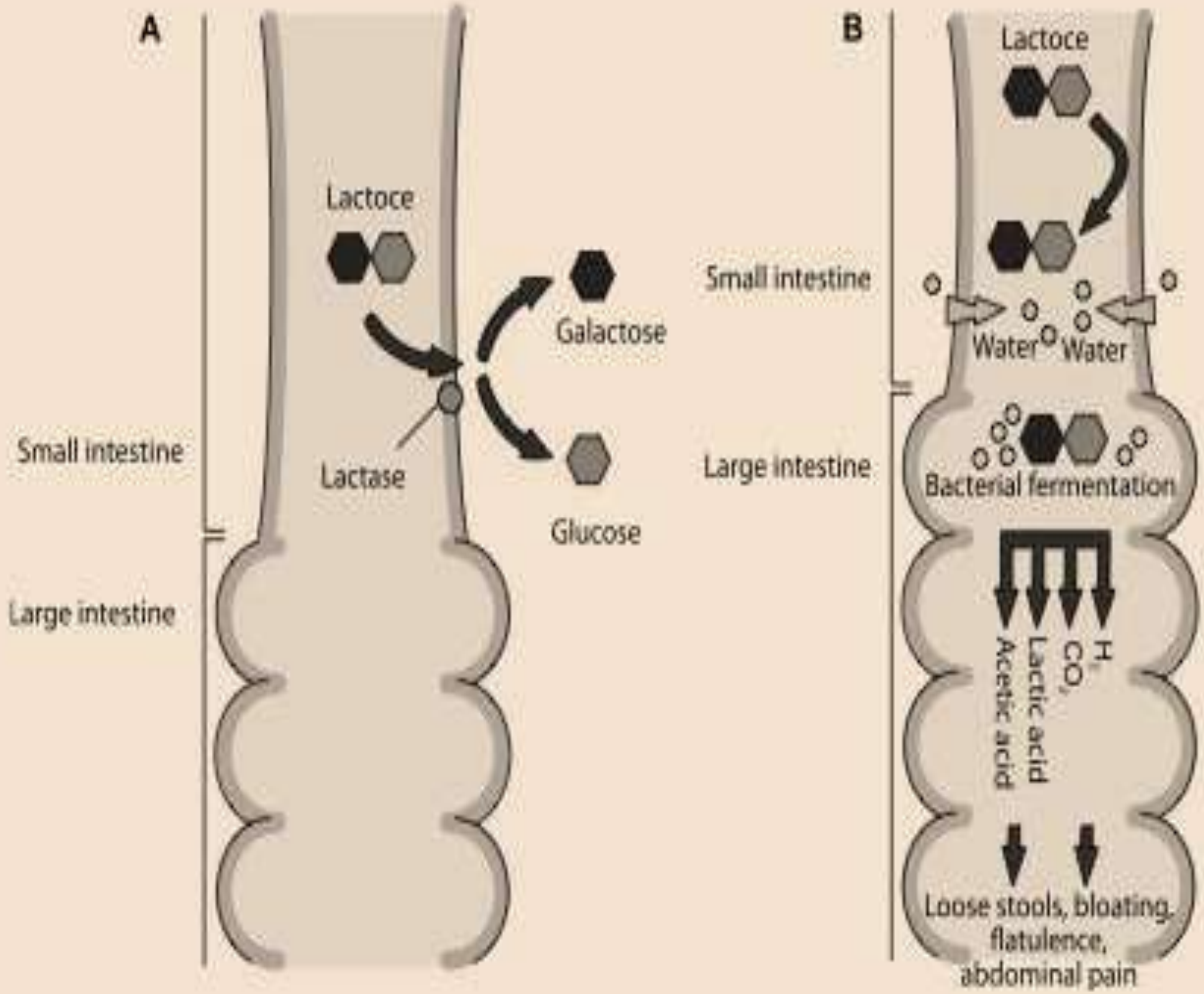
Lactose is the sugar present in milk.
It is a reducing disaccharide.



Lactose forms osazone which resembles "pincushion with pins" or "hedgehog" or flower of "touch-me-not" plant.

Lactose is hydrolyzed to its monosaccharide components by lactase enzyme in human beings and by β galactosidase in bacteria.

