OCR (B) Biology A-level

2.1 Cells and chemicals for life

Notes

2.1.1 Cells and microscopy

Microscopy has revolutionized the development of cell theory and aids in our understanding of cell structure.

Light microscopy

- Commonly used microscope to appreciate cell structure
- Relatively inexpensive equipment
- Minimal user training required

The image can be viewed directly at the eyepiece. A number of lenses are used to produce the final image. A wide variety of specimens may be observed – including live specimens; whole specimen; specimen embedded in wax.

The light passes from the light source (i.e. bulb) under the stage, through the condenser lens and specimen slide. The beam of light is focused through the objective lens and finally the eyepiece lens. The specimen can be viewed through the objective lens at different magnifications – i.e. x4, x10, x40, x100. The final lens – 'eyepiece lens' also magnifies the image by an approximate factor of x10. The focus of the specimen may also be altered using the dials within the microscope.

Therefore, the final magnification is calculated by:
multiplying the objective lens x eyepiece lens

image source: microscopeworld.com

Example: Blood cells and light microscopy

Light microscopy may be used to appreciate many specimens and samples – i.e. living cells. The components of our blood including red blood cells (erythrocytes), platelets, neutrophils, lymphocytes and monocytes may also be recognized using this technique. Appreciation of the shape, size and quantity of these cells is crucial in medicine and enables identification of disease.

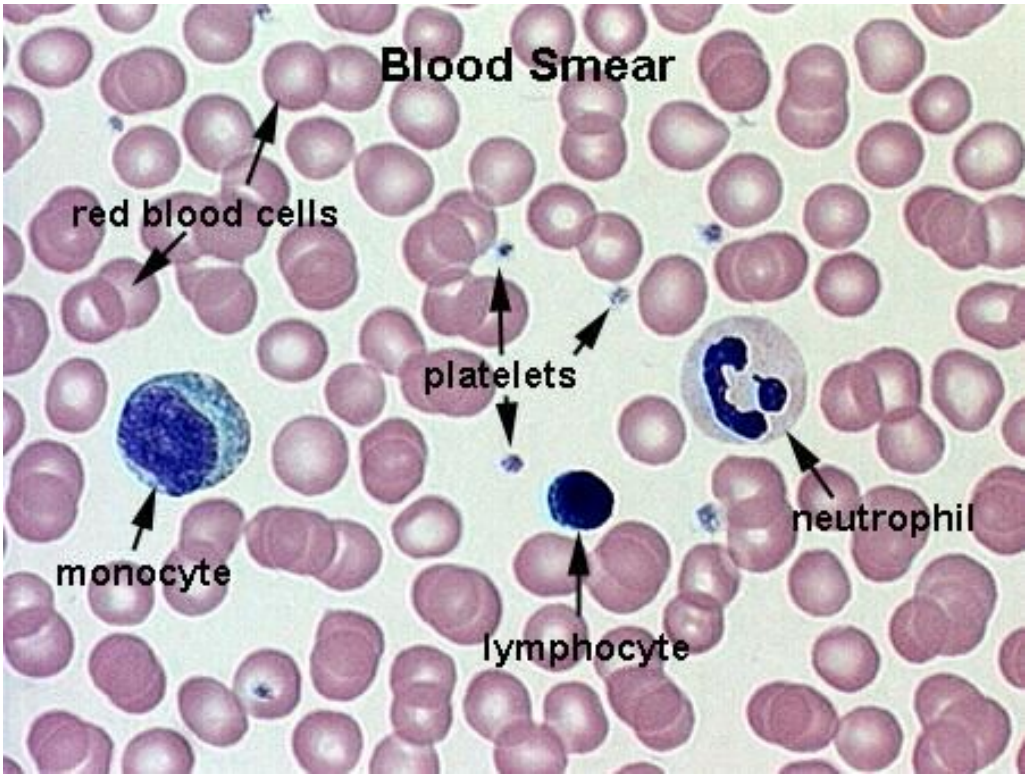


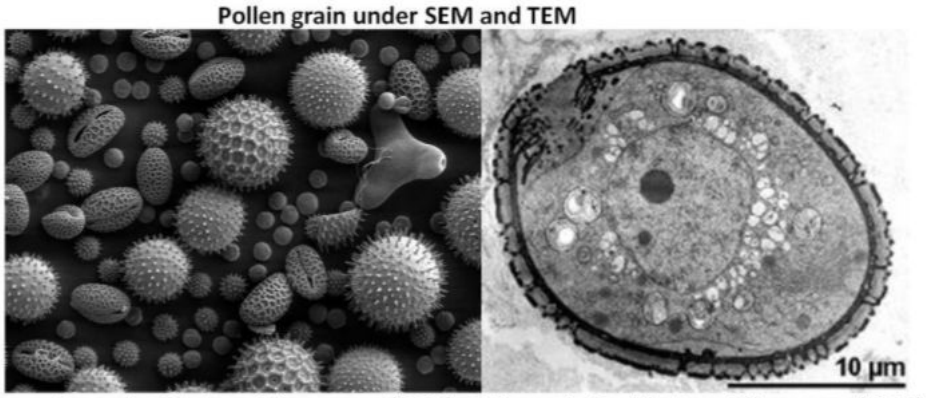
Image source: serc.carleton.edu

Electron microscopy

There are two types of electron microscopy:

- Transmission Electron Microscopy (TEM): emits electron beam through very thin prepared samples. Electrons penetrate dense parts of sample with greater difficulty, hence providing the contrast in images produced. The maximum magnification of TEM may be up to x500,000.
- Scanning Electron Microscopy (SEM): emits electron beam directly onto a sample such that none of the electrons are able to penetrate it. They 'bounce' off the specimen and produce a 3D image. The specimen can be any thickness. The maximum magnification of SEM may be up to x100,000.

Electron microscopes are expensive to operate and require high skill for optimum results. As they are larger, they are less portable. Whereas live specimens can be observed in light microscopy, for use of electron microscopy the specimen must be dead or denatured. Electron beams are deflected in air, so sample must be prepared in a vacuum.



Scanning Electron Microscope (SEM) vs Transmission Electron Microscope(TEM)

Image source: majordifferences.com

Recent developments

The **confocal scanning microscope** makes use of laser beams to analyse a sample. They allow higher resolution images, scanning of different depths in living tissue which is useful for medical slides and the use of computer software to combine multiple images. However, they have low magnification, require specialist training to use and the equipment required for its use is expensive.

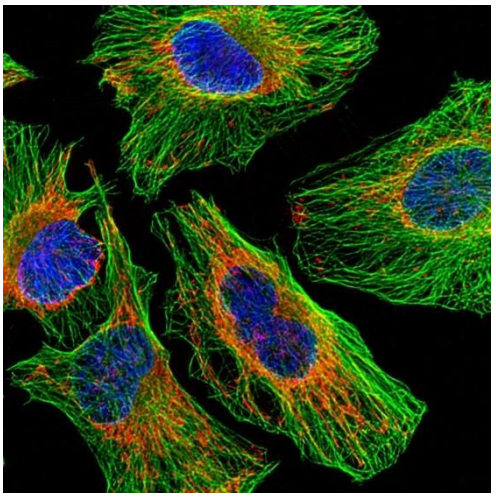


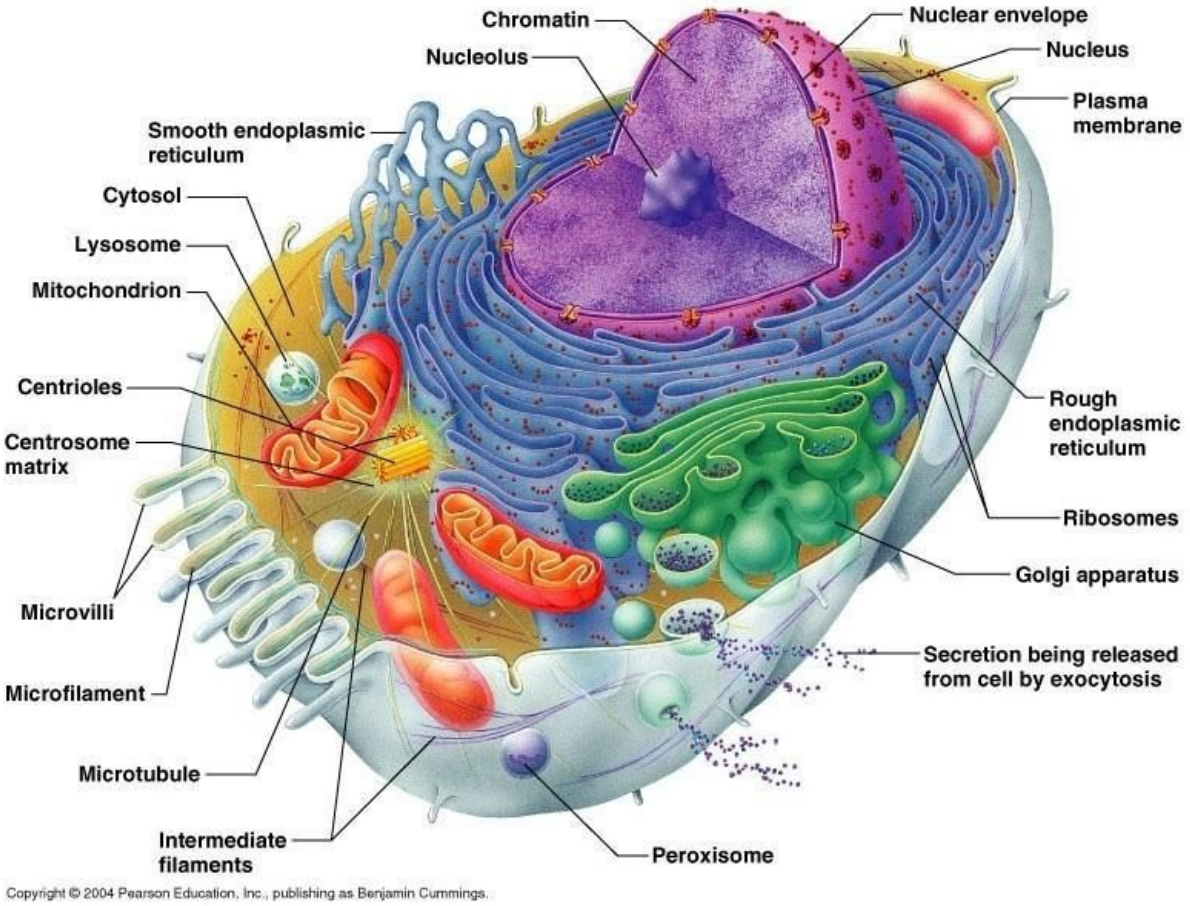
Image source: igb.illinois.edu

Cell Structure

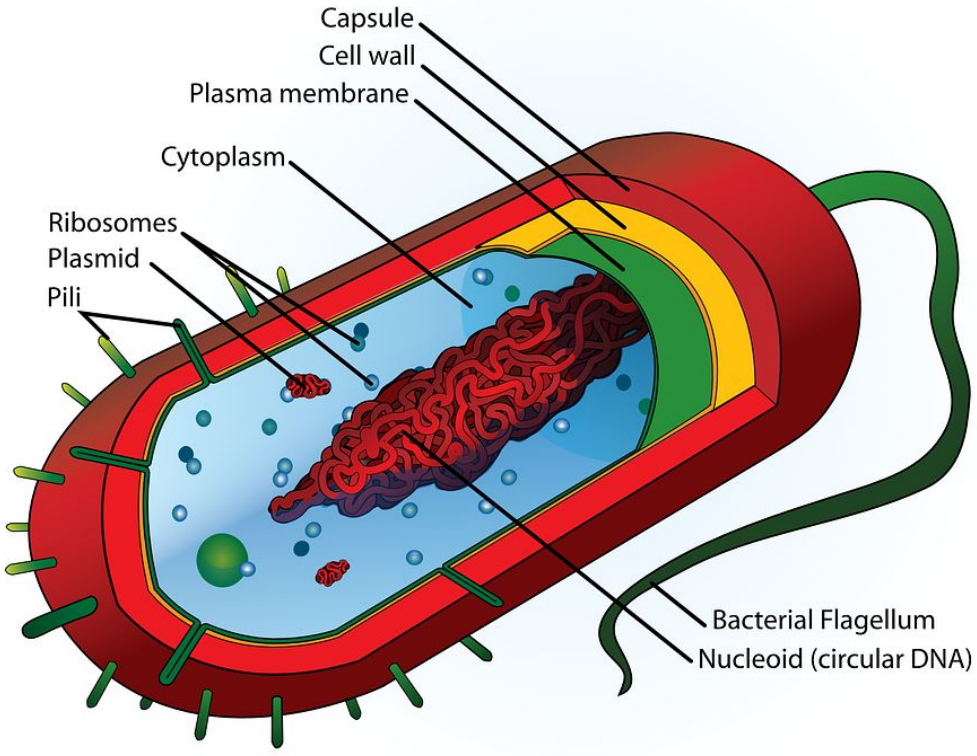
All living organisms are made of cells. In multicellular organisms, cells are organised into **tissues**, tissues into **organs** and organs into **organ systems**. There are several different types of cells; some of them share common features. Humans are made up of **eukaryotic cells**, which contain a **nucleus** and **membrane-bound organelles**. A more detailed structure of a cell, called the **ultrastructure**, can be observed using a microscope.

Ultrastructure of eukaryotic cells:

- Nucleus – surrounded by a **double membrane** called the envelope, which contains pores enabling molecules to enter and leave the nucleus. The nucleus also contains **chromatin**, and a **nucleolus**, which is the site of **ribosome production**.
- Rough Endoplasmic Reticulum – a series of **flattened sacs enclosed by a membrane** with ribosomes on the surface. The RER **folds and processes proteins** made at the ribosomes.



