OCR A Level Biology

A (H420)
Revision Notes for Year 1

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Microscopy

The properties of a microscope are determined by its **magnification** and **resolution**:

- **Magnification**: How many **times larger** an image appears **compared** to the original object's size.
- **Resolution**: The level of **detail** which can be seen in an image.

The table below outlines the different types of microscopes:

Microscope Type	Key Features	Limitations
Optical Microscope	- Cheap, portable, easy to use - Can view live specimens - Stains increase contrast	- Low resolution - Limited magnification
Confocal Microscope	- High-resolution 2D and 3D images - Depth selectivity on thick specimens - Can view live cells	- Expensive - Requires fluorescent tagging
Transmission Electron Microscope (TEM)	- Very high resolution and magnification - Reveals internal structure	- Specimens must be dead - Thin sectioning needed - Requires staining and vacuum
Scanning Electron Microscope (SEM)	- 3D surface images - High magnification and detail	- Specimens must be dead - Requires coating with conductive material - Vacuum environment

Properties of Microscopes

The table below provides an overview of the key properties of each type of microscope:

Type	Magnification*	Resolution	Wavelength	Cost	Ease of Use
Optical	x1500	200 nm	400 - 700 nm	Cheap	Portable and easy
Confocal	x2000	200 nm	400 - 700 nm	Moderate	Less portable and medium
Scanning	x100,000	0.2 nm	0.004 nm	Expensive	Bulky and difficult
Transmission	x500,000	0.2 nm	0.004 nm	Expensive	Bulky and difficult

*These are approximate values most commonly cited in examination materials.

Module 2: Microscopy

Microscopy

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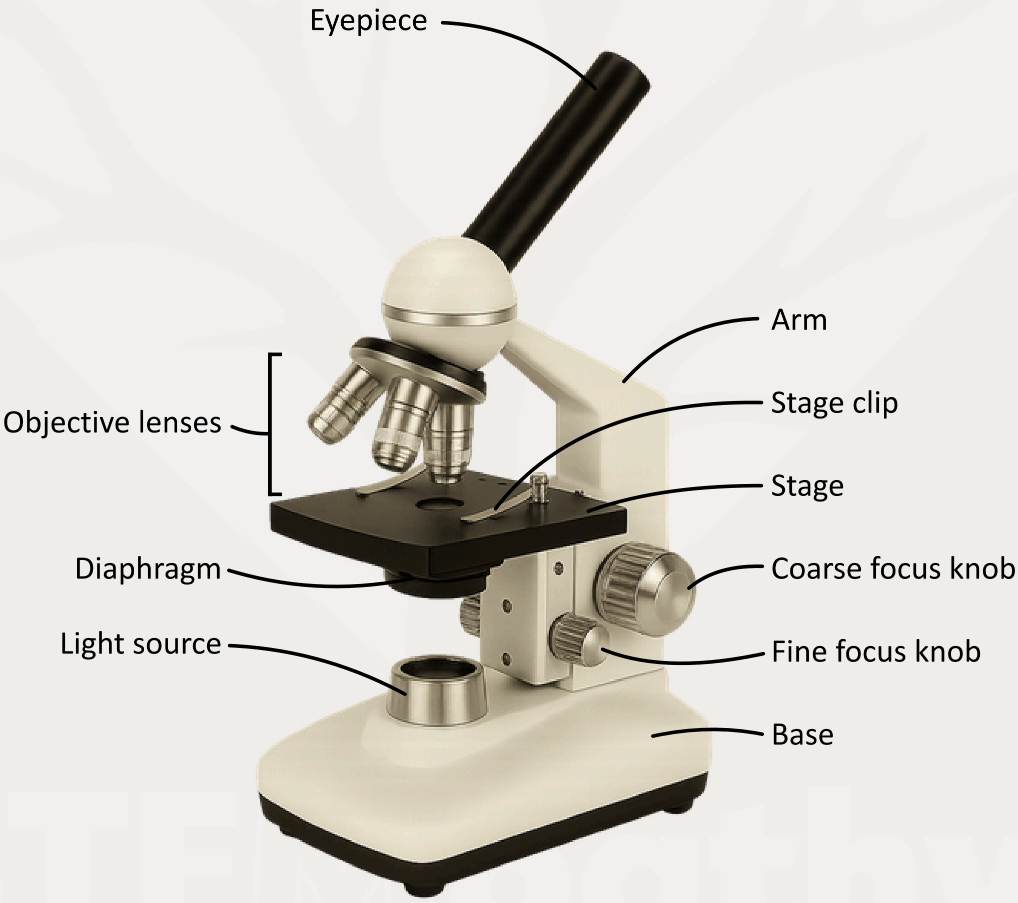
Microscopy Calculations

When using a microscope to look at samples, it is useful to know the:

- **Total magnification**: The overall **magnifying power** of a microscope.
- **Magnification**: The factor by which the **image of an object is increased** compared to its actual size.
- **Actual size**: The **true size** of the object being observed.
- **Image size**: The **measured size** of the magnified object in the image.

Total Magnification (of a Microscope)

If you know the magnification of the **eyepiece lens** and the **objective lens** on your (optical) microscope, then you can calculate its **total magnification**.



Formula:

Total Magnification = Eyepiece Magnification × Objective Magnification

Where:

- Eyepiece Magnification: The magnification of the ocular lens.
- Objective Magnification: The magnification of the objective lens.

Module 2: Microscopy Calculations

Magnification (of an Image)

If you have an **image** produced by a microscope and know the **actual size** of the object, then you can calculate the **magnification**.

Formula:

Magnification = Image Size ÷ Actual Size

Where:

- Image Size: The measured size of the image.
- Actual Size: The real size of the object.

A common mistake, or misunderstanding, is to measure the whole picture, rather than **just** the object of interest within it.

Actual Size

If you know **how many times** an image has been **magnified** and can measure the image of the object, then you can calculate what its **actual size is**.

Formula:

Actual Size = Image Size ÷ Magnification

Where:

- Image Size: The measured size of the image.
- Magnification: The magnification factor used.

Image Size

If you lack the actual image produced by a microscope, but know the **magnification** and the **actual size** of the object of interest, then you can calculate **how big it appears** in the image.

Formula:

Image Size = Actual Size × Magnification

Where:

- Actual Size: The real size of the object.
- Magnification: The magnification factor used.

Module 2: Preparing Microscope Slides

Preparing Microscope Slides

The table below outlines the key steps for the 3 main types of **slide samples**:

Sample Type	Key Steps
Bacterial smear	Air dry → heat fix → Gram stain → rinse → blot dry → apply cover slip
Thin section or smear	Place on slide → add stain → cover slip at angle → blot excess
Living organism	Water drop → add specimen → lower cover slip at angle → avoid bubbles

Staining

Staining enhances **contrast**, making cell structures easier to **identify**.

The table below outlines examples of stains you may encounter:

Stain	Function
Methylene blue	General-purpose stain for making specimens more visible.
Acetic orcein	Binds to DNA and stains chromosomes dark red.
Eosin	Stains cytoplasm.
Sudan red	Stains lipids.
Iodine	Stains cellulose in plant cell walls yellow and starch granules blue/black (appearing violet under the microscope).

Module 2: Preparing Microscope Slides

Bacteria: Gram Staining

Gram staining is a **differential staining** technique; it **distinguishes** between Gram-positive and Gram-negative bacteria based on **differences** in their cell wall structure.

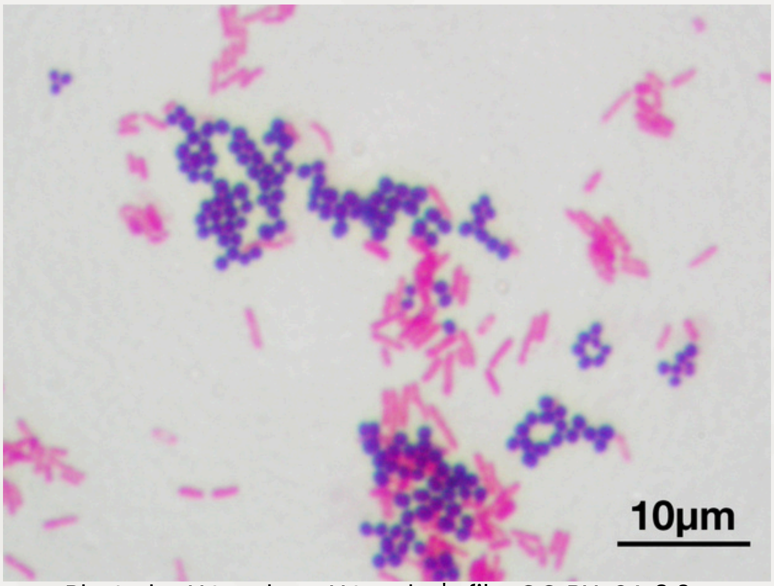


Photo by Y tambe - Y tambe's file, CC BY-SA 3.0

Tissues: Samples and smears

Preparing Smears and Thin Sections:

1. Place the sample directly onto a clean slide.
2. If needed, stain the edge of the sample before applying the cover slip.
3. Lower the cover slip at an angle to prevent air bubbles.
4. Blot away excess stain if required.

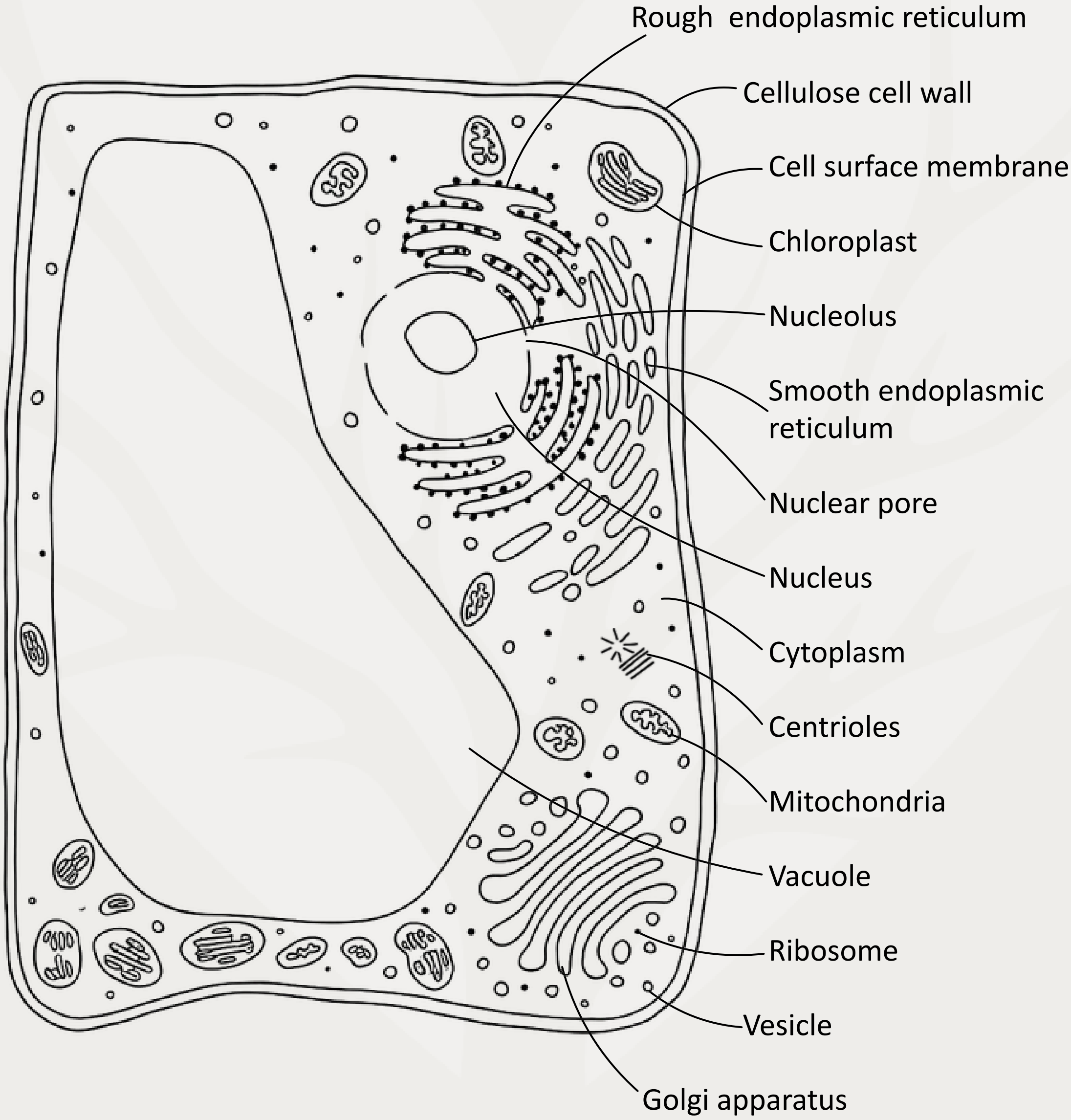
Preparing a Microscope Slide for Living Organisms

Preparing Living Samples (e.g. Amoeba):

1. Add a drop of water to the slide.
2. Add the living organism gently.
3. If appropriate (for small prokaryotic organisms), place the cover slip on carefully and gently to avoid damaging the specimen and prevent air bubbles.

Eukaryotic Cell Structure

The diagram below illustrates generic eukaryotic cell structure.



Membrane-Bound Organelles

The table below outlines the structure and function of **membrane-bound organelles**:

Organelle	Structure	Function
Nucleus	Double membrane (nuclear envelope) with nuclear pores. Contains nucleolus (RNA & proteins).	Stores DNA as chromatin. Controls protein synthesis via mRNANucleolus makes ribosomes.
Rough ER (RER)	Flattened sacs (cisternae) with ribosomes on the surface.	Folds proteins. Transports them via cisternae. Sends them in vesicles to the Golgi.
Smooth ER (SER)	Flattened sacs without ribosomes.	Synthesises lipids, cholesterol, phospholipids, steroid hormones
Golgi Apparatus	Stack of membrane-bound sacs.	Modifies proteins/lipids. Packages them into vesicles for transport.
Mitochondrion	Double membrane. Inner membrane folds to form cristae. Fluid interior is called the matrix.	Does Aerobic respiration to make ATP. Contains its own mDNA. Can self-replicate.
Chloroplast	Double membrane. Stacks of thylakoids (grana). Stroma with enzymes.	Does photosynthesis: Thylakoids: light-dependent*. Stroma: Calvin cycle*. Contains its own cpDNA.
Permanent Vacuole	Large fluid-filled sac (cell sap). Tonoplast membrane.	Maintains turgor pressure for structural support.
Lysosome	Membrane sac with hydrolytic enzymes.	Digests old organelles, pathogens or debris via enzyme breakdown.

*Stages of photosynthesis studied in A2.

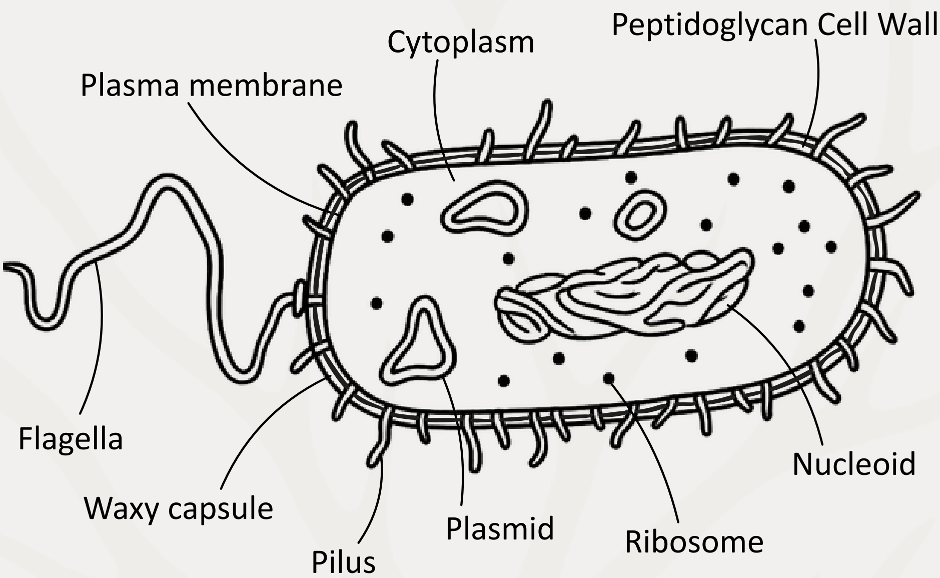
Organelles Without A Membrane

The table below outlines the structure and function of **organelles without membranes**:

Organelle	Structure	Function
Cilia	Short projections from the cell membrane. Made of microtubules from centrioles.	Move substances across the cell surface. Some act as receptors in cell signalling.
Undulipodia	Long cilium.	Moves the whole cell (e.g. sperm).
Ribosome (80s)	Made of RNA & protein. Made of two subunits.	Synthesises proteins from mRNA. Free in the cytoplasm or attached to the RER.
Centrioles / Centrosome	Two microtubule cylinders at a right angle. Centrosome is the centriole & surrounding matrix.	Forms a spindle during cell division. Forms cilia.
Cytoskeleton	Network of protein filaments (microtubules, actin, etc.). Has motor proteins which move along microtubules.	Supports shape and strength. Enables movement of organelles, vesicles and entire cells.Used in cytokinesis. Stabilises tissues. Involved in cell signalling.
Cellulose Cell Wall	Rigid outer layer made of cellulose fibres.	Provides support; maintains shape. Prevents lysis when the cell is turgid.
Chitinous Cell Wall	Rigid outer layer of chitin and proteins.	Provides support; maintains shape. Prevents lysis when the cell is turgid.

Prokaryotic Organisms

P**rokaryotic** organisms are defined by their **lack of membrane-bound organelles**, such as a nucleus. Their DNA, typically in the form of a **single circular chromosome**, is free-floating in the **cytoplasm** in a region called the **nucleoid**.



The table below outlines the cell structures that can be found in prokaryotic cells:

Cell Structure	Structure	Function
Cell Wall	Made of peptidoglycan in bacteria, it varies in Archaea.	Provides mechanical support and protection. Prevents lysis when the cell is turgid.
Cytoplasm	Gel-like substance with dissolved solutes.	Site of metabolic reactions.
Ribosomes (70S)	Made of RNA.	Synthesises proteins from mRNA.
Nucleoid	Region of the cytoplasm with a circular chromosome (naked, no histones).	Contains genes. Controls cell activity via mRNA for protein synthesis.
Plasmids	Small circular DNA loops in the cytoplasm.	Carry extra genes that can be shared via conjugation.
Flagella	Long whip-like structure.	Moves the cell. Enables chemotaxis.
Pili	Short, needle-like protein projections.	Attach to surfaces or other cells. Share plasmids by conjugation.
Capsule	A thick waxy layer outside the cell wall.	Prevents drying out.

Module 2: Organelle Involvement in Protein Synthesis

Protein Synthesis and Organelles

Protein synthesis assembles **amino acids into a polypeptide chain**, which is then **folded and modified into a protein**.

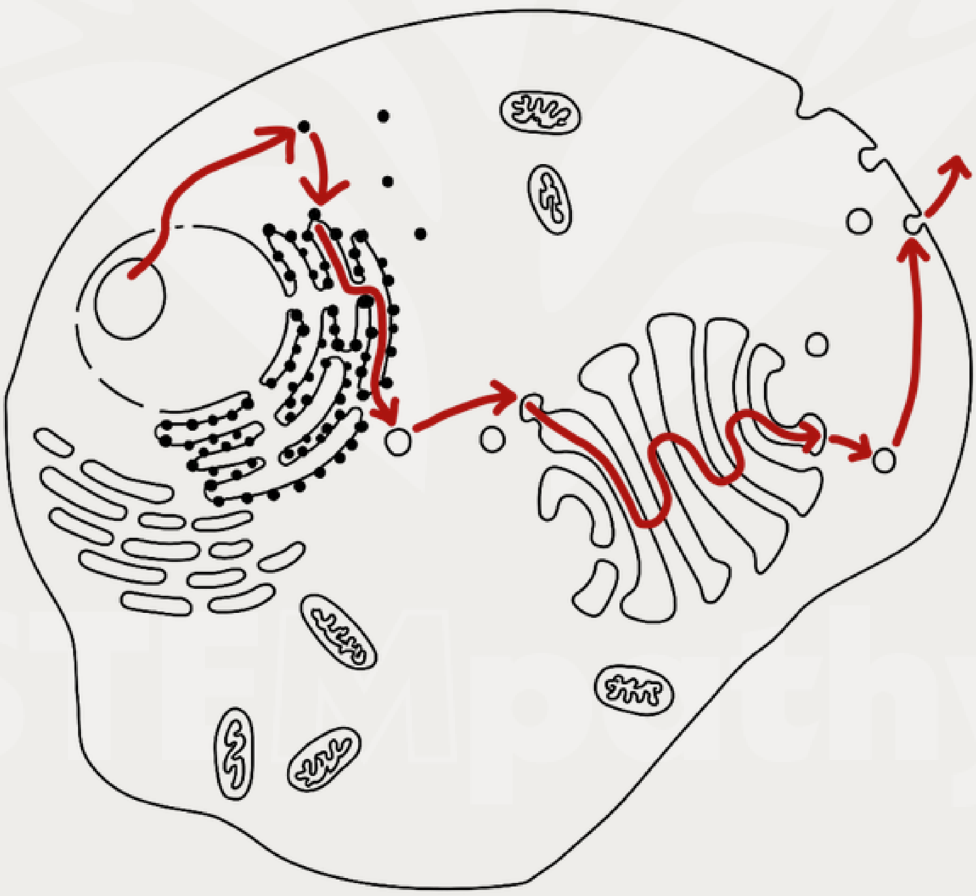
It consists of two phases, **transcription** and **translation**:

- **Transcription** is when a gene is transcribed (copied) to **produce mRNA** (messenger RNA).
- **Translation** is when **ribosomes** make a polypeptide (protein) chain by 'reading' the bases on mRNA to **assemble amino acids** in the correct order.

However, it takes many organelles working together to produce a fully functioning protein.

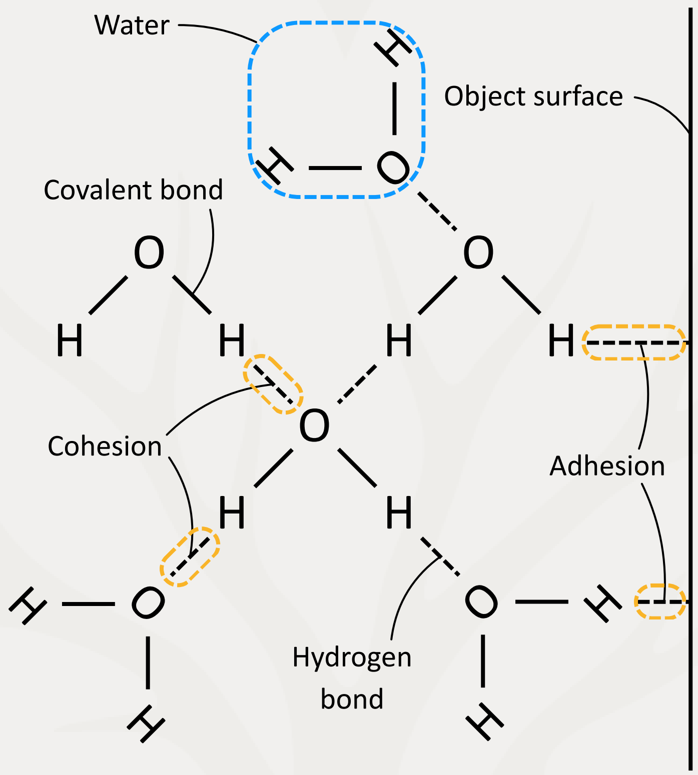
The order of **organelles involved** (usually) is:

Nucleolus → Nuclear Membrane → Ribosome → Rough Endoplasmic Reticulum → Vesicle → Golgi Apparatus → Secretory Vesicle → Cell Surface Membrane



The Biological Importance of Water

Water is **essential** to life as we know it, with unique **properties** arising from its structure. Water molecules are **polar**, which allows them to **form hydrogen bonds** with each other and other important molecules.



