Chemistry of Carbohydrates

Chemistry of Carbohydrates

Topics: Monosaccharides, Glucose, Fructose, Mannose, Galactose

Monosaccharides

Definition

• Simplest carbohydrates; cannot be hydrolyzed further.
• General formula: **C?H??O?**.

Classification by Number of Carbons

• **Trioses** – glyceraldehyde
• **Tetroses** – erythrose
• **Pentoses** – ribose, deoxyribose
• **Hexoses** – glucose, fructose, galactose, mannose

Classification by Functional Group

• **Aldoses** ? contain aldehyde group (CHO)
• **Ketoses** ? contain keto group (CO)

Isomerism in Monosaccharides

• **D and L forms** ? based on penultimate carbon orientation
• **Epimers** ? differ at one carbon
• **Anomers** ? differ at hemiacetal carbon (?, ?)
• **Mutarotation** ? ? ? ? interconversion in solution

Glucose

Structure

• Aldohexose; pyranose ring form in solution.
• Four chiral centers.

Important Reactions

• Oxidation ? gluconic acid / glucuronic acid
• Reduction ? sorbitol
• Glycosidic bond formation ? disaccharides & polysaccharides

Biochemical Importance

• Primary fuel of body.
• Required by RBCs, retina, brain.
• Forms glycogen, lactose, triglycerides, amino acids.

Clinical Points

• Hyperglycemia & hypoglycemia disorders
• Sorbitol accumulation ? cataract, neuropathy

Fructose

Structure

• Ketohexose; furanose ring form.
• Sweetest natural sugar.

Metabolism

• Rapid hepatic metabolism; bypasses PFK-1 ? faster glycolysis
• Fructokinase forms **fructose-1-phosphate**

Clinical Points

• Hereditary fructose intolerance ? aldolase B deficiency
• Essential fructosuria ? benign fructokinase deficiency

Mannose

Structure

• C-2 epimer of glucose; aldohexose.

Functions

• Required for **N-linked glycoprotein synthesis**
• Mannose-6-phosphate ? lysosomal enzyme targeting

Clinical Notes

• Congenital disorders of glycosylation (CDG)

Galactose

Structure

• C-4 epimer of glucose; aldohexose.

Metabolism

• Leloir pathway ? glucose
• UDP-galactose ? lactose synthesis

Clinical Points

• Classic galactosemia (GALT deficiency)
• Galactokinase deficiency ? cataracts
• Galactitol accumulation in lens

Comparative Summary (Exam-Oriented)

• **Glucose** ? major fuel, sorbitol pathway
• **Fructose** ? rapid metabolism, HFI
• **Mannose** ? glycoproteins, mannose-6-phosphate
• **Galactose** ? lactose synthesis, galactosemia

Reducing vs Nonreducing Sugars

Reducing Sugars

• Contain a **free aldehyde or keto group** (free anomeric carbon).
• Can **reduce** $Cu^{2?}$? Cu? or Ag? ? Ag.
• All **monosaccharides** are reducing sugars.
• **Examples:** glucose, fructose, galactose, lactose, maltose.

Nonreducing Sugars

• Do NOT have a free anomeric carbon (both anomeric carbons involved in glycosidic bond).
• Cannot reduce Benedict's or Fehling's reagent.
• **Examples:** sucrose, trehalose.

Clinical Note

• Reducing sugar detection in urine ? diabetes mellitus, galactosemia, hereditary fructose intolerance.

Reactions of Monosaccharides

1. Oxidation

• Aldehyde ? acid
• Examples:
– Glucose ? gluconic acid
– Glucose ? glucuronic acid (detoxification)
– Diabetic complications via oxidative stress

2. Reduction

• Aldoses & ketoses ? **sugar alcohols**
• Examples:
– Glucose ? sorbitol
– Galactose ? galactitol
• Excess sorbitol ? cataract, neuropathy.

3. Glycoside Formation

• Hemiacetal reacts with alcohol ? glycosidic bond.
• Basis of disaccharides (maltose, lactose) & polysaccharides (glycogen).

4. Isomerization

• Aldose ? ketose & vice versa.
• Glucose ? fructose ? mannose.

5. Esterification

• OH groups esterified by phosphates.
• Examples: glucose-6-phosphate, fructose-1-phosphate.

