AS PER PCI REGULATIONS
FIRST YEAR B. PHARM. | SEMESTER-II

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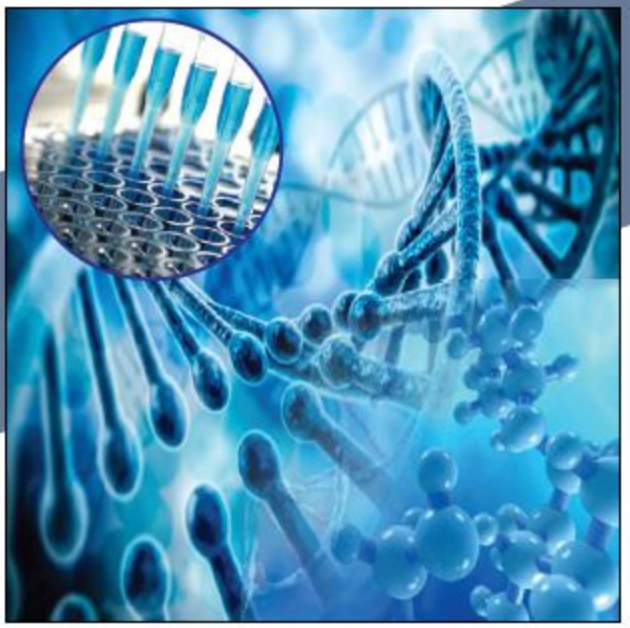

NIRALI PRAKASHAN
ADVANCEMENT OF KNOWLEDGE

A Text Book Of

BIOCHEMISTRY

As Per PCI Regulations

First Year B. Pharm.

Semester II

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This book is dedicated to Dr. Hemant S. Agarkar.

Earnestly blissful for his constant encouragement and incessant guidance.

Authors

Preface

I feel a deep sense of gratitude to find overwhelming response to all seven editions of my book*-, “Biochemistry: Basic and Applied". This new, book entitled "Biochemistry" is orchestrated according to latest PCI (Pharmaceutical Council of India) Syllabus. The book provides systematic coverage of basic, clinical, applied and molecular aspects of biochemistry which can be viewed as standard textbook as well as a review before examination.

Sound knowledge of Biochemistry is imperative for students to understand the significance of molecular aspects of life processes in biological science. One has to accept the fact that biology is fast becoming a molecular science. A student can easily keep pace with latest advances in the subject by learning biochemistry thoroughly which deserves a special place in pharmaceutical and medical science.

New topics included in this edition are:

(i) Diabetes and Insulin

(ii) Metabolism of cholesterol into (a) Bile acid, (b) Vitamin D, (c) Steroid hormones

(iii) Substrate level phosphorylation

(iv) Glucose-6-phosphate dehydrogenase deficiency

(v) Decarboxylation of amino acids

(vi) Catabolism of heme (bilrubin production), hyperbilirubinemia, Jaundice

(viii) Catabolism of nucleotides, hyperurecemia and gout.

(IX) Role of Cyclic AMP

(X) Energy coupling reactions

I do hope in addition to pharmacy, medical, dental, veterinary, microbiology and biotechnology students will find this book a worthy reference.

I am grateful beyond measure to my guru, reverend professor S.B. Gokhale for his blessings and guidance in the venture of of the book.

Thank you to wonderful team of Nirali Prakashan specially Mrs. Manasi Pingle, Mr. Akbar Shaikh, Mrs. Prachi Sawant and Mrs. Roshan Khan for their earnest efforts behind making every edition beautiful and error free.

And most of all, I would like to express my sincere gratitude towards respected Mr. Jigneshbhai Furia of Nirali Prakashan for his guidance and support which is beyond reckoning. I cannot complete preface without thanking profusely my valued coauthors Dr.Rammohan Rao and Dr.Yogesh Kulkarni for their timely help.

I do hope that students will find this book “Biochemistry” equally helpful like its previous book "Biochemsitry : Basic and Applied".

Dr. Padmaja Hemant Agarkar

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Previous Editions

Following List Displays Publication Years of all previous Editions of the Book, 'Biochemistry: Basic and Applied'.

Edition No.	Year
Ist Edition	May 2004
IInd Edition	June 2005
IIIrd Edition	October 2006
IVth Edition	August 2009
Vth Edition	September 2011
VIth Edition	October 2013
VIIth Edition	July 2015

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Syllabus

Unit I **[08 Hours]**

- **Biomolecules:** Introduction, Classification, Chemical Nature and Biological Role of Carbohydrate, Lipids, Nucleic Acids, Amino Acids and Proteins.
- **Bioenergetics:** Concept of Free Energy, Endergonic and Exergonic Reaction, Relationship between Free Energy, Enthalpy and Entropy; Redox Potential.
  Energy Rich Compounds; Classification; Biological Significances of ATP and Cyclic AMP.

Unit II **[10 Hours]**

- **Carbohydrate Metabolism:** Glycolysis - Pathway, Energetics and Significance.
  Citric Acid Cycle - Pathway, Energetics and Significance.
  HMP Shunt and its Significance; Glucose-6-Phosphate Dehydrogenase (G6PD) Deficiency.
  Glycogen Metabolism Pathways and Glycogen Storage Diseases (GSD).
  Gluconeogenesis - Pathway and its Significance.
  Hormonal Regulation of Blood Glucose Level and Diabetes Mellitus.
- **Biological Oxidation:** Electron Transport Chain (ETC) and its Mechanism.
  Oxidative Phosphorylation and its Mechanism and Substrate Level Phosphorylation.
  Inhibitors ETC and Oxidative Phosphorylation/Uncouplers.