Cohesion is where water molecules form hydrogen bonds **among themselves**.

Adhesion is where water molecules form hydrogen bonds with **other molecules**.

The table below outlines the important **properties of water** and their **importance** in biology:

Property	Description	Biological Importance
Density	Ice is less dense than liquid water.	Ice floats, forming an insulating layer, allowing aquatic organisms to survive in stable temperatures.
Solvent	Polar molecule that dissolves ionic and polar substances.	Allows solutes to dissolve in the cytoplasm. Enables transport and metabolic reactions.
High specific heat capacity	Absorbs lots of heat before the temperature rises due to hydrogen bonding.	Stabilises temperature in organisms and environments.
High latent heat of vaporisation	Requires lots of energy to evaporate.	Evaporation removes heat (e.g. sweat, transpiration). Helps cool organisms and regulate body temperature.
Cohesion and adhesion	Water sticks to itself (cohesion) and surfaces (adhesion). Due to hydrogen bonds.	Supports capillary action in xylem. Enables surface tension – lets small organisms walk on water.
Role in metabolism	Reactant in hydrolysis and photosynthesis. Product of condensation reactions and respiration.	Involved in anabolic and catabolic reactions. Medium for reactions and solvent for transport.

Macromolecules

Macromolecules are **large biomolecules**, important to the structure and function of living organisms, made up of **covalently bonded monomers**.

The table below gives an overview of these four groups of biomolecules.

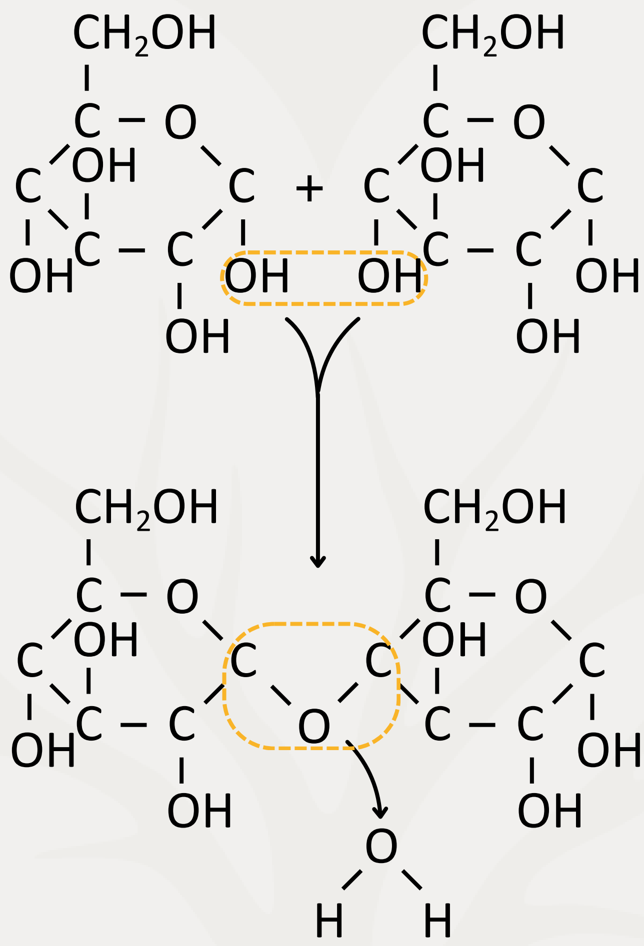
Biomolecule	Elements Present	Monomer	Polymer(s)	Examples
Carbohydrates	C, H, O	Monosaccharides	Polysaccharides	Maltose, Sucrose, Lactose, Starch, Glycogen, Cellulose
Lipids	C, H, O	Fatty acids & Glycerol	Triglycerides, Phospholipids	Phospholipids, Cholesterol, Steroids
Proteins	C, H, O, N, S**most	Amino acids	Polypeptides, Proteins	Collagen, Enzymes, Antibodies
Nucleic Acids	C, H, O, N, P	Nucleotides	DNA, RNA	mRNA, tRNA, rRNA

Monomers are **small molecules** which, when joined to other molecules of the same type, form a **polymer**.

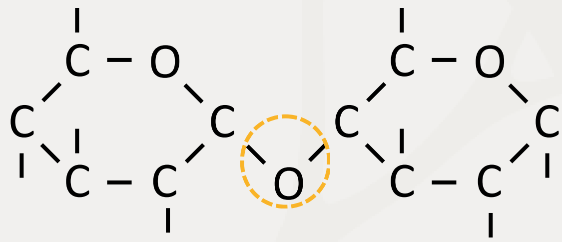
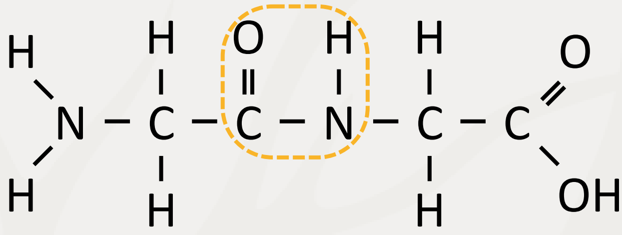
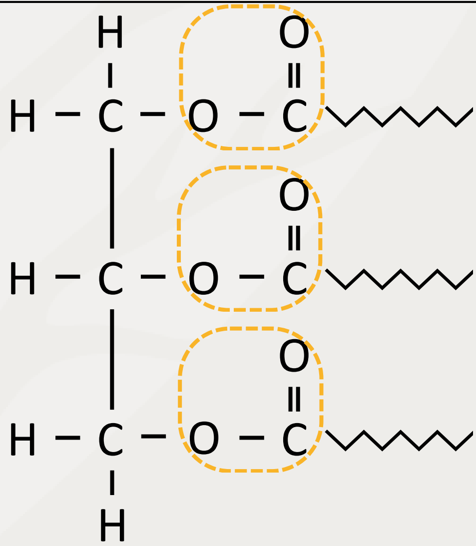
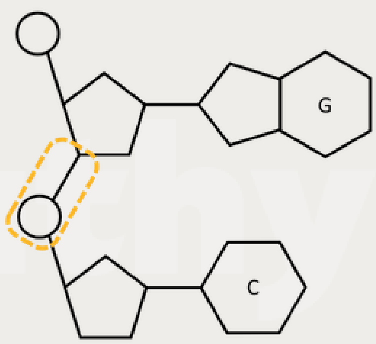
A **polymer** is a large molecule made from **many monomers** joined together in **condensation reactions**.

A **condensation reaction** is when two molecules are **joined** together with a **covalent bond**, forming (and releasing) a **water molecule** in the process.

The diagram below shows a covalent bond (a glycosidic bond) being formed from a reaction between the hydroxyl groups on two different molecules:



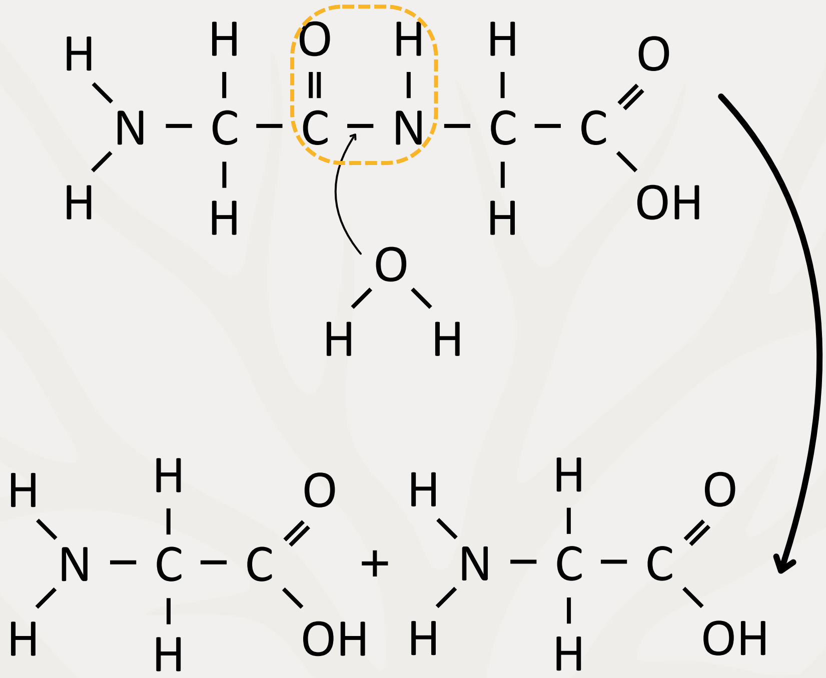
The table below gives an overview of the bonds in biological molecules formed by condensation reactions.

Biomolecule	Monomer	Bond Type	Image
Carbohydrates	Monosaccharides	Glycosidic	
Proteins	Amino acids	Peptide	
Lipids	Glycerol & Fatty acids	Ester	
Nucleic Acids	Nucleotides	Phosphodiester	

Polymers can be **broken down** (digested) into monomers again in **hydrolysis reactions**.

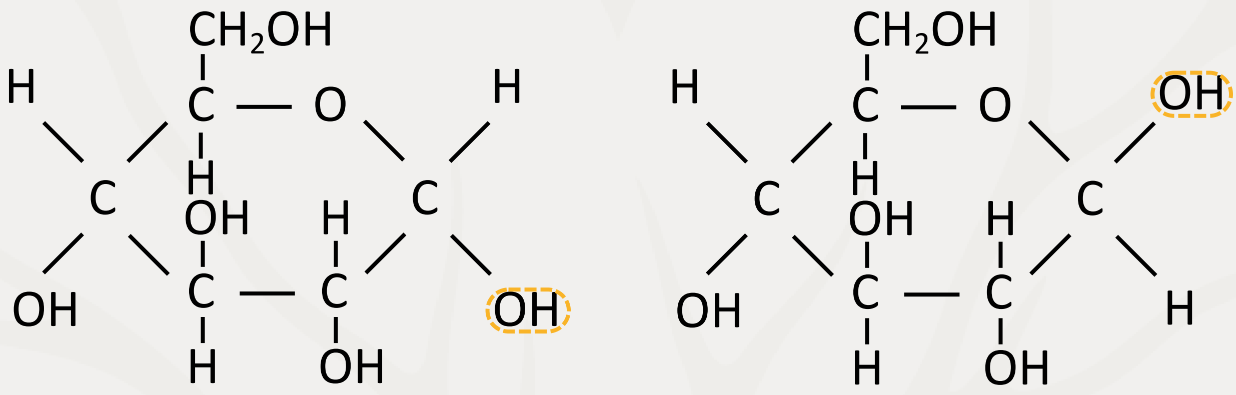
A **hydrolysis reaction** is when a water molecule is used to **break** a **covalent bond**, producing two molecules from one.

The diagram below shows a covalent bond (specifically a peptide bond) being broken in a dipeptide to produce two amino acids.



Carbohydrates

Carbohydrates are a group of biological molecules that are a key source of **energy** and have structural roles in both animals and plants; **glucose** is one of the most important. **Glucose** comes in **two forms** (isomers) called α (alpha) glucose and beta (β) glucose.



Alpha-glucose   Beta-glucose

Monosaccharides

Monosaccharides are individual **sugar monomers**, such as glucose.

The table below outlines some of the most **common monomers** used to build larger carbohydrates:

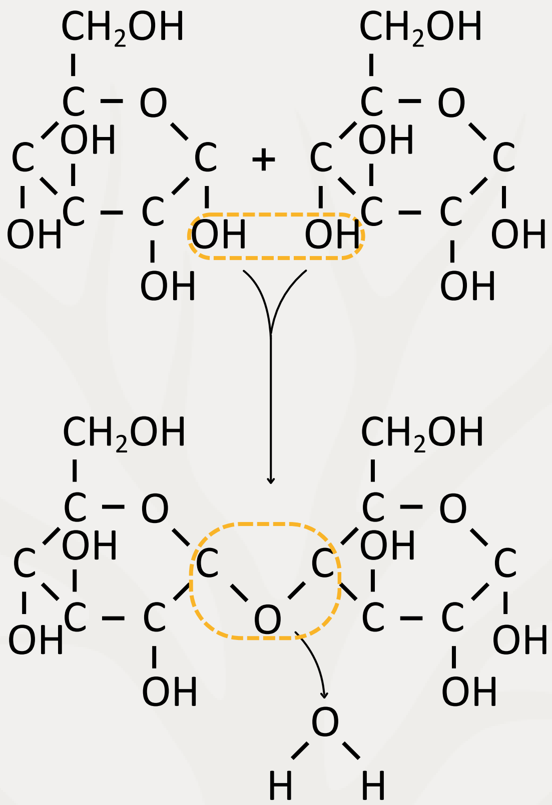
Monosaccharide	Molecular Formula	Type	Use
α-Glucose	$C_6H_{12}O_6$	Hexose	Energy source and primary respiratory substrate.
β-Glucose	$C_6H_{12}O_6$	Hexose	Energy source, a component of glycolipids and glycoproteins
Ribose	$C_5H_{10}O_5$	Pentose	A component of nucleotides (e.g. ATP, RNA)

All of these monosaccharide monomers are reducing, so they test positive in a Benedict's test.

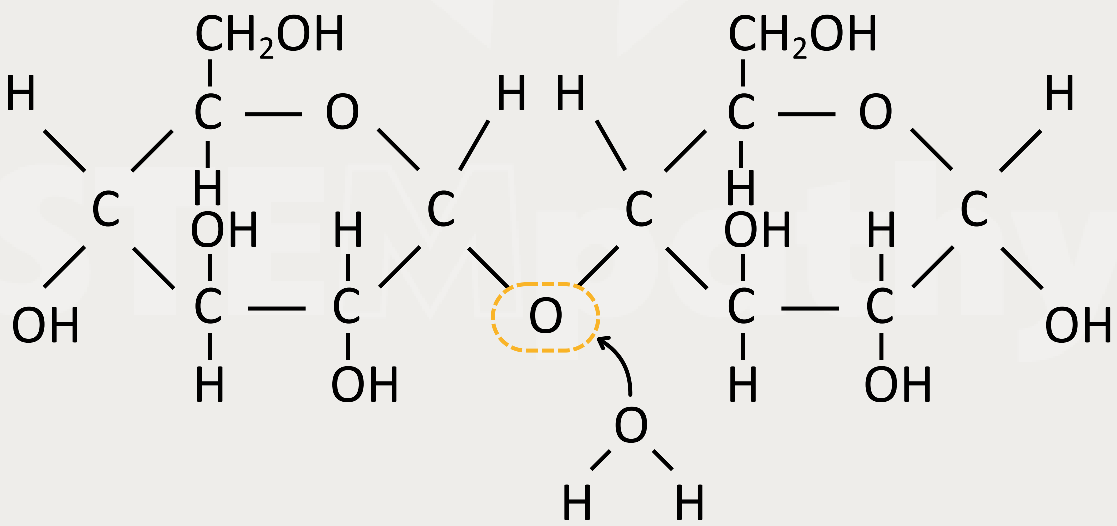
Disaccharide and Polysaccharide Formation

Carbohydrates like disaccharides and polysaccharides are made by joining monosaccharides using **glycosidic bonds**.

Glycosidic bonds form through **condensation reactions** between the **hydroxyl groups** of two monosaccharides, releasing a water molecule as a byproduct.



When carbohydrates are **hydrolysed** (digested), **enzymes** (e.g. amylase or maltase) break the **glycosidic bonds** using water, releasing smaller sugars or monosaccharides.



Maltose

Disaccharides

Disaccharides are two sugar molecules joined together with a **glycosidic bond**.

The table below outlines the most common **disaccharides** formed from monosaccharides:

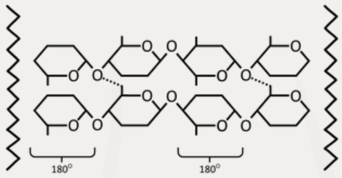
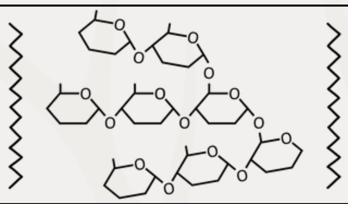
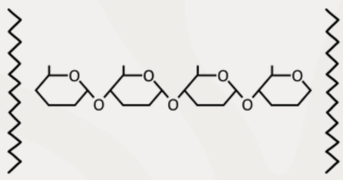
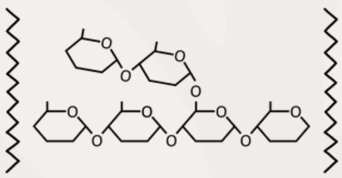
Disaccharide	Monomers joined	Use
Cellobiose	β-Glucose + β-Glucose	Intermediate in cellulose breakdown
Lactose	α-Glucose + β-Galactose	Sugar in milk and an energy store
Maltose	α-Glucose + α-Glucose	Intermediate in starch digestion
Sucrose	α-Glucose + Fructose	Transport sugar in plants

Of these disaccharides, **only sucrose is non-reducing**, so it gives a **negative result** in a **Benedict's test**.

Polysaccharides

Polysaccharides are long chains of **sugar monomers** joined by **glycosidic bonds**.

The table below outlines the structure of the 4 main **polysaccharides**:

Polysaccharide	Monomers	Image	Glycosidic Link	Structure	Compact?
Cellulose	β-Glucose + β-Glucose		1-4	Straight chain with many hydrogen bonds between and within chains.	✗
Glycogen	α-Glucose + α-Glucose		1-4 and 1-6	Coiled (less than starch) and highly branched.	✓
Amylose	α-Glucose + α-Glucose		1-4	Coiled into a spiral, held together by hydrogen bonds.	✓
Amylopectin	α-Glucose + α-Glucose		1-4 and 1-6	Coiled into a spiral held together by hydrogen bonds, but with branches (less than glycogen).	✓

The table below outlines how structure relates to the function of each polysaccharide's use:

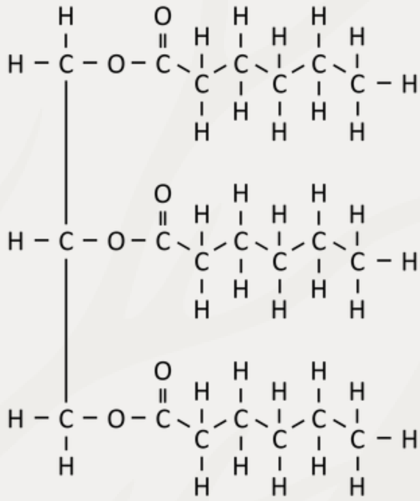
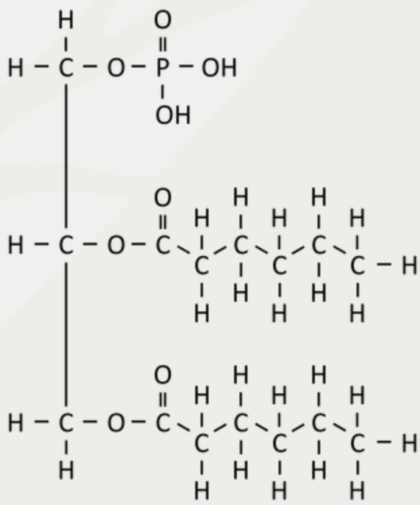
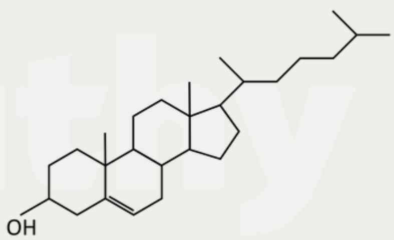
Polysaccharide	Use(s)	How Structure Supports Function
Cellulose	Structural support in plant cell walls	Many hydrogen bonds between fibres provide tensile strength and rigidity.
Glycogen	Energy storage in animals	Compact spiral to store many glucose molecules. 1-6 glycosidic bonds create branches providing many access points for enzymes to release glucose molecules quickly.
Amylose	Long-term (slow-release) energy storage in plants	Compact spiral to store many glucose molecules.
Amylopectin	Energy storage in plants	Compact spiral to store many glucose molecules. 1-6 glycosidic bonds create branches providing many access points for enzymes to release glucose molecules quickly.

Polysaccharides are **broken down** into monomers and disaccharides during **digestion** by **enzymes**, typically to release monomers, which can then be used to **release energy** in respiration.

Module 2: Lipids

Lipids

Lipids are a group of molecules with a wide variety of structures and functions in organisms, but most importantly, they are used in cell **plasma membranes** and for **energy storage** and **thermal insulation**.

Lipid Type	Components	Ester bonds?	Image
Triglyceride	Glycerol + 3 fatty acids	Yes	
Phospholipid	Glycerol + 2 fatty acids + phosphate group	Yes	
Steroid*	Four fused carbon rings	No	

*The OCR A level Biology specification uses cholesterol to represent all steroids.

Lipids are (mostly) **non-polar**, so they are (usually) **insoluble** in water; however, they do dissolve in alcohol.

Fatty acids

Fatty acids are one of the components that make up **triglycerides** and **phospholipids**, the other being glycerol.

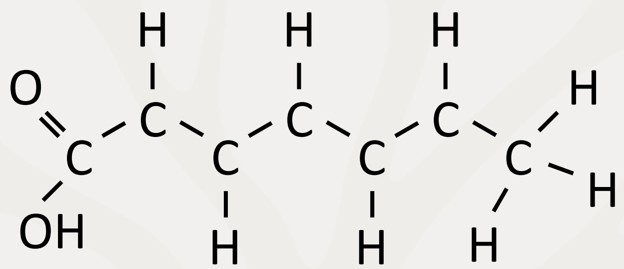
Fatty acids are **not lipids**, but are instead used to make them.

Fatty acids are **long-chain hydrocarbons** with a carboxyl group on one end.

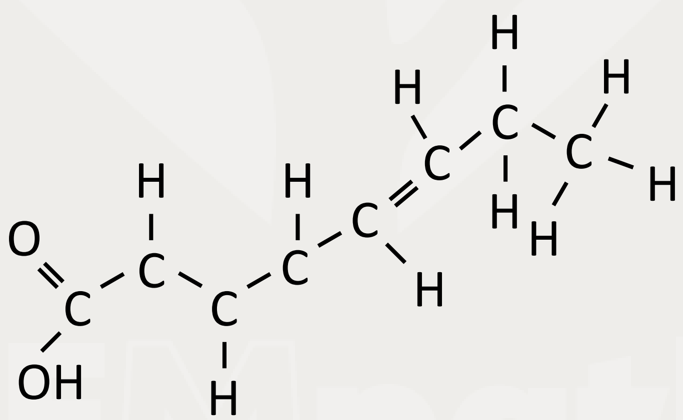
They can either be **saturated** or **unsaturated**.

Saturated fatty acids have no **C=C bonds**, and are a **straight chain**.

Unsaturated fatty acids have at least one **C=C bond**, which causes a **kink in the chain**.



