Chapter 2: Biomolecules

H2 Biology

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Introduction

Cells and their contents are built up from **biomolecules**. Cellular functions and life itself depends on these molecules.

Some important biomolecules and their functions are:

- **Carbohydrates**: Energy source
- **Lipids**: Main component of cell membrane
- **Proteins**: Structural and enzymatic function
- **Nucleic acids**: Store and transmit hereditary information

Carbohydrates

Carbohydrates are one of the most abundant class of biomolecules.

They contain the elements **carbon, hydrogen and oxygen** in the ratio of C:H:O = 1:2:1. Their general formula is **$(CH_2O)_n$**, where n = number of carbon atoms.

Carbohydrates can be classified in different ways:

1) Complexity – Monosaccharide, Disaccharide, Oligosaccharide, Polysaccharide
2) Number of carbon atoms – triose (3C), pentose (5C), hexose (6C)
3) Reducing properties – reducing sugars vs non-reducing sugars
4) Position of carbonyl groups – aldose vs ketose

Carbohydrates

Monosaccharides are simple sugars, which are the **monomers** that make up **disaccharides** and **polysaccharides**.

They mainly function as **energy sources** since they contain many **carbon-hydrogen bonds (C—H)**, which **release energy** upon **oxidation**.

They also act as **building blocks** for the **synthesis of larger molecules**.

Physical properties: Sweet, soluble and possess crystalline structures.

Chemical Properties: All monosaccharides are **reducing sugars** meaning they can carry out a chemical reaction called reduction.

No. of C atoms	General Name	Chemical Formula	Examples	Functions
3	Triose sugar	$C_3H_6O_3$	Glyceraldehyde	Intermediate compound in respiration and photosynthesis
5	Pentose sugar	$C_5H_{10}O_5$	Ribose	Component of RNA and ATP
			Deoxyribose	Component of DNA
6	Hexose sugar	$C_6H_{12}O_6$	Glucose	Main source of energy for cellular respiration.
			Fructose	An energy source. Component of sucrose.
			Galactose	Component of lactose. Found in dairy products.

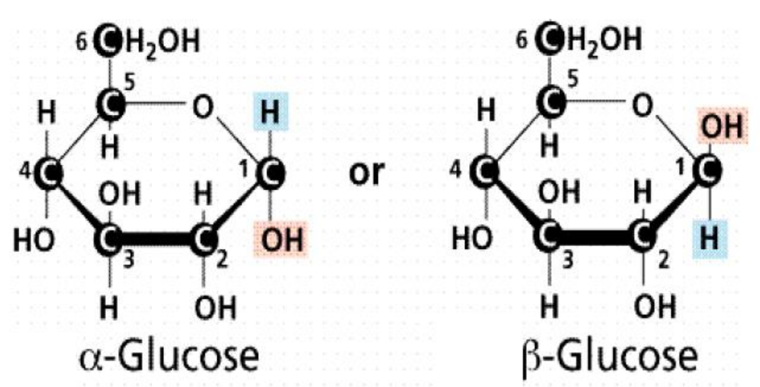
Carbohydrates

Key Example of Monosaccharides:

Glucose:
The most abundant **hexose sugar** and the **main respiratory substrate** for all living things. Energy is produced in the form of **adenosine triphosphate (ATP)** during **cellular respiration**.

Structure:
Chemical formula of $C_6H_{12}O_6$
There are two possible ring structures of glucose namely the **α-glucose** and **β-glucose**, depending on the hydroxyl group on carbon-1.

Below the ring (α-glucose) or above the ring (β-glucose).