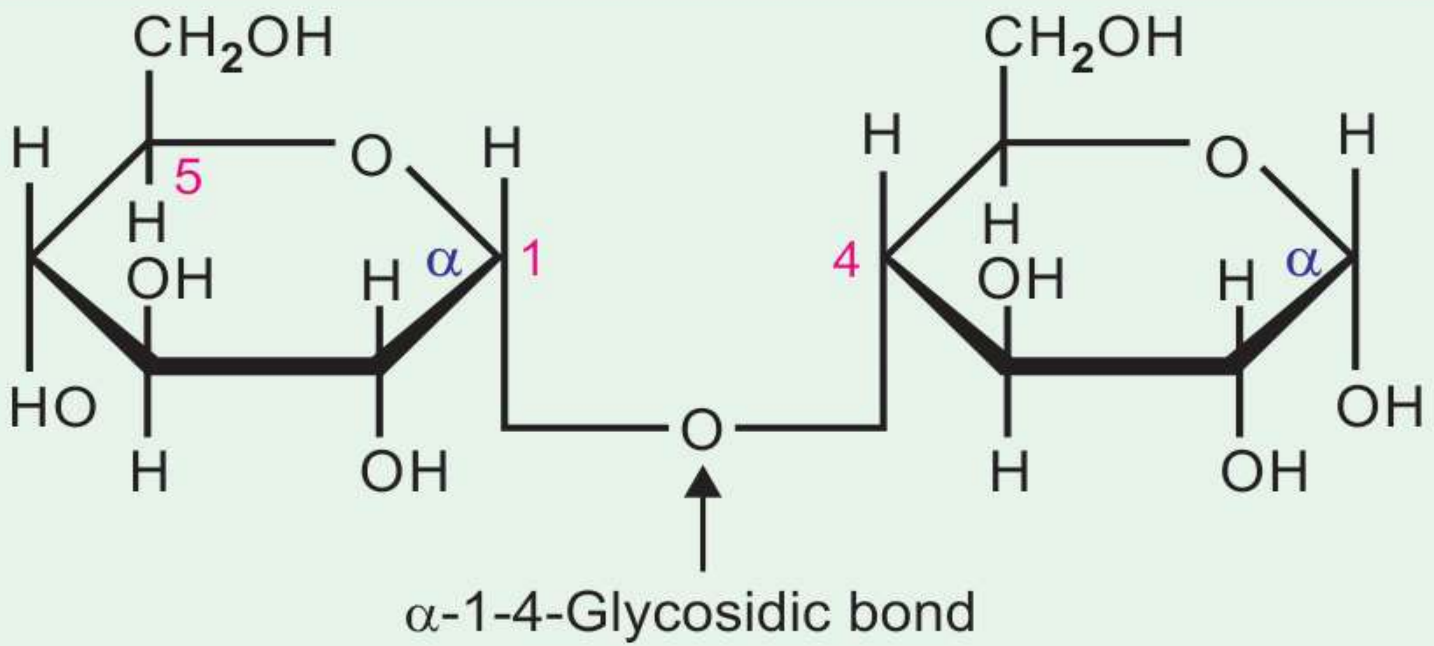
Deficiency of lactase causes Lactose intolerance, manifested by diarrhea, abdominal cramps, bloating and distension.


A
Lactoce
Galactose
Small intestine
Lactase
Glucose
Large intestine
B
Lactoce
Small intestine
Water
Water
Large intestine
Bacterial fermentation
H_2
CO_2
Lactic acid
Acetic acid
Loose stools, bloating,
flatulence,
abdominal pain

Maltose

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

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



α-D-Glucosyl (1–4) α-D-Glucose

-Produced by partial hydrolysis of starch either by Salivary or Pancreatic amylase.

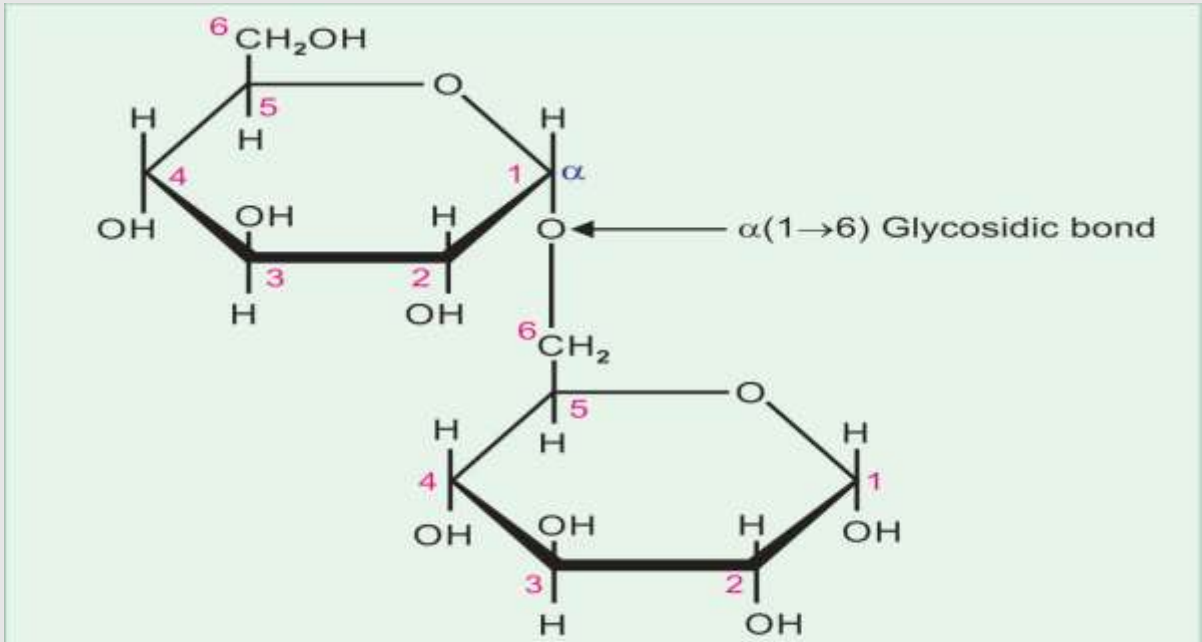
-Fermentable sugar.

