Edexcel (B) Biology A-level

Topic 1: Biological Molecules

Notes

Carbohydrates

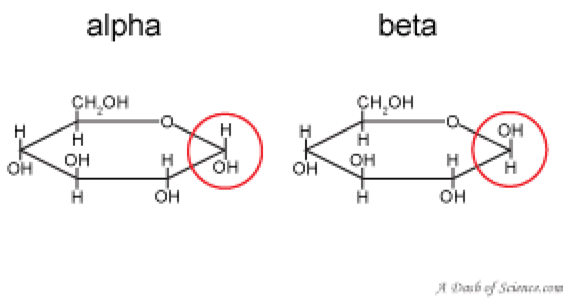
Carbohydrates are molecules which consist only of carbon, hydrogen and oxygen. They are long chains of sugar units called saccharides. There are three types of saccharides - **monosaccharides, disaccharides and polysaccharides**.

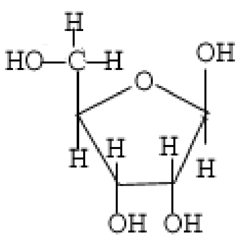
- Monosaccharide = single sugar monomer
- Disaccharide = two monosaccharides
- Polysaccharide = many monosaccharides

Monosaccharides can join together to form disaccharides and polysaccharides by **glycosidic bonds** which are formed in **condensation reactions**.

Monosaccharides

Glucose is a monosaccharide containing six carbon atoms in each molecule and is the main **substrate for respiration**. It has two isomers – alpha and beta glucose with the following structures (right):





Ribose is a monosaccharide containing five carbon atoms. It is a pentose sugar and **a component of RNA. DNA** contains an isomer of ribose called **deoxyribose,** which lacks the OH group on the second carbon of the sugar ring.

Disaccharides

- **Maltose** is a disaccharide formed by condensation of **two glucose molecules**
- **Sucrose** is a disaccharide formed by condensation of **glucose & fructose**
- **Lactose** is a disaccharide formed by condensation of **glucose & galactose**

Polysaccharides are formed from many glucose units joined together and include:

- **Glycogen** and **starch** which are both formed by the condensation of **alpha glucose**
- **Cellulose** formed by the condensation of **beta glucose**

Glycogen is the main energy storage molecule in animals and is formed from many molecules of **alpha glucose** joined together by **1, 4 and 1, 6 glycosidic bonds**. It has a **large number of side branches** meaning that the molecule can be hydrolysed and energy can be released quickly. Moreover, it is a relatively **large, but compact** molecule thus maximising the amount of energy it can store.

Starch stores energy in plants and it is a mixture of two polysaccharides called **amylose and amylopectin**:

- **Amylose** – amylose is an **unbranched chain** of glucose molecules joined **by 1, 4 glycosidic bonds**. As a result, amylose is **coiled** and thus it is a very **compact** molecule meaning it can store a lot of energy.

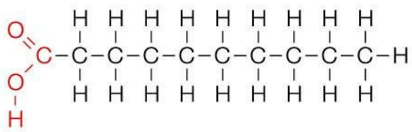
- **Amylopectin** is made up of glucose molecules joined by 1,4 and 1,6 glycosidic bonds, making it a **branched molecule.** Due to the presence of many side branches, it is rapidly digested by enzymes, therefore, energy is released quickly. It is also a compact molecule, although not as compact as amylose.

Cellulose is a component of cell walls in plants and is composed of long, unbranched chains of **beta glucose monomers** which are joined by **1,4** glycosidic bonds. **Microfibres and microfibrils** are strong threads which are made of long cellulose chains joined together by **hydrogen bonds** and they provide **structural support** in plant cells.

