Carbohydrates

LECTURE 1

DATE:16TH MARCH 2021

LEARNING OBJECTIVES

What are carbohydrates

Classification of carbohydrates

Their general properties and biomedical properties.

List of monosaccharide of biological importance and their properties

List of disaccharide of biological importance and their properties

Chemistry & properties of various polysaccharides.

Functions of carbohydrates.

Carbohydrates

Polyhydroxy alcohols(OH) with potentially

active carbonyl groups which may either

be aldehyde (H-C=O) or ketone(C=O)

or

compounds which yield them on hydrolysis

Carbohydrates

Organic compounds – carbon, hydrogen, and oxygen

General formula **$(CH_2O)_n$ or $C_nH_{2n}O_n$**

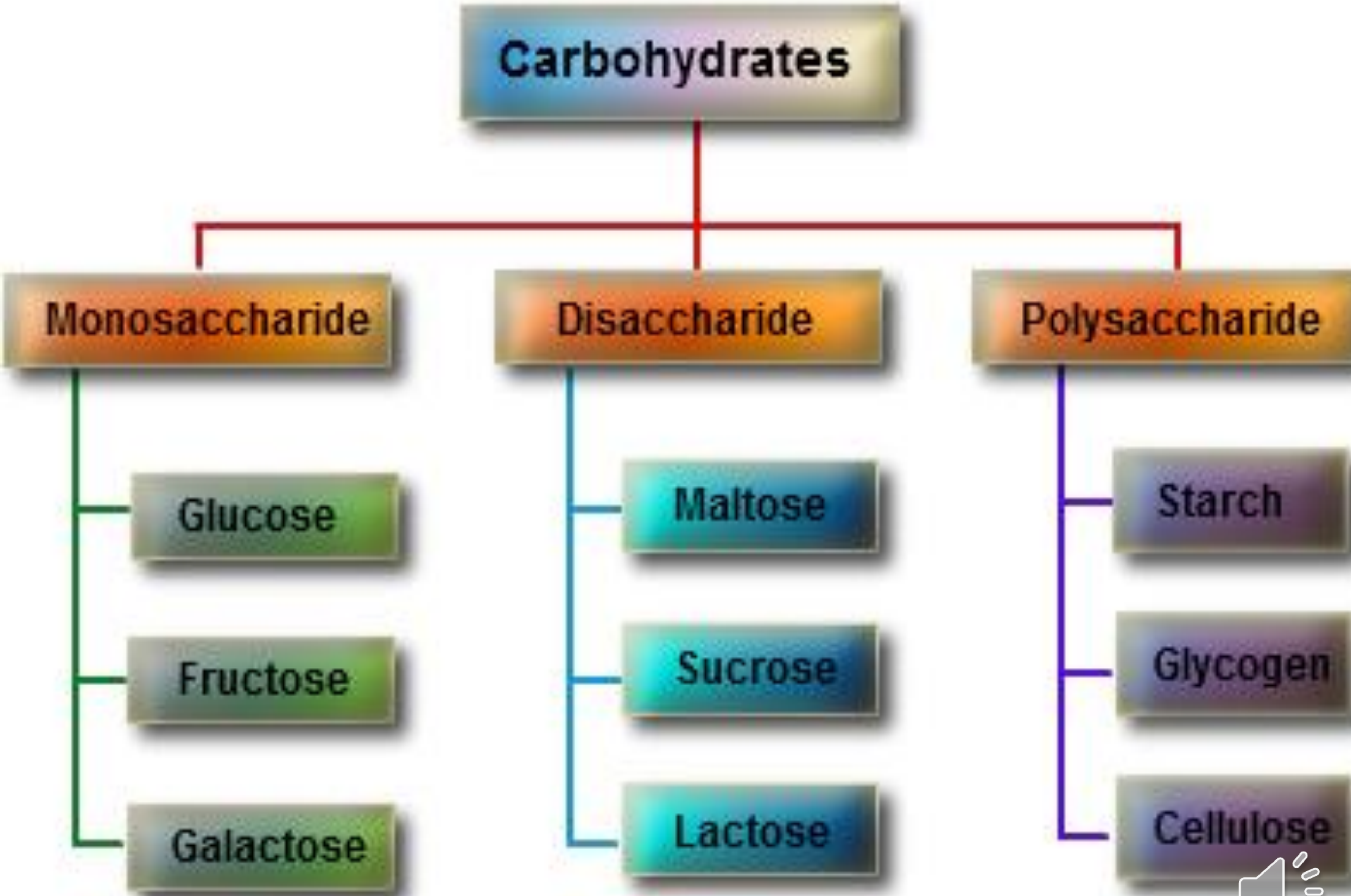
"hydrate of carbon"

Carbohydrates are also called "Saccharide", some carbohydrates also contain nitrogen & Sulphur, in plants CHO is present in the form of cellulose & starch which are synthesized by the process of PHOTO SYNTHESIS.

In animals tissue they have a great role and are present in the form of glucose & glycogen. Glycogen is the storage form of carbohydrates in animals.

Classification of Carbohydrates

- Simple carbohydrates
  - Monosaccharide
  - Disaccharide
  - Perceived as sweeter than complex carbohydrates
    - Mixes with saliva and reacts with taste buds
- Oligosaccharides
- Complex carbohydrates
  - Polysaccharides


Carbohydrates
Monosaccharide
Disaccharide
Polysaccharide
Glucose
Fructose
Galactose
Maltose
Sucrose
Lactose
Starch
Glycogen
Cellulose

Carbohydrates

Carbohydrates are classified as biomolecules.

Carbohydrates (sugars) - **abundant dietary source of energy**

Glucose is the primary carbohydrate, our bodies use to produce energy.

Four Major Types of Biological Macromolecules

Type of Polymer	Monomers making up Polymer	Example
I. Carbohydrates (Polysaccharides)	Monosaccharides	Sugars, Starch, Cellulose
II. Lipids	Fatty acids and glycerol	Fats, steroids, cholesterol
III. Proteins	Amino acids	Enzymes, structural components
IV. Nucleic Acids	Nucleotides	DNA, RNA

Biomedical importance

- Precursor for many organic compounds(fats , cholesterols amino acids)

- Constituents of compound lipids and conjugated proteins

- Carbohydrates as glycoprotein & glycolipids, participate in structure of cell membrane & cellular functions(cell growth, adhesions, fertilization)

Biomedical importance

- **Cell surface recognition receptors**

  act as "road signs" allowing molecules to distinguish one cell from another.

- ***ABO blood markers*** (RBC)

  allow us to distinguish our body's blood type from a foreign blood type

- **Prevent blood clotting**

Biomedical importance

Certain carbohydrate derivatives are used as drugs like cardiac glycosides/antibiotics

Lactose principal sugar of milk—in lactating mammary gland

Constituents of mucopolysaccharides which form the ground substance of mesenchymal tissues.

Biomedical importance

- Found in our genetic material.

- Human gastric glycoprotein (mucin) contains more than 60% carbohydrate.

- A structural component of many organisms:
  - a) cell walls of bacteria
  - b) exoskeleton of insects
  - c) cellulose of plants

Biomedical importance

- Inherited deficiency of certain enzymes in metabolic pathways of different carbohydrates can cause diseases, e.g. galactosemia, glycogen storage diseases (GSDs),lactose intolerance, etc.

- Derangement of glucose metabolism is seen in diabetes mellitus.

General properties of CHO

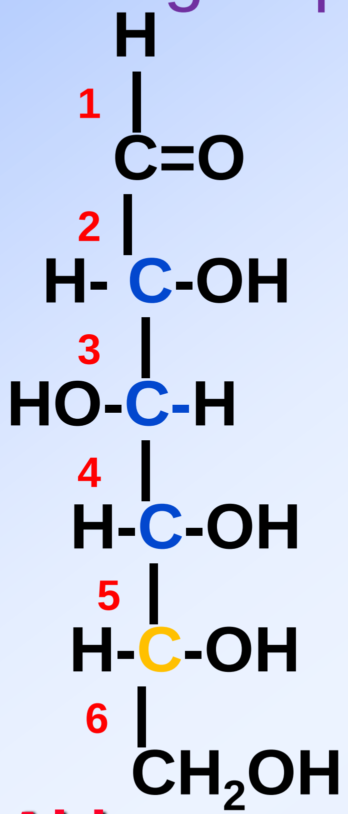
ASYMMETRIC CARBON:

A carbon atom to which four different atoms or groups of atoms are attached is said to be asymmetric.

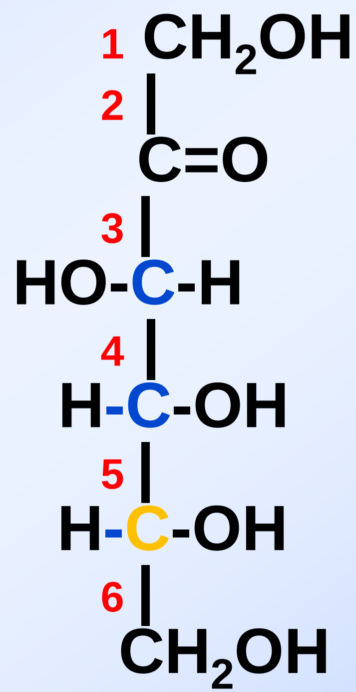
```
       CHO
        |
H----  C ---- OH
        |
        R
```

Penultimate carbon

Last asymmetric C or C farthest from the aldehyde or keto group or C adjacent to the terminal primary alcohol groups



Aldose
aldehyde H-C=O



Ketose
ketone C=O

ISOMERS:

The compounds having the same molecular(chemical) formula but different structural formulae are called isomers & the phenomenon is called "isomerism".

e.g. $C_6H_{12}O_6$ = fructose, glucose, mannose& galactose.

Types Of Isomers In Monosaccharides

Stereoisomerism.

Enantiomers (mirror images)

Diastereomers (non-mirror images)

Epimers

Anomers

Optical isomer

Pyranose –furanose isomerism

ISOMERS TYPES IN GLUCOSE

STERO-ISOMERS:

"The compounds having the same structural formula but different in spatial configuration (arrangement of atoms in three dimensional space) are called stero isomers." and the phenomenon is called stero-isomerism.

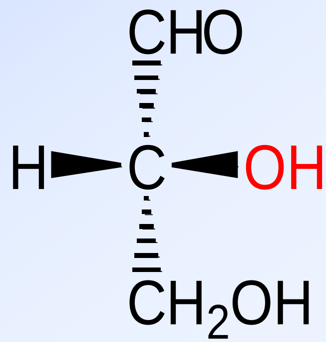
D and L ISOMERS:

When the OH group is on the carbon atom adjacent to terminal primary alcohol carbon is on the right side, the sugar is a member of "D" series and when the OH groups is on the left side of the carbon atom adjacent to the terminal primary carbon, the sugar is member of "L" series.

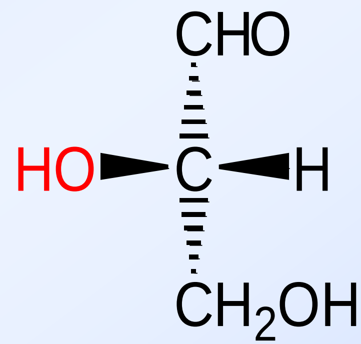
Stereoisomers- Enantiomers

Chirality rules 1

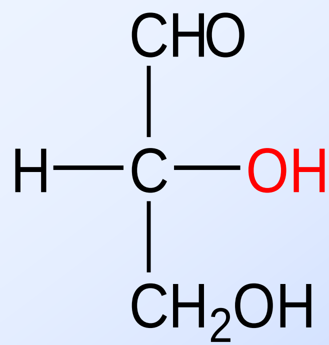
You must have at least one asymmetric carbon to have stereoisomers.



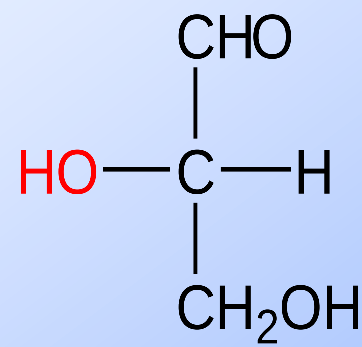
D-glyceraldehyde



L-glyceraldehyde



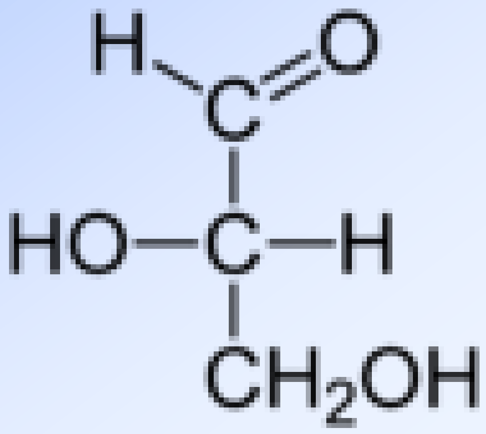
D-glyceraldehyde



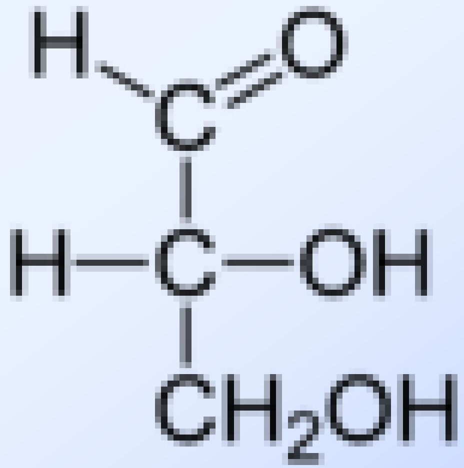
L-glyceraldehyde

IMAGES OF D & L- GLECERALDEHYDE (REFERENCE SUGAR)

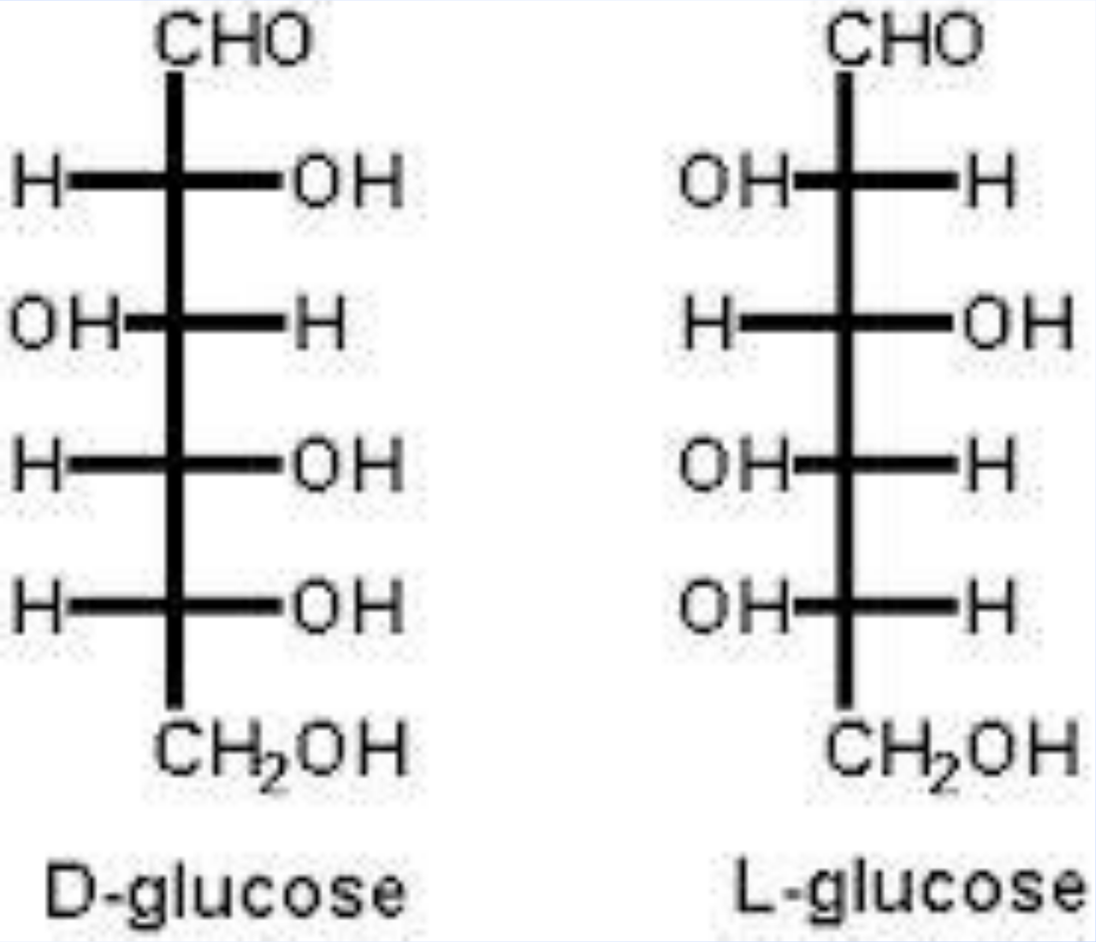
L- Glyceraldehyde



D- Glyceraldehyde



IMAGES OF D & L GLUCOSE

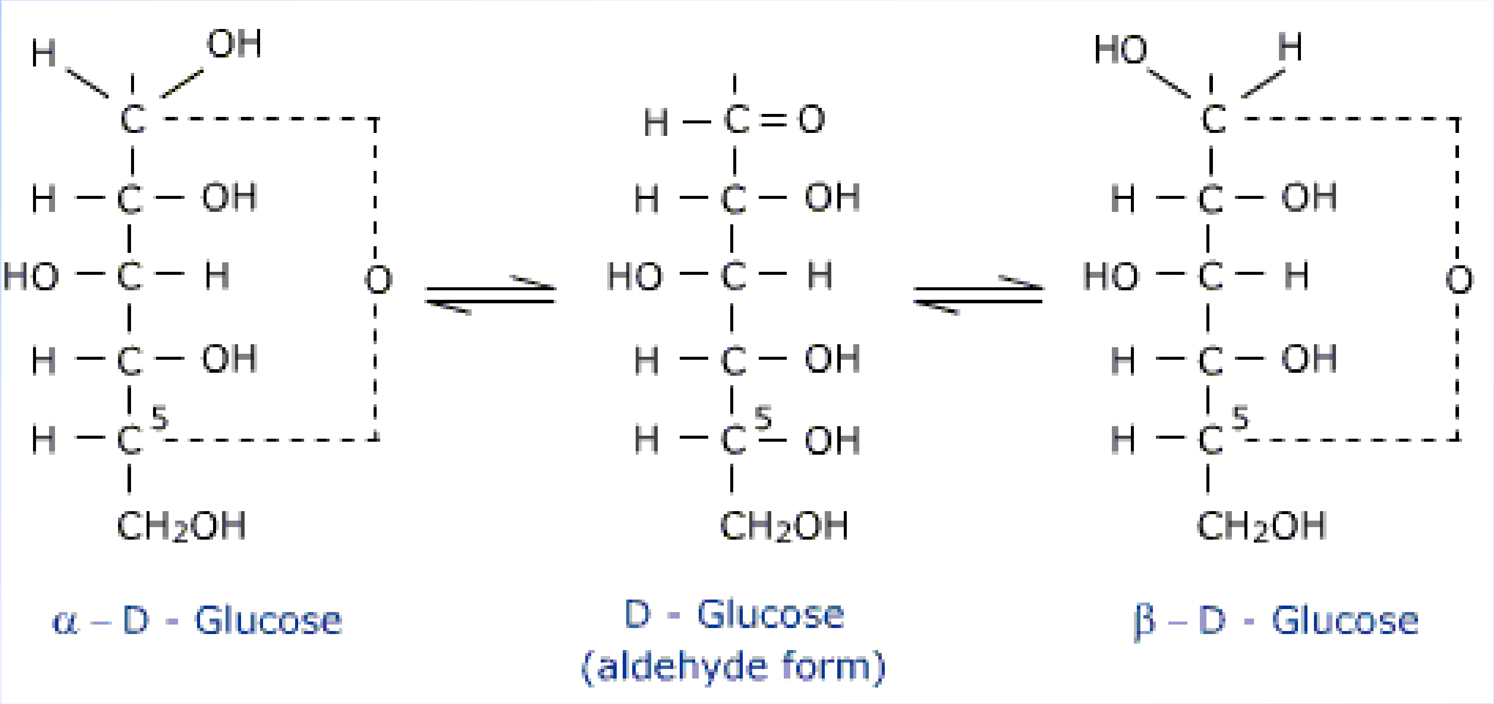


Vant Hoff`s Law

Asymmetric carbon atom is responsible for the isomers. The number of asymmetric carbon atoms denoted by “n” and is equal to 2^n , e.g. Glucose has 4 asymmetric carbon atoms so it has 2^4=16 isomers. But in glucose the carbon number 1 (aldehyde group) is responsible for the “mutarotation“ which also gives another asymmetric carbon atom, so the number of isomers in glucose is 2^5=32 isomers.

MUTA ROTATION

It is a process ,in a freshly prepared solution of glucose , in which the direction of angle of plane polarized light goes on changing for sometime till it becomes fixed .The reason for this is the formation of ring structure from the straight chain form. All these forms have different angles of rotations. The angle of rotation becomes fixed when they reach an equilibrium.


α – D - Glucose
D - Glucose
(aldehyde form)
β – D - Glucose

OPTICAL ISOMERISM

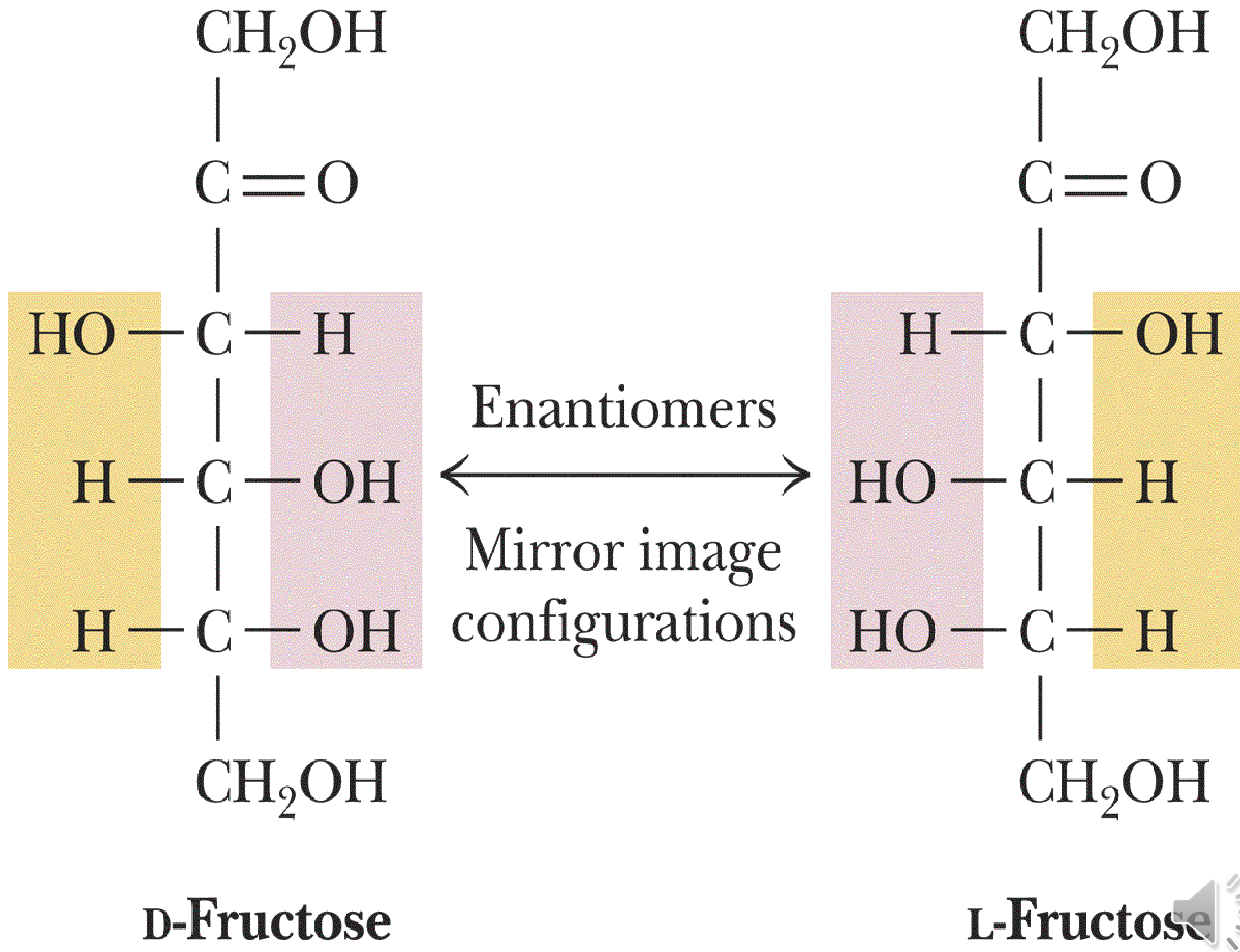
The ability of a compound to rotate plane polarized light either of the right (dextro) or left (levo) is called optical activity of a compound.

The presence of asymmetric carbon atoms also confers optical activity on the compound. When a beam of plane polarizes light is passed through a solution of an optical isomers it will be rotated either to the right (dextro) or the left (levo). A compound may be designated D (-), D(+), L(-) or L(+).

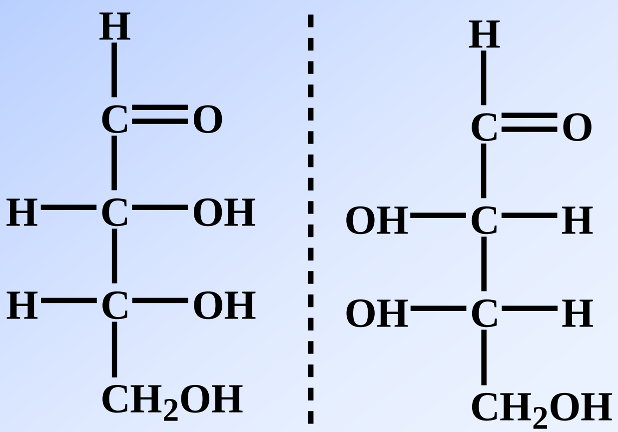
* When equal amount of dextro &levo isomers are present the resulting mixture has no optical activity, since the activity of each isomer cancel
one another, such a mixture is said to be "Racemic Mixture"or" Externally compensated solution". * Compounds called "Mesocompounds"have molecules which has two halves one rotating
the light towards right & other half rotating it towards left leading to no net rotation of light.

Enantiomers

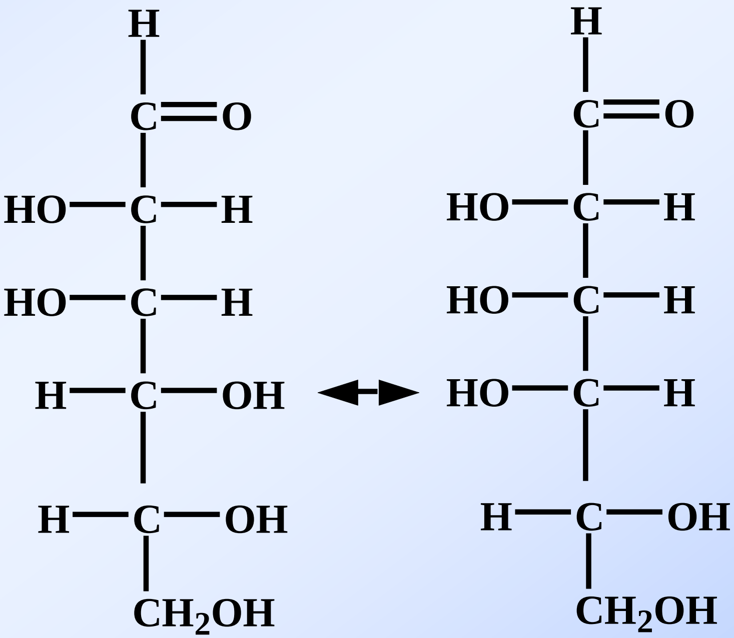
D and L isomers (sugars) are the mirror images of one another and the degree of optical rotation in each compound is exactly the same but in opposite direction. E.g. D- glucose (+) 52.7 &L- glucose (-) 52.7. &D- Glyceraldehyde (+) 140 & L-Glyceraldehyde (-) 140.All their physical & chemical properties are the same.


CH2OH
C=O
HO—C—H
H—C—OH
H—C—OH
CH2OH
Enantiomers
Mirror image configurations
CH2OH
C=O
H—C—OH
HO—C—H
HO—C—H
CH2OH
D-Fructose
L-Fructose

Enantiomers and epimers



these two aldotetroses are enantiomers. They are stereoisomers that are mirror images of each other



these two aldohexoses are C-4 epimers. they differ only in the position of the hydroxyl group on one asymmetric carbo (carbon 4)

diastereomers

Stereoisomers that are not enantiomers are called ***diastereomers***.

Diastereomers are stereoisomers that are not exact mirror images.