- Smooth Endoplasmic Reticulum – a system of **membrane-bound sacs**. The SER **produces and processes lipids**.
- Golgi Apparatus – a series of fluid-filled, flattened and **curved sacs** with **vesicles** surrounding the edges. The Golgi apparatus **processes and packages proteins** and lipids. It also produces lysosomes.
- Mitochondria – usually oval shaped and bound by a **double membrane** called the envelope. The inner membrane is folded to form projections called **cristae**, with matrix on the inside containing the enzymes needed for cellular **respiration**.
- Centrioles – **hollow cylinders** containing a ring of microtubules arranged at right angles to each other. Centrioles are involved in **cell division**.
- Ribosomes – composed of two subunits. The site of **protein synthesis**.



- Lysosomes – vesicles, containing **digestive enzymes**, bound by a single membrane.

Ultrastructure of prokaryotic cells, such as bacteria:

- Cell Wall – the cell's rigid outer covering made of **peptidoglycan**. Provides the cell with **strength and support**.
- Slime Capsule – protective slimy layer which helps the cell to **retain moisture** and **adhere** to surfaces.
- Plasmid – circular piece of DNA.

- Flagellum – a tail-like structure which **rotates to move** the cell.
- Pili – hair-like structures which attach to other bacterial cells.
- Ribosomes – composed of two subunits. The site of **protein synthesis**.
- Mesosomes – **infoldings** of the inner membrane which contain **enzymes required for respiration**.

The bacterial cell wall

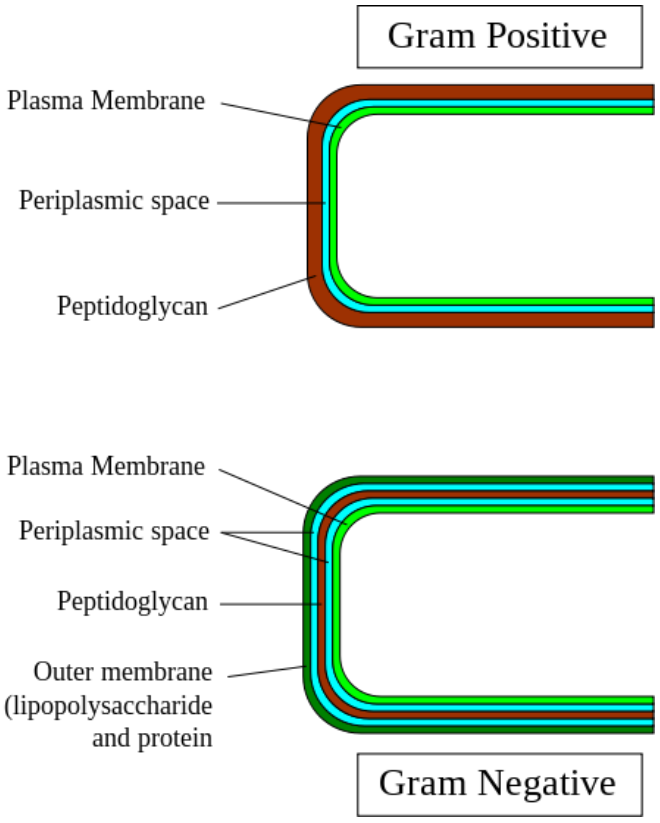


Image source: wikidoc.org

Bacteria can be classified according to their **shape** and their reaction to **Gram stain.**

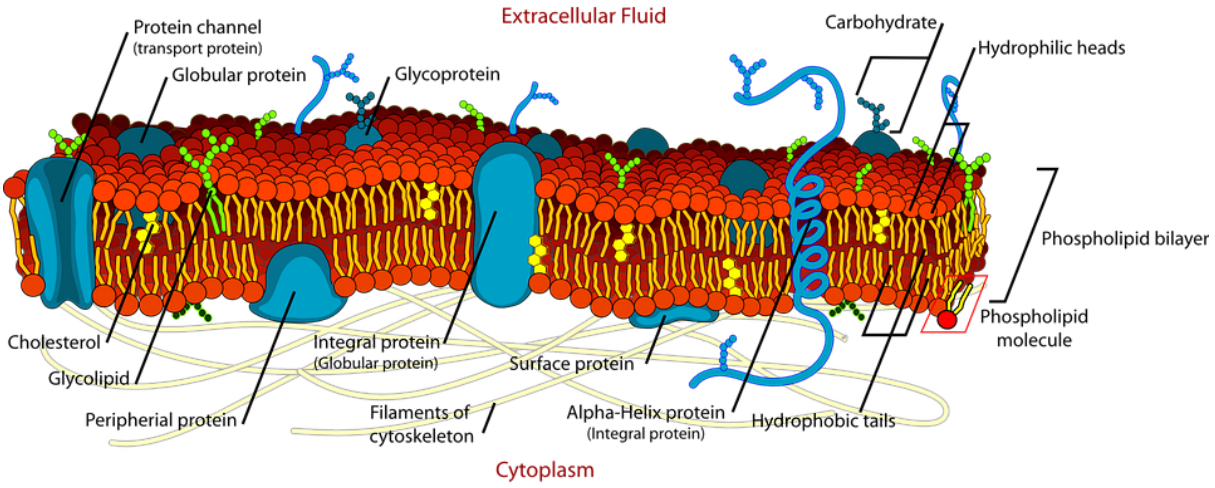
There are two types of bacteria, **Gram positive and Gram negative**.

