OCR A Level Biology

A (H420)
Revision Notes for Year 1

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Contents

All topics below are hyperlinks
Click home to come back to this page

Module 2: Foundations in Biology

Module 3: Exchange and Transport

Module 4: Biodiversity, Evolution and Disease

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.

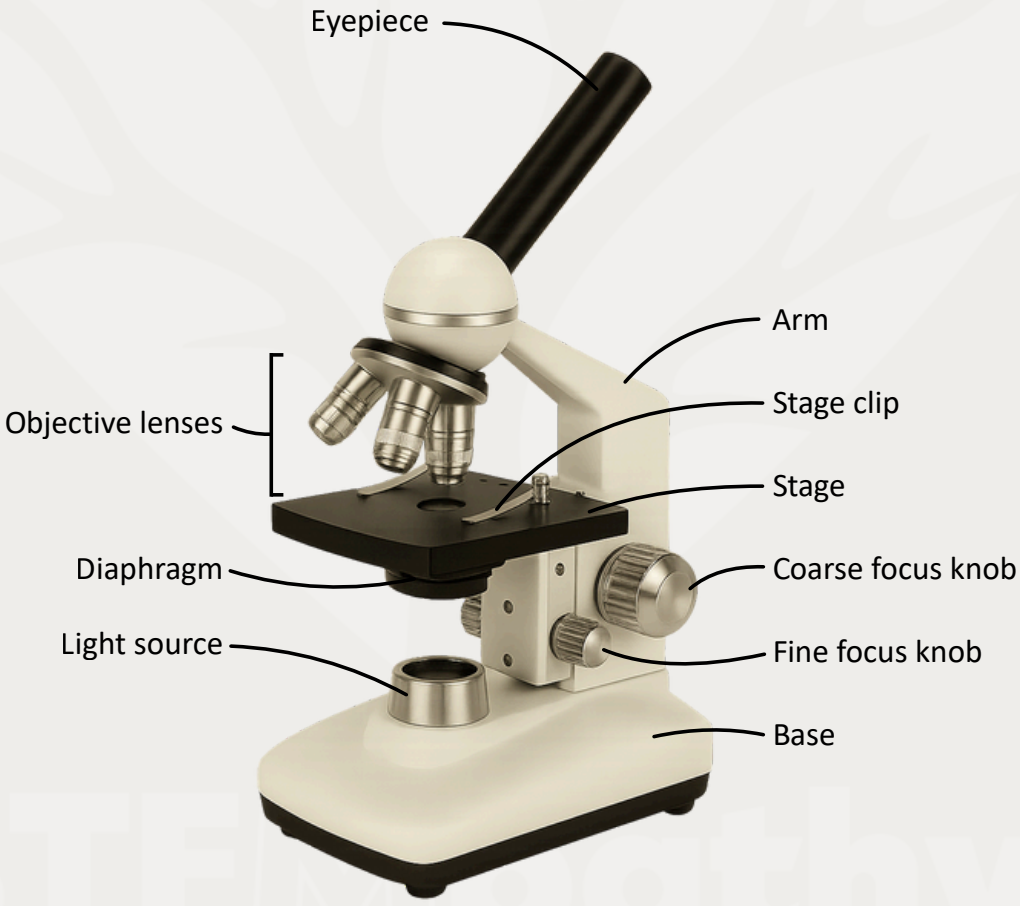
Microscopy Calculations

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:

$$Magnification = Image\ Size \div Actual\ Size$$

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:

$$Actual\ Size = Image\ Size \div Magnification$$

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:

$$Image\ Size = Actual\ Size \times Magnification$$

Where:

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

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.

