Chemistry of Life

Revision:

- The further from the nucleus, the higher the electron's energy
- Valence shell electrons participate in biological reactions

Atoms exchange electrons with other elements to form compounds. The type of compound formed depends on the electronegativity of the elements involved;

- Large EN difference = ionic compound
- Small EN difference = covalent compound

Polarity

Electron sharing in covalent bonds is not always even; depends on relative EN of atoms and molecular shape.

- Non-polar covalent bonds *share electrons equally*
- Polar covalent bonds have *unequal electron sharing*

Water

- Each molecule of water can form **4 hydrogen bonds**
- Solid water has regular *crystalline structure* due to *hydrogen bonding*
    - Volume expands when frozen (causes cells to burst)
    - Less dense than liquid form (important for aquatic environment)

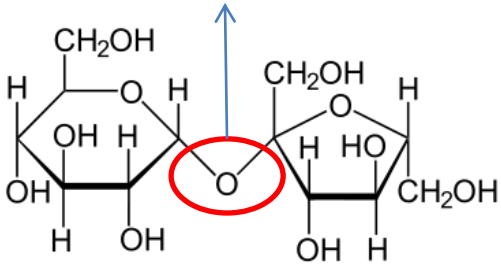
Water is a versatile solvent for polar and ionic substances. It forms hydration shells around macromolecules *(main classes of macromolecules; carbohydrates, lipids, nucleic acids, proteins)*.

Carbohydrates

Carbohydrates are compounds of C, H and O with the formula Cx(H2O)y, commonly called sugars.

- **Monosaccharides**: simple sugars
- **Disaccharides**: two monosaccharide units links together
- **Polysaccharides**: polymers of monosaccharide units

Carbohydrates are formed by a ***dehydration/condensation*** reaction between two monosaccharides. This forms a ***glycosidic bond***.



Carbohydrate	Structure	Animal or Plant	Found in
Cellulose	Long chains of β glucose	Plant	Plant cell walls
Starch	α glucose coiled - Amylose (straight chained) - Amylopectin (branched)	Plant	Cytoplasm of cells
Glycogen	Highly branched α glucose	Animal	Muscle and liver cells

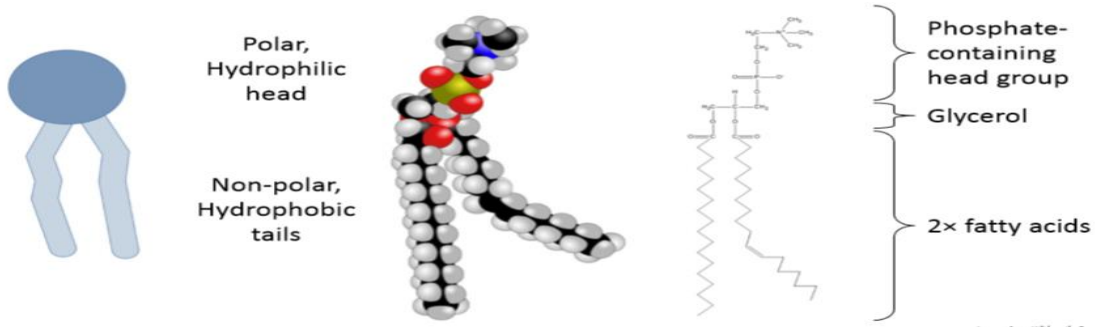
Lipids

Lipids are a diverse group of macromolecules that are insoluble in water as most are hydrophobic.

- A fat consists of one glycerol molecule bonded to three fatty acid molecules
- Fatty acids are either saturated *(animal fat)* or unsaturated *(plant fat)*
    - An unsaturated fat is liquid at room temperature – oil
- Lipids allow very compact energy storage

Phospholipids

Phospholipids consist of *one glycerol molecule covalently bonded to two fatty acids and one phosphate containing polar head group*. They are the main components of **cellular membranes**.