Gram Positive bacteria have cell wall comprised of a thick layer of **peptidoglycan**. Gram Negative bacteria have a thin layer of peptidoglycan with an **outer lipopolysaccharide membrane**.

Gram staining occurs as following: firstly, **crystal violet** is used to stain over a fixed culture. After a minute, the stain is poured off and the slide is rinsed with water. Subsequently, **iodine solution** is added and removed after a minute. Alcohol is then added.

Lipopolysaccharides are soluble in alcohol, whereas peptidoglycan is not, so gram negative bacteria are **decolourised**. The final step of the procedure is **counterstaining with red safranin** for another minute. The sample is then dried and examined. Gram positive bacteria is **violet/purple** under the microscope whereas Gram negative bacteria appears **red.**

Biological Membranes



All cells and organelles are surrounded by a partially permeable membrane composed of a sea of phospholipids with protein molecules between the phospholipid molecules. The main function of the membrane is controlling the movement of substances in and out of the cell/organelle. However, it also contains receptors for other molecules such as hormones and enables adjacent cells to stick together. The fluidity of the membrane and the mosaic arrangement of the protein give the structure of the membrane its name – **fluid mosaic model**.

The movement of molecules through cell membrane depends on the properties of the molecule as well as the requirements of the cell. There are several types of movement:

- **Diffusion** is the passive movement of small, non-polar lipid soluble molecules such as carbon dioxide and oxygen from an area of high concentration to an area of low concentration. The molecules move directly through the phospholipid bilayer.

- **Facilitated diffusion** requires a **channel protein** in the cell membrane to transport polar molecules, charged and water-soluble molecules across the membrane.

- **Osmosis** is the diffusion of water molecules from an area of low solute concentration to an area of high solute concentration through a partially permeable membrane.

- **Active transport** can transport all types of molecules through carrier proteins from an area of low concentration to an area of high concentration. However, this process requires energy in the form of ATP.

- **Exocytosis** and endocytosis transport large particles. The particles are enclosed in vesicles made from the cell surface membrane and transported into the cell in endocytosis. In exocytosis, vesicles containing large particles are fused with the cell surface membrane.

The rate of **gas exchange** by diffusion becomes more rapid as:

- **Surface area** of the surface increases
- **Diffusion distance** decreases
- **Diffusion gradient** becomes more steep

2.1.2 Water and its importance to plants and animals

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

- Water is a **polar molecule** due to **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.

- 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** in which many metabolic reactions occur .

- It has a **high specific heat capacity** meaning that a lot of energy is required to warm water up therefore **minimising temperature fluctuations** in living things therefore it acts as a **buffer.**

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

- There is **strong cohesion** between molecules enables effective transport of water in tube like transport cells as the **strong cohesion supports columns of water** (capillary action), as a result of strong cohesion **the surface tension at the water-air boundary is high**.

Water potential is the **pressure exerted by water molecules that are free to move in a system**. It is measured in **kPa**. Pure water has a water potential of 0 pKa, the higher the water potential the larger the number of water molecules that are free to move. **A solution's water potential falls as solutes are added** as water molecules cluster around the solute. The contribution of solute to the water potential is called the **solute potential.**

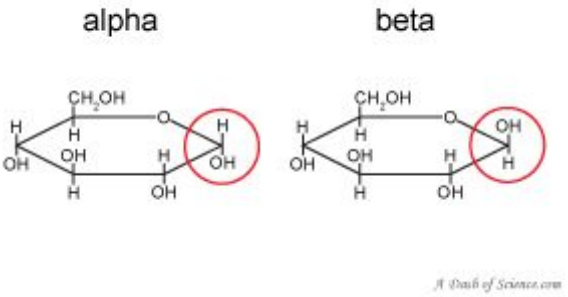
Hydrolysis and condensation of biological molecules in cell metabolism

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 monomers joined together. A **condensation** reaction is a reaction which joins monomers by chemical bonds and it involves the elimination of a water molecule.
Hydrolysis is the opposite of condensation and it's 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. There are three types of saccharides - **monosaccharides, disaccharides and polysaccharides**. Monosaccharides can join together to form disaccharides and polysaccharides by **glycosidic bonds** which are formed in **condensation reactions**.