UNIT III **[10 Hours]**

- **Lipid Metabolism:** β-Oxidation of Saturated Fatty Acid (Palmitic Acid).
  Formation and Utilization of Ketone Bodies; Ketoacidosis.
  De Novo Synthesis of Fatty Acids (Palmitic Acid).
  Biological Significance of Cholesterol and Conversion of Cholesterol into Bile Acids, Steroid Hormone and Vitamin D.
  Disorders of Lipid Metabolism: Hypercholesterolemia, Atherosclerosis, Fatty Liver and Obesity.
- **Amino Acid Metabolism:** General Reactions of Amino Acid Metabolism: Transamination, Deamination and Decarboxylation, Urea Cycle and its Disorders.
  Catabolism of Phenylalanine and Tyrosine and their Metabolic Disorders (Phenyketonuria, Albinism, Alkeptonuria, Tyrosinemia).
  Synthesis and Significance of Biological Substances; 5-HT, Melatonin, Dopamine, Noradrenaline, Adrenaline.
  Catabolism of Heme; Hyperbilirubinemia and Jaundice.

UNIT IV **[10 Hours]**

- **Nucleic Acid Metabolism and Genetic Information Transfer:** Biosynthesis of Purine and Pyrimidine Nucleotides.
  Catabolism of Purine Nucleotides and Hyperuricemia and Gout Disease.
  Organization of Mammalian Genome.
  Structure of DNA and RNA and their Functions.
  DNA Replication (Semi Conservative Model).
  Transcription or RNA Synthesis.
  Genetic Code, Translation or Protein Synthesis and Inhibitors.

UNIT V **[07 Hours]**

- **Enzymes:** Introduction, Properties, Nomenclature and IUB Classification of Enzymes.
  Enzyme Kinetics (Michaelis Plot, Line Weaver Burke Plot).
  Enzyme Inhibitors with Examples.
  Regulation of Enzymes: Enzyme Induction and Repression, Allosteric Enzymes Regulation.
  Therapeutic and Diagnostic Applications of Enzymes and Isoenzymes.
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UNIT I

Chapter ... 1

CHEMISTRY OF CARBOHYDRATES

♦ LEARNING OBJECTIVES ♦

- *Understand Chemical Structures, Types of Bonding and Isomerisms in different Carbohydrate. Molecules like Monosaccharides, Disaccharides and Polysacharides.*
- *Recognize of Intricacies of Structures of all Carbohydrates.*
- *Know Chemical Reactions of Monosaccharides.*
- *Appreciate the Concepts of Invert Sugar and Inversion.*
- *Acknowledge Biochemical properties of different Carbohydrate Molecules.*

1.1 INTRODUCTION

Carbohydrates may be defined as 'polyhydroxy aldehydes or ketones, or compounds which yield one of these compounds on hydrolysis'.

Many carbohydrates have empirical formula $(CH_2O)_n$, where n is three or larger. Basically, these compounds are made up of C, H and O. On earth, there are probably more carbohydrates than any other organic compounds. The very meaning of term carbohydrate is *hydrates of carbon*. In the course of time, many other compounds have been discovered, that have general properties of carbohydrates, but contain nitrogen, phosphorus and sulfur in addition to carbon, hydrogen and oxygen. There are several non-carbohydrate compounds like acetic acid [CH_3COOH], lactic acid [$C_3H_6O_3$], which can also be called as hydrates of carbon. Moreover, most abundant cellular sugar, deoxyribose, has the molecular formula $C_5H_{10}O_4$, rather than $C_5H_{10}O_5$. Therefore, all carbohydrates cannot be called as hydrates of carbon.

1.2 BIOCHEMICAL ROLE OF CARBOHYDRATES

1. Carbohydrates are important constituents of the cell structure in the form of glycolipid, glycoproteins, heparin, cellulose, starch etc.
2. Carbohydrates serve as an important source as well as a store of energy.
3. Carbohydrates are important starting material for many organic compounds like amino acids, nucleic acid and lipids.
4. Carbohydrates are the first storage form of energy, in the form of glycogen, to compensate for immediate energy demands of body.
5. Carbohydrates are an important raw material for the production of products like glucose, maltose, enzymes, alcohol, acids etc.

1.3 CARBOHYDRATE CLASSIFICATION

There are four major groups of carbohydrates:

1. Monosaccharides, 2. Disaccharides, 3. Oligosaccharides, 4. Polysaccharides.

1.3.1 Monosaccharides: (Synonym – Simple Sugars)

They have the general formula $C_n(H_2O)_n$. They cannot be further hydrolysed into simpler forms.

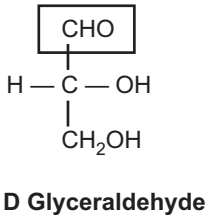
Monosaccharides are further subdivided into different classes depending on the number of carbon atoms or functional group.

(A) Classification of Monosaccharides based on Functional Group

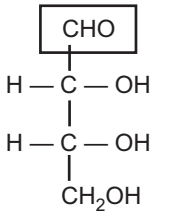
Aldoses: Aldoses are those monosaccharides having the (– C(=O)H) aldehyde as one of their functional groups. e.g. glucose, galactose, glyceraldehyde.

Ketoses: Ketoses are those monosaccharides having the (– C(=O) –) keto group, as one of their functional groups e.g. fructose, dihydroxy acetone, ribulose.

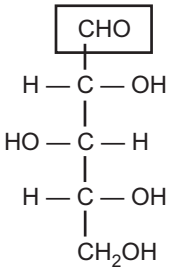
Structures of some aldoses:



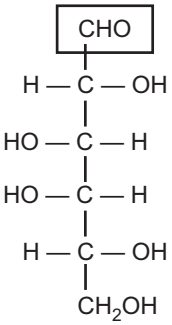
D Glyceraldehyde



D Erythrose



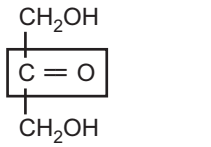
D Xylose



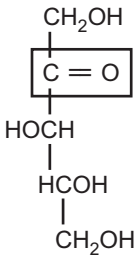
D Galactose

Examples of aldoses of biochemical importance

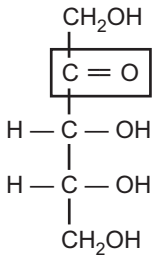
Structures of some ketoses:



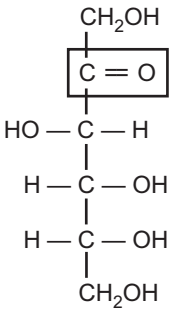
Di-hydroxy acetone



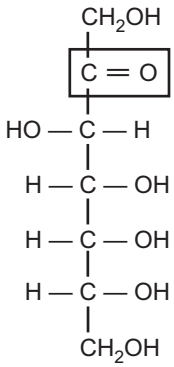
D-Xylulose



D-Ribulose



D-Fructose



D-Sedoheptulose

Examples of ketoses of biochemical importance

(B) Classification of Monosaccharides based on the Number of Carbon Atoms

Number of Atoms	Name	Example
3	Triose	Dihydroxy acetone, Glyceraldehyde
4	Tetrose	Erythrose
5	Pentose	Ribulose, Xylulose, Ribose
6	Hexose	Glucose, Fructose, Mannose, Galactose
7	Heptose	Glucoheptose, Galactoheptose, Sedoheptose

Classification of monosaccharides can also be done according to the number of carbon atoms present in their structure.

Trioses

Glyceraldehyde and dihydroxy acetone are examples of trioses. These two monosaccharides are formed in the glycolytic pathway. 3-Phosphoglyceraldehyde is another triose and is found in the hexose monophosphate (HMP) shunt pathway.

Tetrose

An example of tetrose, erythrose 4-phosphate is formed by HMP shunt pathway.

Pentoses

Ribose and deoxyribose are examples of pentoses. These two pentoses are important constituents of nucleic acids. Xylulose and ribulose are ketopentoses.

Hexoses

Glucose, galactose, fructose, mannose etc. are examples of hexoses of which glucose is the fuel of life. Galactose is a constituent of lactose (milk sugar). Fructose is found in fruits, honey and as a constituent of sucrose, and mannose is a constituent of plant polysaccharides.

Heptoses

Sedoheptulose is a ketoheptose existing in the plant kingdom. Sedoheptulose-7-phosphate is one of the intermediates of the HMP shunt. The same compound is one of the products of photosynthesis.

1.4 ISOMERISM IN MONOSACCHARIDES

1.4.1 Stereoisomers or Geometric Isomers

Stereoisomers: Stereoisomers are compounds which have same structural formula but differ in their spatial configuration.

The presence of asymmetric carbon atoms in the compounds allows the formation of such isomers.

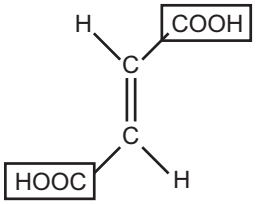
1.4.1.1 Asymmetric Carbon Atom

The carbon atom to which four different atoms or groups are attached is called as asymmetric carbon atom.

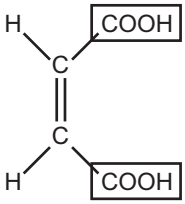
Thus, it is the number (n) of asymmetric carbon atoms in the compound which determines the number of possible isomers of the compound. Thus, galactose with 4 asymmetric carbon atoms has 2^n i.e. 2^4 = 16 isomers.

1.4.2 Cis and Trans Isomerism

Compounds with double bonds show this type of isomerism. Rigidity of double bond, resulting in restriction in rotation about the carbon-carbon double bond is responsible for geometrical isomerism. ***Cis*** isomer is one in which two similar groups are on the same side of the double bond.



Fumaric acid (Trans-structure)



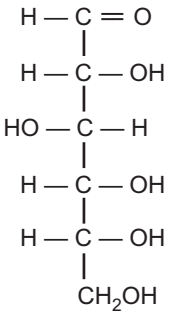
Maleic acid (Cis-structure)

Trans isomer is one in which two similar groups are on the opposite side of the double bond.

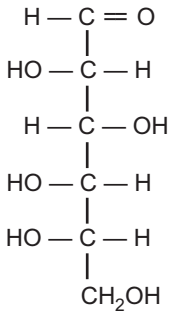
1.4.3 D and L Isomerism

The D and L isomers are mirror images of each other. All the naturally occurring monosaccharides of mammalian tissues are mostly of D-configuration. All the cellular enzymes are specific for D series of monosaccharides.

The spatial orientation of –H and –OH groups on the carbon atom that is adjacent to terminal primary alcohol carbon (e.g. C_5 of glucose) determines whether the sugar is D or L series.



D-Glucose



L-Glucose

1.4.3.1 Optical Activity of Sugars

When a beam of polarised light is passed through a solution of optical isomers, it will be rotated either to the right or left. The term dextro rotatory (+) is used for compounds that rotate the plane of polarised light to the right i.e. clockwise and levo rotatory (–) is used for compounds that rotate the plane of polarised light to left i.e. anti-clockwise.

Optical isomers: Optical isomers are a type of stereoisomers. The unique feature of optical isomers is that they have the ability to rotate plane polarised light. This property is referred to as optical activity.

1.4.3.2 D-L mixture (Racemic mixture)

The mixture that contains equal amounts of dextro rotatory and levo rotatory isomers is called as D-L mixture or racemic mixture.

Such a mixture has no optical activity as the optical activity of one isomer is cancelled by the other isomer. Synthetically produced compounds are generally racemic.

1.4.3.3 Resolution

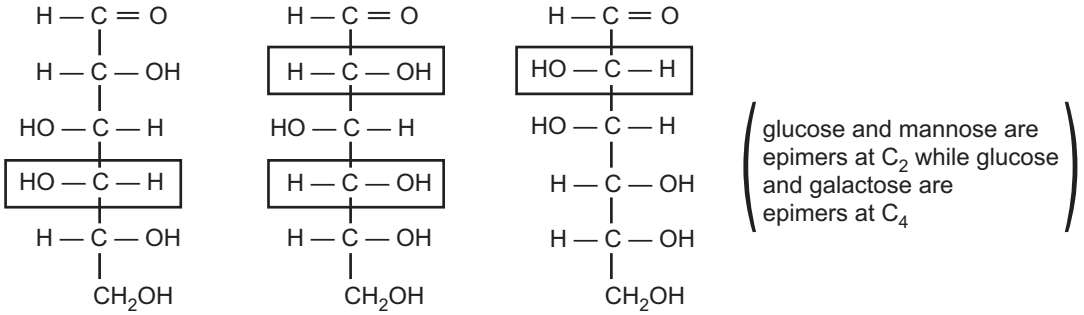
Synthesis of an optically active compound produces a mixture of both (+) and (–) isomers in equal amounts. Such a mixture is called racemic mixture or racemate.