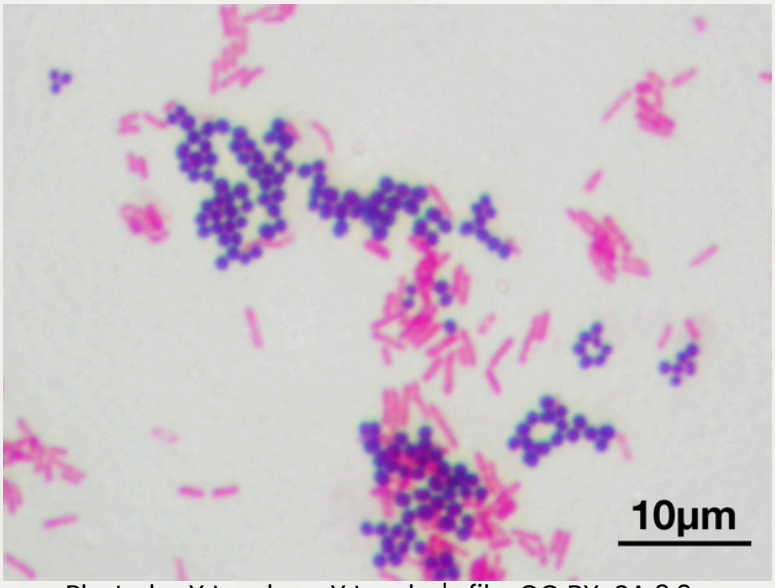


Photo by Y tambe - Y tambe's file, CC BY-SA 3.0

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.

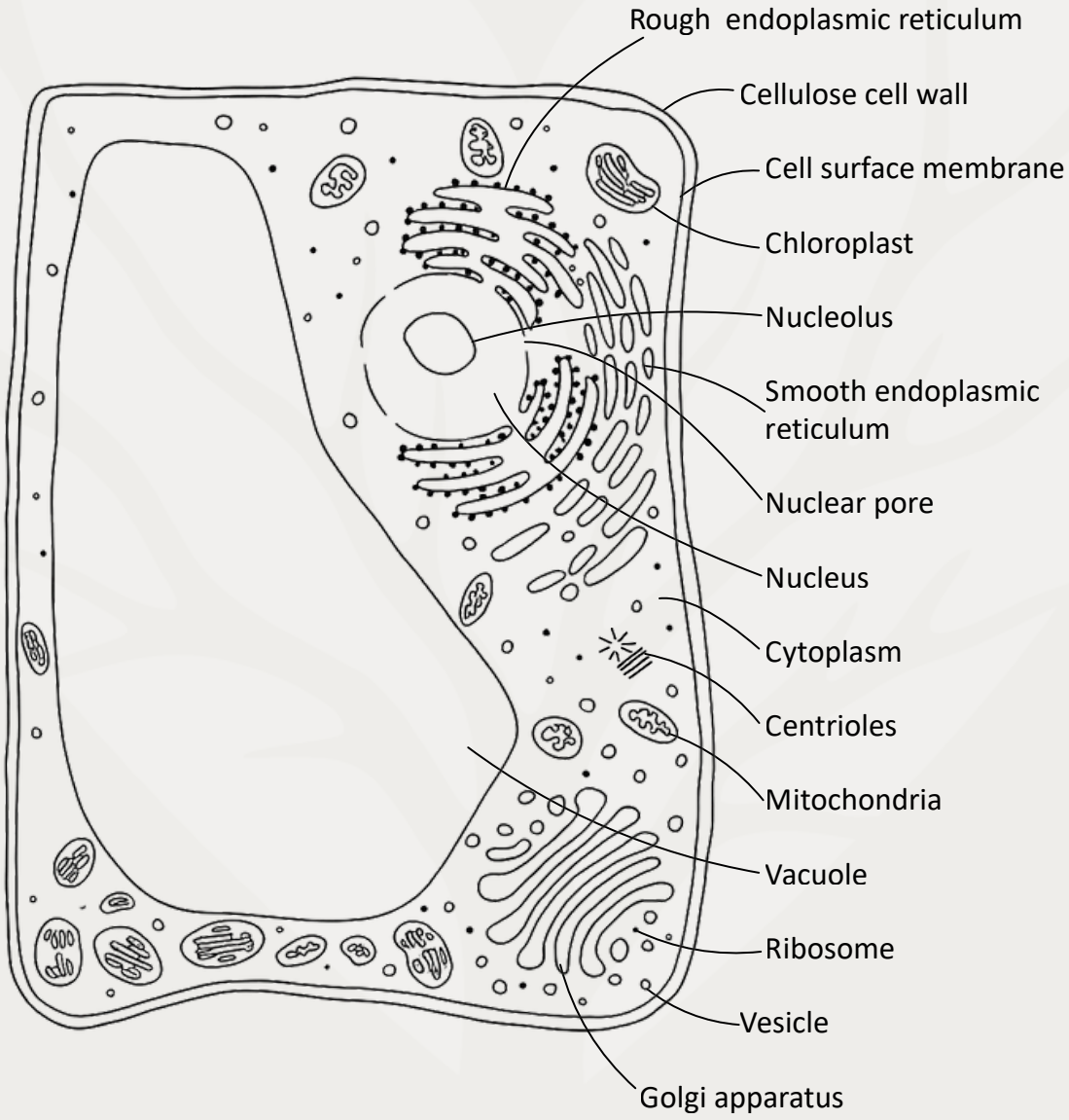
Preparing a Microscope Slide for Living Organisms