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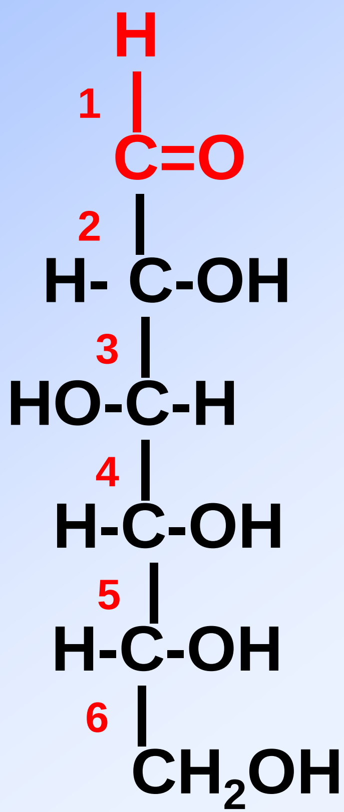
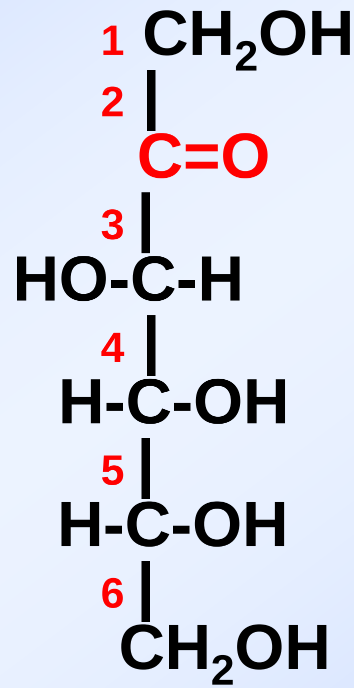
Anomeric carbon atom

carbon atom of the carbonyl group



Aldose

aldehyde H-C=O



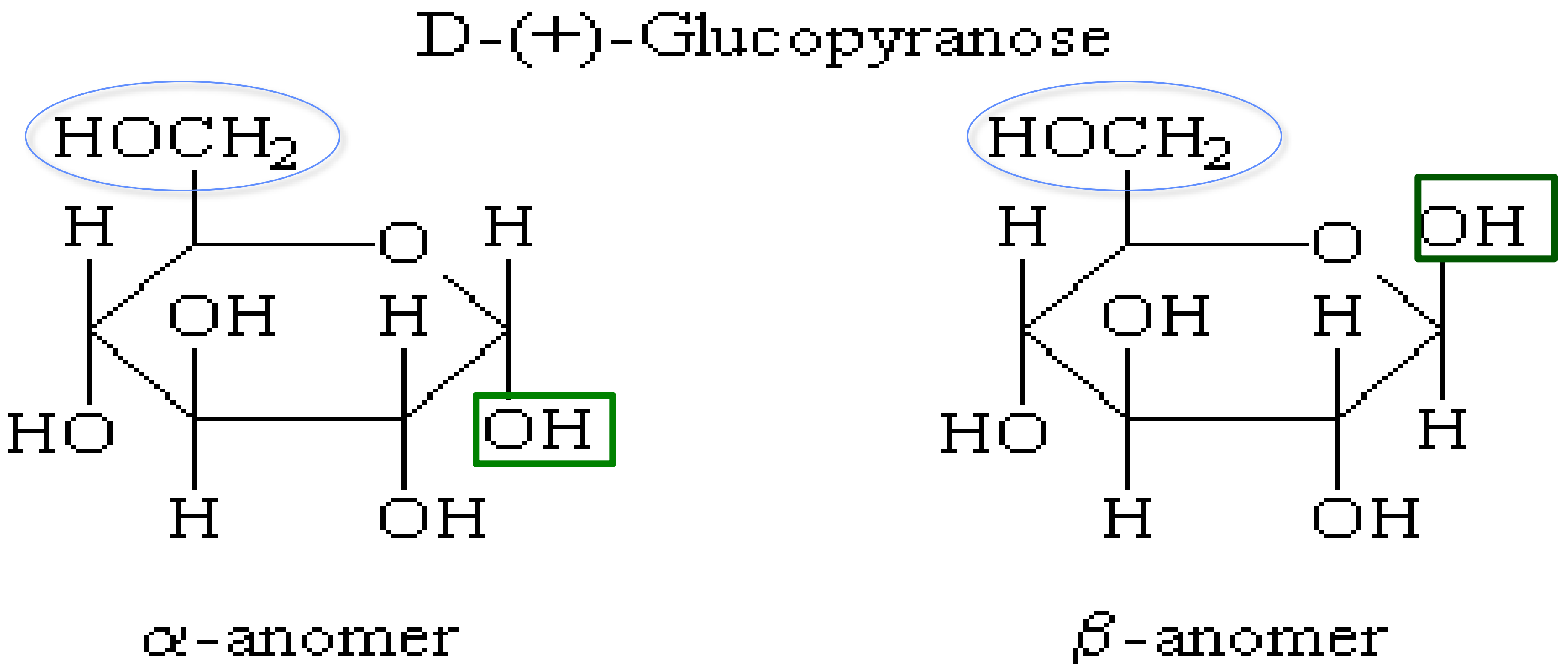
Ketose

ketone C=O

carbon 1 in aldoses and carbon 2 in ketoses

Intramolecular cyclization

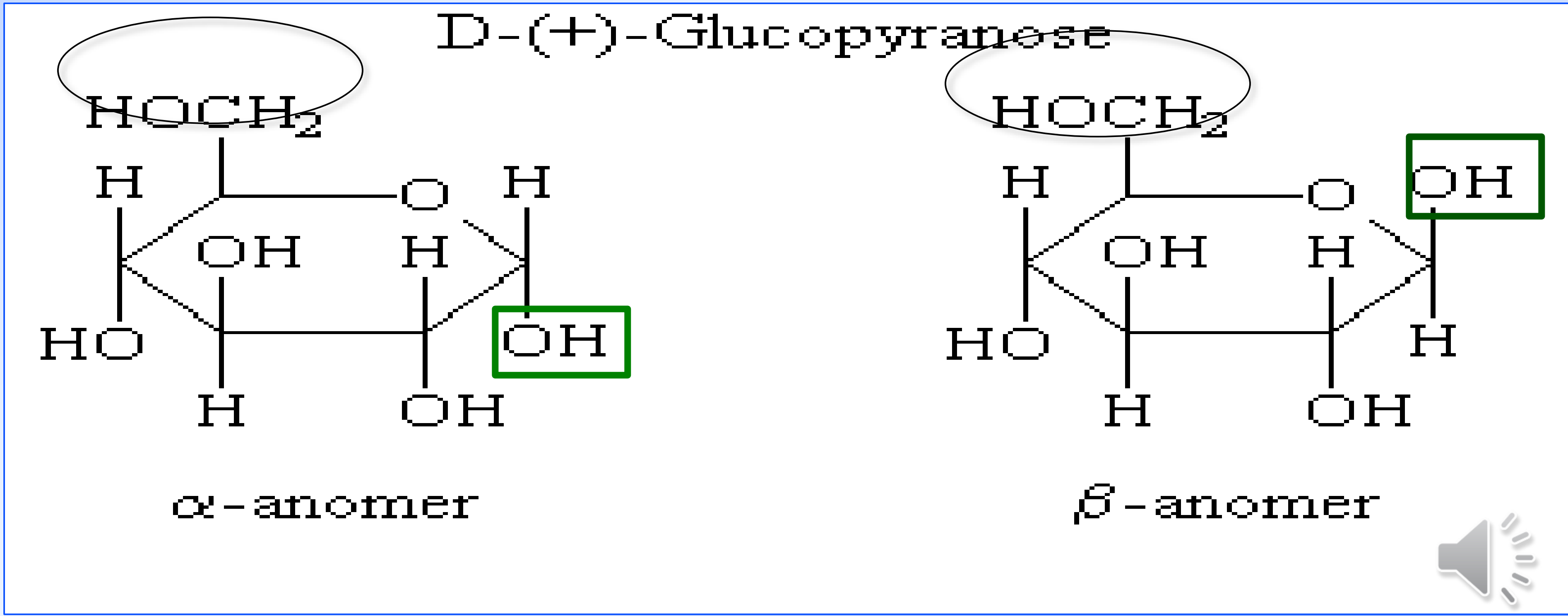
The -OH group that forms can be above or below the ring resulting in two forms - **anomers**



Intramolecular cyclization

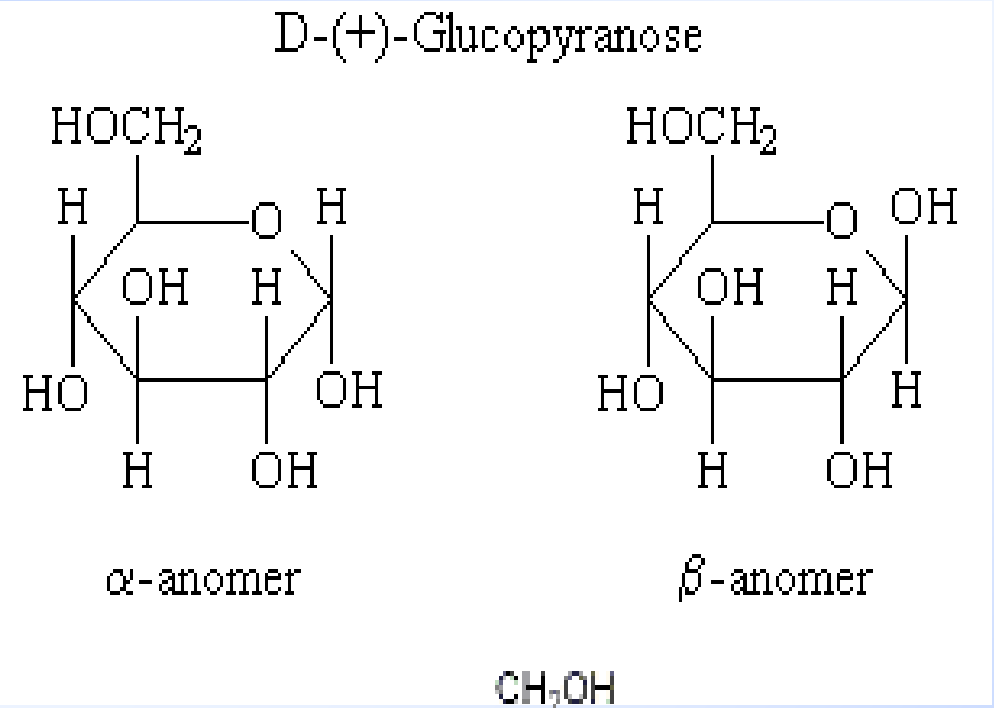
α and β are used to identify the two forms.

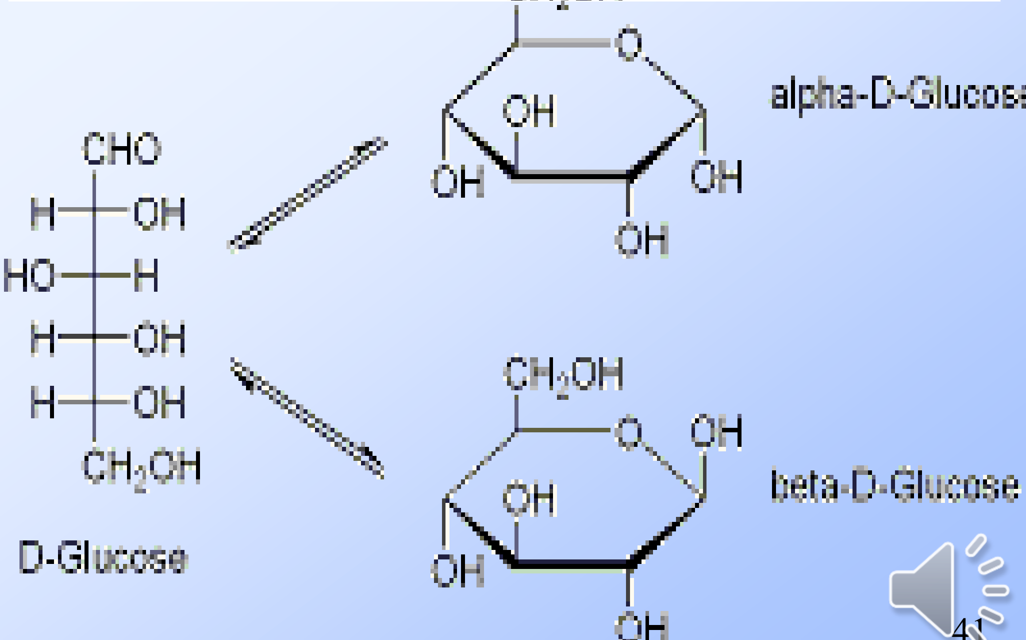
- α - OH group is down compared to CH_2OH (trans).
- β - OH group is up compared to CH_2OH (cis).



α Anomers

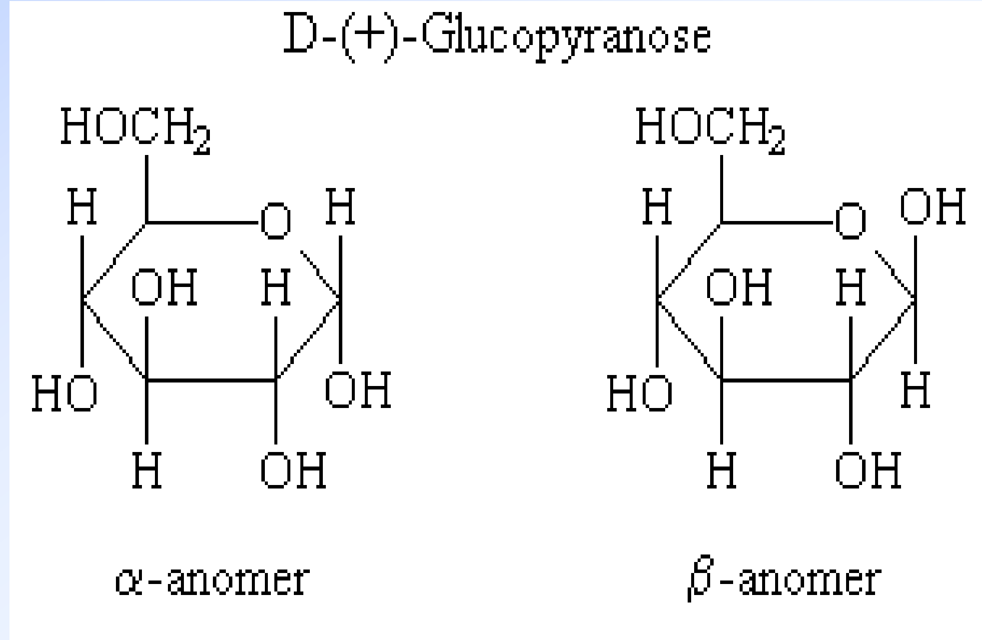
the – OH group attached to the anomeric carbon is on the opposite side of group –CH2OH of sugar attached

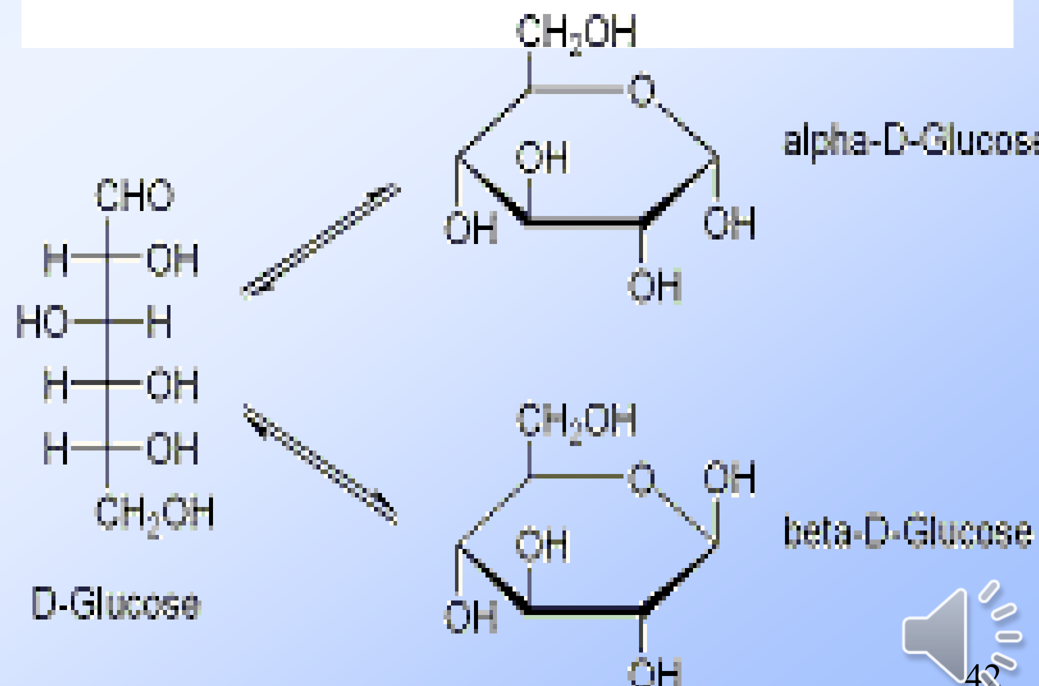




β Anomers

the – OH group attached to the anomeric carbon is on the same side of group –CH2OH of sugar attached





EPIMERS:

If two sugars differ in configuration around one specific carbon atom, these are called epimers. E.g. Epimers of glucose are mannose & galctose formed by epimerization at carbon no. 2 and 4 respectively.

Epimers

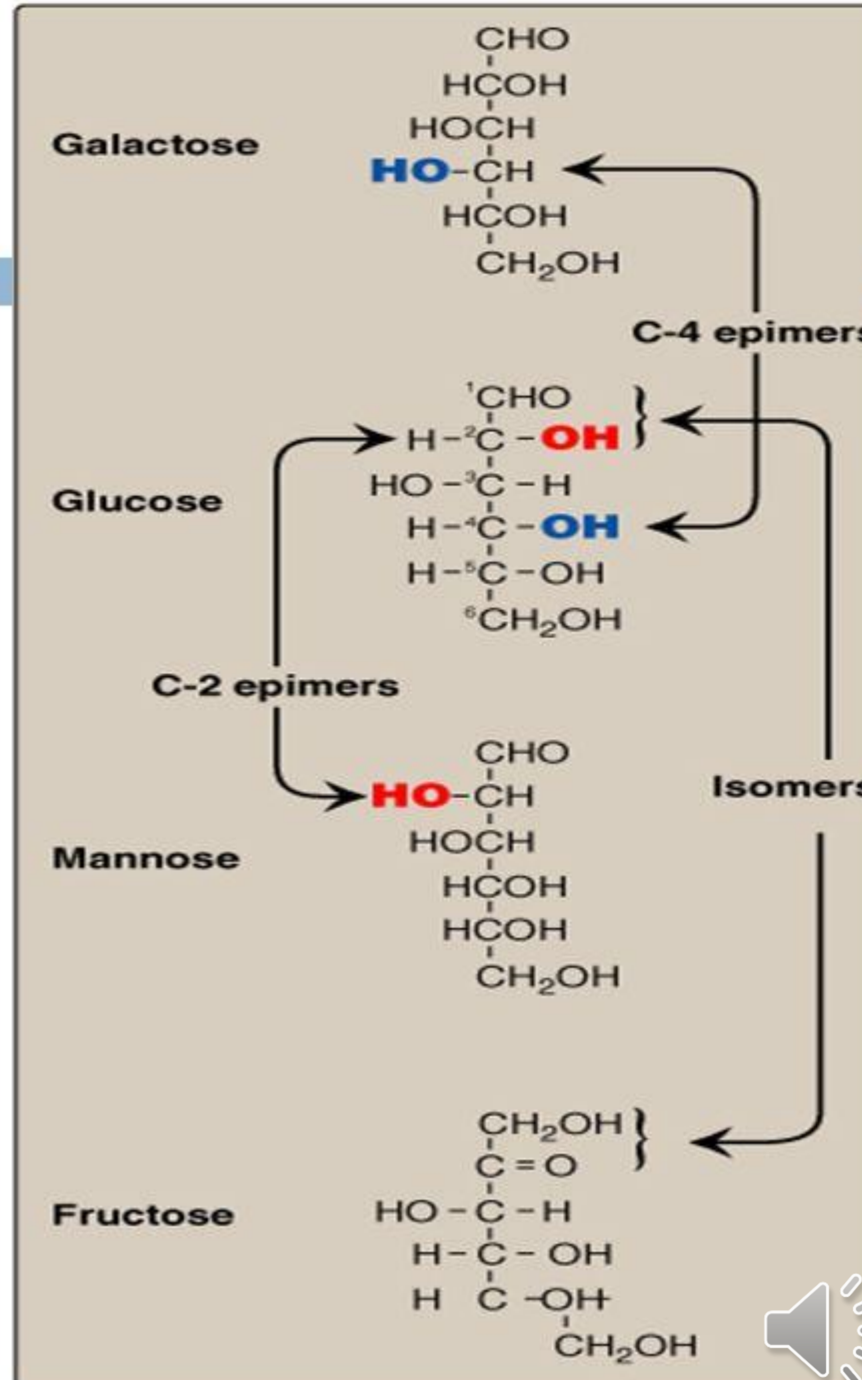
- Epimers

CHO dimers that differ in configuration around only one specific carbon atom

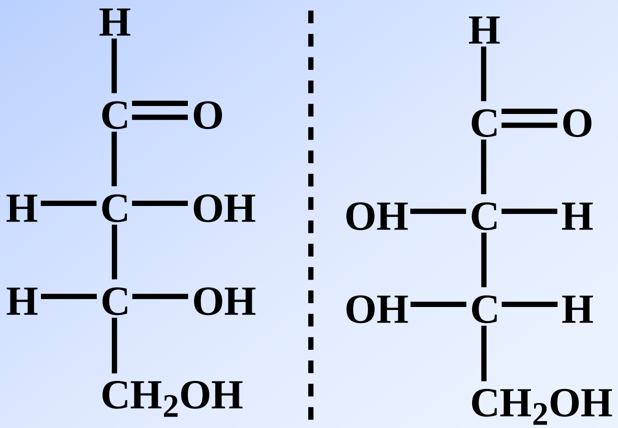
-Glucose and galactose, C4

-Glucose and Mannose, C2

Galactose and mannose are not epimers



Enantiomers and epimers



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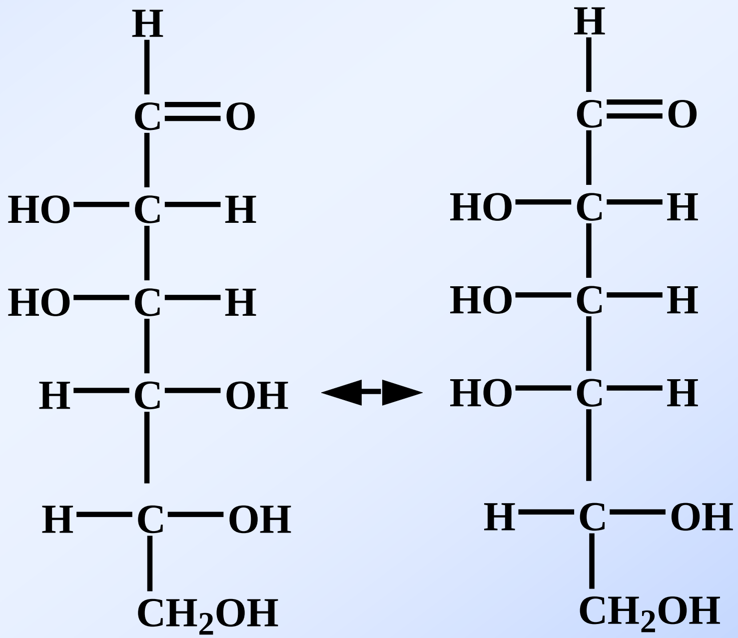


these two aldohexoses are C-4 epimers. they differ only in the position of the hydroxyl group on one asymmetric carbo (carbon 4)

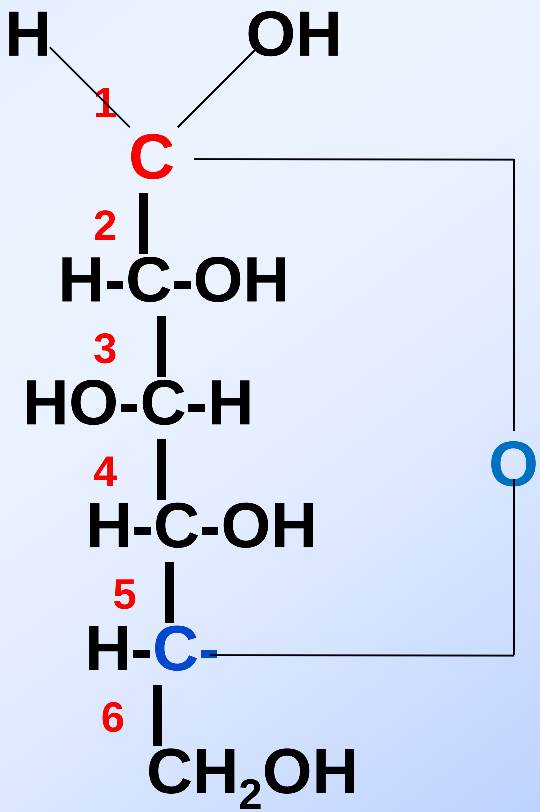
Ring Formation

Cyclization

via intramolecular hemiacetal(hemiketal) formation

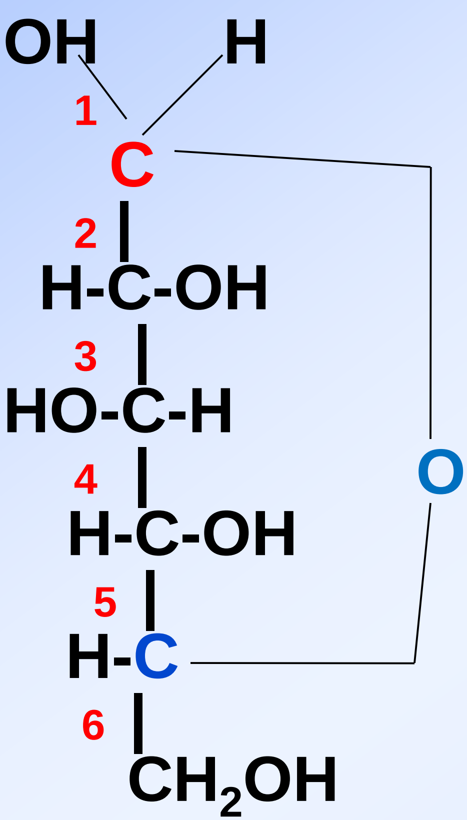
hemiacetal - forms from alcohol and aldehyde

hemiketal - forms from alcohol and ketone

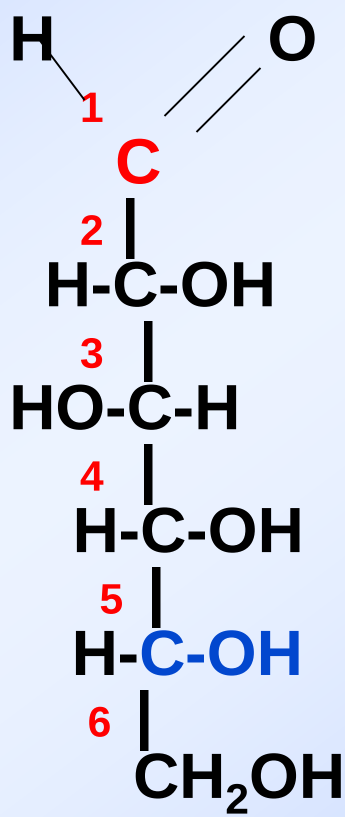


α D GLUCOSE

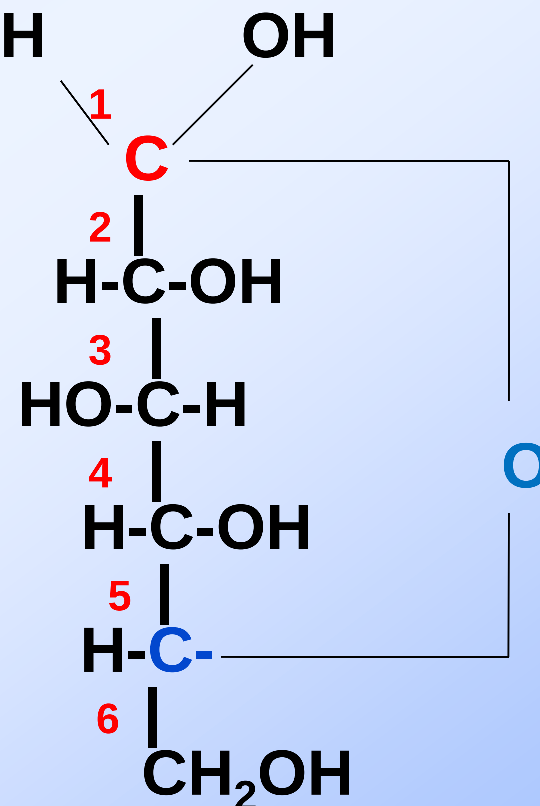
Ring Formation- Intramolecular cyclization



β D GLUCOSE



D GLUCOSE



α D GLUCOSE

LECTURE 2

DATE:18TH MARCH 2021

Classes of carbohydrates

Classifications based on number of sugar units in total chain.

Monosaccharides	- single sugar unit
Disaccharides	- two sugar units
Oligosaccharides	- 3 to 10 sugar units
Polysaccharides	- more than 10 units

Chaining relies on 'bridging' of oxygen atom -- **glycoside bonds**

Monosaccharides

- Simplest carbohydrates
- Cannot be broken down to smaller carbohydrates.
- Contain the elements carbon, hydrogen, and oxygen
- General formula $c_n(h_2o)_n$, where *n* is a whole number 3 or greater.

MONOSACCHARIDES

Monosaccharide are grouped according to the number of carbon atoms present in a sugar molecule, such as trioses, tetroses, pentoses & hexoses. Each of these can be further names as aldoses or ketoses depending on the presence of an aldehyde or ketone group respectively.

List of important monosaccharide.

- Glucose
- Mannose
- Galactose
- Fructose

Monosaccharides

Classification According to the number of base carbon atoms.

Most common monosaccharides have three to six carbon atoms.

Triose contains three carbons.

Tetrose contains four carbons.

Pentose contains five carbons.

Hexose contains six carbons.

Monosaccharides

Aldehydes

- an organic compound containing the carbonyl group

- **Aldehydes** always contain:

✓ a carbonyl group with a hydrogen atom

✓ bonded to one side and an alkyl or aromatic bonded to the other.

Monosaccharides

Classification According to the Functional Group

Monosaccharides containing an aldehyde group -***aldose***.

Monosaccharides containing a ketone group -***ketose.***

Functional Group	Sugar Class	No of Carbons	Name of Sugar
Aldehyde	Aldose	3 (aldotriose)	Glycerose
		4 (aldotetrose)	**Erythrose**
		5 (aldopentose)	**Ribose**
		6 (aldohexose)	**Glucose**
			Galactose
			Mannose
Ketone	Ketose	3 (ketotriose)	Dihydroxyacetone
		4 (ketotetrose)	**Erythrulose**
		5 ketopentose)	**Xylulose**
		6 (ketohexose)	**Fructose**
		7 Ketopeptose	**Sedoheptulose**

Monosaccharides

Monosaccharides can contain

- an aldehyde group **(H-C=O)** on one end of the molecule
- in addition to multiple hydroxyl groups.

functional groups of glucose

Monosaccharides

Ketones

- contains the carbonyl group

- but has an alkyl or aromatic group on both sides of the carbonyl group.

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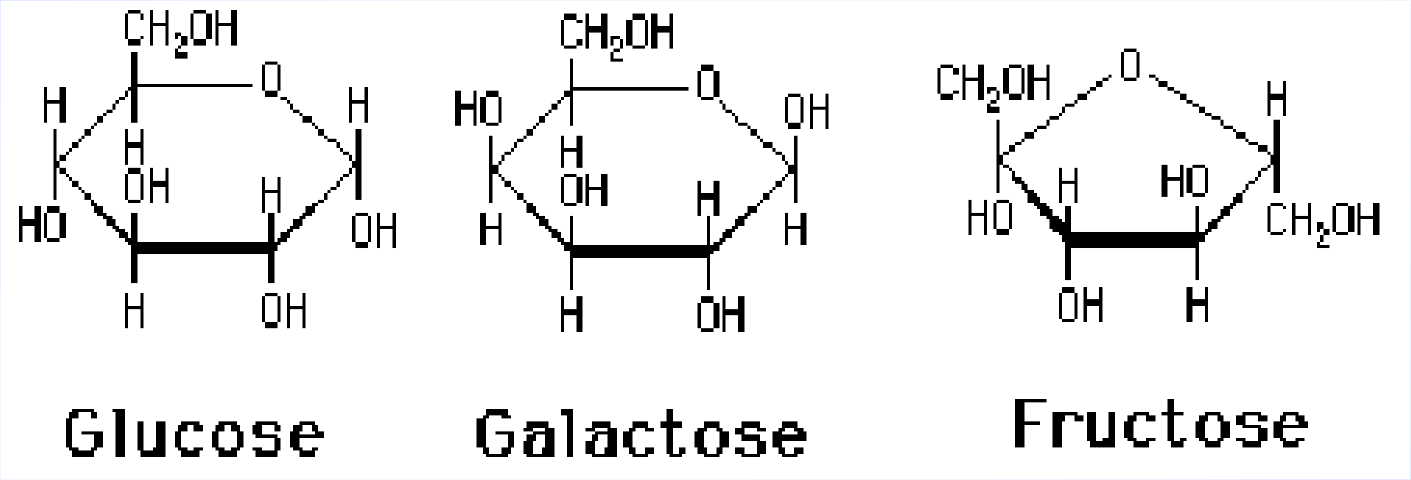

Glucose
Galactose
Fructose

GLYCERALDEHYDE

It is the smallest sugar

It has got three carbons -Triose sugar

Aldose sugar

Its carbon 2 is asymmetric carbon

All monosaccharides having more than 3 carbons will have two or more asymmetric carbon atoms.