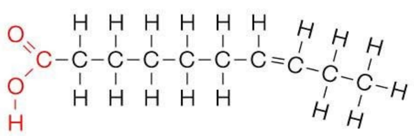
Lipids

Lipids are biological molecules which are only soluble in **organic solvents** such as alcohols. There are two types of lipids:

Saturated



Unsaturated

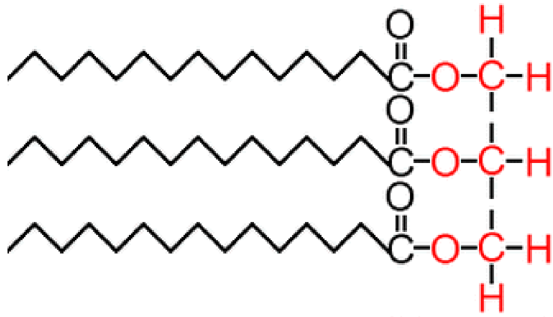


- **Saturated lipids** such as those found in **animal fats** – saturated lipids only contain carbon-carbon single bonds.
- **Unsaturated lipids** which can be found in **plants** – unsaturated lipids contain carbon-carbon **double bonds** and melt at lower temperatures than saturated fats.

Intermolecular forces are weaker in unsaturated lipids and therefore they have a lower **melting point.** As a result, saturated lipids are solid at room temperature and unsaturated lipids are liquid at room temperature. Saturated lipids are more compact as the molecules can pack closer together because there are no **kinks** in the carbon chain.

Properties of lipids:

- Lipids are **waterproof** because the fatty tail is hydrophobic.
- Very compact, and better gram-for-gram energy release than carbohydrates or proteins because more C-O bonds are hydrolysed.
- Lipids are **non-polar** and **insoluble** in water, therefore they are good for storage - they don't interfere with the water-based reactions in the cytoplasm.
- Lipids **conduct heat slowly** therefore they provide **thermal insulation.**

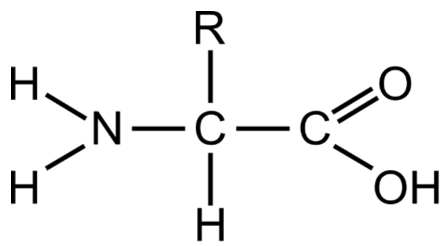


Triglycerides are lipids made of one molecule of **glycerol** and **three fatty acids** joined by ester bonds formed in **condensation reactions**. Fatty acid chains can vary in length and have different types of carbon-carbon bonds; **C-C single bonds** and **C-C double bonds.** Triglycerides are used as energy reserves in plant and animal cells.

In **phospholipids**, one of the fatty acids of a triglyceride is substituted by a phosphate-containing group. Phosphate heads are **hydrophilic** and the tails are **hydrophobic** and as a result, phospholipids form **a bilayer** in the cell membrane, with the phosphate heads pointing towards the aqueous environment and fatty acid tails pointing away from the aqueous environment.

Proteins

Amino acids are the monomers from which proteins are made. Amino acids contain an **amino group**, NH2, a **carboxyl group**, COOH, and a **variable R group.** There are 20 different amino acids with different R groups. The R group determines the chemical properties of the amino acid. Amino acids are joined by peptide bonds formed in condensation reactions. A dipeptide contains two amino acids and polypeptides contain three or more amino acids.



Structure of proteins is determined by the order and number of amino acids, bonding present and the shape of the protein:

- The **primary structure** of a protein is the linear sequence of amino acids in the polypeptide chain, held together by peptide bonds.

- The **secondary structure** is formed by the folding of the polypeptide chain into an **alpha helix** or **beta pleated sheet**. The secondary structure only contains hydrogen bonds (electrostatic forces of attraction between an oxygen, nitrogen or fluorine atom and an electron-deficient hydrogen atom).

- The **tertiary structure** of a protein is the 3D folding of the secondary structure into a complex shape. The shape is determined by the type of bonding present, such as **hydrogen bonding, ionic bonding** (salt bridges, form between oppositely charged groups on the R groups) and **disulphide bridges** (covalent bonds between sulphur atoms in cysteine).

- The **quaternary structure** of a protein is the 3D arrangement of more than one polypeptide.

Not all proteins have all levels of structure. Proteins can be **fibrous** or **globular**.