Monosaccharides

Image source: a dash of science.com

Glucose is a monosaccharide containing six carbon atoms in each molecule, it is the main **substrate for respiration** therefore it is of great importance. It has two isomers – alpha and beta glucose with following structures:

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

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 it's 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. 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**

- **Amylose** – amylose is an **unbranched chain** of glucose molecules joined **by 1, 4 glycosidic bonds**, as a result of that amylose is **coiled** and thus it is a very **compact** molecule meaning it can store 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** it is **rapidly digested by enzymes** therefore energy is released quickly.

- **Cellulose** is a component of cells wells in plants and it's 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 joined together by **hydrogen bonds** and they provide **structural support** in plant cells.

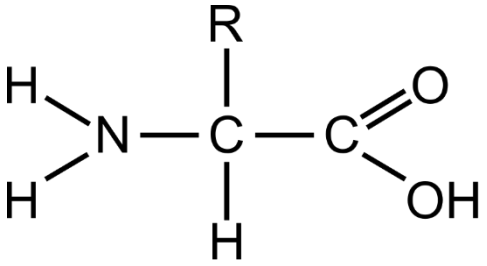
Biochemical tests:

- **Benedict's solution** can be used to test for the presence of **reducing sugars**. Therefore it can be used to test for glucose, fructose, maltose and other sugars but not sucrose. The test involves heating the sugar with Benedict's solution – if the colour changes from **blue to orange** then glucose is present.

- A chemical test for starch is **iodine/potassium iodide**. If the solution turns blue/black in colour then starch is present.

2.1.3 Proteins and enzymes

Proteins



Amino acids are the monomers from which proteins are made. Amino acids contain an amino group – NH2, carboxylic acid group and a variable R group which is a carbon-containing chain. There are 20 different amino acids with different R groups. 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:

- **Primary structure** of a protein is the order and number of amino acids in a protein.

- The **secondary structure** is the shape that the chain of amino acids chains – **either alpha helix** or **beta pleated sheet**. The shape is determined by the type of bonding present such as **hydrogen bonding, ionic bonds and disulphide bridges**.

- **Tertiary structure** of proteins is the 3D shape of the protein, it 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.

The Biuret test can be used to test for the presence of **peptide bonds** in a protein therefore it can be used to detect proteins in food. Firstly, you add an equal volume of Biuret reagent to the sample and observe the colour change. If the solution turns **lilac/purple** then a protein is present. No colour change means that no protein is present in the sample.

Enzymes

Enzymes increase the **rate of reaction** by lowering the **activation energy** of the reaction they catalyse. **Active site** is the area of the enzyme where the reaction with the **substrate** takes place. 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 form a **complex**, 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**.

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, the 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

- **Temperature** – rate of reaction increases up to the optimum temperature which is the temperature enzymes work best at, rate of reaction decreases beyond the optimum temperature

- **Concentration of competitive reversible inhibitors** – as concentration of competitive reversible inhibitors increases,the 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, the rate of reaction decreases as the shape of the enzyme (not the active site) is altered by the inhibitors

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Inhibitors

An **inhibitor** is a substance which slows down or stops a reaction by affecting the **binding of substrate to the enzymes**. Inhibitors can either be **re**versible and **irreversible**.

Examples of **irreversible inhibitors** include **heavy metal ions such** as **mercury and silver** which cause **disulphide bonds** within the protein structure to break, as a result causing the **shape of the active site** to change, thus affecting protein activity. Other examples include **cyanide** which is a nerve gas that covalently binds to the active site, therefore preventing the binding of the substrate.

Reversible inhibitors bind to the active site through **hydrogen bonds and weak ionic interactions** therefore they do not bind permanently. Reversible inhibitors can either be **competitive or non-competitive.**

Competitive inhibitors are similar in structure to the substrate molecule therefore they **bind to the active site of the enzyme**, decreasing its activity as they compete with substrate for the enzyme. The **amount of product formed remains the same**, however the rate at which

product formation occurs decreases. The higher the concentration of competitive inhibitor the lower the reaction rate. Increasing the substrate reverses the effect of competitive inhibitors by outcompeting them.

Non-competitive inhibitor does not bind to the active site, it **binds at another site on the enzyme known as the allosteric site.** Binding of the non-competitive inhibitors **changes the shape of the active site therefore preventing the binding of the substrate**. Increasing the concentration of substrate has no effect on non-competitive inhibition.