Saturated fatty acid



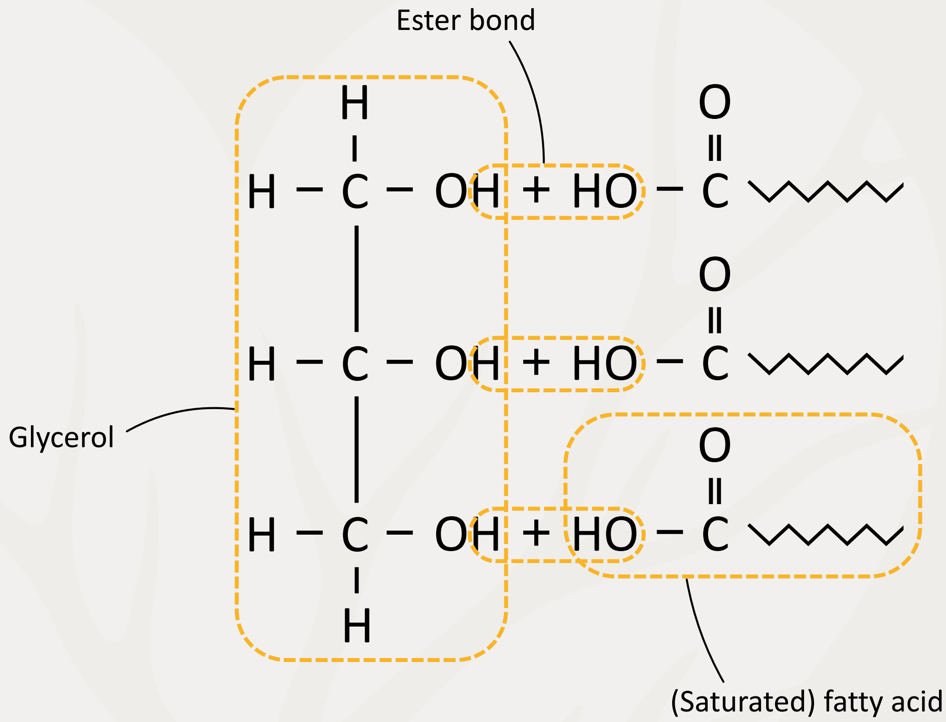
Unsaturated fatty acid

The **more** C=C bonds an unsaturated fatty acid has, the **lower** its melting point.

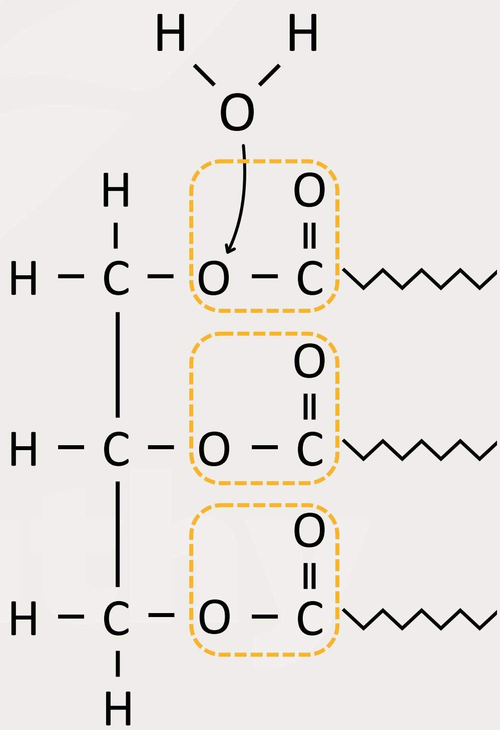
Triglyceride Synthesis

Triglycerides are made by joining **glycerol** to **three fatty acids** using **ester bonds**.

Ester bonds are formed in **condensation reactions** between the **hydroxyl** (–OH) group on glycerol and the **carboxyl** group on a fatty acid. This produces a molecule of water as waste.



When lipids are **hydrolysed** (digested), enzymes such as **lipase** break the ester bonds using water, releasing **glycerol** and **fatty acids**.



Module 2: Lipids

Biological Functions of Lipids

The table below outlines how **structure** relates to the **function** of each **lipid** type's use:

Lipid Type	Use(s)	How Structure Supports Function
Triglyceride	Energy storage, insulation, protection	Hydrophobic and compact. Stores large amounts of energy.
Phospholipid	Forms membranes, emulsifier	Amphipathic: hydrophilic phosphate head and hydrophobic fatty acid tails allow bilayer formation and emulsification of fats in water.
Steroid	Hormones, membrane stability	Small, flat, mostly hydrophobic molecules, so they can diffuse through membranes. Cholesterol fits between phospholipid tails to stabilise membranes.
Wax	Waterproofing and protection	Hydrophobic and solid at room temperature, so it forms protective barriers against water loss or microbial entry.

Lipid **insolubility** is important because they do **not affect water potential**, allowing energy-rich molecules to be stored without significant changes in osmotic balance.

Proteins

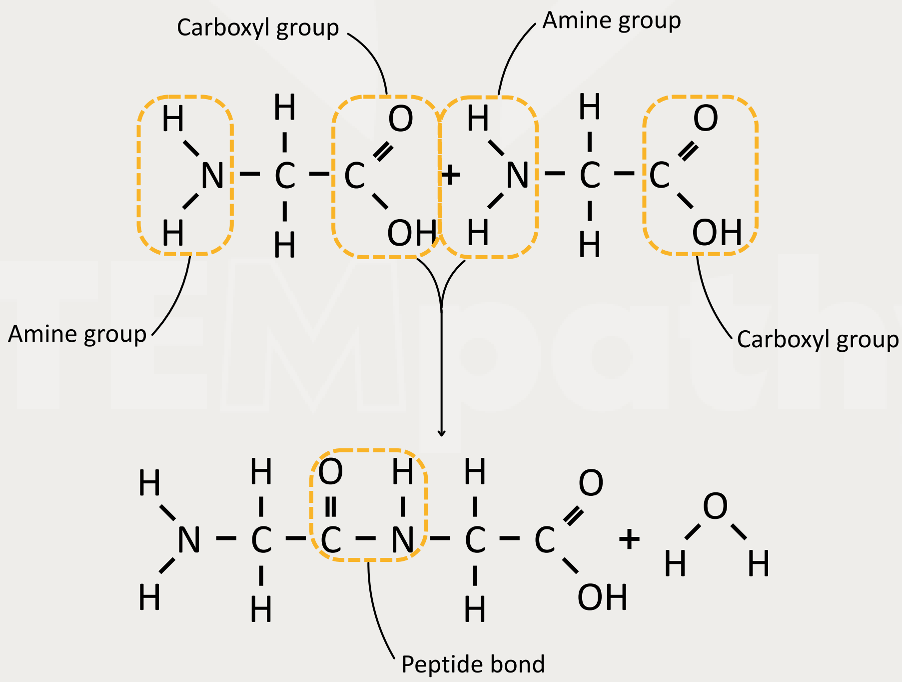
Proteins are important biological molecules with structural and metabolic roles determined by their structure. They can be **enzymes**, **hormones**, **antibodies**, structural scaffolds or transport molecules.

The table below outlines the **structural levels** of a protein:

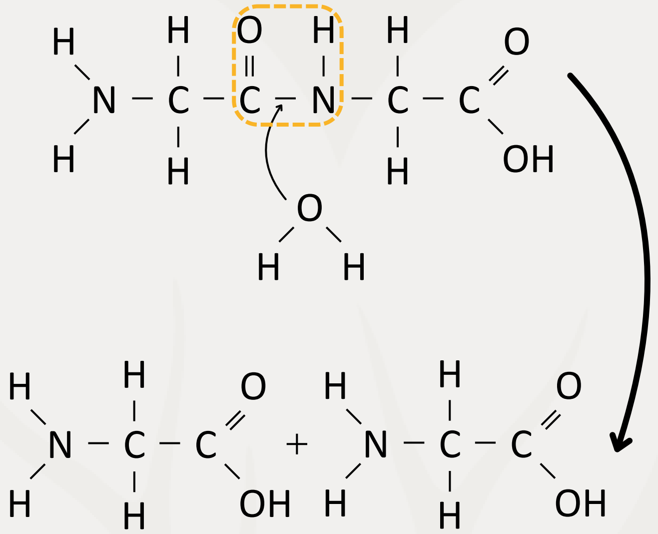
Level	Definition	Structural Bonds
Primary	Order of amino acids in a polypeptide chain	Peptide bonds
Secondary	Coiling and folding of the polypeptide chain into α-helix or β-pleated sheets (zig-zag)	Hydrogen bonds (between different amino acids' -NH and -CO groups)
Tertiary	The 3D shape of the protein, stabilised by interactions between R-groups	- Hydrogen bonds* - Ionic bonds* - Disulfide bridges* - Hydrophobic and hydrophilic interactions
Quaternary	Two or more polypeptide chains associating	- Hydrogen bonds - Ionic bonds - Disulfide bridges - Hydrophobic and hydrophilic interactions

*between different amino acids' R groups.

Proteins are formed in condensation reactions between **amino acids**, forming **peptide bonds** between an amine group on one amino acid and a hydroxyl group on the other.



When proteins are hydrolysed (digested), enzymes (like protease) break the peptide bonds (with water) to break long chains into smaller chains, and may release individual amino acids from the end of a chain.



Fibrous and Globular Proteins

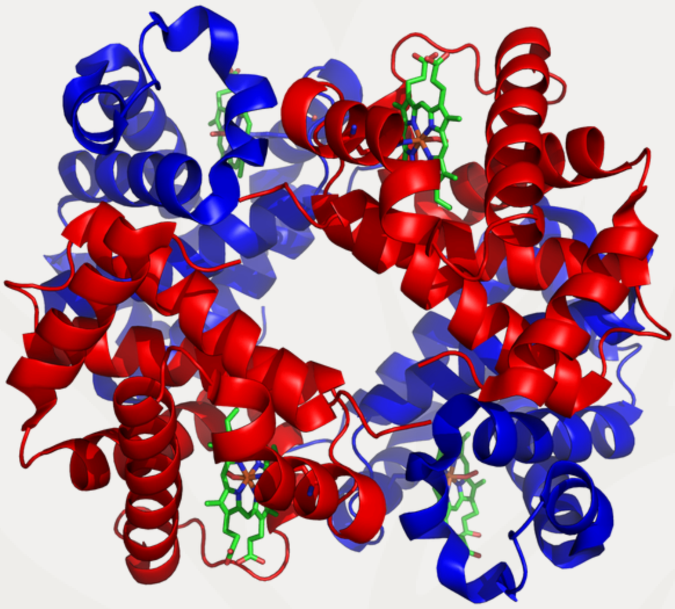
There are **2 types** of protein: **fibrous** and **globular**.

What type of protein a polypeptide chain becomes depends on the properties of its tertiary and quaternary structure.

	Fibrous Proteins	Globular Proteins
Structure	Long, thin, and strong fibres.	Compact spherical structures.
Solubility	Insoluble.	Soluble.
Function	Structural, providing tensile strength and mechanical support.	Metabolic, enzymes, hormones, and transport molecules.
Amino Acid Sequence	Regular, repetitive amino acid sequences.	Irregular amino acid sequences.
Examples	Collagen, elastin, keratin.	Haemoglobin, insulin, pepsin.

Conjugated Proteins

A **conjugated protein** is a protein that is associated with a **prosthetic group** - a non-protein component that is permanently included in the final functioning protein.



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Inorganic Ions

Inorganic ions are **essential** to the maintenance of physical structures and physiological mechanisms in organisms. A **lack** of an inorganic ion can result in **deficiency symptoms** or **diseases**.

Positive ions are called **cations,** and **negative** ions are called **anions**.

The table below lists the common cations:

Name	Symbol
Calcium	Ca^{2+}
Sodium	Na^{+}
Potassium	K^{+}
Hydrogen	H^{+}
Ammonium	NH_4^{+}

The table below lists the common anions:

Name	Symbol
Nitrate	NO_3^{-}
Hydrogencarbonate	HCO_3^{-}
Chloride	Cl^{-}
Phosphate	PO_4^{3-}
Hydroxide	OH^{-}

These inorganic ions will appear throughout the biological processes studied throughout the AS and A level course. You are expected to recognise and recall their symbols.

Chemical Tests for Biomolecules

Biochemical **tests** can either be **qualitative** or **quantitative**.

Qualitative tests only give a **positive or negative** response, allowing you to **identify** a substance.

Quantitative tests allow you to **determine the concentration** of a substance in a solution.

Qualitative Tests

The table below provides an overview of the different qualitative tests for identifying biological molecules:

Chemical	Reagent(s) Used	Positive Result	Negative Result
Biuret Test (Proteins)	Biuret reagent (or NaOH → $CuSO_4$)	Lilac	Stays blue
Benedict's Test (Reducing Sugars)	Benedict's reagent (+ 80°C heat)	Green → Yellow → Orange → Brick-red	Stays blue
Benedict's Test (Non-Reducing Sugars)	HCl (hydrolysis) + $NaHCO_3$ → Benedict's reagent (+ 80°C heat)	Green → Yellow → Orange → Brick-red	Stays blue
Iodine Test (Starch)	Iodine solution	Blue-black color	Yellow-brown (no starch)
Emulsion Test (Lipids)	Ethanol → Water	Cloudy white emulsion	Solution remains clear

Colorimetry

Colorimetry is a **quantitative** method used to determine the **concentration** of a coloured solution by measuring how much **light** is **absorbed** (or transmitted) through a solution.

A **colorimeter** measures how much light (of a specific wavelength) passes through a solution placed in a cuvette.

A blank (usually distilled water) is used to **calibrate** the colorimeter to zero absorbance (or 100% transmission) for **comparison** with the solution being tested.

Colorimetry for reducing sugars

Procedure:

1. Add excess Benedict's reagent to your sample and heat it to 80°C.

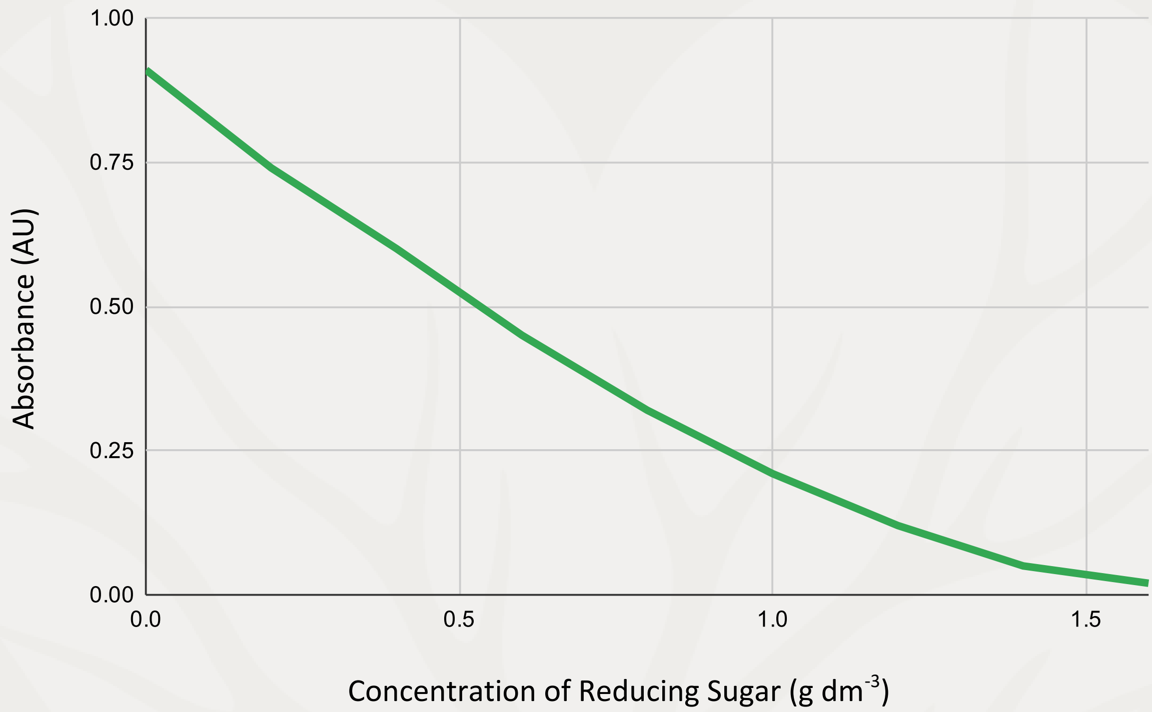
The more reducing sugar present, the more precipitate that forms, and the fewer copper(II) ions remain in solution.

2. Centrifuge the mixture to remove the precipitate.
3. Collect the supernatant (the clear liquid) and place into a cuvette.
4. Calibrate a colorimeter with distilled water (for comparison).
5. Use a colorimeter to measure the absorbance of the supernatant.

Use a red filter (blue Benedict's solution absorbs red light).

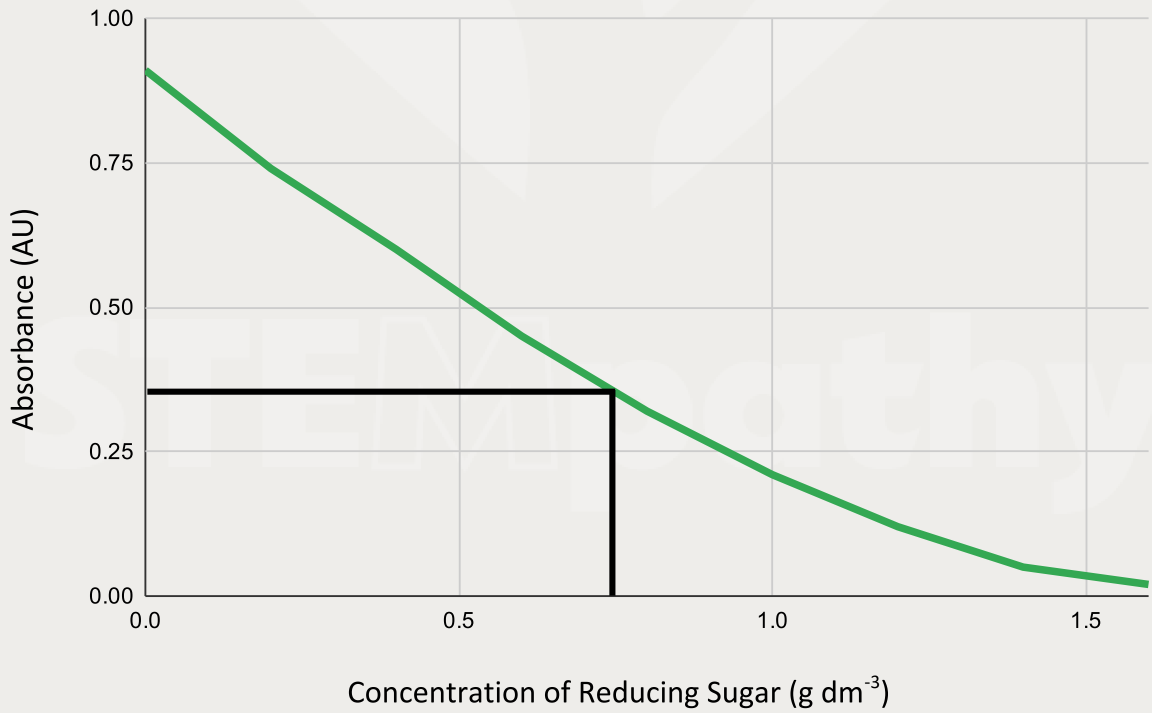
6. Compare absorbance readings to those from solutions of known concentration to create a calibration curve by plotting absorbance vs concentration.

Absorbance (AU) vs Concentration of Reducing Sugar (g dm^{-3})



Less absorbance = higher concentration of reducing sugar.
Then use the graph to find the concentration of unknown samples by interpolation.

Absorbance (AU) vs Concentration of Reducing Sugar (g dm^{-3})



Chromatography

Chromatography is a technique used to **separate** and identify **biological molecules**.

Substances which are **highly soluble** and have a **low affinity** towards the material will travel at a **greater rate** than those with a lower solubility and/or higher affinity.

Larger molecules also move **more slowly** than smaller molecules (of the same solubility and affinity).

The two components used are:

- **Stationary phase**: A paper (cellulose) or TLC plate (plastic covered in silica or aluminium hydroxide).
- **Mobile phase**: A solvent in which the biological molecule is dissolved.

The table below outlines example molecules that can be separated:

Molecule Separated	Use in Biology
Amino acids	Identify components in proteins (e.g. protein digestion analysis)
Carbohydrates (sugars)	Detect the presence and type of sugars in a sample
Vitamins	Separate and identify different vitamins in food samples
Nucleic acids	Used in genetic research to analyse DNA/RNA fragments
Hormones/Drugs	Athletic anti-doping tests

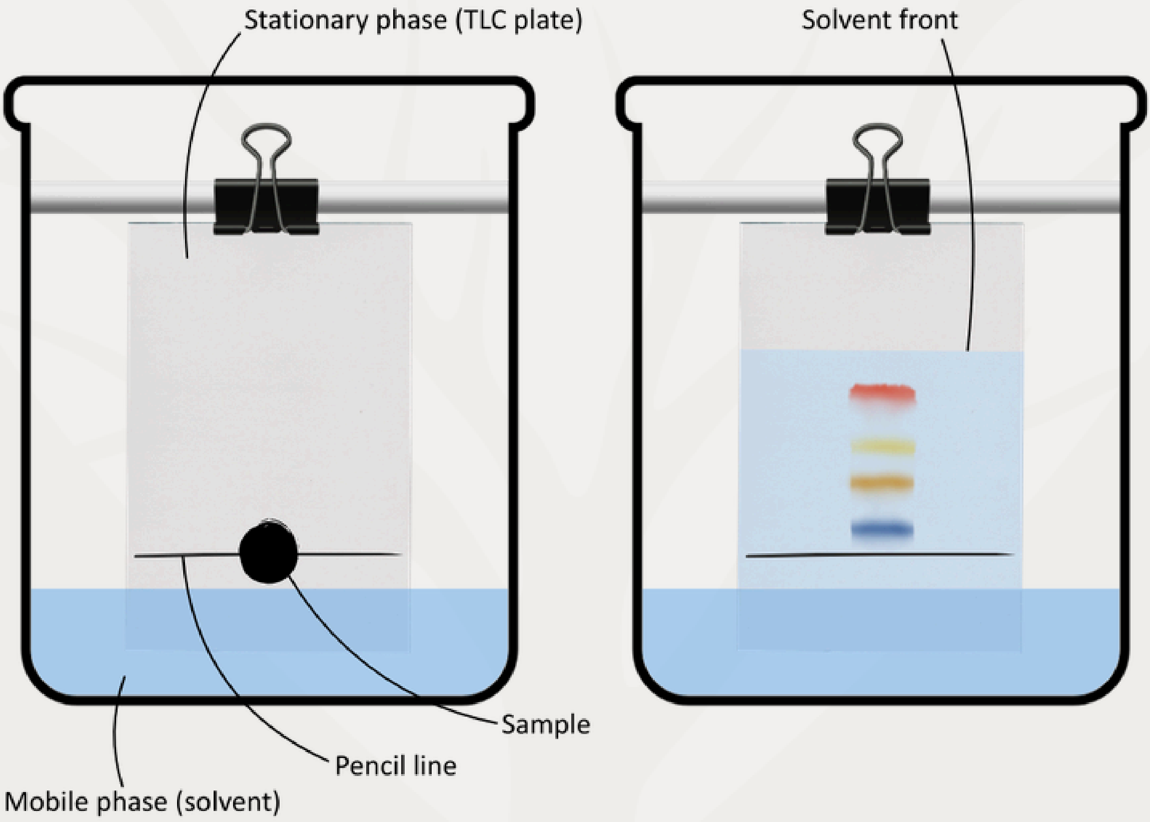
Practical method:

1. A sample is spotted onto a pencil line (used to measure how far substances have travelled) on chromatography paper or the TLC plate.
2. The plate/paper is placed in a solvent (the mobile phase) with the pencil line above the solvent.
3. The solvent moves up the stationary phase via capillary action, coming into contact and dissolving the sample molecules.
4. Sample molecules move upwards and separate out, based on their affinity and solubility.
5. Once the solvent front reaches the top, the chromatogram is removed and dried.
6. Calculate each molecule's Rf value (how much it dissolves into the mobile phase.