-Used as a nutrient (malt extract; *Hordeum vulgare*); as a sweetener and as a fermentative reagent

-Has a free active group and hence exhibits reducing properties, mutarotation and α-β isomerism.

Isomaltose

Partial hydrolysis of glycogen and starch produces isomaltose.



Two glucose residues in alpha-1,6 linkage

Polysaccharides

Polymerised products of many monosaccharide units.

1. **Homoglycans** composed of single kind of monosaccharides, e.g. **starch, glycogen and cellulose**.

2. **Heteroglycans** are composed of two or more different monosaccharides, e.g. **agar, hyaluronic acid, chondroitin sulphate, glycoproteins**

Starch

It is the **reserve carbohydrate** of plant kingdom.

Sources: Potatoes, tapioca, cereals (rice, wheat) and other food grains.

Glucose units with **alpha-1,4 glycosidic linkages** to form a long chain.

Highly branched. The branching points are made by alpha-1,6 linkage.

Starch forms a **blue coloured complex with iodine**; this colour disappears on heating; reappears when cooled. **Sensitive test for starch.**

Starch is **non reducing** because the free sugar groups are **negligible** in number.

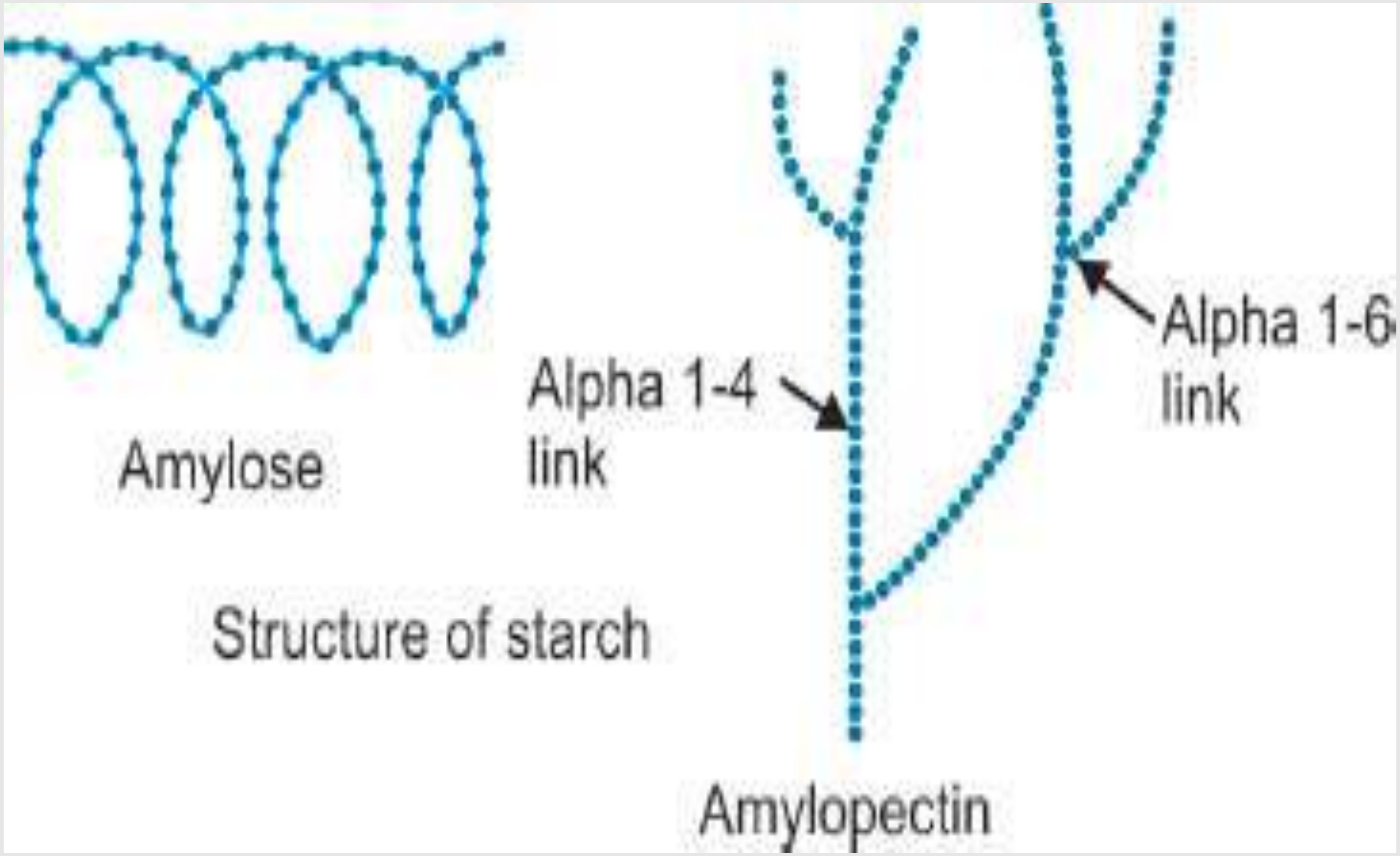
When starch is hydrolysed by **mild acid**, smaller and smaller fragments are produced.

