

Chapter 3 Carbohydrates and Metabolism

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Carbohydrates

- Commonly called sugars and starches.
- Functions include: source of energy, the production of structural components, and conversion into other compounds.
- Carbohydrates contain three elements: carbon, hydrogen, and oxygen (C,H, O). The ratio of hydrogen to oxygen is typically 2:1 (H₂O).
- They are usually divided into four groups:
 - **Monosaccharides** are the simple sugars. They cannot be decomposed into simpler sugars by hydrolysis.
 - **Disaccharides** consist of two monosaccharide units.
 - **Oligosaccharides** contain a small number of monosaccharide units (usually defined as from three to twelve monosaccharide units).
 - **Polysaccharides** contain more than 12 monosaccharide units. Typically, they contain hundreds of sugar units

MONOSACCHARIDES

- Monosaccharides are the single unit or simple sugars. They cannot be decomposed into simpler sugars by hydrolysis.
- Monosaccharides are usually constructed into a single chain or into a single ring structure and are the building blocks of more complex sugars.
- Monosaccharides may be named according to the number of carbon atoms they contain. Two important examples are the pentose (five carbon) and the hexose (six carbon) sugars.

Pentose-carbon sugars

- Pentose-carbon sugars include ribose and deoxyribose, the two monosaccharides found in the nucleic acids;
 - ribose in ribonucleic acid (RNA) and
 - deoxyribose in deoxyribonucleic acid (DNA).

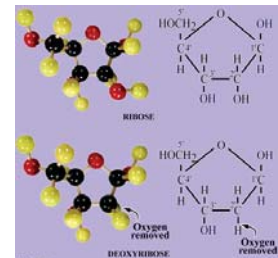


Fig 3A-1

Hexose-carbon sugars

- Hexose-carbon sugars include glucose, galactose, and fructose. These simple sugars are found in many fruits and vegetables and are the common building blocks for the more complex sugars.

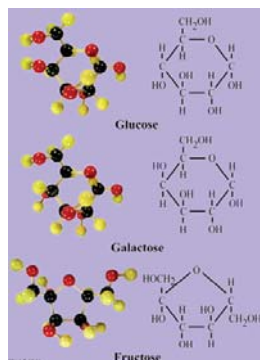


Fig 3A-2

Chemical Formulas

- The **empirical** formula, the simplest ratio of elements in a compound, for many of the simple carbohydrates is (CH₂O)_n. The interpretation of the formula is: the molecule consists of one atom of carbon atom, two atoms of hydrogen, and one atom of oxygen, all multiplied by the same number.
- The **chemical** formula gives the kind and the number of the atoms in the compound. The chemical formula for glucose is C₆H₁₂O₆. The interpretation of the formula is: the molecule consists of six atoms of carbon, twelve atoms of hydrogen, and six atoms of oxygen.
- The **structural** formula shows how the atoms are bonded in a compound.

Structural Formulas and Isomers

- The structural formulas for glucose, galactose, mannose, and fructose are shown in the following illustration. The structural formula is the "blue-print" of the compound.
- Isomers are compounds that have the same chemical formulas. For example, the chemical formula of $C_6H_{12}O_6$ can be expressed as four structural isomers: glucose, galactose, mannose, and fructose.

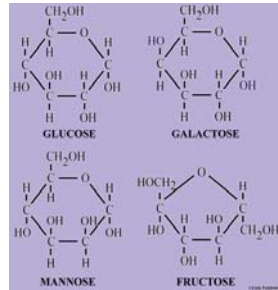
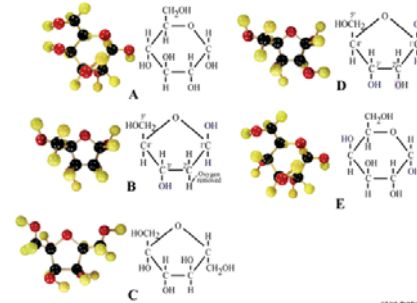


Fig 3A-3

Lab Activity 1 Molecular Model Kit



DISACCHARIDES

- Disaccharides may be considered as double sugars because they are formed from the union of two monosaccharides.
- Important disaccharides include
 - sucrose (glucose + fructose or common table sugar),
 - lactose (glucose + galactose or milk sugar),
 - maltose (glucose + glucose).

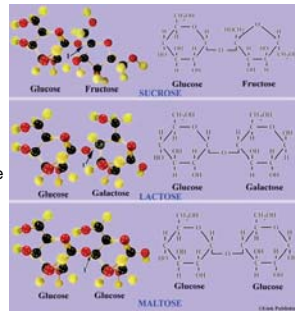


Fig 3A-4

OLIGOSACCHARIDES

- Oligosaccharides are formed from the union of three to twelve monosaccharides.
- They are common in the formation of oligosaccharide-glycoproteins commonly found in the extracellular phospholipid bilayer of the cell membrane.
- Functions of membrane bound oligosaccharide-glycoproteins include cell surface recognition (especially for hormones and other cells), and cell surface antigenicity (such as the antigens for blood groups).