Calculating Rf Values:

Rf = Distance moved by the solute ÷ Distance moved by the solvent front

- Distance moved by solute: Measure from the baseline (pencil line) to the centre of the spot.
- Distance moved by solvent: Measure from the baseline to the solvent front (before it dries!).
- Compare Rf values with known standards to identify molecules.



Detecting Colourless Molecules

In GCSE practicals, coloured pigments are typically used to observe the separation of substances, but many biomolecules do **not** have a discernible **colour**.

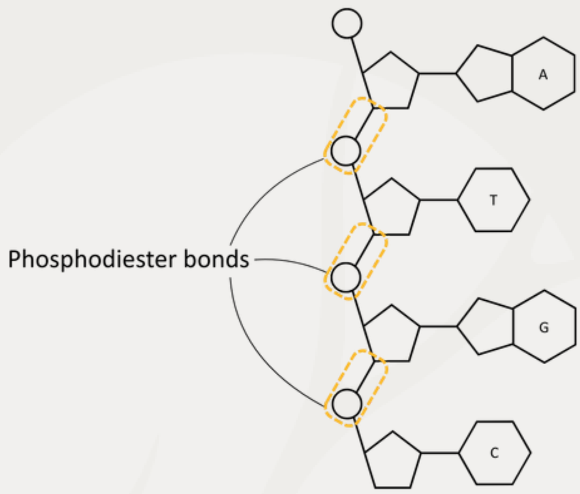
The following treatments make them **visible**:
- **Iodine vapour**: Iodine binds to **organic** molecules, staining them **brown**.
- **Ninhydrin spray**: Reacts with **amino acids**, turning them **brown** or **purple**.
- **Ultraviolet (UV) light**: TLC plates may have a UV-reactive coating. Molecules block fluorescence, revealing **dark spots**.

Module 2: Nucleotides and Nucleic Acids

Nucleic Acids

Nucleic acids are **DNA** and **RNA**, polymers involved in the encoding and transmission of information in biological life.

Nucleic acids are made up of many **nucleotide monomers** joined together by **phosphodiester bonds**.

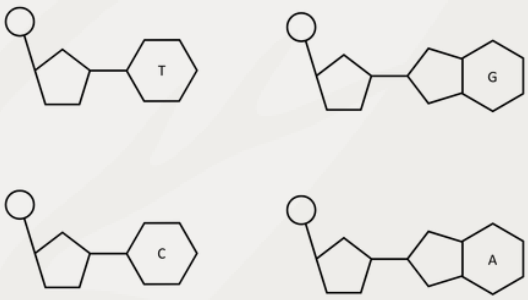


Nucleotides

Nucleotides consist of **three** components:

- A **phosphate group**
- A **pentose sugar**: Deoxyribose (in DNA) or ribose (in RNA)
- A **nitrogenous base**: Adenine, cytosine, guanine, thymine, uracil (in RNA)

The image on the right shows the 4 DNA nucleotides:



There are two types of nitrogenous bases: **purines** and **pyrimidines**.

	Purines	**Pyrimidines**
Bases	Adenine (A), Guanine (G)	Cytosine (C), Thymine (T), Uracil (U)*
Structure	Double-ring	Single-ring

*__Uracil__ is only found in **RNA**, replacing the use of Thymine.

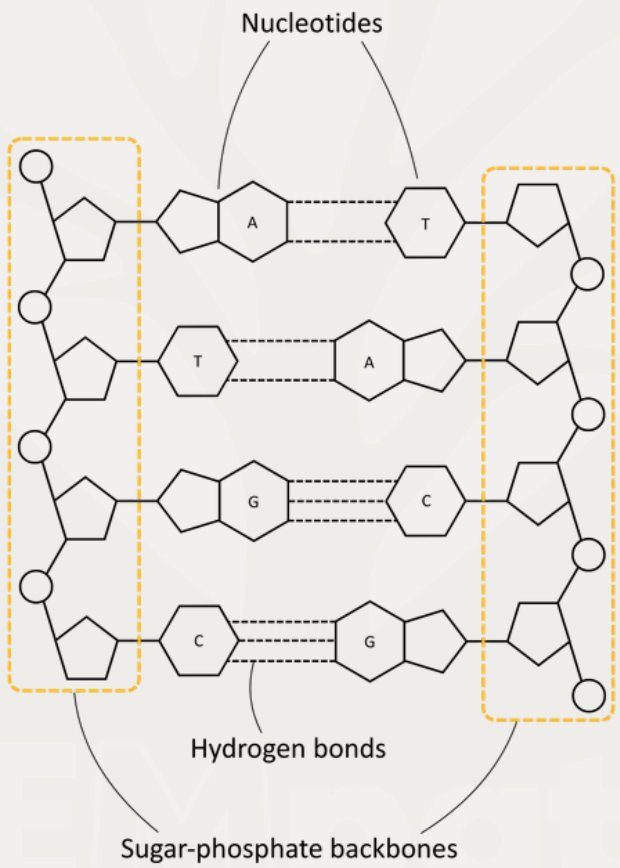
Phosphodiester Bonds

Phosphodiester bonds form in **condensation reactions**, where a molecule of water is lost, joining nucleotide monomers together to form nucleic acid polymers.

Phosphodiester bonds are **broken** in **hydrolysis reactions** (e.g., during digestion or replication) by using water, breaking nucleic acids back down into their nucleotide monomers.

Nucleotides and DNA Structure

Nucleotides form the **sugar-phosphate backbone** of the DNA double helix and in RNA. The **DNA double helix** is formed when **two** DNA strands are joined together by **hydrogen bonds** between their **nitrogenous bases**.



The table below compares and outlines **DNA** and **RNA**:

	DNA	**RNA**
Full name	Deoxyribonucleic acid	Ribonucleic acid
Strands	Double-stranded	Single-stranded
Sugar	Deoxyribose	Ribose
Bases	A, T, C, G	A, U, C, G
Function	Stores genetic information	Transfers and translates genetic information
Structure	Long, double helix	Shorter, varies in shape
Base pairing	A–T (2 H bonds) C–G (3 H bonds)	A–U (2 H bonds) C–G (3 H bonds)
Location	Nucleus (some in mitochondria and chloroplast)	Made in nucleus, functions in cytoplasm
Polymer	Yes	Yes

ATP (Adenosine Triphosphate)

Nucleotides also form **ADP** and **ATP** when they are **phosphorylated**.

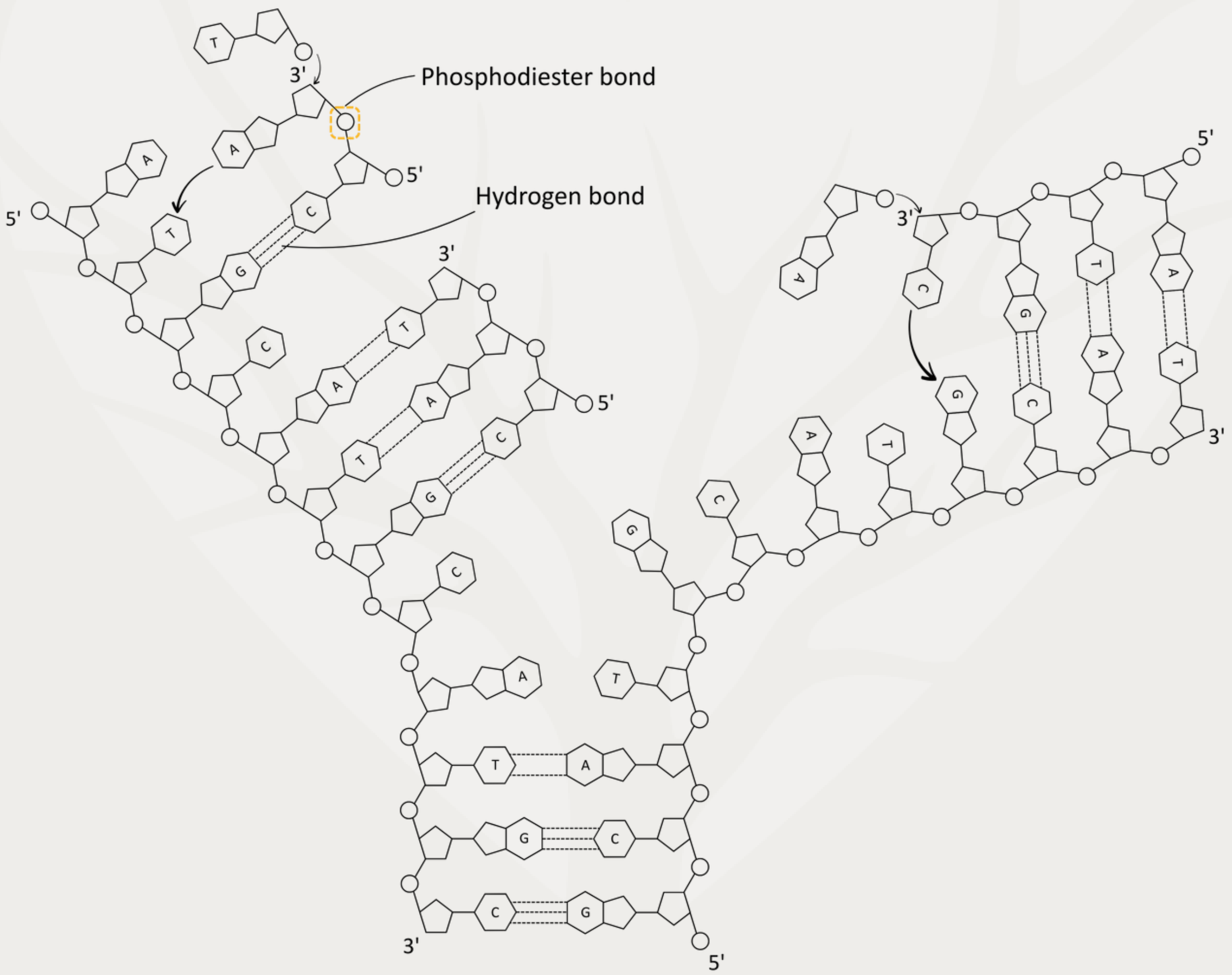
ATP → ADP + Pi + energy

This **releases energy**, which is used for active transport, muscle contraction, metabolic reactions, and more.

DNA Replication

DNA synthesis refers to the assembly of a **new DNA polymer** from nucleotides.

Nucleotides are joined together by **DNA polymerase**, which catalyses condensation reactions between the phosphate groups of adjacent nucleotides in the **5′ → 3′ direction**.



This forms a **phosphodiester bond**, building the sugar-phosphate backbone of the DNA strand.

"5′ → 3′" refers to the orientation of a nucleic acid strand in DNA. The phosphate group on the 5′ carbon of one nucleotide is bonded to the hydroxyl group of the 3′ carbon of the next nucleotide, so the strand is built up from the 5′ end towards the 3′ end.

DNA replication is the process by which an accurate **copy of the DNA** molecule is made during the **S phase** of the cell cycle.

Step-By-Step: DNA Synthesis

1. Nucleotide Formation
Each DNA nucleotide is formed by a condensation reaction between a deoxyribose sugar, a phosphate group, and a nitrogenous base (A, T, C, or G).

2. DNA Unwinding
DNA helicase breaks hydrogen bonds between bases, separating the two strands of the helix.

3. Primer Binding
RNA primers are added to both strands by primase, providing a starting point for DNA polymerase to begin synthesis.

4. Complementary Base Pairing
Free activated nucleotides pair with exposed bases on each template strand:

- A pairs with T
- C pairs with G

5. DNA Polymerase Activity
DNA polymerase adds nucleotides to the 3′ end of the new strand, synthesising in the 5′ → 3′ direction.

It forms phosphodiester bonds between adjacent nucleotides using energy from hydrolysing the extra phosphate groups.

6. Leading Strand Synthesis
On the leading strand (template runs 3′ → 5′), DNA polymerase works continuously in the same direction as the replication fork.

7. Lagging Strand Synthesis
On the lagging strand (template runs 5′ → 3′), DNA polymerase works discontinuously away from the fork, producing short sections called Okazaki fragments.
Each fragment requires a new primer.

8. Joining of Fragments
DNA ligase joins Okazaki fragments by forming phosphodiester bonds, creating a complete and continuous strand.

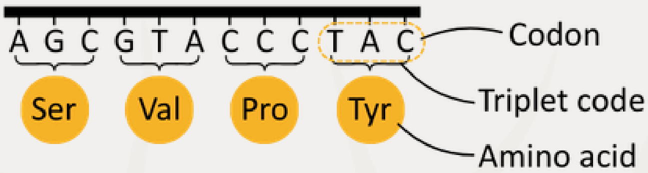
9. Semi-Conservative Replication
Each resulting DNA molecule contains one original strand and one newly synthesised strand - this is semi-conservative replication.

The Nature of the Genetic Code

Genes are **sections** of DNA that **code** for **proteins** (and some code for RNA).

The **order of bases** in a gene **determines** the **sequence of amino acids** in a polypeptide.

These bases are read in **groups of three**; this is known as the **triplet code**, and each group of three bases forms a **codon**.



The key features of the triplet genetic code are that it is **degenerate**, **non-overlapping,** and **universal**.

Property	Description	Biological Importance
Degenerate	64 codons but only 20 amino acids.	Most amino acids have multiple codons. Reduces the impact of point mutations.
Non-overlapping	Bases are read in triplets (codons), each base used once.	Each base affects only one amino acid.
Universal	The same codons specify the same amino acids in almost all organisms.	Evidence for a common evolutionary ancestor.

Protein synthesis

Protein synthesis is when a **ribosome** uses genetic code (from transcription) to **make** a **polypeptide** chain **from amino acids** (during translation).

The table below outlines **transcription** and **translation**:

Process	Location	Purpose
Transcription	Nucleus (in eukaryotes) Cytoplasm (in prokaryotes)	Synthesise a complementary mRNA copy of a gene
Translation	Cytoplasm (on ribosomes)	Read mRNA and assemble amino acids into a polypeptide chain

Transcription

1. The DNA double helix unwinds and the hydrogen bonds between bases break.
2. RNA polymerase binds to the DNA and adds free complementary RNA nucleotides to the DNA bases (A–U, C–G); these are held in place by temporary hydrogen bonds.
3. Phosphodiester bonds form between RNA nucleotides, producing a strand of pre-mRNA that is a copy of the coding strand.

In eukaryotes, this **pre-mRNA** undergoes **splicing**:

- **Introns** (non-coding regions) are **removed**.
- **Exons** (coding regions) are **joined** to form mature mRNA.

In eukaryotes, mRNA must leave the nucleus via a nuclear pore and travel to the **cytoplasm** for **translation**.

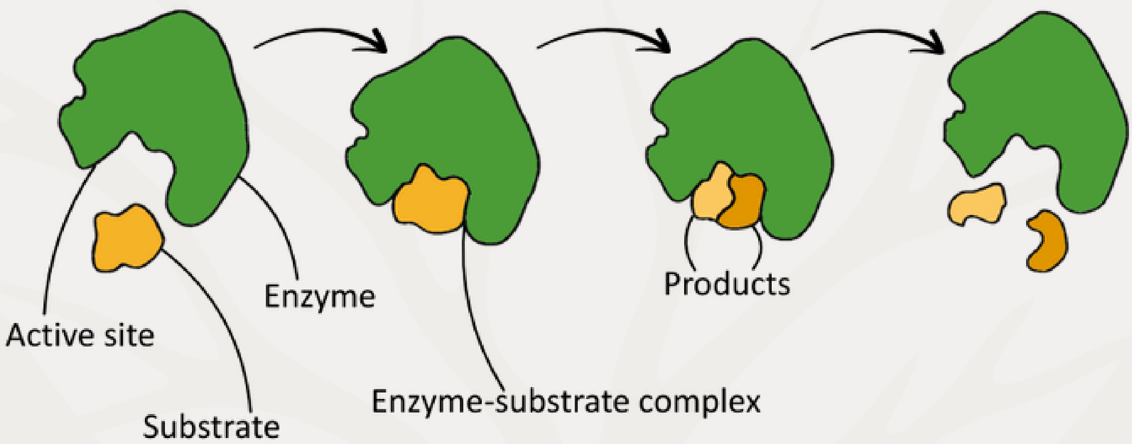
Translation

1. mRNA binds to the ribosome.
2. tRNA brings specific amino acids.
3. The anticodon on tRNA pairs with codon on mRNA via temporary hydrogen bonds.
4. Ribosomes hold tRNA in place (with temporary hydrogen bonds).
5. Ribosome catalyses the formation of peptide bonds between amino acids using energy from ATP.
6. The ribosome moves along mRNA until a stop codon is reached (and then detaches from the polypeptide).

Enzymes

Enzymes are **globular proteins** with a **specific active site** (determined by their tertiary structure) that **catalyse** biochemical reactions by **lowering the activation energy** required.

This **active site** is **complementary** (specific) to a **substrate** with a specific **shape** (or at least substrates similar enough to fit into the active site). This is known as '**enzyme specificity**'.



Enzymes can break apart molecules (catabolism) or join them together (anabolism).

The two examples you need to know about are **amylase** (extracellular) and **catalase** (intracellular):

	Amylase (humans)	Catalase (humans)
Location	Extracellular	Intracellular
Function	Breaks down starch into maltose during digestion	Breaks down hydrogen peroxide (H_2O_2) into water and oxygen; protects cells from oxidative damage
Location (of work)	Mouth and small intestine	Found inside most cells
Produced By	Salivary glands and pancreatic cells	Most aerobic cellsHigh levels in liver and white blood cells
Substrate	Starch	Hydrogen peroxide (H_2O_2)
Products	Maltose	Water and oxygen
Biological Role	Digestive enzyme	Protects against oxidative damage, used to kill pathogens (with oxidative damage)
Optimal pH	~7 (salivary)~6.7–7.0 (pancreatic)	~7
Optimal Temperature	~37°C	~45°C

Enzyme Action: Lock and Key, and Induced Fit

The table below summarises the two models of enzyme action:

Model	Description
Lock and Key	The active site is a perfect fit for the substrate (they are complementary); like a key fitting into a lock.
Induced Fit	The active site undergoes a conformational change (changes shape slightly) to better fit the substrate when it binds. This improves binding and catalysis.

These two models are typically discussed separately and compared, but the induced-fit hypothesis **builds upon** the lock-and-key hypothesis to **improve it**.

The table below summarises the process of enzyme action:

Stage	Description
1. Enzyme + Substrate (E+S)	Substrate collides with the enzyme's active site.
2. Enzyme–Substrate Complex (ESC)	Substrate binds to the enzyme's active site with temporary hydrogen bonds, ionic attractions, hydrophobic interactions and van der Waals forces.
3. Enzyme–Product Complex (EPC)	The enzyme catalyses (anabolism or catabolism) the conversion of substrate into product.
4. Enzyme + Product (E+P)	The product is released from the active site.

Significance of Enzymes

The table below outlines some examples of the **structural** and **functional importance** of enzymes:

Level	Structure	Function
Molecular	Build proteins, nucleic acids, and membranes	Catalyses essential chemical reactions
Cellular	Affects cell wall, cytoskeleton, and organelle shape	Controls respiration, division, and signalling
Tissue/Organ	Shapes connective tissue, cartilage, etc.	Supports digestion, immunity, and nerve function
Organism	Developmental patterning	Growth, anatomical development, and repair

Cofactors

Cofactors are **non-protein** substances that help or enable an enzyme's function by making it **easier** for a substrate to **bind** to the **active site**.

They do this by:
- **Stabilising** charge distribution
- **Helping** substrates bind
- Directly **participating** in the reaction

Cofactors typically bind to the enzyme's active site, or near it, either **temporarily** or **permanently**.

The table below outlines each type:

Type	Description
Cofactor	Inorganic ions that temporarily bind to the enzyme to aid its function.
Cosubstrate	Organic molecules that act like substrates to complete the complementary shape.
Coenzyme	Organic, non-protein molecules derived from vitamins that temporarily bind to the enzyme's active site.
Prosthetic Group	Non-protein group permanently bound to the enzyme (covalently). Essential for enzyme function.

Coenzymes and Vitamins

Organic **coenzymes** are usually derived from **vitamins**, and a **deficiency** in one or more of these impacts **metabolic function** due to the effects of **poor enzyme activity**.

The table below outlines these different vitamins:

Vitamin	Vitamin Name	Coenzyme Derived	Human Deficiency Disease
B_{12}	Cobalamin	Cobalamin coenzymes	Pernicious anaemia (progressive, fatal anaemia)
B_9	Folic acid (Folate)	Tetrahydrofolate	Megaloblastic anaemia (large irregularly shaped erythrocytes)
B_3	Niacin (Nicotinamide)	NAD, NADP	Pellagra (dementia, dermatitis, diarrhoea)
B_5	Pantothenic acid	Coenzyme A	Elevated blood-plasma triglyceride levels
B_1	Thiamine	Thiamine pyrophosphate (TPP)	Beriberi (heart failure, irregular heartbeat, mental confusion, muscular weakness, paralysis)

Pearson's 2015 edition textbook for OCR A-level Biology incorrectly labels pantothenate as vitamin B_6, when it should be vitamin B_5 (pantothenic acid), and also (inconsistently) omits specifying that folic acid is vitamin B_9.

Inhibitors

Inhibitors are substances that **reduce** the **rate** of enzyme-controlled reactions.

Inhibitors work by **interfering** with the enzyme's ability to **form enzyme-substrate complexes**.

Inhibition is defined by:

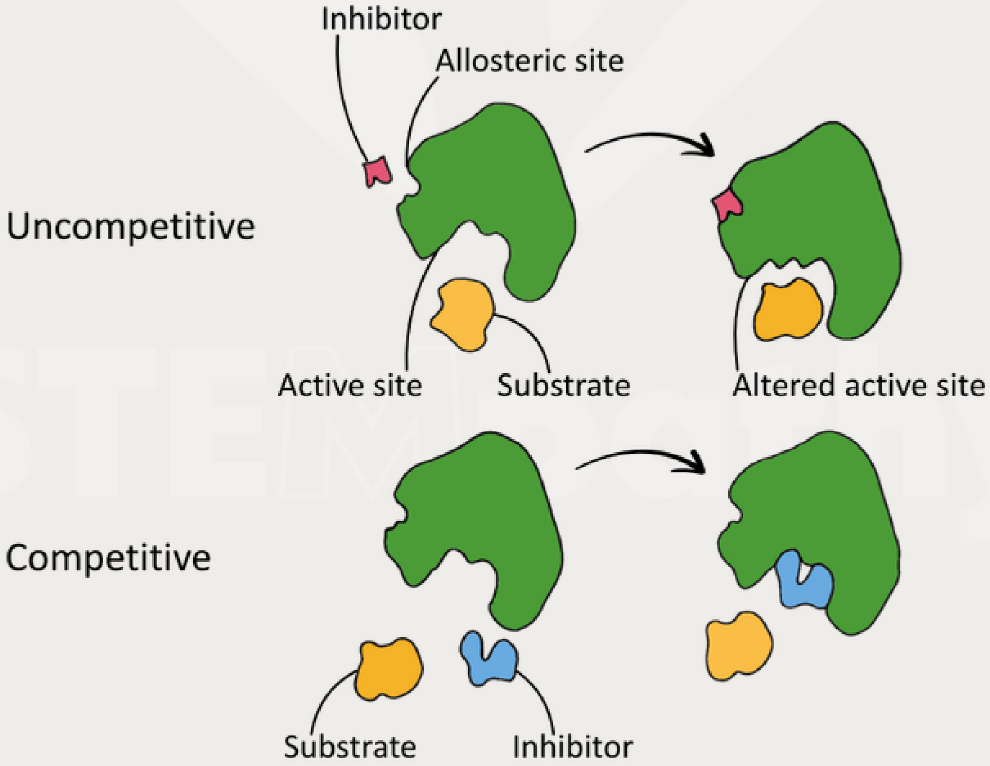
- **Reversibility** - Can the enzyme function normally 'if' the inhibitor unbinds?
- **Competition** - Does the inhibitor compete with the substrate for the active site?
- **Binding site** - Does the inhibitor bind to the active site, or the allosteric site (an external region on the enzyme)?

