TOPIC: NUCLEIC ACIDS & PROTEINS

Key Knowledge:

- Nucleic acids as information molecules that encode instructions for the synthesis of proteins
- The structure of DNA, the three main forms of RNA and a comparison of their respective nucleotides
- Amino acids as the monomers of a polypeptide chain and the resultant hierarchical levels of structure that give rise to a functional protein
- Proteins as a diverse group of molecules that collectively make an organism's proteome, including enzymes as catalysts in biochemical pathways

NUCLEIC ACIDS

Nucleic acids are the genetic material of the cell and are composed of recurring monomeric subunits called **nucleotides**. Each nucleotide is comprised of three principal components: pentose sugar, phosphate group and nitrogenous base. Nucleotides combine to form gene sequences that encode specific proteins.

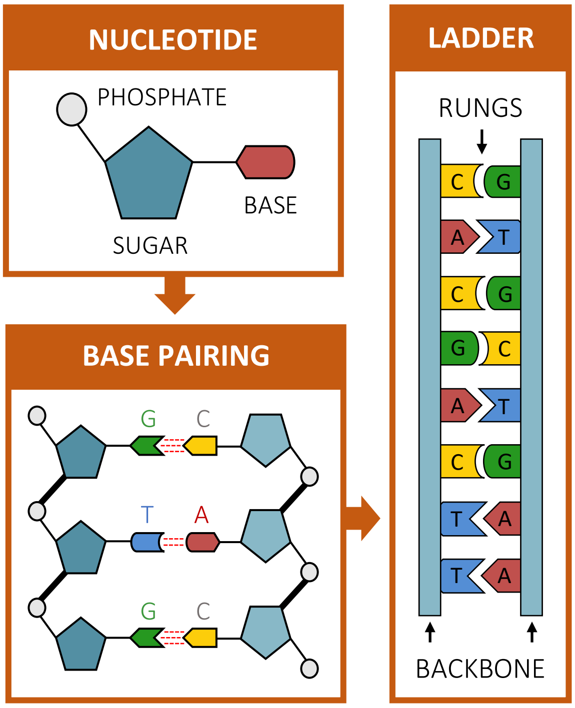
DNA

DNA is composed of double-stranded polynucleotide chains. The phosphate and sugar from two separate nucleotides are joined by a **covalent bond** (condensation reaction) to form a sugar-phosphate backbone. Two DNA chains are then held together by **hydrogen bonds** between complementary bases.

DNA has four nitrogenous bases. Adenine and guanine are double-ringed purine molecules, while cytosine and thymine are single-ringed pyrimidine molecules. In terms of pairing:

- Adenine (**A**) pairs with thymine (**T**) via two H bonds
- Cytosine (**C**) pairs with guanine (**G**) via three H bonds

In order for the complementary bases to pair, the two DNA strands must be running in opposite directions, and hence the two strands are **antiparallel**. Double-stranded DNA will arrange into the most stable configuration: a **double helix**.



RNA

DNA is a master template while RNA functions as a transient copy. There are three main types of RNA:

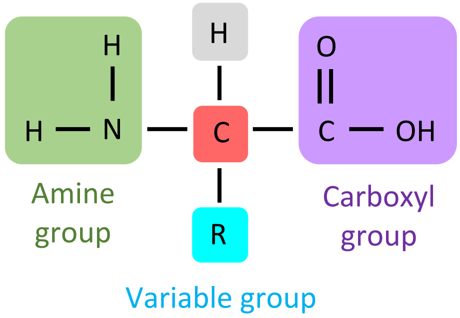
- **Messenger RNA** (**mRNA**): A transcript of a DNA sequence that is translated by ribosomes into protein
- **Transfer RNA** (**tRNA**): Brings amino acids to the ribosome according to the specific mRNA sequence
- **Ribosomal RNA** (**rRNA**): A component of the ribosome that enables it to interact with mRNA and tRNA

There are a number of key differences between the structures and functions of DNA and RNA:

- In DNA nucleotides the pentose sugar is **deoxyribose**, whereas RNA nucleotides use the sugar **ribose**
- In RNA, the nitrogenous base **thymine** is replaced by **uracil** (i.e. DNA uses T, whereas RNA uses U)
- Whereas DNA is a **double-stranded** molecule, RNA is always a **single-stranded** molecule
- DNA is confined to the **nucleus**, whereas RNA molecules enact their functions within the **cytosol**