For D and L designation all monosaccharides are compared with glyceraldehyde.

Thus it is called a **reference sugar.**

H
|
C=O
|
H-C-OH
|
CH_2OH

aldotriose

D-glyceraldehyde

Glucose

An aldohexose sugar

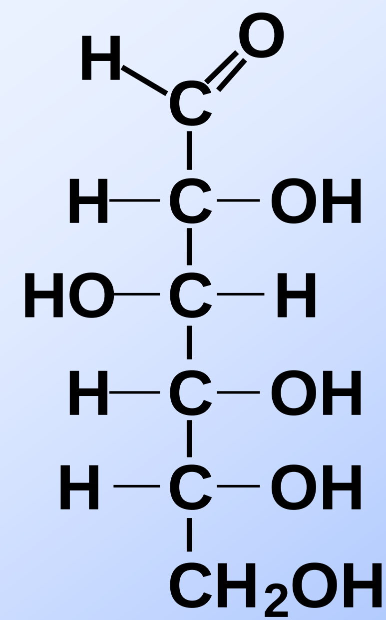
Glucose is the most abundant monosaccharide found in nature.

Glucose is also known as dextrose, blood sugar, and grape sugar.

The cell uses it as a source of energy and metabolic intermediate.

Glucose is produced in the process of photosynthesis, and is used in both prokaryotes and eukaryotes.

D-glucose



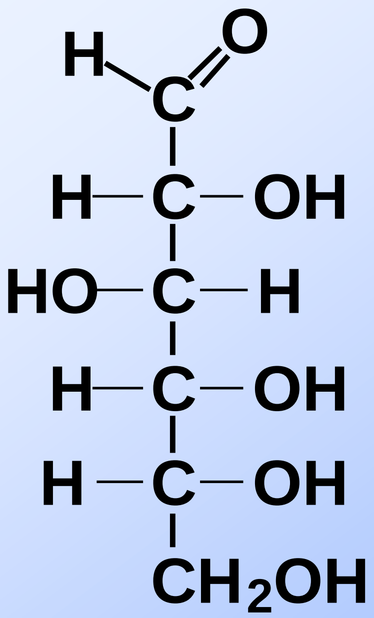
Glucose

Fasting blood glucose level is 80-110 mg/100 m Ml

. Diabetics have difficulty getting glucose in their cells, which is why they must monitor their blood glucose levels regularly.

Glucose is one of the monosaccharides of sucrose (table sugar) and lactose (milk sugar) as well as the polysaccharides glycogen, starch, and cellulose.

D-glucose



Fructose (Levulose); Fruit sugar

ketohexose

is the sweetest monosaccharide ,**estimated to be twice as sweet as sucrose**

is found in fruits, vegetables, and honey.

Fructose is not an epimer of glucose, but it can be broken down for energy in the body.

Fructose is combined with glucose to give sucrose, or table sugar.

is produced from the digestion of sucrose

CH_2OH
C=O
HO-C-H
H-C-OH
H-C-OH
CH_2OH

D-fructose

Galactose

is found combined with glucose in the disaccharide lactose, which is present in milk and other dairy products.

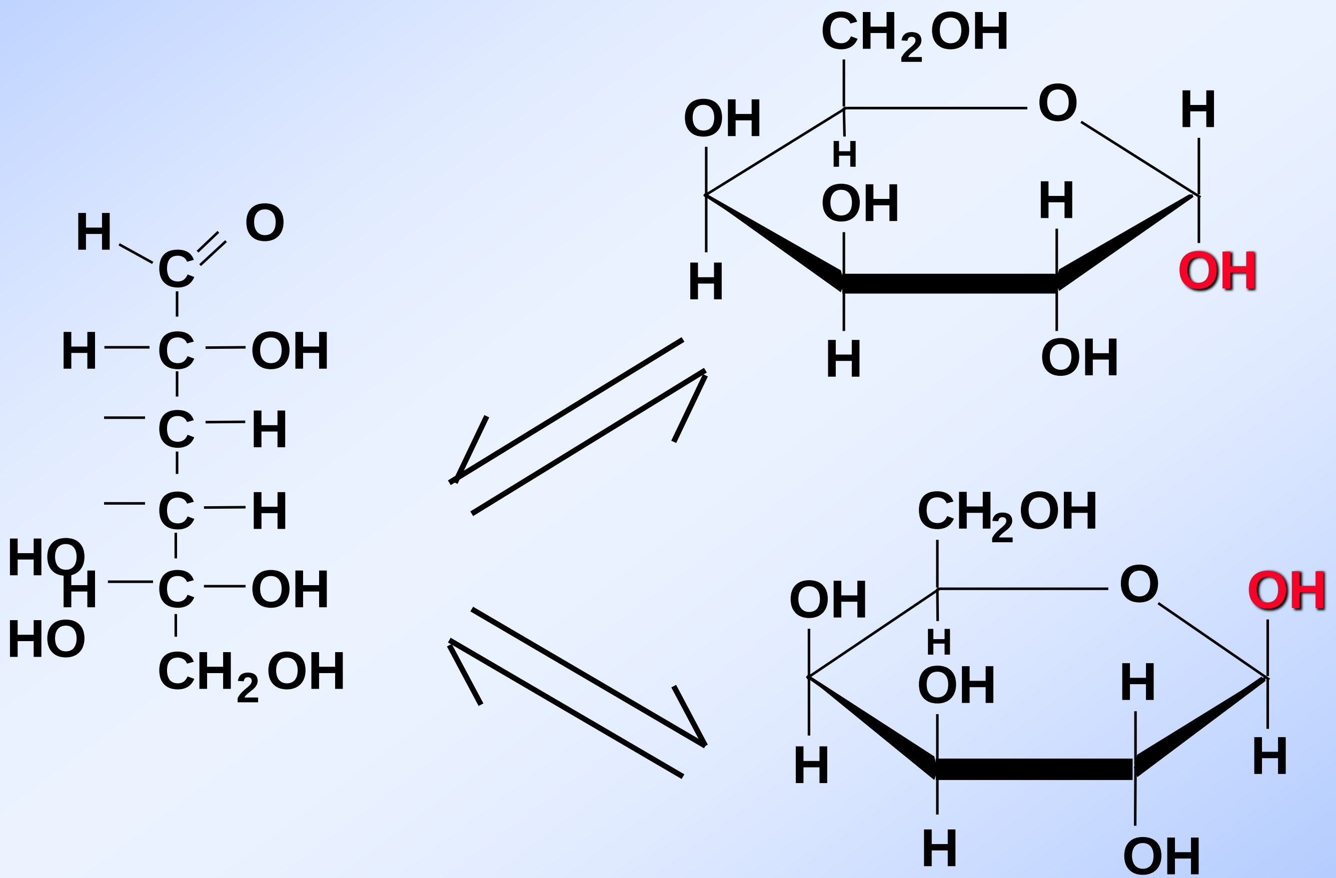
A single chiral center (carbon 4) in galactose is arranged opposite that of glucose, which makes it a diastereomer of glucose.

Diastereomers that differ by one chiral center are called ***epimers***.

It forms part of glycolipids and glycoproteins in several tissues of the body

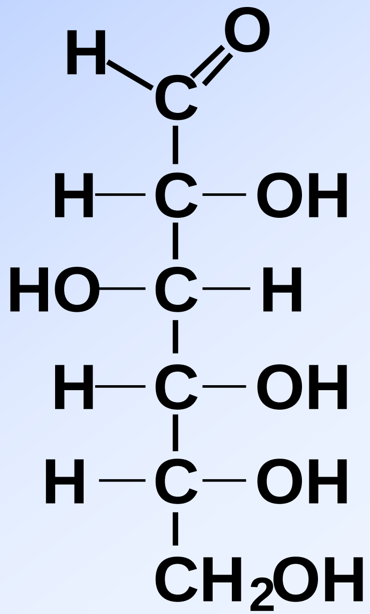
5.2 Monosaccharides, Continued

D-galactose

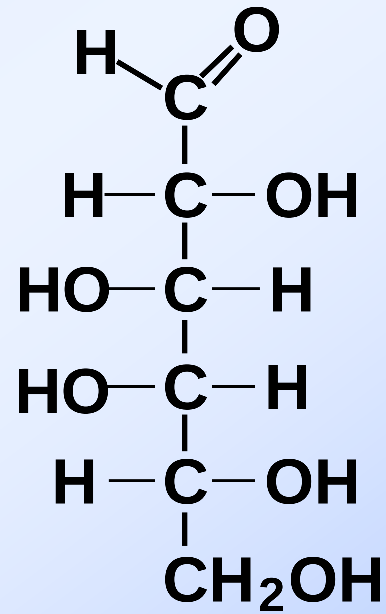


D-glucose vs. D-galactose

D-glucose



D-galactose



Can you find a difference? Your body can!

You can't digest galactose - it must be converted to glucose first.

Mannose

a monosaccharide, is found in some fruits and vegetables.

Cranberries contain high amounts of mannose, which has been shown to be effective in urinary tract infections.

Mannose is an epimer of glucose.

Pentoses

five-carbon sugars

Include ribose and 2-deoxyribose, which are parts of nucleic acids that make up genetic material.

Ribonucleic acid (RNA) contains ribose,

deoxyribonucleic acid (DNA)contains 2-deoxyribose.

The difference between these two pentoses is the absence of an oxygen atom on carbon 2 of deoxyribose.

Ribose is also found in the vitamin riboflavin and other biologically important molecules.

PROPERTIES OF MONOSACCHARIDES

1. Iodocompounds
2. Acetylating or ester formation
3. Osazone formation
4. Interconversion of sugars
5. Oxidation to produce sugar acids
6. Reduction of sugars to form sugar alcohols
7. Action of acids on carbohydrates
8. Action with alkalies
9. Reducing action of sugars in alkaline solution

IMPORTANT CHEMICAL PROPERTIES OF MONOSACCHARIDES

Monosaccharides

Functional Groups in Monosaccharides

Aldehydes

Ketones

Alcohols

1.
REACTIONS OF ALDEHYDE OR KETONE GROUPS

2.
REACTIONS OF ALCOHOLIC GROUPS

1. REACTIONS OF ALDEHYDE OR KETONE GROUPS

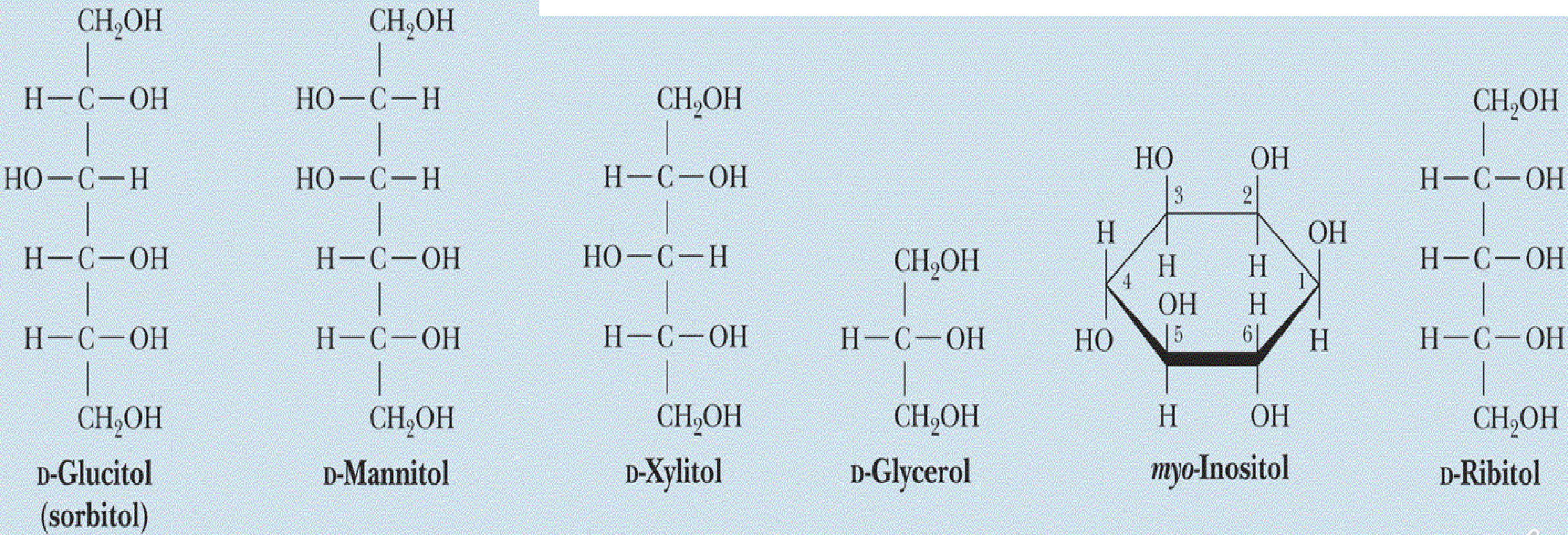
- **<u>Reduction to form sugar alcohols</u>:**

Both aldoses & ketones maybe reduced at their aldehyde & ketone groups to form the corresponding polyhydroxy alcohols. This may be accomplished with sodium amalgum or in the presence of catalyst.

D- glucose + H_2 → D - Sorbitol

D- manose + H_2 → D - Mannitol

Structures of some sugar alcoho



Oxidation to form sugar acids

When oxidized under proper conditions ,the aldoses give rise to 3 types of sugar acids with generic names aldonic ,uronic ,saccharic acids. The three forms of sugar acids derived from glucose are

Gluconic acid

Glucuronic acid

Glucaric acid

Oxidation and Reduction Reactions

Oxidation and Reduction Reactions

Redox reactions.

Oxidation

Reduction

Some biological reactions undergo oxidation and reduction.

Oxidation and Reduction Reactions

Oxidation - loss of electrons.

Organic molecules are oxidized

gain oxygen

lose hydrogen

Oxidation and Reduction Reactions

Reduction -- gain of electrons.

Organic molecules are reduced

lose oxygen

gain hydrogen

CHARACTERISTICS OF OXIDATION AND REDUCTION REACTIONS

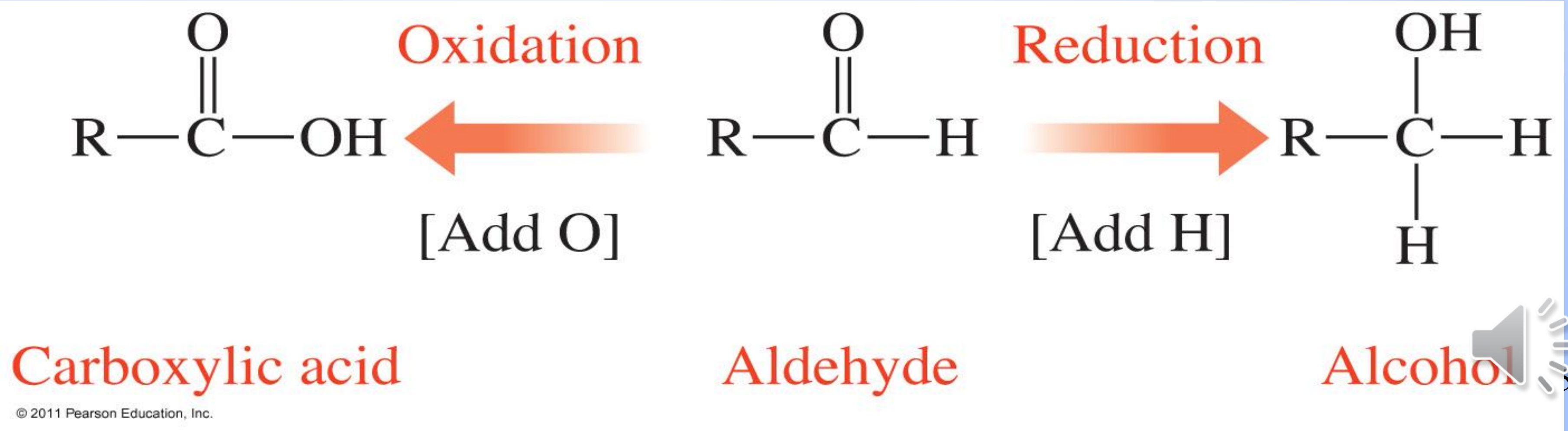
Oxidation	
Always Involves	**May Involve**
Loss of electrons	Addition of oxygen
	Loss of hydrogen

Reduction	
Always Involves	**May Involve**
Gain of electrons	Loss of oxygen
	Gain of hydrogen

Monosaccharides and Redox

An aldehyde functional group can undergo

✓oxidation by gaining oxygen.



Monosaccharides and Redox

An aldehyde functional group can undergo

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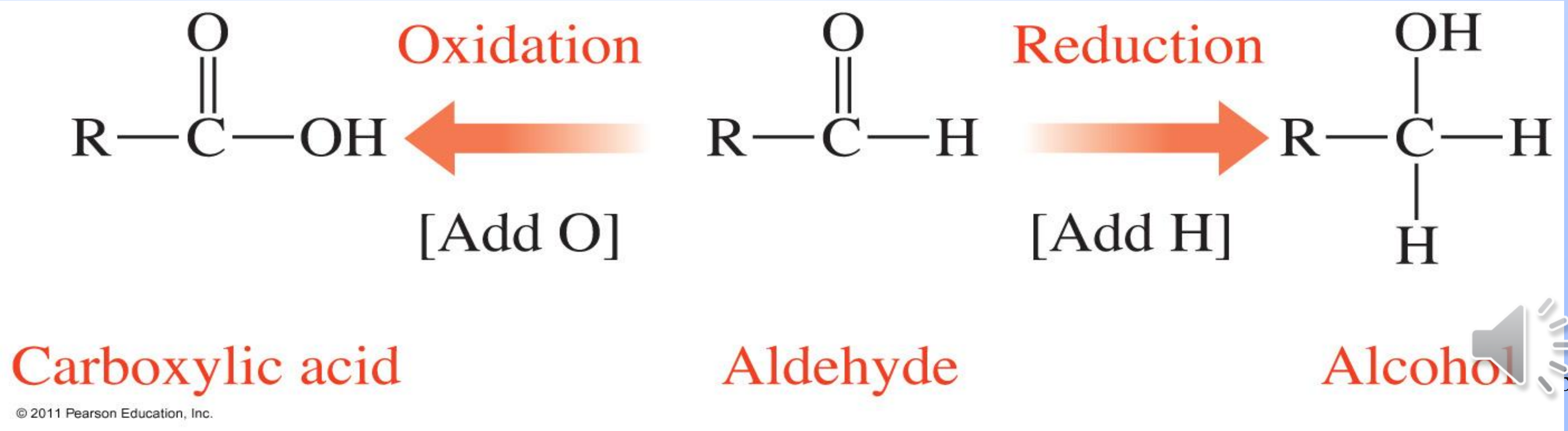


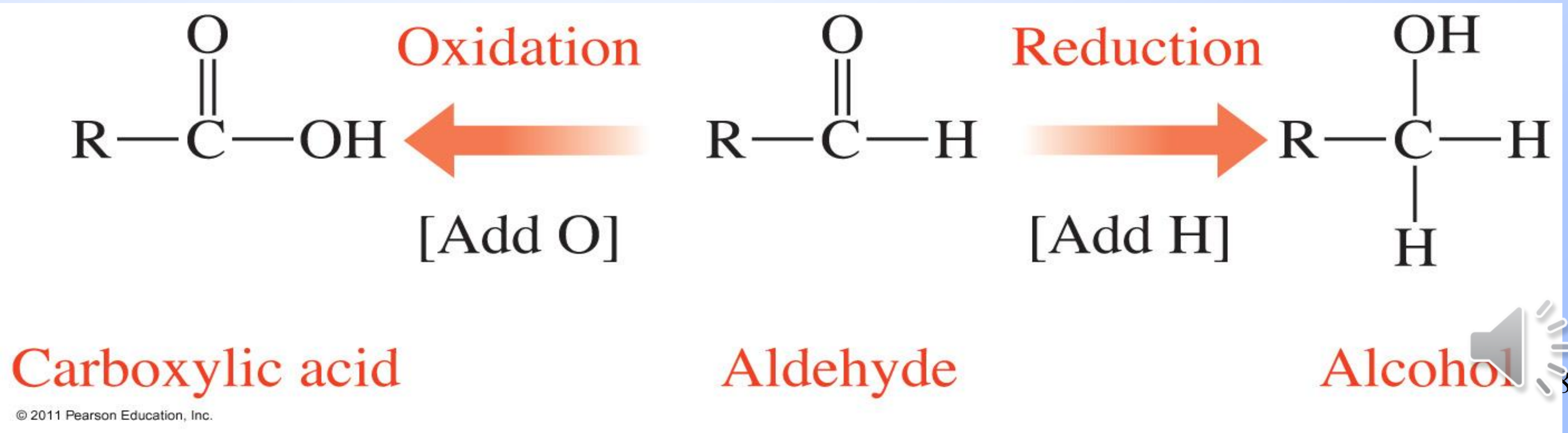
Oxidation Reactions

Monosaccharides and Redox

During oxidation

Aldehydes form carboxylic acids

Monosaccharides produces a sugar acid



Biomedical importance of D-Glucuronic acid- sugar acids

formed from Glucose in liver by uronic acid pathway

occurs as constituent of certain mucopolysaccharides

conjugates toxic substances, drugs, hormones and even bilirubin and converts them to a soluble nontoxic substance, a glucuronide, which is excreted in urine.

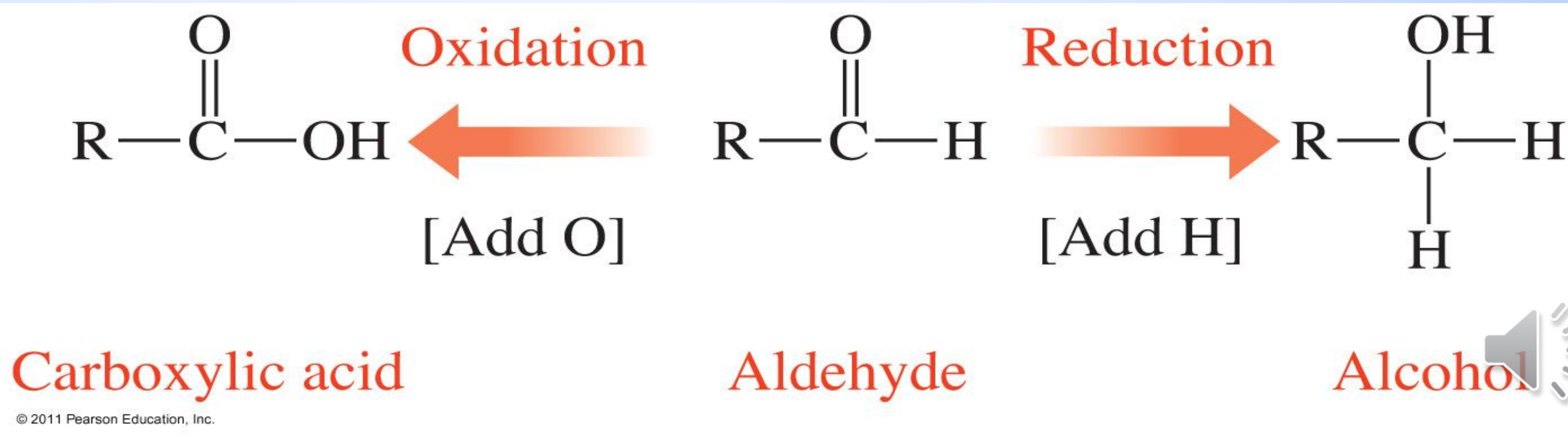
Reduction Reactions

Monosaccharides and Redox

During reduction

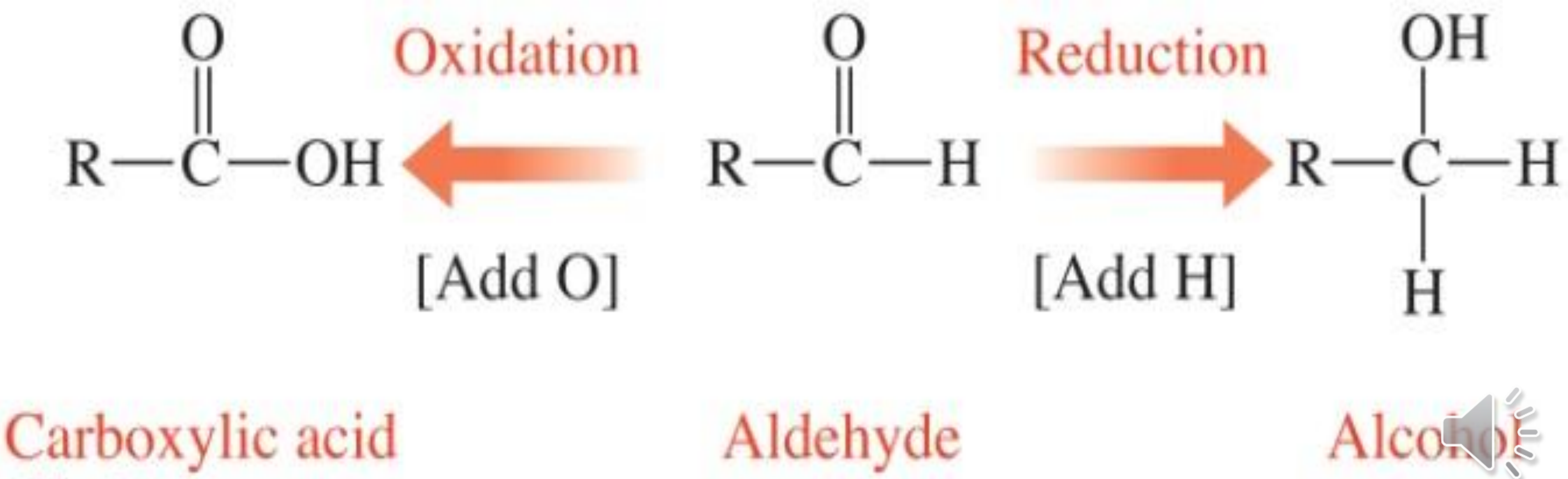
Aldehydes form alcohols.

Monosaccharides produces a sugar alcohol.



Reduction of sugars → sugar alcohols

Monosaccharides may be reduced to their corresponding alcohols by reducing agents such as Na-Amalgam.



Reduction of sugars → sugar alcohols

Glucose yields Sorbitol.

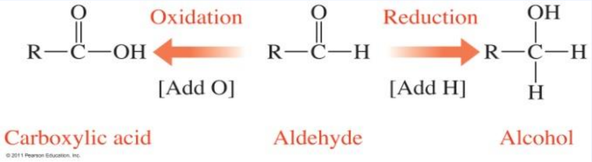
Galactose ------ Dulcitol.

Mannose---------Mannitol.

Fructose ---Mannitol and Sorbitol.

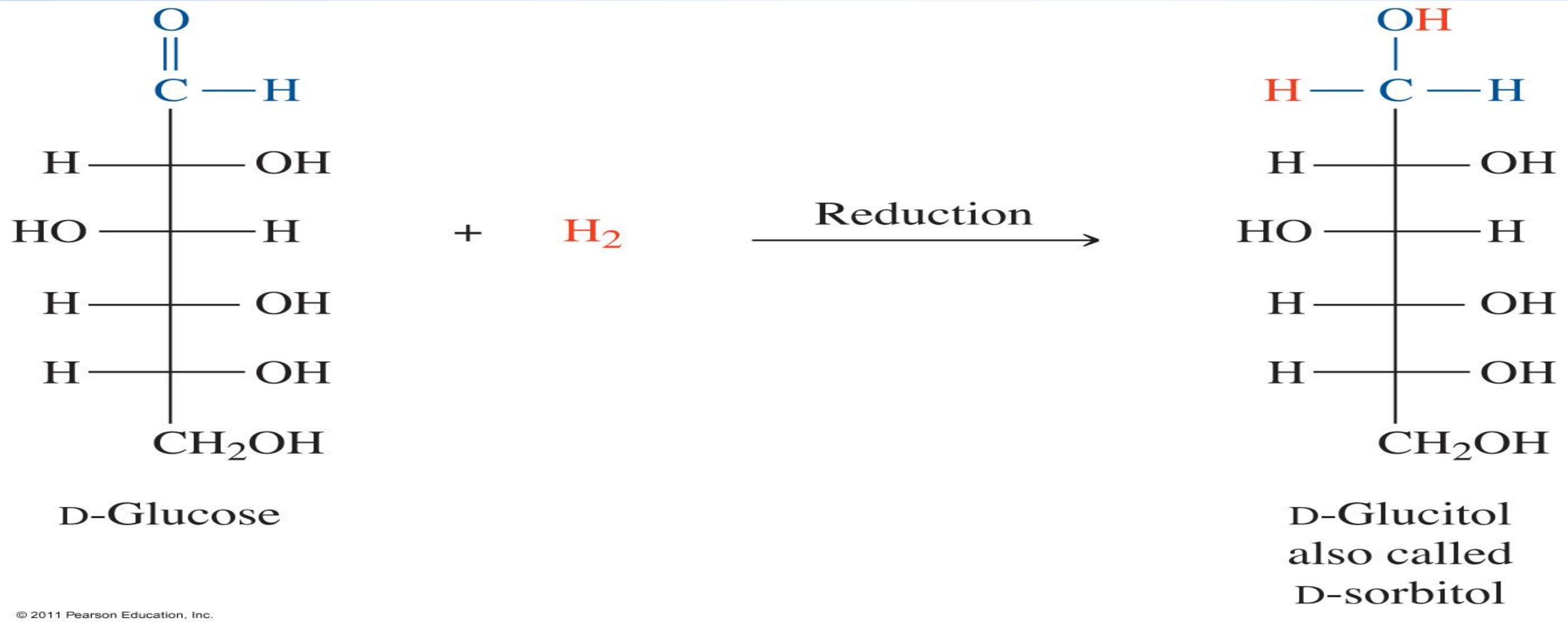
Ribose ----------Ribitol

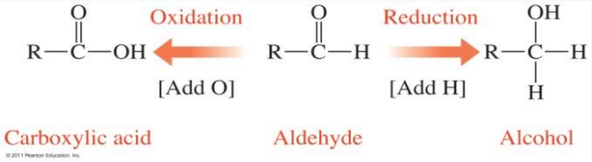
Glyceraldehydes—Glycerol



Reduction of sugars ⟶ sugar alcohols

Reduction of glucose produces the sugar alcohol, sorbitol(artificial sweetener)





Reduction of sugars → sugar alcohols

When glucose levels are high in the blood stream, sorbitol can be produced by an enzyme called ***aldose reductase***.