Many **drugs** are inhibitors. Examples include **penicillin** which is used to fight bacterial infections, it is an inhibitor of enzyme **transpeptidase** which plays an important role in cell wall formation. Other examples include Ritonav**ir** which is an antiretroviral drug used to treat HIV which inhibits HIV protease which is responsible for assembly of new viral particles and spread of infection.

Coenzymes

A **cofactor** is a **non-protein compound** required for the enzyme's activity to occur. There are three types of cofactors: **coenzymes, activators and prosthetic groups**.
Coenzymes are organic cofactors which do not bind permanently. They **facilitate the binding of substrate to enzyme.** Many of coenzymes are **vitamin derived**, examples include **NAD derived from niacin**, which acts as a **hydrogen acceptor**.
Activators are **inorganic metal ions** which temporarily binds to the enzyme and alters its active site, making the reaction more feasible. For instance, **magnesium ion** is an important activator which is involved in processes such as **shielding negative charge**.
Prosthetic groups are organic molecules which are permanently attached to the enzyme. For instance, **haemoglobin contains a prosthetic haem group** which contains iron, permanently bound to the molecule, which serves as a means of binding oxygen.

2.1.4 Nucleic Acids

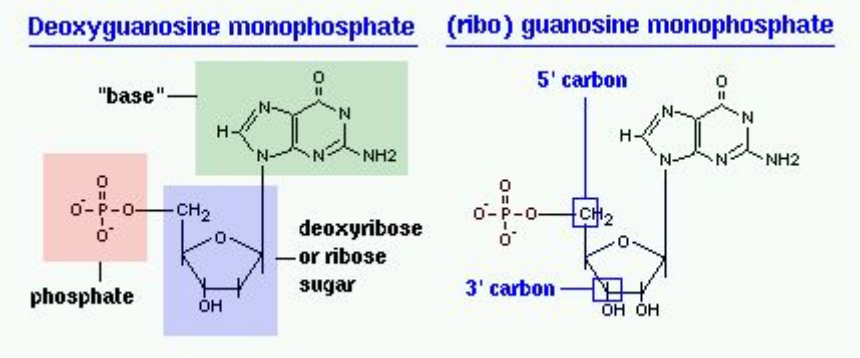

Image source: wikibooks.org

Both **DNA** and **RNA** carry information, for instance DNA holds genetic information whereas RNA then transfers this genetic information from DNA to **ribosomes** made of 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, a phosphate group and one of the organic bases adenine, cytosine, guanine or thymine.**
- The components of an **RNA** nucleotide are **ribose, a phosphate group and one of the organic bases adenine, cytosine, guanine or uracil**.
- Nucleotides join together by **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 whereas **RNA is a relatively short polynucleotide chain.**

ATP

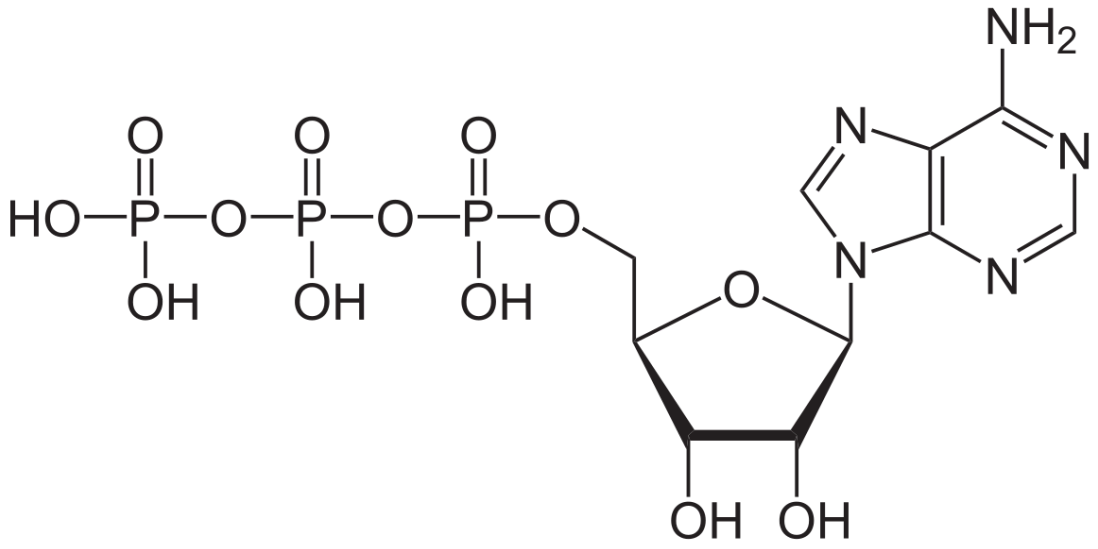

Image source: en.wikipedia.org

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 **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.