Hydrolysis for a short time dextrin which gives violet colour with iodine and is non reducing.

Hydrolysis for a long time : Maltose and glucose (Reducing)

- **Amylose**:
- Water soluble(15-20%)
- Long unbranched chain with 200-1000 D-glucose units held by α (1-4) glycosidic linkage.

- **Amypectin**:
- Water insoluble(80-85%)
- Branched chain with 200-1000 D-glucose units held by
  α (1-6) glycosidic linkage.
- Branching point are present.


Amylose
Alpha 1-4
link
Alpha 1-6
link
Structure of starch
Amylopectin

Action of Amylases on Starch

i) **Salivary and pancreatic amylases** are alpha-amylases, which act at random on alpha-1,4 glycosidic bonds to split starch into smaller units (**dextrins**), and finally to **alpha-maltose**.

ii) **Beta-amylases** are of plant origin. It acts to release, maltose units from the ends of the branches of **amylopectin**.

iii) The action stops at branching points, leaving a large molecule, called limit **dextrin** or residual dextrin.

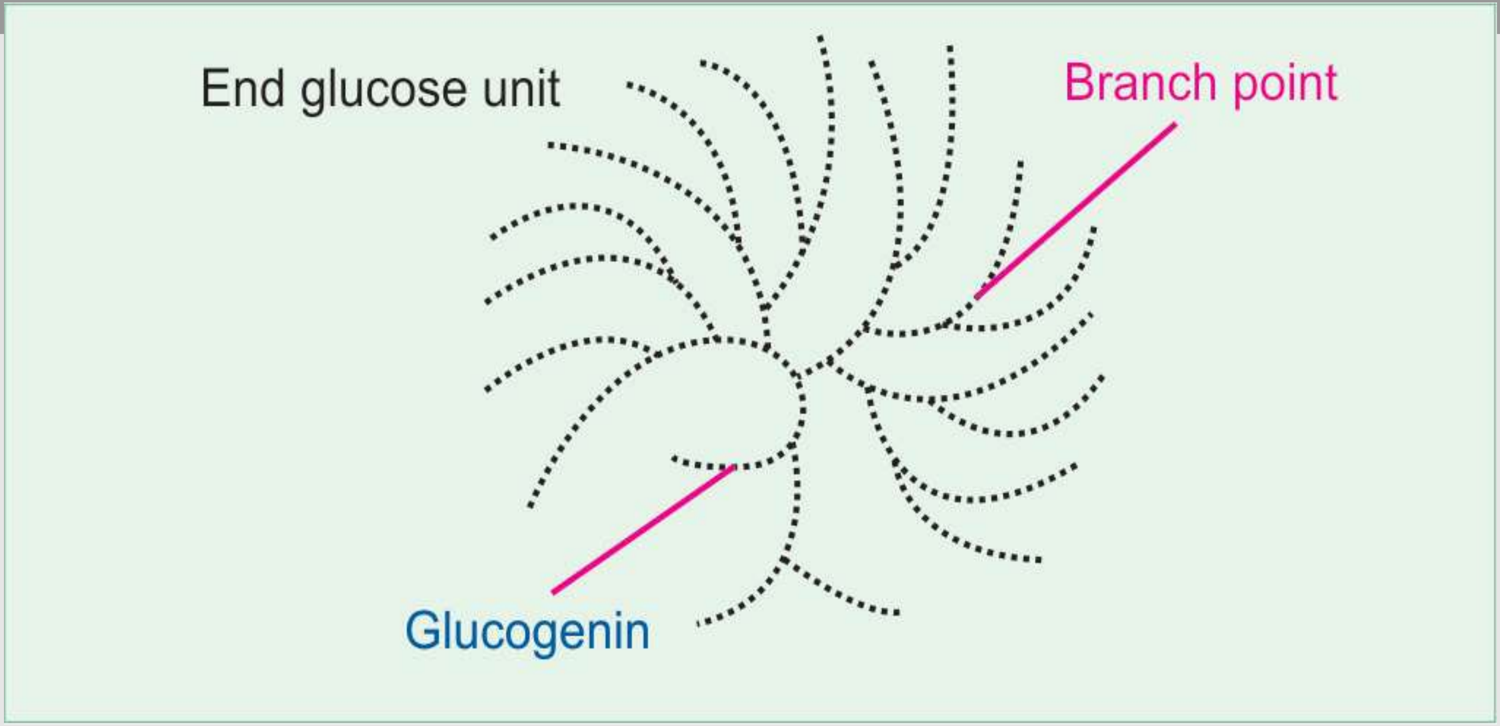
Glycogen

- It is the **reserve** carbohydrate in animals. It is stored in **liver and muscle**. About **5% of weight** of liver is made up by glycogen.

