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Quick Review of BIOCHEMISTRY *for Undergraduates*

Questions and Answers

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Contents

1. **Cell and Plasma Membrane** **1–8**
2. **Enzymes** **9–24**
3. **Chemistry of Carbohydrates** **25–31**
4. **Digestion, Absorption and Metabolism of Carbohydrates** **32–56**
5. **Chemistry of Lipids** **57–63**
6. **Digestion, Absorption and Metabolism of Lipids** **64–89**
7. **Amino Acid and Protein Chemistry** **90–103**
8. **Digestion, Absorption and Metabolism of Proteins** **104–134**
   - Glycine *113*
   - Phenylalanine *116*
   - Tryptophan *121*
   - Methionine *123*
   - Cysteine *126*
   - Histidine *128*
   - Branched Chain Amino Acids *129*
   - Aspartate and Asparagine *131*
   - Glutamate *131*
9. **Biological Oxidation** **135–140**
10. **Vitamins** **141–157**
    - Fat-soluble Vitamins *142*
    - Water-soluble Vitamins *149*

Contents

11. Minerals **158–165**
- Macrominerals *158*
- Microminerals *162*

12. Nutrition **166–173**

13. Nucleic Acid Chemistry **174–180**
- Chemistry of Nucleotides *174*
- Structure and Functions of Nucleic Acids *176*

14. Nucleic Acid Metabolism **181–189**

15. Molecular Biology-I **190–206**
- Replication *190*
- Transcription *194*
- Translation *199*

16. Molecular Biology-II **207–232**
- DNA Repair and Mutations *207*
- Regulation of Gene Expression *212*
- Cancer Genetics *215*
- Molecular Biology Techniques *220*
- Acquired Immunodeficiency Syndrome *228*

17. Acid-Base Balance and Disorders **233–241**

18. Organ Function Tests **242–253**
- Liver Function Tests *242*
- Renal Function Tests *245*
- Thyroid Function Tests *248*
- Gastric Function Tests *250*
- Pancreatic Function Tests *252*
- Biochemical Tests for Cardiac Diseases *253*

19. Radioisotopes **254–259**

20. Metabolism of Xenobiotics (Detoxification) **260–263**

21. Miscellaneous **264–279**
- Hormones *264*
- Feed-Fast Cycle *267*
- Free Radical Metabolism *271*
- Techniques *273*
- Electrolytes *275*

22. Hemoglobin Metabolism **280–293**

Index *295*

3 Chemistry of Carbohydrates

1. Define and classify carbohydrates with suitable examples.

Definition: Carbohydrates are polyhydroxy aldehydes (HC=O) or ketones (C=O) with an empirical formula $C_n(H_2O)_n$ (Fig. 3.1).

Exceptions: Deoxy sugars, e.g. deoxyribose—formula is $C_5H_{10}O_4$.

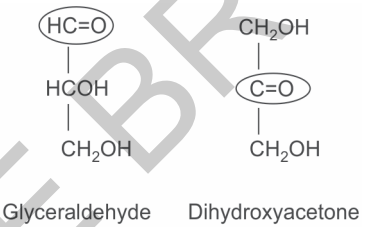

Fig. 3.1: Carbohydrates: Aldose (glyceraldehyde) and ketose (dihydroxyacetone)

Classification

i. **Monosaccharides:** Are simplest sugars, which cannot be hydrolyzed further to a simpler form of sugar, e.g. glucose, fructose.

ii. **Disaccharides:** Made up of two monosaccharide units joined by a glycosidic bond, e.g. sucrose, trehalose, lactose, maltose.

iii. **Oligosaccharides:** Made up of 3–10 monosaccharide units joined by glycosidic bonds, e.g. raffinose (glucose + galactose + fructose), stachyose (2 galactose + glucose + fructose), verbascose (3 galactose + glucose + fructose).

iv. **Polysaccharides:** Made up of more than 10 monosaccharide units joined by glycosidic bonds (Table 3.1). They are of two types.

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a. **Homopolysaccharides:** Made up of **same** monosaccharide units joined by glycosidic bonds, e.g. starch, cellulose, glycogen, dextrin, inulin.
b. **Heteropolysaccharides (glycosaminoglycan):** Made up of **different** monosaccharide units joined by glycosidic bonds, e.g. heparin, chondroitin sulfate, dextran.

Table 3.1: Composition and importance of some polysaccharides

Sugar	Composition and importance
Inulin	Homopolysaccharide; used for measuring glomerular filtration rate
Hyaluronic acid	N-acetylglucosamine + glucuronic acid, not covalently attached to protein; lubricant, shock absorber—present in synovial fluid, vitreous humor, umbilical cord, loose connective tissue
Chondroitin sulfate	N-acetylgalactosamine + glucuronic acid; present in cartilage, tendons, ligaments
Dextran	Heteropolysaccharide; used as plasma volume expander
Dermatan sulfate	N-acetylgalactosamine + L-iduronic acid; present in skin, blood vessels, heart valves
Heparin	Glucosamine + glucuronic acid or iduronic acid; present in liver, lung, spleen; anticoagulant
Keratan sulfate	N-acetylglucosamine + galactose; present in cartilage, cornea; only glycosaminoglycan not having uronic acid

2. What are the various functions of carbohydrates?

[MN: TERN]

- Part of connective **T**issue, e.g. hyaluronic acid in joints
- Source of **E**nergy: 65% of the calorie requirement comes from carbohydrates
- Fiber (**R**oughage): Relieves constipation, e.g. cellulose
- Part of **N**ucleic acids: Ribose in deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

3. Explain different types of carbohydrate isomers with examples.

Definition: Compounds, which have **same molecular formula**, but:

i. Have different structures are called structural isomers (Fig. 3.2).

