Carbohydrates

Introduction

Carbohydrates are a fundamental class of biomolecules essential for the survival of all living things. As the primary fuel source for cellular respiration and a key component of cell structures, they are ubiquitous in nature, ranging from simple sugars to complex fibrous polymers.

- Carbohydrates are the most abundant biomolecules on Earth, often referred to as saccharides or sugars.
- They are primary energy sources for living organisms, especially the central nervous system.
- They are also crucial for structural support (e.g., in plants) and cell-to-cell communication.
- Their general empirical formula is $(CH_2O)_n$, literally meaning "hydrates of carbon".

Learning Objectives

By the end of this module, you will be able to:

- Describe the structure, general properties, and functional groups (aldose/ketose) of carbohydrates.
- Classify carbohydrates into monosaccharides, disaccharides, oligosaccharides, and polysaccharides.
- Describe the principles of carbohydrate analysis (Benedict's, Iodine, etc.).
- Identify key biological carbohydrates (e.g., Glucose, Glycogen, Cellulose) and explain their specific physiological roles.

Key Concepts and Definitions

Term	Definition

Monosaccharide	The simplest carbohydrate unit (monomer) that cannot be hydrolyzed further (e.g., Glucose).
Glycosidic Bond	A covalent ether bond linking two sugar molecules, formed via a condensation reaction.
Reducing Sugar	A sugar with a free anomeric carbon (aldehyde or ketone) capable of acting as a reducing agent (e.g., Glucose, Maltose).
Anomer	Isomers that differ at a new asymmetric carbon atom formed on ring closure (α or β forms).
Polysaccharide	A long polymer chain of monosaccharides used for energy storage (Starch) or structure (Cellulose).

Detailed Discussion

Structure, Functions, and General Properties

- Chemical Structure: Carbohydrates are defined as polyhydroxy aldehydes or polyhydroxy ketones. This means they contain a carbonyl group (C=O) and multiple hydroxyl groups (-OH).
    - Aldose: Contains an aldehyde group at the end of the chain (e.g., Glucose, Galactose).
    - Ketose: Contains a ketone group within the chain (e.g., Fructose).
- Chirality (Stereoisomerism): Because they have asymmetric carbons, carbohydrates exist as stereoisomers. The D-isomer is the form used in biological systems (e.g., D-Glucose).
- Ring Formation: In aqueous solution, pentoses (5-carbon) and hexoses (6-carbon) spontaneously cyclize to form stable rings. The carbonyl carbon becomes the anomeric carbon, creating α and β isomers.
- Solubility: Due to the many hydroxyl (-OH) groups, simple carbohydrates are highly polar and hydrophilic (water-soluble).