- Glycogen is composed of glucose units joined by **alpha-1,4 inkagess** in the straight chains. It also have **alpha-1,6 glycosidic linkages** at the branching points

- **Glycogenin** is protein primer of glycogen synthesis.

- Upto 25,000 glucose units



Exterior branches are composed of 6-7 glucose units and there are about 3-4 units between branches.

Cellulose

Supporting tissues of plants. Cellulose constitutes 99% of cotton, 50% of wood Most abundant organic material in nature.

Made up of glucose units combined with **beta-1,4 linkages.**

Synthetic fibres, celluloids, nitrocellulose and plastics are made from cellulose.

- Beta-1,4 bridges are hydrolysed by the enzyme **cellobiase.**
  This enzyme is absent in animal and human digestive system, and hence **cellulose cannot be digested.**
- **It functions as non-digestable fiber in human nutrition and decreases absorption of glucose and cholesterol from intestine with increasing bulk of feces.**

- **Herbivorous animals** have large caecum, which harbor bacteria. These bacteria can hydrolyze cellulose, and the glucose produced is utilized by the animal.

Inulin

Homoglycan Composed of **D-fructose units** with repeating **beta-1,2 linkages**.

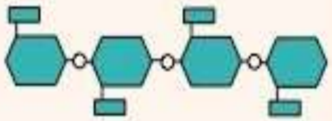
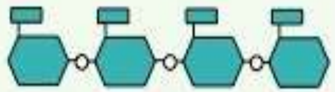
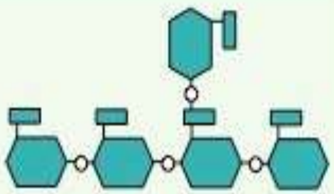
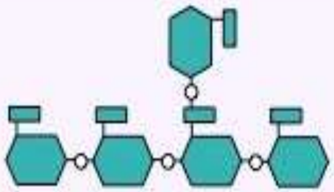
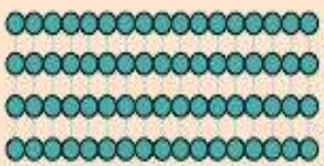
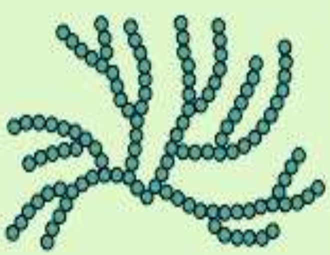
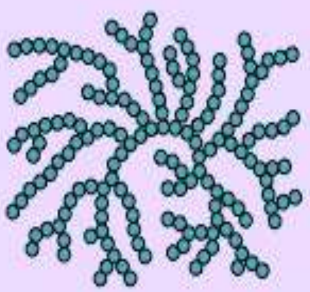
It is the reserve carbohydrate present in various **bulbs and tubers** such as **chicory, dahlia, dandelion, onion, garlic**.

It is clinically used to find **Renal clearance value** and **Glomerular filtration rate**.

Chitin

It is present in **exoskeletons of crustacea and insects.**

It is composed of units of **N-acetyl-glucosamine combined by beta-1,4 glycosidic linkages**.

	Cellulose	Starch		Glycogen
		Amylose	Amylopectin	
Source	Plant	Plant	Plant	Animal
Subunit	β-glucose	α-glucose	α-glucose	α-glucose
Bonds	1-4	1-4	1-4 *and* 1-6	1-4 *and* 1-6
Branches	No	No	Yes (~per 20 subunits)	Yes (~per 10 subunits)
Diagram				
Shape				

Heteroglycans

These are polysaccharides containing more than one type of sugar residues.

Agar and Agarose
Hyaluronic acid

Heparin and Heparan Sulphate
Chondroitin Sulphate

Keratan Sulphate
Dermatan Sulphate

Agar

Prepared from **sea weeds**.
Contains **galactose, glucose and other sugars**.

It is **dissolved in water at 100°C**, which upon cooling sets into a **gel**.

Agar cannot be digested by bacteria and hence used widely as a **supporting agent to culture bacterial colonies**.

Agar

supporting medium for **immuno-diffusion and immuno-electrophoresis.**

Agarose

galactose units;

used as **matrix for electrophoresis**.

MUCOPOLYSACCHARIDES or **glycosamino glycans** (**GAGs**) are heteropolysaccharides, containing uronic acid and amino sugars.

GLYCOSAMINOGLYCANS - EXAMPLES

N-Acetyl groups, sulfate and carboxyl groups are also present.

These charged groups attract water molecules; **viscous solutions**

Mucopolysaccharides in combination with proteins form **Mucoproteins**.

