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#### PHYSIOLOGY HONOURS (CBCS) SEMESTER-I (MODULE-CC-2)



Prepared by: Dr. Madhumita Debnath Asst. Professor in Physiology, Dr. K.L. Bhattacharyya College Carbohydrates are probably the most abundant and widespread organic substances in nature, and they are essential constituents of all living things. The general formula  $C_x(H_2O)_y$  is commonly used to represent many carbohydrates, which means "watered carbon."

## **Definition:**

A carbohydrate is a bio-molecule consisting of carbon (C), hydrogen (H) and oxygen (O) atoms, usually with a hydrogen–oxygen ratio of 2:1 (as in water) and thus with the empirical formula of  $C_m(H_2O)_{n}$ .

 $\circ$  Many do not obey this formula- Fucose (C<sub>6</sub>H<sub>12</sub>O<sub>5</sub>)  $\circ$ Many contain other molecules such as N  $\circ$ Non-carbohydrates have similar formula- Formaldehyde (CH<sub>2</sub>O)



Therefore carbohydrates are polyhydroxy aldehydes or polyhydroxy ketones.

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# **Classification of Carbohydrates**



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#### MONOSACHHARIDES

**Definition:** Simplest form of carbohydrate which cannot be hydrolyzed further into smaller molecules. Usually contains 5-7 carbons. Have a general formula of  $C_n H_{2n} O_n$ .

#### **General properties:**

Water soluble substance
Sweet in taste
Usually colourless and odourless
Form isomers
Shows optical activity

#### **Structures:** Depending upon number of carbon atoms in a monosaccharide.

- Trioses (C3)- Glyceraldehyde, Dihydroxy acetone
- Tetroses (C4)- Erythrose, Erythrulose
- Pentoses (C5)- Ribose and Ribulose
- Hexoses (C6)- Glucose, Fructose, Galactose, Mannose
- Heptoses (C7)- Sedoheptulose

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# **TRIOSE (C3)**

![](_page_5_Figure_3.jpeg)

![](_page_6_Picture_0.jpeg)

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# **TETROSE (C4)**

![](_page_6_Figure_3.jpeg)

![](_page_6_Picture_4.jpeg)

D-Erythrulose

L-Erythrulose

## **PENTOSE (C5)**

![](_page_7_Figure_3.jpeg)

![](_page_7_Figure_4.jpeg)

**D-Ribose** 

Ribulose

Xylulose

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## **ALDOHEXOSE (C6)**

![](_page_8_Figure_3.jpeg)

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# **Ketohexose (6C)**

![](_page_9_Figure_3.jpeg)

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## **ISOMERISM IN MONOSACHARIDES:**

Isomers are compounds having same molecular formulae but different structural formulae.

- 1) Aldose Ketose isomerism
- 2) Epimerism
- 3) D-L steoisomerism
- 4) Optical Isomerism
- 5) Pyranose- Furanose Isomerism
- 6) Anomerism

\*Concept of asymmetric carbon atom: An asymmetric carbon carries 4 different groups (or atoms) in its four valencies. For eg. Glucose contains 4 asymmetric carbon atoms.

![](_page_10_Figure_11.jpeg)

•Concept of Stereoisomerism: A molecule bearing an asymmetric carbon may hold different groups or atoms around it and thus may exists in more than one structural configuration (3D-spatial arrangement). This is known as stereo-isomerism. Epimerism, optical isomerism, D-L stereoisomerism and anomerism are different types of stereoisomerism.

\**Van't Hoff Rule*: The maximum possible number of isomers of a compound with n number of asymmetric carbon would be 2<sup>n</sup>.

Examples:

1. Glucose has 4 chiral carbons in its aldehyde form, and so there are  $2^4 = 16$  possible stereoisomers of this formula.

2. Fructose has 3 chiral carbons in its aldehyde form, and so there are  $2^3 = 8$  possible stereoisomers of this formula.

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#### **16 stereoisomers of Glucose**

![](_page_12_Figure_3.jpeg)

L-isomers

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a) Aldose- Ketose Isomerism: An aldose (monosaccharides with aldehyde group at C1) and a Ketose (Monosachharides with ketone group at a position other than C1) are isomer to each other because they have same molecular formula but different functional group in their structure. For Eg., Glucose (Aldose) and Fructose (Ketose) are 'aldo-keto' isomer to each other,

![](_page_13_Figure_3.jpeg)

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## 2. Epimerism

Isomers differ from each other in the configuration around one asymmetric carbon atom.