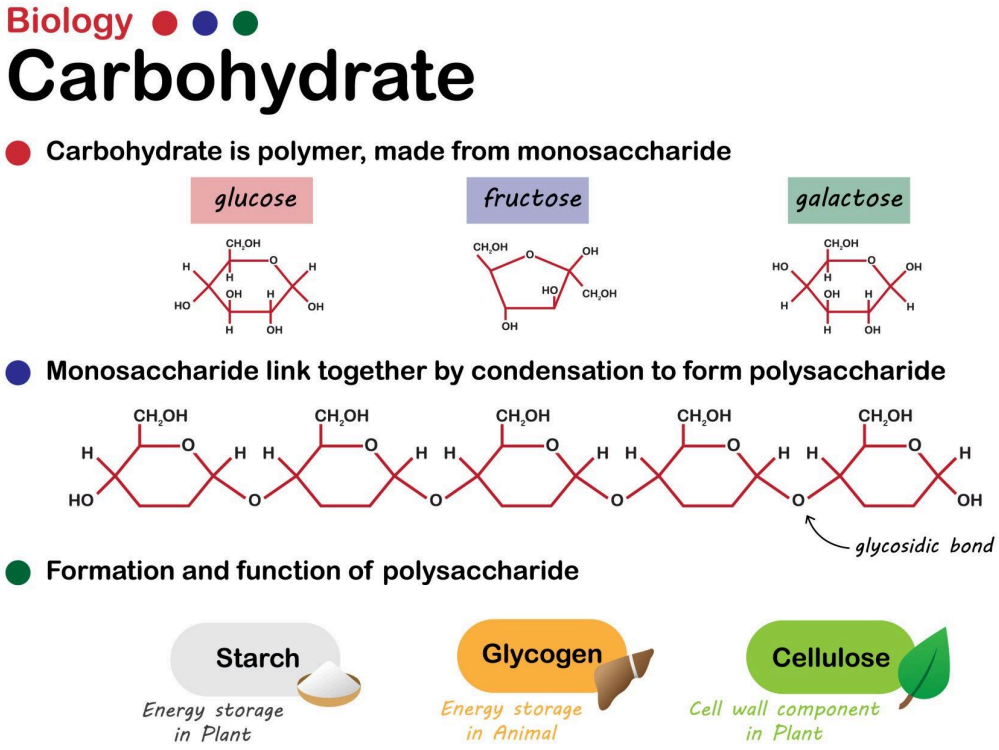
Classes of Carbohydrates

Carbohydrates are classified by the number of sugar units they contain:

1. **Monosaccharides (Simple Sugars):**
    - The basic units (monomers).

- Classified by carbon count: Triose (3C), Pentose (5C, e.g., Ribose), Hexose (6C, e.g., Glucose).
- Examples: Glucose (Blood sugar), Fructose (Fruit sugar), Galactose.

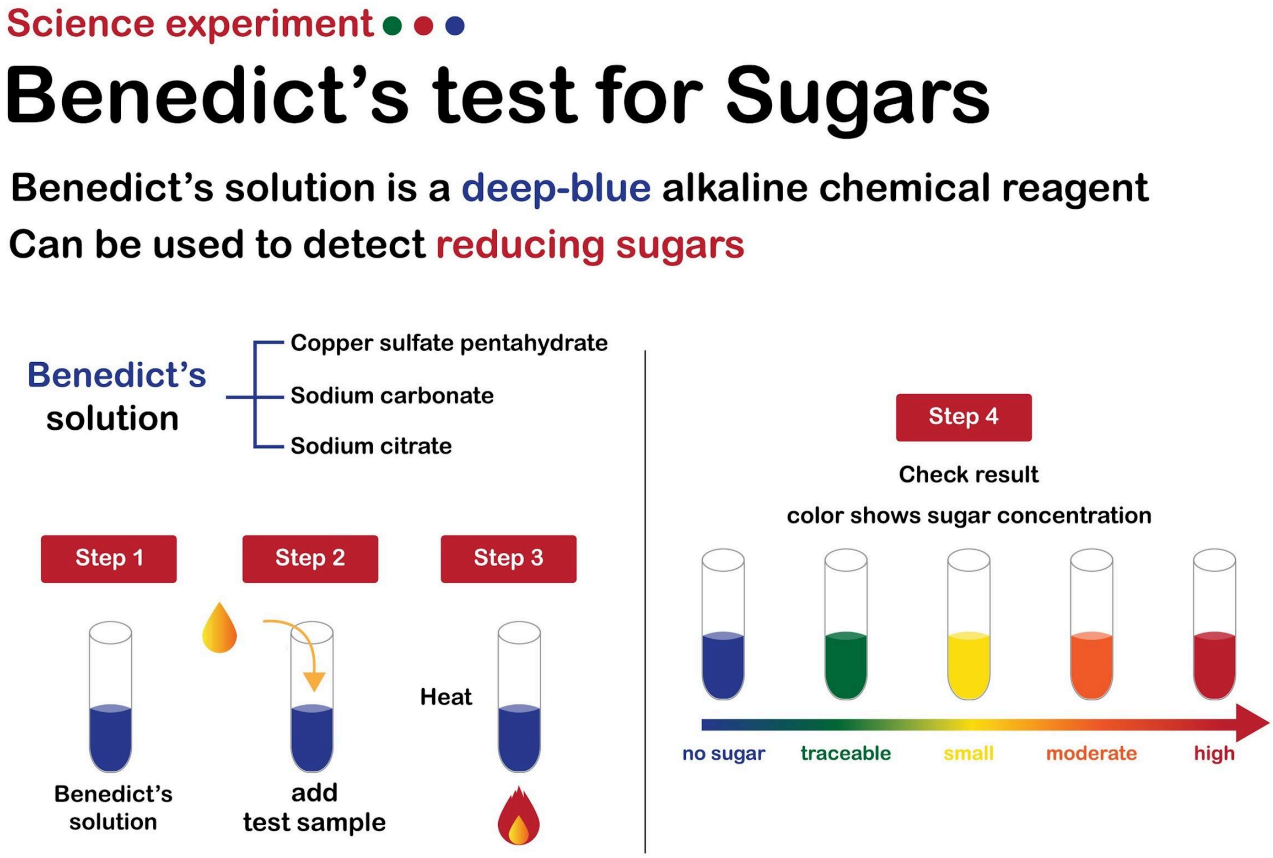
2. **Disaccharides**:
   - Two monosaccharides linked by a glycosidic bond.
   - Maltose: Glucose + Glucose (α-1,4 linkage). Breakdown product of starch.
   - Sucrose: Glucose + Fructose (α-1,2 linkage). Non-reducing sugar (Table sugar).
   - Lactose: Glucose + Galactose (β-1,4 linkage). Milk sugar.
3. **Oligosaccharides**:
   - Short chains (3–10 units).
   - Often found attached to proteins (glycoproteins) or lipids (glycolipids) on cell membranes, serving as ID tags for cell recognition (e.g., Blood types).
4. **Polysaccharides (Complex Carbohydrates):**
   - Long chains of hundreds/thousands of units.
   - Storage: Starch (Plants), Glycogen (Animals).
   - Structural: Cellulose (Plants), Chitin (Fungi/Insects).