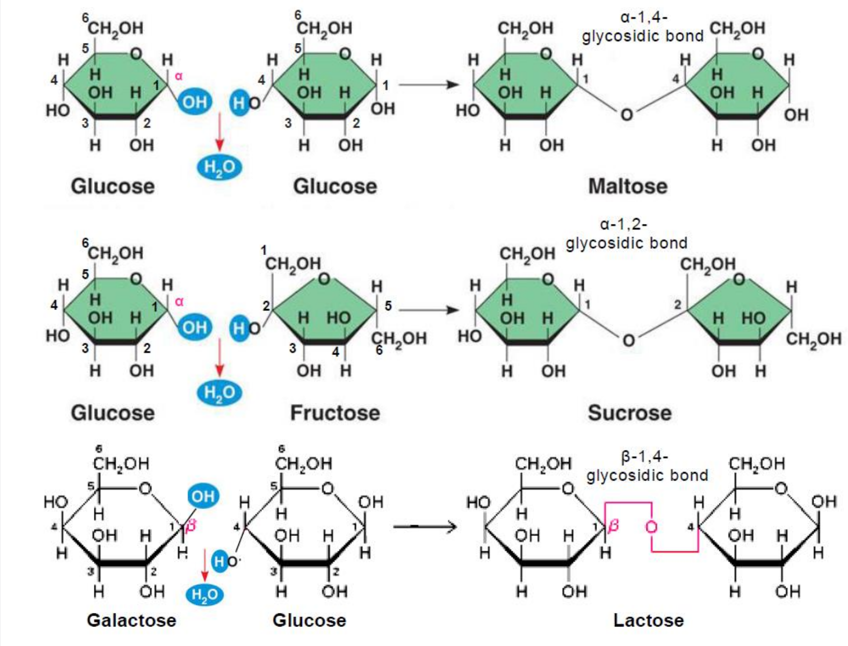


Carbohydrates

Disaccharides:
A glycosidic bond is formed between two monosaccharides in a **condensation reaction** with the **removal of one molecule of water**.

Conversely, the glycosidic bond is broken between two monosaccharides (in a disaccharide) in a **hydrolysis reaction** with the **addition of one molecule of water**, to form the hydroxyl group on two different monosaccharides.

Examples of disaccharides formed from condensation reactions are shown in the figure on the right.



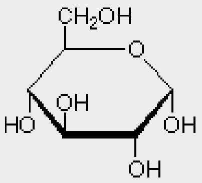
Carbohydrates

A **polysaccharide** is formed when **many monosaccharides combine** by condensation reaction, linking via **glycosidic bonds**.

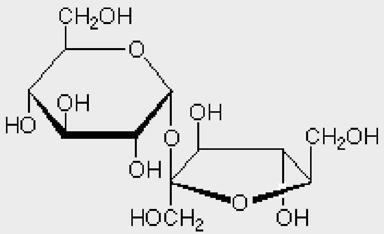
Polysaccharides can be classified into two groups according to their functions:

Storage Polysaccharides – e.g. **Starch** and **Glycogen**

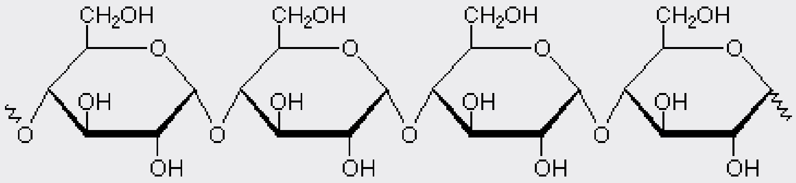
Structural Polysaccharides – e.g. **Cellulose**



monosaccharide (glucose)



disaccharide (sucrose)



polysaccharide (amylose starch)

Carbohydrates

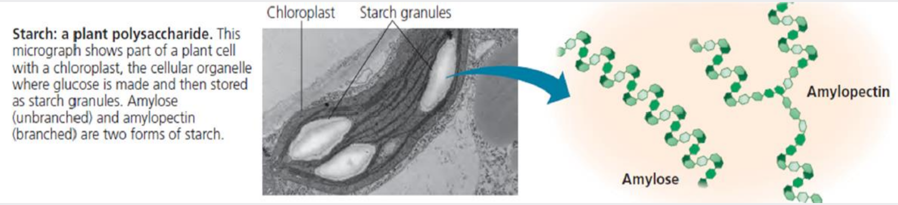
Properties of storage polysaccharides:

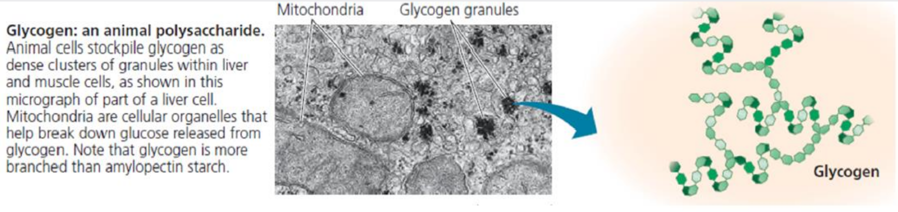
- They are **<u>large and thus insoluble in water</u>**. As a result, they **<u>exert no osmotic effect on cells when stored in large amounts</u>** and do not interfere with chemical reactions of the cells.

- They are **<u>large and unable to diffuse out of the cells</u>**.

- They **<u>fold into compact shapes</u>** and thus large amounts can be stored within a fixed volume.

- They are **<u>easily hydrolysed into monosaccharides</u>** when required by the cells.