![](_page_14_Figure_4.jpeg)

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c) **D-L steroisomer:** This isomerism is based on spatial orientation of H and OH groups on **penultimate carbon** (the asymmetric carbon farthest from aldehydic or ketonyl carbon) of a molecule. If H and OH groups on the penultimate carbon of a monosaccharide are oriented like the H and OH groups of the middle carbon of D-glyceraldehyde, that monosaccharide is called D-isomer. Similarly, If H and OH groups on the penultimate carbon of a monosaccharide are oriented like the H and OH groups of the middle carbon of D-glyceraldehyde, that carbon of a monosaccharide are oriented like the H and OH groups of the middle carbon of be penultimate carbon of a monosaccharide are oriented like the H and OH groups of the middle carbon of L-glyceraldehyde, it is called L-isomer. D-isomer and L-isomer are said to be mirror image to each other. For Eg., D-glucose and L-glucose.

![](_page_15_Figure_3.jpeg)

**D. Optical isomerism:** If **polarized light** (not ordinary light) is allowed to pass through a solution of substance having **asymmetric carbon atoms**, the plane of polarized light is rotated either **clockwise (dexrorotation)** or **anticlockwise (levorotation**). This is due to unequal influence of electromagnetic field (around asymmetric carbons of a substance) on the plane of polarized light.

Therefore, only a substance with asymmetric carbon in its structure can demonstrate optical activity. The magnitude and direction of rotation will depend on sum of dextrorotatory and levorotatory effects of all asymmetric carbon atoms.

![](_page_16_Figure_4.jpeg)

- Dextrorotatory isomer (d or '+' as prefix) rotates plane of polarized light clockwise. Eg, d-glucose (+52.7°)
- 2) Levorotatory isomer (I or '-' as prefix) rotates plane of polarized light anti-clockwise.
   Eg, I-fructose (-92°)
- **3) Meso-isomer** is optically inactive because dextrorotatory effects of some of its asymmetric carbon exactly cancel out the levorotatory effects of remaining asymmetric carbons. Eg., Vitamin Inositol.
- **4) Racemic mixture** (dl mixture) has equimolar mixture of two optical isomers of a substance and thus has no optical activity.

#### **POLARIMETER:**

![](_page_17_Figure_5.jpeg)

![](_page_18_Picture_2.jpeg)

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\*Specific rotation: Optical rotation (in degrees) of the polarized light of a standard wavelength (sodium D light) at a specified temperature (25°C) due to the passage of light through 1 dm long column of solution containing 1 gm solute/ml.

Specific rotation [a] 
$$_{D}^{25} = \frac{a}{l x c} = \frac{100a}{l x C}$$

Where, a = specific rotation, a= observed rotation in degree at 25°C with Sodium D light, l= length of the solution column in dm, c= solute concentration in gm/ml, C= solute concentration in gm/dl.

#### E. Pyranose Furanose Isomerism:

□ Aldoses and ketoses (C6 or more) and aldopentoses (C5) exist in **tautomeric ring forms** due to the presence of **highly reactive aldehydeic or ketonyl C=O group** in the molecule. This C=O group reacts with an alcoholic OH group of another carbon of the molecule to produce **'hemiacetal'** or a **'hemiketal**'. The carbonyl group thus gets linked to the alcoholic carbon by a C-O-C bridge and the aldehyde or ketone group is changed into an OH group.

□ Because of this, the monosaccharide either forms a **6-member pyran ring** (5 carbons and 1 oxygen) or a **5-member furan ring** (4 carbons and 1 oxygen). So, the monosaccharide may exist either as pyranose or furanose isomeric forms.

□In aqueous solution, a hexose thus exists as an equilibrium mixture of Pyranose isomer, Furanose isomer and open chain form. For example, D-glucose exists as D-glucopyranose, D-glucofuranose and open-chain D-glucose.

\*Note: Ketopentose, trioses and tetroses cannot form Pyranose and Furanose isomers and therefore exists in open –chain form only.