High levels of sorbitol can contribute to cataracts (clouding of the lens in the eye).

Cataracts are commonly seen in diabetics.

- **<u>Action of acids on carbohydrates.</u>**

Polysaccharides are hydrolysed into their constituents monosaccharide's by boiling with acids. While the monosaccharide are stable to these acids but when concentration of acid is increased the monosaccharide are decomposed.

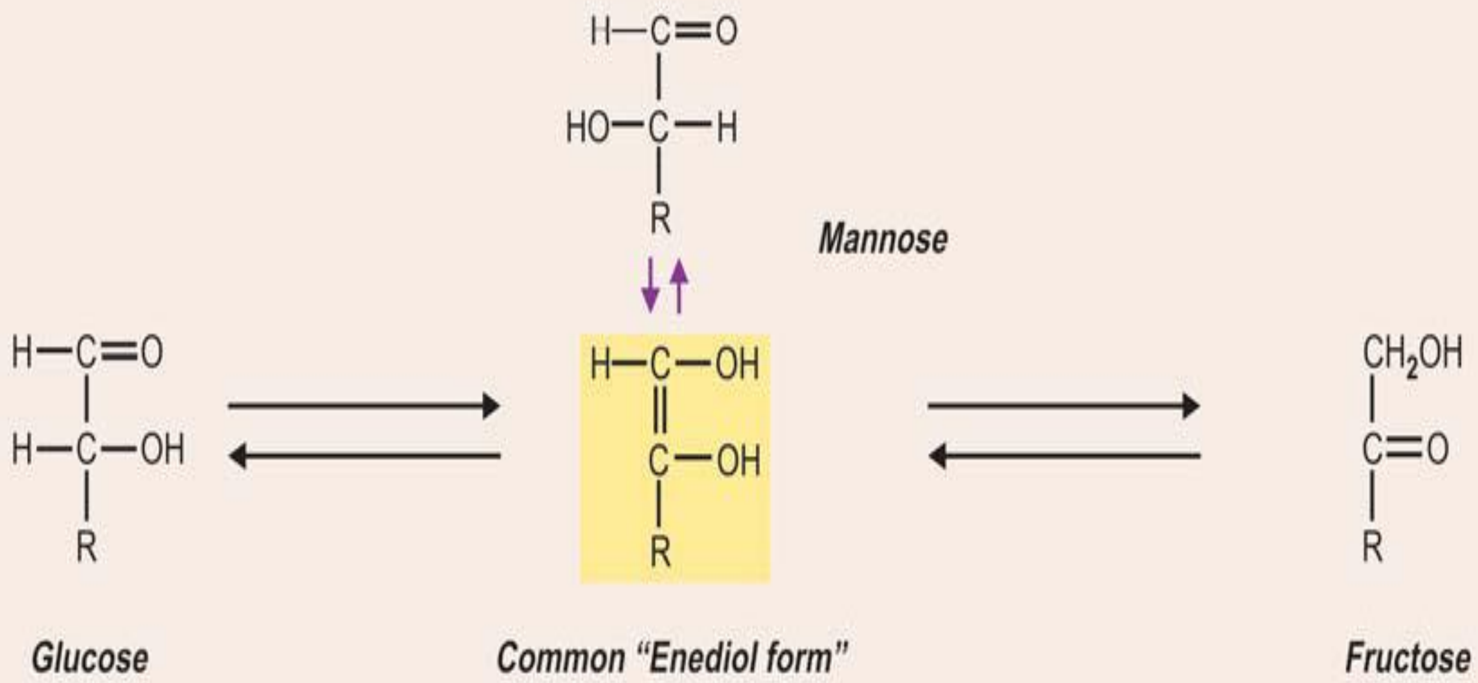
D Glucose+ HCL → Furfural + $3H_2O$

*** furfural derivatives are cyclic crystalline compounds.**

Interconversion of sugars

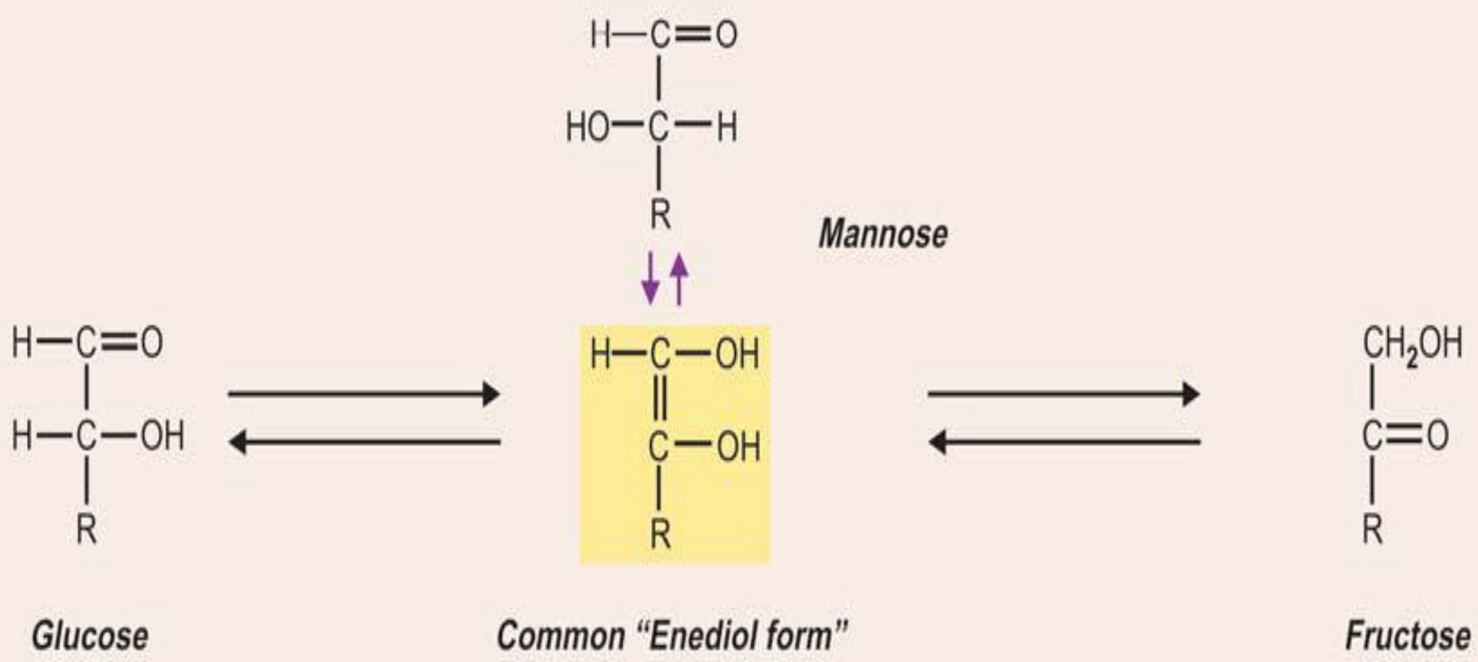
Interconversion of sugars:

Glucose, fructose and mannose interconvertible in solutions of weak alkalinity such as Ba (OH)2 or Ca(OH)2



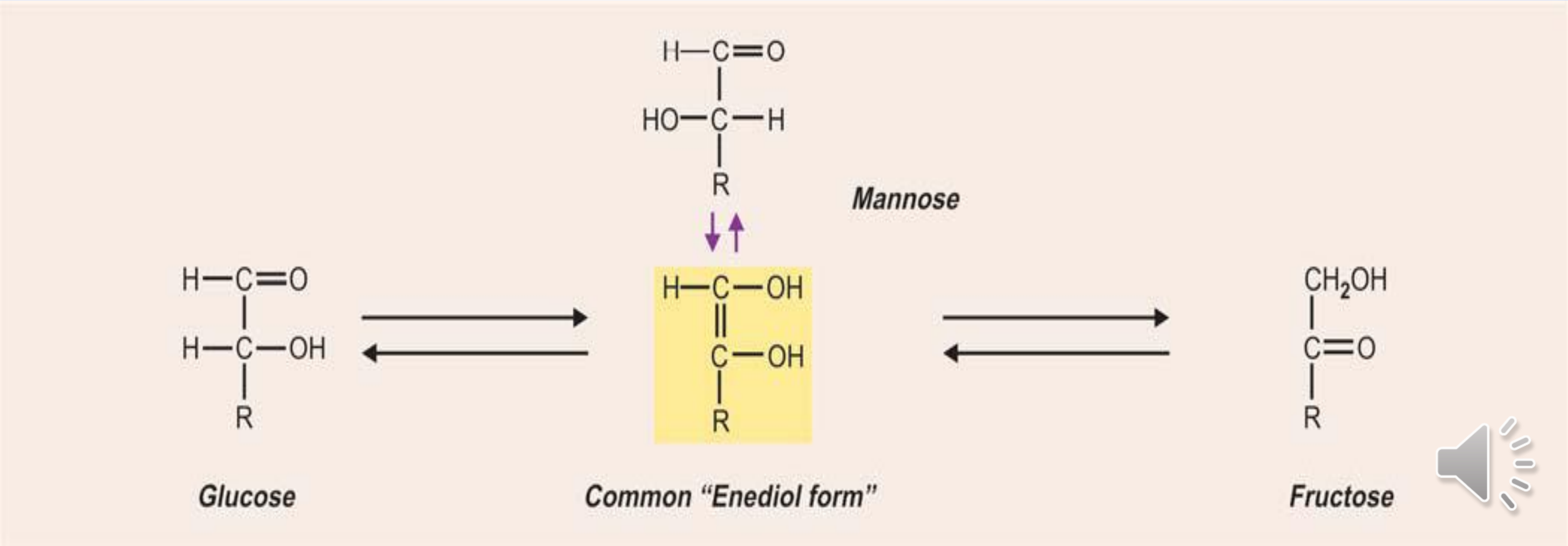
Interconversion of sugars:

all give the same Enediol form, which tautomerizes to all three sugars.



Interconversion of sugars:

This interconversions of related sugars by the action of dilute alkali is referred to as ***Lobry de Bruyn-Van Ekenstein reaction.***



Action with alkalies:

With alkalies, monosaccharides react in various ways

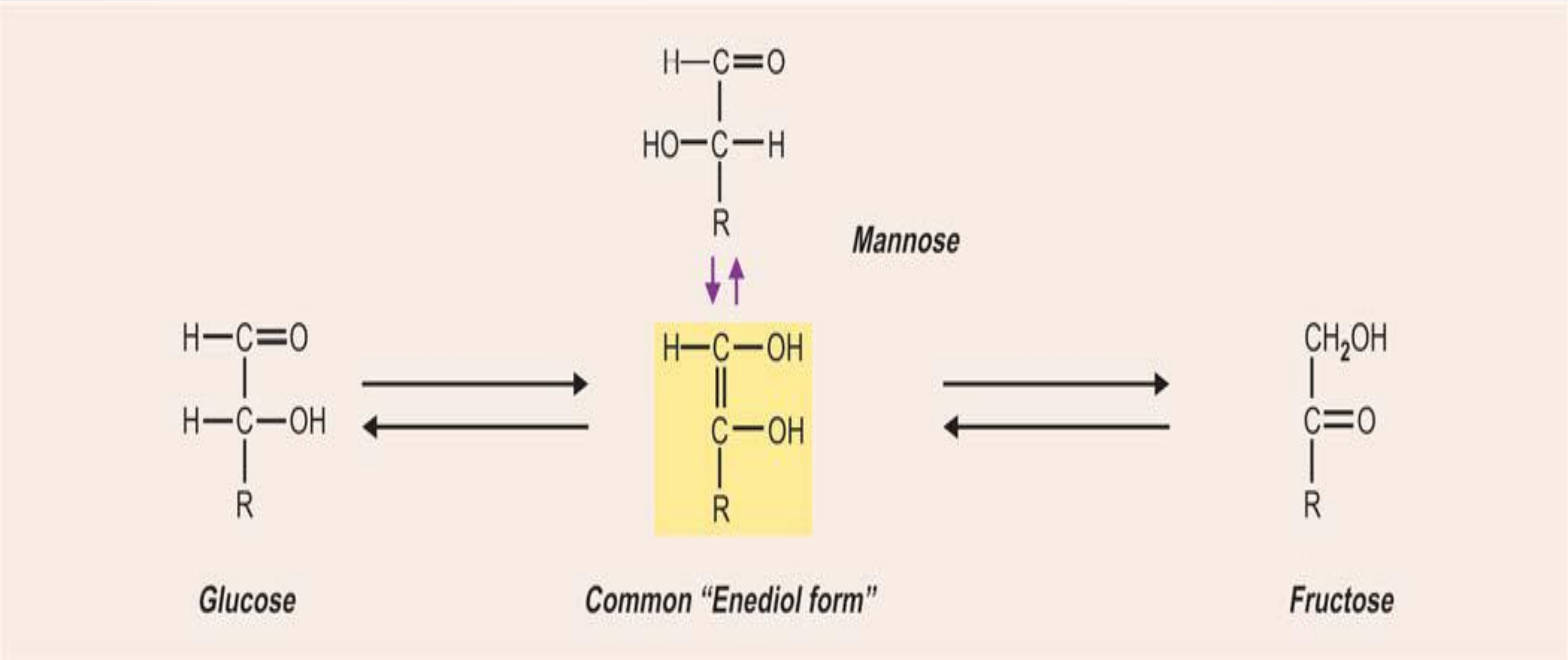
(a) *In dilute alkali:*

(b) In conc. alkali:

Action with alkalies:

(a) In dilute alkali

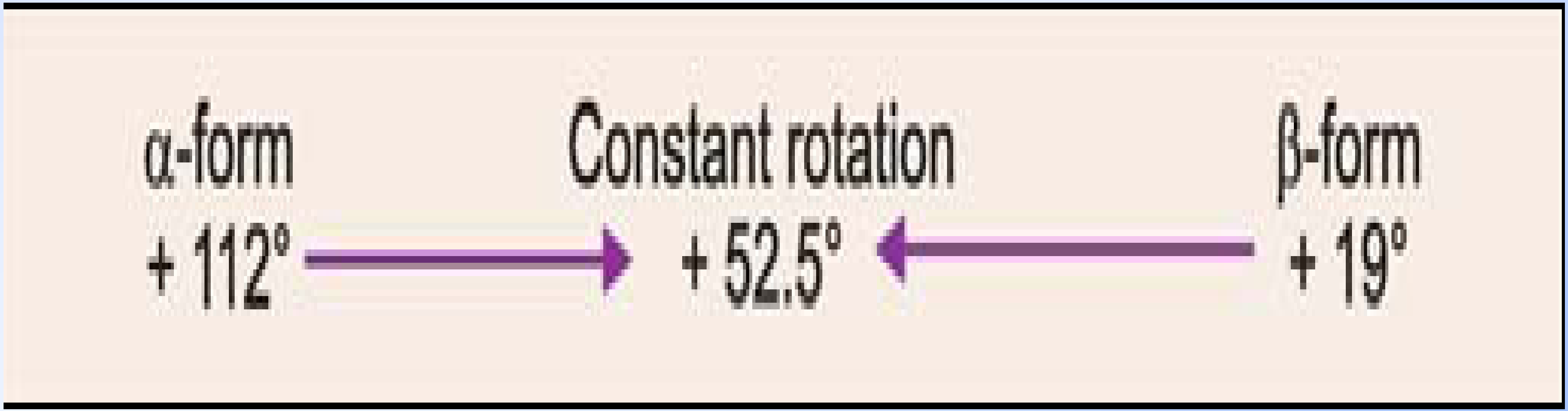
On standing--- A rearrangement will occur which **produce an equilibrated mixture of glucose, fructose and mannose through the common "enediol" form (interconversion).**



8. Action with alkalies

(a) *In dilute alkali:*

The sugar will change to the cyclic **α and β forms with an equilibrium between the two isomeric form (mutarotation).**



Action with alkalies:

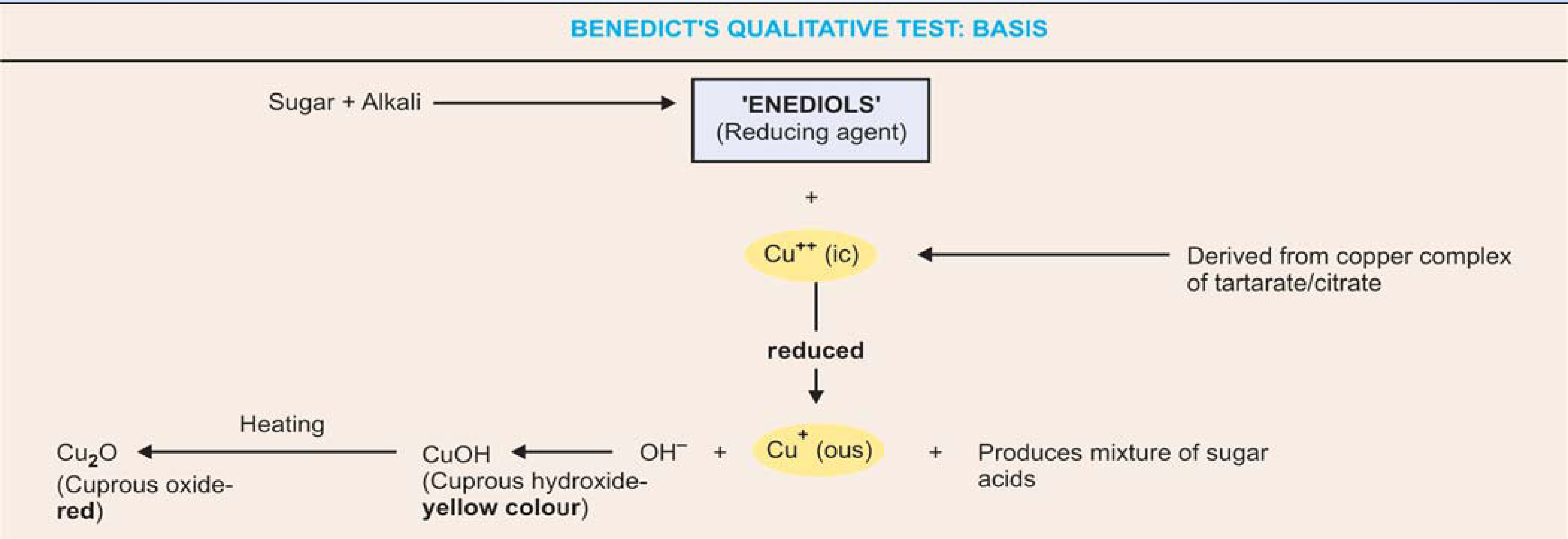
(b) In conc. alkali:

The sugar caramelises and produces **a series of decomposition products, yellow and brown pigments develop**

Reducing action of sugars in alkaline solution

Reducing action of sugars in alkaline solution

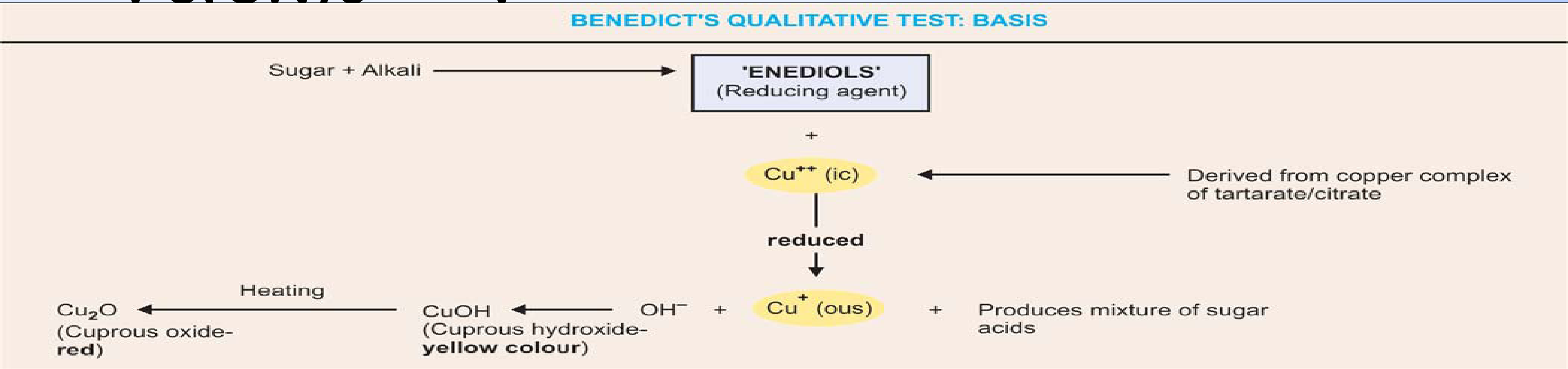
All the sugars that contain free sugar group undergo enolisation and various other changes when placed in alkaline solution.



Reducing action of sugars in alkaline solution

The enediol forms of the sugars are highly reactive and are easily oxidised by O2 and other oxidising agents and forms sugar acids.

As a consequence they readily reduce oxidising ions such as Ag+. Hg+, Bi+++, Cu++ (cupric) and Fe(CN)6– – –.



2. REACTIONS OF ALCOHOLIC GROUPS

Action of acids on carbohydrates

Action of acids on carbohydrates

With dilute mineral acids

Polysaccharides/compound carbohydrates are hydrolyzed into their constituent monosaccharides

With conc. mineral acids

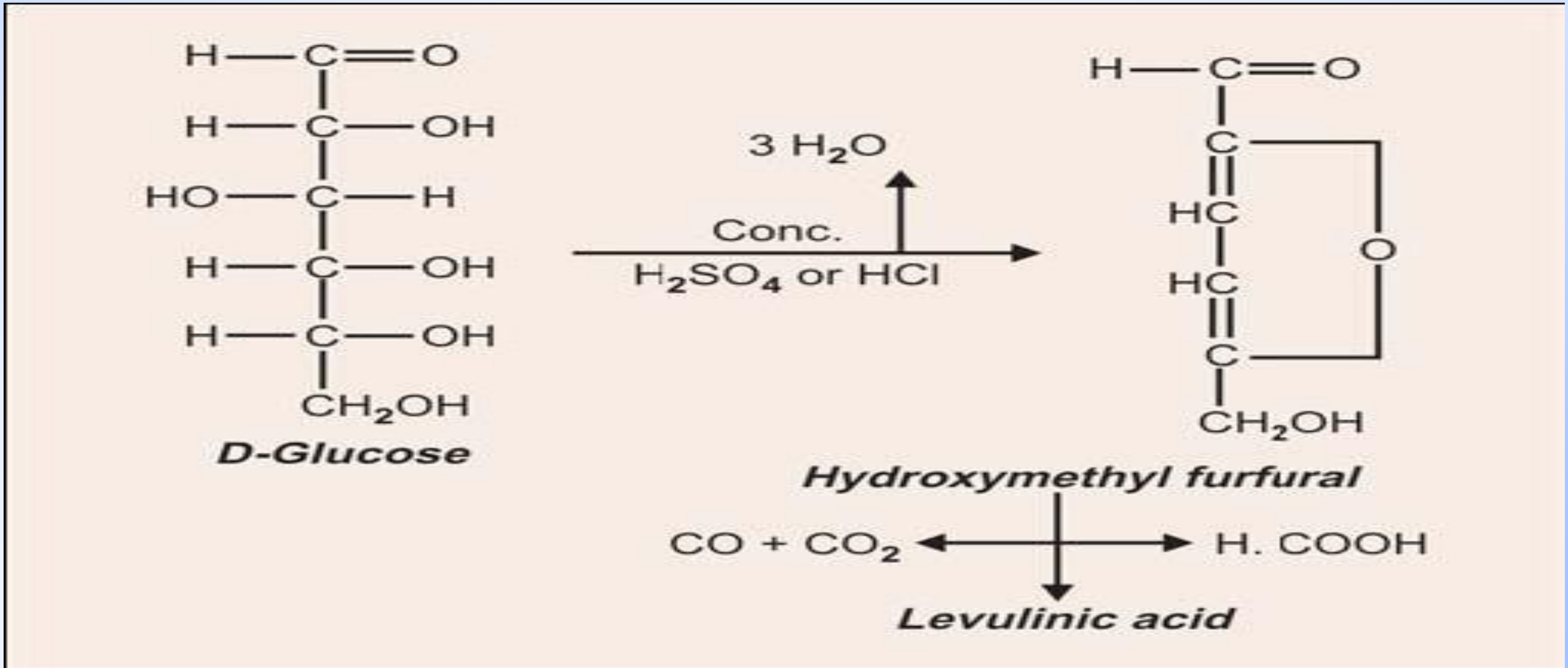
Monosaccharides are decomposed.

Action of acids on carbohydrates

Practical Application

Molisch's test:

With α-naphthol (in alcoholic solution) gives red-violet ring.



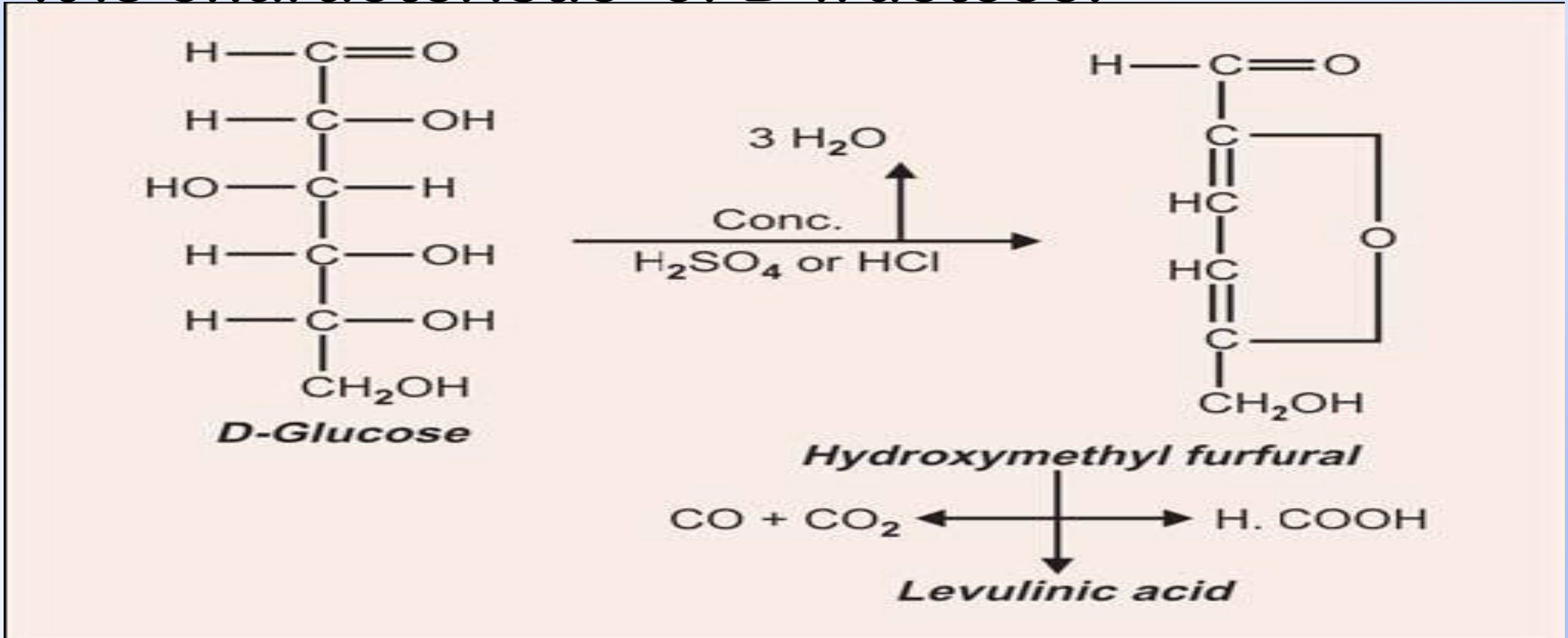
Action of acids on carbohydrates

Practical Application

Seliwanoff's test:

With resorcinol, a cherry-red colour is produced.

It is characteristic of D-fructose.



Molisch's test :

It is a qualitative test for detection of carbohydrates in the given solution and is positive for all carbohydrates.

Molisch's test

PRINCIPLE:

The polysaccharides and disaccharides are hydrolyzed by **conc sulphuric acid** into monosaccharides.

The monosaccharides are dehydrated by the conc sulphuric acid to form furfural or one of its derivatives like hydroxymethyl furfural.

Furfural or its derivatives condense with alpha naphthol to form a violet coloured complex.

Molisch’s test

Chemicals

Molisch’s reagent.

5% alpha naphthol in 95% ethyl alcohol.

Conc sulphuric acid.

Molisch's test

PROCEDURE :

- Take 2ml carbohydrate solution in test tube
- Add 2-3 drops of Molisch's reagent in t tube.
- Mix thoroughly
- incline the test tubes and run 3ml of conc. sulphuric acid along the wall of test tubes.

Molisch's test

Interpretation :

Appearance of a reddish violet ring at the junction of the two liquids indicates the presence of a carbohydrate in test tube.

PRECAUTION :

After formation of the ring, do not shake the tube contents, it may distort the ring shape.

Seliwanoff's test

This test is positive for ketose sugars only

it is positive for fructose, sucrose and other fructose containing carbohydrates

it is used to differentiate between ketoses and aldoses.

Seliwanoff's test :

PRINCIPLE :

- The carbohydrates are converted into **furfural derivatives by the conc HCl** present in the selivanoff's reagent .

- Only furfural derivatives of ketohexose (5-hydroxymethyl furfural) **condense with resorcinol** to form cherry red coloured complex.

Seliwanoff's test :

PRINCIPLE :

- Sucrose will also give seliwanoff's test positive because the acidity of reagent is sufficient enough to hydrolyze sucrose to glucose and fructose.

→

→

Seliwanoff's test :

Seliwanoff's reagent consists of :

1. Resorcinol
2. Conc. hydrochloric acid

PROCEDURE :

i. Take 3ml of Seliwanoff's reagent and 1ml of the given carbohydrate solution in a test tube and mix them.
ii. Boil for 30 seconds only and then cool the solution. Note the appearance of the colour.

Seliwanoff's test :

Interpretation :

The appearance of a cherry red or pink colour within 30 seconds indicates the presence of a ketohexose.fructose

No colour--- galactose and glucose

PRECAUTION :

Prolonged boiling may also convert the aldohexoses into ketohexoses. Hence boiling should be restricted to 30 seconds.

Ester formation

Ester formation

Ester

- ✓ class of organic compounds corresponding to the inorganic salts
- ✓ Esters are formed by reaction of hydroxyl groups (alcohols) with acids

The ability to form sugar esters indicates the presence of alcohol groups.

Esterification

The most important biological esters of carbohydrates are phosphate esters.

Example. Phosphoryl group from ATP forms an ester with D-glucose, catalyzed by kinases.

$$\text{D-glucose + ATP} \xrightleftharpoons{\text{kinases}} \text{D-glucose-6-phosphate + ADP}$$

OTHER SUGAR DERIVATIVES OF BIOMEDICAL IMPORTANCE

Deoxy sugars

Deoxy sugars represent sugars in which the *oxygen of a –OH gr. has been removed, leaving* the hydrogen.

Thus, –CHOH becomes –CH2

and –CH2OH becomes –CH3.