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

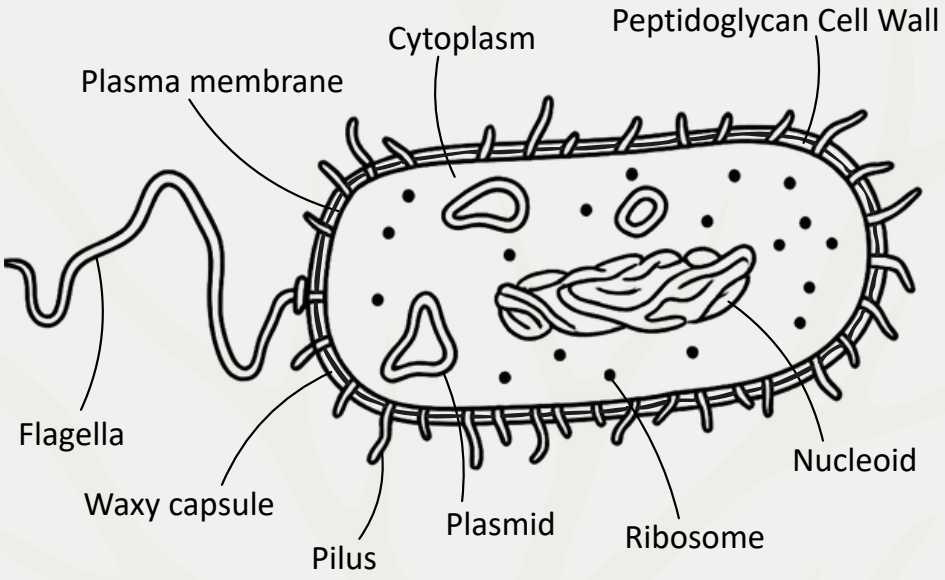
The table below outlines the structure and function of **organelles without membranes**:

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.

Module 2: Prokaryotic Cell Structure

Prokaryotic Organisms

Prokaryotic 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**.