Carbohydrates

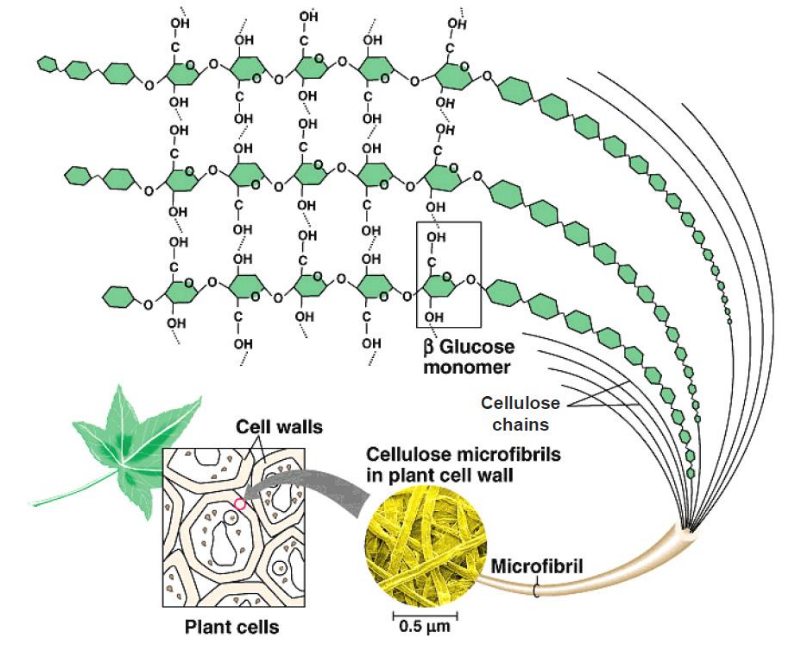
Properties of structural polysaccharides:

- They are **unbranched polymers**.
- They form **long straight chains** which are ideal for **formation of strong fibres**.

Example: **Cellulose**

Main component of **cellulose cell wall of plants** for **structural support**.

Large intermolecular spaces between macrofibrils cause the **cell wall to be permeable** because they allow free movement of molecules in and out of the cell.



Lipids

Lipids contain the same elements as carbohydrates: carbon, hydrogen and oxygen.

They do not have a general formula but have proportionally less oxygen compared to hydrogen.

Lipids are **non-polar** due to even distribution of charge. In general, lipids are formed by **condensation reactions between fatty acids and an alcohol.**

Lipids can be classified into three types:

- Triglycerides (e.g. fats and oils)
- Phospholipids (e.g. phosphatidylcholine)
- Steroids and sterols (e.g. cholesterol)

Lipids

Triglycerides are the most common lipids in nature. They are made up of **3 fatty acid chains and 1 glycerol molecule**.

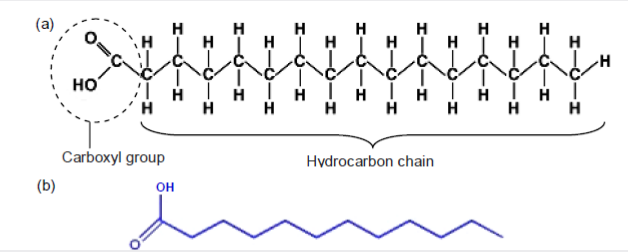
Fatty acids consist of a **hydrophobic hydrocarbon chain** (only carbon and hydrogen atoms) and a **hydrophilic carboxyl group** (-COOH).

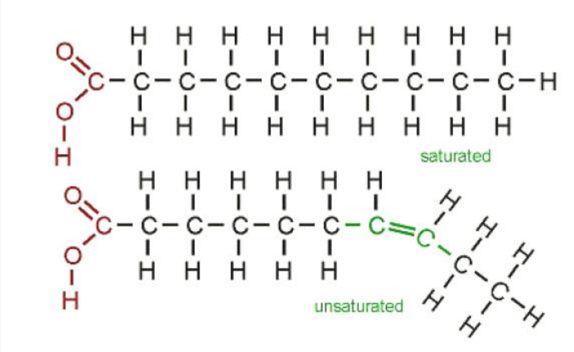
Are **relatively polar** due to the carboxyl group.

General formula of **R-COOH, where R is the hydrocarbon chain**.

Two types of fatty acids:
Saturated fatty acids contain only **carbon-carbon single bond (C-C)** in the hydrocarbon chain.