The separation of optically active isomers from the racemic mixture is called as resolution. The mixture is resolved into optically active counterparts or compounds (+ and – isomers). Resolution is of two types – (1) Chemical resolution, (2) Enzymatic resolution.

1.4.4 Epimers

Glucose, galactose and mannose are called as the epimers of each other. They are formed by interchange of the –OH and –H, on the carbon atom 2 or 4 of glucose. Enzyme epimerase is responsible for the interconversions of epimers.

Structure of Epimers:



1.4.5 Pyranose and Furanose Ring Structures



Pyran **Furan**

Ring structures of sugars were proposed by Haworth in 1929 in which all sugars forming six membered rings are called pyranose from their relation to pyran and name furanose was given to those sugars, forming a five membered ring. Pyranose and furanose forms of the glucose are given below.

Structure of glucose-pyranose and -furanose forms.

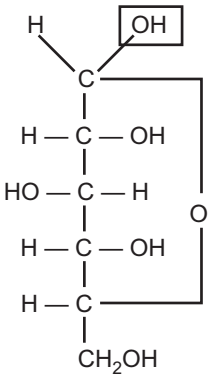


α-D-Glucopyranose **α-D-Glucofuranose**

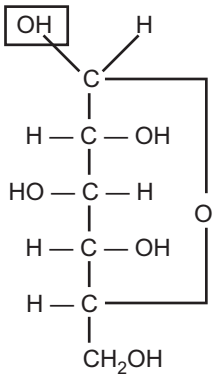
1.4.6 α and β Anomers of D-glucose

The cyclic structure of glucose is retained in the solution. But isomerism takes place around the carbon atom 1. This occurs along with the optical rotation by which the positions of H and –OH groups are changed around carbon number 1. α and β cyclic forms of glucose are called as anomers. They differ from each other in configuration only at C_1 known as anomeric carbon atom. The physical and chemical properties of anomers are different.

Mutarotation: Intraconversion of α and β glucose in solution along with the change in their optical activity is called as *mutarotation*. It can be defined as 'the change in the optical rotation due to interconversion of α and β forms of D-glucose to form an equilibrium mixture'.



α-D-Glucose

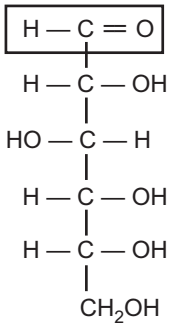


β-D-Glucose

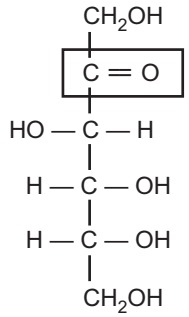
1.4.7 The Aldoses and Ketoses

Glucose has the same molecular formula as that of the fructose. But both of them differ from each other with respect to their structural formula. Glucose is an aldose sugar due to the presence of aldehyde group and fructose is a ketose sugar due to the presence of the keto group in its structure.

Chemical structures of D-glucose (aldohexose) and D-fructose (ketohexose) are given below:



D-Glucose (Aldohexose)



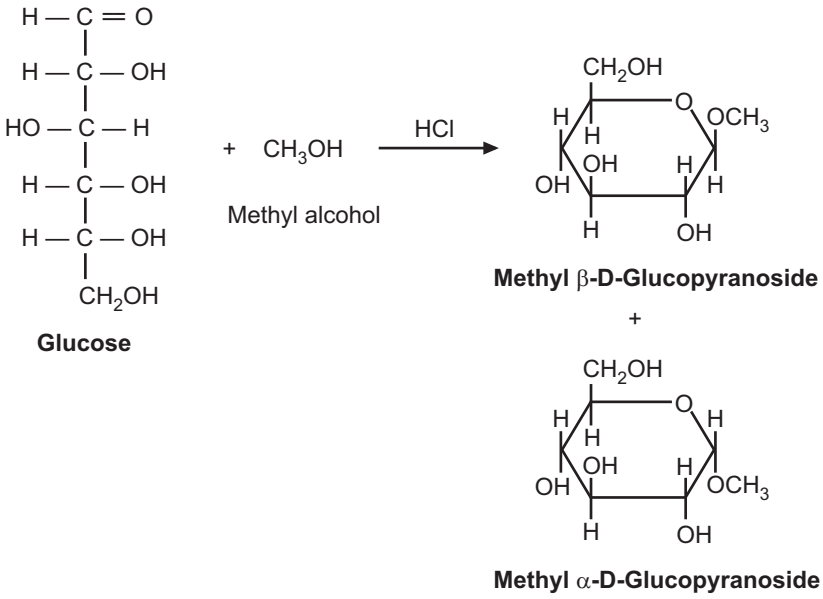
D-Fructose (Ketohexose)

1.5 GLYCOSIDES

A condensation reaction between sugar and hydroxyl group of other compounds, also called as a aglycone, forms a compound known as a glycoside. The aglycone may or may not be another sugar. If the carbohydrate portion is glucose, the resulting compound is undergoes condensation *glucoside*, if galactose the compound formed is called as *galactoside*. One of the important properties of monosaccharide is its ability to form glycosides.

Condensation of the reducing sugar with dry methyl alcohol in the presence of catalyst like dry HCl results in glycoside formation.

Glycoside Formation:



Some examples of aglycones are as follows:

methyl alcohol, glycerol, other sugars and sterol.

Glycosides are found in many species, in animal tissues and in many drugs. An antibiotic like streptomycin is a glycoside. Some cardiac glycosides are very important in medicine because of their action on the heart. All the cardiac glycosides contain steroid as the aglycone component. These glycosides are obtained from digitalis e.g. digoxin and strophanthus e.g. ouabain, are inhibitors of Na^+–K^+ ATPase of the cell membrane.

