Carbohydrates

Learning Outcomes:

- **Cellular Functions**
    - Describe the formation and breakage of a glycosidic bond
- **Cellular Physiology and Biochemistry**
    - Compare the storage and structural forms of starch, glycogen and cellulose and their roles in plants/animals
- **Others**
    - Carry out tests for reducing and non-reducing sugars (Semi-quantitative Benedict's Test), and for starch (Potassium iodide solution test)

Glycosidic Bonds

Condensation Reaction

- Glycosidic bond formed between 2 monosaccharides with the loss of a water molecule in condensation reaction

Hydrolysis Reaction

- Glycosidic bond broken with the addition of water in hydrolysis reaction
- For maltose, enzymatic action of maltase required/acid hydrolysis by heating with HCl.

	Cellulose	**Starch**
Monomer	β-glucose monomers	α-glucose monomers
Bond between monomers	β(1-4) glycosidic bond links monomers	Amylose: • α(1-4) glycosidic bond links monomers within a branch Amylopectin: • α(1-4) glycosidic bond links monomers within a branch • α(1-6) glycosidic bond links monomers at branch points
Orientation of	Alternate glucose monomers are	All glucose units in the chain have

monomer	<u>rotated 180° with respect to each other</u>	the <u>same orientation</u>
Structure of each molecule	Cellulose is a long linear chain	Amylose in starch is a helical strand Amylopectin in starch is a coiled branched molecule
Bonds between molecules	OH groups projecting outwards in both directions allow intermolecular hydrogen bonding	No intermolecular hydrogen bonding in starch
Branching	No branching present in cellulose	Branching with α(1-6) glycosidic bonds in amylopectin

Cellulose
Structure:

- Structural polysaccharide
- Monomers: β glucose monomers
- Bonds: β(1-4) glycosidic bonds ⇒ Cellulases that break down β(1-4) glycosidic bonds not commonly found in organisms ⇒ Cellulose not readily used as a respiratory substrate
- Alternate glucose residues inverted 180° wrt each other ⇒ Forms straight linear chains
- Hydroxyl groups project out in both directions ⇒ Intermolecular hydrogen bonds form between parallel cellulose molecules ⇒ Forms microfibrils ⇒ Cable-like microfibrils have high tensile strength + {Fewer hydroxyl groups available for hydrogen bonding with water ⇒ Insoluble in water}
- Meshwork of criss-crossing microfibrils form a cellulose cell wall ⇒ {Porous structure makes it freely permeable to water and solutes ⇒ Allows free movement of substances in and out of cells} + {Strong and rigid structure of meshwork distributes the stresses in all directions ⇒ Encloses plant cells and protects them from physical damage + Prevent bursting due to osmotic stress}

<u>Structure</u>	**<u>Function</u>**
β glucose monomers are linked by β(1-4) glycosidic bonds	Enzymes that hydrolyse these bonds are rarely found in nature and thus, are likely to remain intact

Alternate glucose residues inverted 180° with respect to each other allowing straight chains to be formed with OH groups projecting out in either direction Hydrogen bonding between adjacent chains form microfibrils	Straight chains allow packing of cellulose molecules into bundles of microfibrils with high tensile strength (*Note: cellulose does not have high tensile strength)
Hydrogen bonding between adjacent chains to form microfibrils	Cellulose has relatively few hydroxyl groups available for hydrogen bonding with water, making it insoluble in water

Starch
Structure:

- Storage polysaccharide in plants
- Monomer: α-glucose
- Bonds: α(1-4) glycosidic bonds in amylose; α(1-4) glycosidic bonds within a branch and α(1-6) glycosidic bonds at branch points in amylopectin
- Consists of amylose (unbranched) and amylopectin (branched)
- α(1-4) glycosidic bonds ⇒ Each residue is bent in one direction wrt the previous residue ⇒ Helical shape ⇒ Compact storage molecule that packs many glucose residues per unit volume ⇒ Hydrolysed to produce many glucose molecules which are the major respiratory substrate to produce ATP ⇒ Large energy store
- Helical shape maintained by intramolecular hydrogen bonding ⇒ Relatively few hydroxyl groups available for hydrogen bonding with water ⇒ Insoluble in water ⇒ Does not affect water potential ⇒ Does not affect water potential of cells
- α(1-6) glycosidic bonds at branch points ⇒ Branching of amylopectin ⇒ Multiple branch ends allow multiple amylases to work at the same time ⇒ More efficient to release glucose