Deoxy sugars:

Deoxy sugars of biological importance are:

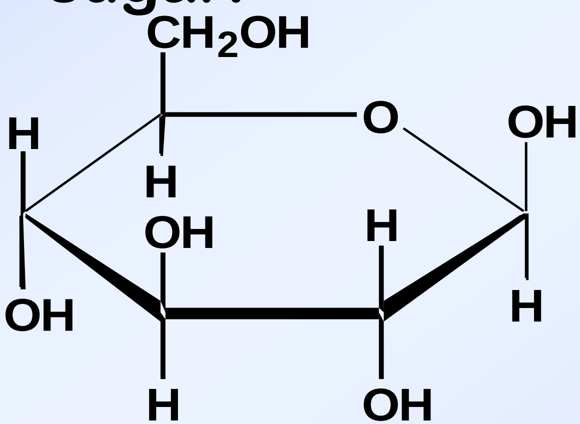
- 2-deoxy-D-Ribose –
  found in nucleic acid *(DNA).*

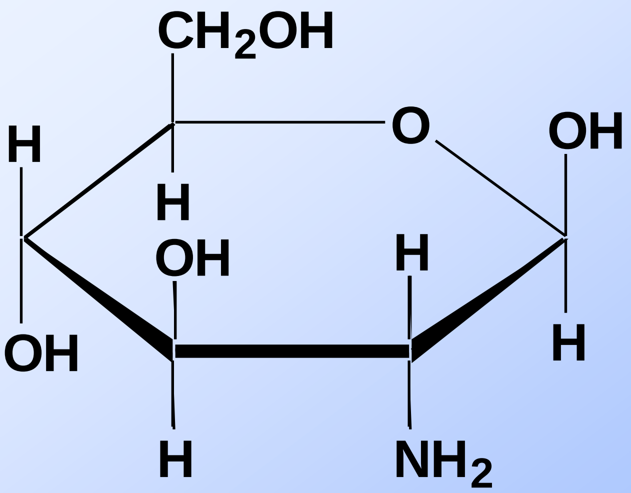
- 6-deoxy-L-Galactose-
  found as a constituent of glycoproteins, blood group substances and bacterial polysaccharides.

Amino derivatives

Sugars containing an –NH2 group in their structure are called *amino sugars*

The replacement of a hydroxyl group on a carbohydrate by amino gp results in an amino sugar.





β-D-glucose

β-D-2-

aminoglucose

Amino sugars (hexosamines)

two types of amino sugars of physiological importance are:

Glycosylamine:

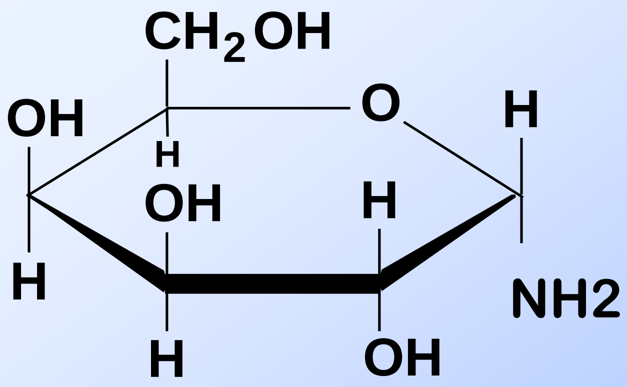
Glycosamine (Glycamine)

Amino sugars (hexosamines)

Glycosylamine:

The anomeric –OH group is replaced **by an –NH2 group.**

Example:

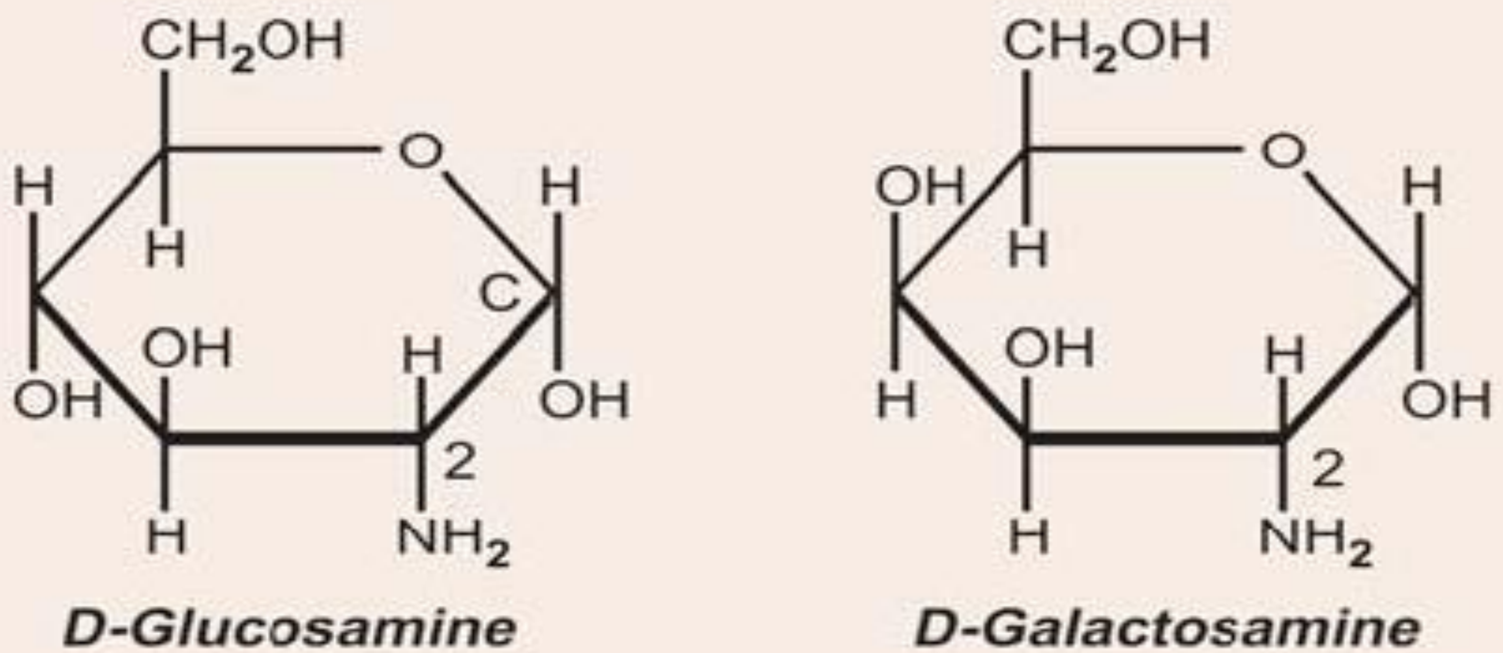


Ribosylamine, a derivative of which is involved in the **synthesis of purines.**

Amino sugars (hexosamines)

Glycosamine (Glycamine):

In this type, the alcoholic – OH group of the sugar molecule is replaced by – NH2 group.



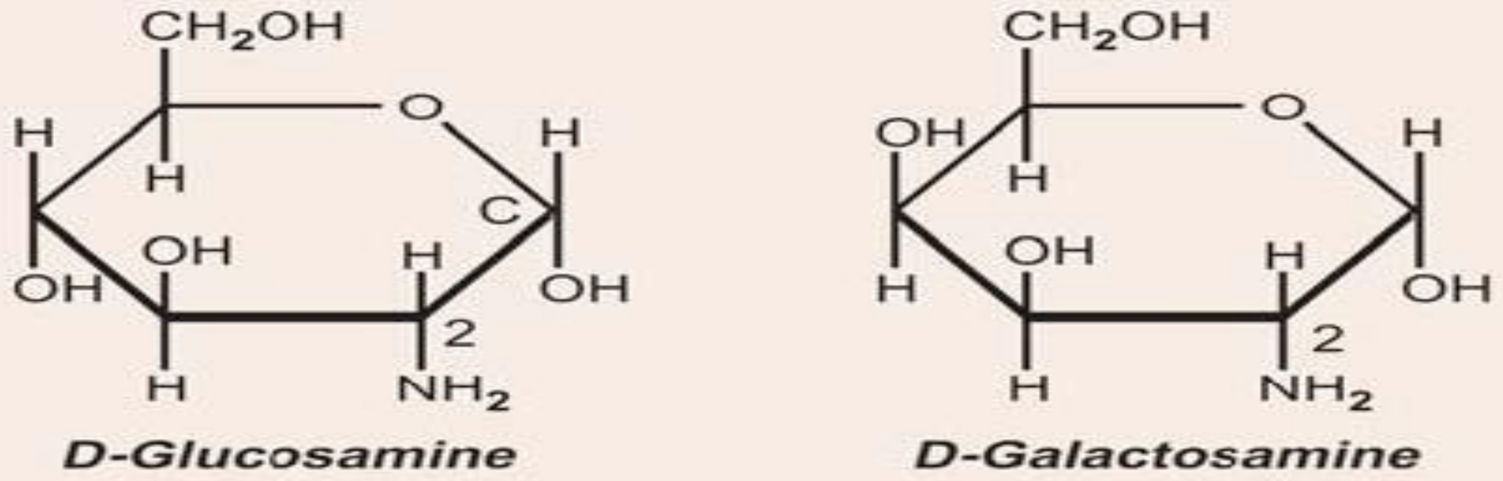
Amino sugars (hexosamines)

Glycosamine (Glycamine):

Two naturally occurring members of this type are derived from glucose **and** galactose**,**

in which – OH group on carbon 2 is replaced by – NH2 group,

and forms respectively *Glucosamine* ***and*** *Galactosamine*



Biomedical Importance of D-Glucosamine

constituent of

cell wall of fungi,

shells of (crabs , Lobsters)

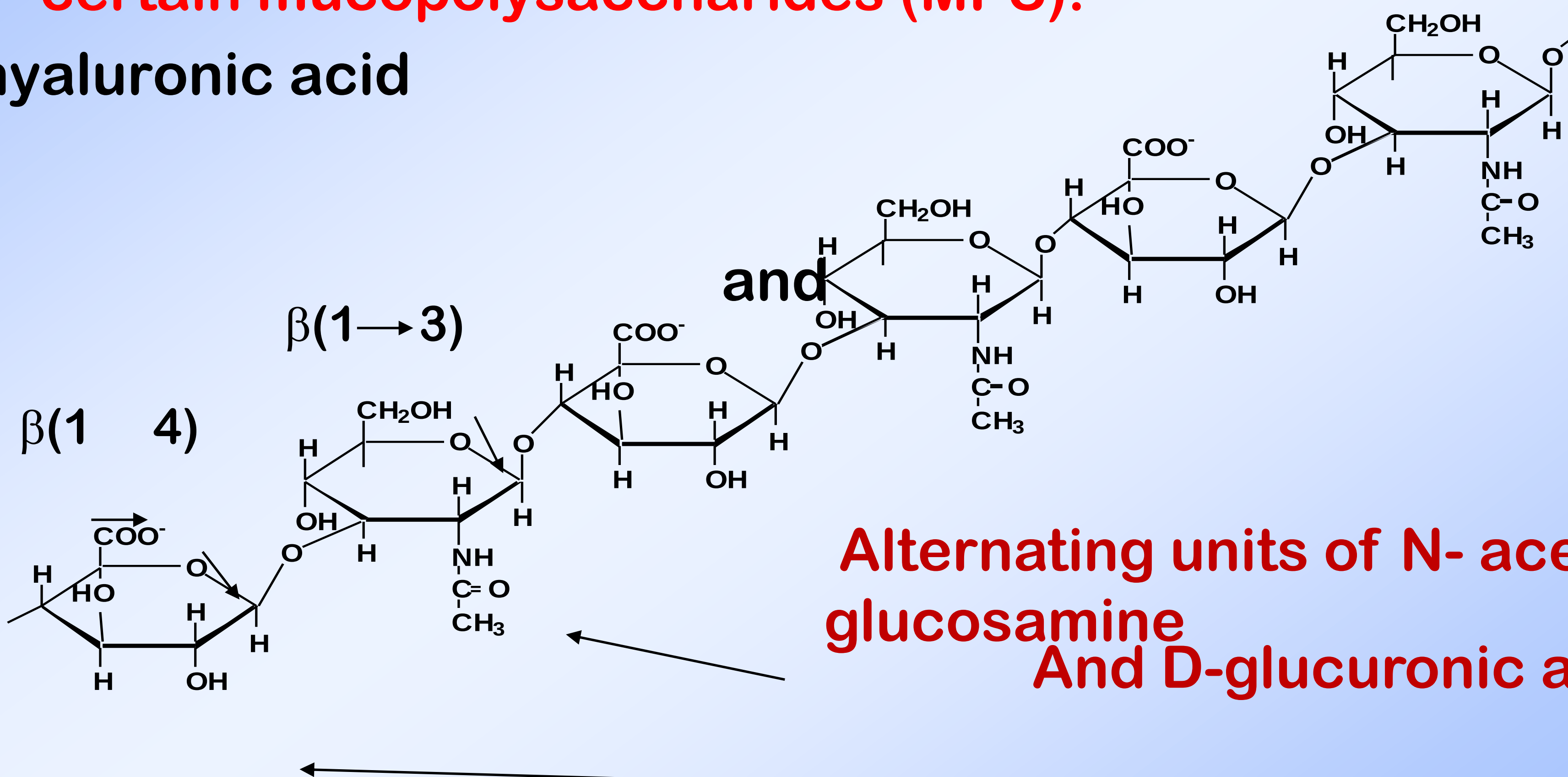
exoskeleton of insects

where it occurs as Chitin, which is made of repeating units of N-acetylated glucosamine. Hence Glucosamine is often called as Chitosamine.

Biomedical Importance of D-Glucosamine

N-acetyl derivative of D-Glucosamine a constituent of certain mucopolysaccharides (MPS).

hyaluronic acid



Alternating units of N- acetyl glucosamine

And D-glucuronic acid

Mucopolysaccharide

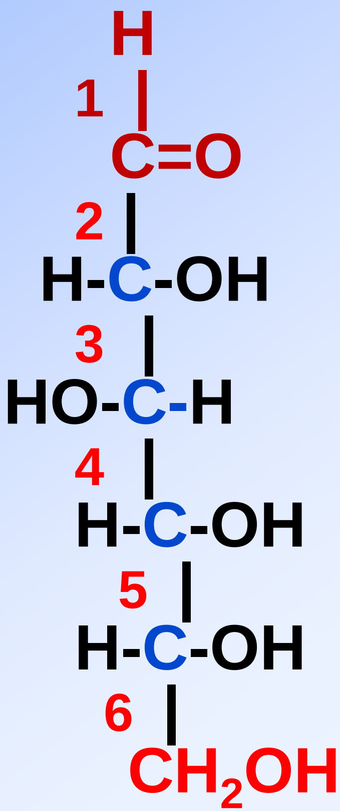
Biomedical Importance Galactosamine

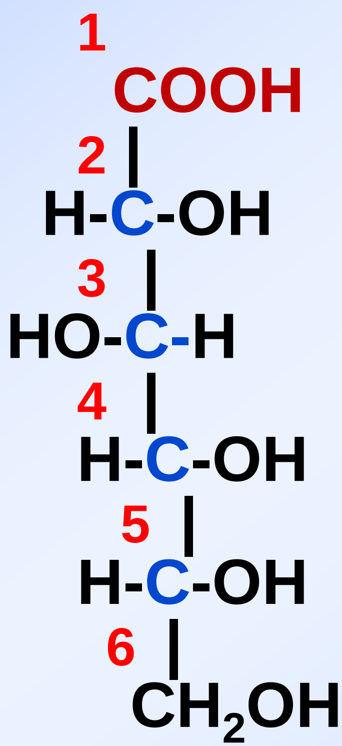
Galactosamine occurs as N-acetyl-Galactosamine in chondroitin sulphates (present in cartilages, bones, tendons and heart valves). Hence Galactosamine is also known as Chondrosamine.

Biomedical Importance amin0 sugars

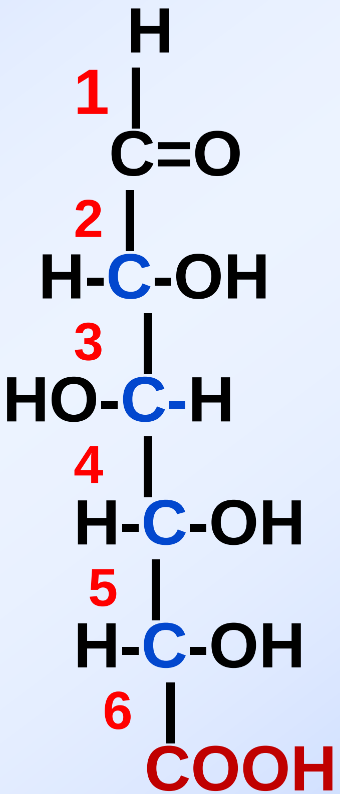
Antibiotics: Certain antibiotics, such as Erythromycin, carbomycin, contain amino sugars.

It is believed that amino sugars are related to the antibiotic activity of these drugs.

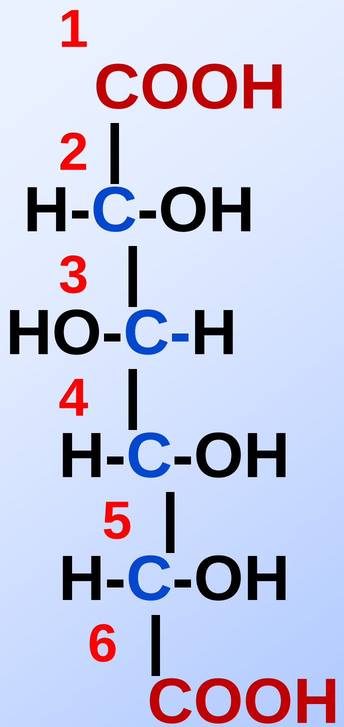




Gluconic acid



Glucuronic acid



Glucaric acid

Amino Sugar Acids

✓ ***Neuraminic acid:***

Muramic acid:

Amino Sugar Acids

Neuraminic acid:

- ✓ *amino sugar acid*
- ✓ structurally an condensation product of pyruvic acid and D-Mannosamine.
- ✓ Neuraminic acid is unstable and found in nature in the form of acylated derivatives known as *Sialic acids (N-acetyl Neuraminic acid —NANA).*

Amino Sugar Acids

Muramic acid:

- ✓ *amino sugar acid*
- ✓ structurally a condensation product of D Glucosamine and Lactic Acid.

Biomedical Importance

Neuraminic acid and sialic acids occur in a number of mucopolysaccharides and in glycolipids like gangliosides.

A number of nitrogenous oligosaccharides which contain neuraminic acid are found in human milk.

Certain bacterial cell walls contain muramic acid.

Neuraminidase is the enzyme which hydrolyses to split "NANA" from the compound

Glycosides

are compounds containing a carbohydrate and a noncarbohydrate residue in the same molecule.

In these compounds the carbohydrate residue is attached by an *acetal linkage of carbon-I to the noncarbohydrate* residue.

The noncarbohydrate residue present in the glycoside is called as Aglycone*.*

Biomedical Importance

- ✓ Glycosides are found in many drugs, spices and in the constituents of animal tissues.
- ✓ They are widely distributed in plant kingdom.

Biomedical Importance

Cardiac glycosides:

It is important in medicine because of their action on heart and thus used in cardiac insufficiency.

They all contain steroids as aglycone component in combination with sugar molecules.

They are derivatives of digitalis plants, e.g.

Digitonin ------------- Galactose + Xylose
+ Digitogenin
(Aglycone)

Disaccharides

Disaccharides

sugars composed of two monosaccharides residues linked by a glycoside bond

On hydrolysis they yield 2 monosaccharide.

Disaccharides

3 main disaccharides-sucrose

maltose

lactose

All are isomers with molecular formula $C_{12}H_{22}O_{11}$.

Soluble in water

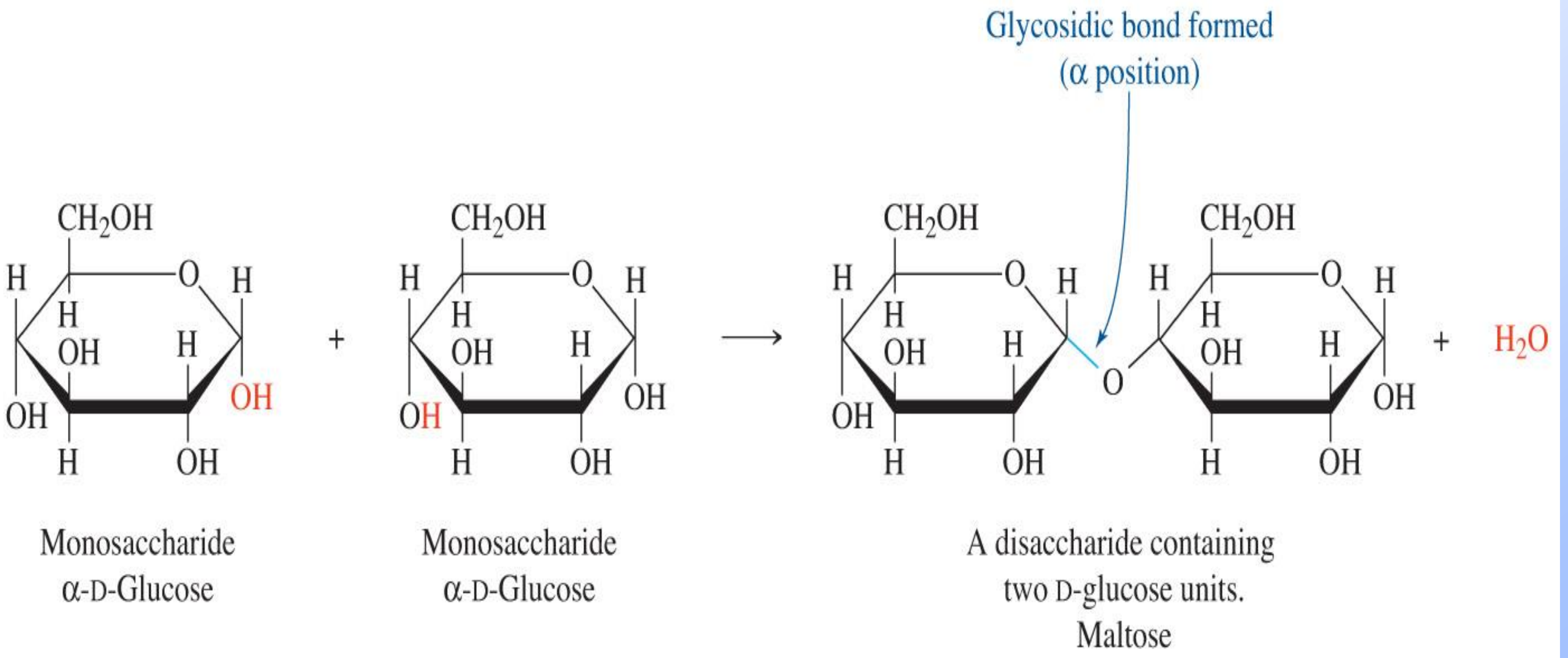
Too large to pass through the cell membrane.

Condensation reaction

Hydrolysis reaction

Naming Glycosidic Bonds

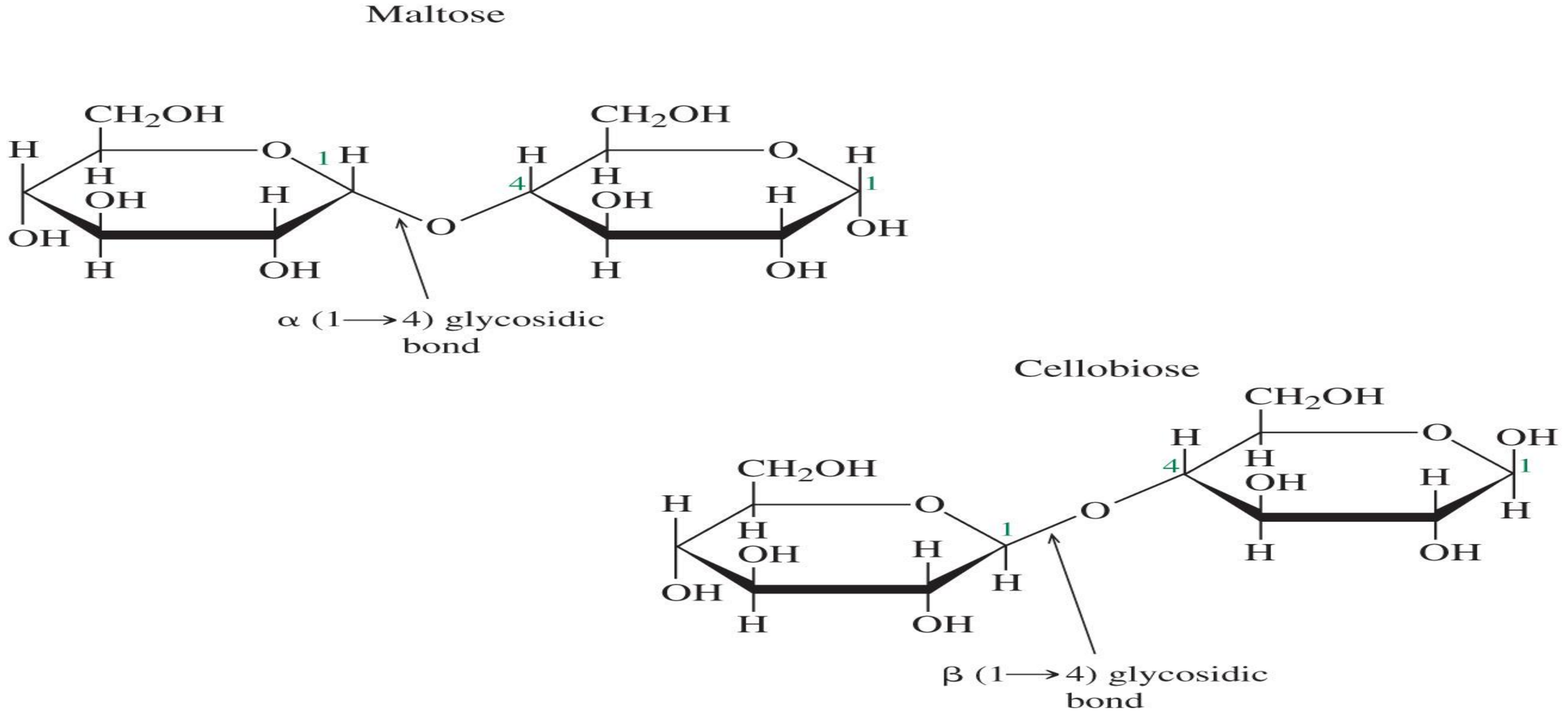
In the case of maltose, the Glycosidic bond is specified as α (1 → 4)



Naming Glycosidic Bonds

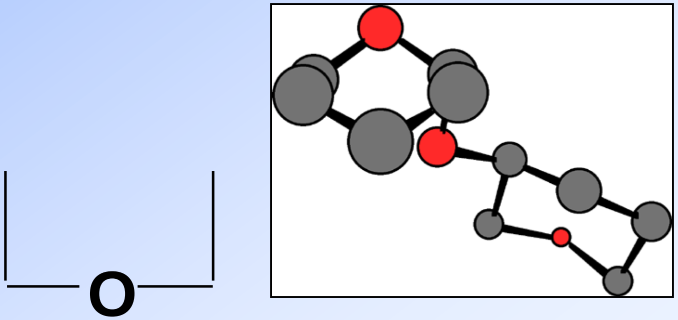
If the –OH group had been in the beta configuration when the Glycosidic bond was formed, the bond would be in the β(1→4) configuration.

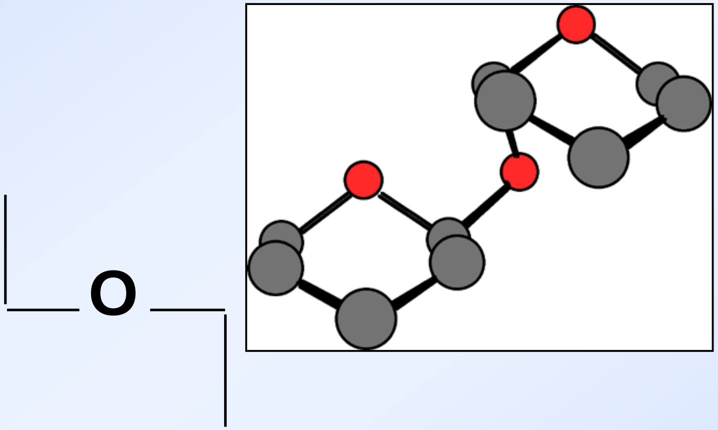
The molecule formed would be named cellobiose



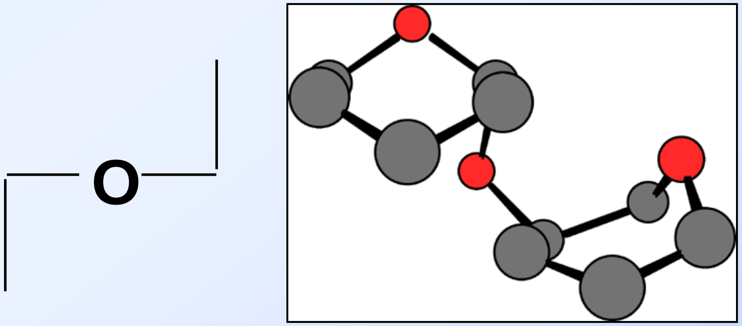
Glycosidic bonds

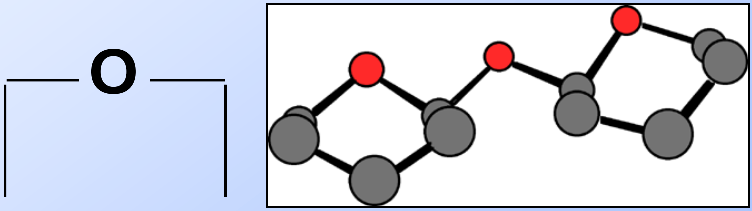
α bonds





β bonds



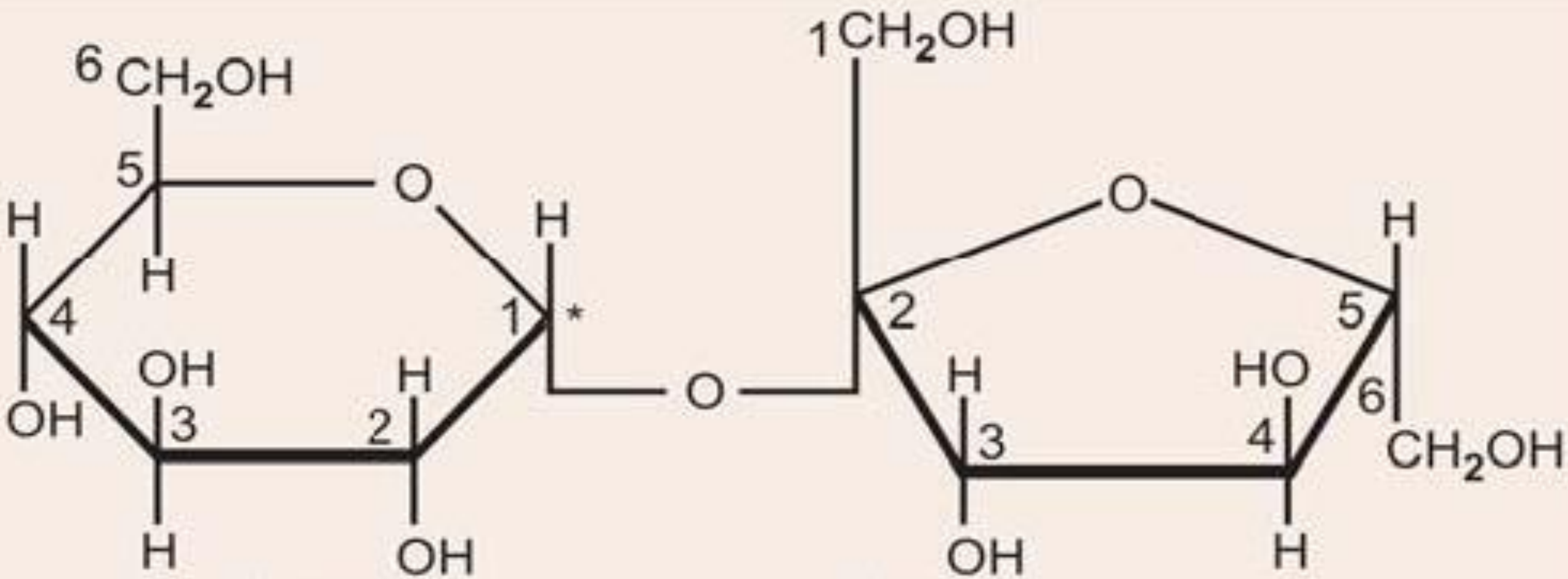


C-4 end can be either up or down depending on the orientation of the monosaccharide.