PROTEINS

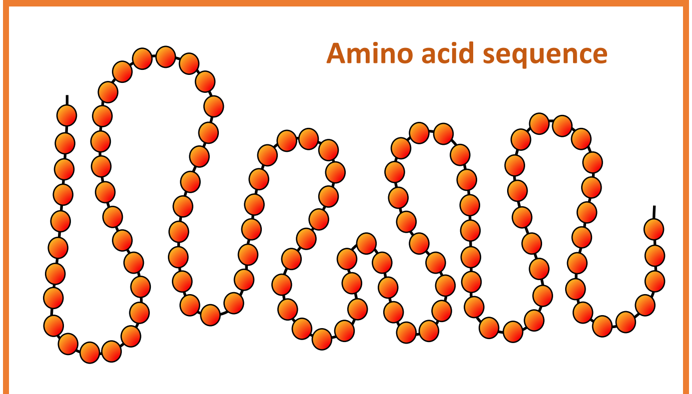
Proteins serve a wide variety of functions in living organisms. They enact the genetic instructions encoded by DNA, and thus regulate cellular activity. Proteins are comprised of long chains of recurring monomers called **amino acids**. Amino acids share a common basic structure, with a central carbon atom bound to an **amine group**, a **carboxyl group** and a variable side chain. There are 20 amino acids, each with a distinct side chain (i.e. **R group**) with specific properties.



PROTEIN STRUCTURE

Amino acids are joined via condensation polymerisation to form polypeptides that are linked by peptide bonds. These polypeptide chains may be organised into four hierarchical levels of protein structure:

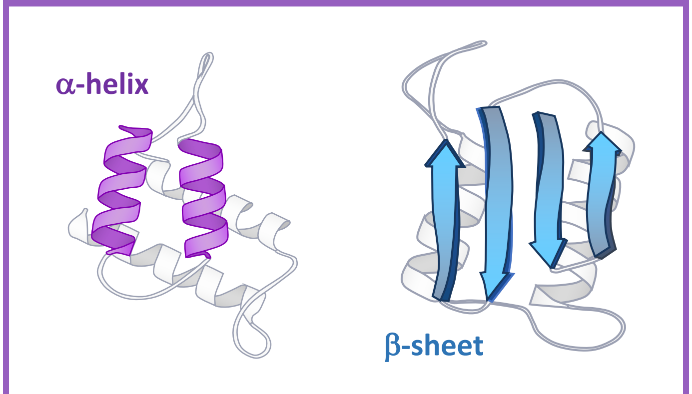
PRIMARY STRUCTURE:



The order of amino acids in a polypeptide chain (determines all subsequent levels of structure)

Formed by covalent bonding between the amine and carboxyl groups of adjacent amino acids

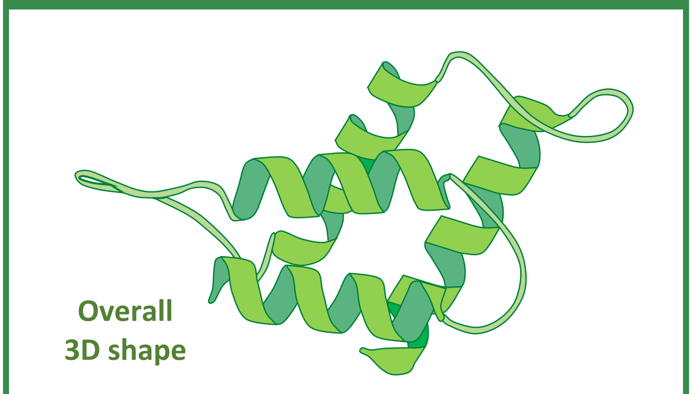
SECONDARY STRUCTURE:



The folding of a polypeptide chain in a repeating arrangement to form α-helix or β-pleated sheet

Formed by hydrogen bonding between the amine and carboxyl groups of non-adjacent amino acids

TERTIARY STRUCTURE:

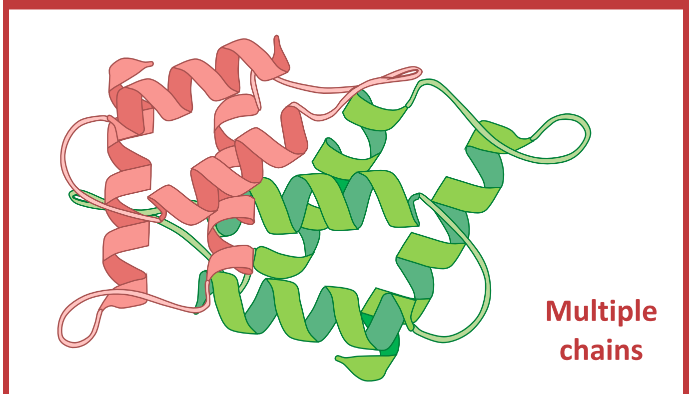


Folding of a polypeptide into a complex 3D shape

Formed by interactions between variable groups (e.g. H bonds, ionic bonds, disulphide bonds, etc.)