- ***Waxes*** are diverse and mainly consist of fatty acids joined covalently to other chemical groups
- ***Steroids*** consist of covalently linked rings e.g. *cholesterol*

Nucleic acids

Nucleic acids are polymers of nucleotides. A nucleotide is made up of;

- **Nitrogenous base**
- **Sugar**
- **Phosphate group**

Nitrogenous bases include: *Adenine, Thymine, Guanine and Cytosine*. Polynucleotides contain genetic information in the sequence of nitrogenous bases.

- The nucleotides are joined by a ***phosphodiester*** bond
- Polynucleotides have a 5’ to 3’ orientation determined by carbon numbering

- Nitrogenous bases are joined together by hydrogen bonds with compatible bases (A=T, C≡G)

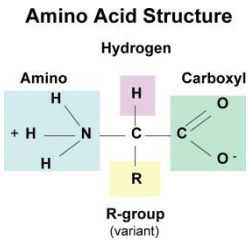
DNA

DNA exists as two polynucleotides. The two strands are ***antiparallel***. The pentose is *deoxyribose*.

RNA

The pentose is *ribose*. It is single stranded and uracil replaces thymine.

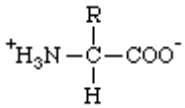
Proteins – macromolecules



Overview: Proteins consist of one or more **polypeptides**. Polypeptides consist of **amino acids** joined by **peptide bonds** which are formed from **condensation reactions**.

Amino acids contain both an **amine** and **carboxylic acid** functional group.

- The side chain (R) differs between amino acids and has different biochemical properties which is important in determining polypeptide structure and function
    - Non-polar = hydrophobic, negative = acidic, positive = basic, polar = hydrophilic
- At physiological pH, the amino acid exists as a zwitterion – amino and carboxylic group become charged



Protein structure:

1. Primary structure: Amino acids sequence of polypeptide
2. Secondary structure: Structures created due to hydrogen bonding between atoms of the polypeptide **backbone** *(α helix, β sheet)*
3. Tertiary structure: Non-covalent or disulfide interactions between the **side chains**
    a. *Hydrogen bonding between polar side chains*
    b. *Ionic interactions between negative/acidic and positive/basic chains*
    c. *Disulfide bridges between two cysteine side chains*
    d. *Hydrophobic interactions between hydrophobic side chains, towards the interior*
4. Quaternary structure: Two or more polypeptides coming together to form a functional protein

The final 3D conformation of a protein is dependent on its primary structure. ***Chaperones*** are proteins that help other proteins fold (chaperonin). *Denatured proteins* are unfolded and have lost their 3D structure. This may be temporary or permanent.

Structures and function of proteins:

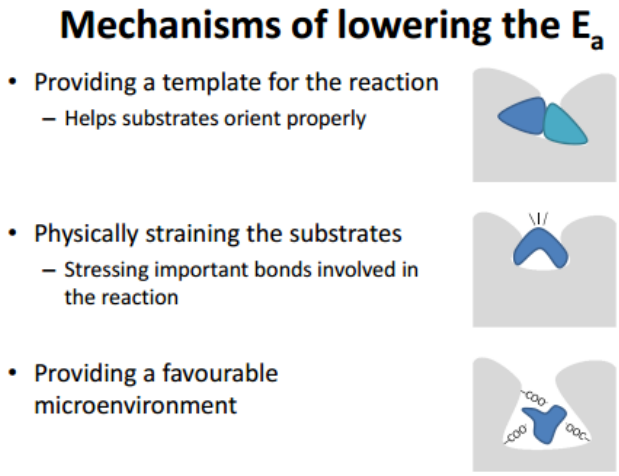
- Transport
- Storage
- Hormonal
- Structural
- Enzymatic

Metabolism: the chemical reactions that occur within cells

- ***Catabolism*** – breaking down organic matter to release energy
    - Catabolic reactions typically release net energy
- ***Anabolism*** – using energy to produce cellular components
    - Anabolic reactions typically require net energy input

Activation energy is the energy input needed to initiate any reaction. Enzymes are catalytic proteins that lower activation energy.