If both of the two potential aldehyde/or ketone groups are involved in the linkage

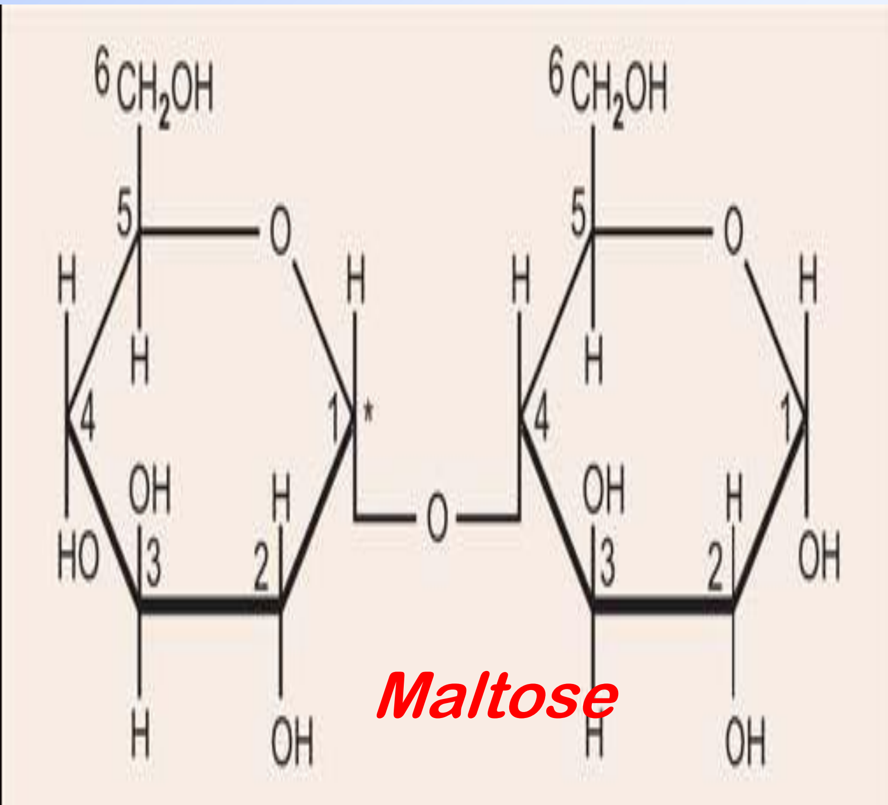
the sugar will not exhibit reducing properties

will not be able to form Osazones, e.g. *sucrose.*

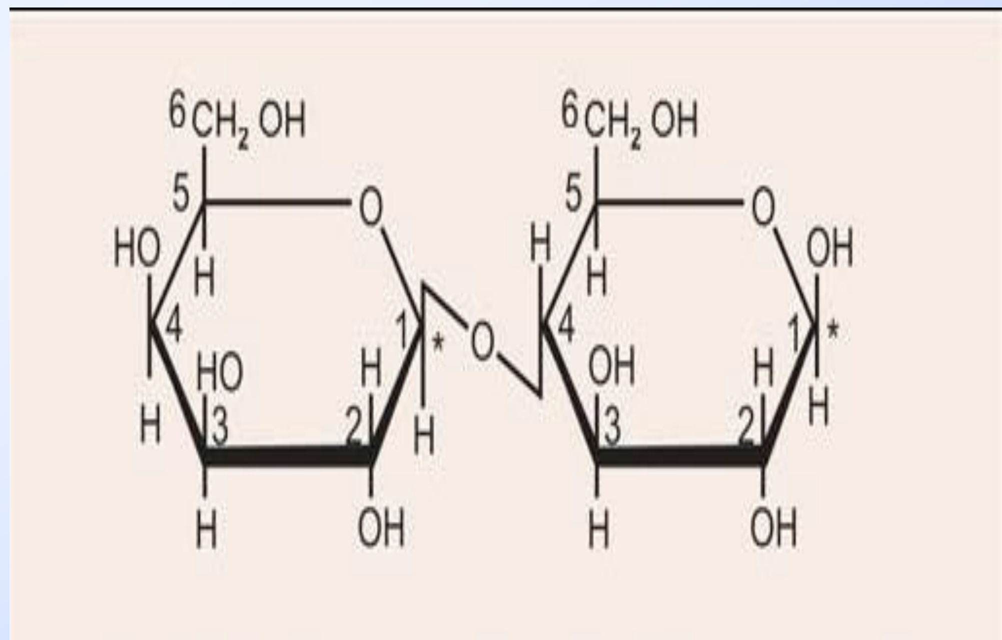


O-α-D-Glucopyranosyl-(1 → 2)-β-D-fructofuranoside

But if one of potential **aldehyde/or ketone groups is not bound in the linkage , it will permit reduction and Osazone formation by the sugars**



Maltose



O-β-D-Galactopyranosyl-(1 → 4)-β-D-glucopyranoside

Lactose

Maltose

Maltose

Maltose - malt sugar.

Dimer of two alpha –glucose molecule

An intermediary in acid hydrolysis of starch and can also be obtained by enzyme hydrolysis of starch.

Course of Hydrolysis

Starch

↓

Soluble starch

↓

Amylodextrin

↓

Erythrodextrin

↓

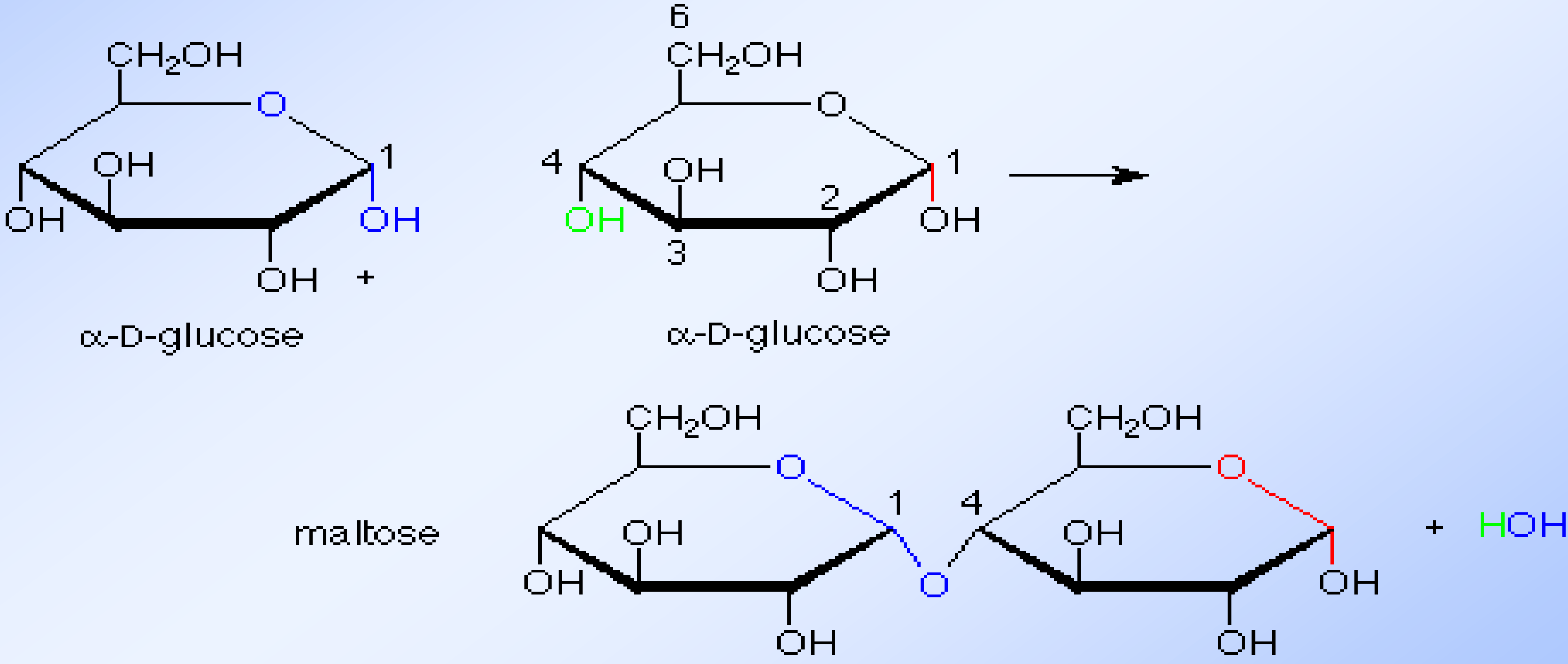
Achroodextrin

↓

Maltose

Formation of maltose

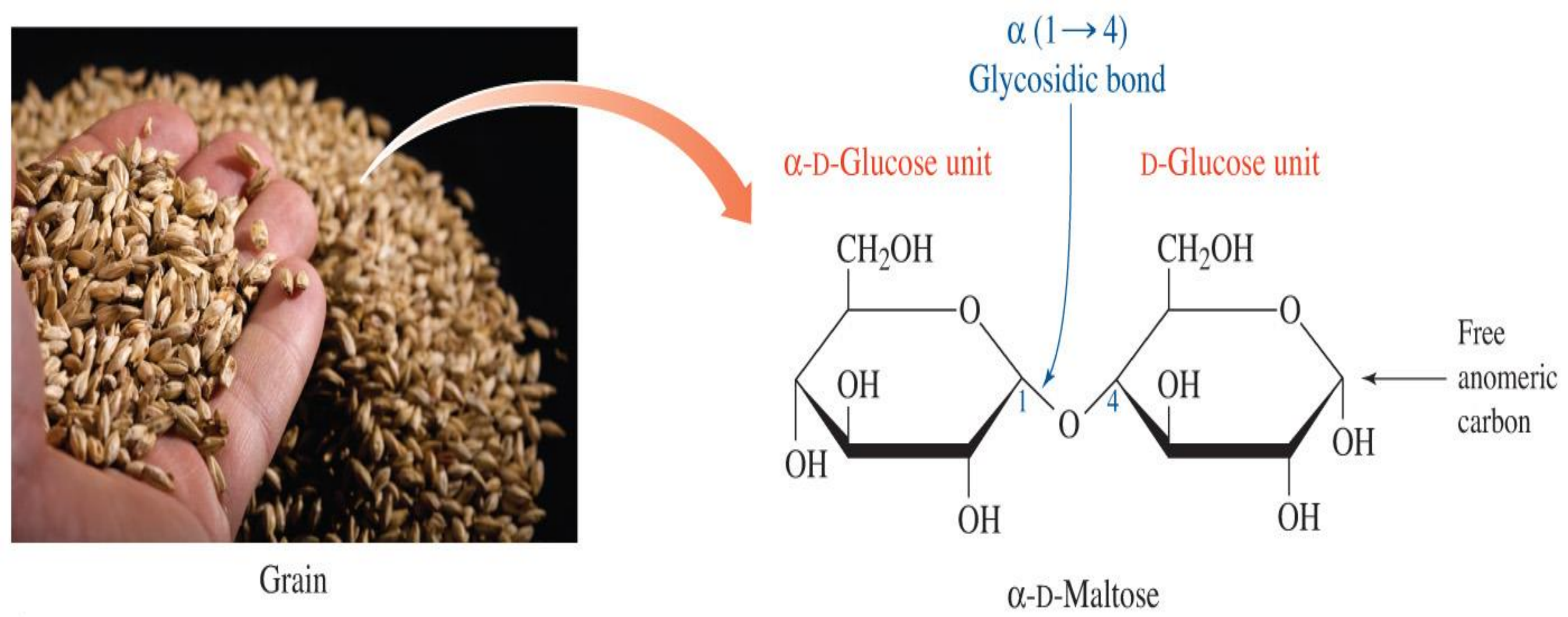
combination of two alpha –glucose molecule together , the product is a maltose and water



Disaccharides--- Maltose

The Glycosidic bond is α(1→4).

One of the anomeric carbons is free, so maltose is a reducing sugar.

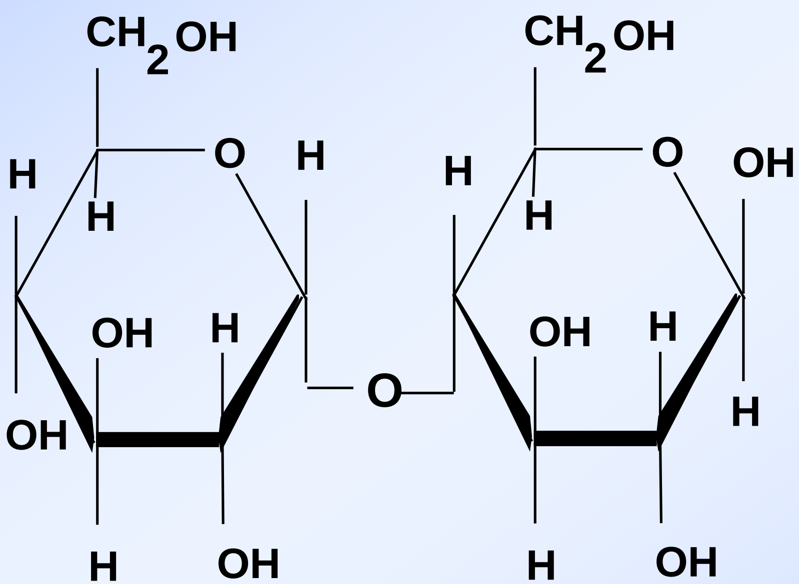


Cellobiose

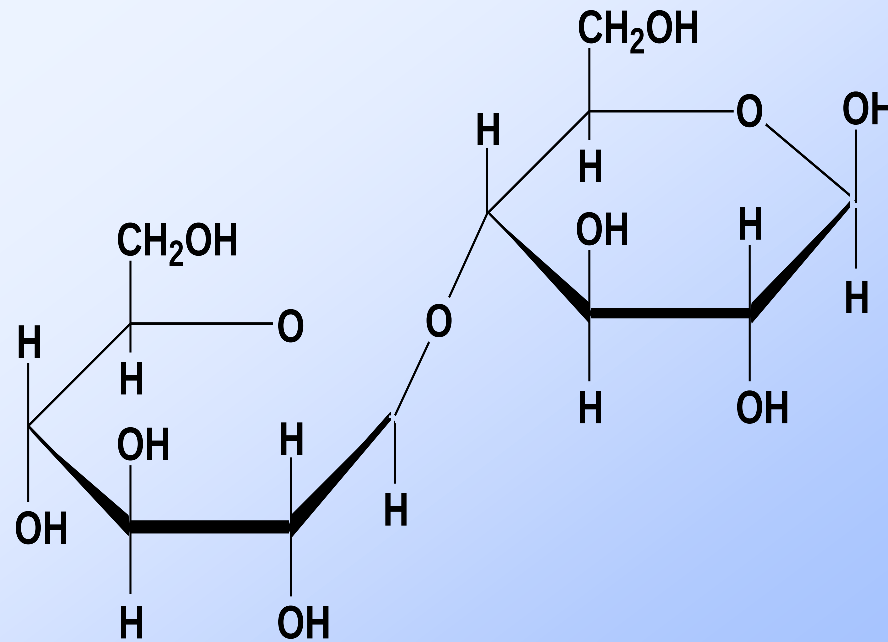
Cellobiose

Like maltose, it is composed of two molecules of D-glucose

but with a β (1 → 4) linkage.



maltose, α (1 → 4)



cellobiose β (1 →

Lactose

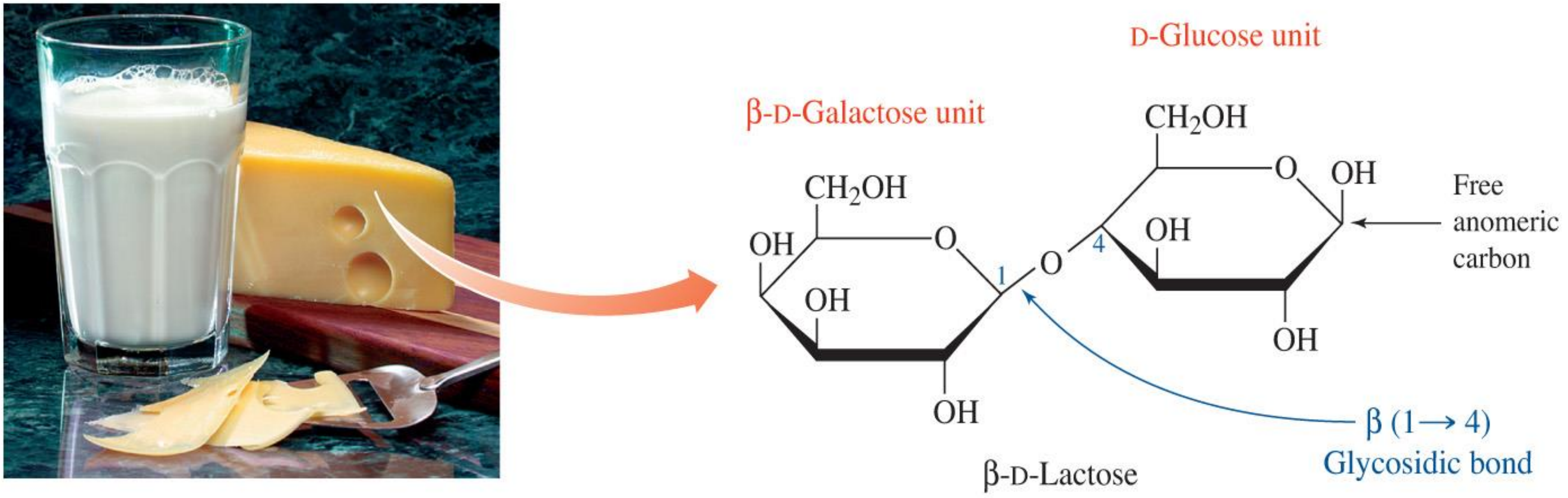
Disaccharides--- Lactose

milk sugar.

milk and milk products.

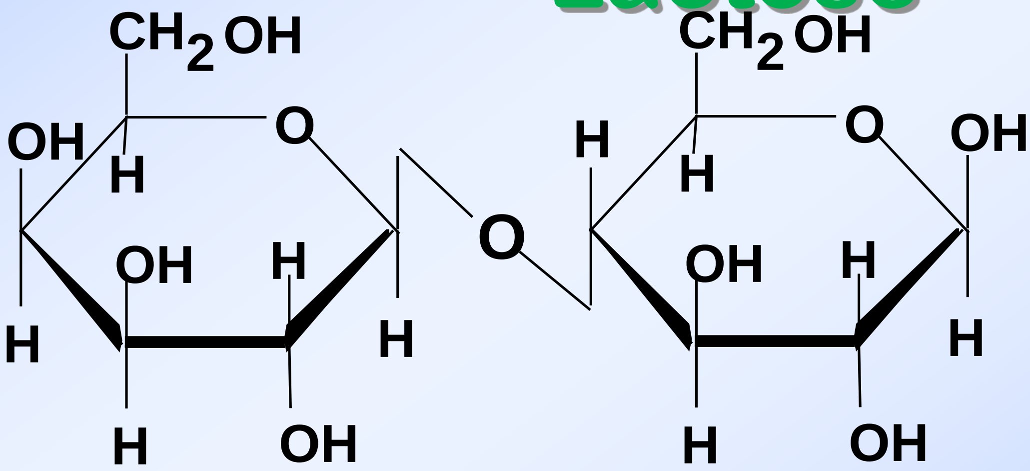
dimer of β-D-galactose and either the α or β - D-glucose.

The glycosidic bond is β (1→4).

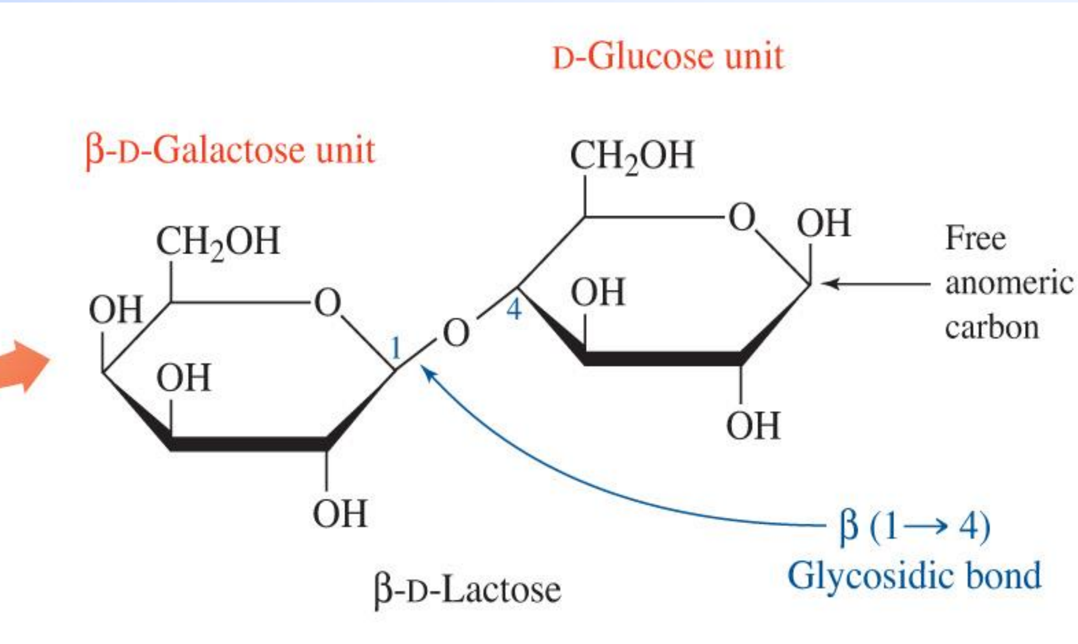


Lactose

β-Lactose



β-D-galactose β-D-glucose



Lactose

One of the anomeric carbons is free, so lactose is a reducing sugar

Lactase - Enzyme required to hydrolyze lactose.

Lactose intolerance

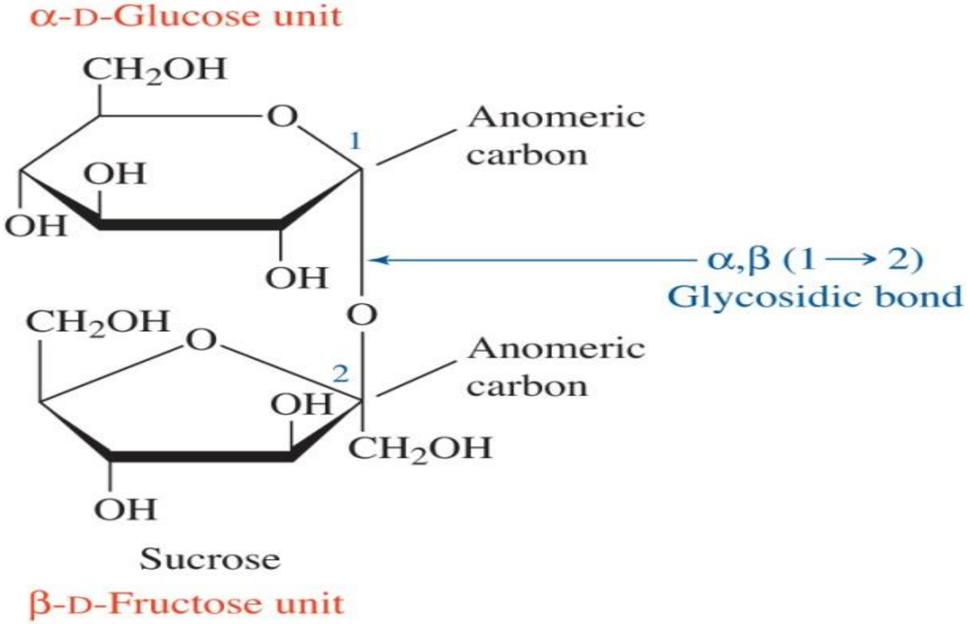
inherit **Lack or insufficient amount of the enzyme** lactase that hydrolyzes lactose into its monosaccharide units

If lactose enters lower GI, it can cause cramps

Sucrose

Disaccharides--- Sucrose

- table sugar.
- most abundant disaccharide found in nature.
- found in sugar cane and sugar beets.
- **Disaccharide of α-glucose and β-fructose**
- The Glycosidic bond is β (1→2).



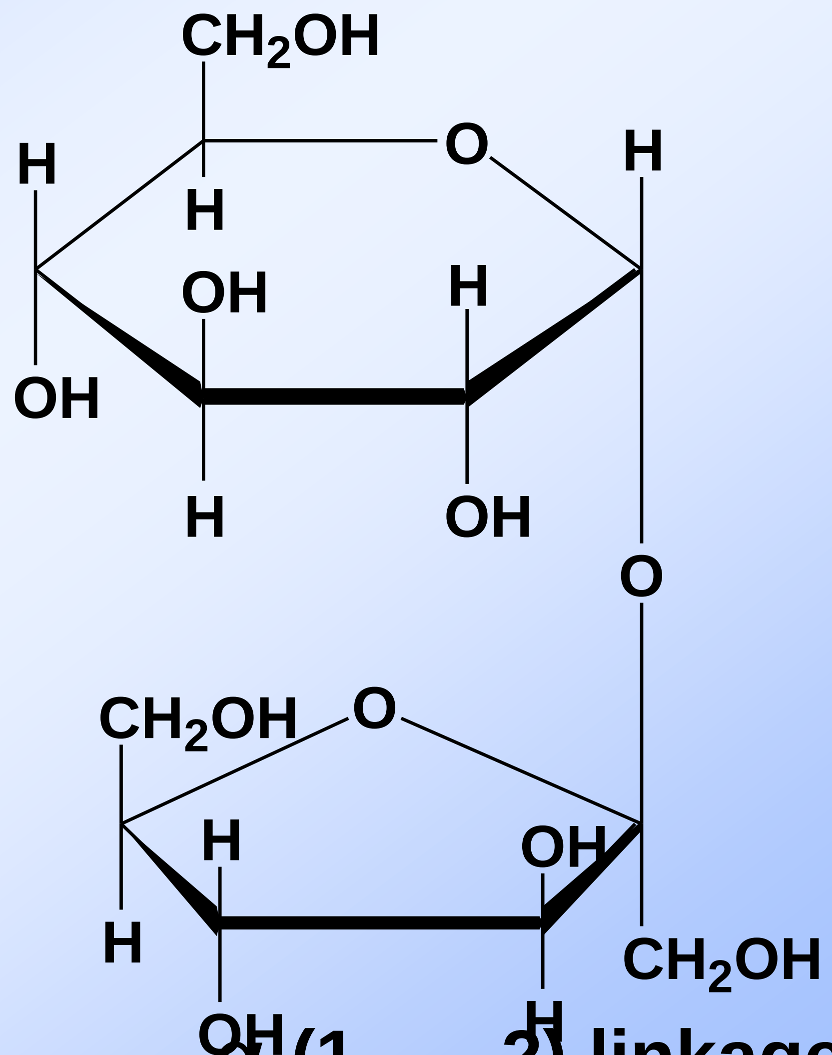
Sucrose

Both anomeric carbons of the monosaccharides in sucrose are bonded, therefore

sucrose is not a reducing sugar.

It will not react with Benedict's reagent.

it does not exhibit mutarotation

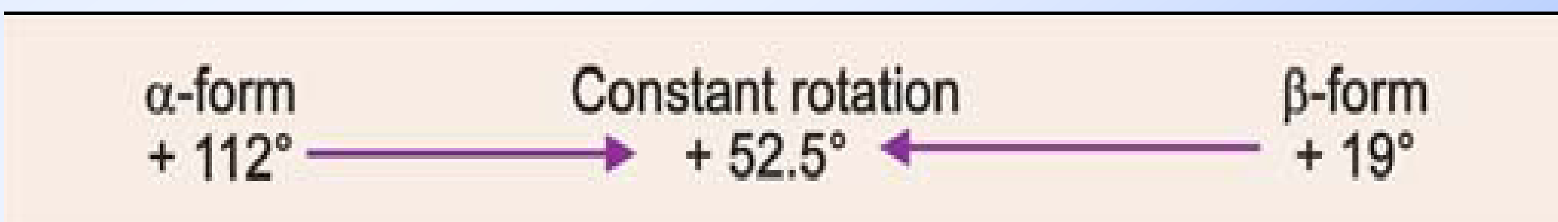


α (1 ⟶ 2) linkage

Invert Sugars and ‘Inversion’

Sucrose is dextrorotatory (+62.5°)
but its hydrolytic products are laevorotatory

because fructose has a greater specific laevorotation than the dextrorotation of glucose.



Invert Sugars and 'Inversion'

As the hydrolytic products invert the rotation,

The resulting mixtures of glucose and fructose (hydrolytic
products) is called as *Invert Sugar*

the process is* called as *Inversion.

How sweet it is!

Sugar	Sweetness relative to sucrose
lactose	0.16
galactose	0.32
maltose	0.33
sucrose	1.00
fructose	1.73
saccharin	450

Biomedical Importance of Disaccharides

Various food preparations available, are produced by hydrolysis of grains and contain large amounts of maltose

In lactating mammary gland, the lactose is synthesized from glucose by the duct epithelium and lactose present in breast milk is a good source of energy for the newborn baby.

OLIGOSACHHARIDES.

These are condensation products of two to ten simple sugars or monosaccharide. These are represented by general formula:

$$C_n(H_2O)_{n-1}.$$

Physiologically important oligosaccharides are sucrose maltose & lactose which are disaccharides and raffinose which are trisaccharides.

All oligosaccharides yield monosaccharide on hydrolysis.