Fibrous Proteins:

- Long parallel polypeptides
- Very little tertiary/quaternary structure - mainly secondary structure.
- Occasional cross-linkages which form microfibres for tensile strength
- Insoluble
- Used for structural purposes

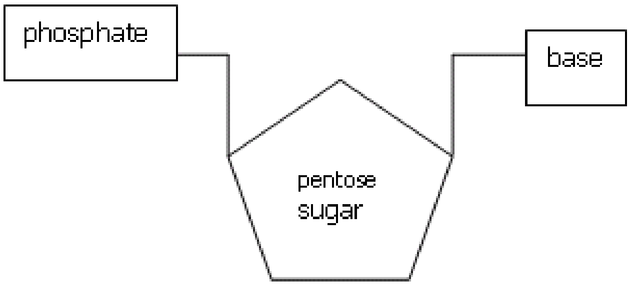
Globular Proteins:

- Complex tertiary/quaternary structures
- Form colloids in water
- Many uses e.g. hormones, antibodies

Collagen is an example of a **fibrous** protein. It has high tensile strength due to the large number of **hydrogen bonds** in the structure. Collagen molecules are made up of three distinct α-chains which form a triple gamma helix. Multiple of these helices link together to form fibrils and strong collagen fibres. Collagen forms the structure of **bones, cartilage and connective tissue** and is a main component of **tendons** which connect muscles to bones.

Haemoglobin is a **water-soluble globular protein** which consists of **four polypeptide chains**; two alpha and two beta. Each subunit contains a haem group, which contains the Fe^{2+} ion. It **carries oxygen** in the blood as oxygen can bind to the Fe^{2+} and is then released when required, such as in tissues for respiration.

DNA and Protein Synthesis



Both deoxyribonucleic and ribonucleic acid are **nucleic acids**, which are **polymers of nucleotides**. **Nucleotides** consist of **pentose** which is a 5 carbon sugar, a nitrogen-containing **organic base** and a **phosphate group**:

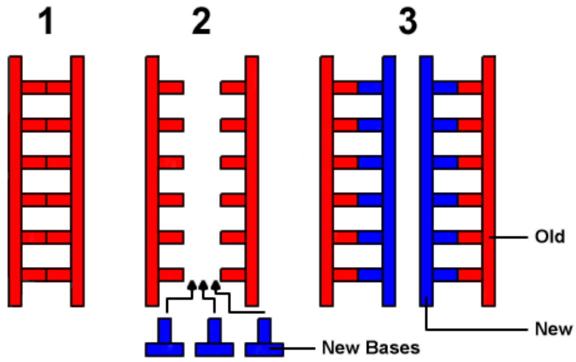
- The components of a **DNA** nucleotide are **deoxyribose, a phosphate group and one of the organic bases adenine, cytosine, guanine or thymine.** Adenine and guanine both have two nitrogen-containing rings and are classified as **purine** bases.
- The components of an **RNA** nucleotide are **ribose, a phosphate group and one of the organic bases adenine, cytosine, guanine or uracil**. Thymine, uracil and cytosine all have a single ring structure and are classified as **pyrimidines**.
- Pyrimidines are smaller than purines as they only contain one nitrogen-containing ring.
- Nucleotides join together via **phosphodiester bonds** formed in **condensation reactions.**

A DNA molecule is a **double helix** composed of two polynucleotides joined together by **hydrogen bonds** between complementary bases - there are two hydrogen bonds between adenine and thymine, and three hydrogen bonds between cytosine and guanine.
RNA is **single-stranded** and comes in multiple different forms, such as **mRNA (messenger RNA), tRNA (transfer RNA)** and **rRNA (ribosomal RNA),** which are involved in protein synthesis.

DNA Replication

The **semi-conservative replication** of DNA ensures genetic continuity between generations of cells meaning that genetic information is passed on from one generation from the next.

The steps of semi-conservative DNA replication are as follows:



1. The DNA double helix unwinds as hydrogen bonds are broken between complementary bases. DNA helicase catalyses the unravelling of the DNA double helix.
2. One of the strands is used as the template. Free nucleotides line up and complementary base pairing occurs between the template strand and free nucleotides.
3. Adjacent nucleotides are joined by phosphodiester bonds formed in condensation reactions. This is catalysed by DNA polymerase.
4. The new DNA molecules automatically fold into double helices as hydrogen bonds are formed within the molecules.

DNA replication is said to be semi-conservative because the new DNA molecules contain one original strand of DNA and one newly-synthesised strand of DNA.

Genetic Code

The genetic code consists of triplets of bases called codons. Each codon codes for an amino acid. The amino acids are then joined together by peptide bonds and form a polypeptide chain. Therefore, a gene is a sequence of bases on a DNA molecule coding for a sequence of amino acids in a polypeptide chain. Not all of the genome codes for proteins – the non-coding regions of DNA are called introns and the coding regions are called exons.