Unsaturated fatty acids contain **carbon-carbon double bond (C=C)** in the hydrocarbon chain, resulting in **kinks that prevent the tight packing of fatty acid chains.**

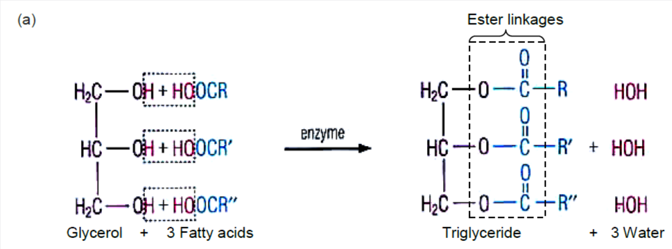




Lipids

Formation of triglycerides:

- Triglycerides are formed from **3 fatty acid molecules with 1 glycerol** molecule by **condensation reaction**.
- **3 ester bonds are formed with the removal of 3 water molecules.**
- The **hydroxyl (-OH)** groups in glycerol reacts with a **carboxyl group (-COOH)** in a fatty acid molecule to form an **ester bond or linkage**.
- Ester bonds can be broken by **hydrolysis**.



Lipids

Properties of triglycerides:

- Triglycerides can be classified as **fats** or **oils**.
- Fats are solid at 20°C while oils are liquid at 20°C.
- Melting points depend on the **composition of saturated/unsaturated fatty acid chains**. (More unsaturated – lower melting point)

- They are **insoluble in water but soluble in organic solvents** such as ether, chloroform and benzene.

- Triglycerides have **lower density than water** and thus float on water.

Functions of triglycerides:

- Energy storage – respiratory substrate – used to produce ATP
- Heat insulation – as they are poor conductors of heat
- Protection from shock and physical impact
- Buoyancy

Lipids

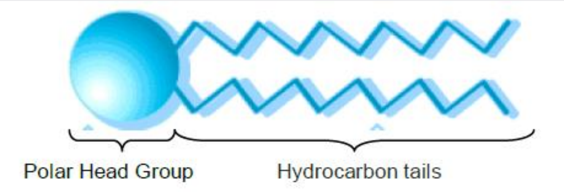
<u>Phospholipids</u> are lipids containing a **<u>phosphate group</u>**.

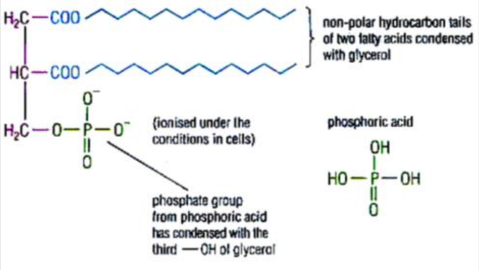
They consist of **<u>1 glycerol molecule</u>**, **<u>2 fatty acid molecules</u>** and **<u>1 phosphate group</u>** (derived from phosphoric acid).

Formed by a **<u>condensation reaction</u>** resulting in the **<u>formation of two ester bonds and one phosphoester bond</u>** with the **<u>removal of 3 water molecules</u>**.

They are **<u>amphipathic molecules</u>** due to the **<u>hydrophilic phosphate head</u>** and **<u>two hydrophobic fatty acid chains</u>**.

Phospholipids function in forming the **<u>basic structure of cell surface membrane</u>** and **<u>internal membranes of cells</u>** called the **<u>phospholipid bilayer (Fluid Mosaic Model).</u>**





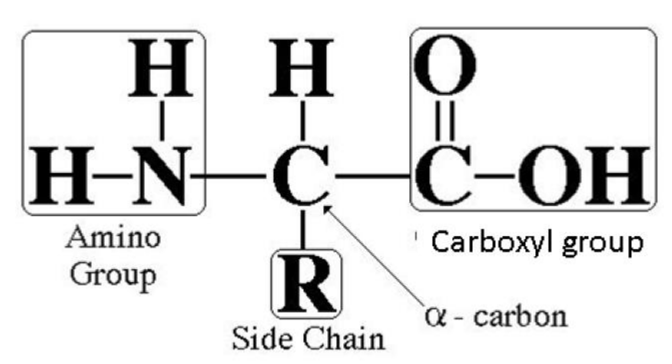
Proteins

Proteins contain the elements **carbon, hydrogen, oxygen and nitrogen**, and **in some cases sulphur**. Each protein has a **unique 3-dimensional conformation.**