Mutarotation

Definition

Interconversion of **? and ? anomers** through an open-chain form when dissolved in water.

Feature

• Leads to change in optical rotation until equilibrium is reached.
• Occurs in **reducing sugars** only.

Examples

• ?-D-glucose ? ?-D-glucose
• Lactose mutarotates; sucrose does NOT.

Stereoisomers of Monosaccharides

Definition

Compounds with the same molecular formula but **different spatial orientation**.

D and L Forms

• Determined by configuration at **penultimate carbon**.
• Most human sugars are **D-isomers**.

Number of Stereoisomers

For a sugar with *n* chiral centers ? **2? stereoisomers**.

Epimers

Definition

Monosaccharides that differ only at **one specific carbon atom**.

Important Human Examples

• **Glucose & Mannose** ? epimers at **C-2**
• **Glucose & Galactose** ? epimers at **C-4**

Clinical Insight

• Epimerization is used in metabolism (UDP-glucose ? UDP-galactose).

Benedict's Reaction

Principle

• Reducing sugars convert **cupric ions ($Cu^{2?}$)** to **cuprous oxide (Cu?)** forming a **red/orange precipitate**.

Indicates

• Presence of **reducing sugar** in sample (urine, blood, CSF).

Clinical Uses

• Diabetes mellitus (glucosuria)
• Galactosemia (galactose in urine)
• Fructosuria
• Inborn errors of carbohydrate metabolism

Colors (Approximate Correlation)

• Green ? trace
• Yellow ? moderate
• Orange/brick red ? strong positive

Osazone Formation

Principle

Reducing sugars react with **phenylhydrazine** to form **crystalline osazones**.

Utility

Differentiates sugars based on **shape & rate** of crystal formation.

Characteristic Osazones

• **Glucose, fructose, mannose** ? *needle-shaped* “broomstick” osazones
• **Maltose** ? *sunflower-like* crystals
• **Lactose** ? *puff-ball* crystals

Mechanism

Reaction occurs at **C-1 and C-2**, so sugars identical at these carbons produce identical osazones.

Clinical Note

Helpful in older lab setups for carbohydrate identification.

Exam-Oriented Summary

• All **monosaccharides** = reducing sugars.
• Sucrose = **nonreducing**, no mutarotation.
• Mutarotation ? ? ? ? anomers interconversion.
• Epimers differ at **one carbon** (C-2, C-4 important).
• Benedict’s test detects reducing sugars in urine.

• Osazone crystals differentiate common sugars.

Structural vs Storage Carbohydrates

Storage Carbohydrates

• Serve as **energy reserves**.
• Easily mobilized.
• Examples:
– **Glycogen** (animals)
– **Starch** (plants: amylose + amylopectin)

Structural Carbohydrates

• Provide **rigidity and support**.
• Not easily digested.
• Examples:
– **Cellulose** (plant cell wall; ?-1,4 link ? non-digestible)
– **Chitin** (exoskeleton; N-acetylglucosamine polymer)
– **Hyaluronic acid** (ECM component)

Glycoproteins

Definition

Proteins covalently linked with carbohydrate chains (**short, branched oligosaccharides**).

Types

• **N-linked** ? attached to **Asn**
• **O-linked** ? attached to **Ser/Thr**

Functions

• Cell recognition
• Hormones (TSH, FSH, LH)
• Antibodies (IgG)

• Receptors
• Enzymes

Clinical Points

• Congenital disorders of glycosylation (CDG) ? neurological symptoms.
• Blood group antigens are glycoproteins.

Glycosaminoglycans (GAGs)

Definition

Long, unbranched polysaccharides containing repeating **acidic disaccharide units**.

General Composition

Amino sugar + uronic acid
• Glucosamine or galactosamine
• Glucuronic or iduronic acid

Functions

• Hydration
• Lubrication (synovial fluid)
• ECM structure
• Shock absorption

Important GAGs

• **Hyaluronic acid**
• **Chondroitin sulfate**
• **Dermatan sulfate**
• **Heparin**
• **Heparan sulfate**
• **Keratan sulfate**

Clinical Notes

• Defective degradation ? **mucopolysaccharidoses (MPS)**
– Hurler syndrome (?-L-iduronidase deficiency)
– Hunter syndrome (iduronate sulfatase deficiency)

Glycosides

Definition

Carbohydrate linked to a **non-sugar moiety (aglycone)** through a **glycosidic bond**.

