B1.1 Carbohydrates and lipids

Form and function—Molecules

Standard level and higher level: 4 hours

Guiding questions

• In what ways do variations in form allow diversity of function in carbohydrates and lipids?

• How do carbohydrates and lipids compare as energy storage compounds?

Note: There is no additional higher level content in B1.1.

SL and HL

B1.1.1—Chemical properties of a carbon atom allowing for the formation of diverse compounds upon which life is based
Students should understand the nature of a covalent bond. Students should also understand that a carbon atom can form up to four single bonds or a combination of single and double bonds with other carbon atoms or atoms of other non-metallic elements. Include among the diversity of carbon compounds examples of molecules with branched or unbranched chains and single or multiple rings.

- A **covalent bond** arises when two atoms share 1 electron each
  - The resultant bond is composed of a pair of electrons that are attracted to the nuclei of both atoms (the electrons are shared between them)
- Since carbon has 4 valence electrons, it can form up to 4 single covalent bonds or a combination of **single** and **double** bonds with itself or with atoms of other non-metallic elements
- **Organic compounds** are molecules with one or more carbons that are covalently linked to other elements like hydrogen, nitrogen oxygen
- Within organic compounds, carbon can form single rings (e.g. glucose) or multiple rings (e.g. cholesterol)
  - It can also form **branched chains** (e.g. glycogen) or **unbranched chains** (e.g. amylose)
- **Biomolecules** are organic molecules that are vital to the survival of living organisms
  - These include carbohydrates, lipids, nucleic acids, and proteins

B1.1.2—Production of macromolecules by condensation reactions that link monomers to form a polymer
Students should be familiar with examples of polysaccharides, polypeptides and nucleic acids.

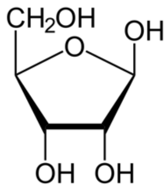
- Many biomolecules are **macromolecules** (large molecules)
- **Polymers** are macromolecules made of smaller repeating units called **monomers**
- Polymers are formed through **condensation reactions** in which two monomers combine together & 1 water molecule is formed as a byproduct
- **Monosaccharides** are the simplest sugars; they are monomers composed of a single ring of 5-6 carbons
- **Disaccharides** are simple sugar made up of two monomers joined together by condensation
- **Polysaccharides** are polymers of monosaccharides
- **Amino acids** are monomers that can be joined by condensation to form polypeptides
- **Nucleotides** are monomers that are synthesized through 2 condensation reactions
  - **1** condensation to connect a pentose sugar and a phosphate group together
  - **1** condensation reaction to connect a pentose sugar and a nitrogenous base
  - **2** water molecules are released in the synthesis of 1 nucleotide
- **DNA** and **RNA** molecules are polymers of nucleotides

B1.1.3—Digestion of polymers into monomers by hydrolysis reactions
Water molecules are split to provide the -H and -OH groups that are incorporated to produce monomers, hence the name of this type of reaction.

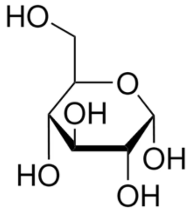
- **Hydrolysis** reactions digest polymers into monomers (reverse of condensation)
- The covalent link between two monomers is broken by the use of 1 water molecule
  - Water is split to provide the -H and -OH groups that are incorporated to produce the monomers

B1.1.4—Form and function of monosaccharides
Students should be able to recognize pentoses and hexoses as monosaccharides from molecular diagrams showing them in the ring forms. Use glucose as an example of the link between the properties of a monosaccharide and how it is used, emphasizing solubility, transportability, chemical stability and the yield of energy from oxidation as properties.

Ribose



Glucose



- The general chemical formula of monosaccharides is $\mathbf{C_nH_{2n}O_n}$
- **Pentose monosaccharides** (e.g. ribose, fructose) are composed of 5-carbon single rings
- **Hexose monosaccharides** (e.g. glucose, galactose) are composed of 6-carbon single rings
- Sugars contain a carbon ring & hydroxyl groups, which give rise to distinct properties:
  - **Solubility**: glucose is polar & can dissolve in water by forming hydrogen bonds with it
  - **Transportability**: due to its solubility and chemical stability, it is easy to transport in aqueous media like the cytosol or blood
  - **Chemical stability**: the hydrocarbon ring of glucose provides the chemical stability needed to store energy & synthesize polysaccharides
  - **Energy yield**: oxidation of glucose releases a lot of energy that can be used to make ATP
  - **Isomerism**: isomers are molecules with identical chemical formulas but different atom arrangements
    - Glucose exhibits isomerism at carbon 1, which leads to isomers with completely different physical and chemical properties
    - **Alpha (α) glucose** has its OH group on carbon 1 pointing <u>down</u>
    - **Beta (ß) glucose** has its OH group on carbon 1 pointing <u>up</u>

B1.1.5—Polysaccharides as energy storage compounds

Include the compact nature of starch in plants and glycogen in animals due to coiling and branching during polymerization, the relative insolubility of these compounds due to large molecular size and the relative ease of adding or removing alpha-glucose monomers by condensation and hydrolysis to build or mobilize energy stores.

