

AQA Biology A-level

Topic 1: Biological Molecules

Notes

MEGA LECTURE

Monomers and polymers

Monomers are small units which are the components of larger molecules, examples include **monosaccharides** such as **glucose**, **amino acids** and **nucleotides**. **Polymers** are molecules made from many monomers joined together.

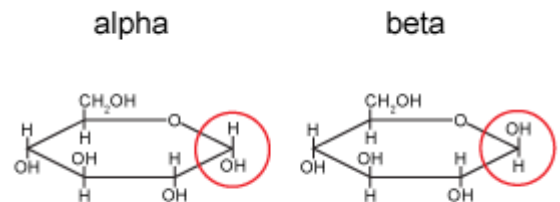
Monomers are joined by a chemical bond in a **condensation** reaction whereby a water molecule is eliminated. **Hydrolysis** is the opposite of a condensation reaction and is when water is added to break a chemical bond between two molecules.

Carbohydrates

Carbohydrates are molecules which consist only of carbon, hydrogen and oxygen and they are long chains of sugar units called saccharides. A single monomer is called a **monosaccharide** with a pair of monomers being called a **disaccharide**. Combining many monosaccharides results in the formation of a **polysaccharide**. These are all joined together with a **glycosidic bond** formed in a **condensation reaction**.

Monosaccharides

Glucose is a monosaccharide containing six carbon atoms in each molecule, and is the main **substrate for respiration** and therefore of great importance. It has two isomers - alpha and beta glucose with structures being seen on the right.

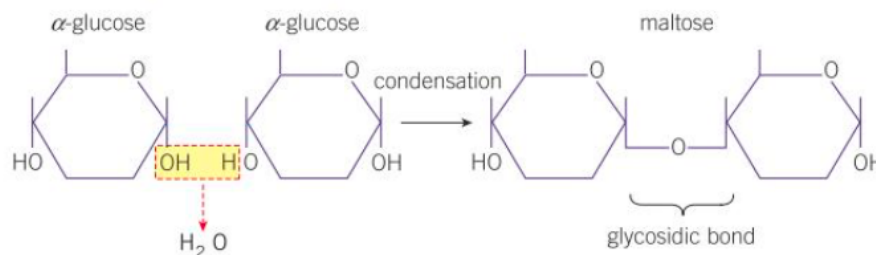


Common monosaccharides include glucose, galactose and fructose. These are typically sweet tasting, soluble substances which have the general formula $(\text{CH}_2\text{O})_n$ where n can any number from three to seven.

Disaccharides:

Two monosaccharides can join together in a condensation reaction to form a **disaccharide**. In this process a molecule of water is produced. The diagram below shows the formation of a 1,4 glycosidic bond between two alpha glucose molecules in order to form a molecule of maltose.

a Formation of glycosidic bond by removal of water (condensation reaction)



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Examples of some common disaccharides and how they are formed are shown below:

- **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

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 energy can be released quickly as enzymes can act simultaneously on these branches. Moreover, it is a relatively **large but compact** molecule thus maximising the amount of energy it can store. Finally being insoluble means it will not affect the water potential of cells and cannot diffuse out of cells.

Starch stores energy in plants and 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**, and as a result amylose is **coiled** and thus a very **compact** molecule storing a lot of energy.
- **Amylopectin** is **branched** and is made up of glucose molecules joined by **1, 4 and 1, 6 glycosidic bonds**. Due to the presence of many **side branches** these can be acted upon simultaneously by many enzymes and thus broken down to release its energy.
- Some key properties of starch that make it suitable are that; its insoluble so will not affect cell water potential, it is compact so a lot of energy can be stored in a small space and when it is hydrolysed the released alpha glucose can be transported easily.

Cellulose is a component of cells walls in plants and is composed of long, unbranched chains of **beta glucose** which are joined by glycosidic bonds. **Microfibrils** are strong threads which are made of long cellulose chains running parallel to one another that are joined together by **hydrogen bonds** forming strong cross linkages. Cellulose is important in stopping the cell wall from bursting under osmotic pressure. This is because it exerts inward pressure that stops the influx of water. This means that cells stay turgid and rigid, helping to maximise the surface area of plants for photosynthesis.