Formation

• Hemiacetal OH of sugar reacts with alcohol/phenol.

Examples

• Cardiac glycosides ? **Digitalis, digoxin**
• Anthocyanins (plant pigments)

Importance

• Drug metabolism
• Stability of plant toxins
• Formation of glycolipids, nucleosides (adenosine, guanosine)

Amino Sugars

Definition

Sugars where an OH group is replaced by an **NH? group**.

Examples

• **Glucosamine**
• **Galactosamine**
• **N-acetylglucosamine (NAG)** ? chitin
• Present in GAGs, glycoproteins.

Clinical Importance

• Building blocks of cartilage and connective tissue.

Deoxy Sugars

Definition

Sugars in which an OH group is replaced by **H**.

Examples

• **Deoxyribose** ? DNA
• **L-fucose** ? blood group antigens
• **Rhamnose** ? plant products

Disaccharides

Disaccharides = two monosaccharides joined by a **glycosidic bond**.

General Concepts

• Reducing or nonreducing depends on availability of free anomeric carbon.
• Important in diet and digestion.

Sucrose

Composition

• Glucose + Fructose
• Linkage: **?-1,?-2** glycosidic bond
• **Nonreducing sugar**

Sources

• Cane sugar, beet sugar

Notes

• Does not show mutarotation
• No reaction with Benedict’s reagent

Lactose

Composition

• Galactose + Glucose
• Linkage: **?-1,4**

Nature

• **Reducing sugar**

Clinical

• Lactose intolerance ? lactase deficiency ? bloating, diarrhea

Maltose

Composition

• Glucose + Glucose
• Linkage: **?-1,4**

Nature

• **Reducing sugar**

Importance

• Product of starch digestion (amylase activity)

Exam-Oriented Summary

• Storage carbs = glycogen, starch; structural = cellulose, chitin.
• Glycoproteins = short, branched sugars; GAGs = long, unbranched, acidic.
• Amino sugars = glucosamine, galactosamine; deoxy sugars = deoxyribose.

• Sucrose = nonreducing; lactose & maltose = reducing.
• Lactose ? ?-1,4; Maltose ? ?-1,4; Sucrose ? ?-1,?-2.

Polysaccharides

Definition

Large polymers of monosaccharides linked by **glycosidic bonds**.

Types

• **Storage polysaccharides** – starch, glycogen
• **Structural polysaccharides** – cellulose, chitin
• **Mucopolysaccharides (GAGs)** – hyaluronic acid, chondroitin sulfate, etc.

Starch

Composition

• Plant storage carbohydrate
• Mixture of:
– **Amylose** ? linear ?-1,4 link
– **Amylopectin** ? branched ?-1,4 and ?-1,6 links

Features

• Digested by **salivary and pancreatic amylase**
• Major dietary carbohydrate

Clinical Notes

• Lack of amylase ? poor starch digestion
• Resistant starch ? improves gut flora (prebiotic)

Glycogen

Composition

• Major **animal storage polysaccharide**
• Highly branched polymer of glucose
• Linkages: **?-1,4** (chains) and **?-1,6** (branches)

Location

• Liver ? maintains blood glucose
• Muscle ? for contraction energy

Clinical Correlation

• **Glycogen storage diseases (GSD)**
– Type I: von Gierke (G6Pase deficiency)
– Type V: McArdle (muscle phosphorylase deficiency)
– Type II: Pompe (lysosomal acid maltase deficiency)

Cellulose

Composition

• Linear chains of glucose linked by **?-1,4** bonds.

Characteristics

• Humans cannot digest (lack cellulase)
• Provides **dietary fiber** ? gut motility, reduced cholesterol

Mucopolysaccharides (GAGs)

Definition

Long, negatively charged polysaccharides composed of **repeating disaccharide units** containing an **amino sugar** + **uronic acid**.