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 to the next.

The steps of semi conservative replication of DNA are as following:

- The **double helix unwinds** and the **hydrogen bonds between the complementary bases break** using **DNA helicase** thus separating the two strands of DNA
- One of the strands is used as the **template** and **complementary base pairing occurs** between the template strand and **free nucleotides**
- Adjacent nucleotides are joined by **phosphodiester bonds** formed in condensation reactions using **DNA polymerase**

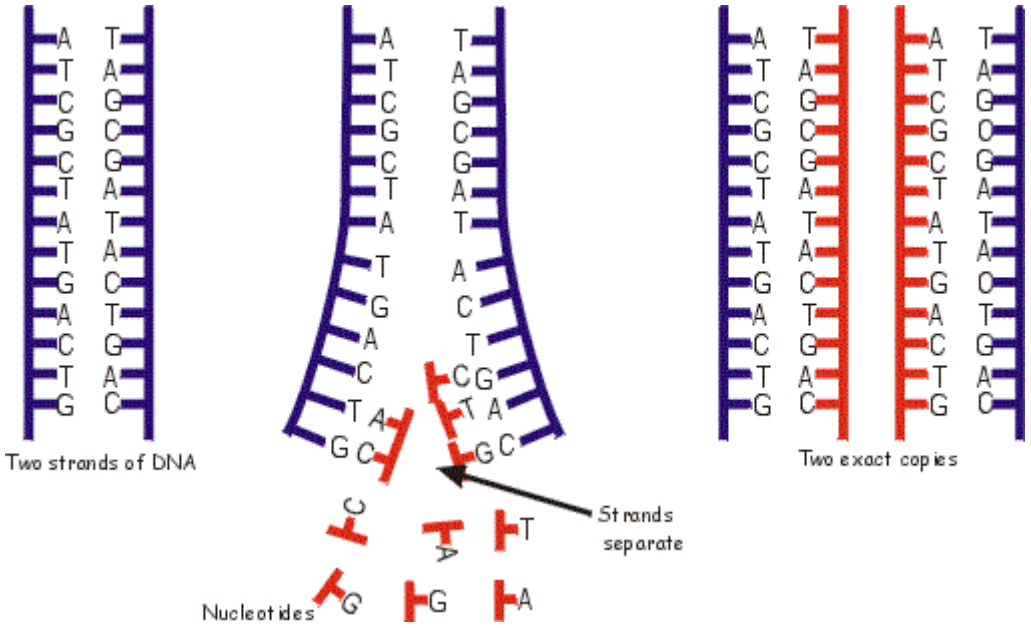

Image source: biology.stackexchange.com

Genetic code

The order of bases on DNA is called the **genetic code** which consists of **triplets of bases**, each triplet of bases codes for a particular amino acids and is known as a **codon**. 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. However, not all the genome codes for proteins – the non-coding sections 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.

- Genetic code is also **degenerate** meaning that more than one triplet codes for the same amino acids, this reduces the number of **mutations** which are mistakes in the base sequence such as **base deletion, insertion or substitution**. A change in the base sequence of DNA alters the amino acid sequence and the protein therefore it can have various effects. Some mutations are harmful such as the mutation which leads to production of sticky mucus and causes cystic fibrosis or sickle cell anaemia in which a mutated form of haemoglobin distorts the shape of red blood cells

- The genetic code contains **start and stop codons** which either start of stop protein synthesis

Protein synthesis

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

Transcription:

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

- The **hydrogen bonds** between the complementary bases break and the **DNA uncoils** thus separating the two strands
- One of the DNA strands is used as a **template** to make the mRNA molecule, the template is called the **antisense strand**
- **Free nucleotides** line up by **complementary base pairing** and adjacent nucleotides are joined by phosphodiester bonds thus forming a molecule of mRNA
- mRNA then moves out of the nucleus through a **pore** and attaches to a **ribosome** in the cytoplasm which is the site of next stage of protein synthesis - called **translation**

Translation:

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

- **mRNA** attaches to a ribosome and **transfer RNA** collects amino acids from the cytoplasm and carries them to the ribosome. tRNA is a **single stranded** molecule with a **binding site** at one end thus it can only carry one type of amino acid, and a **triplet of bases** at the other
- **tRNA** attaches itself to mRNA by **complementary base pairing** – two molecules attach to mRNA at a time
- The amino acids attached to two tRNA molecules join by a **peptide bond** and then **tRNA molecules detach** themselves from the amino acids, leaving them behind
- This process is repeated thus leading to the formation of a **polypeptide chain** until a **stop codon** is reached on mRNA and ends the process of protein synthesis