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Biochemical tests:

- **Benedict's reagent** can be used to test for the presence of **reducing sugars**. All monosaccharides and some disaccharides (e.g. maltose) are reducing sugars. These are therefore sugars that can donate an electron to the Benedict's Reagent. Benedict's reagent is a alkaline solution of Copper(II) Sulfate. When a reducing sugar is added to this and heated it forms an insoluble red precipitate (copper (I) oxide). The Benedict's Test is summarised below:
 1. Add 2cm³ of the food sample to be tested (needs to be in liquid form to begin with).
 2. Add 2cm³ of Benedict's Reagent.
 3. Heat the mixture gently in a water bath for five minutes. If the solution turns brick red (orange-brown) then a reducing sugar is present and it is a positive result.

Although some disaccharides are reducing sugars other disaccharides as well as polysaccharides are **non-reducing** and therefore the Benedict's Test has to be altered in order to test for these. The process occurs as follows:

1. 2cm³ of food sample (must be in liquid form) is added to 2cm³ of Benedict's Reagent. This is then placed in a water bath for 5 minutes to gently warm.
 2. If the colour does not change from **blue to brick red** then a reducing sugar is **not** present.
 3. Another 2cm³ of the same food sample is then taken and 2cm³ of **dilute hydrochloric acid** is added. The test tube is then placed in a water bath for 5 minutes. The dilute HCl will hydrolyse the disaccharides and polysaccharides into their constituent monosaccharides.
 4. After this some **sodium hydrogencarbonate** is added in order to neutralise the test tube as the Benedict's Reagent will not work in acidic conditions. pH paper is used to check that the solution is neutralised.
 5. The solution can now be retested by adding 2cm³ of Benedict's Reagent to the solution and placing in a water bath for 5 minutes.
 6. If a non reducing sugar is present in the original sample then a colour change from the **blue** Benedict's Reagent to **brick red (orange-brown)** will be observed.
- A chemical test for starch is **iodine/potassium iodide**. If the solution turns blue/black in colour from orange-brown then starch is present.

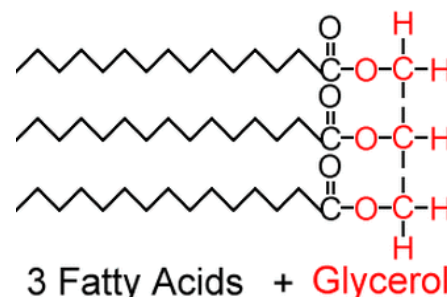
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Lipids

Lipids are biological molecules made of carbon, hydrogen and oxygen which are only soluble in **organic solvents** such as alcohols. The main lipid types are **triglycerides** and **phospholipids**.

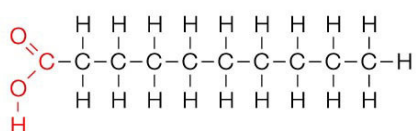
Triglycerides

Triglycerides are lipids made of one molecule of **glycerol** and **three fatty acids** joined by ester bonds formed in **condensation reactions**. There are many different types of fatty acids (over 70 different types) which vary in chain length, presence and number of double bonds.

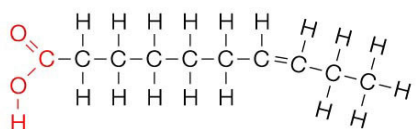


The presence of double bonds changes the name of the lipid, they can either be saturated or unsaturated. These are explained below:

Saturated



Unsaturated



• **Saturated lipids** such as those found in **animal fats** - saturated lipids don't contain any carbon-carbon double bonds.

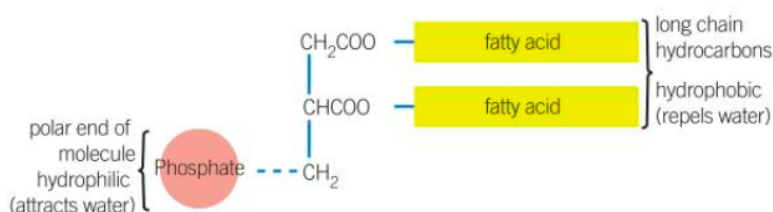
• **Unsaturated lipids** which can be found in **plants** - unsaturated lipids contain carbon-carbon **double bonds**. The presence of a double bond means that the molecule is able to bend. As a result unsaturated fats cannot pack together as tightly and are therefore liquid at room temperature.