For example, glucose, galactose and fructose.

ii. Have different spatial configuration are called stereoisomers (refer Fig. 3.2).

a. *Epimers:* Stereoisomers, which differ in orientation of H and OH around only one carbon. For example, glucose and galactose (4 epimer of glucose).

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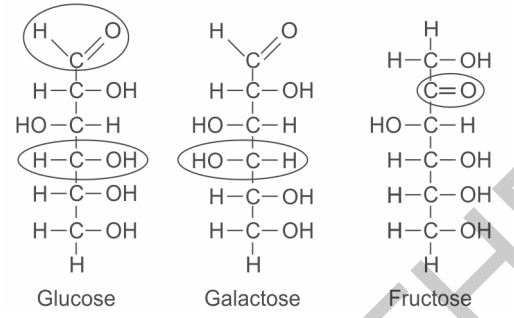

Fig. 3.2: Isomers of glucose

b. *Enantiomers:* Stereoisomers, which are mirror images of each other. For example, D- and L-glucose (Fig. 3.3).

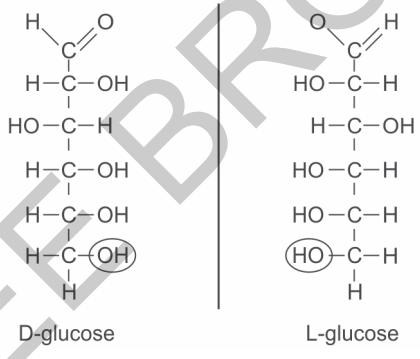

Fig. 3.3: Enantiomers

c. *Anomers:* Stereoisomers which differ in orientation of H and OH around anomeric carbon (Fig. 3.4, p. 28). For example, α-glucose and β-glucose.

iii. Have different optical rotation are called optical isomers: dextro (d or +) and levo (l or –).

- The rotation of polarized light either to the right or left determines whether an isomer is dextro (d) or levorotatory (l) respectively (Fig. 3.5).

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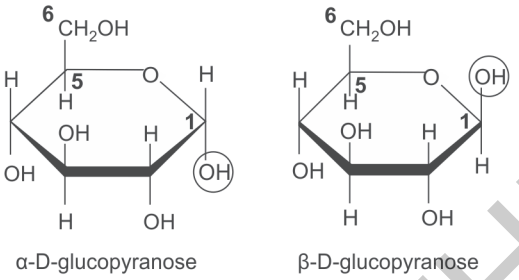

Fig. 3.4: Anomers [MN: **A**lpha-OH is not **A**bove, **B**eta-OH is not **B**elow]

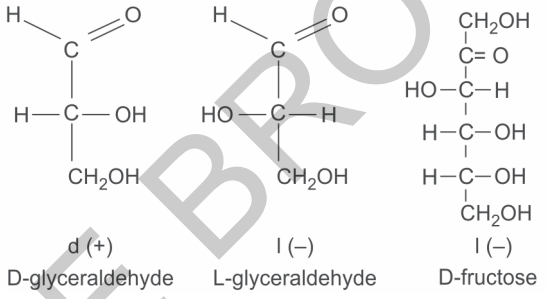

Fig. 3.5: Optical isomers

4. What are the modified sugars encountered in our metabolism?

Modified sugars are formed when the primary or secondary alcohol groups of sugars get oxidized/reduced or replaced by amino group to form sugar acids/sugar alcohols or amino sugars respectively. Some are often seen in our body tissues and genetic materials (Table 3.2 and Fig. 3.6).

Table 3.2: Modified sugars

Name	Modification	Examples
Deoxy sugars	OH group is reduced to H	Deoxyribonucleic acid (DNA)
Amino sugars	OH group replaced with amino group	Glucosamine, galactosamine
Sugar acid	Alcohol group of first carbon of glucose is oxidized to COOH	Gluconic acid

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Name	Modification	Examples
Uronic acid	Last carbon of glucose is oxidized to COOH	Glucuronic acid
Saccharic acid	Alcohol groups of first and last carbon atoms of glucose are oxidized to COOH	–
Sugar alcohol	Reactive aldehyde group of sugar is reduced to alcohol	Sorbitol, mannitol, glycerol

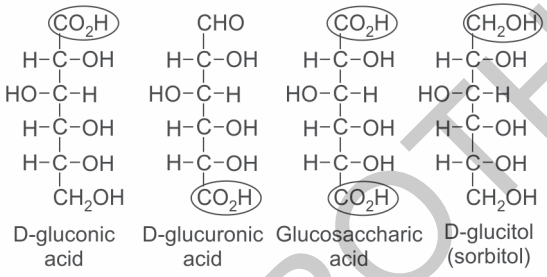

Fig. 3.6: Modified sugars

5. What is mutarotation? Explain with an example.

Definition: Mutarotation is defined as the change in specific optical rotation, with time, of a sugar in solution to reach an equilibrium mixture.