#### Pyranose isomer of glucose

#### Fischer Projection

![](_page_21_Figure_2.jpeg)

![](_page_22_Figure_0.jpeg)

## Anomerism in Glucose

- 1) If the OH-group of anomeric carbon is oriented close to the terminal  $CH_2OH$  at the other end of the molecule (or above the plane of Haworth's ring) it is called  $\beta$ -anomer.
- 2) If the OH-group of anomeric carbon is oriented furthest from the terminal  $CH_2OH$  at the other end of the molecule (or below the plane of Haworth's ring) it is called **a**-anomer.

![](_page_23_Figure_5.jpeg)

![](_page_24_Figure_0.jpeg)

Haworth projection

![](_page_24_Figure_2.jpeg)

# **Fructose Anomersim**

![](_page_25_Picture_1.jpeg)

![](_page_25_Picture_2.jpeg)

![](_page_25_Picture_3.jpeg)

β-D-Fructopyranose

![](_page_25_Picture_5.jpeg)

![](_page_25_Picture_6.jpeg)

## **MUTAROTATION:**

1. Mutarotation is the property of a reducing sugar that possesses Anomerism. It is the change in the optical rotation of a freshly prepared aqueous solution of a reducing sugar until the optical rotation attains equilibrium.

2. It occurs due to **spontaneous inter-conversion of a and \beta anomer of a reducing sugar** in an aqueous solution. Non-reducing sugars, trioses, tetroses and keto-pentoses don't exhibit mutarotation because they don't have free anomeric –OH groups in their structure.

3.  $\alpha$  and  $\beta$  anomer of any reducing sugar differs in their optical rotation. In a solution, any of the anomer can changes into other anomer gradually until an equilibrium mixture is obtained. Optical rotation too gradually changes until it stabilizes as the resultant optical rotation of both the anomers.

4. For example: a-D glucopyranose (obtained from cold ethanol solution at 30<sup>o</sup>) initially shows specific rotation of +112.2<sup>o</sup>. On standing, the specific rotation gradually falls to +52.7<sup>o</sup>. It's because some a–D glucopyranose on standing changes into  $\beta$ –D-glucopyranose (specific rotation +18.7<sup>o</sup>).

5. Similarly,  $\beta$ –D-glucopyranose in aqueous solution (crystals obtained from hot pyridine solution) initially shows specific rotation of +18.7°. On standing the rotation gradually rises and stabilizes at +52.7°. This is due to spontaneous inter-conversion of  $\beta$  to the  $\alpha$  anomer showing the resultant optical rotation of equilibrium mixture of two anomers.

![](_page_27_Figure_0.jpeg)

#### **REACTIONS OF MONOSACHHARIDES**

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#### **1. REACTION WITH STRONG ACIDS:**

When a sugar is heated with a strong acid, it loses water and form **furfural** compound. Furfurals can then react with a-napthol, thymol, resorcinol, orcinol etc and form coloured complexes.

![](_page_28_Figure_5.jpeg)

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#### **2. REACTION WITH ALKALI:**

When aldose or ketose (with free aldehyde or ketone group) is treated with dilute aqueous alkali, both aldose and ketose change in to *Enediol*. Enediols are good reducing agents. The Enediol then reduces Cu<sup>2</sup>+, Fe<sup>3</sup>+, Ag+, Bi<sup>3</sup>+ etc. and itself gets oxidized to sugar acids.

# **ENEDIOL FORMATION**

![](_page_29_Figure_5.jpeg)

Biochemical importance:

- 1. Benedict's test
- 2. Fehling's test
- 3. Barfoed's test

reducing and non-reducing sugars

![](_page_29_Figure_11.jpeg)

#### Aldoses are reducing sugars

- 2-ketoses are usually nonreducing (reducing under basic conditions)
- 3- or 4-ketoses are always nonreducing

## **3. REACTION WITH PHENYLHYDRAZINE:**

A monosaccharide or a reducing disaccharide (containing free aldehyde or ketonyl group) when heated with phenyl hydrazine in acetic acid solution, it first changes into a **sugar-phenylhydrazone**. This product then reacts with more of the reagent to produce **sugar-osazone**. Osazone formation requires C1 and C2 of the sugar only.

A sugar-osazone **forms microscopic crystals** of orange or yellow colour with specific form and melting point. This test can distinguish between glucose, lactose and maltose by their characteristics osazone crystals under microscope.

![](_page_30_Figure_3.jpeg)

## Amino sugar:

Two types of amino sugar are available.