The two types of inhibitor are competitive and non-competitive:

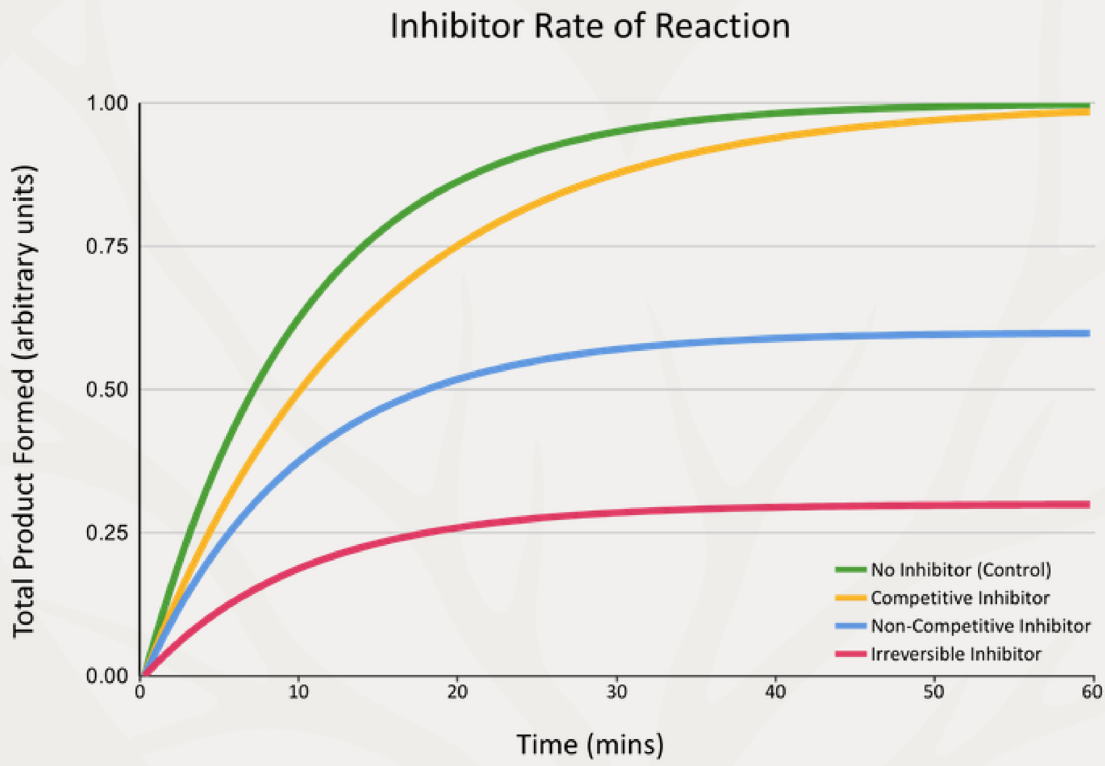
Type	Binding Site	Substrate Competition	Reversible?
Competitive	Active site	Yes	Yes*
Non-Competitive	Allosteric site	No	Varies

*Usually

The diagram below shows the binding action of competitive and non-competitive inhibitors.



The graph below shows the rates of reaction observed when different types of inhibitors are added to a reaction catalysed by enzymes:



Biological Membranes

Biological membranes are **selectively** (partially) **permeable** lipid barriers that enable the **separation** of a cell's contents from its **external environment**.

In addition to **controlling** the **movement of substances**, membranes have many more functions important to both prokaryotic and eukaryotic cells, detailed in the table below:

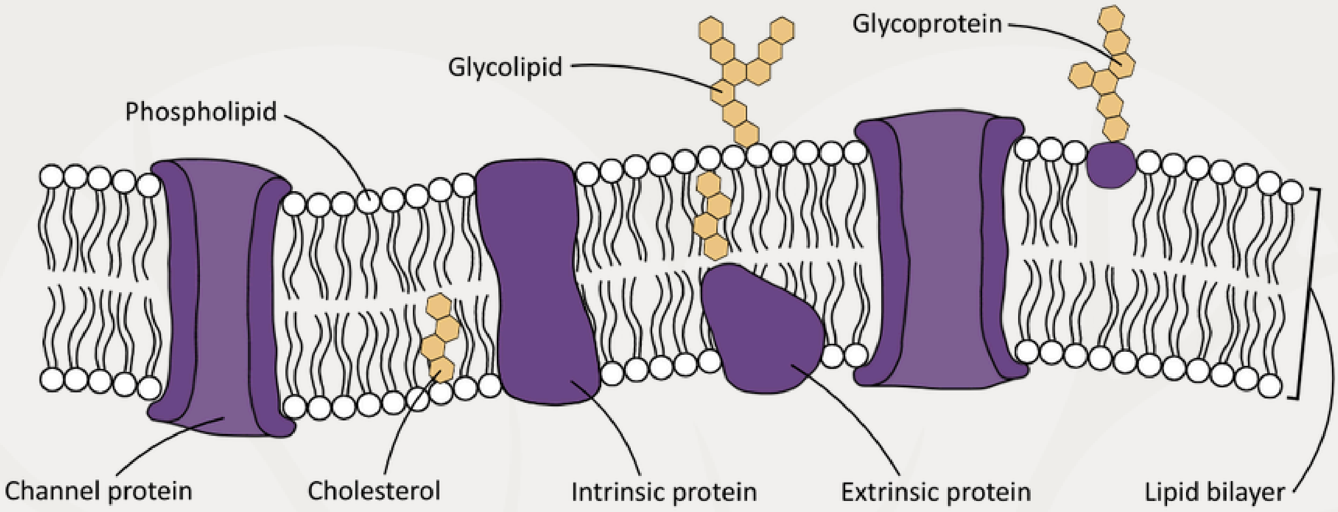
Role of Membrane	Structure(s) Involved	Main example
Control the entry and exit of substances	- Phospholipid bilayer* - Proteins	- Cell surface membrane - Organelle membranes (e.g. mitochondria, nucleus)
Cell communication	- Glycoproteins - Receptor proteins - Vesicles	- Cell surface membrane
Cell recognition	- Glycoproteins - Glycolipids	- Cell surface membrane
Chemical reactions	- Embedded enzymes	- Inner mitochondrial membrane (aerobic respiration) - Thylakoid membranes (photosynthesis)
Maintains electrochemical gradients	- Proton pumps - Ion channels	- Inner mitochondrial membrane - Thylakoid membranes - Cell surface membrane
Transport and secretion	- Vesicles	- Golgi apparatus - Endoplasmic reticulum - Cell surface membrane

The Fluid Mosaic Model

The **cell surface membrane** consists of a **phospholipid bilayer** with proteins (and some other molecules) embedded in it.

At GCSE it was enough to call it 'the cell membrane', but at A level this is too vague to score any marks.

Module 2: Biological Membranes



The **protein components** (e.g. glycoprotein, carrier protein) can be classified as either

- **Integral proteins**: Go from one side of the lipid bilayer to another
- **Peripheral proteins**: Are located only on one side of the lipid bilayer

Because the components are **free to move** around each other (it's fluid) and the components are **interspersed** with each other (like a mosaic), this **model** of how the plasma membrane works is called the **fluid mosaic model**.

The table below outlines the components of the plasma membrane:

Component	Structure	Function
Phospholipid bilayer	Two layers of phospholipids with hydrophobic fatty acid tails facing inwards and hydrophilic phosphate heads facing outwards	- Provides a barrier to most water-soluble substances - Allows lipid-soluble molecules to pass - Allows small uncharged molecules to pass through
Cholesterol	Found between phospholipids	- Gives mechanical stability and flexibility - Stabilises the membranes' fluidity by reducing fluidity at high temperatures and preventing rigidity at low temperatures
Glycolipids	Phospholipids with a carbohydrate chain attached	- Used in cell signalling and recognition - Stabilises the plasma membrane, as carbohydrate chains interact with the aqueous environment
Glycoproteins	Proteins with carbohydrate chains	- Antigens - Receptors - Important in signalling and immune response - Stabilises the plasma membrane, as carbohydrate chains interact with the aqueous environment
Channel proteins	Globular proteins with a pore (integral)	Passive movement (diffusion) of ions and small polar molecules.
Carrier proteins	Globular proteins with a pore (integral)	Used in facilitated diffusion and active transport.
Embedded proteins	Globular proteins (peripheral)	- Enzymes - Antigens - Receptors

Membrane Permeability

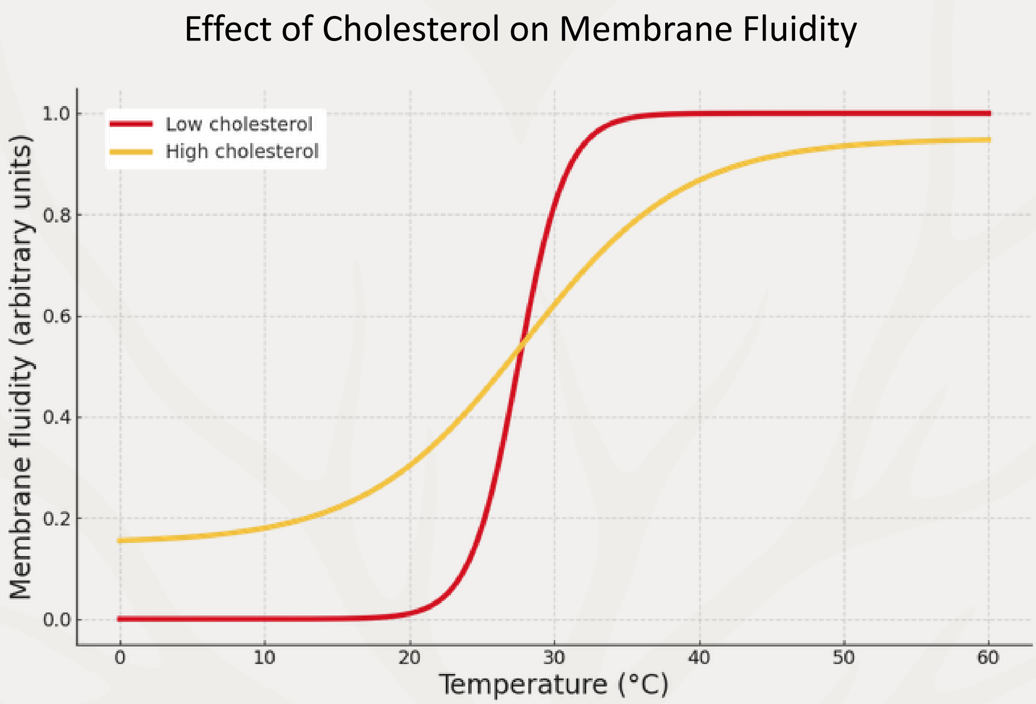
The relative abundance of each component in a plasma membrane affects its permeability to different substances, for example:

An Increase In...	Effect on Permeability
Phospholipids	↑ permeability to small, non-polar molecules (e.g. O_2, CO_2)
Cholesterol	↓ permeability to water and small polar molecules
Channel proteins	↑ permeability to ions (e.g. Na^+, K^+, Cl^-)
Carrier proteins	↑ permeability to larger polar molecules (e.g. glucose)
Aquaporins	↑ permeability to water

The structure of a membrane can be affected by environmental conditions listed in the table below:

Factor	Effect	Mechanism
Low temperature	- Membrane becomes less fluid and more rigid (brittle) - Permeability decreases	Saturated fatty acid tails on the phospholipids pack together more closely
High temperature	- The membrane becomes more fluid - Permeability increases - Proteins may denature	- Phospholipids move more, so there are more gaps in the membrane - Tertiary structure bonding (hydrogen and ionic) disrupted or denatured
Solvents (e.g. ethanol)	- Disrupt membrane structure - Increase permeability	Organic solvents dissolve lipids, disrupting the bilayer and allowing substances to leak through
pH changes	- Denatures membrane proteins	Alters ionic and hydrogen bonding in the tertiary structure
Detergents	- Break apart the membrane completely	Detergents emulsify phospholipids, disrupting the plasma bilayer

The diagram below shows the combined effects of temperature and cholesterol on the fluidity of a plasma membrane.



Transport Across Membranes

Cellular transport processes are divided into **two types**:

- **Active**: Uses ATP
- **Passive**: Does not use ATP

The movement of substances in **passive transport** processes is driven by **concentration gradients**, from a high concentration to a low concentration.

The table below outlines the different transport processes:

Process	Definition	Needs ATP?	Suitable molecules
Simple diffusion	Net movement from high to low concentration through the bilayer.	✗	SmallNon-polarLipid soluble
Facilitated diffusion	Movement down conc. gradient via channel or carrier proteins.	✗	SmallPolarLipid insoluble
Osmosis	Net movement of water from high to low water potential across a plasma membrane.	✗	Water (only)
Active transport	Movement against a concentration gradient using ATP and carrier proteins.	✓	Charged ions Polar molecules Lipid insoluble
Co-transport	Movement of one substance down its gradient pulls another against its gradient (ATP indirectly).	✓ (indirect)	Small Polar Lipid insoluble
Endocytosis	Bulk transport into the cell via vesicle.	✓	Too large
Exocytosis	Bulk transport out of the cell via vesicle.	✓	Too large

Effect of distance

Diffusion distance (mostly) applies to simple diffusion. It is just the idea that the **further a substance** has to move to get from 'A to B', the **lower** its **rate of diffusion**.

This is minimised in **exchange surfaces** to decrease the **distance** between 'A and B' as much as possible.

The table below gives the specialised exchange surfaces that **minimise diffusion distance** encountered in A level Biology:

Exchange Surface	Adaptation	Substances
Alveoli	- One-cell-thick alveolar wall - One-cell-thick capillary wall - Squamous epithelium	O_2, CO_2
Capillaries	- One cell-thick endothelium	O_2, CO_2, glucose, amino acids
Villi and microvilli	- Single-layer epithelial cells	Glucose, amino acids, fatty acids
Root hair cells	- Thin cell wall	Water, mineral ions (e.g. nitrates)
Leaf mesophyll	- Thin, flat cells - Air spaces between cells	CO_2, O_2
Placenta	- A thin membrane between maternal and fetal blood	O_2, glucose, urea, CO_2

Effect of size (of molecule)

Smaller molecules diffuse at a **faster rate** than larger ones, which (mostly) applies to simple diffusion.
For processes using transport proteins, size mainly relates to whether or not the molecule can fit into the transport protein shaped specifically for it, and is irrelevant for bulk transport.

Effect of surface area (of the cell)

The **greater the surface area**, the **more** of a substance can **cross the plasma membrane**, at the same time, through its transport process.

In cells using transport proteins, the surface area may directly affect how many they have to use.

Specialised cells will have **adaptations** to increase their surface area.

The table below gives an overview of two specialised exchange surfaces that minimise diffusion distance:

Exchange Surface	Adaptation to Increase Surface Area	Substances Exchanged
Alveoli	- Millions of small alveoli - Folded internal structure	O_2, CO_2
Root hair cells	- Long, thin root hair extensions - Numerous root hairs	Water, mineral ions (e.g. nitrates)

Osmosis and Water Potential

Osmosis is the **net movement of water** across a **partially permeable** membrane, from an area of **higher** water potential to an area of **lower** water potential.

Water potential (Ψ) measures how **likely** water is to move from one area to another. It's measured in **kilopascals** (kPa) because water molecules exert **pressure**.

Water potential is determined by:

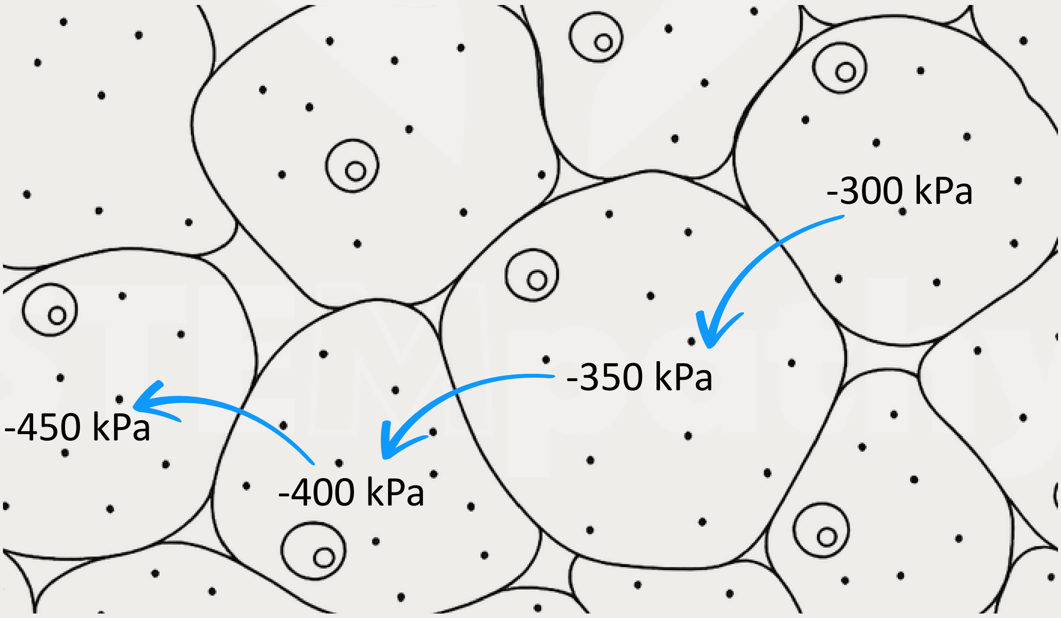
- **Solute potential** (Ψs): Solute molecules attract water, reducing **how freely** water can move.
- **Pressure potential** (Ψp): The **pressure** from the cell's contents **pressing** on the membrane or wall.

Giving us: Ψ = Ψs + Ψp

- **Pure water** has the highest water potential: **0 kPa**.
- **Adding solutes** lowers water potential, making the **value more negative**.
- In animal cells, Ψp is usually very small.

When **comparing** two places with different water potentials, the difference is called the **water potential gradient**.

The diagram below shows water potential gradient between cells in animal tissue:



Osmotic Effects on Cells

Osmosis can affect the physical structure and metabolic function of a cell.
Cells can shrink, swell, and even burst if the pressure exerted by the solution contained within the cell surface membrane is too high.

Effects of Osmosis on Animal Cells

External Solution	Direction of Water Movement	Effect on Cell
Higher Ψ (hypotonic)	Into cell	Swells and may burst (cytolysis)
Equal Ψ (isotonic)	No net movement	No change
Lower Ψ (hypertonic)	Out of cell	Shrinks (crenation)

Effect of Osmosis on Plant Cells

External Solution	Direction of Water Movement	Effect on Cell
Higher Ψ (hypotonic)	Into cell	Becomes turgid
Equal Ψ (isotonic)	No net movement	No change
Lower Ψ (hypertonic)	Out of cell	Plasmolysed (the plant tissue as a whole becomes flaccid)

Water transport pathways in plants

Water potential and **osmosis** are important in plants as they drive the **movement** of many other substances (dissolved in water-based solutions).

The table below outlines the different pathways that water can take through plant tissue:

Pathway	Route	How it works	Features
Apoplast	Through cell walls and intercellular spaces	Water moves by mass flow, no membranes involved	Fastest route; blocked by Casparian strip in endodermis
Symplast	Through the cytoplasm, via plasmodesmata	Water moves by osmosis from cell to cell through the cytoplasm	Slower than apoplast; allows selective control of substances
Vacuolar	Through the cytoplasm and vacuoles	Water crosses the tonoplasts and cell membranes between cells	Even slower, less common than the other two

The diagram below shows the pathways that water can take through plant tissue from a root hair cell to the xylem:

The Eukaryotic Cell Cycle

The **cell cycle** is the distinct **phases** a cell goes through in preparation for **cell division**.

The cell cycle in **eukaryotes** is outlined in the table below:

Stage	Description
Interphase	Cellular growth and DNA replication; broken into G_1, S and G_2 and (sometimes) G0 phase.
Mitosis (M)	Division of the nucleus to produce two genetically identical nuclei.
Cytokinesis	Division of the cytoplasm, producing two genetically identical cells.

The three phases (G_1, S and G_2) are separated by **restriction points**; checkpoints that reduce the risk of a cell failing to divide and **mutating**.

The table below gives an overview of the **phases of the cell cycle**, and some of the mechanisms in place to reduce the risk of mutation:

Phase	Events	Anti-mutation mechanisms
G_1	- The cell grows in size - Protein synthesis (transcription and translation) - Organelles duplicate	- p53 (a tumour suppression gene), CDKs (cyclin-dependent kinases) and cyclins (proteins) regulate this phase. - G_1/S restriction point prevents uncontrolled division and repairs damaged DNA.
S	- DNA is replicated, producing sister chromatids	- CDKs and cyclins regulate this phase.
G_2	- Proteins responsible for forming the spindle and condensing chromosomes are made	- CDKs and cyclins regulate this phase. - G2/M restriction point prevents uncontrolled division and repairs damaged DNA
M	- Mitosis occurs, the nucleus' contents divide	- Spindle restriction point (in metaphase) ensures that the right number of chromosomes end up in each daughter cell
Cytokinesis	- Cytoplasmic division	n/a
G0	- The cell cycle pauses - Differentiation - Senescence (ageing) - Apoptosis	n/a: p53 can cause cells to enter G0 as a result of mutation and undergo apoptosis.

Cancer cells typically arise from mutations in the genes responsible for regulating the cell cycle directly (p53) or indirectly (cyclins and CDKs that control the restriction points).

If a restriction point is unable to repair damaged DNA, or fix a nutrient deficiency or lack of organelles, then the cell may undergo apoptosis (programmed cell death); this eliminates a potentially cancerous cell to protect the entire organism.

Module 2: Mitosis and Cytokinesis

Mitosis

Mitosis is the process of **nuclear division** in **eukaryotic** cells and consists of four stages:

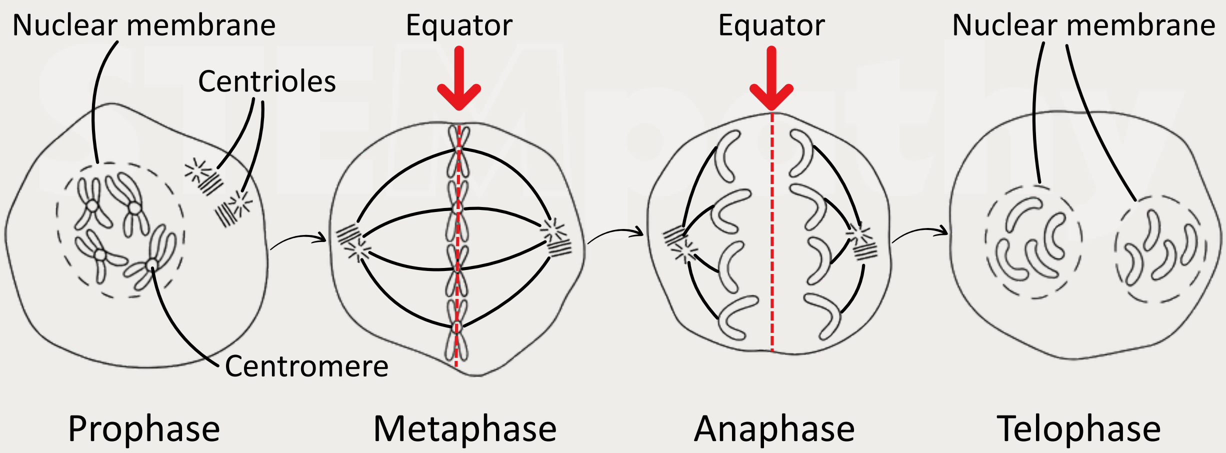
- Prophase
- Metaphase
- Anaphas
- Telophase

Mitosis produces **two genetically identical** daughter cells; they each have the same (and number of) chromosomes.