1.6 AMINO SUGARS (HEXOSAMINES)

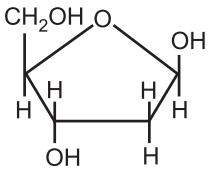
These sugars are components of glycoproteins, gangliosides and glycosaminoglycans.

Sugars containing amino groups are called as the amino sugars. Examples of amino sugars are D-glucosamines, D-galactosamine and D-mannosamine.

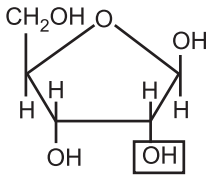
Several antibiotics contain amino sugars e.g. erythromycin and carbomycin. Erythromycin contains dimethyl amino sugars. Carbomycin contains 3 amino-sugars e.g. 3 amino D-ribose. The antibiotic activity of the drug is due to the presence of amino sugars. Glucosamine is also a constituent of hyaluronic acid.

1.7 DEOXY SUGARS

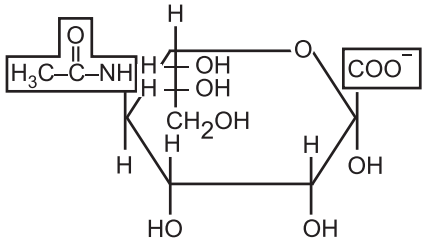
Hydroxyl group attached to the ring structure of these sugars has been replaced by hydrogen atom. e.g. deoxyribose sugar is found in the DNA (nucleic acid). Deoxy sugars cannot form osazones. These sugars are very unstable and form resins.



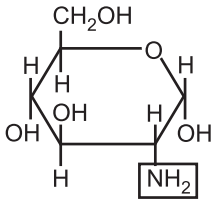
D-2-Deoxyribose (β-form)



D-ribose (β-form)



N acetyl neuraminic acid



αD-Glucosamine

Structures of few monosaccharides and monosaccharide derivatives

1.8 MONOSACCHARIDE: GLUCOSE

Glucose: Glucose is the most important monosaccharide in the body. It is the most widely distributed sugar in the body. The molecular formula of glucose is $C_6H_{12}O_6$. The structural formula of glucose was given earlier in the chapter.

1.8.1 Structure of Glucose

The molecule of glucose contains five –OH groups.

The presence of five hydroxyl groups is confirmed due to the formation of a pentacetyl derivative on acetylation. It gives the following set of reactions:

$$\text{Glucose} \xrightarrow{\text{Reduction}} \text{Sorbitol} \quad \ldots (1.1)$$

$$\text{Glucose} \xrightarrow{\text{Oxidation}} \text{Gluconic acid} \quad \ldots (1.2)$$

$$\text{Glucose} \xrightarrow[\text{Killiani Reaction}]{\text{HCN}} \text{Heptylic acid} \quad \ldots (1.3)$$

All three reactions of glucose indicate the presence of $\left(\begin{matrix}-C-H\\ \| \\ O\end{matrix}\right)$ group.

Killiani reaction involving reaction with HCN, hydrolysis of cyanohydrin and reduction with HI gives normal heptylic acid, which is a straight chain compound. This confirms that glucose is also a straight chain compound.

However, straight chain structure of glucose is unable to explain the following properties:

1. Mutarotation of glucose.
2. No compound formation with $NaHSO_3$.
3. No restoration of colour with Schiff's reagent.
4. Formation of two isomeric glucosides with methyl alcohol and dry HCl gas.

In order to explain the above properties of glucose, Fischer suggested that glucose molecule must be existing in the ring structural form. Both six membered ring and five membered ring are possible and their existence has also been proved experimentally. Six membered ring i.e. a pyranose form is more stable. Further, glucose exists in α and β forms too.

1.9 CHEMICAL REACTIONS OF MONOSACCHARIDES

1.9.1 Reduction

Monosaccharides are reduced to their corresponding alcohols by reducing agents such as sodium amalgam.

$$\text{Glucose} \xrightarrow[\text{Na/Hg}]{\text{Reduction}} \text{Sorbitol (gluatol)}$$

$$\text{Galactose} \xrightarrow[\text{Na/Hg}]{\text{Reduction}} \text{Dulcitol (galactitol)}$$

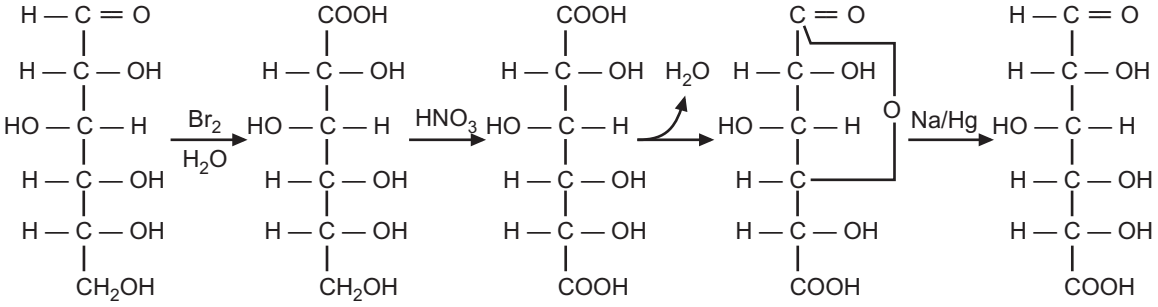
$$\text{Mannose} \xrightarrow[\text{Na/Hg}]{\text{Reduction}} \text{Mannitol}$$

$$\text{Fructose} \xrightarrow[\text{Na/Hg}]{\text{Reduction}} \text{Mannitol + Sorbitol}$$

1.9.2 Oxidation

Oxidation of the aldehyde group of the glucose forms aldonic acids. If the aldehyde group does not participate in the reaction and if the primary alcoholic group is oxidised then uronic acids are formed. The oxidation of glucose gives glucuronic acid under the following sets of conditions.