**1. Glycosamine**: An alcoholic –OH of the monosaccharide is replaced by a basic amino (-NH2 group). Example: Glucosamine, Galactosamine etc. Sometimes these amino sugar molecules are either acetylated or sulfated. These hexosamines are important part of structural polysaccharides.

**2. Glycosylamine:** If the anomeric –OH of a monosaccharide is replaced by a basic amino group. For example, Ribosylamine. Its phosphoryl derivative (5-phospho ribosylamine) is required for purine nucleotide synthesis.

![](_page_31_Figure_7.jpeg)

## Glycosylamines

A sugar in which an amino group replaces the anomeric OH is called a glycosylamine.

Examples are B-D-glucopyranosylamine and adenosine.

![](_page_31_Figure_11.jpeg)

Nucleosides are glycosylamines in which the amino component is a pyrimidine or a purine and in which the sugar component is either D-ribose or 2deoxy-D-ribose **2. De-oxy sugar:** Alcoholic –OH group of one of the carbon in monosaccharide is deprived of its oxygen. Example, 2-deoxyribose, 6-deoxy L-galactose (known as L-fucose) etc.

**3.** Sugar alcohol: If monosaccharides are reduced in presence of Na-amalgam, Naborohydride or  $H_2$  at high pressure with Ni-catalyst, then poly-hydroxy sugar alcohol are produced. For example: glucose is reduced to sorbitol.

![](_page_32_Figure_2.jpeg)

## 4. Sugar acid:

a. In presence of **mild–oxidizing agents** (such as HOBr or Na-hypoiodite) the aldehyde group of aldose is oxidized to produce aldonic acid. Ex: Gluconic acid.

b. In presence of **strong–oxidizing agents** (such as HNO3) both the aldehyde group and the –OH group at the farthest from it is oxidized. The aldose thus changes into sachharic acid. Ex: Galactosaccharic acid (mucic acid).

c. In presence of **platinum carbon catalyst**, only the terminal -CH2OH group of an aldose is oxidized only. This changes the aldose into uronic acid. Ex: Glucuronic acid.

![](_page_33_Figure_4.jpeg)

**5.** Sugar ester: The -OH groups of monosachharide form esters with acyl groups (from acyl chloride or acyl anhydride) or phosphate grou). Ex: glucose is esterified to Glucose-pentaacetate., glucose -6 phopsphate etc.

Glucose-6-Phosphate

![](_page_34_Figure_2.jpeg)

Note: an ester has been made.

## LACTOSE:

□A disaccharide consists of one galactose and one glucose molecule.

Anomeric C<sup>1</sup> –OH group of β-D galactopyranose remain connected to C<sup>4</sup> –OH group of D-glucopyranose by a β-1,4 glycosidic bond.

 $\Box$ Exists as a and  $\beta$  anomers.

□Water soluble, dextrorotatory sugar.

□ It is a reducing sugar because anomeric C1-OH group of the glucose molecule is free.

□ It shows mutarotation and forms lactosazone crystal.

Abundant in milk. It can be fermented to lactic acid by lactobacilli.

![](_page_35_Figure_10.jpeg)

## MALTOSE:

□A disaccharide consists of two molecules of glucose.

□Anomeric C<sup>1</sup> –OH group of α-D glucopyranose remain connected to C<sup>4</sup> –OH group of anther D-glucopyranose by a α-1,4 glycosidic bond.

□Water soluble, dextrorotatory sugar.

 $\Box$ Exists as a and  $\beta$  anomers.

□ It is a reducing sugar because anomeric C1-OH group of the second glucose molecule is free.

□ It shows mutarotation and forms maltosazone crystal.

Abundant in malt, germinating grains and amylase-catalyzed products of starch digestion.

![](_page_36_Figure_8.jpeg)

## SUCROSE:

A disaccharide composed of one molecule of each of glucose and fructose.

Anomeric  $C^2$  –OH group of  $\beta$ -D-fructofuranose remain connected to  $C^1$  –OH group of

**α- D-glucopyranose** by a **β-2, 1 glycosidic bond**.

□It is a **non-reducing–sugar** because there is no free anomeric –OH group in its structure.

□It shows no mutarotation.

Let forms no osazone.

Abundant in sugar cane, ripe sweet fruits etc.