Features of the genetic code:

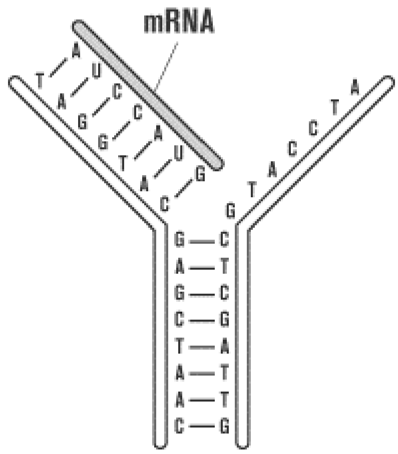
- The genetic code is non-overlapping meaning that each triplet is only read once and triplets don't share any bases.
- The genetic code is degenerate, meaning that more than one triplet codes for the same amino acid. This reduces the effect of mutations which are changes to the base sequence such as base deletions, insertions or substitutions. A change in the base sequence of DNA may not affect the amino acid coded for as the new triplet may still code for the same amino acid. Some mutations which do change the base sequence are harmful, such as the mutation which leads to sickle cell anaemia, in which a mutated form of haemoglobin distorts the shape of red blood cells. A deletion or insertion is more likely to be harmful because it causes a 'frameshift', in which all codons 'downstream' of the mutation are read differently.
- The genetic codes contains start and stop codons which either start or stop protein synthesis.
- The genetic code is universal, meaning it is the same in all organisms and species.

Protein Synthesis

There are two stages of **protein synthesis: transcription,** which occurs in the nucleus and involves **DNA and mRNA,** and **translation,** which occurs at the ribosomes in the cytoplasm and involves **mRNA and tRNA**. During transcription, the DNA strand is transcribed into mRNA and during translation, amino acids are assembled together to form a polypeptide chain.

Transcription

During transcription, a molecule of mRNA is made in the nucleus:

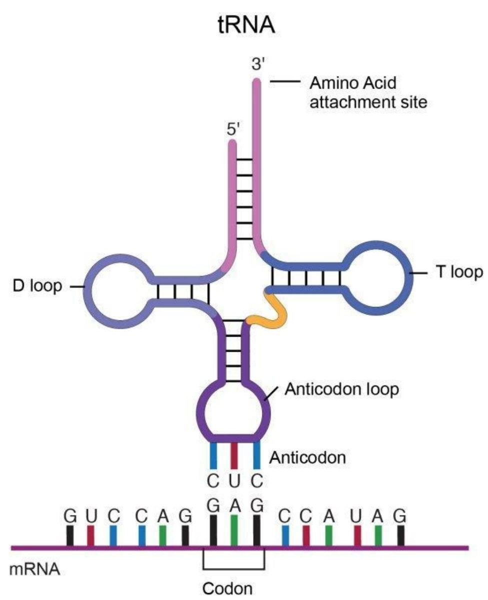


- The **hydrogen bonds** between the complementary bases of the DNA double helix break and **DNA uncoils,** thus separating the two strands. This is catalysed by **DNA helicase.**
- One of the DNA strands is used as a **template** to make the mRNA molecule. The template strand is called the **antisense strand.** The coding strand is called the **sense strand** and has the same nucleotide sequence as the strand being synthesised.
- **Free nucleotides** line up on the template strand by **complementary base pairing** and adjacent nucleotides are joined together by phosphodiester bonds, thus forming a molecule of mRNA. This is catalysed by **RNA polymerase.**
- mRNA then moves out of the nucleus through a **nuclear pore** and attaches to a **ribosome** in the cytoplasm which is the site of next stage of protein synthesis.

Translation

During translation amino acids join together to form a polypeptide chain:

- mRNA attaches to a ribosome on the **rough endoplasmic reticulum.** A tRNA molecule, which has a specific amino acid attached to its **amino acid binding site**, binds to the mRNA via its anticodon.
- **Hydrogen bonds** form between the anticodon of the tRNA and the codon of the mRNA.
- A second tRNA molecule binds to the next codon of the mRNA and the two amino acids form a **peptide bond.**
- A third tRNA molecule joins and the first one leaves the ribosome.