<u>**Structure**</u>	<u>**Function**</u>
α glucose molecules are linked by α(1-4) glycosidic bonds	Enzymes that hydrolyse these bonds are readily available, allowing the glucose units to be readily released for respiration to yield energy
α glucose monomers are linked by α(1-4) glycosidic bonds which gives rise to helical molecules of amylose and amylopectin	Helical arrangement allows more glucose residues per unit volume, making it a compact storage molecule

Branching with α(1-6) glycosidic bonds in amylopectin	Branching presents more ends for hydrolytic action by amylases, making it more efficient to release glucose
Intramolecular hydrogen bonding within helical structure of amylose and amylopectin Branching with α(1-6) glycosidic bonds in amylopectin	Relatively few hydroxyl groups available for hydrogen bonding with water, making it insoluble in water and hence, does not affect the water potential

Glycogen
Structure:

- Storage polysaccharide in animals
- Monomer: α-glucose
- Bonds: α(1-4) glycosidic bonds within a branch and α(1-6) glycosidic bonds at branch points in amylopectin
    - Branching occurs more frequently than starch
- See starch

Benedict's Test
Procedure:

1. Place $2cm^3$ of test solution in a test tube
2. Add equal volume of Benedict's reagent
3. Shake the mixture
4. Heat the mixture by immersing the test tube in a boiling water bath for 3-4 minutes

Observations:

- If reducing sugar absent, blue solution remains
- If reducing sugar, coloured ppt is observed (Green→Yellow→Orange→Brick Red)
    - Colour depends on amount of reducing sugar present

Iodine Test

- Colour change: Yellowish brown to blue black

Carbohydrates = Hydrated Carbon Compounds

General Formula: $C_m (H_2O)_n$ where m,n are whole numbers

Carbohydrates

- Simple Carbohydrates
    - Monosaccharide (1 monomer)
        - Cannot be hydrolysed further to simpler carbohydrates
        - Contains a carbonyl group (C=O) and multiple hydroxyl groups (O-H)
        - Classification
            - Number of C atoms (3-7 C atoms long)
            - Location of Carbonyl Group
                - Aldose (aldehyde sugar)
                - Ketose (ketone sugar)
            - Spatial arrangement of atoms
                - Linear form
                - Ring form
                    - α- form
                        - C6 and hydroxyl group (attached to C1) on opposite sides
                    - β- form
                        - C6 and hydroxyl group (attached to C1) on same side
                - 3 forms of glucose are interconvertible in aqueous solution
        - Significance of molecular structure
            - Small in size, General Formula: $(CH_2O)_n$
                - Many OH groups
                    - OH groups can form H bonds with water
                - Hence, readily soluble in water
                    - Transported easily in water
            - Pentoses and hexoses exist as rings
                - Very stable
                - Can be linked together to form larger molecules (Disaccharides/Polysaccharides)
            - Ring Structures exhibit α- and β- isomerism
                - Same chemical formula, structurally different molecules
                - Increases diversity of monosaccharides which are building blocks for larger molecules
            - Free carbonyl group
                - Reducing agent
                - Positive result to Benedict's test
    - Disaccharides (2 monomers)
        - Maltose = Glucose + Glucose
        - Lactose = Glucose + Galactose
        - Sucrose = Glucose + Fructose
- Complex Carbohydrates
    - Oligosaccharides (3-10 monomers)
    - Polysaccharides (>100 monomers)
        - Starch

- Plant storage polysaccharide
- Made of α-glucose monomers
- Amylose