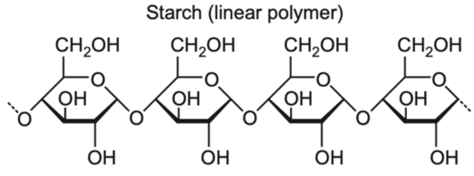
- Polymers of glucose are used as energy storage compounds in organisms
- The property of each polymer depends on the glucose **isomer** & the **type of linkage** between monomers
- **Starch** is found in plant cells
  - Composed of **α-glucose** monomers that may be branched or unbranched:
  - **Amylose** (unbranched) is composed of **1-4’ glycosidic linkages** and forms a **helix**
    - **Amylopectin** (branched) is composed of 1-4’ and **1-6’ glycosidic linkages**
    - When plants need to store excess glucose during photosynthesis to regulate osmolarity, they synthesize starch
  - **Glycogen** is found in animals
    - Branched, containing both 1-4’ and 1-6’ glycosidic linkages between α-glucose monomers, with a higher frequency of 1-6’ linkages than amylopectin
- Due to the similarity in their structures, starch and glycogen share many properties:
  - Both are **insoluble** in water due to their large molecular size
  - Due to their repeating structure, it is easy to add or remove alpha-glucose monomers by condensation and hydrolysis in starch and glycogen to build or mobilize energy stores

B1.1.6—Structure of cellulose related to its function as a structural polysaccharide in plants

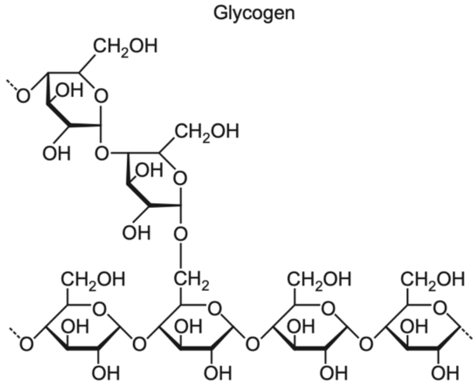
Include the alternating orientation of beta-glucose monomers, giving straight chains that can be grouped in bundles and cross-linked with hydrogen bonds.

- **Cellulose** is a polysaccharide found in plant cell walls
  - Composed of **ß-glucose monomers** arranged in a **linear chain**
  - Every ß-glucose monomer is **oriented 180° about its axis** with respect to its neighboring monomer as this is the only orientation which allows the formation of **ß-1-4’ glycosidic linkages**
  - Since each monomer can form hydrogen bonds, single linear chains of cellulose can form cross-linking hydrogen bonds with other linear chains, resulting in **cellulose fibers**
    - Cellulose fibers provide strength for plant cells that helps support plant structure

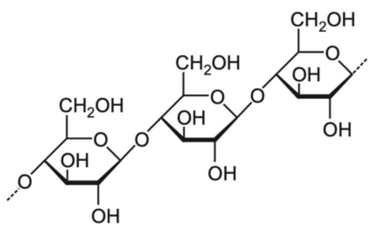
Starch (linear polymer)



Glycogen



Cellulose



B1.1.7—Role of glycoproteins in cell–cell recognition

Include ABO antigens as an example.

- Biomolecules can be combined to increase the diversity of their functions
  - Carbohydrate + protein = **glycoprotein**
  - Carbohydrate + lipid = **glycolipid**
  - Lipid + protein = **lipoprotein**
- Red blood cells contain a glycoprotein on their surface
  - Individuals with the A allele produce an enzyme that adds glycoprotein A onto red blood cells
  - Individuals with the B allele produce an enzyme that adds glycoprotein B onto red blood cells
  - Individuals with the O allele produce an enzyme with no function
- Glycoproteins play an important role in cell-cell recognition by helping to distinguish foreign cells from self-cells
- The same blood type must be administered during blood transfusions, otherwise the immune system will recognize the transfused blood with different glycoproteins as foreign and initiate a fatal response

B1.1.8—Hydrophobic properties of lipids

Lipids are substances in living organisms that dissolve in non-polar solvents but are only sparingly soluble in aqueous solvents. Lipids include fats, oils, waxes and steroids.