Functions

• Lubrication (synovial fluid)
• Shock absorption

• Structural ECM support
• Hydration due to negative charge

Main Types

• **Hyaluronic acid** – synovial fluid, ECM
• **Chondroitin sulfate** – cartilage
• **Dermatan sulfate** – skin, vessels
• **Heparin** – anticoagulant
• **Heparan sulfate** – basement membranes
• **Keratan sulfate** – cornea, cartilage

GAG Disorders (Mucopolysaccharidoses – MPS)

General Features

• Lysosomal storage disorders
• Due to failure to degrade GAGs
• Accumulation ? coarse facies, hepatosplenomegaly, joint stiffness, developmental delay

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Important MPS Disorders

1. Hurler Syndrome (MPS I – severe)

• **Enzyme:** ?-L-iduronidase deficiency
• **Accumulated GAGs:** dermatan sulfate, heparan sulfate
• **Features:**
– Coarse facies
– Corneal clouding
– Hepatosplenomegaly
– Developmental delay

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2. Hunter Syndrome (MPS II – milder, X-linked)

• **Enzyme:** iduronate sulfatase deficiency
• **Accumulated GAGs:** dermatan sulfate, heparan sulfate
• **Features:**
– Coarse facies
– **No corneal clouding**
– Behavioral issues

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3. Sanfilippo Syndrome (MPS III)

• **Defects in heparan sulfate degradation**
• **Predominantly neurological** deterioration

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4. Morquio Syndrome (MPS IV)

• **Enzyme:** galactose-6-sulfatase deficiency
• **Accumulated GAG: keratan sulfate**
• **Features:**
– Skeletal abnormalities
– Short stature
– Normal intelligence

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5. Maroteaux–Lamy Syndrome (MPS VI)

• **Enzyme:** arylsulfatase B deficiency
• **Accumulated GAG:** dermatan sulfate
• **Features:**
– Similar to Hurler
– Normal intelligence

Clinical Correlations (Carbohydrate Chemistry)

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1. Cataracts in diabetes

• Excess glucose ? sorbitol (aldose reductase) ? osmotic swelling ? lens opacity.

2. Lactose intolerance

• Lactase deficiency ? bloating, diarrhea.

3. Galactosemia

• GALT deficiency ? galactose ? ? galactitol in lens ? cataracts.

4. Hereditary fructose intolerance

• Aldolase B deficiency ? vomiting, hypoglycemia, jaundice.

5. Mucopolysaccharidoses

• Accumulation of GAGs ? coarse facies, organ enlargement, joint deformity.

6. Glycogen storage diseases

• Impaired glycogen metabolism ? hypoglycemia, muscle weakness.

7. Dietary fiber (cellulose)

• Prevents constipation, lowers cholesterol.

Exam-Oriented Quick Summary

• Starch ? amylose (?-1,4) + amylopectin (?-1,4 & ?-1,6).
• Glycogen ? highly branched (?-1,4 & ?-1,6).
• Cellulose ? ?-1,4; non-digestible.
• GAGs ? long, acidic, structural polysaccharides.
• MPS disorders ? failure to degrade GAGs.
• Hurler = corneal clouding; Hunter = no clouding.
• Morquio = skeletal deformity, keratan sulfate accumulation.

Pentoses: Ribose, Deoxyribose, Clinical Points

Pentoses

Definition

Pentoses are **5-carbon monosaccharides** important in nucleic acid structure and metabolic pathways.

General Properties

• Formula: **C?H??O?** (ribose)
• Exist mainly in **furanose (5-membered) ring** form
• All pentoses are **reducing sugars**

Ribose

Structure

• Aldopentose
• Component of **RNA**, ATP, NAD?, FAD, CoA

Biochemical Roles

• Part of **ribose-5-phosphate** in the HMP shunt
• Required for synthesis of:
– RNA nucleotides
– ATP, GTP
– Coenzymes (NAD?, NADP?, FAD, CoA)

Formation

• Generated from **glucose-6-phosphate** via:
– **HMP shunt (oxidative)**
– **Transketolase reactions (non-oxidative)**

Deoxyribose

Structure

• Aldopentose
• Differs from ribose by **absence of OH at C-2** ? replaced by **H**
• Component of **DNA**

Importance

• Gives DNA chemical stability (less reactive than RNA).
• Essential for genome replication and repair.

Formation

• Produced from ribose via **ribonucleotide reductase** (requires NADPH).

Clinical Points

1. HMP Shunt Disorders

• Defects in enzymes like **transketolase** decrease ribose-5-phosphate production.
• Thiamine deficiency reduces transketolase function ? neurological symptoms.