Triglyceride structure related to their properties

- High ratio of energy storing carbon-hydrogen bonds to carbon atoms and therefore they are an excellent energy store.
- A low mass to energy ratio meaning that they are a good storage molecule, with a lot of energy being stored in a small volume. This is beneficial for animals as it is less mass to move around.
- Being large and non-polar lipids are insoluble in water and therefore their storage does not affect the water potential of cells.
- A high ratio of hydrogen-oxygen atoms means that triglycerides release water when they are oxidised and therefore provide an important source of water for organisms to live in dry environments.

Phospholipids

In **phospholipids**, one of the fatty acids of a triglyceride is substituted by a phosphate-containing group. Phosphate heads are **hydrophilic** (loves water) and the tails are **hydrophobic** (hates water) and as a result phospholipids form **micelles** when they are in contact with water. The molecule is therefore known as **polar**. The structure of a phospholipid is shown below.



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Phospholipids structure related to their properties

- In an aqueous environment being polar means a bilayer can be formed.
- The hydrophilic heads of the phospholipids can be used to hold at the surface of the cell surface membrane.
- Their structure allows them to form glycolipids with carbohydrates which are important on the cell surface membrane for cell recognition.

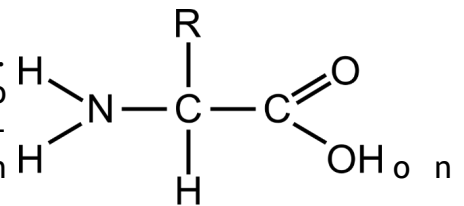
Emulsion Test

An **emulsion test** can be used to test for the **presence of lipids**. This is carried out as follows:

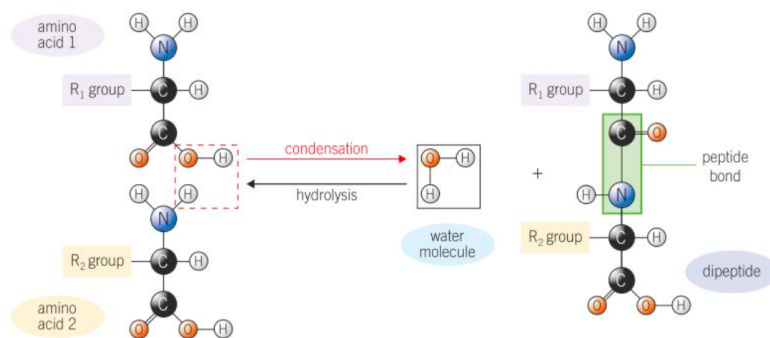
1. Take a completely grease free test tube and add 2cm³ of the sample to be tested and 5cm³ of ethanol.
2. Shake the test tube thoroughly to dissolve all the lipid in the solution.
3. Add 5cm³ of water and shake gently.
4. A cloudy-white colour indicates the presence of a lipid.
5. As a control repeat the experiment using water as the sample, the final solution should remain clear.

Proteins

Amino acids are the monomers from which proteins are made. Amino acids contain an amino group (NH₂), carboxylic acid group (-COOH) and a variable R group which is a carbon-containing chain. The basic structure of an amino acid is shown the right.



There are 20 different amino acids, each determined by their different R groups. Amino acids are joined by peptide bonds formed in condensation reactions. In this reaction a molecule of water is formed, with the process shown in the image below:



A dipeptide contains two amino acids and polypeptides contain three or more amino acids.

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Structure of Proteins

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

- **Primary structure** of a protein is the order and number of amino acids in a protein. This primary structure contains the initial sequence of amino acids and will therefore determine the proteins function in the end.
- The **secondary structure** is the shape that the chain of amino acids makes - **either alpha helix** or **beta pleated sheet**. The hydrogen in the $-NH$ has a slight positive charge whilst the oxygen in the $-C=O$ has a slight negative charge. As a result weak hydrogen bonds can form leading to alpha helices or beta pleated sheets.
- **Tertiary structure** of proteins is the 3D shape of the protein and is formed from further twisting and folding. A number of different bonds maintain the structure, these are:
 - **Disulfide bridges** - interactions between the sulfur in the R group of the amino acid **cysteine** these are strong and not easily broken.
 - **Ionic bonds** - form between the carboxyl and amino groups that are not involved in the peptide bond. They are easily broken by pH and are weaker than disulfide bridges.
 - **Hydrogen bonds** - numerous and easily broken.
- Proteins can be globular or fibrous. **Globular proteins** such as enzymes are compact whereas **fibrous proteins** such as keratin are long and thus can be used to form fibres.