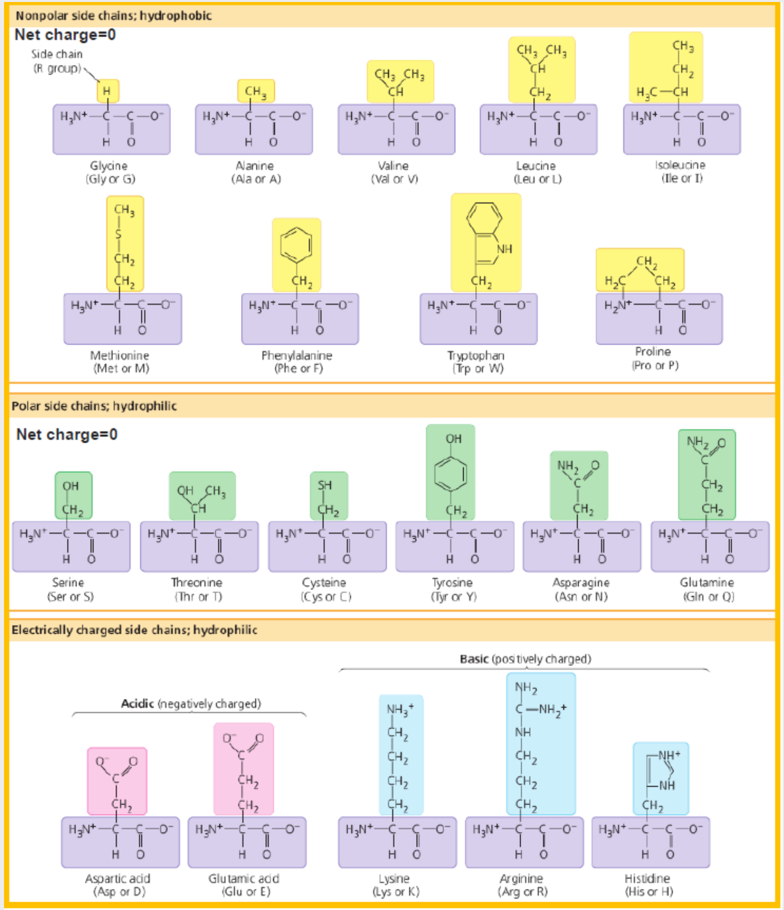
Amino acids are the monomers of proteins and there are 20 common amino acids found in plant and animal proteins, divided into essential and non-essential amino acids.

Amino acids have a structure where the **central carbon atom**, known as the **α-carbon** is **bonded to 4 different groups of atoms**:

1. Hydrogen atom
2. Basic amino group (-NH2) which accepts protons
3. Acidic carboxyl group (-COOH) which donates protons
4. R group / side chain which is unique to each amino acid



Proteins



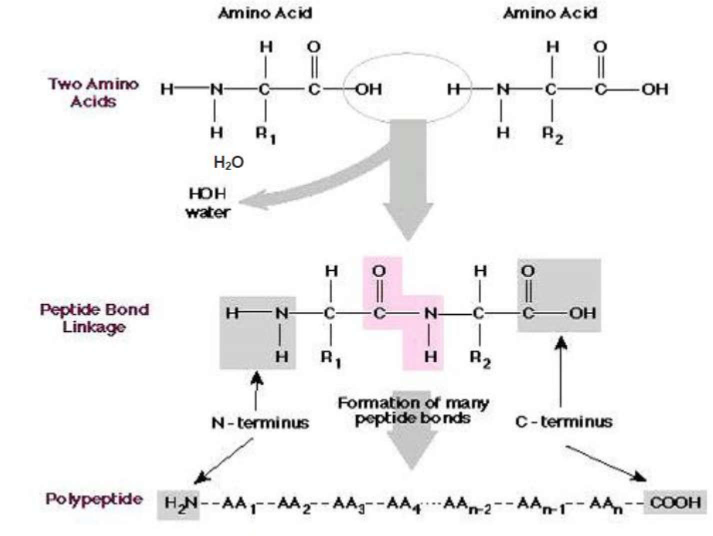
The 20 amino acids of proteins

Proteins

A **peptide bond** is the **covalent bond between two amino acids**.

Peptide bonds are formed **between the carboxyl group of one amino acid and the amino group of another in a condensation reaction** with the **removal of one molecule of water.**

The **peptide bond is broken between two amino acids** (in a dipeptide) in a **hydrolysis reaction with the addition of one molecule of water**, to **form the amino group and the carboxyl group** on two different amino acids.



The formation of a peptide bond

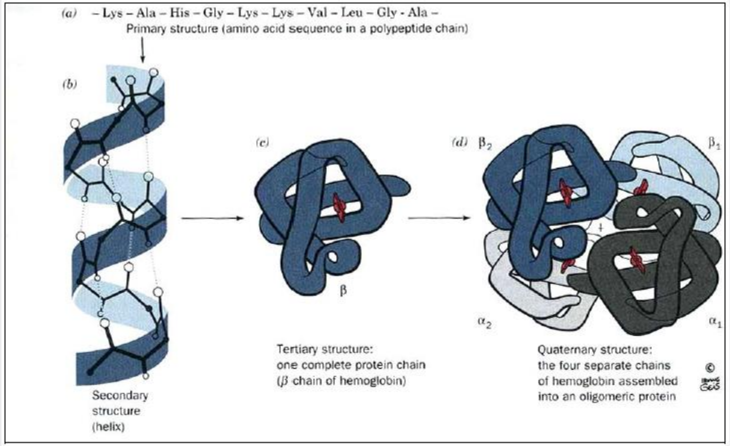
Proteins

Each protein possesses a **unique three-dimensional conformation**. There are 4 levels of structural organisation in proteins: **primary, secondary, tertiary and quaternary**.