2. DNA Repair Disorders

• Deoxyribose deficiency affects DNA stability and repair mechanisms.
• Seen in some inherited nucleotide metabolism disorders.

3. Oxidative Stress

• Ribose is needed for NADPH production (via pentose phosphate pathway).
• NADPH deficiency ? increased oxidative damage (RBC hemolysis in G6PD deficiency).

4. Rapid Cell Division

• Cancer cells require **high ribose** for accelerated nucleotide synthesis.
• Basis for targeting nucleotide metabolism in chemotherapy.

5. Genetic Diseases of Purine/Pyrimidine Metabolism

• Overproduction or underutilization of ribose-based nucleotides causes:
– Gout (excess purines)
– SCID (adenosine deaminase deficiency)
– Orotic aciduria (pyrimidine synthesis defect)

Exam-Oriented Summary

• Ribose ? RNA, ATP, NAD?, FAD, CoA
• Deoxyribose ? DNA
• Ribose made from HMP shunt; deoxyribose from ribose via ribonucleotide reductase
• Pentoses are reducing sugars
• Clinically relevant in G6PD deficiency, cancer metabolism, nucleotide disorders

FAQs

1. What are pentoses?

Pentoses are **5-carbon monosaccharides** important for nucleic acid structure and cellular metabolism.

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2. What is the main difference between ribose and deoxyribose?

Deoxyribose lacks the **OH group at carbon-2**, making DNA more stable than RNA.

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3. Where is ribose found in the body?

In **RNA**, ATP, GTP, NAD?, FAD, and CoA.

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4. Where is deoxyribose found?

In **DNA** only.

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5. How is ribose produced in the cell?

From **glucose-6-phosphate** via the **HMP shunt**.

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6. How is deoxyribose formed?

By reduction of ribonucleotides via **ribonucleotide reductase**, using **NADPH**.

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7. Are pentoses reducing sugars?

Yes, all pentoses are **reducing sugars**.

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8. What is the clinical relevance of the HMP shunt in RBCs?

It generates **NADPH**, protecting RBCs from oxidative damage.
Defect ? **G6PD deficiency** ? hemolysis.

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9. Why does DNA use deoxyribose instead of ribose?

Deoxyribose is **less reactive** and provides long-term **chemical stability** to DNA.

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10. How does ribose relate to cancer cell metabolism?

Cancer cells require **large amounts of ribose** for rapid nucleotide synthesis.

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11. What happens if ribose-5-phosphate levels fall?

Nucleotide synthesis decreases ? impaired cell proliferation and DNA repair.

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12. Which enzyme defect reduces ribose formation?

Transketolase deficiency (exacerbated by thiamine deficiency).

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13. Which metabolic disorder affects deoxyribose in DNA?

Defects in nucleotide metabolism (e.g., **adenosine deaminase deficiency**) impair DNA synthesis.

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14. Is ribose involved in oxidative stress defense?

Yes. Ribose ? NADPH ? antioxidant protection via glutathione.

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15. Why does fructose enter glycolysis faster than glucose?

Because fructose bypasses the **PFK-1** step and enters at the triose phosphate level (side concept linking monosaccharides).

Important Points to Remember

• **Ribose = RNA sugar**, **Deoxyribose = DNA sugar**
• Deoxyribose has **no OH at C-2** ? increases DNA stability
• Ribose is essential for **ATP, NAD?, FAD, CoA, RNA**
• Ribose-5-phosphate is formed via the **HMP shunt**
• Deoxyribose is formed by **ribonucleotide reductase** (needs NADPH)
• All pentoses are **reducing sugars**
• NADPH generated by ribose pathway protects RBCs (G6PD deficiency ? hemolysis)
• Deoxyribose defects affect **DNA replication and repair**
• Pentose metabolism is tightly linked to **cell division, cancer metabolism, oxidative balance**
• Ribose and deoxyribose form the **backbone of nucleic acids**

Clinical Importance of Carbohydrates

Carbohydrates are essential for **energy metabolism, structural integrity, cellular communication, and detoxification**. Their clinical importance becomes clear when examining genetic diseases, acquired metabolic disorders, nutritional issues, and diagnostic applications.