For example, glucose in solution has two forms α (+ 112.2°) and β (+ 18.7°); with time, an equilibrium mixture of the two is formed with net rotation of (+ 52.7°).

6. What is a glycoside? Give some examples.

Definition: Glycoside is a molecule formed when the hemiacetal or hemiketal hydroxyl group of anomeric carbon of a monosaccharide reacts with hydroxyl/amine group of another carbohydrate or a non-carbohydrate (methanol, phenol, glycerol, sterol) with removal of water. The non-carbohydrate moiety in a glycoside is referred to as aglycone (Table 3.3).

For example, streptomycin, erythromycin, ouabain, digitalis are glycosides.

Table 3.3: Glycoside and its components

Glycoside	Carbohydrate	Aglycone
Phlorizin (rose bark)	Glucose	Phloretin
Digitonin (foxglove)	Galactose/xylose	Digitogenin
Indican (stain)	Glucose	Indoxyl

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7. Compare the structure of starch and glycogen.

The comparison between starch and glycogen is given in Table 3.4.

Table 3.4: Starch and glycogen—structural features

Starch	Glycogen
Reserve carbohydrate of plant kingdom	Reserve carbohydrate of animal kingdom
10%–20% amylose and 80% amylopectin	Predominantly amylopectin-like structure
15–18 glucose residues/branch	6–7 glucose residues/branch
Branch every 8–9 residue	Branch every 3–4 residues
Gives blue color with iodine	Red-brown/violet color with iodine

8. What are glycoproteins? Give some examples.

Definition: These are proteins to which short chain of oligosaccharides are attached. Unlike glycosaminoglycans, they lack uronic acids. They have comparatively less carbohydrates (protein > carbohydrate) than glycosaminoglycans.

For example,

- *Structural glycoproteins:* Collagen
- *Enzymes:* Ribonuclease, prothrombin
- *Glycoproteins in transport:* Ceruloplasmin, transferrin
- *Hormone:* Thyroid stimulating hormone (TSH)
- *Glycoproteins in immune system:* Blood group antigen, immunoglobulins
- *Membrane glycoprotein:* Glycophorin of red blood cells (RBCs)
- *Glycoprotein as lubricant:* Mucin
- *Receptor:* Hormone receptors and receptors on surface of viruses.

Key Points

Lactose: Lactose is a milk sugar, which is digested by the enzyme lactase. A deficiency of this enzyme can lead to lactose intolerance where the person cannot tolerate lactose in the diet.

Sucrose and trehalose: They are non-reducing sugars because anomeric hydroxyl group of individual subunits in both of them are involved in formation of glycosidic bonds. Non-reducing sugars will not answer Benedict's test, Barfoed's test and osazone test.

Inulin: It is a homopolysaccharide used for measuring glomerular filtration rate.

Hyaluronic acid: It is a heteropolysaccharide that is not covalently attached to protein. Hyaluronidase enzyme is present in sperm head—it breaks this sugar (present on the outer layer of human egg) and helps in entry of sperm. Absence of this enzyme on sperm head can lead to infertility.

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Keratan: It is the only glycosaminoglycan not having uronic acid.
Dextran: It is a heteropolysaccharide used as plasma expander.
Sorbitol: It accumulates in lens in diabetics resulting in cataract.
Mannitol: It is an osmotic diuretic, which can be used to treat cerebral edema.
Olestra: It is an artificially synthesized glycoside using sucrose + fatty acids. It can be used as a fat substitute that adds no fat or calories.
Digitalis: It is a glycoside used to treat congestive cardiac failure.

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Quick Review of BIOCHEMISTRY

for Undergraduates Questions and Answers

This book is designed to give a quick glance through common examination topics. Concepts have been correlated with clinical aspects wherever possible. There are flow charts and tables to help in quick learning. Acronyms (mnemonics) are designed carefully for easy recollection. An effort has been made to summarize key concepts at the end of each topic to have quick review during viva voce. It has been written in a simple language and will be useful for students of various undergraduate courses.

Krishnananda Prabhu MD is an Associate Professor in the Department of Biochemistry, Kasturba Medical College, Manipal, Karnataka, India. He has 10 years of teaching experience and has been an examiner to several universities. To his credit he has several articles in national and international journals. He has undergone Internal Audit Training supported by National Accreditation Board for Testing and Calibration Laboratories (NABL). He was awarded FAIMER fellowship in 2014 by PSG-FAIMER Regional Institute at PSG Institute of Medical Sciences & Research, Coimbatore, Tamil Nadu, India.



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