Biuret Test - Test for Proteins

The Biuret test can be used to test for the presence of **peptide bonds** in a protein and therefore to detect proteins in food. The test is carried out as follows:

1. Place the sample to be tested in a test tube and add an equal volume of sodium hydroxide at room temperature.
2. Add a few drops of very dilute (0.05%) copper (II) sulfate solution and mix gently.
3. A purple colouration indicates the presence of a peptide bond and hence a protein. A negative result would mean the solution remains blue.

Enzymes

Enzymes increase **rate of reaction** by lowering the **activation energy** of the reaction they catalyse. They are 3D tertiary structured globular proteins whose shape is determined by the primary sequence of amino acids.

The **active site** is an area of the enzyme that is made up of only a few amino acids and forms a small depression in the overall enzyme. The molecule that the enzyme acts upon is called the **substrate**. Enzymes are **specific to substrates** they bind to meaning that only one type of substrate fits into the active site of the enzyme. When the enzyme and substrate bind they form an **enzyme substrate complex**, and the structure of the enzyme is altered so that the active site of the enzyme fits around the substrate. This is called the **induced fit model**.

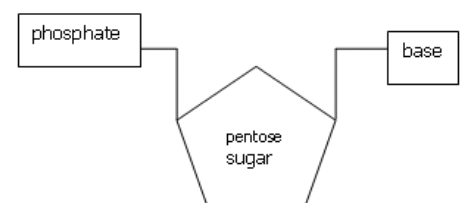
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Factors affecting the rate of enzyme-controlled reactions:

- **Temperature** - rate of reaction increases up to the optimum temperature as the kinetic energy of the enzyme increases. Above the optimum temperature rate of reaction decreases beyond the optimum temperature as the enzyme becomes denatured.
- **pH** - The pH of a solution is a measure of the hydrogen ion concentration. The pH of a solution can be calculated using the following formula: $\text{pH} = -\log_{10}[\text{H}^+]$. A hydrogen ion concentration of 1×10^{-9} therefore has a pH of 9. pH affects the enzymes shape as it can disrupt the bonds in the tertiary structure of the enzyme. Like temperature all enzymes work at different optimum pH's e.g. pepsin in the stomach works in very acidic conditions.
- **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 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.
- **Concentration of competitive reversible inhibitors** - as concentration of competitive reversible inhibitors increases, rate of reaction decreases as the active sites are temporarily blocked by inhibitors so substrates cannot bind to them.
- **Concentration of non-competitive reversible inhibitors** - as concentration on non-competitive reversible inhibitors increases, rate of reaction decreases as the shape of the enzyme (not the active site) is altered by the inhibitors.

Structure of DNA and RNA

Both **DNA** and **RNA** carry information, for instance DNA holds genetic information, whereas RNA transfers this genetic information from DNA to **ribosomes** for protein synthesis. Ribosomes are formed of ribosomal RNA and proteins. Both deoxyribonucleic and ribonucleic acid 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 sugar, a phosphate group and one of the nitrogen containing organic bases adenine, cytosine, guanine or thymine**.
- The components of an **RNA** nucleotide are **ribose sugar, a phosphate group and one of the nitrogen containing organic bases adenine, cytosine, guanine or uracil**.

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- Nucleotides join together by **phosphodiester bonds** formed in **condensation reactions**. The result is a dinucleotide, which join to form polynucleotides. The bond forms between the deoxyribose sugar of one nucleotide and the phosphate group of another.

A DNA molecule is a **double helix** composed of two polynucleotides joined together by a **hydrogen bonds** between complementary bases **whereas RNA is a relatively short polynucleotide chain**.

Base pairing nitrogen containing organic bases occurs as follows:

Adenine ALWAYS pairs with Thymine
Guanine ALWAYS pairs with Cytosine

DNA is a stable molecule for the following reasons:

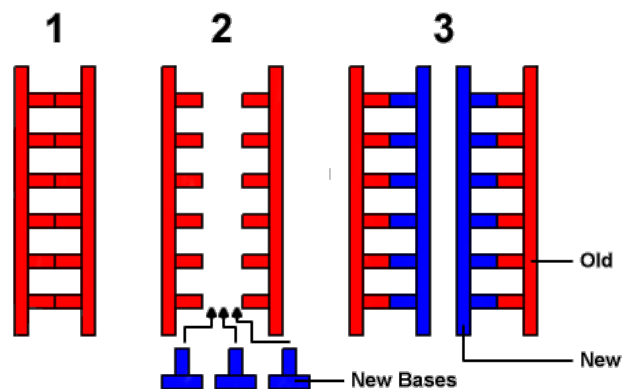
- The **phosphodiester backbone** protects the more chemically reactive nitrogen containing organic bases inside the double helix.
- Hydrogen bond form bridges** between the phosphodiester uprights. As there are **three hydrogen bond between guanine and cytosine**, rather than **two for adenine and thymine**, a higher proportion of C–G pairings makes DNA more stable.