1. Energy Supply & Metabolic Needs

Primary Fuel in Humans

• Glucose is the **universal fuel** for most tissues.
• Brain, RBCs, renal medulla, retina ? highly glucose-dependent.
• Hypoglycemia ? confusion, seizures, coma.

Clinical Point

• Any condition causing **low blood glucose** (insulin overdose, sepsis, adrenal insufficiency) becomes a medical emergency.

2. Genetic Disorders of Carbohydrate Metabolism

A. Glycogen Storage Diseases (GSD)

Type I – von Gierke Disease

• Glucose-6-phosphatase deficiency
• Severe fasting hypoglycemia, lactic acidosis, hepatomegaly.

Type II – Pompe Disease

• Lysosomal acid maltase deficiency
• Cardiomegaly, hypotonia.

Type V – McArdle Disease

• Muscle phosphorylase deficiency
• Exercise intolerance, muscle cramps, myoglobinuria.

B. Disorders of Monosaccharide Metabolism

1. Galactosemia

• GALT deficiency
• Jaundice, vomiting, cataracts, hepatomegaly.
• Galactitol accumulation ? lens opacity.

2. Hereditary Fructose Intolerance

• Aldolase B deficiency
• Hypoglycemia, liver failure after consuming fruits/sucrose.

3. Essential Fructosuria

• Benign fructokinase deficiency
• Fructose spills into urine.

C. Pentose Pathway Defects

G6PD Deficiency

• Low NADPH ? oxidative stress ? hemolysis.
• Triggers: fava beans, infections, sulfa drugs, antimalarials.

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3. Disorders of Disaccharide Digestion (Acquired/Genetic)

Lactose Intolerance

• Lactase deficiency (genetic or post-infectious).
• Bloating, diarrhea, gas.

Sucrase-Isomaltase Deficiency

• Intolerance to sucrose and starch digestion.
• Watery diarrhea in infants.

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4. Acid-Base Homeostasis & Carbohydrates

• Anaerobic glycolysis ? **lactate production**.
• Excess lactate ? **lactic acidosis** in:
– Shock
– Sepsis
– Liver failure
– Thiamine deficiency
– Metformin toxicity

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5. Carbohydrates in Diet & Nutrition

Role in Balanced Diet

• 50–60% of daily calories.
• Complex carbs preferred over simple sugars.

High Carbohydrate Intake

• Hyperinsulinemia ? weight gain
• Increased triglycerides
• Increased risk of fatty liver

Low-Carb Diets (Keto, Atkins)

• Used for weight loss and type 2 diabetes control.
• Risk: ketoacidosis in type 1 diabetics if insulin is absent.

6. Dietary Fiber (Cellulose, Pectins, Gums)

Benefits

• Prevents constipation
• Reduces postprandial glucose spikes
• Lowers LDL cholesterol
• Improves gut microbiota
• Reduces colon cancer risk

Clinical Use

• Recommended in diabetes, obesity, hyperlipidemia.

7. Carbohydrates in Cell Structure & Immunity

Glycoproteins & Glycolipids

• Blood group antigens
• Immunoglobulins
• Cell adhesion molecules
• Receptor recognition (viral attachment)

Clinical Point

• Carbohydrate defects contribute to congenital disorders of glycosylation (CDG).

8. Carbohydrates in Connective Tissue

Glycosaminoglycans (GAGs)

• Important in joints, cartilage, ECM.

Defects ? Mucopolysaccharidoses (MPS)

• Hurler (cloudy cornea)
• Hunter (no corneal clouding)
• Morquio (skeletal deformity)
• Sanfilippo (CNS degenerative)

9. Carbohydrate Toxicity & Complications

A. Advanced Glycation End Products (AGEs)

• Chronic hyperglycemia ? nonenzymatic glycation of proteins.
• Complications:
– Retinopathy
– Nephropathy
– Neuropathy

– Atherosclerosis

B. Sorbitol Accumulation

• In lens, nerves, kidney ? osmotic damage.
• Seen in uncontrolled diabetes.

10. Carbohydrates in Cancer Biology

Warburg Effect

• Cancer cells rely on **aerobic glycolysis**, converting glucose to lactate even with oxygen.
• High glucose uptake ? basis of **FDG-PET scans**.

Clinical Use

• PET scan detects tumors based on glucose uptake.