□Water soluble sugar

![](_page_37_Figure_9.jpeg)

## Inversion

Sucrose shows **Inversion.** Sucrose is a dextrorotatory sugar (+66.5<sup>o</sup>). If it hydrolyzed in presence of HCl, the hydrolyzed product finally shows a levorotation of (-20<sup>o</sup>). This **change of optical rotation from dextro- to levorotation following the hydrolysis of sucrose is called inversion.** The mixture of glucose and fructose in the hydrolyzed solution is called 'invert sugar'. Intestinal sucrose enzyme is also known as invertase. Inversion occurs because, following hydrolysis, the levorotation of equilibrium mixture of fructopyranose anomers (-92<sup>o</sup>) exceeds dextrorotation of equilibrium mixture of glucopyranose anomers (+52.7<sup>o</sup>).

C <sub>12</sub> H <sub>22</sub> O <sub>11</sub> + H <sub>2</sub> O	$ \xrightarrow{H^{+}} C_{6}H_{12}O_{6} $	+ C <sub>6</sub> H <sub>12</sub> O
Sucrose	Glucose	Fructose
(dextro – rotatory)	(dextro – rotatory)	(leavo – rotatory)
+ 66.5 <sup>0</sup>	+ <b>52.5</b> °	– 92 <sup>0</sup>
	(leavo – rotatory)	

#### POLYSACCHARIDES

1. Polysaccharides are major classes of bio-molecules. They are **long chains of carbohydrate molecules, composed of several smaller monosaccharides.** These complex bio-macromolecules functions as an important source of energy in animal cell and form a structural component of a plant cell.

2. It can be **a homopolysaccharide or a heteropolysaccharide** depending upon the type of the monosaccharides.

3. Polysaccharides can be **a straight chain** of monosaccharides known as linear polysaccharides, or it can be **branched** known as a branched polysaccharide.

4. They are not sweet in taste and many are **insoluble** in water.

5. They are hydrophobic in nature. And they do not form crystals on desiccation.

6. They are high molecular weight carbohydrates and can be extracted to form a white powder.

## STARCH:

□Starch is the most important source of carbohydrates in the human diet and accounts for more than 50% of our carbohydrate intake. It occurs in plants in the form of granules, and these are particularly abundant in seeds (especially the cereal grains) and tubers.
 □Starch is a mixture of two polymers: **amylose and amylopectin**. Natural starches consist of about 10%–30% amylase and 70%–90% amylopectin.

 $\Box$  Amylose is a **linear polysaccharide** composed entirely of D-glucose units joined by the  $\alpha$ -1,4-glycosidic linkages.

Amylopectin is a **branched-chain polysaccharide** composed of glucose units linked primarily by  $\alpha$ -1,4-glycosidic bonds but with occasional  $\alpha$ -1,6-glycosidic bonds, which are responsible for the branching. A molecule of amylopectin may contain many thousands of glucose units with branch points occurring about every 25–30 units. It readily dissolves in hot water. On cooling, it forms a starch paste or starch gel.

![](_page_40_Picture_4.jpeg)

BASIS OF COMPARISON	AMYLOSE	AMYLOPECTIN
Description	Amylose is an un-branched chain polymer of D-glucose units.	Amylopectin is a branched chain polymer of D-glucose units.
Iodine Test	It gives a dark blue/black color when iodine solution is added.	It gives a reddish brown color when iodine solution is added.
Solubility	It is less soluble in water.	It is more soluble in water.
Reaction With Hot Water	It does not form a gel when hot water is added.	It forms a gel when hot water is added to it.
Percentage In Starch	Constitutes about 20-30% of the starch.	It constitutes about 70-80% of the starch.
Hydrolysis	It can be hydrolyzed with $\alpha$ amylase and $\beta$ amylase enzymes completely.	It cannot be hydrolyzed with $\alpha$ amylase and $\beta$ amylase enzymes completely.
Glycosidic Linkages	It has $\alpha$ 1-4 glycosidic linkages.	It has $\alpha$ 1-4 glycosidic linkages and $\alpha$ 1-6 glycosidic linkages.
Structure	It is a straight chain structure.	Branched structure.
Energy Content	It is a great storage system for energy.	It only stores a small amount of energy.
Units Of Glucose	It has 300-several thousand units of glucose.	It has 2000-200,000 units of glucose.

## **GLYCOGEN:**

□Glycogen is the **energy reserve** carbohydrate of animals. Practically all mammalian cells contain some stored carbohydrates in the form of glycogen, but it is especially abundant in the liver (4%–8% by weight of tissue) and in skeletal muscle cells (0.5%–1.0%).