Hyaluronic Acid

Important GAGs

It is present in **connective tissues, tendons, synovial fluid and vitreous humor of eye.**

Lubricant and shock absorber in joints.

It is composed of **repeating units of N-Acetyl-glucosamine → Glucuronic acid**

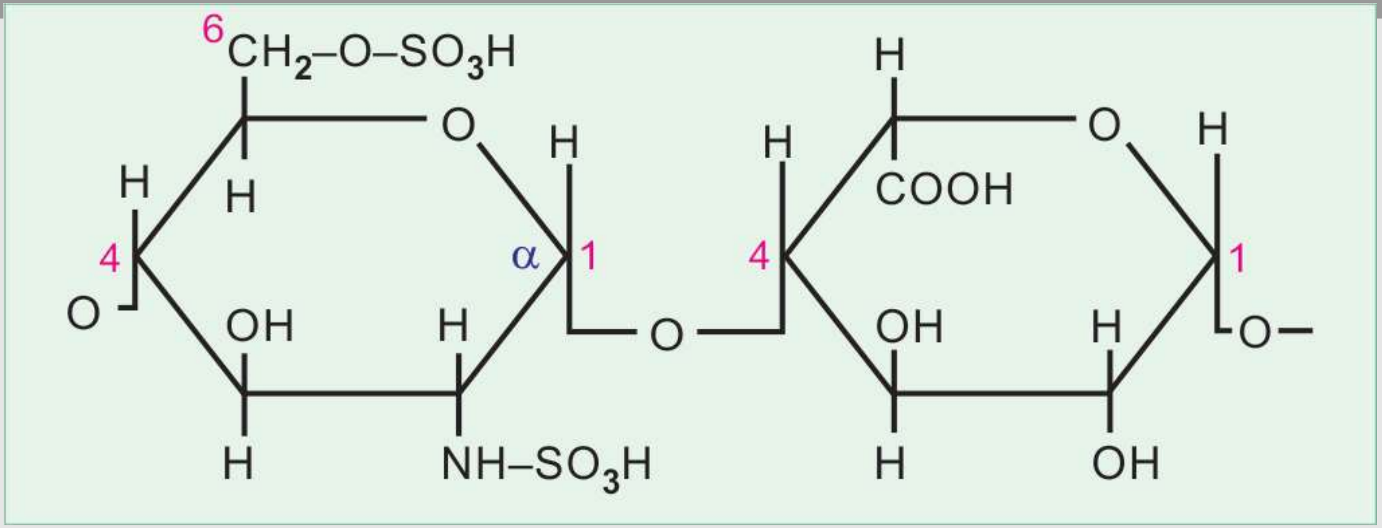
Hyaluronidase : plays important role in fertilization
Present in testes, seminal fluid and in snake and insect venoms.

Heparin

Anticoagulant for taking blood.
used **in vivo to** prevent intravascular coagulation.

It activates **antithrombin III**, which in turn **inactivates thrombin**, so blood is not clotted.

Heparin is present in **liver, lungs, spleen and monocytes.**

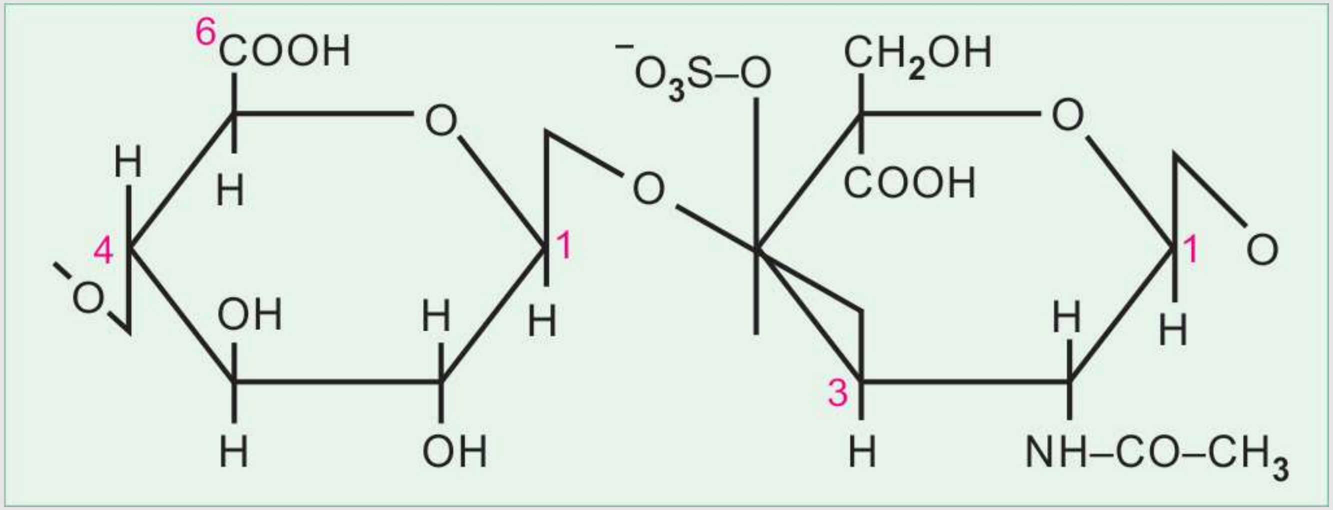


Heparin contains repeating units of **sulphated glucosamine → alpha-1, 4-L-iduronic acid → and so on**.