The table below outlines the stages of mitosis, and the key events of each:

Stage	Key Events
Prophase	- DNA supercoils and condense into chromosomes - Nuclear envelope breaks down - Centriole divides, and the daughter centrioles migrate to opposite poles - Spindle begins to form from centrioles (in animals) - Spindle begins to form from cytoplasm (in plants)
Metaphase	- Chromosomes line up along the equator (also called the metaphase plate) - Spindle fibres attach to the chromosomes' centromeres - Restriction point (M phase) ensures all chromosomes are correctly attached
Anaphase	- Chromosome centromeres divide, separating sister chromatids - Spindle fibres shorten, pulling chromatids to opposite sides of the cell - Motor proteins pull sister chromatids towards opposite poles
Telophase	- Chromatids reach the poles - Chromosomes uncoil and uncondense (back into chromatin) - Nuclear envelopes reform around each set of chromosomes - Spindle fibres disassemble

The diagram below shows the changes which occur in each phase of mitosis:



Cytokinesis

Cytokinesis is the **division** of the cellular **cytoplasm** (to produce two genetically identical cells).

In **animal cells** the plasma membrane '**pinches inwards**' around the **equator**, contracting further until the two halves separate.

In **plant cells**, the cell elongates and then **divides itself** into two by forming a **new cellulose cell wall** along the metaphase plate and depositing a **new plasma membrane** on either side of it.

Importance of Mitosis

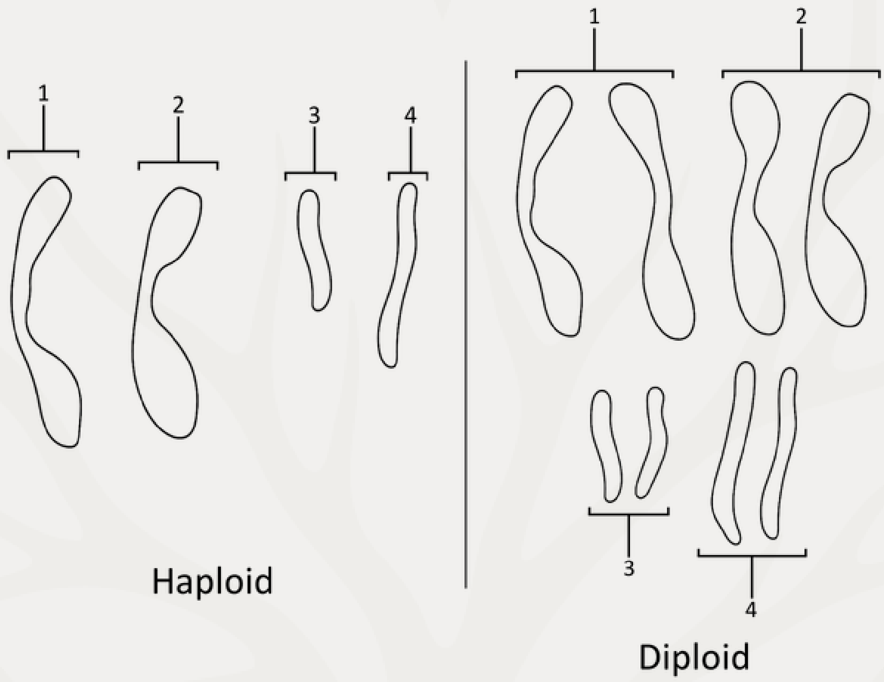
Mitosis ensures that DNA is **replicated exactly** to ensure it remains the **same** within all cells of an organism, and in any asexually produced offspring.

It is essential in the life cycles of multicellular eukaryotes:
- **Growth**: Of either the whole organism, or tissues and organs.
- **Tissue repair**: By replacing damaged or dead cells
- **Asexual reproduction**: For some animals, plants and fungi.

Meiosis

Meiosis is a type of **nuclear division** that produces **haploid gametes**.

Haploid means they only have one of each type of **chromosome**, whilst **diploid** means they have **2** of each.



Humans have **46** chromosomes (their **diploid** number) in their **body cells**, whilst their **gametes** (sperm and ova) have 23 (their **haploid** number).

Gametes are sex cells, and will typically be **haploid** so that when fertilisation occurs, the newly formed organism will have a 'full' genome with the **correct number of chromosomes**. This is true of most animals and plants, whilst some fungi can have more complex reproductive lifecycles.

Sexual Reproduction: Genetic Variation

Meiosis enables **sexual reproduction** to occur, and is important because it:
- Maintains chromosome numbers across generations.
- Introduces genetic variation (crossing over, independent assortment, and random fertilisation).
- Enables natural selection (and long-term species survival).

The table below outlines the mechanisms that generate genetic variation:

Source of Variation	Explanation
Crossing over	Non-sister chromatids swap DNA sections during prophase I → shuffling alleles → creating new allele combinations → more potential genotypes
Independent assortment*	The side of the cell that homologous chromosomes (in metaphase I) and sister chromatids (in metaphase II) line up on the equator is random → random segregation → more potential genotypes
Random fertilisation	Haploid gametes containing a random set of chromosomes can fuse with another gamete in numerous genetic possibilities.

*It is important to note that independent assortment occurs during metaphase (I or II), whilst random segregation occurs during anaphase (I or II).

Stages of Meiosis

The table below outlines the events which occur during each stage of **meiosis I and II**, the differences between each stage's I and II are indicated in bold:

Stage	Events and Notes
Prophase I	- DNA supercoils and chromosomes condense - Nuclear envelope breaks down **- Homologous chromosomes pair up and form a bivalent: non-sister chromatids cross arms at the chiasmata** **- Crossing over occurs: alleles are shuffled** - Spindle begins to form (from centrioles in animals; from cytoplasm in plants)
Metaphase I	**- Bivalents (homologous pairs of crossed-over chromosomes) line up at the equator** - Spindle fibres attach to centromeres - Chromosome arrangement is random: independent assortment occurs
Anaphase I	**- Homologous chromosomes are pulled to opposite poles** **- Bivalents separate: Allele shuffling has occurred** - Independent segregation: **Homologous chromosomes are pulled to opposite sides**
Telophase I(animals only)	- Nuclear envelope (may) reform around each set of chromosomes (in animals) - Most plant cells skip telophase I and go to prophase II
Cytokinesis (animals only)	**1 cell splits into 2 haploid cells, but the chromosomes consist of two sister chromatids**
Interphase(animals only)	Short interphase: chromosomes uncoil
Prophase II	- Reformed nuclear envelopes break down (if they reformed) - DNA supercoils and chromosomes condense
Metaphase II	**- Chromosomes line up on the equator** - Spindle fibres attach to centromeres - Chromatid arrangement is random: independent assortment occurs
Anaphase II	**- Sister chromatids are pulled to opposite poles** **- Centromeres are pulled apart (as sister chromatids separate)** - Independent segregation: sister chromatids are pulled to opposite sides
Telophase II	Nuclear envelopes form around each set of chromosomes
Cytokinesis	**Each cell divides, producing 4 haploid gametes.**

Stem Cells

Stem cells are **unspecialised** cells that can **divide** and **differentiate** by expressing different genes when needed.

Stem cells are important because they give rise to **new cells**, allowing an organism to **grow, replace** dead or damaged cells (repair tissues) and (in some organisms) enable **asexual reproduction**.

Mitosis is done by **stem cells**, which is why they share those three important roles.

Potency

Potency is the **number** of types of cells a stem cell can **give rise to** (differentiate into).

The main types of stem cell potency are outlined in the table below:

Potency	What it can become	Example
Totipotent	All body + placental cells	Zygote
Pluripotent	All body cells	Embryonic stem cells
Multipotent	A range of related cell types	Bone marrow stem cells
Unipotent	One specific type only	Skin stem cells

A **zygote** (fertilised egg cell) is **totipotent** and can become **all types** of cells, because it can express all of its genes.

Other types of (animal) stem cells cannot differentiate into as many types of cells because some of their **genes** will be **permanently** turned off (or on).

Uses of Stem Cells

Stem cells have enormous potential in the field of medicine; a select few are described in the table below:

Application	Description
Tissue Repair	Treat damaged cartilage, skin and cardiac tissue
Neurological Therapy	For replacing damaged neurones/nerve tissue: - Spinal injuries - Parkinson's - Alzheimer's
Developmental Biology	Helps understand differentiation, signalling and regeneration

Differentiated and Specialised Animal Cells

In **multicellular** animals, cells become **specialised** to perform **specific roles** more effectively.

These **differentiated** cells **work together** to form **tissues**, **organs**, and **organ systems**.

Specialised Cells

Specialised cells are metabolically and structurally **adapted** for their role.

These are the specialised cells you need to know about for OCR A level Biology:

Cell Type	Function	Adaptations
Erythrocytes	Transport oxygen	- Biconcave shape - No nucleus - No mitochondria - Flexible cytoskeleton - Lots of haemoglobin
Neutrophils	Phagocytosis	- Flexible multi-lobed nucleus - Lysosomes - Move by chemotaxis
Squamous Epithelium	Lining cells that exchange gases	Flat thin cells, to reduce the diffusion distance
Ciliated Epithelium	Lining cells that move mucus	Has cilia that move in waves
Sperm Cells	Fertilise ovum	- Haploid nucleus - Acrosome with enzymes to digest the outer layer of the ovum - Many mitochondria for making ATP for the undulipodium - Undulipodium for swimming

Erythrocytes and **neutrophils** are examples of two different specialised cells which both arise from the same multipotent stem cells in the **bone marrow**.

The table below gives an overview of how they compare:

Feature	Erythrocyte	Neutrophil
Function	Transports oxygen from the lungs to the tissues	Engulfs and digests pathogens via phagocytosis
Origin	Derived from stem cells in the bone marrow	Derived from stem cells in the bone marrow
Nucleus	✗ - nucleus is ejected to increase space for haemoglobin	✓ - multi-lobed nucleus aids movement through narrow capillaries and tissue
Mitochondria	✗ - relies on anaerobic respiration	✓ - Lots of ATP needed for chemotaxis and phagocytosis
Cell Division	✗ - cannot divide - enucleated	✗ - cannot divide - short-lived
Cytoplasm contents	Contains a high concentration of haemoglobin	Contains lysosomes for hydrolytic digestion
Motile?	✗ - Transported by blood flow	✓ - Moves by chemotaxis to infection sites
Shape	Biconcave shape increases the surface area:volume ratio for gas exchange, and is flexible to pass through capillaries	Flexible cytoskeleton and surface receptors for pathogen recognition

Animal Tissues

A **tissue** is a **group** of the **same type** of **specialised cell**, all working together to fulfil a function.

These are the animal tissues you need to know about for OCR A level Biology:

Tissue	Description	Function
Squamous Epithelium	Flat, smooth lining cells	Allows rapid diffusion (e.g. lungs)
Ciliated Epithelium	Lining cells with cilia and goblet cells	Moves mucus and traps pathogens
Cartilage	Connective tissue with matrix	Structural support; flexible but strong
Muscle	Long fibres with myofilaments made up of actin and myosin	Enables movement through contraction

Animal Organs

An **organ** is where **two or more tissues** come together to fulfil a **function**.

Here are some of the most common animal organs encountered in OCR A level Biology:

Organ	Function
Heart	Pumps blood around the body
Lungs	Carry out gas exchange
Kidneys	Filter blood and regulate water balance
Liver	Metabolises toxins, produces bile

Animal Organs

An **organ** is where **two or more tissues** come together to fulfil a **function**.

Here are some of the most common animal organs encountered in OCR A level Biology:

System	Main Organs/Structures	Function
Circulatory	Heart, blood vessels	Transport of gases, nutrients, and hormones
Respiratory	Lungs, trachea, diaphragm	Gas exchange, excretion
Urinary	Kidneys, ureters, and bladder	Osmoregulation, excretion
Nervous	Brain, spinal cord, nerves	Communication, control and coordination

Differentiated and Specialised Plant Cells

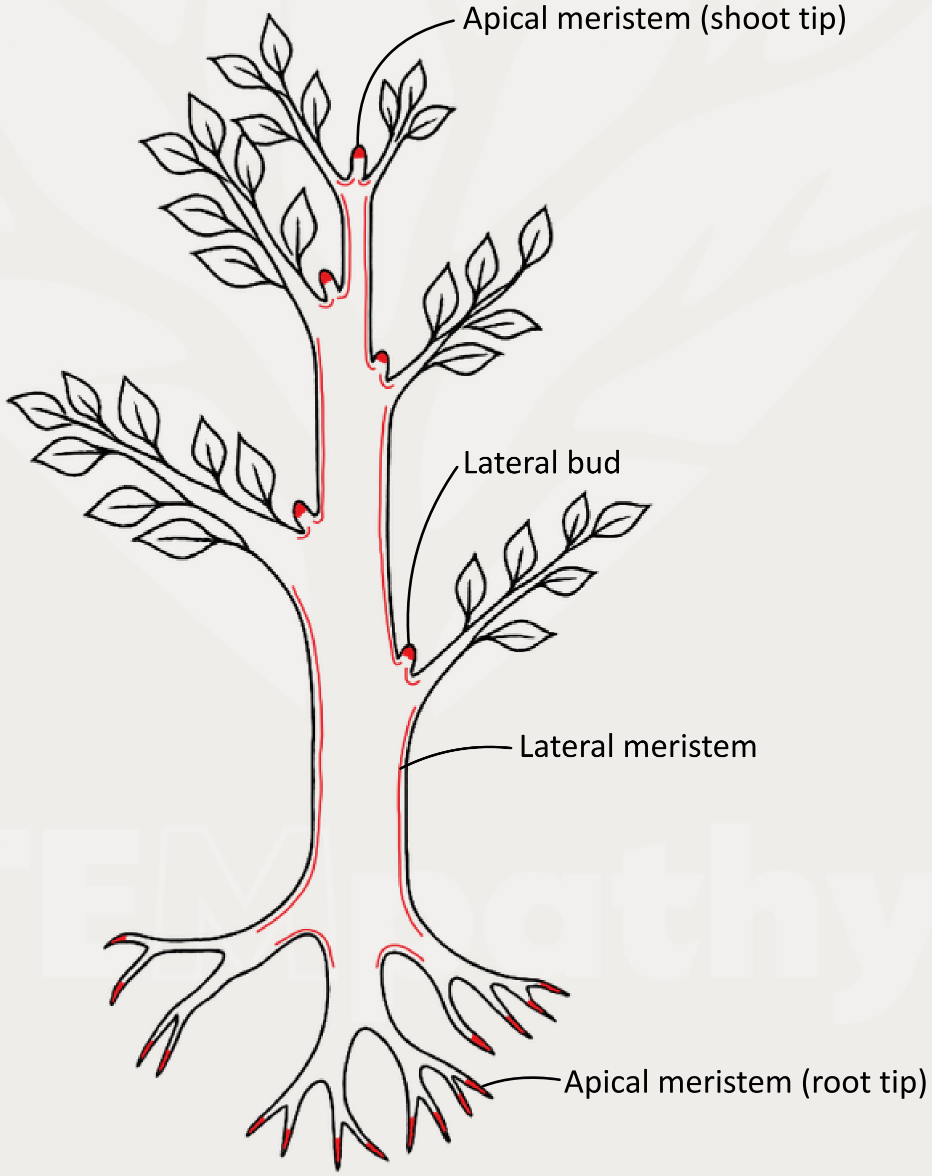
In plants, cells become **specialised** to perform specific roles more effectively.

These **differentiated** cells work together to **form tissues**, **organs**, and **organ systems**.

Specialised Cells

Meristem cells (plant stem cells) **differentiate** into specialised cells.

They are found in the tips of plant shoots, roots and in a ring in the cambium; this allows the plant to grow longer and wider.



Specialised cells are metabolically and structurally **adapted** for their role, with unneeded genes switched off.

The table below provides an overview of the examples you need to know for OCR A level Biology:

Cell Type	Function	Adaptations
Palisade Cells	Photosynthesis	- Many chloroplasts - Large vacuole pushes chloroplasts to the edge for light maximisation - Cylinder shape allows for close packing in palisade mesophyll with space for CO_2 diffusion
Root Hair Cells	Water and mineral ion absorption	- Long projections increase the surface area - Mitochondria make ATP for active transport - Many carrier proteins for active transport - No chloroplasts (as there is no light)
Guard Cells	Control stomatal opening for gas exchange	- Chloroplasts make ATP for the active transport of K^+ (cannot do photosynthesis) - Can inflate and deflate vacuole - Uneven cellulose cell wall thickness causes the pore to open/close

Plant Tissues

The table below outlines the most common **plant tissues** encountered in A level OCR biology:

Tissue	Structure	Function
Xylem	Dead vessels with lignin	Transport of water and minerals
Phloem	Living sieve tubes with companion cells	Transport of sugars via mass flow
Meristematic	Small, undifferentiated stem cells	Divide to form other tissue types, enabling growth

Xylem and phloem are examples of two different specialised cells which both arise from the **same meristematic tissue** in the cambium, forming vascular bundles.

The table below gives an overview of how they compare:

Feature	Xylem	Phloem
Cell Type	Dead hollow tubes	Living sieve tubes (supported by companion cells)
Transported Substance	Water and mineral ions	Sucrose (and other solutes)
Differentiation Changes	Cell death, lignification	Sieve plates form, organelles are lost in sieve tubes
Mechanism	Capillary action: cohesion & adhesion	Mass flow: sucrose loading/unloading changes water potential/pressure

Plant Organs

Plant **tissues** come together to **form organs** in plants.

Here are some of the most common **plant organs** encountered in OCR A level Biology:

Organ	Function
Leaf	- Photosynthesis - Gas exchange
Root	- Water/mineral ion uptake - Anchorage - Starch storage
Stem	- Supports leaves - Transport - Stores photosynthesis products (starch and/or sugars)

Specialised Exchange Surfaces

Exchange surfaces are adaptations to overcome the limits of surface area.

Surface area to volume ratio

Surface area to volume ratio (SA:V) compares the surface area of an object to its internal volume.

It is calculated using the formula:

Surface area to volume ratio = Surface area ÷ Volume

The table below gives some examples:

Cube Length (cm)	Surface Area (cm^2)	Volume (cm^3)	SA:V Ratio
1	$6 \times 1^2 = 6$	$1^3 = 1$	6:1
2	$6 \times 2^2 = 24$	$2^3 = 8$	24:8 = 3:1
3	$6 \times 3^2 = 54$	$3^3 = 27$	54:27 = 2:1
4	$6 \times 4^2 = 96$	$4^3 = 64$	96:64 = 1.5:1

As **size increases**, the **SA:V ratio decreases**, so larger organisms (or cells) have less surface area per unit volume.

The illustration below demonstrates how the **surface area to volume ratio** (in micrometres) of organisms **decreases with their size**.

Exchange Surfaces

To **maximise the rate** of diffusion, osmosis or active transport, exchange surfaces are adapted to their function with a variety of different features.

In OCR A level Biology, the **lungs**, **gills** and **root hair cells** are the relevant exchange surfaces for transport systems that are studied.

The table below breaks down their specialised exchange surfaces by their features:

Feature	Alveoli (Lungs)	Gills (Fish)	Root Hair Cells (Plants)
Large surface area	~300 million alveoli provide ~70 m^2 surface area.	Gill filaments and lamellae create a large folded surface.	Long, thin extensions of root hair cells provide a vast surface area.
Thin barrier	Alveolar and capillary walls are one cell thick (~0.5 μm) and in close contact for a short diffusion distance.	Lamellae have thin epithelial layers for a short diffusion distance.	The cell membrane is thin to allow easy diffusion.
Good transport	An extensive capillary network for continuous blood flow to bring/remove substances.	Counter-current blood flow system maintains a steep gradient.	Active transport of ions maintains a steep water potential gradient.
Bulk movement	Ventilation by breathing refreshes air in the alveoli, maintaining concentration gradients.	Mouth and operculum create pressure that pushes water over the gills, maintaining concentration gradients.	Continuous uptake of minerals and water maintains flow into the root.

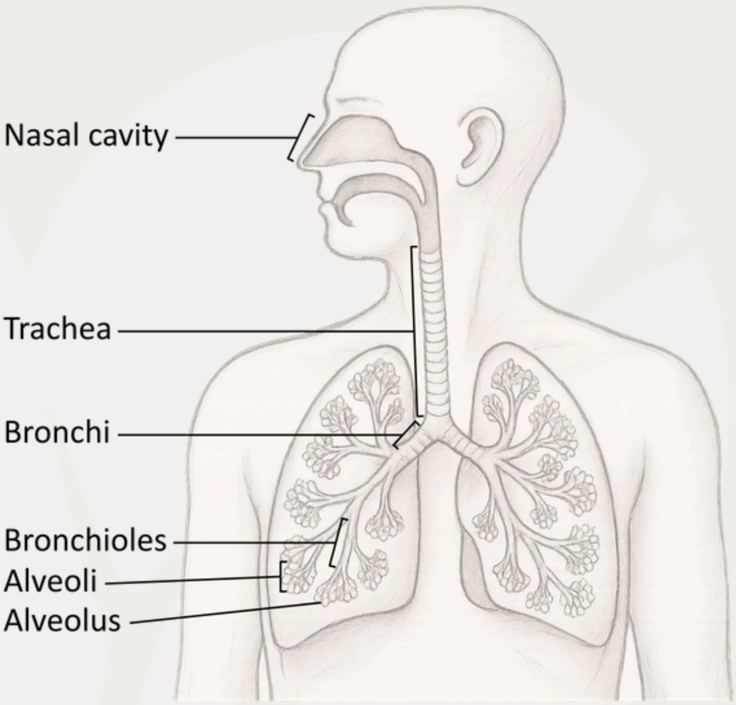
Module 3: Mammalian Gaseous Exchange System

Gaseous Exchange

For the effective exchange of oxygen and carbon dioxide, mammals have a **highly specialised gaseous exchange system** consisting of a series of airways that filter, warm, and moisten air before it reaches the alveoli.

The pathway that air follows during inhalation is:

Nasal cavity → Trachea → Bronchi → Bronchioles → Alveoli



The table below provides an overview of some functions and features of these structures:

Part	Structure	Function(s)
Trachea	- Single-wide tube supported by C-shaped cartilage rings. - Lined with ciliated epithelium and goblet cells. - Contains smooth muscle and elastic fibres.	- Cartilage prevents the collapse of the airway. - Cilia and mucus trap and remove debris. - Smooth muscle regulates airway diameter. - Elastic fibres recoil after stretching.
Bronchi	- Two tubes branching from the trachea into each lung. - Supported by cartilage plates. - Lined with ciliated epithelium and goblet cells. - Contains smooth muscle and elastic fibres.	- Cartilage prevents airway collapse. - Cilia and mucus trap and remove debris and microorganisms. - Smooth muscle controls airway diameter. - Elastic fibres provide recoil after stretching.
Bronchioles	- Narrower tubes containing smooth muscle and elastic fibres. - Ciliated epithelium and goblet cells are present in larger bronchioles.	- Elastic fibres help keep airways open and allow recoil after stretching. - Cilia and mucus trap and remove debris and microorganisms.
Alveoli	- Large surface area with an extensive capillary network. - Short diffusion distance (~0.5 μm). - Microscopic air sacs with squamous epithelium and many elastic fibres.	- Main site of gas exchange. - Elastic fibres allow recoil to expel air during exhalation.