The **primary structure** is the **specific number and sequence of amino acids** joined by peptide bonds in a polypeptide chain.

The **secondary structure** is the **repeated coiling and folding of a polypeptide chain**, maintained by **hydrogen bonds** formed between peptide bonds.

Hydrogen bonds are **formed between N-H group in a peptide bond** of an amino acid and **C=O group in a peptide bond** of another amino acid.



The structural hierarchy in proteins

(a) Primary structure, (b) secondary structure, (c) tertiary structure and (d) quaternary structure

Proteins

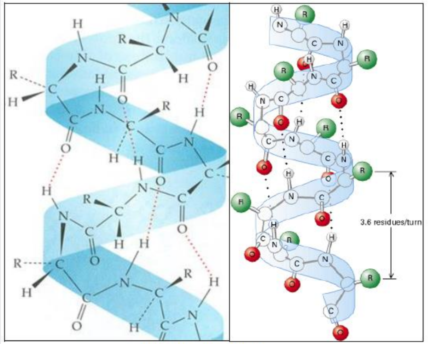
There are two main forms of secondary structures, namely **α-helix** and **β-pleated sheets**.

α-helix:

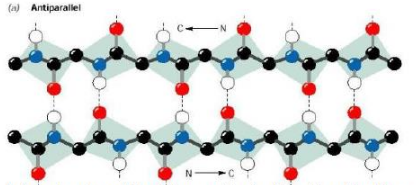
- **Unbranched polypeptide chain** tightly **coiled into a spiral**.
- Each **turn of the helix** consists of **3.6 amino acids**.
- Held by **intra-chain hydrogen bonding between N-H group in a peptide bond of an amino acid and C=O group in a peptide bond of another amino acid** four amino acids away.

β-pleated sheets:

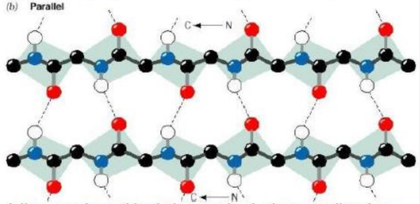
- Consist of extended **adjacent polypeptide chains arranged in a parallel or antiparallel manner**.
- Held together by **hydrogen bonding which exists between the N-H group in a peptide bond of a chain and C=O group in a peptide bond of adjacent chain**.



Structure of a α-helix



Adjacent polypeptide chains running in alternating directions.



Adjacent polypeptide chains running in the same direction.

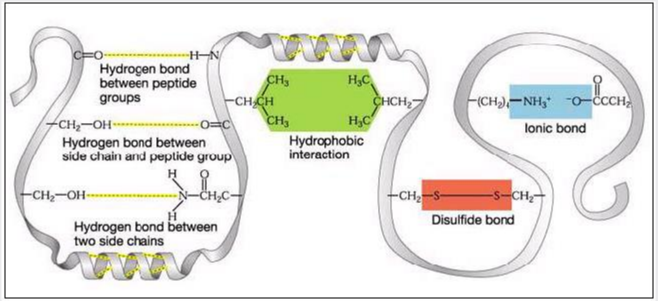
Proteins

The **<u>tertiary structure</u>** is the **<u>compact unique three-dimensional conformation</u>** due to **<u>further coiling and folding of secondary structures.</u>**

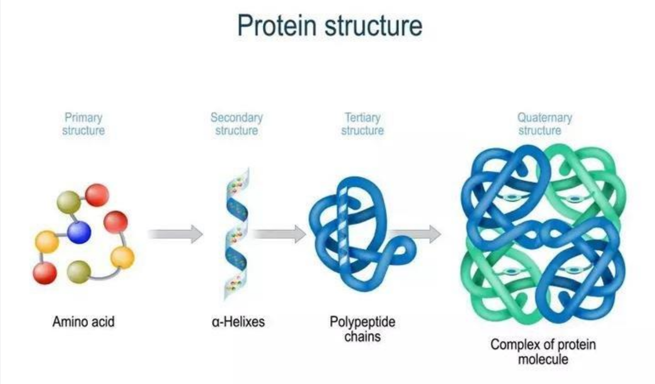
The tertiary structure of a protein is held by **<u>hydrogen bonds, ionic bonds, disulfide bonds, and/or hydrophobic interactions</u>** between R groups/side chains of amino acids on a single polypeptide chain.