- Catalysts ***increase rate of reaction*** but are not consumed
- Catalysts ***do not change net energy loss/gain***
- Enzymes can ***function in both directions***



Active site substrate specificity

The active site of an enzyme binds to its substrate; enzymes are unique to one substrate – **enzyme specificity.**

- Determined by the shape and biochemistry of the active site
    - *Side groups* interact with the substrate
- **Induced fit**: when the substrate/s bind, the shape of the enzyme changes to fit the substrate/s more closely

Influences on enzyme activity

- *Temperature* – higher temperatures increase reactions rate and disrupt weak interactions
- *pH* – pH alters the charge on acidic and basic side chains causing denaturation, extreme pH can lead to peptide bond hydrolysis
- *Cofactors* – inorganic molecules that bind to the enzyme and are necessary for catalysis, coenzymes are organic cofactors
- *Substrate concentration* – more substrate will lead to faster reaction rates up to a point
- *Enzyme concentration*
- *Inhibitors* – binds to enzyme and inhibits reactions by mimicking substrate or changing the shape of the active site

Intracellular structure and function

Cellular life can be divided into three domains:

- Prokaryotic cells – archaea and bacteria
- Eukaryotic cells – eukarya

Cells and SA:V

Cells need to maintain a high SA:V for biochemical reactions and to exchange molecules with the environment.

Cellular membranes

All cells are bound by a plasma membrane. Additionally, eukaryotes have membrane-bound organelles.

Nucleus

The nucleus is surrounded by the nuclear envelope (*double bilayer*). Substances travel in and out of the nucleus by nuclear pores. The nucleus stores genetic information in the form of **chromatin**.

- Inside the nucleus is the nucleolus which makes ribosomal components

RIBOSOMES

Ribosomes join amino acids together to make polypeptides.

- ***Free ribosomes*** are floating in the cytosol – mostly make cytosolic proteins
- ***Bound ribosomes*** are associated with the endoplasmic reticulum – mostly make proteins for membranes, export, and some organelles

The Endomembrane System

The endomembrane system is a series of interconnected membrane bound organelles, including;

- Nuclear envelope
- Endoplasmic reticulum (rough, smooth)
- Golgi
- Lysosomes
- Vesicles
- Vacuoles
- Plasma membrane
    - Each compartment contains a unique set of enzymes.

Component	Structure	Function
Smooth Endoplasmic Reticulum	No associated ribosomes Tubular structure Present in all cells but limited, except for specialized cells	Lipid synthesis Calcium storage
Rough Endoplasmic Reticulum	Ribosomes associated with it Continuous with outer nuclear	Polypeptides made and modified

	membrane	
Golgi Apparatus	Layers of flattened membranous sacs (single phospholipid bilayer) Each sac has a different set of enzymes	Receives vesicles at its *cis* face Proteins coming from the RER may be further modified Ships vesicles at its *trans* face Targets vesicles towards other organelles or plasma membrane
Lysosomes	Membranous sacs containing hydrolytic enzymes Made by RER, pH maintained at ~5	Hydrolyses macromolecules (breakdown)
Vacuoles	Very large fluid filled vesicles (membranous sacs) found in most plant and fungal cells	Central vacuole Lytic vacuole Storage vacuole Contractile vacuole

Getting around the endomembrane

Parts of the endomembrane system are connected by:

- *Physical continuity* (physically joined)
- *Vesicle traffic*
    - Fusing – receiving (merges with membrane of destination organelle)
    - Budding – sending off

Mitochondria	**Contain own DNA and ribosomes**	**Aerobic cellular respiration**
Chloroplast		Photosynthesis

The Cytoskeleton

Cytoskeletons elements are dynamic and have varied functions;

- Structure and support
- Motility
- Anchorage

They consist of three protein based fibres; microfilaments, intermediate filaments and microtubules.

Element	Structure	Function
Microtubule	Comprised of tubulin (protein)	Track for organelle movement Whole cell movement as part of cilia and flagella Separating chromosomes during mitosis
Microfilaments	Called actin filaments (protein) Form network just inside plasma membrane	Maintain cell shape Contraction of muscle cells Cytoplasmic streaming Animal cell division
Intermediate filaments	Many different proteins for many structural functions (keratin)	