- This process is repeated thus leading to the formation of a polypeptide chain until a stop codon is reached on mRNA.

Enzymes

Enzymes are biological catalysts which increase the rate of a chemical reaction by lowering the activation energy of the reactions they catalyse, including both anabolic and catabolic and intracellular and extracellular reactions. The active site is the area of the enzyme where the substrate binds. Enzymes are specific to substrates they bind to, as only one type of substrate fits into the active site of the enzyme.

When the enzyme and substrate form a complex, the structure of the enzyme is distorted so that the active site of the enzyme moulds around the substrate. This is called the induced fit model of enzyme action. The initial rate of reaction can be measured by calculating the gradient of a concentration-time graph at t=0.

Factors affecting the rate of enzyme-controlled reactions:

- Enzyme concentration – the rate of reaction increases as enzyme concentration increases as there are more active sites for substrates to bind to. However, increasing the enzyme concentration beyond a certain point has no effect on the rate of reaction as there are more active sites than substrates so substrate concentration becomes the limiting factor.

- Substrate concentration – as concentration of substrate increases, rate of reaction also increases as more enzyme-substrate complexes are formed. However, beyond a certain point, the rate of reaction no longer increases as enzyme concentration becomes the limiting factor.

- Temperature – the rate of reaction increases up to the optimum temperature which is the temperature each enzyme works best at. Rate of reaction decreases beyond the optimum temperature because enzymes become denatured as hydrogen bonds are broken within the protein.

Inhibitors

Inhibitors are substances which stop the enzyme from binding to its substrate, therefore controlling the progress of a reaction. Inhibition may be reversible or irreversible.

There are two categories of inhibition:

- Competitive inhibition – an inhibitor molecule competes with the substrate for binding to the active site of the enzyme, therefore preventing the substrate from binding. It can be reversed by increasing the substrate concentration.

- **Non-competitive inhibition** - an inhibitor doesn't bind to the active site but binds to a different part of the enzyme (the allosteric site) and changes the shape of the enzyme. This decreases the reaction rate as the active site doesn't fit the substate and the substrate cannot bind to the enzyme. It cannot be reversed by increasing substrate concentration.

Sometimes, the end-product of a multi-step reaction may act as an inhibitor to the enzyme which catalyses the initial stage of the reaction. This is called **end-product** or **feedback inhibition.**

Inorganic Ions

Inorganic ions occur in solution in the cytoplasm and body fluid of organisms.

Ions required for plant growth and development include:

- **Nitrate ions** – they are required to make **DNA and amino acids**
- **Calcium ions** – they are needed to form **calcium pectate** for the **middle lamellae** in plants
- **Phosphate ions** are required to make **ADP and ATP,** and **DNA and RNA**
- **Magnesium ions** are needed to produce **chlorophyll**

Water

Water is a very important molecule which is a major component of cells.
The main properties of water include:

- Water is a **polar molecule** due to **uneven distribution of charge** within the molecule – the oxygen atoms are more electronegative than the hydrogen atoms and attract the electrons more strongly, causing one end of the molecule to be more positive than the other. This means ionic substances, such as NaCl, can dissolve in water.

- It is a **polar solvent** in which many metabolic reactions occur.

- It has a **high specific heat capacity,** meaning that a lot of energy is required to change the temperature, therefore **minimising temperature fluctuations.** This is crucial as it allows organisms in rivers and lakes to survive in different seasons.

- It has a **relatively large latent heat of vaporisation**, meaning evaporation of water provides a **cooling effect** with little water loss.

- **Cohesion and adhesion** - water molecules stick together (cohesion) due to the hydrogen bonding between adjacent water molecules, meaning it can be transported in plants in xylem tubes. Cohesion also means the **surface tension** at the water-air boundary is high. Water molecules can also adhere to the sides of tube-like cells (adhesion).

- **Maximum density of water is at 4 degrees Celsius** – this means that **ice is less dense than water** as the water molecules are spread out and fixed in place. Therefore, ice floats on top of the water, creating an **insulating layer.** This increases the chance of survival of organisms in large bodies of water as it prevents them from freezing when temperatures decrease (such as in winter).

- Water is **incompressible,** therefore it provides good support and can be used in hydraulic mechanisms.