The quaternary structure is when **<u>more than one polypeptide chain is held together by hydrogen bonds, ionic bonds, disulfide bonds and/or hydrophobic interaction between R-groups of different polypeptide chains.</u>**

Quaternary structure involves **<u>inter-chain interactions</u>**, in addition to the intra-chain interactions seen in the primary, secondary and tertiary structure.



The different bonds present in the tertiary structure of a protein

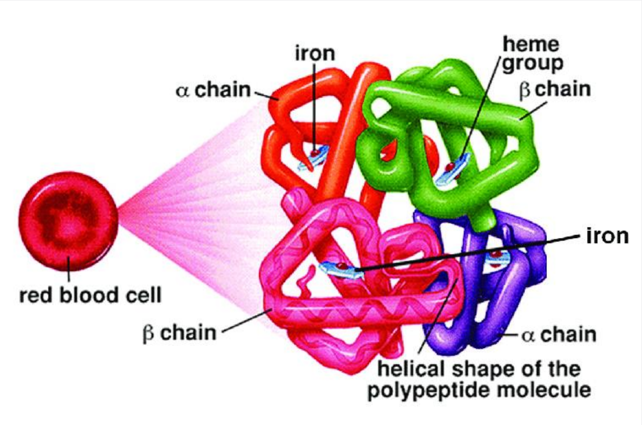


Proteins

Proteins can be classified into **globular proteins** and **fibrous proteins**.

Globular Protein Example: **Haemoglobin**

- A red pigment in red blood cells responsible for transporting oxygen in blood.
- A **quaternary globular protein of 4 subunits**, each consisting of a polypeptide chain and a prosthetic group called haem group.
- **2 identical α-chains of 141 amino acids** and **2 identical β-chains of 146 amino acids.**
- Each polypeptide is coiled into α-helices and then folded into a spherical globular shape. (No β-pleated sheets)
- **Hydrophobic amino acid residues** are in the **interior of the folded structure** and **hydrophilic amino acid residues are found at the exterior surface** to maintain solubility of the protein.
- The four polypeptides are held by hydrophobic interactions, ionic bonds and hydrogen bonds. (No disulfide bonds are involved)



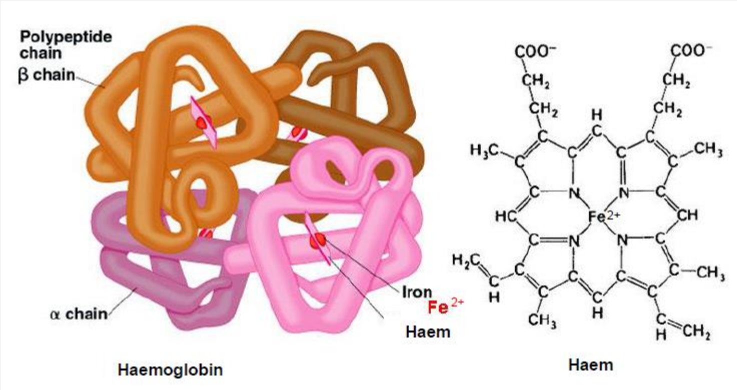
Proteins

- The **hydrophobic amino acids** are found in the **interior of the protein** and **hydrophilic amino acids** found at the **exterior surface**.
- This allows the haemoglobin to be **soluble** to take part in chemical reactions.

- The haem group is held in the **hydrophobic pocket of the polypeptide chain**.
- This allows haemoglobin to **bind reversibly to oxygen** and transport oxygen to the rest of the body.

- The quaternary structure, of four subunits, are held by **weak bonds** such as **hydrophobic interactions**, **ionic bonds** and **hydrogen bonds**
- This allows for **cooperative binding of oxygen to haemoglobin**.
- Binding of one O_2 molecule to one subunit results in a **conformation change** of the adjacent subunits in the haemoglobin molecule, making it easier for another O_2 molecule to bind with the other haem groups in the molecule. This increases the rate of uptake of oxygen by haemoglobin.

- Haemoglobin is a **globular** protein and is folded into a **spherical** shape.
- The protein is **compact** and many haemoglobin molecules to be dissolved in the cytoplasm of a red blood cell.