Glycogen is structurally quite similar to amylopectin, although glycogen is more **highly branched** and the branches are shorter. Glycogen is a branched polymer of glucose. Glucose residues are linked linearly by  $\alpha$ -1,4 glycosidic bonds, and approximately every ten residues a chain of glucose residues branches off via  $\alpha$ -1,6 glycosidic linkages. When treated with iodine, glycogen gives a reddish brown color.

![](_page_42_Figure_3.jpeg)

![](_page_42_Figure_4.jpeg)

A core protein of glycogenin is surrounded by branches of glucose units. The entire globular complex may contain approximately 30,000 glucose units.

#### **DEXTRIN:**

Dextrins are glucose polysaccharides of **intermediate size.** Dextrins are shorter, broken starch segments that form as the result of the **random hydrolysis of internal glucosidic bonds in starch.** Human saliva and pancreatic secretion contain a large amount of alpha-amylase for starch digestion.

Dextrins are mixtures of polymers of D-glucose units linked by  $\alpha$ -(1 $\rightarrow$ 4) or  $\alpha$ -(1 $\rightarrow$ 6) glycosidic bonds.

Dextrins are more easily digested than starch and are therefore used extensively in the commercial preparation of infant foods.

The shine and stiffness imparted to clothing by starch are due to the presence of dextrins formed when clothing is ironed. Because of their characteristic stickiness with wetting, dextrins are used **as adhesives on stamps**, envelopes, and labels; as binders to hold pills and tablets together; and as pastes.

**Dextrinization** is the process involving the browning of starch foods when subjected to dry heat. It is defined as the breakdown of starch into dextrins (disaccharides) and it is a non-enzymatic browning.

![](_page_44_Figure_0.jpeg)

According to the molecular weight of the degradation products of starch

![](_page_44_Figure_2.jpeg)

High molecular weight polymer. It gives a blue color with iodine and does not reduce Fehling's solution.

Medium molecular weight polymer. It gives a red color with iodine and reduces Fehling's solution.

Low molecular weight polymer. No color with iodine and reduces Fehling's solution.

#### **CELLULOSE:**

Cellulose, a fibrous carbohydrate found in all plants, is the structural component of plant cell walls. Because the earth is covered with vegetation, **cellulose is the most abundant of all carbohydrates, accounting for over 50% of all the carbon found in the vegetable kingdom**. The largest use of cellulose is in the manufacture of paper and paper products.

Like amylose, cellulose is a **linear polymer** of glucose. It differs, however, in that the glucose units are joined by  $\beta$ -1,4-glycosidic linkages, producing a more extended structure than amylase.

**Humans are unable to metabolize cellulose** as a source of glucose. Our digestive juices lack enzymes that can hydrolyze the  $\beta$ -glycosidic linkages found in cellulose, so although we can eat potatoes, we cannot eat grass.

However, certain microorganisms can digest cellulose because they make the enzyme cellulase, which catalyzes the hydrolysis of cellulose. Termites also contain cellulase-secreting microorganisms and thus can subsist on a wood diet.

![](_page_45_Figure_5.jpeg)

#### **GLYCOSAMINOGLYCANS:**

1. Glycosaminoglycans (GAGs) or mucopolysaccharides are **negatively charged long linear polysaccharides consisting of repeating disaccharide units** (i.e. two-sugar units). One or both of the monosaccharide units contains at least one **negatively charged** sulphate or carboxylate group.

2. There are disaccharides repeating regions in glycosaminoglycans chains which are composed of **uronic acid**-like D-glucoronic acid or L-iduronic acid and **amino sugar** like D-glactosamine or D-glucosamine.

GAGs are classified into four groups based on core disaccharide structures. They are Heparin, chondroitin sulfate, Keratan sulfate and hyaluronic acid.