- **Lipids** are fatty, waxy, oily, or steroidal compounds that are soluble in non-polar solvents but are only sparingly soluble in aqueous solvents (like water)
- Lipids are hydrophobic because their chemical structure is dominated by non-polar C–H bonds
  - Polar groups in some lipids are overshadowed by large hydrophobic regions in their structures

B1.1.9—Formation of triglycerides and phospholipids by condensation reactions

One glycerol molecule can link three fatty acid molecules or two fatty acid molecules and one phosphate group.

- **Triglycerides** are a class of lipids made from **1 glycerol** molecule and **3 fatty acids**
  - An **ester** bond forms between glycerol each fatty acid through a condensation reaction
- **Phospholipids** are a class of lipid made of **1 glycerol**, **2 fatty acids**, & **1 phosphate group**
  - An ester bond also links the phosphate to the glycerol.

B1.1.10—Difference between saturated, monounsaturated and polyunsaturated fatty acids

Include the number of double carbon (C=C) bonds and how this affects melting point. Relate this to the prevalence of different types of fatty acids in oils and fats used for energy storage in plants and endotherms respectively.

- The number of double carbon (C=C) bonds affects the chemical and physical properties of lipids
- **Saturated fatty acids** have no C=C bonds
    - This leads to a straight, linear fatty acid chain with a high melting point, so saturated lipids are solid at room temperature (e.g. animal meat fat & butter)
- **Monounsaturated fatty acids** have 1 C=C bond (can be in any location)
  - **Cis monounsaturated fatty acids** have hydrogens on the same side of a C=C double bond
    - This leads to a **kink/bend** in the hydrocarbon chain, which lowers their melting point, so monounsaturated lipids are liquid at room temperature (e.g. some animal fat and plant oils)
  - **Trans monounsaturated fatty acids** have hydrogens on opposite sides of a C=C double bond
    - This does **NOT** lead to a kink/bend in the lipid, so they have a higher melting point than cis monounsaturated lipids & are solid at room temperature
- **Polyunsaturated fatty acids** have two or more C=C bonds at varying locations
  - Their melting points depend on the amount of trans & cis double bonds present

B1.1.11—Triglycerides in adipose tissues for energy storage and thermal insulation

Students should understand that the properties of triglycerides make them suited to long-term energy storage functions. Students should be able to relate the use of triglycerides as thermal insulators to body temperature and habitat.

- Triglycerides are used in animal adipose tissues for energy storage & insulation due to their properties
  - **Energy storage**:
    - Per gram, triglycerides release about twice as much energy as that released by sugars
    - They are convenient to store since they are insoluble and do not affect osmotic balance
  - **Thermal insulation**: a thick layer of adipose tissue in animals acts as an insulator by trapping the heat generated from internal metabolic processes
    - This aids endotherms in thermoregulation (e.g. in cold habitats)

NOS: Students should understand that scientific conventions are based on international agreement (SI metric unit prefixes “kilo”, “centi”, “milli”, “micro” and “nano”).

Prefix	Multiplicative factor	In words
nano	1×10^{-9}	Billionth
micro	1×10^{-6}	Millionth
milli (m)	1×10^{-3}	Thousandth
centi (c)	1×10^{-2}	Hundredth
deci (d)	1×10^{-1}	Tenth
	1	
deca (da)	1×10^{1}	Ten
hecto (h)	1×10^{2}	Hundred
kilo (k)	1×10^{3}	Thousand
mega (m)	1×10^{6}	Million
giga (G)	1×10^{9}	Billion

B1.1.12—Formation of phospholipid bilayers as a consequence of the hydrophobic and hydrophilic regions
Students should use and understand the term “amphipathic”.

- **Amphipathic** molecules have both hydrophobic and hydrophilic regions, like phospholipids
- To reduce energetically unfavorable interactions between hydrophobic regions & water, phospholipids arrange themselves in a **bilayer**
  - Phosphate heads face the cytosol and hydrocarbon chains face each other

B1.1.13—Ability of non-polar steroids to pass through the phospholipid bilayer
Include oestradiol and testosterone as examples. Students should be able to identify compounds as steroids from molecular diagrams.

- **Steroids** are lipids composed of 4 hydrophobic carbon rings
  - They can contain some polar functional groups like OH, so they can be non-polar or amphipathic
- **Cholesterol** is an amphipathic steroid that forms a significant portion of the human plasma membrane
- **Oestradiol** is a non-polar steroidal hormone that is involved in the development of primary and secondary sexual characteristics in females
- **Testosterone** is a non-polar steroidal hormone that is involved in the development of primary and secondary sexual characteristics in males
- Non-polar steroids, like oestradiol and testosterone, are able to pass through the hydrophobic core of the phospholipid bilayer to alter gene expression

Linking questions

• How can compounds synthesized by living organisms accumulate and become carbon sinks?

• What are the roles of oxidation and reduction in biological systems?

References

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