Can be described as globular (functional proteins) or described as fibrous (structural proteins)

QUATERNARY STRUCTURE:



Interaction of multiple polypeptides or prosthetic groups to form a single biologically active protein

Quaternary structures may be held together by a variety of bonds (similar to tertiary structure)

Not all proteins will have a quaternary structure

DENATURATION

The structure of a protein determines its chemical properties and hence contributes to biological function.

- An α-helix may increase the **tensile strength** of a protein, while β-sheets confer **mechanical stability**
- Soluble proteins will need their surface to be lined with polar or charged amino acids *(hydrophilic),* while insoluble proteins will need their surface to be lined with non-polar amino acids *(hydrophobic)*

Denaturation is a change in protein structure that causes a loss of biological activity *(usually permanent)*.

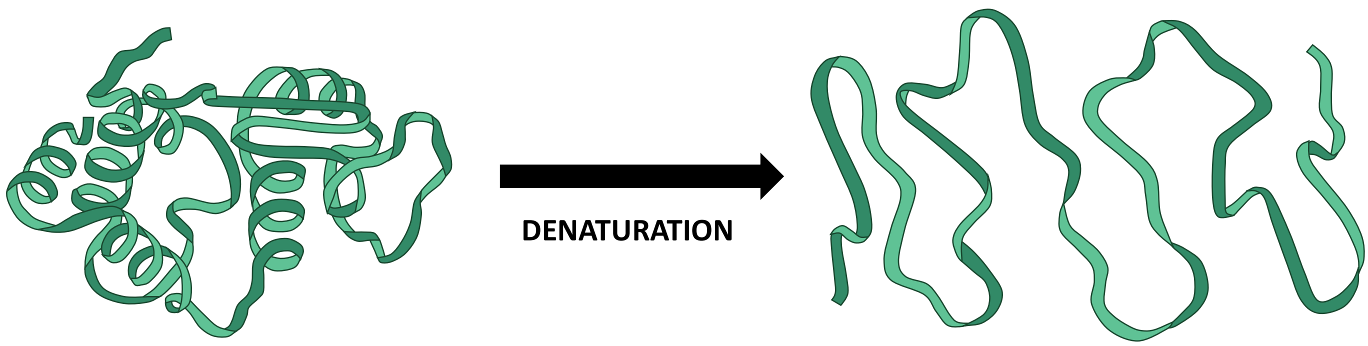
- The denaturation of a protein can most typically be caused by two conditions – temperature and pH

Temperature:

- High levels of thermal energy may **disrupt the hydrogen bonds** that hold the protein together
- As the bonds are broken, the protein will begin to unfold and lose its capacity to function as intended
- Temperatures at which proteins begin to denature may vary, but most human proteins will optimally function at body temperature (37°C)

pH:

- Amino acids are zwitterions, neutral molecules with both negative (COO^-) and positive (NH_3^+) regions
- Changing the pH will **alter the charge of a protein**, which in turn will alter protein solubility and shape
- All proteins have an optimal pH which is dependent on the environment in which it typically functions



Folded Protein

Unfolded Protein

PROTEIN FUNCTIONS

Proteins are a very diverse class of organic compounds that serve a wide variety of different roles in cells. Examples of protein functions include:

- **Structure** *(e.g. collagen is found in skin, keratin is found in hair)*
- **Hormones** *(e.g. insulin and glucagon regulate blood sugar levels)*
- **Immunity** *(e.g. immunoglobulins target foreign pathogens)*
- **Transport** *(e.g. protein channels enable facilitated diffusion)*
- **Sensation** *(e.g. rhodopsin is an eye pigment required for vision)*
- **Movement** *(e.g. actin and myosin are used in muscle contraction)*
- **Enzymes** *(e.g. Rubisco is responsible for carbon fixation in plants)*

Hint: Use a mnemonic device!

The totality of all proteins expressed within a cell, tissue or organism is called the **proteome**. The proteome of any given individual will be unique, and protein expression levels can change with time and conditions.