Composition of Glycosaminoglycans		Functions of Glycosaminoglycans	
Glycosaminoglycan	Repeating disaccharide	Heparin, with a very high negative charge, is a	
Hyaluronan	D-Glucuronic acid and N-acetylglucosamine	<ul> <li>Hyaluronates (consisting of up to 25,000 disaccharide units) are components of the vitreous</li> </ul>	
Chondroitin sulfate	D-Glucuronic acid and N-acetylgalactosamine	humor of the eye and of synovial fluid, the lubricant fluid of the body's joints	
Dermatan sulfate	D-Glucuronic acid/L-iduronic acid and N-acetylgalactosamine	Chondroitins and keratan sulfate are found in tendons, cartilage, and other connective tissue	
Heparan sulfate	D-Glucuronic acid/L-iduronic acid	Dermatan sulfate is a component of the extracellular matrix of skin	
Keratan sulfate	D-Galactose and N-acetylglucosamine	proteoglycans (discussed later in this chapter)	

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	AMINO SUGAR	URONIC ACID	SULFATE
HYALURONIC ACID	N-ACETYLGLUCOSAMINE	GLUCURONIC ACID	_
CHONDROITIN SULFURIC	N-ACETYLGALACTOSAMINE	GLUCURONIC ACID	+
CHONDROITIN SULFURIC ACID B (#-HEPARIN)	N-ACETYLGALACTOSAMINE	IDURONIC ACID	+
CHONDROITIN SULFURIC	N-ACETYLGALACTOSAMINE	GLUCURONIC ACID	+
CHONDROITIN	N-ACETYLGALACTOSAMINE	GLUCURONIC ACID	_
KERATOSULFATE	N-ACETYLGLUCOSAMINE	(GALACTOSE)	+
HEPARIN	GLUCOSAMINE (N-SULFATED)	GLUCURONIC ACID	+
HEPARIN MONOSULFURIC	GLUCOSAMINE	(?)	+

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They are found in collagen and elastin and water sticks to GAGs which allows resistance to pressure. Hence in the **aqueous solution of GAGs**, during compression, water is squeezed out and the GAGs are forced to occupy a smaller volume. As the compression is removed, they regain their original hydrated volume due to the repulsion arising from their negative charges.

**Sulfation:** The amino sugar in glycosaminoglycans may be sulphated on C4 or C6 or on the non-acetylated nitrogen. The sugar backbone of GAGs can be sulphated at various positions; hence a simple octasaccharide can have over 1000 000 different sulphation sequences. GAGs are negatively charged due to numerous sulfate groups. And carboxyl groups. The **negatively charged** glycosaminoglycans cover the animal cell surfaces and interact with hundreds of extracellular signalling molecules.

•Heparin is a glycosaminoglycan which contains the highest net negative charge of the disaccharides and acts as a natural anticoagulant substance. It can bond strongly to antithrombin III (a protein involved in terminating the clotting process) and inhibits blood clotting.

•Another example is **Hyaluronate molecules** consist of around 25,000 disaccharide units with molecular weights of up to 107. They are important components of the vitreous humor in the eye and of synovial fluid which is a lubricant fluid of joints in the body. The keratan sulphate and chondroitins are also examples of glycosaminoglycans found in connective tissue like cartilage and tendons.

•Due to their structural complexity, they have been claimed to be the **most information-dense biopolymers** found in nature. GAGs have been demonstrated to modulate numerous biological processes, ranging from embryonic development, regulation of enzymatic activities, extracellular matrix assembly, and ligand binding to receptors to the regulation of cell signaling, through the regulation of distinct proteins, such as growth factors, chemokines, and adhesion molecules

As the name suggests,

- The "glyco-" prefix refers to galactose or a uronic sugar (glucuronic acid or iduronic acid) attached to
- An aminoglycan, or amino sugar (N-acetylglucosamine or N-acetylgalactosamine)

#### Hyaluronic Acid

- 1. HA is ubiquitous in body tissues and is best known for its capability of attracting water molecules. The highly polar structure of HA makes it capable of binding 10000 times its own weight in water. Due to this characteristic, it plays a key role in the lubrication of synovial joints and wound healing processes.
- 2. HA is also used exogenously by clinicians for the promotion of tissue regeneration and skin repair and has demonstrated safety and efficacy for this purpose.
- 3. HA is used in a variety of cosmetic products and shows promising efficacy in promoting skin tightness, elasticity, and improving aesthetic scores.
- 4. In addition to its water-binding capabilities, HA has also been shown to be involved in the promotion and inhibition of angiogenesis and therefore involved in the process of carcinogenesis.