Sulphated heparin or **heparan sulfate** is also present in tissues.

Chondroitin Sulphate

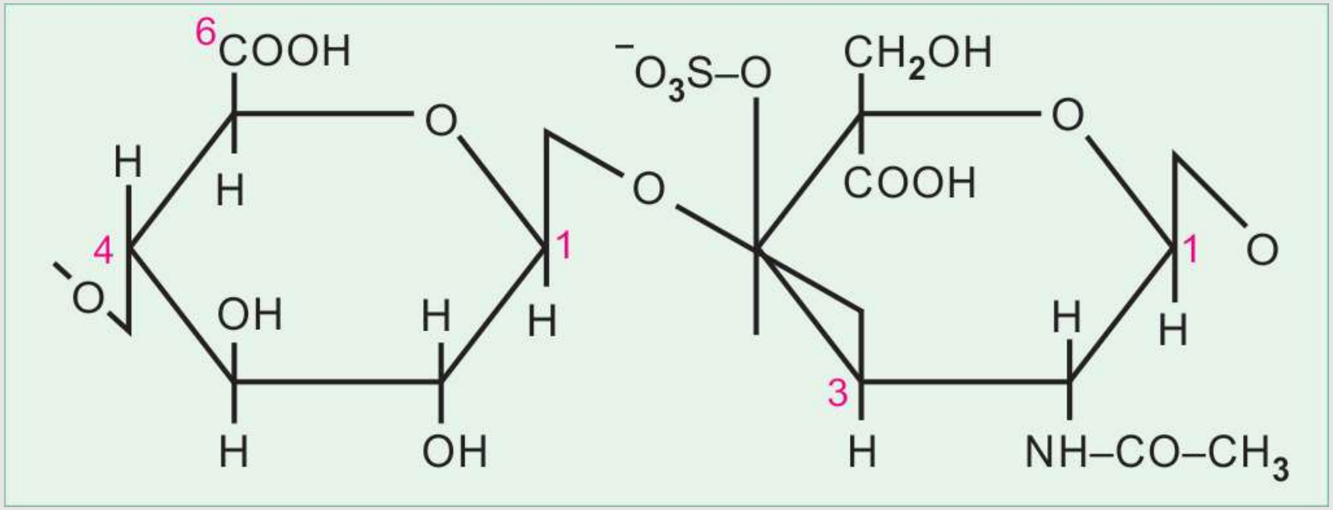
Connective tissues -- in **cartilage, bone, tendons, cornea and skin. Structurally same as hyaluronic acid.**



Repeating units of **glucuronic acid → N-acetyl galactosamine 4- sulphate → and so on.**

Chondroitin Sulphate

Connective tissues -- in **cartilage, bone, tendons, cornea and skin.**



Repeating units of **glucuronic acid → N-acetyl galactosamin sulphate → and so on**.

Keratan Sulphate

It is the only GAG which **does not contain any uronic acid.**

The repeating units are **galactose and N-acetyl glucosamine 6-sulphate**

It is found in **cornea and tendons**.

Dermatan Sulphate

L-iduronic acid and N-acetyl galactosamine in beta -1, 3 linkage.

It is found in **skin, blood vessels and heart valves**.

Mucopolysaccharides

- Hyaluronic acid
- Heparin
- Chondroitin Sulphate
- Keratan Sulphate
- Dermatan Sulphate

Box 5.6. Repeating Units in Polysaccharides

Polysaccharide	Repeating units
Homoglycans	
Inulin	D-fructose, beta-1,2 linkages
Dextran	Glucose, 1-6, 1-4, 1-3 linkages
Chitin	N-acetyl glucosamine; beta 1-4 links
Heteroglycans	
Agar	Galactose, glucose
Agarose	Galactose, anhydrogalactose
Hyaluronic acid	N-acetyl glucosamine, glucuronic acid
Heparin	Sulphated glucosamine, L-iduronic acid
Chondroitin S	Glucuronic acid, Nacetyl galactos-amine
Keratan S	Galactose, N-acetyl glucosamine
Dermatan S	L-iduronic acid, N-acetyl galactos-amine

Characteristics of GAGs

GAG	Localization	Comments
Hyaluronate	synovial fluid, vitreous humor, ECM of loose connective tissue	large polymers, shock absorbing
Chondroitin sulfate	cartilage, bone, heart valves	most abundant GAG
Heparan sulfate	basement membranes, components of cell surfaces	contains higher acetylated glucosamine than heparin
Heparin	component of intracellular granules of mast cells lining the arteries of the lungs, liver and skin	more sulfated than heparan sulfates
Dermatan sulfate	skin, blood vessels, heart valves	
Keratan sulfate	cornea, bone, cartilage aggregated with chondroitin sulfates	