Analysis of Carbohydrates

Biochemists use specific qualitative tests to identify sugar types based on their chemical properties:

- **Benedict's / Fehling's Test (For Reducing Sugars):**
  - **Principle**: The free aldehyde/ketone group of a reducing sugar reduces copper ions (Cu^{2+}, blue) to cuprous oxide (Cu^{+}, red precipitate) under alkaline conditions and heat.
  - **Result**: Blue → Brick Red Precipitate = Positive for Reducing Sugar (e.g., Glucose, Lactose). Sucrose is negative



- **Barfoed's Test:**
  - Principle: Distinguishes Monosaccharides from Disaccharides. Monosaccharides react faster in acidic conditions.
  - Result: Red precipitate within ~2-3 minutes indicates a Monosaccharide.
- **Seliwanoff's Test:**
  - Principle: Distinguishes Ketoses (Fructose) from Aldoses. Ketoses dehydrate faster to form furfural derivatives that react with resorcinol.
  - Result: Cherry Red color = Positive for Ketose.
- **Iodine Test:**
  - Principle: Iodine interacts with the coiled helix structure of starch.
  - Result: Blue-Black color = Positive for Starch. Glycogen gives a reddish-brown color.

Biological Carbohydrates and Roles

Carbohydrate	**Type**	**Biological Role**
Glucose	Monosaccharide	The universal energy currency. Circulates in blood; substrate for glycolysis to produce ATP.
Glycogen	Polysaccharide	Energy storage in animals. Stored in the liver (to maintain blood sugar) and muscles (for activity). Highly branched structure allows rapid release.
Starch	Polysaccharide	Energy storage in plants. Composed of Amylose (linear) and Amylopectin (branched). Major dietary source for humans.
Cellulose	Polysaccharide	Structural support in plants (cell walls). Linear chains linked by β-1,4 bonds make it rigid and indigestible by humans (fiber).

Ribose	Monosaccharide	Structural backbone of RNA and ATP.
Chitin	Polysaccharide	Structural component of exoskeletons (crabs, insects) and fungal cell walls.

References

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2. Nelson, D. L., & Cox, M. M. (2021). Lehninger principles of biochemistry (8th ed.). W. H. Freeman.
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