Ventilation (Breathing) In Mammals

Ventilation enables the effective exchange of oxygen and carbon dioxide in the alveoli by taking in oxygen and removing waste carbon dioxide; this **maintains a concentration gradient to maximise diffusion**.

The table below compares the events of **inhalation** and **exhalation**:

Step	Inhalation	Exhalation
1	The diaphragm contracts and flattens	Diaphragm relaxes: returns to a dome shape
2	External intercostal muscles contract, pulling the ribs up and out	External intercostal muscles relax, allowing ribs to move down and in
3	The thoracic cavity volume increases	The thoracic cavity volume decreases
4	Pulmonary lung pressure decreases below atmospheric pressure (negative pressure)	Pulmonary lung pressure increases above atmospheric pressure (positive pressure)
5	Air flows into the lungs down the pressure gradient	Air flows out of the lungs down the pressure gradient
(Forced only)	Internal intercostal muscles relax (inactive during normal inhalation)	Internal intercostal muscles contract (during forced exhalation), pulling ribs down and in further, decreasing thoracic volume more rapidly

Forced inhalation and **forced exhalation** are active breathing processes involving **additional muscle groups** beyond those used in normal, quiet breathing, such as during exercise, singing or coughing.

The table below outlines the key changes which occur during **inhalation** and **exhalation**:

Change	Inhalation	Exhalation
Diaphragm	Contracts	Relaxes
External intercostals	Contract	Relax
Internal intercostals	Relax (inactive)	Contract (when forced)
Thoracic volume	Increases	Decreases
Pulmonary pressure	Decreases (below atmospheric)	Increases (above atmospheric)
Air movement	Into lungs	Out of lungs

Oxygen Uptake

Oxygen uptake is the rate at which oxygen moves into the bloodstream (in mammals) per minute.

The **rate of oxygen uptake** is affected by the effectiveness of **pulmonary ventilation**.
It can be measured as the volume of air breathed per minute, calculated as:

Tidal Volume × Breathing Rate

Where:
- **Tidal volume** is the volume of air inhaled or exhaled in a breath at rest
- **Breathing rate** is the number of breaths per minute

Tidal volume is affected by the lung's vital capacity, a key indicator of respiratory health.

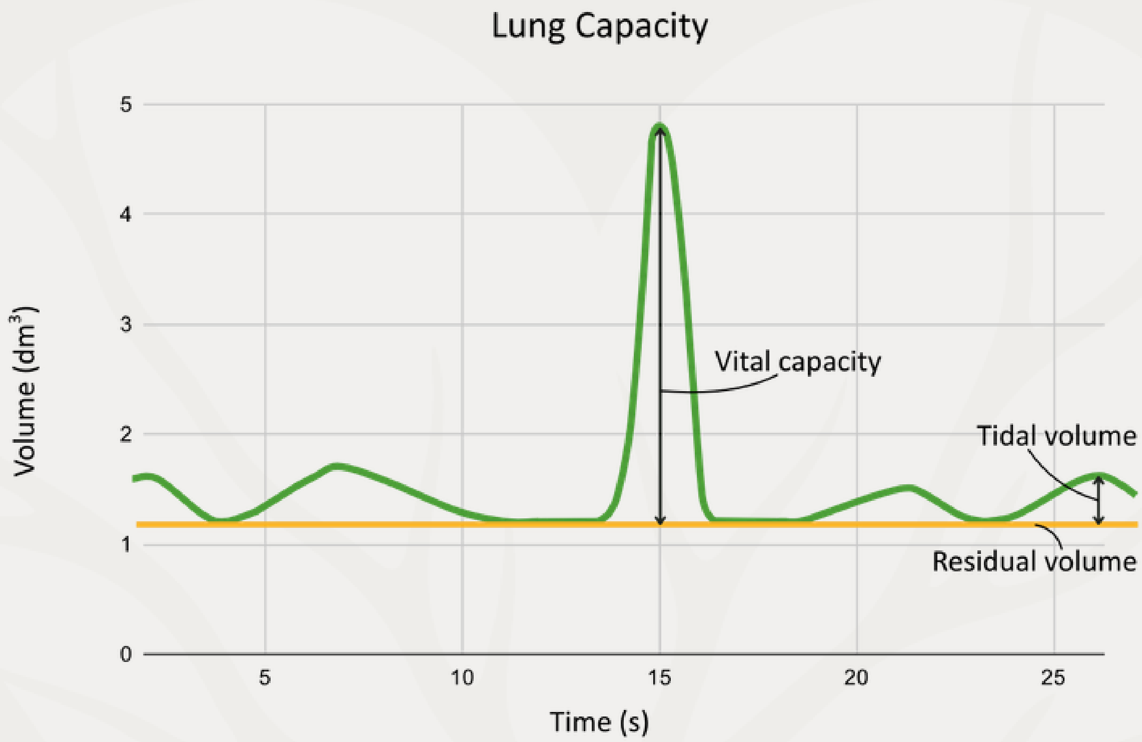
Vital capacity is the maximum volume of air that can be inhaled and exhaled during a forced breath.

So, **oxygen uptake** can increase if:
- Tidal volume increases (deeper breaths)
- Breathing rate increases (more breaths per minute)

Vital capacity is a fixed **maximum** and only changes with lung health and fitness.

Residual volume is the volume of air that **remains** in the lungs after forced exhalation.

The diagram below shows how these factors affect each other:

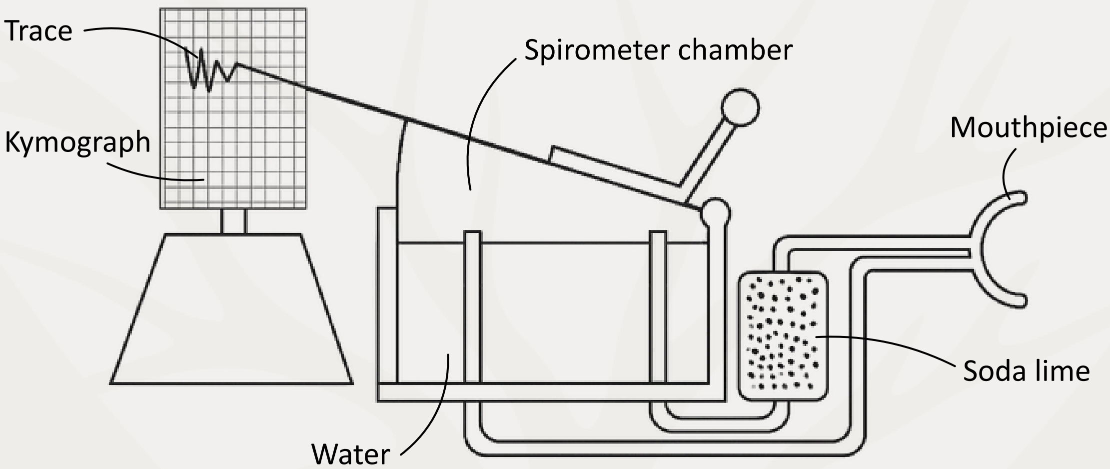


Measuring oxygen uptake: Respirometer vs Spirometer

A r**espirometer** is a device that can be used to measure **oxygen uptake.**

A **spirometer** measures **breathing patterns**, and produces a **trace** on **graph paper** as the test subject breaths; the graph produced is a reflection of the subject's **tidal volume** and **breathing rate**.

The diagram below presents a typical spirometer set-up and accompanying spirometer trace.



The table below outlines the key components needed to set up a spirometer and their function:

Component	Purpose
Soda lime (KOH)	Absorbs carbon dioxide, so that the volume changes reflect oxygen uptake only
Spirometer chamber	A sealed air tank that moves up and down with each breath
Kymograph/data logger	Records breathing patterns (tidal volume, breathing rate, etc.)
Water bath/heater	Maintains a constant temperature for the spirometer chamber, preventing volume changes due to thermal expansion
Nose clip	Ensures all air is breathed through the mouthpiece

Module 3: Measuring Oxygen Uptake in Mammals

Spirometer interpretation

A spirometer trace allows you to calculate:

- **Tidal Volume**: Height of each wave
- **Breathing Rate**: Number of waves per minute
- **Oxygen Uptake**: Overall volume change over time

These measurements can be used to assess respiratory health, athletic performance, and how someone is affected by conditions like asthma or emphysema.

The table below outlines how you determine these values:

Measurement	What to Measure	How to Calculate
Tidal Volume (TV)	Height between the peak of inhalation and the trough of exhalation.	The value gives the volume of air per breath (usually in dm^3 or ml).
Breathing Rate (BR)	The number of complete breathing waves in a set time period.	Divide the number of breaths by the time interval (in minutes) to get breaths per minute.
Oxygen Uptake (VO_2)	The overall drop in baseline volume is due to oxygen absorption over time.	Measure volume change over time (e.g. per minute) to calculate oxygen uptake rate in $dm^3\ min^{-1}$.

Gills: Gaseous exchange in bony fish

Gas exchange systems in bony fish **maximise the rate of diffusion** of oxygen into the bloodstream and carbon dioxide out into the water.

A single **gill** (of which there are many on each side) consists of a **bony** or **cartilaginous gill arch**, from which extend many **gill filaments**: long, thin, (horizontal) tubular projections.

The table below outlines the structure and function of the gill's components:

Component	Structural Description	Function
Gill Arch	A bony or cartilaginous structure that supports a gill.	Provides rigid support for the gill filaments and lamellae, keeping them well-positioned for gas exchange.
Gill Filaments	Long, thin horizontal projections extending from the gill arches.	Increases the surface area available for gas exchange, maximising oxygen uptake and carbon dioxide removal.
Lamellae	Thin, plate-like structures lined up along each gill filament; they have a rich capillary network.	Provides a large surface area and thin diffusion distance, maximising oxygen uptake and carbon dioxide removal.
Capillary Network	A dense network of capillaries within each lamella.	- Blood flows opposite to the water flow (counter-current system). - The capillary network maintains a steep oxygen concentration gradient across the entire gill, maximising gas exchange.
Operculum	A bony flap covering and protecting the gills.	- Protects delicate gill structures. - Pumps water over the gill surfaces when the fish is stationary to ensure a constant oxygen supply.

Ventilation in fish follows the three stages outlined in the table below:

Stage	Action
Inhalation	- Mouth opens - Floor of buccal cavity lowers → volume increases - Water enters
Buccal cavity rises	- Mouth closes - Buccal cavity contracts → pressure increases - Water forced over the gills
Exhalation	- Operculum (bony flap) opens - Water exits via the opercular cavity

Module 3: Ventilation and Gas Exchange in Insects

Tracheae: Gaseous exchange in insects

Gas exchange systems in insects are adapted for the air.

The table below outlines the structure and function of each component:

Component	Structure	Function
Spiracles	Small external openings are located along the thorax and abdomen.	- Allow air to enter and carbon dioxide to exit the body. - Open and close to regulate gas exchange and reduce water loss.
Tracheae	Large air-filled tubes are supported with chitin rings (taenidia) to prevent collapse.	A passage for air from the spiracles to travel deeper into the body.
Tracheoles	Fine, unreinforced tubes branching from tracheae, extending to individual cells with fluid-filled ends.	Provide a short diffusion distance between the air and the cell cytoplasm for gas exchange.
Tracheole Fluid	A thin layer of fluid at the ends of tracheoles.	Oxygen dissolves in this fluid before diffusing into cells, supporting gas exchange.

Ventilation in Insects

Gas movement through the tracheal system can occur by **passive diffusion**, and may be sufficient when the insect is at rest, but is **actively ventilated** during periods of high activity.

These ventilation mechanisms are outlined below:

Method	Description
Diffusion at rest	Gases diffuse down concentration gradients: oxygen diffuses in, carbon dioxide diffuses out.
Abdominal contractions	In active insects, abdominal muscles contract and relax, compressing air sacs and the tracheae, pumping air in and out of the network.
Spiracle control	Spiracles open and close (done by muscular valves) to regulate gas exchange and minimise water loss.

Carbon dioxide is expelled from the cells via **diffusion** through the **tracheoles** and out through the **spiracles**, ensuring the **removal** of metabolic waste.

The Need for Transport Systems

As an animal (and plant) **increases in size** and complexity, their **surface area to volume ratio** (SA:V) **decreases**; diffusion alone cannot meet its metabolic requirements.

The table below outlines the limitations on diffusion in multicellular animals:

Limitation	Reason
Low SA:V ratio	A lower SA:V provides less space for substances to enter or leave the organism via the skin compared to their volume.
High metabolism	Metabolically active tissues (e.g. muscles, brain) need a high rate of oxygen and glucose delivery for making ATP.
Long diffusion distance	Internal cells are far from the external surface, and those that aren't may be covered by an impermeable barrier; it takes too long for substances to get to where they are needed.

To overcome these limitations, animals have evolved **specialised transport systems** which:

- Deliver substances to cells (e.g. oxygen, glucose, amino acids, hormones)
- Remove toxic waste products (e.g. carbon dioxide, urea)
- Deliver hormones (hormonal signalling)

Types of Circulatory Systems

There are different types of circulatory systems, **open** and **closed**.

The table below compares closed and open circulatory systems:

Feature	Open Circulatory System	Closed Circulatory System
Definition	Blood (or haemolymph) is not enclosed in vessels.	Blood is enclosed in vessels.
Examples	Insects (e.g. grasshoppers), molluscs (e.g., snails).	Vertebrates (e.g. mammals, fish), some invertebrates (e.g. annelid worms).
Transport Medium	Haemolymph: blood and tissue fluid (does not transport oxygen in insects).	Blood: remains separate from tissue fluid.
Pressure	Low-pressure.	High pressure (overall, varies).
Pumping Mechanism	Varies: - Body movement - Peristalsis - Heart (simple and open)	The heart pumps blood through vessels; capillaries allow exchange with tissues.

Types of Closed Circulatory Systems: Single and double

In OCR A level Biology, you need to know about the structure of the double circulatory system in mammals and the single circulatory system in fish (as well as the open circulatory system in insects).

The table below outlines the features of these three types of circulatory systems for comparison:

Feature	Double (Mammals)	Single (Fish)	Open (Insects)
No. of circuits	2	1	0
Pathway	Heart → pulmonary → heart → systemic	Heart → gills → body	Heart → body
Heart passes per cycle	2	1	1
Blood pressure to body	High	Low	Low
Oxygen flow to body	High flowHigh pressure	Lower flowLower pressure	None:No oxygen in haemolymph.Via tracheae.
Blood vessels	Closed	Closed	Mostly absent*

*Some insects have open-ended tubular extensions on their heart that deliver blood to more metabolically active regions.

Blood Vessels

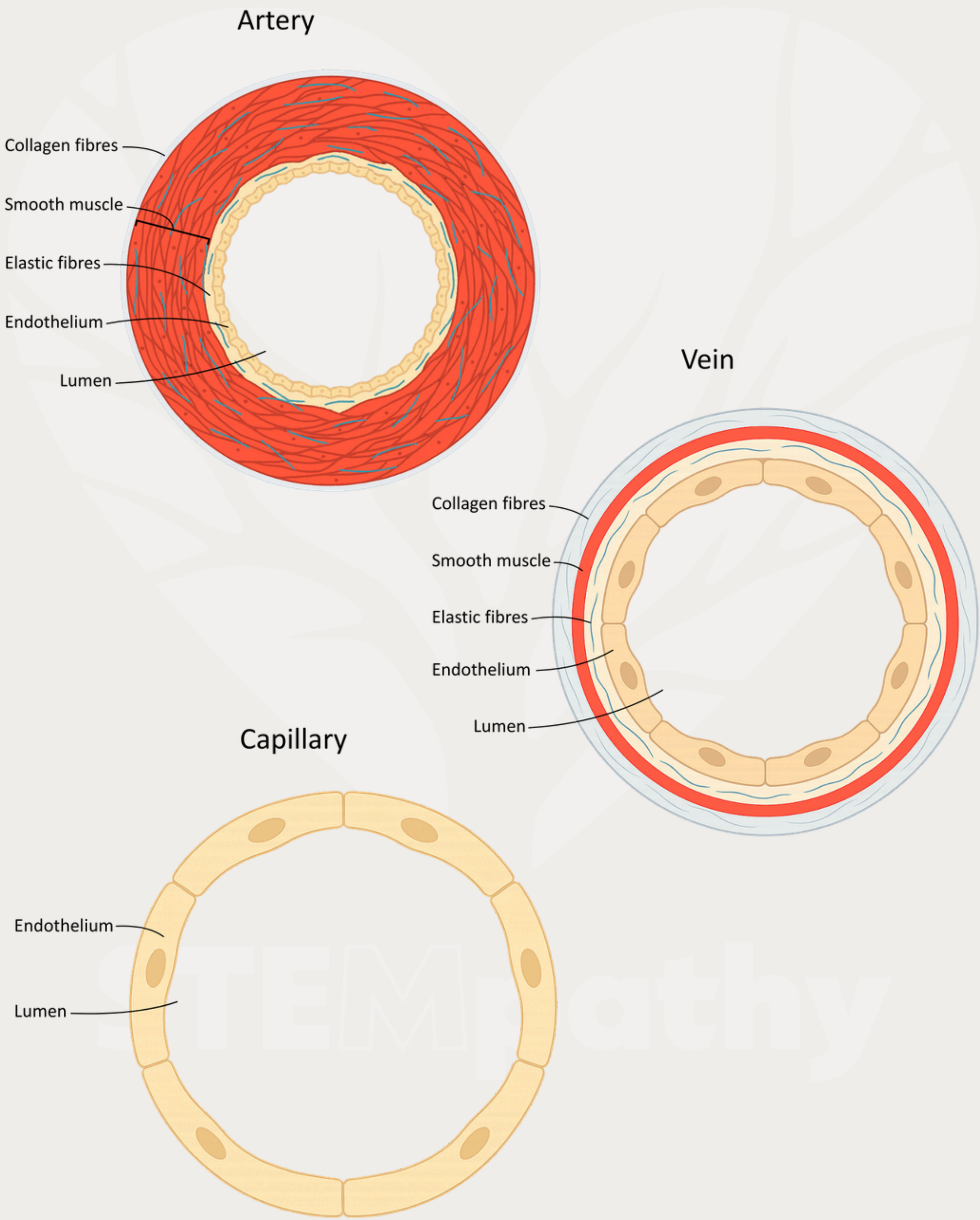
The mammalian **circulatory system** uses a network of blood vessels to transport blood throughout the body.

The **structure** and **function** of these vessels vary depending on their **role** and **position** in the circulatory system.

The table below outlines the structure and function of these blood vessels:

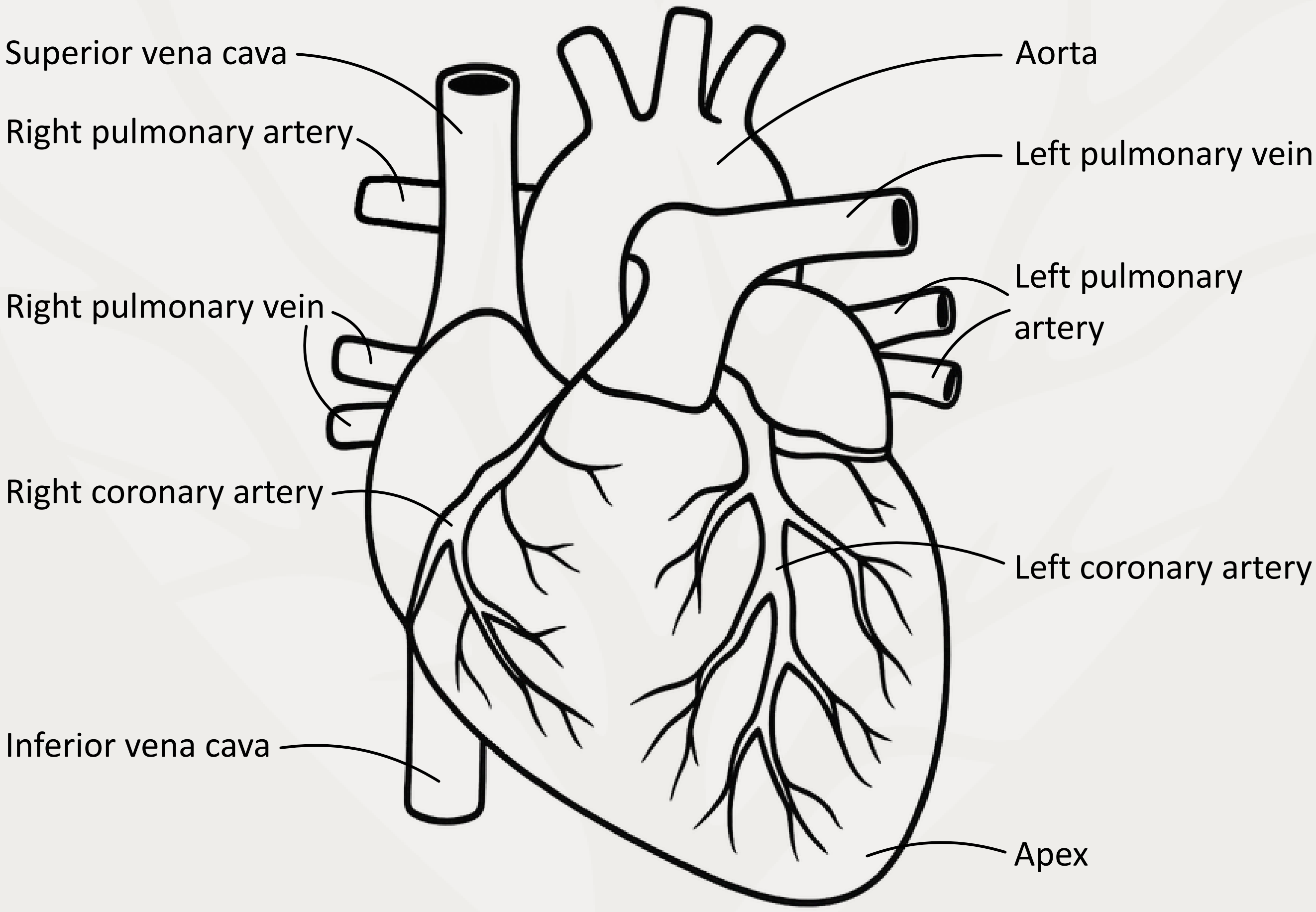
Vessel Type	Function	Structure
Arteries	Carries blood away from the heart at high pressure.	- Thick muscular walls with elastic tissue to recoil and maintain blood flow. - Narrow lumen. - No valves
Arterioles	- Carries blood into the capillaries. - Controls blood flow into the capillaries by vasoconstriction or vasodilation.	- Smaller than arteries. - More smooth muscle, less elastic tissue. - Narrow lumen.
Capillaries	- Exchanges substances between blood and tissues. - Short diffusion distance and large surface area.	- One-cell-thick walls (endothelium only). - Very narrow lumen (one red blood cell wide, to reduce diffusion distance).
Venules	Carries blood from the capillaries and returns it to the veins.	- Small vessels with thin walls - Some smooth muscle, little elastic tissue. - Wider lumen than capillaries.
Veins	Returns blood to the heart.	- Thin walls, wide lumen. - Little smooth muscle and elastic tissue. - Skeletal muscles help blood flow. - Valves are present to prevent backflow.

The diagram below shows the different structural compositions of blood vessel types:



External Structure Of The Heart

The heart is a muscular organ located in the **thoracic cavity** between the lungs. It is enclosed in a tough, fluid-filled sac called the **pericardium**, which **protects** the heart and **reduces friction** as it beats.