Oxidation of Glucose:



1.9.3 Heat

Glucuronic acid on heating produces lactones. These are cyclic structures which resemble pyranoses and furanoses.

1.9.4 Alkali

Monosaccharides react in various ways with alkali:

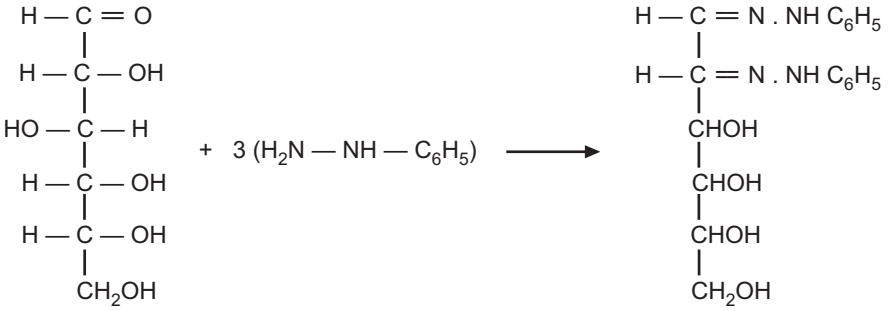
(a) In dilute alkali, sugar will change to the cyclic α- and β- structures with equilibrium between two isomeric forms.
On standing the rearrangement will occur which produces an equilibrium mixture of glucose, fructose and mannose through enediol form.

(b) Sugar produces a series of decomposition products in concentrated alkali. Yellow and brown pigments are developed and salts may be formed. Many double bonds between carbon atoms are formed, C-C bonds (carbon to carbon) may also rupture.

1.9.5 Osazone Formation

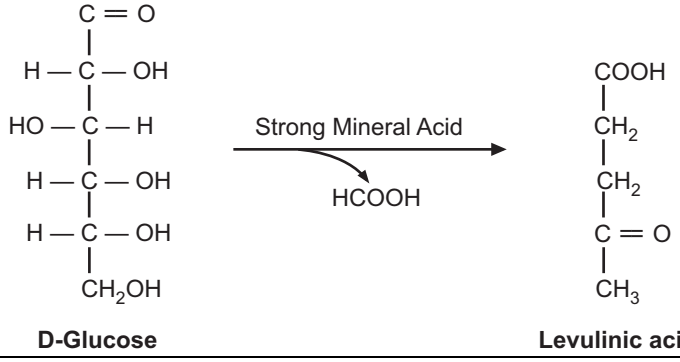
On addition of a mixture of phenylhydrazine hydrochloride and sodium acetate to sugar solution and heating in the boiling water bath, crystals are formed. The reaction takes place between carbonyl group (aldehyde or ketone) and next adjacent carbon with the N of phenylhydrazine. The reaction with the aldose is shown below. The hydrazone so formed reacts with the two additional molecules of phenylhydrazine to form osazones. The ketones also show a similar reaction.

Osazone formation of Glucose:



1.9.6 Strong Mineral Acids

Glucose on treatment with strong mineral acids gives levulinic acid.



1.9.7 Iodo Compounds

Aldose sugar on heating with concentrated hydroiodic acid (HI) loses all its oxygen and is converted into an iodo compound.

$C_6H_{12}O_6 + HI \longrightarrow C_6H_{13}I$

Glucose Iodohexane

1.9.8 Ester Formation

The presence of hydroxyl group in sugars allows the reaction of esterification. All free – OH groups are esterifiable.

1.10 DISACCHARIDES

Disaccharides are composed of two monosaccharide units joined by a glycosidic bond. Some commonly occurring disaccharides are:

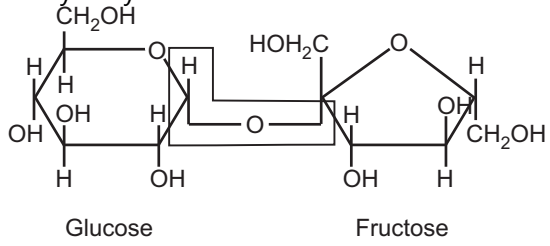
(1) Sucrose = 1 molecule of glucose + 1 molecule of fructose.
(2) Lactose = 1 molecule of glucose + 1 molecule of galactose.
(3) Maltose = 1 molecule of glucose + 1 molecule of glucose.

(A) Sucrose:

It is present in sugarcane, carrot, honey, pineapple, beetroot etc. It does not exist in the human body. The enzyme sucrase also known as invertase hydrolyses sucrose to glucose and fructose. The molecule of sucrose is formed by glycosidic linkage between aldehyde group of glucose and keto group of the fructose. There is no free aldehyde or ketone group available in the sucrose molecule. This is the reason why sucrose is a non-reducing sugar. It does not exhibit mutarotation and does not exist in α and β forms. It is unable to form osazone with phenylhydrazine. It is also unable to reduce Benedict's reagent, Fehling's solution or Barfoed's reagent.

It is also known as *invert sugar* due to the following reasons:

The specific rotation of the sucrose solution is + 66.5°. This rotation changes to –19.5° during hydrolysis. This is because levo rotation of fructose (a hydrolysis product) is greater than dextro rotation of glucose. Sucrose is known as invert sugar because of the inversion in the specific rotation due to hydrolysis.

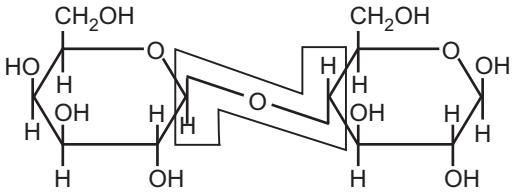


Sucrose

(α-D-glucosyl (1→2) β-D-fructose)

(B) Lactose:

Lactose is also known as milk sugar. It is made up of a molecule of glucose and a molecule of galactose. It is formed in lactating mammary gland. It is present in milk. The enzyme lactase hydrolyses it to glucose and galactose. Lactose has free aldehyde group of glucose. The free aldehyde group of its constituent galactose is engaged in glycosidic linkage with the 4th carbon of glucose. It is a reducing sugar. It shows mutarotation. It can also exist in α and β forms. It can reduce Benedict's solution, Fehling's solution, Barfoed's reagent. It can also form osazone with the phenylhydrazine.