#### Heparan Sulfate/Heparin

- 1. Heparan sulfate is one of the most well-studied GAGs due to its many roles and potential use as a pharmacological target for cancer treatment. Noteworthy functions of heparan sulfate include extracellular matrix (ECM) organization and modulation of cellular growth factor signaling
- 2. Heparin represents the earliest recognized biological role of GAGs for its use as an anticoagulant. The mechanism for this role involves its interaction with the protein antithrombin III (ATIII). The interaction of heparin with ATIII causes a conformational change in ATIII that enhances its ability to function as a serine protease inhibitor of coagulation factors.

#### Keratan Sulfate

Keratan sulfate has been well-studied for its functional role in both the cornea and the nervous system. The cornea comprises the richest known source of keratan sulfate in the body, followed by brain tissue.[14] The role of keratan sulfate in the cornea includes regulation of collagen fibril spacing that is essential for optical clarity, as well as optimization of corneal hydration during development based on its interaction with water molecules

**Chondroitin sulfate** is a chemical found in human and animal cartilage. Chondroitin sulfate is a compound in the body that helps form hyaline cartilage, a connective tissue that cushions the joints. Chondroitin sulfate is a major constituent of <u>cartilage</u>, providing structure, holding water and nutrients, and allowing other molecules to move through cartilage—an important property, as there is no blood supply to cartilage. It is commonly used by mouth with glucosamine or other ingredients for osteoarthritis.

## **GLYCOPROTEINS:**

Glycoproteins are **proteins containing glycans (oligosaccharide chains) attached to amino acid side chains**. Typically, these bonds are formed through a process called **glycosylation**. The carbohydrate content of glycoproteins ranges from less than 1% to over 80% of the molecule.

#### Functions:

1. Some provide **structure** e.g. collagens to add strength and stability to a tissue.

2. Others are involved in **immunity** e.g. immunoglobulins (such as IgG).

**3. Mucins** are secreted into mucus of the respiratory and digestive tracts where they can retain water thus allowing mucus to serve as an effective lubricant.

4. Specific glycoproteins (and glycolipids) present on the surface of red blood cells determine **blood group**.

5. Certain **hormones** are glycoproteins including follicle-stimulating hormone (FSH, erythropoietin etc.

6. Many viruses have **surface glycoproteins** called spike domains; S (including SARS-CoV-2) which enable viruses to bind to their target receptors and enter cells.

7. Their hydrophilic nature allows them to function in the aqueous environment, where they act in **cell-cell recognition** and binding of other molecules.

8. Glycoproteins in plant cells are what **allows plants to stand upright** against the force of gravity.

**9. Blood clotting** depends on the glycoproteins prothrombin, thrombin, and fibrinogen. 10. They are important for **reproduction** because they allow for the binding of the sperm cell to the surface of the egg.

## **Types of Glycoprotein:**

There are three types of glycoproteins based on their structure and the mechanism of synthesis:

**1.** N-linked glycoproteins: N-linked glycoproteins have carbohydrates attached to the R side chain of asparagine residues within a polypeptide. a large preformed carbohydrate containing fourteen or more sugar residues is attached to the asparagines.

**2. O-linked glycoproteins:** O-linked glycoproteins are usually synthesized by the addition of sugar residues to the hydroxyl side chain of serine or threonine residues in polypeptides. Unlike N-linked glycoproteins, O-linked glycoproteins are synthesized by the addition of a single sugar residue at a time.

**3.** Nonenzymatic glycosylated glycoproteins: Nonenzymatic glycosylation or glycation creates glycoproteins by the chemical addition of sugars to polypeptides. This is the basis of the 'glycosylated hemoglobin A1c' diagnostic test used for the monitoring and long-term maintenance of blood sugar levels in diabetics.

![](_page_53_Figure_1.jpeg)

Figure 7-30

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#### SIALIC ACID:

# Sialic acid is a generic term for a family of derivatives of neuraminic acid, an acidic sugar with a nine-carbon backbone.

These acidic sugars with a ninecarbon backbone decorate all cell surfaces and mediate a variety of normal and pathological processes. By virtue of their **negative charge and hydrophilicity**, sialic acids have many structural and modulatory roles.

![](_page_54_Figure_5.jpeg)

For example, the negative charge on human erythrocytes and other cell types provides charge repulsion, preventing unwanted interactions of cells in the blood circulation. The density of sialic acids in the glomerular basement membrane and on the foot-processes of podocytes appears critical in maintaining the normal filtering function of the organ.