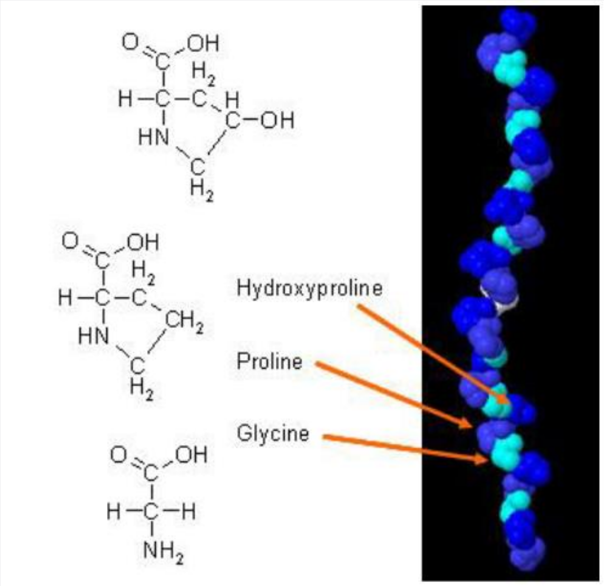
Proteins

Fibrous Protein Example: **<u>Collagen</u>**

<u>Fibrous protein</u> performing a **<u>structural and supportive function</u>** in skin, bone, connective tissue and tendons.

- **<u>Basic structural unit</u>** of collagen is **<u>tropocollagen</u>**, which comprises **<u>3 polypeptide chains wound around each other to form a triple helix</u>**.

Each chain:
- 1050 amino acids residues in each chain.
- Has a high proportion of glycine, proline and hydroxyproline
- A repeated triplet sequence of Gly-X-Y.
- 1/3 of amino acid residues are glycine.
- X is often proline, and Y is often hydroxyproline.
- Proline and hydroxyproline are bulky and relatively inflexible.



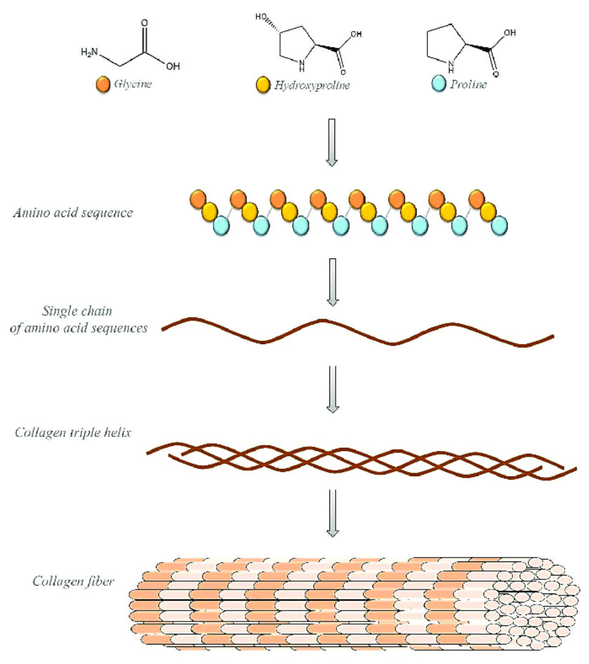
Proteins

- Every **3rd amino acid residue is a glycine** and this allows each helical chain to make a turn every 3 residues and **intertwine around two other chains to form the triple helix**, since **only glycine is small enough** to fit into the centre.
- Allows the structure to be very **compact**.

- The 3 helical chains are **held together by hydrogen bonds** forming **tropocollagen**.
- Allows the structure to be **relatively rigid**.

- **Hydrophobic amino acids are found at the exterior surface of collagen**.
- Allows it to be **insoluble in water** (distinct feature of fibrous proteins) and resistant to chemical changes.

- Many **triple helices lie parallel in a staggered pattern to form fibrils**, with **covalent bonds** between neighbouring triple helix chains.
- **Fibrils unite to form fibres.**
- Allows **collagen to have high tensile strength**, and **high resistance to stretching**.



Proteins

- A protein's **specific 3-dimensional conformation determines its biological function** which may involve recognising and binding to other molecules.

- **Denaturation is the loss of the specific 3-dimensional conformation of a protein molecule**, involving a **breakage of bonds maintaining protein structure**, resulting in the **protein losing its biological function**. Depending on the degree of denaturation, the molecule may partially or completely lose it biological activity.

- The change may be **temporary or permanent**. In the case of temporary denaturation (reversible denaturation), removal of the mildly denaturing conditions will result in spontaneous and correct refolding of the polypeptide chain to regain its normal tertiary structure and the protein is still functional.

- Factors affecting denaturation include:
- **Temperature**
- **pH**
- **Heavy Metals**
- **Oxidizing and Reducing Agents**
- **Organic Solvents**

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