11. Carbohydrates in Liver Disease

• Liver stores glycogen ? fasting glucose maintenance.
• Liver failure ? hypoglycemia + lactic acidosis.
• High carbohydrate diet can worsen **fatty liver disease**.

12. Diagnostic Use of Carbohydrates

Glucose Tolerance Test (GTT)

• Diagnosis of diabetes mellitus and reactive hypoglycemia.

HbA1c

• Measures long-term glycemic control (AGE formation).

Urinary Reducing Sugar Tests

• Screens for galactosemia, fructosuria, glucosuria.

Important Points to Remember

• Glucose is the primary metabolic fuel; brain & RBCs depend on it.
• GSDs, galactosemia, and fructose intolerance are important genetic carbohydrate disorders.
• G6PD deficiency ? oxidative hemolysis; linked to pentose pathway.
• Lactase deficiency ? common cause of carbohydrate malabsorption.
• Sorbitol accumulation ? diabetic cataract and neuropathy.
• Chronic hyperglycemia leads to **glycation**, causing microvascular complications.
• Fiber improves digestion, lowers cholesterol, and helps control diabetes.
• GAG defects ? mucopolysaccharidoses (Hurler, Hunter, Morquio).
• Carbohydrates are essential for nucleic acids (ribose, deoxyribose), immunity, and ECM.
• Excess carbohydrates ? fatty liver, obesity, hypertriglyceridemia.
• PET scans use glucose analogs to detect tumors.
• Hypoglycemia is more dangerous acutely; hyperglycemia dangerous chronically.

MCQs

1. Which tissue is MOST dependent on glucose for its energy supply?

A. Liver
B. Kidney cortex
C. Brain
D. Skeletal muscle

Answer: C

2. Sorbitol accumulation is responsible for which diabetic complication?

A. Retinopathy
B. Cataract

C. Hypoglycemia
D. Ketoacidosis

Answer: B

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3. Hereditary fructose intolerance is caused by deficiency of:

A. Fructokinase
B. Aldolase B
C. Galactokinase
D. Pyruvate kinase

Answer: B

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4. Classical galactosemia is due to deficiency of:

A. Galactokinase
B. Aldose reductase
C. GALT
D. Hexokinase

Answer: C

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5. Which pathway produces ribose-5-phosphate for nucleotide synthesis?

A. Glycolysis
B. TCA cycle
C. Pentose phosphate pathway
D. Beta-oxidation

Answer: C

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6. A 5-year-old child develops cataracts after starting milk feeding. Most likely enzyme deficiency?

A. Galactokinase
B. Aldolase B

C. G6PD
D. Transketolase

Answer: A

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7. Which disorder shows “coarse facial features, corneal clouding, hepatosplenomegaly”?

A. McArdle disease
B. Hurler syndrome
C. Hunter syndrome
D. Pompe disease

Answer: B

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8. Corneal clouding is absent in:

A. Hurler syndrome
B. Maroteaux–Lamy syndrome
C. Hunter syndrome
D. Morquio syndrome

Answer: C

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9. Which enzyme is deficient in McArdle disease?

A. Liver phosphorylase
B. Muscle phosphorylase
C. G6Pase
D. Acid maltase

Answer: B

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10. Severe fasting hypoglycemia is characteristic of:

A. Pompe disease
B. von Gierke disease

C. McArdle disease

D. Cori disease

Answer: B

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11. Which molecule protects RBCs from oxidative damage?

A. NADH

B. NADPH

C. ATP

D. FADH?

Answer: B

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12. G6PD deficiency leads to hemolysis because of accumulation of:

A. Glutathione

B. NAD?

C. Peroxide

D. Sorbitol

Answer: C

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13. Dietary fiber helps prevent all EXCEPT:

A. Constipation

B. Colon cancer

C. LDL elevation

D. Hypoglycemia

Answer: D

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14. Which carbohydrate test is positive in fructosuria?

A. Benedict’s test

B. Seliwanoff test

C. Barfoed test

D. Rapid urease test

Answer: A

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15. Which sugar shows the fastest entry into glycolysis?

A. Glucose
B. Fructose
C. Galactose
D. Ribose

Answer: B

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16. The “flipped LDH pattern” (LDH-1 > LDH-2) indicates:

A. Hemolytic anemia
B. Liver disease
C. Myocardial infarction
D. Muscle injury

Answer: C

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17. Which polysaccharide contains ?-1,4 linkages and is indigestible?