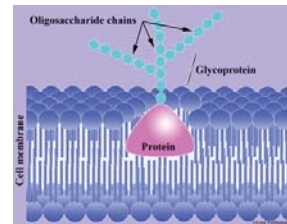


Fig 3A-5

POLYSACCHARIDES

- Polysaccharides are formed from the union of twelve or more monosaccharides. Common polysaccharides include **glycogen** and **starch**.

Starch

- Starch, a carbohydrate produced by plants, typically consists of thousands of glucose units. In plants such as corn and potato, glucose is typically stored in structural units called starch grains.
 - Cooking (heat) denatures the starch grains into macromolecules, which when eaten are digested (hydrolyzed) to glucose. Glucose then enters the blood by crossing the intestinal lining.

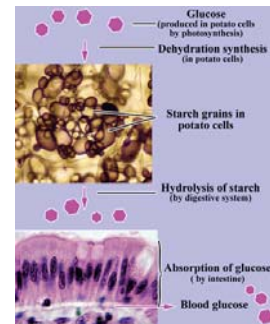


Fig 3A-6

Glycogen

- Glycogen, a carbohydrate produced by animals, typically consists of thousands of glucose units.
- A molecule of glycogen is produced by dehydration synthesis involving thousands of glucose units and is commonly stored as glycogen granules in **liver** and **muscle tissue**.

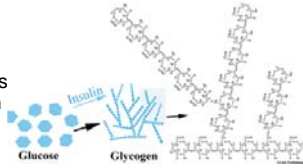


Fig 3A-7

Carbohydrate Dehydration Synthesis

- Dehydration synthesis is the reaction that joins smaller molecules into a larger molecule (synthesis) and produces water (dehydration). In the formation of larger sugar molecules (such as the formation of a disaccharide from two monosaccharides) the union of the two smaller sugars is by an enzymatically driven reaction called dehydration synthesis.

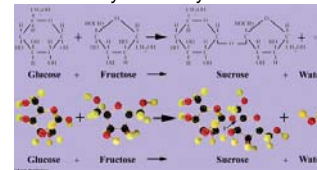


Fig 3A-8

Carbohydrate Hydrolysis

- The enzymatically driven reaction that splits a larger sugar molecule into smaller sugar molecules and also splits and utilizes a molecule of water is called hydrolysis. The following illustration shows the reaction that splits the larger disaccharide, sucrose, into two smaller monosaccharides, glucose and fructose.

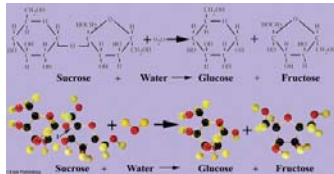


Fig 3A-9

Glycoaminoglycans (GAGs),

- The mucopolysaccharides, now commonly called glycoaminoglycans (GAGs), bind large amounts of water. They produce the viscous, lubricating properties of mucus (which led to the original name of mucopolysaccharides) and the gel-like ground substance found among the fibers of connective tissues.

Glycoaminoglycans

- The glycoaminoglycans are long, unbranched charged polysaccharide chains composed of repeating disaccharide units.

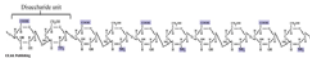


Fig 3A-10

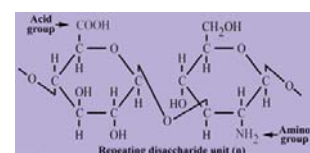


Fig 3A-11

Glycoaminoglycans

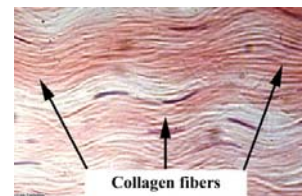


Fig 3A-13

Glycoaminoglycans bind together the collagen fibers of tendon to form a functional unit.

Glycoaminoglycans

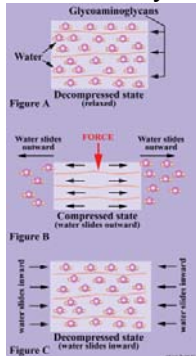


Fig 3A-15

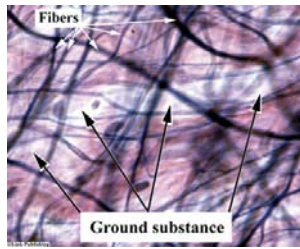


Fig 3A-16
Water is an effective lubricant and shock absorber. In synovial fluids pressure causes water to move away for its associated hydrophilic molecule (GAG).

GLYCOPROTEINS

Glycoproteins are proteins that are bonded to a carbohydrate chain (oligosaccharide).

Glycoproteins are commonly found associated with cell membranes, as part of extracellular matrix, and the mucins of the digestive, urinary and reproductive tracts.