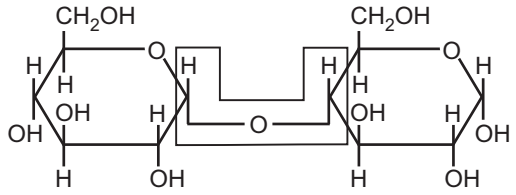
Lactose

(β-D-galactosyl (1→4) β-D-glucose)

(C) Maltose:

Maltose is found in germinating seeds, cereals and malt. It is made up of two molecules of glucose. Maltose is formed during hydrolysis of starch by the enzyme diastase. Chemically, maltose is glucose α-glucoside. Enzyme maltase hydrolyses maltose to glucose. It has free aldehyde groups and hence shows mutarotation. It can exist in α or β forms.

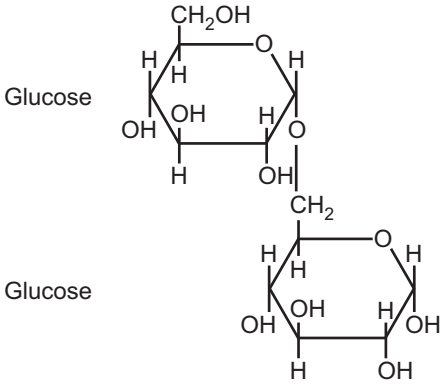
Maltose can reduce Fehling and Benedict's solutions being a reducing sugar. It forms an osazone with phenylhydrazine.



Maltose

(α-D-glucosyl (1→4) α-D-glucose)

(D) Isomaltose: Another disaccharide obtained during the hydrolysis of certain polysaccharides like glycogen, amylopectin and dextran. It is similar to maltose except it has an α (1 → 6) linkage.



Isomaltose

(α-D-glucosyl (1 → 6) α-D-glucose)

1.11 POLYSACCHARIDES

Long chains of monosaccharides joined together are collectively called polysaccharides. Polysaccharides are of two types:

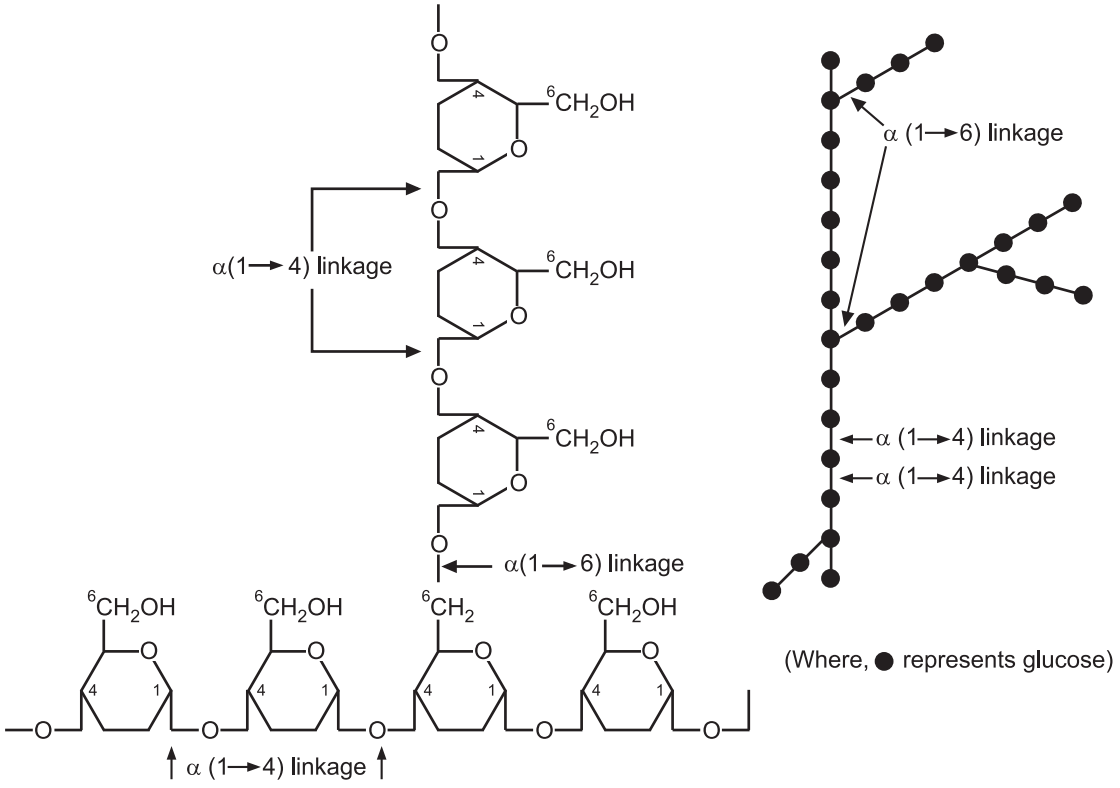
1. **Homopolysaccharides:** These are very large molecules which contain only single type of monosaccharide component. e.g. starch, glycogen, dextran, cellulose etc.
2. **Heteropolysaccharides:** These molecules are formed from one or more monosaccharide component as their basic units e.g. heparin, chondroitin, sulphates, hyaluronic acid, murein etc.

The major storage polysaccharides are glycogen (in animals), starch (in plants) and dextran (in yeast and bacteria). Glycosaminoglycans is a mucopolysaccharide. Cellulose is a structural polysaccharide found in plant cell walls.

(A) Glycogen (Animal Starch):

Glycogen is a storage polysaccharide and is found in animal tissues. It is a branched chain polysaccharides made up of glucose as a basic unit. Glucose molecules are linked by α (1 → 4) bonds with α (1 → 6) branch points. The branching in glycogen makes it more accessible to glycogen phosphorylase during its degradation. It is also referred to as the animal starch.