POLYSACHHARIDES

The majority of carbohydrates found in natural sources occur in the form of polysaccharides. These are increased molecular weight polymers of monosaccharide, represented by general formula

$$(C_6H_{10}O_5)_n$$

Polysaccharides

They may be classified as:

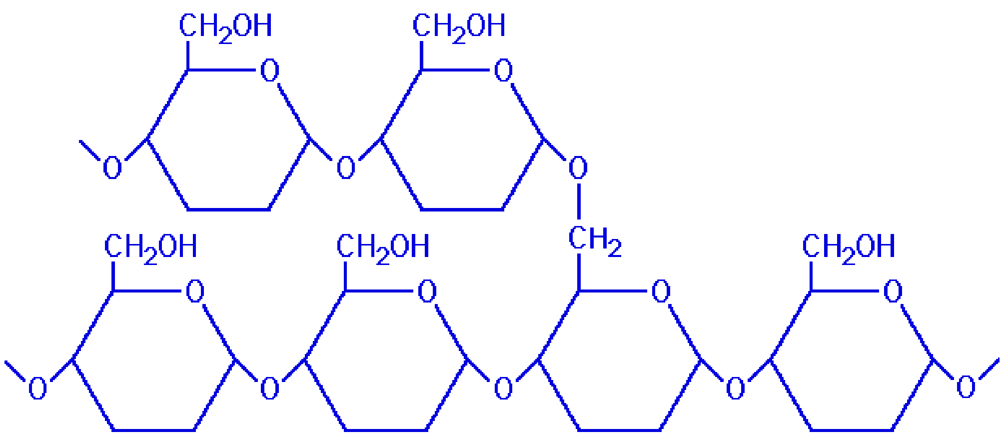
1. Homopolysaccharides
2. Hetropolysaccharides

Homopolysaccharides

On hydrolysis yield only one type of Monosaccharide units. e.g.

Cellulose, starch glucogen and dextrin.

STARCH



It is the best source of CHO in our food as it is present in high concentration in wheat, rice & potato etc.

Starch consists of 2 types of polysaccharides unit amylose & amylopectin.

Amylose is a straight chain polymer similar to cellulose having α-1,4 Glycosidic bond between molecules in a straight chain while Amylopectin contains both α-1,4 & α-1,6 Bonds.

Amylopectin is much bigger & more abundant.

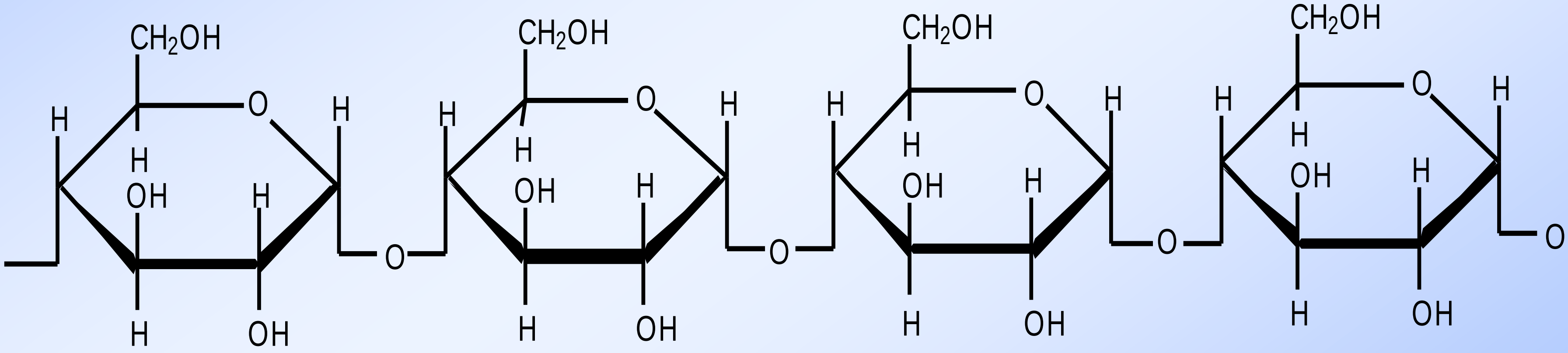
Amylose starch

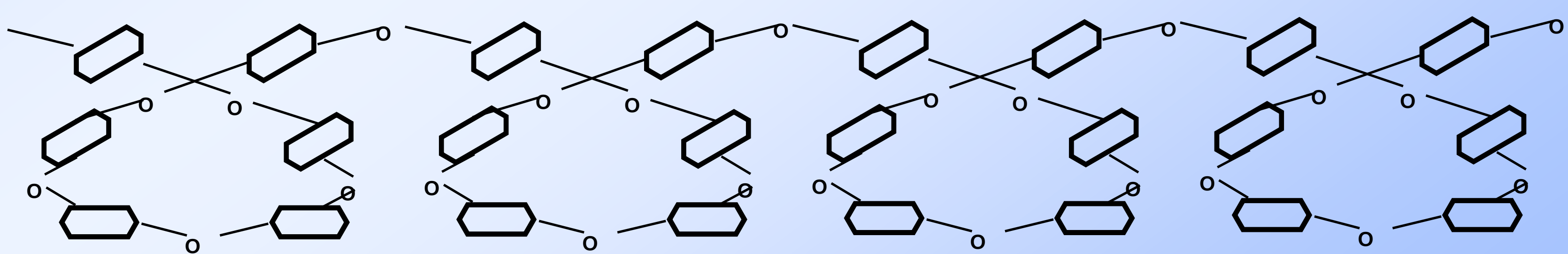
Most common/ major form of starch

makes up 20% of plant starch

made up of 250–4000 D-glucose units bonded α(1 4) glycosidic bonds in a continuous chain.

Long straight chains of Amylose tend to coil.



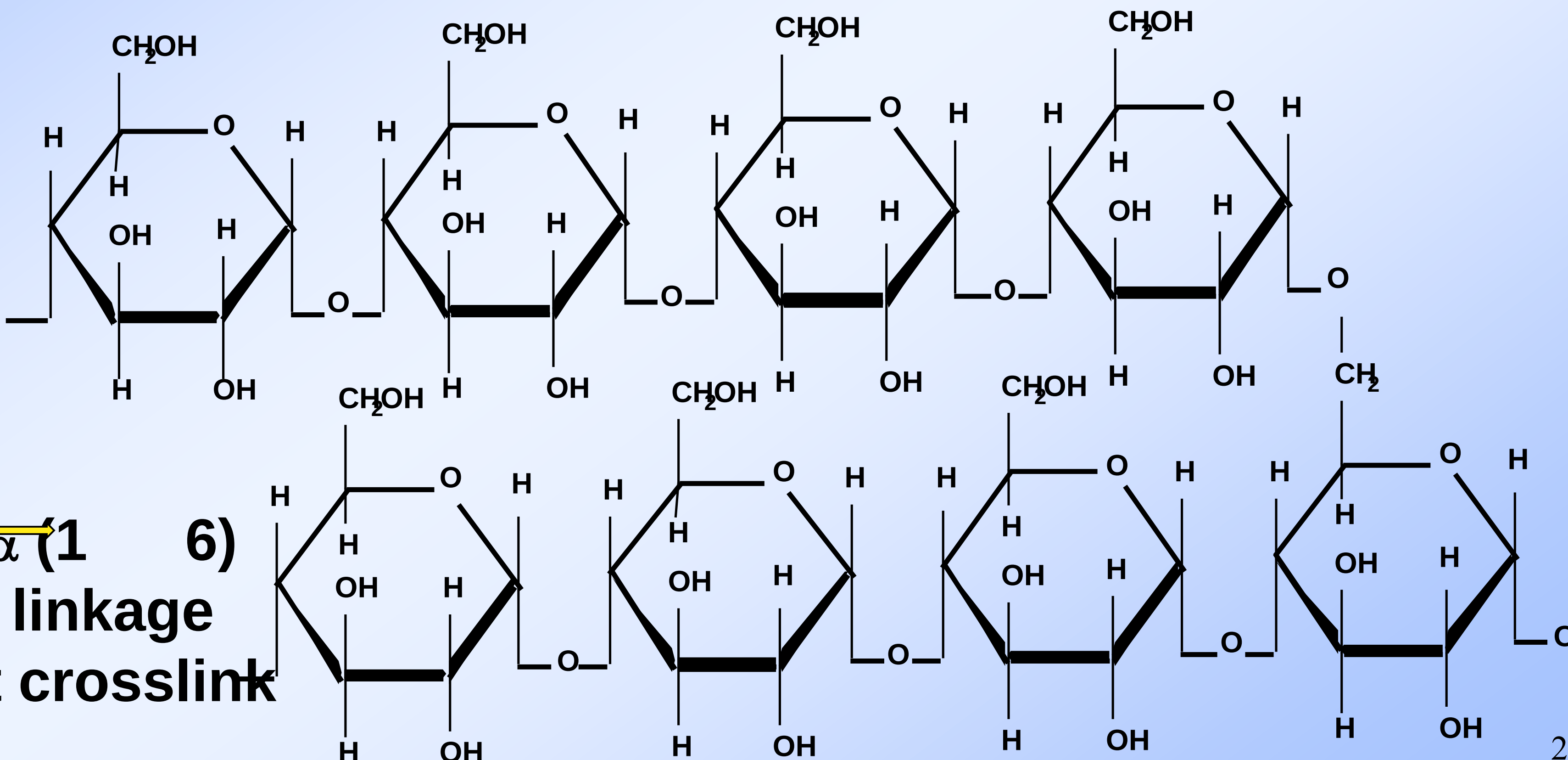


Amylopectin starch

makes up 80% of plant starch

Branched structure due to crosslinks.

About every 25 glucose units of amylopectin, a branch of glucose units are connected to the glucose by an α (1→6) Glycosidic bond.



α (1 → 6) linkage at crosslink

Amylose	Amylopectin
1. Occurs to the extent of 15 to 20%	1. Occurs 80 to 85%
2. Low molecular weight— approx. 60,000	2. High molecular weight— approx. 5,00,000
3. Soluble in water	3. Insoluble in water, can absorb water and swells up
4. Gives blue colour with dilute iodine solution	4. Gives reddish-violet colour with I2 solution

Amylose

Amylopectin

5. Structure

Unbranched

- **Straight chain**
- **250 to 300 D-Glucose units linked by $\alpha 1 \rightarrow 4$ linkages**
- **Twists into a helix , with six glucose units per turn**

5. Structure

- **Highly branched structure**
- **More D-Glucose Units joined together**
- **Structure similar to glycogen**
- **Main stem has α-1 → 4 glycoside bonds**

At branch point $\alpha 1 \rightarrow 6$ linkage, Approx 80 branches. Onebranch after every 24 to 30 D-Glucose units

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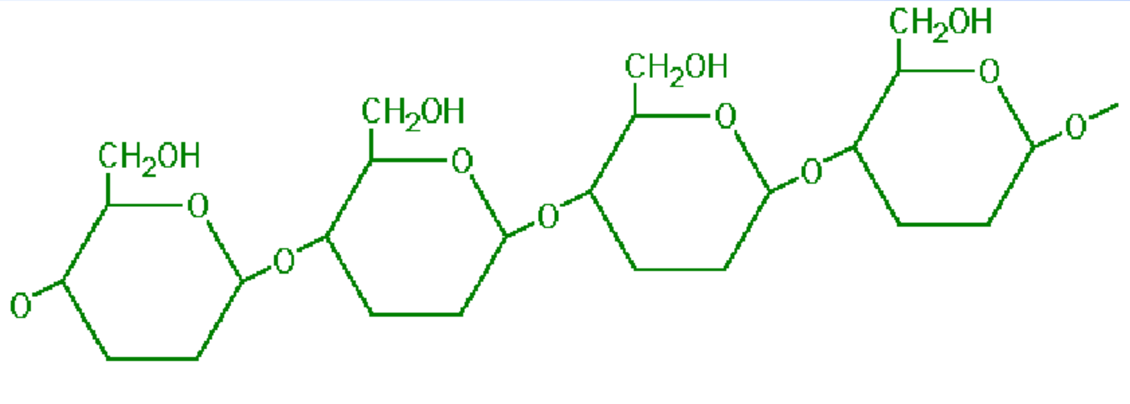
Amylose and amylopectin are the 2 forms of starch. Amylop
is a highly branched structure, with branches occurring eve
to 30 residues

Cellulose:

It is the most abundantly found polysaccharide in nature. It has a linear chain of D-glucose residues linked together by a β-1,4 glycosidic linkage.

Human beings are not able to utilize cellulose because of lack of a GIT enzyme which can cleave the β-1,4 glycosidic bond.



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(in starch)

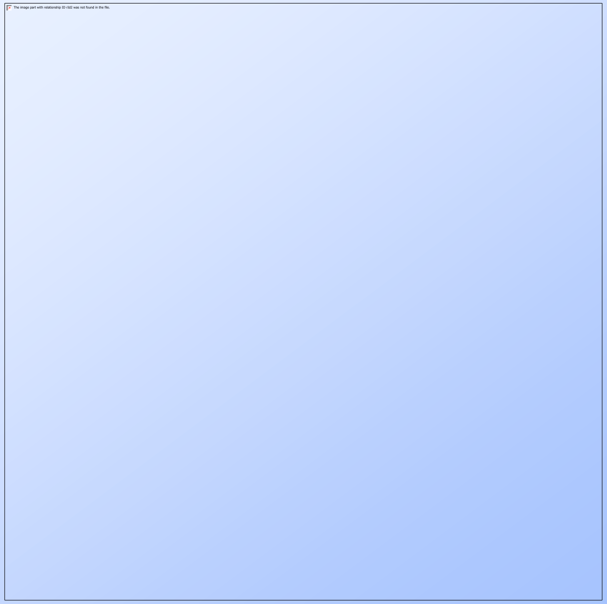
(in cellulose)

❖ <u>Glycogen:</u>

It is the major CHO reserve of human body, stored mainly in the liver and muscles.

The structure of glycogen is similar to amylopectin but is much more complex & branched molecule .

Branching occurs at every 12 Glucose residues.



Hetropolysaccharides.

These polysaccharides contain in their molecules certain groups in addition to CHO. These can be further subdivided into following types:

- **Mucopolysaccharides:**

  These include heparin, hyaluronic acid, chondrotin sulphates, serum mucoids, blood groups Polysaccharides. These are essential components of tissues. These combine with protein to form mucoprotien and mucin.

- **Mucilages:**

  Are complex colloidal materials present in the plants forming gel Or having adhesive property. These include agar, vegetable gums etc.

Derived Carbohydrates:

These are derived from CHO by various chemical reactions. These include the following:

- ✓ **Oxidation products:**

  Various sugar acids are derived from CHO (glucose) on its oxidation. E.g. Gluconic acid, glucuronic acid, glucaric acid.

- ✓ **Reduction Products:**

  Reduction products are alcohol. E.g. Glycerol & ribitol derived from glyceraldehyde& ribose respectively.

- ✓ **<u>Aminosugars:</u>**

  These have –NH2 group at c number 2 & include glucosamine, galactosamine & mannosomine derived from glucose, galactose & mannose respectively.

- ✓ **<u>Deoxy Sugars:</u>**

  These have less number of oxygen atoms than sugar. An important example is 2-Deoxyribose present in DNA molecule.

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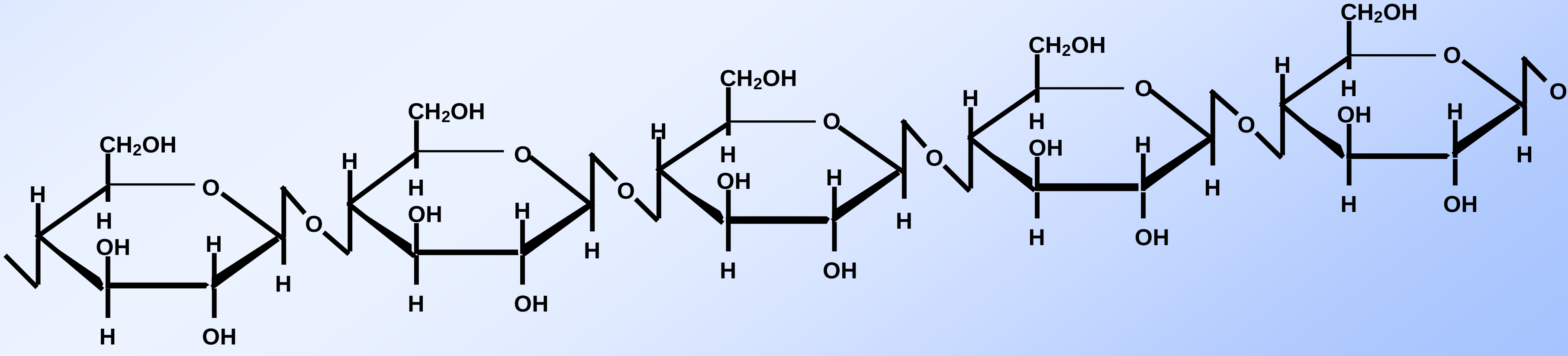
examples of deoxysugars

Examples of deoxysugars

Homopolysaccharide Cellulose

Homopolysaccharide- Cellulose

- Structural Polysaccharides
- **Most abundant polysaccharide.**
- **Is formed of glucose units attached by β (1 ⟶ 4) glycosidic linkages.**
- **Result in long fibers - for plant structure.**

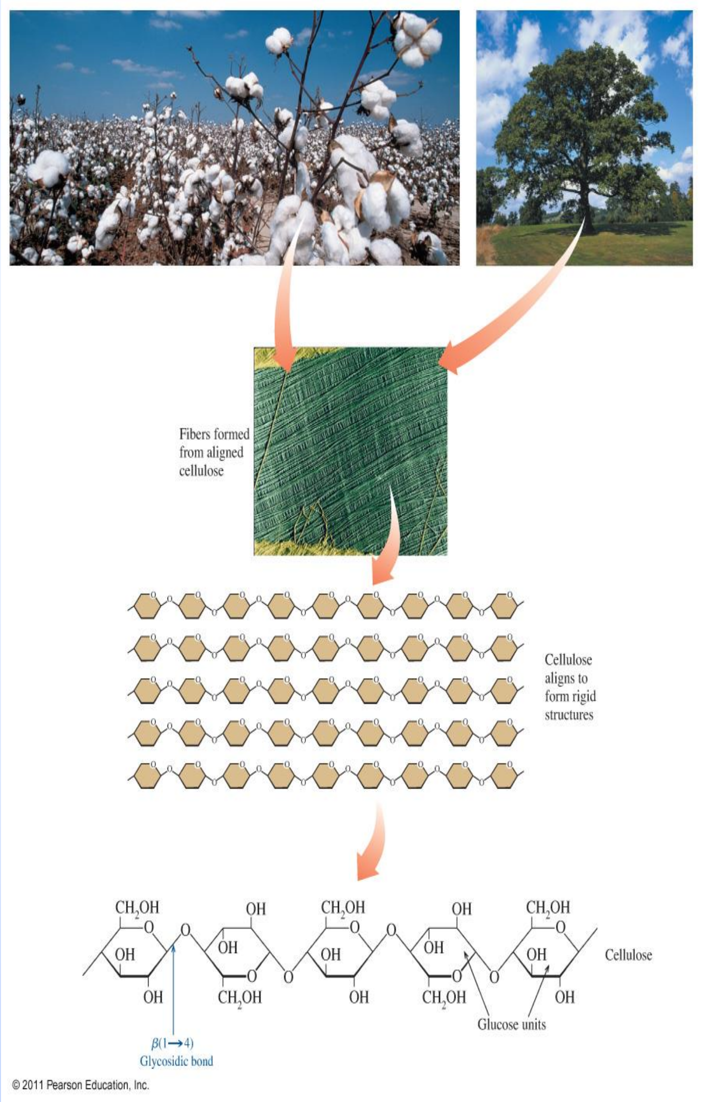


Homopolysaccharide -Cellulose

Is formed of glucose units attached by β (1 4) glycosidic linkages

This glycosidic bond configuration changes the three-dimensional shape of cellulose compared with that of amylose.

The chain of glucose units is straight. This allows chains to align next to each other to form a strong rigid structure.



Biomedical Importance- Cellulose

Cellulose is a very stable insoluble compound.

main constituent of the supporting tissues of plants, it forms a considerable part of our vegetable food.

Herbivorous animals, with the help of bacteria, can utilise a considerable proportion of the cellulose ingested

Homopolysaccharide -Cellulose

but in human beings no cellulose splitting enzyme cellulase **is secreted by GI mucosa,** to hydrolyze the $\beta(1\rightarrow4)$ glycosidic bond**, hence it is not of any nutritional value.**

important in our diet **as it adds bulk to the intestinal contents (roughage) thereby stimulating peristalsis and elimination of indigestible food residues.--** it assists with digestive movement in the small and large intestine.

Whole grains are a good source of cellulose.

Homopolysaccharide - 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*

Biomedical Importance- Dextrins

Dextrin solutions are often used as mucilages

Starch hydrolysates consisting largely of dextrins and maltose are widely used in infant feeding.

Limit Dextrin:

It is a well defined dextrin.

***This is the* product remaining after the β*-Amylase has acted upon* starch until no further action is observed.**

Homopolysaccharide - Dextrans

It is a *polymer of D-Glucose.*

It is synthesized by the action of *Leuconostoc mesenteroides, a non-pathogenic gram* +ve cocci in a sucrose medium.

Exocellular enzyme produced by the organisms bring about polymerisation

of glucose moiety of sucrose molecule, and forms the polysaccharide known as *Dextrans.*

Homopolysaccharide - Dextrans

They differ from dextrins in structure.

They are made up of units of a number of D-Glucose molecules, having $\alpha 1 \rightarrow 6$, $\alpha 1 \rightarrow 4$ or $\alpha 1 \rightarrow 3$ glycosidic linkages, within each unit and the units are joined together to form a network.

Homopolysaccharide - Dextrans

Dextran solution, having molecular wt approx. 75,000 have been used as Plasma Expander.

When given IV, in cases of blood loss (haemorrhage), it increases the blood volume.

Because of their high viscosity, low osmotic pressure, slow disintegration and utilisation, and slow elimination from the body they remain in blood for many hours to exert its effect.

Homopolysaccharide - Agar

Made up of repeated units of galactose which is sulphated.

Present in seaweed. It is obtained from them.

Biomedical Importance

In human:

Used as laxative in constipation. Like cellulose,it is not digested, hence add bulk to the faeces and helps in its propulsion.

In microbiology:

Agar is available in purified form. It dissolves in hot water and on cooling it sets like gel. It is used in agar plate for culture of bacteria.

HETEROPOLYSACCHARIDES (HETEROGLYCANS)—MUCOPOLYSACCHARIDES (MPS)

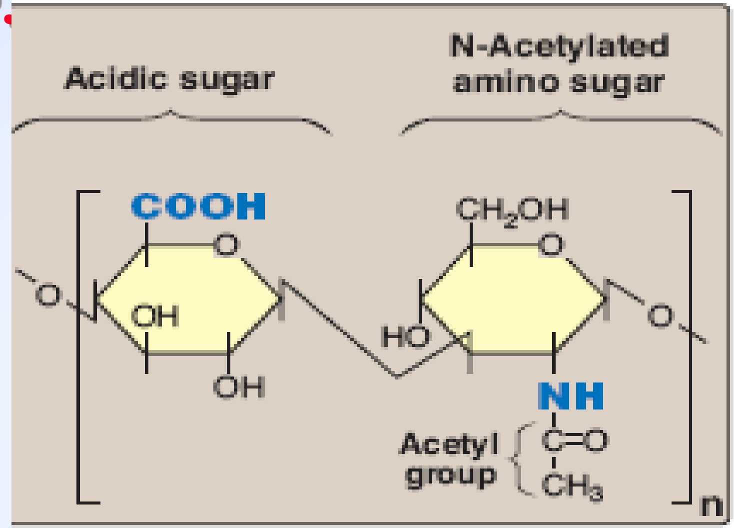
Glycosaminoglycans (GAG)

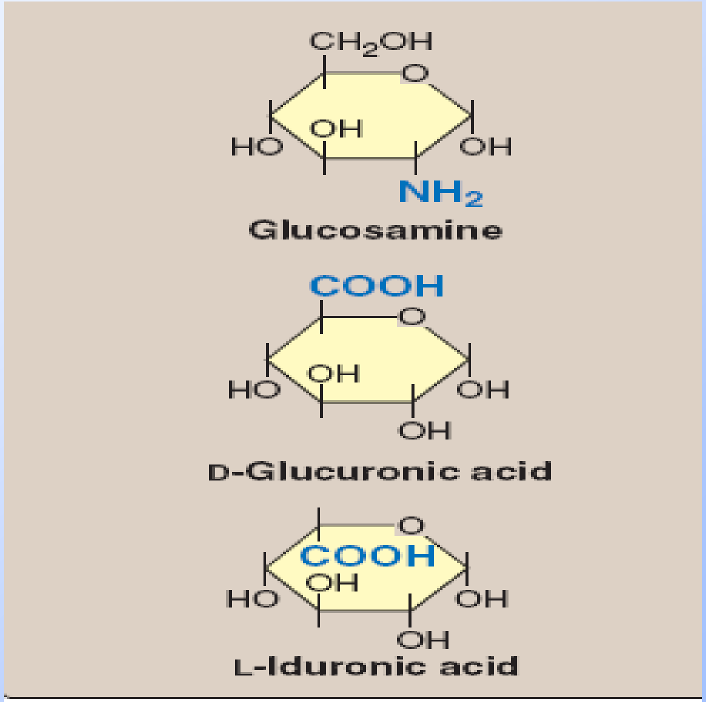
group of substances.

usually composed of *amino sugar* *and* *uronic acid units* as the principal components.

some are chiefly made up of amino sugar and monosaccharide units *without the presence of uronic acid.*

The hexosamine present is generally acetylated.





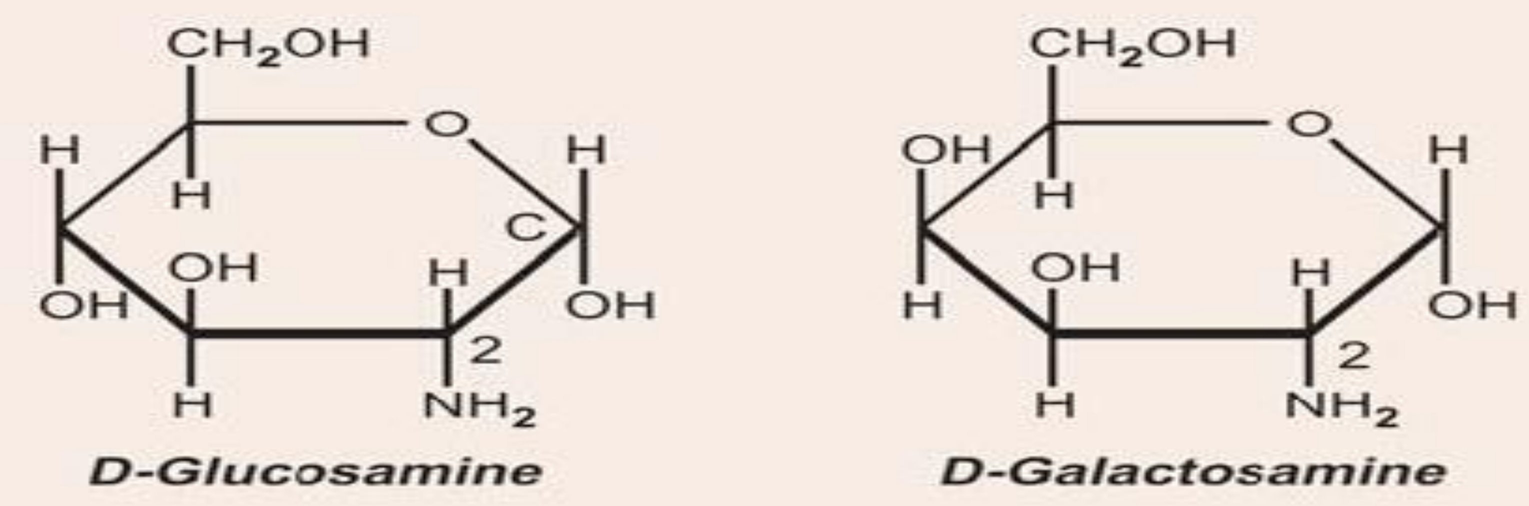
Amino sugars (hexosamines)

Glycosamine (Glycamine):

Two naturally occurring members of this type are derived from glucose **and** galactose,

in which – OH group on carbon 2 is replaced by – **NH2** group,

and forms respectively *Glucosamine* ***and*** *Galactosamine*



Glycosaminoglycans (GAG)

group of substances.

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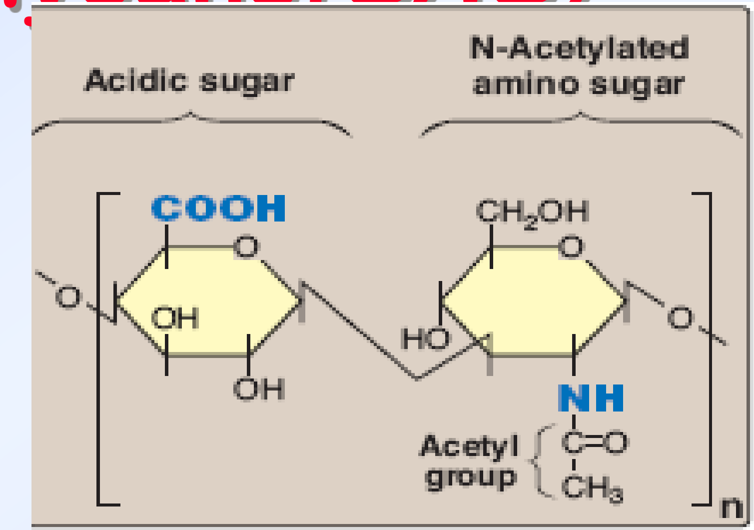
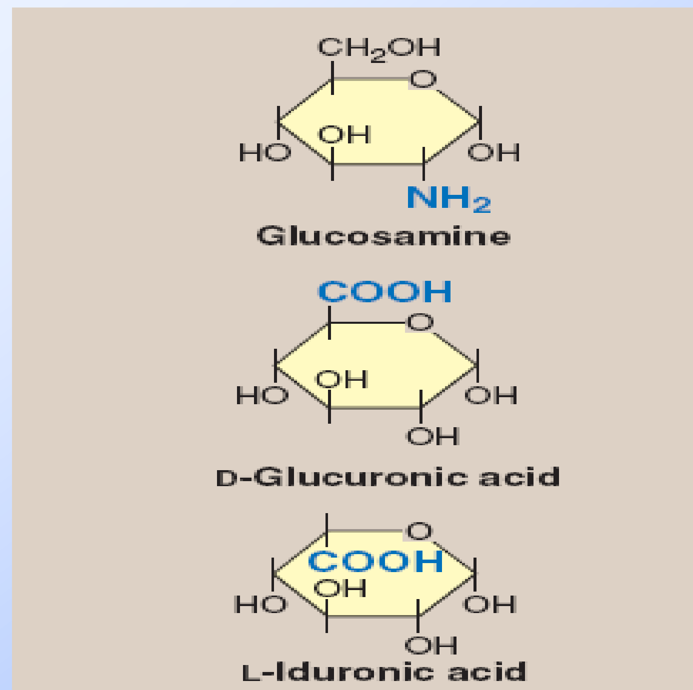




GLYCOSAMINOGLYCANS:

GAGS are large complexes of negatively charged heteropolysaccharide chains.