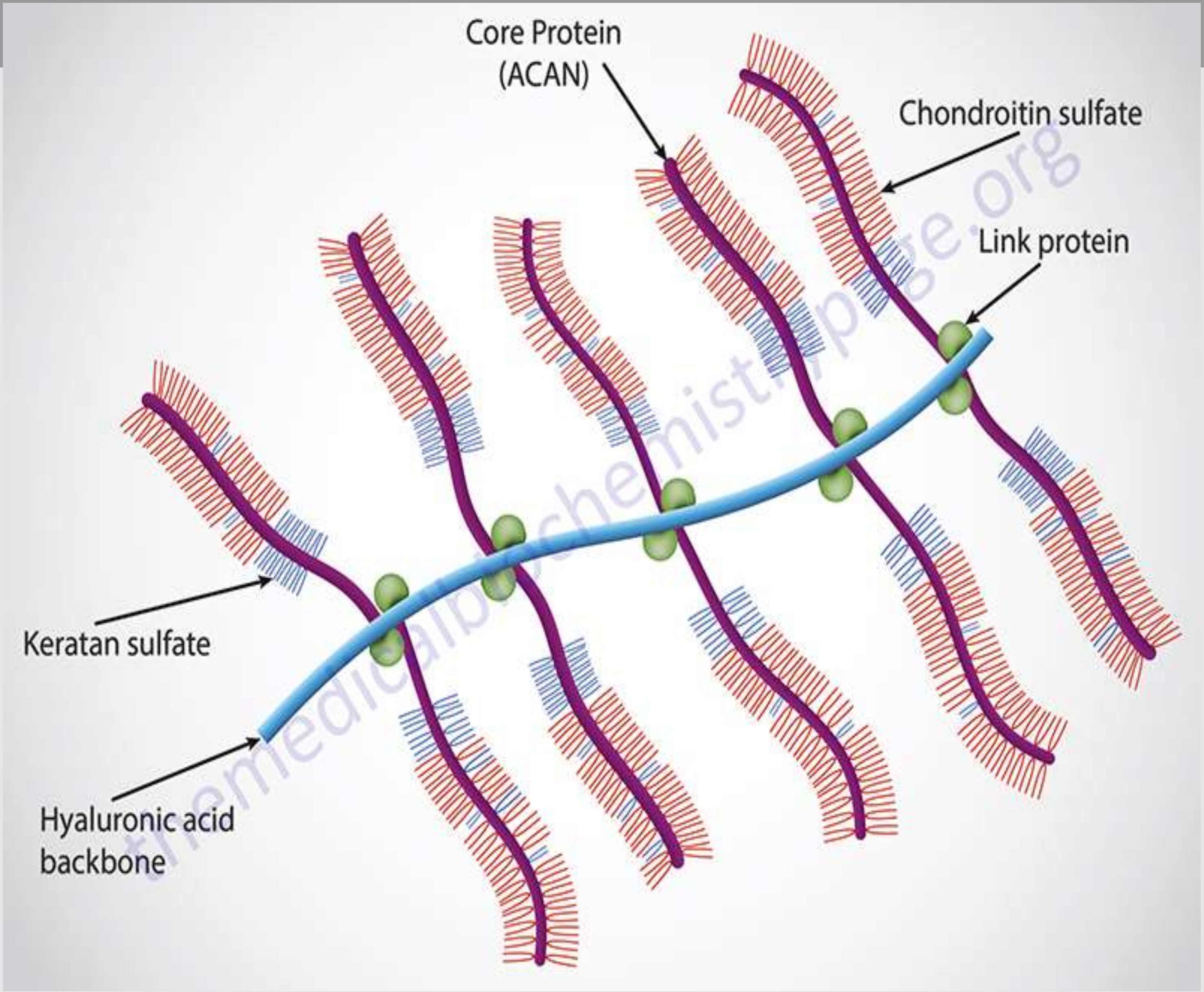
Glycoproteins and Mucoproteins

When the **carbohydrate chains** are attached to a **polypeptide** it is called a **proteoglycan**.

If the carbohydrate content is **less than 10%,** it is generally named as a **glycoprotein**.

If the carbohydrate content is **more than 10%** it is a **mucoprotein.**

Functions: enzymes, hormones, transport proteins, structural proteins and receptors.


Core Protein
(ACAN)
Chondroitin sulfate
Link protein
Keratan sulfate
Hyaluronic acid
backbone

Dietary Fiber

- Dietary fiber is contributed by the **unavailable carbohydrates in the diet**.

- They **contribute the bulk and assist in normal bowel movements**.

- **Cellulose, emicellulose, pectin, alginates, and gums are the usual glycans** which form dietary fiber.

- Cellulose is found in **bran, flour, and tubers**.
- **Pectins** are mixtures of **homoglycans found in fruits**. **Gums and alginates** are found in **legumes and oatmeal**.

Thank You