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 replication of DNA are as following:

- An enzyme, DNA helicase, causes the two strands of DNA to separate breaking the **hydrogen bonds between the complementary bases**.
- One of the strands is used as the **template** and **complementary base pairing occurs** between the template strand and **free nucleotides**.
- Once activated nucleotides are bound the enzyme DNA polymerase joins them together by forming **phosphodiester bonds**. The result is that two identical strands of DNA are formed.

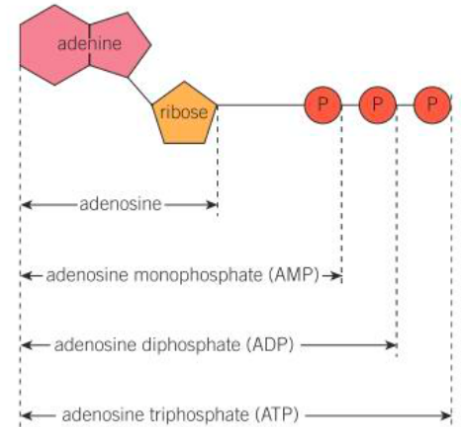


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ATP

Adenosine triphosphate is a nucleotide derivative and consists of **ribose, adenine and three phosphate groups**.

- **Energy is released when ATP is hydrolysed** to form **ADP and a phosphate molecule**. This process is catalysed by **ATP hydrolase**. The energy comes from the bonds between the phosphate molecules. These bonds are very unstable and thus have a low activation energy. The breaking of these is quick and releases a considerable amount of energy.
- The **inorganic phosphate can be used to phosphorylate other compounds**, as a result making them more reactive.
- **Condensation of ADP and inorganic phosphate catalysed by ATP synthase produces ATP** during photosynthesis and respiration.



Properties of ATP:

- ATP is an **immediate source of energy** and is more desirable to use than glucose as ATP can be broken down in a single step to release a **manageable quantity of energy**.
- **ATP isn't stored** in large quantities as it can easily be reformed from ADP in seconds.
- ATP is used in a variety of different ways, these include, **metabolic processes, movement, active transport, secretion and activation of molecules**.

Water

Water is a very important molecule which is a major component of cells, for instance:

- Water is a **polar molecule** due to the **uneven distribution of charge** within the molecule - the hydrogen atoms are more positive than the oxygen atom causing one end of the molecule to be more positive than the other. As a result hydrogen bonding between many water molecules can occur allowing them to stick together.
- It is a **metabolite** in metabolic reactions such as **condensation and hydrolysis** which are used in forming and breaking of chemical bonds.
- It is a **solvent** allowing gases to readily diffuse as well as enzymes and waste products e.g. ammonia and urea.
- It has a **high heat specific capacity**. This is because water molecules stick together with hydrogen bonds meaning that a lot of energy is required to break these bonds. This helps to **minimise temperature fluctuations** in living things therefore it acts as a **buffer**.



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- Hydrogen bonding means that it requires a lot of energy to evaporate 1 gram of water. Therefore water has a **relatively large latent heat of vaporisation**, meaning evaporation of water provides a **cooling effect** with little water loss e.g. sweating.
- **Strong cohesion** between molecules enables effective transport of water in tube like the xylem. The **strong cohesion supports columns of water**, as a result of strong cohesion **the surface tension at the water-air boundary is high**.

Inorganic ions

Inorganic ions occur in solution in the cytoplasm and body fluid of organisms, some in high concentrations and others in very low concentrations.

Some of the essential ions include:

- **hydrogen ions** which **determine the pH** of substances such as blood - **the higher the concentration of hydrogen ions the lower the pH**
- **Iron ions are a component of haemoglobin** which is an oxygen carrying molecule in red blood cells
- **Sodium ions** are **involved in co-transport of glucose and amino acids**
- **Phosphate ions** are a **component of DNA and ATP**