Structure of Glycogen:

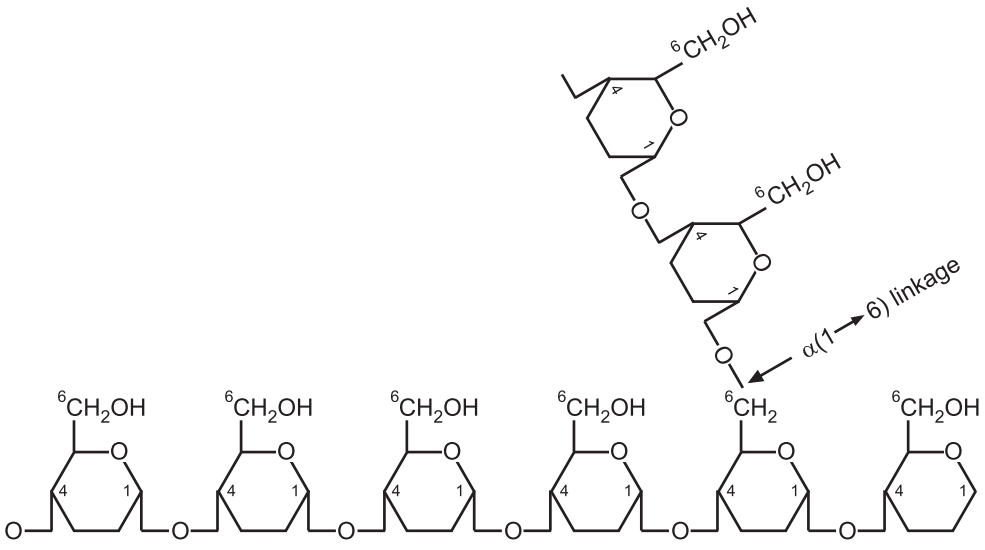


(B) Starch:

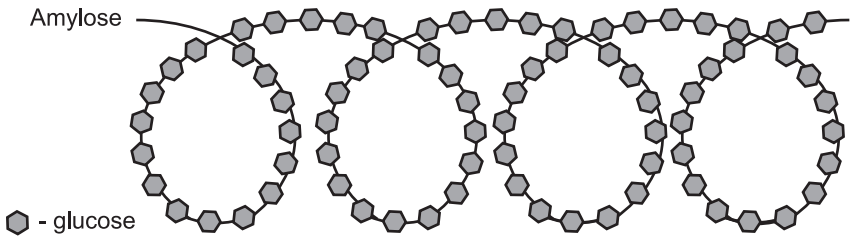
Starch is formed of an α glycoside chain. Such a compound, yielding only glucose on hydrolysis, is a homopolymer called glucan. It is the most important food source of carbohydrate and is found in cereals, potatoes, legumes and other vegetables. The two chief constituents of starch are amylose (15-20%) (amylose is a non-branching helical structure) and amylopectin which contains branched chain composed of 24-30 glucose residues united by (1 → 4) linkage in the chains and by (1 → 6) linkage at the branch points.

Structure of Starch:

(Amylose and Amylopectin)



(Amylopectin) (Branched chains composed of glucose units joined together by α (1→4) linkage in chains and α (1→6) linkage at the branch points.



(Amylose) (non-branching helical structure)

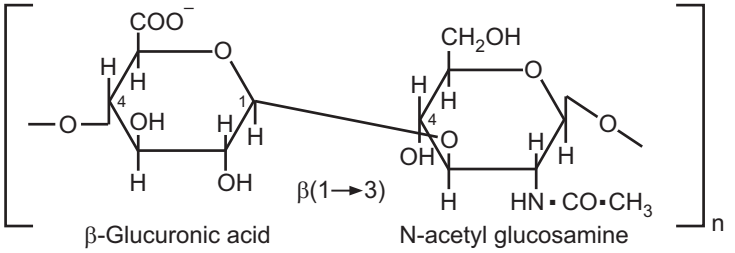
(C) Cellulose:

Cellulose is the chief constituent framework of plants. It is insoluble and consists of β-D-glucopyranose units linked by β (1 → 4) bonds to form long straight chains strengthened by cross-linked hydrogen bonds. It is also known as structural polysaccharide. Cellulose cannot be digested by many mammals including human, because of the absence of a hydrolase that attacks the β linkage. Thus, cellulose is an important source of fibre in the diet. Cellulase, an enzyme that degrades cellulose is absent in mammals, but it is produced by some bacteria, fungi, protozoa and herbivorous animals.

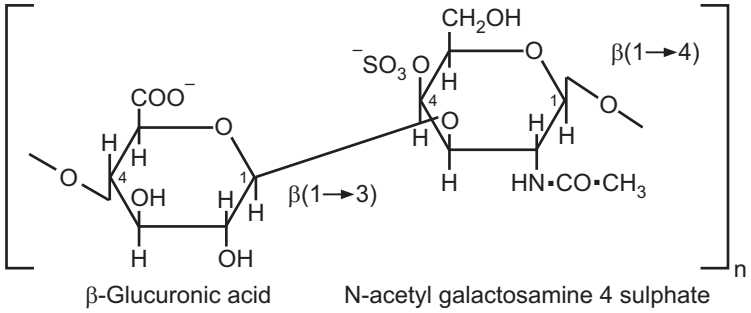
1.12 HETEROPOLYSACCHARIDES (GLYCOSAMINOGLYCANS OR MUCOPOLYSACCHARIDES)

These are composed of derivatives of sugars such as amino sugars and uronic acid. Hence, the name glucosaminoglycans. They consist of repeated disaccharide units in which uronic acid is linked glycosidically to 3-position of an acylated amino sugar. They are acidic and occur in association with peptide group. e.g. hyaluronic acid, chondroitin, sulphate, heparin etc. Mucopolysaccharides are gelatinous substances of high molecular weight (upto 5×10^6) that both lubricate and serve as a sticky cement.

Structures of some complex polysaccharides:



Hyaluronic acid



Chondroitin 4 sulphate