A. Glycogen
B. Amylose
C. Amylopectin
D. Cellulose

Answer: D

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18. The Warburg effect refers to:

A. Glycogen breakdown in liver
B. Aerobic glycolysis in cancer cells
C. Lactose intolerance
D. Ketone body formation in diabetes

Answer: B

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19. Which of the following is a nonreducing disaccharide?

A. Maltose
B. Lactose
C. Sucrose
D. Cellobiose

Answer: C

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20. Which MPS results primarily in neurological symptoms with heparan sulfate accumulation?

A. Hurler
B. Hunter
C. Sanfilippo
D. Morquio

Answer: C

Viva Voce

1. What is the primary function of carbohydrates?

To provide **immediate energy**, mainly in the form of glucose.

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2. Which tissues are absolutely dependent on glucose?

Brain, RBCs, retina, renal medulla.

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3. What is the carbohydrate requirement of the brain per day?

Approximately **120 grams of glucose**.

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4. Why do RBCs use only glucose?

RBCs **lack mitochondria**, so they depend entirely on glycolysis.

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5. What is the most dangerous acute complication of carbohydrate imbalance?

Hypoglycemia, because it affects the brain quickly.

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6. What causes fasting hypoglycemia in von Gierke disease?

Deficiency of **glucose-6-phosphatase** prevents glucose release from liver.

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7. Which enzyme deficiency causes cataracts in infants fed with milk?

Galactokinase deficiency.

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8. What causes severe symptoms immediately after fructose intake in infants?

Aldolase B deficiency ? hereditary fructose intolerance.

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9. What is the biochemical basis of hemolysis in G6PD deficiency?

Low NADPH ? inability to neutralize oxidants ? **oxidative damage to RBCs**.

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10. What triggers hemolysis in G6PD deficiency?

Fava beans, infections, antimalarials, sulfa drugs.

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11. What is the main role of the HMP shunt in RBCs?

To generate **NADPH** for glutathione regeneration.

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12. Which monosaccharide accumulates in diabetics leading to cataract?

Sorbitol, due to aldose reductase activity.

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13. In which tissues does sorbitol accumulation cause complications?

Lens, retina, kidney, peripheral nerves.

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14. What causes lactic acidosis in shock?

Tissue hypoxia ? anaerobic glycolysis ? **lactate accumulation**.

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15. What is the hallmark of lactose intolerance?

Bloating and diarrhea due to undigested lactose fermenting in colon.

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16. Which mucopolysaccharidosis presents with corneal clouding?

Hurler syndrome (?-L-iduronidase deficiency).

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17. Which mucopolysaccharidosis is X-linked and spares the cornea?

Hunter syndrome.

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18. What is the defect in Morquio syndrome?

Defective degradation of **keratan sulfate**.

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19. Why is cellulose indigestible in humans?

Lack of **?-1,4 glucanase** (cellulase).

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20. What is the dietary role of cellulose?

Acts as **fiber**, improving bowel movement and lowering cholesterol.

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21. What is the Warburg effect?

Cancer cells preferentially perform **aerobic glycolysis**, producing lactate even with oxygen.

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22. What diagnostic tool uses glucose analog uptake?

FDG-PET scan for tumor detection.

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23. What causes the “flipped pattern” in LDH during myocardial infarction?

LDH-1 exceeds LDH-2 due to cardiac muscle damage.

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24. Why is sucrose a nonreducing sugar?

Both anomeric carbons are involved in the **?-1,?-2 glycosidic bond**.

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25. What is the biochemical reason for postprandial hyperglycemia after high-carb meals?

Rapid digestion and absorption of **simple carbohydrates** ? glucose spike ? insulin release.

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26. How does dietary fiber help in diabetes?

Slows glucose absorption ? **reduces postprandial spikes**.

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27. What is the function of glucuronic acid in the body?

Helps in **detoxification (conjugation reactions)**.

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28. Which enzyme converts ribonucleotides to deoxyribonucleotides?

Ribonucleotide reductase.

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29. What is the significance of ribose?

Component of **ATP, NAD?, RNA**.

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30. Which test detects reducing sugars in urine?

Benedict’s test.