The table below outlines the heart's external anatomical features:

Feature	Description	Function
Cardiac muscle	The heart wall is made of myogenic striated muscle.	Contracts rhythmically and does not fatigue.
Coronary arteries	Blood vessels on the external surface that branch off from the aorta.	Supply oxygenated blood to the heart muscle.
Apex	The pointed lower end of the heart tilted towards the left.	Helps identify the left side of the heart in dissection or imaging.

The following major blood vessels are visible on the outside of the heart:

Blood Vessel	Description	Function
Vena cava	Large vein entering the right atrium from above (superior) and below (inferior).	Returns deoxygenated blood from the body.
Pulmonary artery	Emerges from the right ventricle; divides into two branches.	Carries deoxygenated blood to the lungs.
Pulmonary veins	Two veins from each lung enter the left atrium.	Return oxygenated blood from the lungs.
Aorta	Large artery leaving the left ventricle, arching over the heart.	Carries oxygenated blood to the rest of the body.

Internal Structure Of The Heart

The mammalian heart is a **double pump**, keeping **oxygenated** and **deoxygenated** blood **separated** to ensure efficient oxygen transport.

The path blood takes through the heart, when returning deoxygenated blood from the body, is as follows:

[Systemic circuit] → Vena cava → Right atrium → Atrioventricular valve → Right ventricle → Semilunar valve → Pulmonary artery → [Pulmonary circuit] → Pulmonary veins → Left atrium → Atrioventricular valve → Left ventricle → Semilunar valve → Aorta → [Systemic circuit]

The table below outlines the structural components of the heart:

Feature	Description	Function
Left atrium	Upper chamber on the left side.	Receives oxygenated blood from the lungs.
Right atrium	Upper chamber on the right side.	Receives deoxygenated blood from the body.
Left ventricle	Lower chamber on the left side; has a thicker muscular wall.	Pumps oxygenated blood to the body via the aorta. Must pump more strongly to transport blood further.
Right ventricle	Lower chamber on the right side; has a thinner muscular wall compared to the left chamber.	Pumps deoxygenated blood to the lungs via the pulmonary artery.
Septum	Muscular wall separating the left and right sides of the heart.	Prevents mixing of oxygenated and deoxygenated blood.
Atrioventricular (AV) valves	Membranes attached by elastic tissue found between the atria and ventricle.	Prevent backflow of blood from ventricles to the atria.
Semilunar valves	Membranes attached by elastic tissue found at the ventricle exits.	Prevent backflow of blood from arteries into the ventricles.
Coronary arteries	Branches from the aorta that return to the outside of the heart, supplying it with oxygenated blood.	Ensure the heart muscle gets oxygen and glucose for continuous aerobic respiration.

The Cardiac Cycle

The cardiac cycle is the sequence of events that occurs during one complete heartbeat.

The table below outlines the 3 stages of the cardiac cycle:

Stage	Key Events
Atrial systole	Both atria contract, increasing the pressure in the atria. Blood is pushed through the AV valves into the ventricles. Ventricles remain relaxed.
Ventricular systole	Both atria relax. Both ventricles contract, increasing the pressure in the ventricles. AV valves close, preventing backflow. Semilunar valves open, forcing blood into the pulmonary artery and the aorta.
Diastole	Ventricles relax, and as the pressure drops, the semilunar valves close to prevent backflow from the arteries. Atrial pressure increases as blood flows passively into the atria.

The table below compares the overall pressure and volume of blood in the heart across the different stages:

Stage	Event	Pressure	Volume (of blood)	Notes
Diastole	Heart relaxes; chambers fill	↓	↑	AV valves open, SL valves closed
Atrial systole	Atria contract → ventricles fill	↑	Same	AV valves remain open
Ventricular systole	Ventricles contract → blood is forced out	↑ ↑	↓	AV valves shut, SL valves open

Coordination Of Heart Contraction

The heart is **myogenic**, meaning it **generates** its own electrical **impulses** to **control** the rhythm of atrial and ventricular **contraction** without stimulation from the nervous system.

Electrical stimulation **coordinates** the atria and ventricular **contractions**, ensuring they do so in the right order and at the right time, to effectively move blood throughout the heart and prevent backflow.

Myogenic control of the heart is carried out by the components outlined in the table below:

Component	Location & Structure	Function
Sinoatrial Node (SAN)	Right atrium wall.	Generates electrical impulses at regular intervals, acting as a natural pacemaker.
Atrioventricular Node (AVN)	In the upper septum between the atria and ventricles.	Delays the impulse slightly to allow the atria to finish contracting before the ventricles contract.
Bundle of His	Conductive fibres running down the septum wall to the apex of the heart.	Transmits impulses from the AVN to the Purkinje* fibres in the ventricles.
Purkinje fibres*	Spread through the ventricular walls up from the apex.	Distribute the impulse throughout the ventricular walls to ensure even ventricular contraction up from the apex.

*Purkinje fibers are also known as Purkyne tissue.

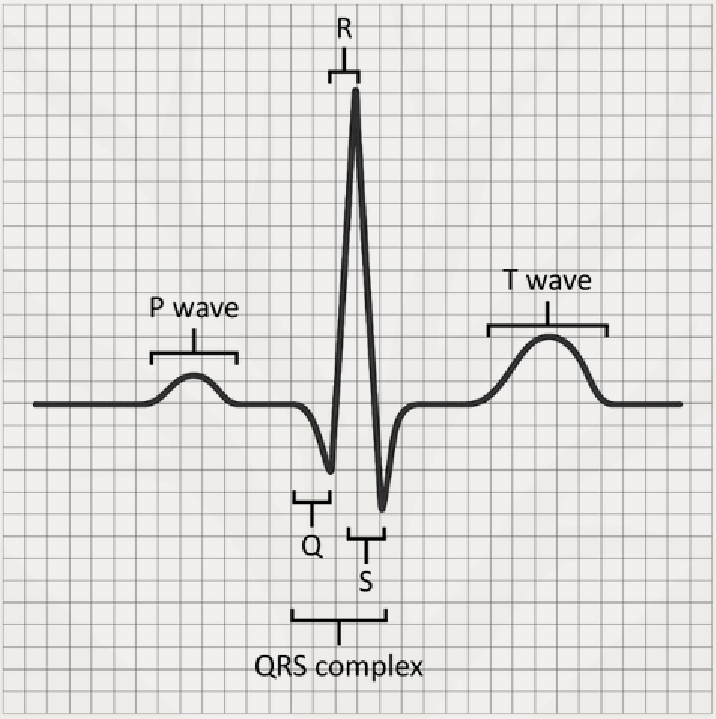
The order of events is as follows:
SAN fires → atria contract → AVN delays the impulse → Bundle of His carries the impulse to Purkyne fibres → Purkyne fibres spread the impulse → ventricles contract from apex upwards

Electrocardiograms

The electrical activity of these events can be recorded, measured and observed with an **ECG**.

There are three distinct 'waves' of polarisation and depolarisation that can be observed:

- **P wave**: Depolarisation of the atria (they are electrically stimulated and contract).
- **QRS** complex: Depolarisation of the ventricles (they are electrically stimulated and contract).
- **T wave**: Repolarisation of the ventricles (the ventricles relax).



Heart conditions can be identified and classified with the use of ECG:

Condition	ECG Feature	Trace	Cause
Tachycardia	Rapid heart rate: >100 bpm		Stress Fever Exercise
Bradycardia	Slow heart rate: <60 bpm		Can be normal Disease
Ectopic beat	Early contraction of atria or ventricles.		Often harmless Can indicate arrhythmia.
Fibrillation	Uncoordinated contractions (an irregular trace).		Damage to myogenic structures

Module 3: Haemoglobin and Red Blood Cells

Red Blood Cells

E**rythrocytes** are specialised cells adapted for the **transport of oxygen** in the blood by using **haemoglobin**.

The table below outlines the structural adaptations of RBCs:

Structure	Function
No nucleus or organelles	Maximises space for haemoglobin (Hb), allowing more oxygen to be carried.
Biconcave shape	Increases the surface area to volume ratio, speeding up the diffusion of oxygen and carbon dioxide.
Flexible membrane	Enables cells to squeeze through narrow capillaries without them rupturing.
Thin cell	Short diffusion distance between plasma and haemoglobin.

Oxygen transport and haemoglobin

RBCs are packed with **haemoglobin**, and each one can bind **reversibly** with up to four oxygen molecules, forming **oxyhaemoglobin** (HbO_2).

Haemoglobin + O → Oxyhaemoglobin

Module 3: Haemoglobin and Red Blood Cells

Oxygen affinity

Whether or not oxygen will bind to haemoglobin depends on the haemoglobin's **affinity** for oxygen.

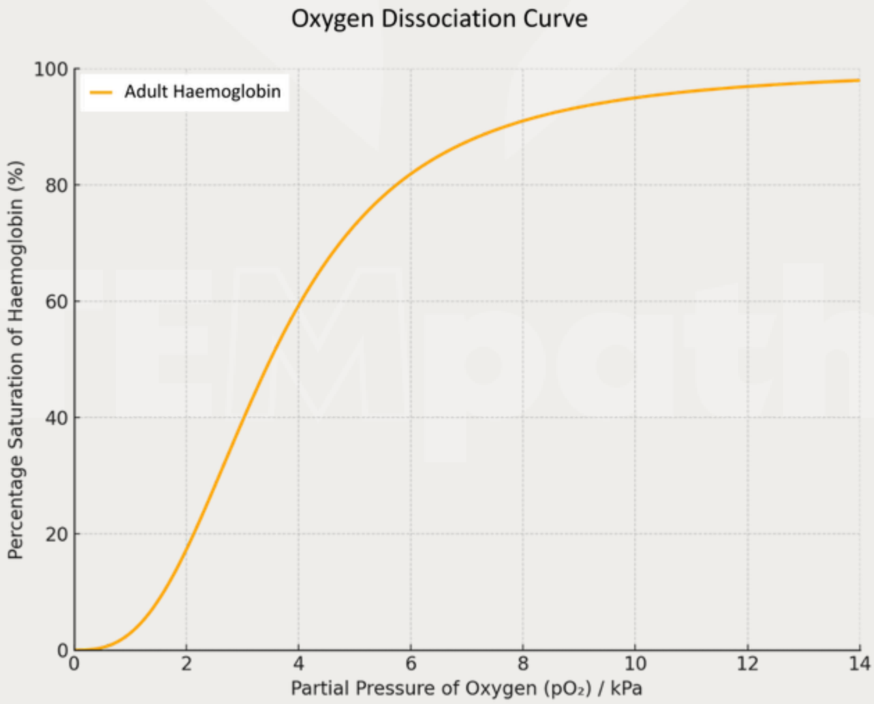
The table below outlines the different factors that can affect haemoglobin's affinity for oxygen:

Factor	Effect on Affinity	Explanation
Cooperative binding	Varies	The number of pre-existing oxygen atoms bound to haemoglobin can make it easier or harder for subsequent oxygen atoms to bind.
Partial pressure of CO_2 (pCO_2)	Decreases with higher pCO_2 (Bohr shift)	CO_2 lowers pH, causing haemoglobin to release oxygen more readily.
pH (H^+ concentration)	Decreases with lower pH	H^+ ions bind to haemoglobin, changing its shape and reducing oxygen affinity.

Cooperative Binding

Cooperative binding is the phenomenon by which the **first** oxygen atom **binding** to haemoglobin makes it easier for **subsequent** oxygen atoms to also bind.

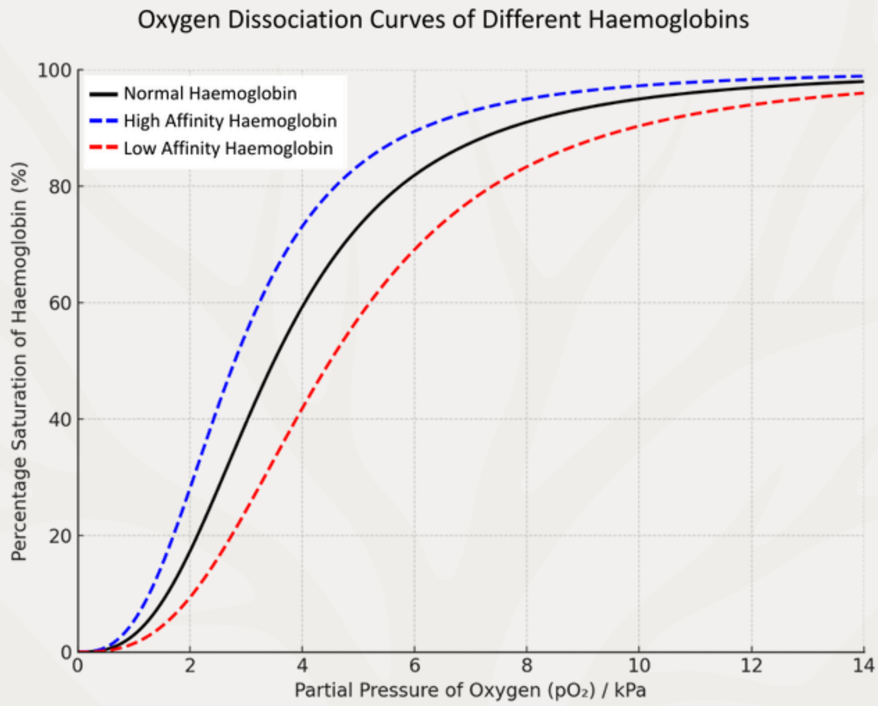
This is reflected in the **sigmoid curve** of an **oxygen dissociation curve** showing **haemoglobin's saturation**.



Module 3: Haemoglobin and Red Blood Cells

Haemoglobin's hold on oxygen **varies at different pO_2 levels** because its shape changes due to carbon dioxide dissolved in the surrounding tissue fluid - the acidity affects its **tertiary structure**.

The graph below compares how easily different haemoglobins bind to oxygen, including normal human haemoglobin, a higher-affinity form (like fetal haemoglobin), and a lower-affinity form (such as in active tissues):



The **black** line is typical **human** haemoglobin, the **blue** line is haemoglobin which **more readily binds** with oxygen (it has a higher affinity), and the **red** line is haemoglobin which **less readily binds** with oxygen (it has a lower affinity).

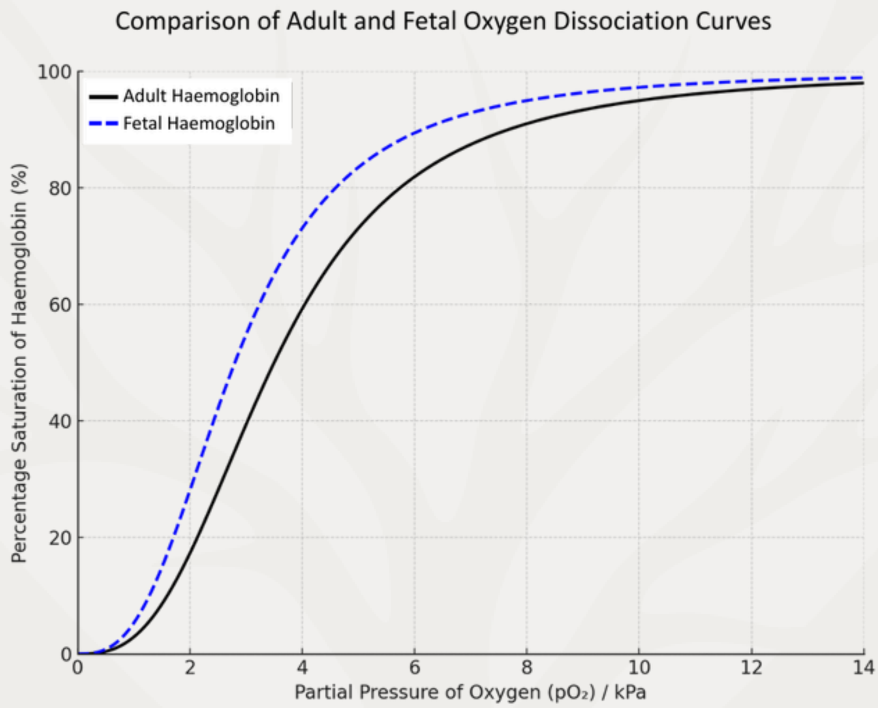
Interpreting a standard (Adult) Oxygen Dissociation Curve:

- The curve is **sigmoidal** (S-shaped) due to **cooperative binding**: as one molecule of oxygen binds to haemoglobin, the molecule's affinity for oxygen increases.
- At **high pO_2** (e.g. in the lungs), haemoglobin becomes **highly saturated** with oxygen.
- At **low pO_2** (e.g. in respiring tissues), haemoglobin releases oxygen, aiding diffusion into cells.

Comparing Adult and Fetal Haemoglobin

The **placenta** has a relatively **low pO_2**, causing maternal haemoglobin to release oxygen, which can then be taken up by fetal haemoglobin (which has a higher affinity for oxygen at the same pO_2).

The **fetal haemoglobin curve** is **shifted to the left** of the adult haemoglobin curve at the same pO_2:



Fetal haemoglobin is more saturated at the same pO_2 compared to **adult haemoglobin**, meaning it will **load** oxygen in conditions where **adult** Hb would **release** it; facilitating the **transfer** of oxygen from maternal blood to fetal blood at the placenta.

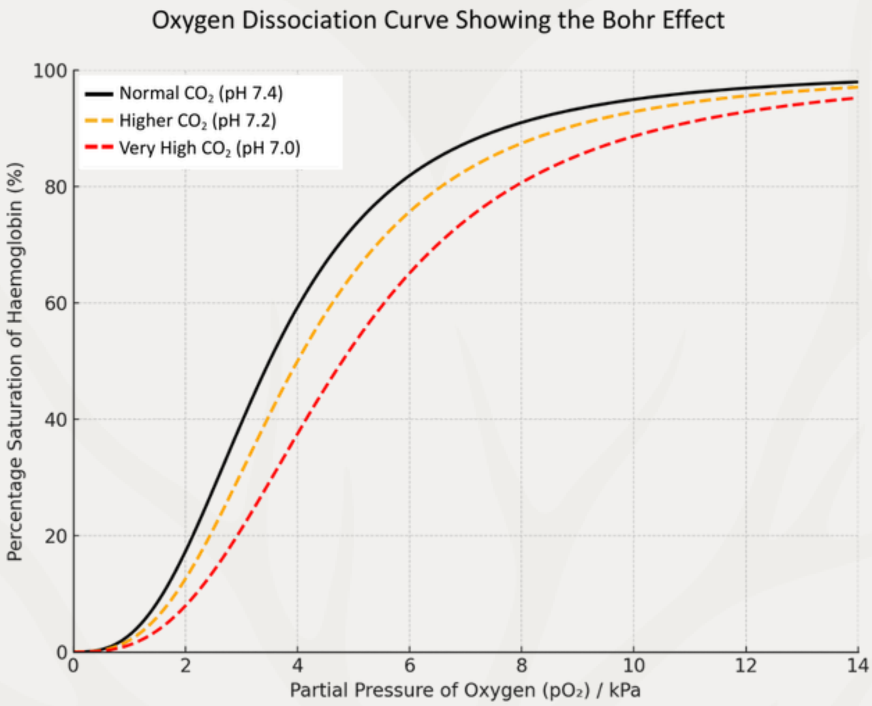
Bohr shift

Bohr shift (also known as the Bohr effect) is where **increasing CO_2** concentrations in the blood plasma **lower** haemoglobin's **affinity** for oxygen.

This is because **CO_2** dissolves in blood plasma to form **carbonic acid**, lowering its pH and changing haemoglobin's **conformational shape**.

The result of a Bohr shift is to **promote** oxygen unloading in actively **respiring tissues**.

The graph below shows the effect of different concentrations of CO_2 on a standard dissociation curve:



If there is **more carbon dioxide**, then the **pH drops**, so haemoglobin is (on average) **less saturated** (as it is releasing oxygen more readily due to a lower affinity). The **curve shifts to the right**. This is the **Bohr effect**.

Carbon Dioxide Transport

CO_2 **diffuses** into red blood cells (RBCs) and reacts with water, **catalysed** by **carbonic anhydrase**:

$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$

The **hydrogencarbonate ions** (HCO_3^-) **diffuse** out of the RBC into the **plasma**.

Chloride ions (Cl^-) move into the RBC from the plasma, balancing out the **electronegativity** of the departing HCO_3^-; this is called the **chloride shift**.

Module 3: Tissue Fluid Formation

Tissue Fluid

Tissue fluid is the liquid that **surrounds** body cells, and enables the **exchange of substances** (e.g. oxygen, glucose, carbon dioxide, urea).

Tissue fluid **forms at the arteriole end** (where there is a higher pressure) of the capillary bed, and then is **'reabsorbed' at the venous ends** (where the osmotic pull of water pulls it back in).

The table below compares the composition of blood plasma, tissue fluid and lymph:

Component	Plasma	Tissue Fluid
Water	✓	✓
Ions (e.g. Na^+, Cl^-)	✓	✓
Glucose	✓	✓
Amino acids	✓	✓
Plasma proteins	✓	✗*
RBCs	✓	✗
WBCs	✓	✗
Function	Transports substances in the blood.	Surrounds cells for substance exchange.

*Some proteins may be present, such as antibodies from lymphocytes.

Tissue Fluid Formation

The **formation** and **return** of tissue fluid is **determined** by two **opposing pressures**:

- **Hydrostatic pressure**: The **outward force** exerted by the blood on capillary walls caused by heart contractions (blood pressure).
- **Oncotic pressure**: The **inward osmotic pull** caused by **plasma proteins** (mainly albumin) that cannot leave the capillaries, causing a low potential.

Module 3: Tissue Fluid Formation

The table below outlines the formation and return of tissue fluid:

Location	Key Events
Arterial end	- Hydrostatic pressure (from heart contraction) is higher than oncotic pressure. - Water and small solutes are forced out of the capillaries into tissue spaces. - Large plasma proteins and red blood cells remain inside.
Venous end	- Hydrostatic pressure is lower than oncotic pressure. - Oncotic pressure draws water (and dissolved solutes) back in by osmosis down a water potential gradient. - Around 90% of the fluid is reabsorbed.
Lymphatic system	- About 10% of fluid is left over and it enters the lymphatic system, becoming lymph, which eventually returns to the blood.

The Need For Transport Systems

Multicellular plants cannot fulfil their metabolic needs or excrete all waste by diffusion alone.

The table below outlines the limitations which make diffusion insufficient:

Limitation	Explanation
Low surface area to volume ratio	As plants increase in size, diffusion of substances via the outer surface cannot keep up with internal demands.
Metabolic activity	Regions of high growth (e.g. meristems, leaves and storage organs) need a constant supply of substrates and to remove excess products.
Diffusion distance	Many specialised cells are too far away from the source of a metabolic input (e.g. leaves from water, or roots from sucrose).

Vascular Systems In Plants

The **vascular bundle** is a collection of **xylem** and **phloem** tissue:

- **Xylem** transports **water** and dissolved **mineral ions** from the roots to the leaves (only up) using **mass flow**.
- **Phloem** transports organic solutes such as **sucrose**, amino acids, and hormones (dissolved as phloem sap) throughout the plant (**up and down**) using **translocation**.

Xylem Tissue

The table below outlines the structural features of **xylem tissue** and its benefits:

Structural Feature	Benefit
Dead hollow cells	Allow an uninterrupted flow of water from the root to the leaf through a continuous column
Vessels with no end walls	Create a continuous tube for mass flow
Lignin rings/spirals in cell walls	Lignification strengthens cell walls to provide mechanical support to the xylem (resisting collapse under tension) and to support the plant
Bordered pits	Gaps in the lignified xylem vessels that allow water to move from one xylem to another, or into surrounding tissue
Narrow lumen	Enables capillary action to support water cohesion, stopping the water column from breaking