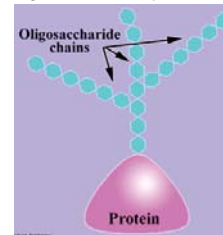


Fig 3A-17

CARBOHYDRATE METABOLISM

Glucose from Dietary Carbohydrates

- Major sources of dietary carbohydrates are starch (from plant materials), glycogen (from animal tissue), and disaccharides such as sucrose (table sugar) and lactose (in milk).
- Digestion converts all multi-unit sugars to monosaccharides, which include glucose, fructose, and galactose. The monosaccharides are absorbed by the intestine and transported by the blood to the liver. The liver converts all non-glucose monosaccharides to glucose, the monosaccharide commonly referred to as "blood sugar."
- The liver metabolizes some of the glucose and the rest circulates to peripheral tissues.

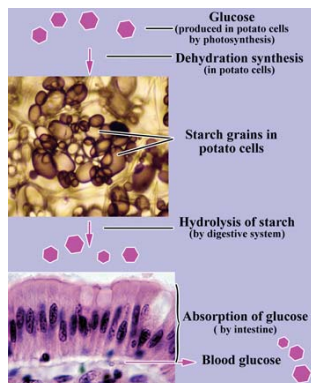


Fig 3A-18

Lab Activity 4 - Raw Potato

- Cut a thin slice of the raw potato and place on a clean microscope slide.

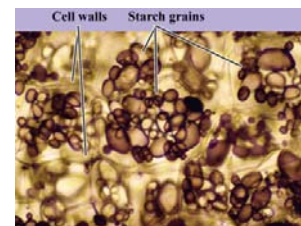


Fig 3A-19

Lab Activity 5 - Cooked Potato

- Cut a thin slice of the cooked potato and place on a clean microscope slide.

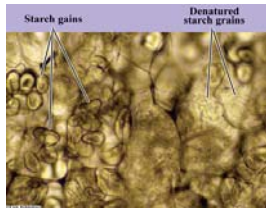


Fig 3A-20

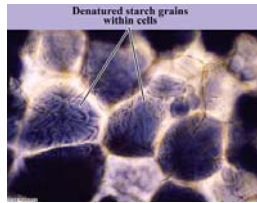


Fig 3A-21

Lab Activity 6 - Liver Glycogen

- High power and oil immersion photographs of liver with glycogen **present**. Glycogen is a storage macromolecule formed of repeating units of glucose.

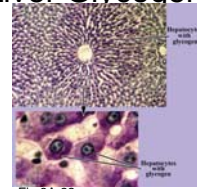


Fig 3A-22

- High power and oil immersion photographs of liver with glycogen **absent**. In this tissue preparation the glycogen was removed by the enzyme amylase.

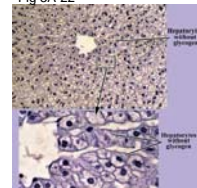


Fig 3A-23

GLUCOSE CATABOLISM

- In the **well-fed state**, the major sources of glucose are dietary, mostly as the end product from the digestion of disaccharides (such as cane sugar) and polysaccharides (such as starch).
- In the **fasting state**, the breaking down of the liver's glycogen, glycogenolysis, into glucose units helps maintain blood glucose levels. Also, glucose can be manufactured from non-glucose substances such as fats and proteins; a process called gluconeogenesis.
- The catabolism (breaking down) of glucose is mostly for the production of energy rich **ATP**. When glucose is oxidized, some of the energy found in its chemical bonds, is transferred to high-energy phosphate bonds in the formation of the energy rich molecule adenosine triphosphate (ATP). The chemical reaction may be summarized as follows:

GLUCOSE CATABOLISM

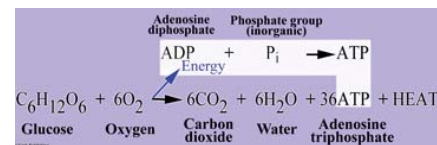


Fig 3A-24

GLUCOSE ANABOLISM

- A major role of glucose in the body is catabolism as a fuel. In glucose anabolism, the constructive phase of glucose metabolism, three major processes are **gluconeogenesis, glycogenesis, and glycogenolysis**.
- **Gluconeogenesis**
 - Glucose can be constructed from non-carbohydrate sources, such as proteins and fats, by a process called gluconeogenesis. Gluconeogenesis occurs when there is a low glucose level, perhaps due to starvation, fasting, or a low carbohydrate diet.
- **Glycogenesis**
 - If glucose levels are high, as seen in increased blood sugar after a carbohydrate rich meal, glucose can be assembled for storage as the polysaccharide glycogen by a process called glycogenesis.
- **Glycogenolysis**
 - Glycogen storage is catabolized to release glucose, a process called glycogenolysis, when blood sugar begins to decrease.