They are generally associated with a small amount of protein (core protein) forming proteoglycans, which typically consists of upto 95% carbohydrates.

This is in comparison with glycoproteins which consist primarily of protein with a variable but typically small amount of carbohydrate.

STRUCTURE OF GAGS

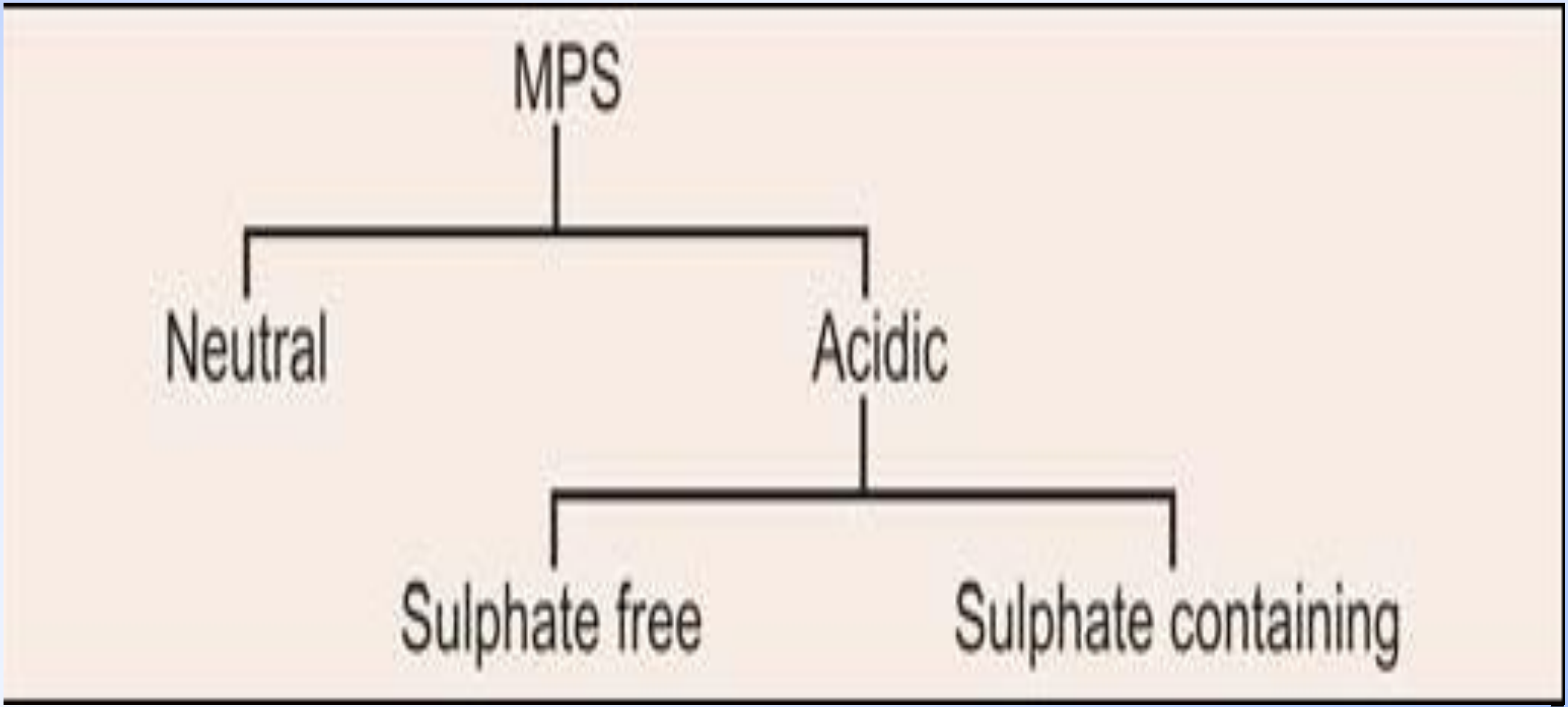
GAGS are long unbranched heteropolysaccharide chains composed of a repeating diasaccharide units.

AMINO SUGAR

- **Amino sugar is either D-GLUCOSE AMINE or D-GALACTOSE AMINE.in which amino group is usually acetylated thus eliminating it positive charge.**

CLASSIFICATION

Heteropolysaccharides (mucopolysaccharides) are classified as follows:



CLASSIFICATION

monomeric composition, type of glycosidic linkages, and degree and location of sulfate units.

I. Acidic Sulphate free MPS

1. Hyaluronic Acid
2. Chondroitin

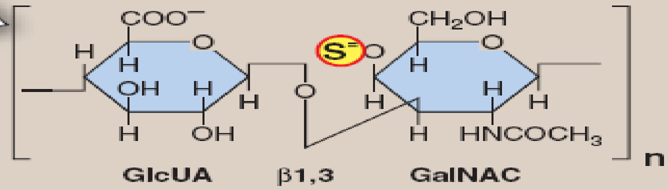
II. Sulphate Containing Acidic MPS

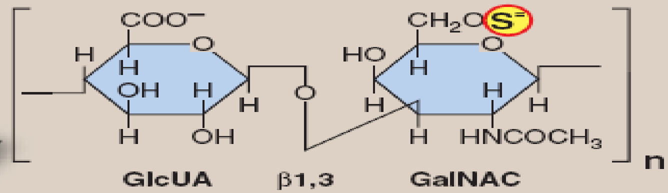
1. Keratan Sulphate (Kerato Sulphate)
2. Chondroitin Sulphates
3. Heparin
4. Heparitin Sulphate

III. Neutral MPS

CHONDROITIN 4- AND 6-SULFATES

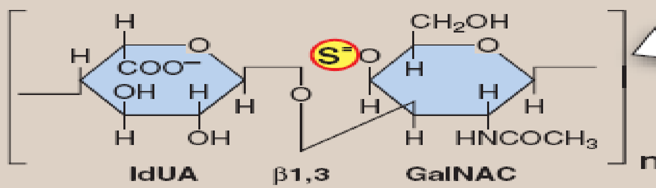
- Disaccharide unit: N-acetylgalactosamine with sulfate on either C-4 or C-6, and glucuronic acid.
- Most abundant GAGs in the body.
- Found in cartilage, tendons, ligaments, and aorta.
- Form proteoglycan aggregates, often aggregating noncovalently with hyaluronic acid.
- In cartilage, they bind collagen and hold fibers in a tight, strong network.





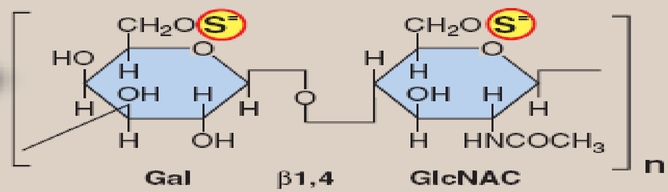
DERMATAN SULFATE

- Disaccharide unit: N-acetylgalactosamine and L-iduronic acid (with variable amounts of glucuronic acid).
- Found in skin, blood vessels, and heart valves.



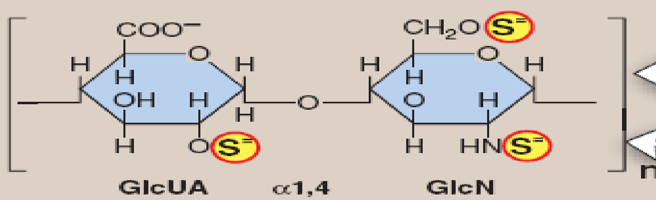
KERATAN SULFATES I and II

- Disaccharide unit: N-acetylglucosamine and galactose (no uronic acid). Sulfate content is variable and may be present on C-6 of either sugar.
- Most heterogeneous GAGs because they contain additional monosaccharides such as L-fucose, N-acetylneuraminic acid, and mannose.
- KS II is found in loose connective tissue proteoglycan aggregates with chondroitin sulfate. KS I is found in cornea.



HEPARIN

- Disaccharide unit: Glucosamine and glucuronic or iduronic acid. Most glucosamine residues are bound in sulfamide linkages. Sulfate is also found on C-3 or C-6 of glucosamine and C-2 of uronic acid (an average of 2.5 S per disaccharide unit).
- α-Linkage joins the sugars.
- Unlike other GAGs that are extracellular compounds, heparin is an intracellular component of mast cells that line arteries, especially in liver, lungs, and skin.
- Serves as an anticoagulant.

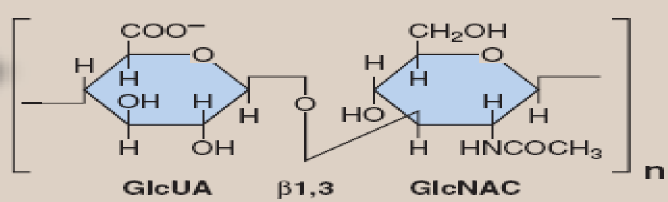


HEPARAN SULFATE

- Disaccharide unit: Same as heparin except some glucosamines are acetylated and there are fewer sulfate groups.
- Extracellular GAG, found in basement membrane and as a ubiquitous component of cell surfaces.

HYALURONIC ACID (HYALURONATE)

- Disaccharide unit: N-acetylglucosamine and glucuronic acid.
- Different from other GAGs: Unsulfated, not covalently attached to protein, and only GAG not limited to animal tissue, but also found in bacteria.
- Serves as a lubricant and shock absorber.
- Found in synovial fluid of joints, vitreous humor of the eye, the umbilical cord, loose connective tissue and cartilage.



Acidic Sulphate free MPS-- Hyaluronic Acid

A sulphate free mucopolysaccharide

vitreous humour of eye, synovial fluid, skin, umbilical cord, haemolytic streptococci and in rheumatic nodule.

It occurs both in free and salt-like combination with *proteins*

These materials provide a thin, viscous, jelly-like coating to cells.

***forms ground substance of mesenchyme, an integral part* of gel-like ground substance of connective and other tissues.**

Acidic Sulphate free MPS-- Hyaluronic Acid

Composition:

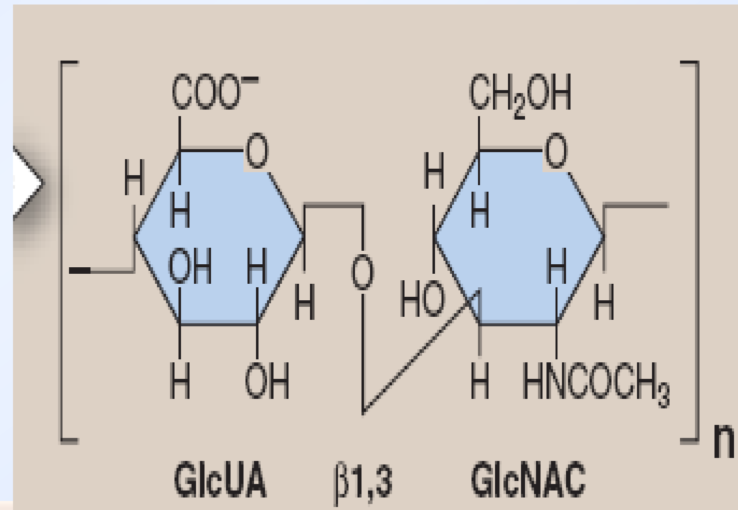
repeating units of N-acetyl glucosamine and D-Glucuronic acid.

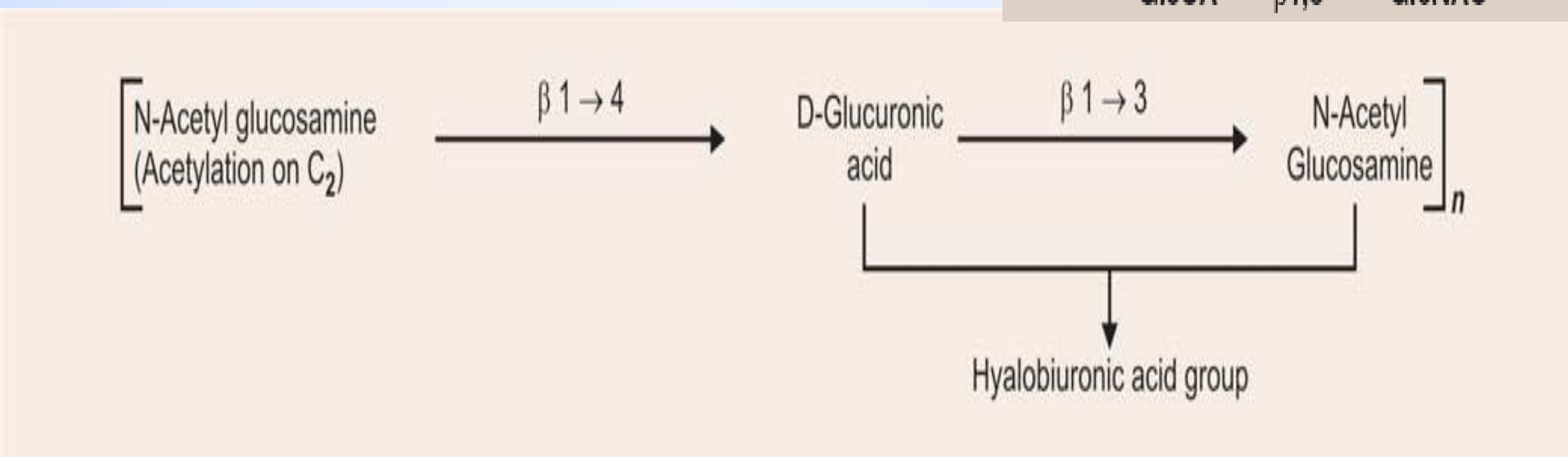
On hydrolysis

it yields equimolecular quantities of

D-Glucosamine,

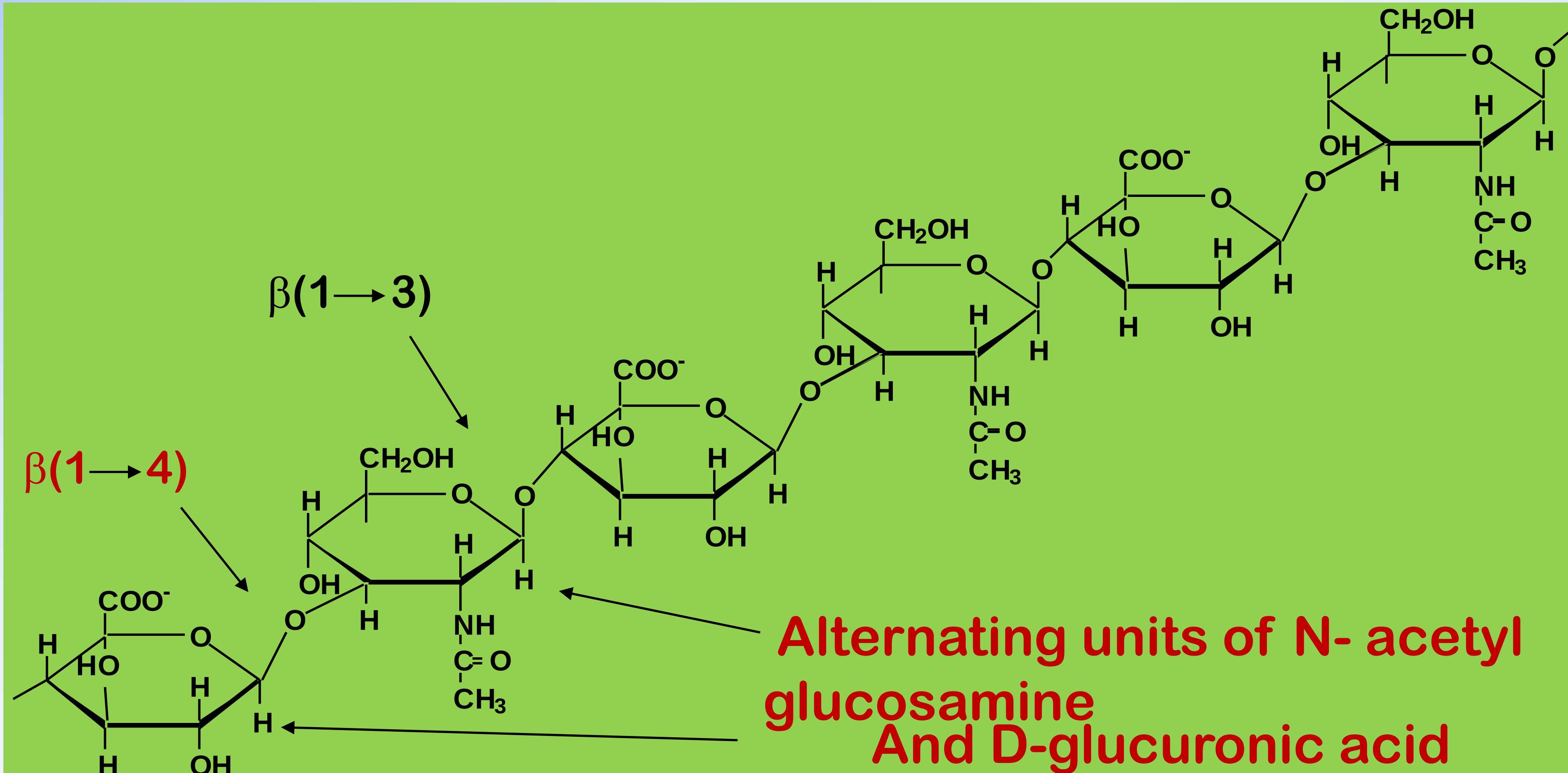
D-Glucoronic acid and acetic acid





Acidic Sulphate free MPS-- Hyaluronic Acid

The most abundant form of Mucopolysaccharides is hyaluronic acid.



Biomedical Importance - Hyaluronic Acid

Acts as a barrier in tissue:

- ✓ in tissues acts as a cementing substance
- ✓ contributes to tissue barrier which permit metabolites to pass through but resist penetration by bacteria and other infective agents.

Acts as lubricant in joints:

- ✓ acts as a lubricant and shock absorbant.
- ✓ Intra articular injection of hyaluronic acid in knee joints is used to alleviate pain in chronic osteoarthritis of knee joints.

Biomedical Importance - Hyaluronic Acid

- **Role in release of hormone:**

  hyaluronic acid are present in storage or secretory granules, where they play part in release of the contents of the granules.

- **Role in cell migration in embryonic tissues:**

  present in high concentration in embryonic tissues is considered to play an important role in cell migration during morphogenesis and wound repair.

Acidic Sulphate free MPS- Chondroitin

Another *sulphate free acid mucopolysaccharide.*

Found in *cornea and has been isolated from cranial cartilages.*

It differs from hyaluronic acid only in that it contains N acetyl galactosamine instead of N-acetyl glucosamine.

[N-acetyl Galactosamine → D-GLUCORONIC ACID → N-Acetyl galactosamine] n

Sulphate Containing Acid MPS

Sulphate Containing Acid MPS
Chondroitin Sulphates

principal MPS in the ground substance of mammalian tissues and cartilage.

occur in combination with proteins -*Chondroproteins.*

Four chondroitin sulphates A, B, C and D.

Sulphate Containing Acid MPS
Chondroitin Sulphates

a. Chondroitin SO4 A:

***present chiefly in** cartilages,* adult bone and cornea.

Structure:

consists of repeating units of

N-acetyl-D galactosamine **and** D-Glucuronic acid.

N-Acetyl galactosamine is esterified with SO4 in *position 4 of galactosamine*

Sulphate Containing Acid MPS
Chondroitin Sulphates

b. Chondroitin SO4 B:

present in *skin, cardiac valves* and tendons aortic wall and lung parenchyma

It has a ***weak*** *anticoagulant property*, ***hence sometimes it*** is called as β-*Heparin.*

As it is found in skin, it is also called as ***Dermatan sulphate.***

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Sulphate Containing Acid MPS
Chondroitin Sulphates

b. Chondroitin SO4 B:

Structure:

It consists of repeating units of

L-iduronic acid and N-acetyl galactosamine.

It has L-iduronic acid in place of glucuronic acid which is found in other chondroitin sulphates.

Sulphate moiety is present **at C4 of N-acetyl galactosamine molecule.**

Sulphate Containing Acid MPS
Chondroitin Sulphates

c. *Chondroitin SO4 C:*

found in cartilage and tendons.

Structure of chondroitin SO4 ***C is the same as that*** **of chondroitin SO4 A**

except that the SO4 group is ***at position 6 of galactosamine molecule instead of position 4.***

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Sulphate Containing Acid MPS
Chondroitin Sulphates

d. *Chondroitin SO4 D:*

isolated from the cartilage of shark.

It resembles in structure to chondroitin SO4 *C except that it has a second SO4 attached* probably at carbon 2 or 3 of uronic *acid moiety.*

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Sulphate Containing Acid MPS- **Heparin**

α-Heparin.

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

also found in lungs, thymus, spleen, walls of large arteries, skin and in small quantities in blood.

α-Linkage joins the sugars.

- **Serves as an anticoagulant.**

Unlike other GAGs that are extracellular compounds, heparin is an intracellular component of mast cells that line arteries, especially in liver, lungs, and skin

Sulphate Containing Acid MPS Heparin

Structure:

polymer of repeating disaccharide units **of**

D-Glucosamine (Glc N) and either of the two uronic acids-D-Glucuronic acid (Glc UA) and L-Iduronic acid (IDUA)

The -NH2 group at C2 and OH group at C6 of D-Glucosamine (Glc N) are sulphated.

A few may contain acetyl group on C2 of D-Glucosamine

In addition, the OH group of C2 of uronic acids, D-Glucuronic acid and/or L-Iduronic acid, are sulphated.

Sulphate Containing Acid MPS Heparin

Structure:

Initially, all of the uronic acids are D-Glucuronic acid (Glc UA), but *"5-epimerase" enzyme converts approximately 90 per*cent of the D-Glucuronic acid residues to L-Iduronic acid

Hence, in fully formed Heparin molecule 90 per cent or more of uronic acid residues are L-Iduronic acid.

NEUTRAL MPS

PROTEOGLYCANS

PROTEOGLYCANS

Proteoglycans are conjugated proteins.

Proteins called “core” proteins are covalently linked to glycosaminoglycans (GAGs).

Any of the GAGs viz. hyaluronic acid (HA); keratan sulphates I and II, chondroitin sulphates A, B, C, heparin and heparan sulphate can take part in its formation.

The amount of carbohydrates in proteoglycans is much greater (upto 95%) as compared to glycoproteins

"Bottle-brush" model of a cartilage proteoglycan monomer.

Proteoglyca n aggregate

Linkage region of

Functions of Proteoglycans

As a constituent of extracellular matrix or ground substance

Interacts with collagen and elastin

Acts as polyanions:

GAGS present in proteoglycans are polyanions and hence bind to polycations and cations such as Na and K. Thus attracts water by osmotic pressure into extracellular matrix contributing to its turgor.

Acts as a barrier in tissue:

Hyaluronic acid in tissues acts as a cementing substance and contributes to tissue barrier which permit metabolites to pass through but resist penetration by bacteria and other infective agents.

Acts as lubricant in joints:

Hyaluronic acid in joints acts as a lubricant and shock absorbant. Intraarticular injection of hyaluronic acid in knee joints is used to alleviate pain in chronic osteoarthritis of knee joints.

Functions of Proteoglycans

Role in release of hormone:

Proteoglycans like hyaluronic acid are present in storage or secretory granules, where they play part in release of the contents of the granules.

Role in cell migration in embryonic tissues:

Hyaluronic acid is present in high concentration in embryonic tissues nd is considered to play an important role in cell migration during morphogenesis and wound repair.

Role in glomerular filtration:

Proteoglycans like hyaluronic acid is present in basement membrane (BM) of glomerulus of kidney where it plays important role in charge selectiveness of glomerular filtration.

Functions of Proteoglycans

Role as anticoagulant in vitro and in vivo:

– In vitro, heparin is used as an anticoagulant. 2 mg/10 ml of blood is used.

Most satisfactory anticoagulant as it does not produce a change in red cell volume or interfere with its subsequent determinations.

– In vivo, heparin is an important anticoagulant. It binds with factor IX and XI,

but its most important action is with plasma antithrombin III. Binding of heparin to lysine residues in antithrombin III produces conformational change (which promotes the binding of the latter to serine protease thrombin which is inhibited)

thus fibrinogen is not converted to fibrin.

Functions of Proteoglycans

Role as a coenzyme:

Heparin acts in the body to increase the activity of the enzyme Lipoprotein lipase.

Heparin binds specifically to the enzyme present in capillary walls,causing a release of the enzyme into the circulation. Hence heparin is called as Clearing factor.

As a receptor of cell:

Proteoglycans like heparan sulphate are components of plasma membrane of cells, where they may act as receptors and can participate in cell adhesion and cell-cell interactions.

Functions of Proteoglycans

Role in compressibility of cartilages:

Chondroitin sulphates and hyaluronic acid are present in high concentration in cartilages and have a role in compressibility of cartilage in weight bearing.

Role in sclera of eye:

Dermatan sulphate is present in sclera of the eye where it has an important function in maintaining overall shape of the eye.

Role in corneal transparency:

Keratan sulphate I is present in cornea of the eye and lie between the collagen fibrils. It plays an important role in maintaining corneal transparency.

Mucopolysaccharidoses:

The mucopolysaccharidoses are hereditary diseases (1:25,000 births)

caused by a deficiency of any one of the lysosomal enzymes normally involved in the degradation of heparan sulfate and/or dermatan sulfate

Biomedical Importance
Mucopolysaccharidoses:

The mucopolysaccharidoses are a group of related disorders,
due to inherited enzyme defect,
in which skeletal changes, mental retardation, visceral involvement and corneal clouding are manifested to varying degrees.

Defect/defects in these disorders result in:

- Widespread deposits in tissues of a particular MPS
- In excessive excretion of MPS in urine.

At least six types of mucopolysaccharidoses have been described

Mucopolysaccharidoses:

- **Types** — **MPS-I (Hurler's syndrome)**
- Inheritance — Autosomal recessive
- Enzyme defect — α-L-Iduronidase (A-Lysosomal hydrolase)
- Somatic skeletal changes — +++
- Mental retardation — Severe after one year
- Cardio- pulmonary — Valvular and coronary disease, Impaired ventilation
- Hepato- splenomegaly — +++
- Corneal clouding — Progressive
- Hearing loss — Present(Conductive)
- Urinary MPS — Dermatan SO4, Heparan SO4

Mucopolysaccharidoses:

- **Types MPS-II (Hunter's syndrome)**
- Inheritance — Sex linked recessive
- Enzyme defect — Iduronate sulfatase
- Somatic skeletal changes — ++ to +++
- Mental retardation — Severe but gradual in onset
- Cardio- pulmonary — Valvular disease , hypertension, Impaired ventilation
- Hepato- splenomegaly — +++
- Corneal clouding — Rare
- Hearing loss — Present (early onset) Perceptive
- Urinary MPS — Dermatan SO4, Heparan SO4

Mucopolysaccharidoses:

- **Types MPS-III(SAN Filipos syndrome) A, B and C**

- Inheritance Autosomal recessive

Enzyme defect sulfamidase,
-α-N-acetyl Glucosaminidase ,
Acetyl transferase

- Somatic skeletal changes Mild
- Mental retardation +++
- Cardio- pulmonary not described
- Hepato- splenomegaly ++ (Moderate)
- Corneal clouding Absent
- Hearing loss Present
- Urinary MPS Heparan SO4

Mucopolysaccharidoses:

- **Types MPS-IV (Morquio syndrome)**

- Inheritance Autosomal recessive

Enzyme defect N-Acetyl galactosamine 6-sulphatase

- Somatic skeletal changes +++
- Mental retardation Absent or slight
- Cardio- pulmonary Aortic regurgitation
- Hepato- splenomegaly Slight
- Corneal clouding Present Late onset

Hearing loss Present but not severe

- Urinary MPS Keratan SO4

Mucopolysaccharidoses:

- **Types MPS-V (Scheie syndrome)**

Inheritance	Autosomal recessive
Enzyme defect	α-L-Iduro- nidase
Somatic skeletal changes	Mild
Mental retardation	Essentially Absent
Cardio- pulmonary	Aortic Valvular disease
Hepato- splenomegaly	Variable
Corneal clouding	+++
Hearing loss	Variable
Urinary MPS	Dermatan SO4

Mucopolysaccharidoses:

- **Types MPS-VI ((Maroteaux-Lamy syndrome)**

- Inheritance — Autosomal recessive

Enzyme defect — N-acetylgalactosamine 4-sulphatase syndrome) (Aryl sulfatase

- Somatic skeletal changes — +++
- Mental retardation — Absent
- Cardio- pulmonary — Cardiac murmurs
- Hepato- splenomegaly — ++
- Corneal clouding — Present

Hearing loss — Variable

- Urinary MPS — Dermatan SO4

Oligosaccharides

It contains 3 to 10 monosaccharide units.

It occurs in glycoproteins, which are proteins to which oligosaccharides are covalently attached.

Carbohydrates and Blood

ABO Blood Types

ABO blood types refer to carbohydrates on red blood cells.

These chemical markers are oligosaccharides that contain either three or four sugar units.

Sugar units are D-galactose, L-fucose, *N*-acetylglucosamine, and *N*-acetylgalactosamine.

Carbohydrates and Blood

Type O blood is considered the universal donor while type AB blood is considered the universal acceptor.

The following table shows the compatibility of blood groups.

Heparin

is a medically important polysaccharide because it prevents clotting in the bloodstream.

It is a highly ionic polysaccharide of repeating disaccharide units of an oxidized monosaccharide and D-glucosamine.

Heparin also contains sulfate groups that are negatively charged.

It belongs to a group of polysaccharides called ***glycosaminoglycans***.

Chapter Summary, Continued

5.5 Disaccharides, Continued

Carbohydrates form glycosides when an anomeric carbon reacts with a hydroxyl group on a second molecule. The bond formed is called a ***glycosidic bond***.

Glycosidic bonds are named by designating the anomer of the reacting monosaccharide and the carbons that are bonded, for example, $\alpha(1\rightarrow4)$.

Chapter Summary, Continued

5.6 Polysaccharides

A ***polysaccharide*** consists of many monosaccharide units bonded together through glycosidic bonds.

Glucose is stored as glycogen in animals and starch in plants.

Starch consists of ***amylose***, a linear chain of glucose, and ***amylopectin***, a branched chain of glucose.

Chapter Summary, Continued

5.6 Polysaccharides, Continued

Glycogen contains many more branches in its structure than amylopectin.

Two important polysaccharides are cellulose in plants and chitin in arthropods and fungi.

Cellulose consists of $\beta(1\rightarrow4)$ and is the structural component of plants. It has a linear structure.

Chapter Summary, Continued

5.6 Polysaccharides, Continued

Chitin is linear. It contains *N*-acetylglucosamine.

Cellulose and chitin form strong, water-resistant materials when the linear chains are aligned to each other.

Chapter Summary, Continued

5.7 Carbohydrates and Blood

The ***ABO blood groups*** are oligosaccharides on the surface of red blood cells.

The O blood group is considered the universal donor.

Heparin, a polysaccharide, functions in the blood as an anticoagulant and is found as a coating on medical tubing and syringes during blood transfusions.

Heteropolysaccharide

classified into neutral and acidic .

Acidic

Sulpher containing

- keratan sulphate
- Chondroitin sulphte
- heparin

Sulpher free

- hyaluronic acid
- chondroitin