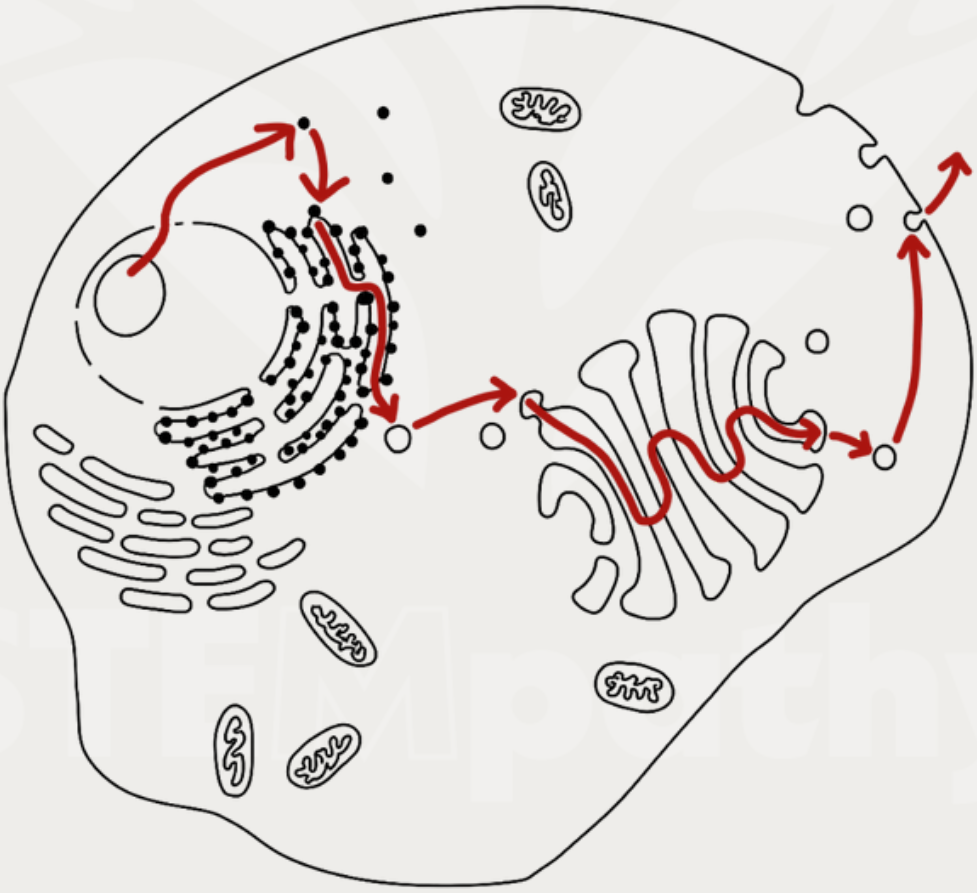
It consists of two phases, **transcription** and **translation**:

- **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.

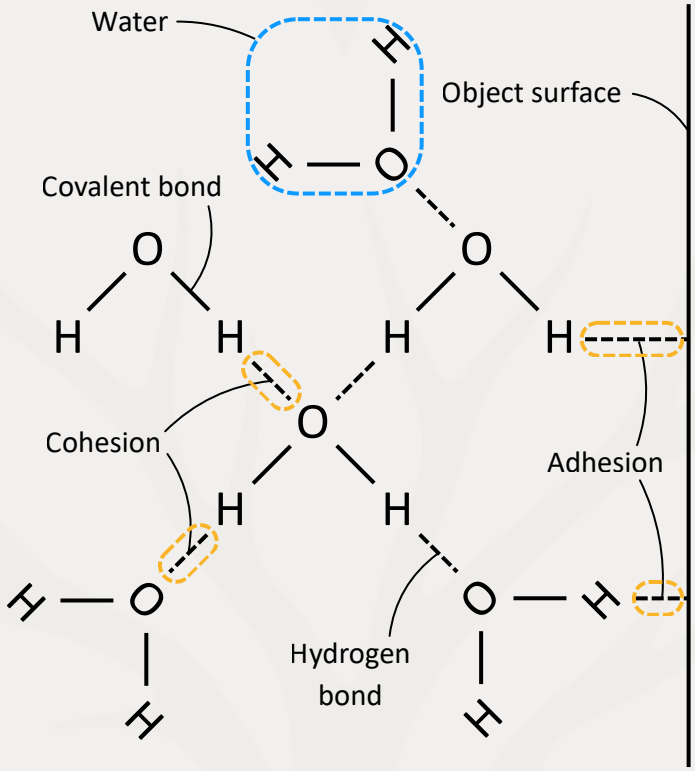
The order of **organelles involved** (usually) is:

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.

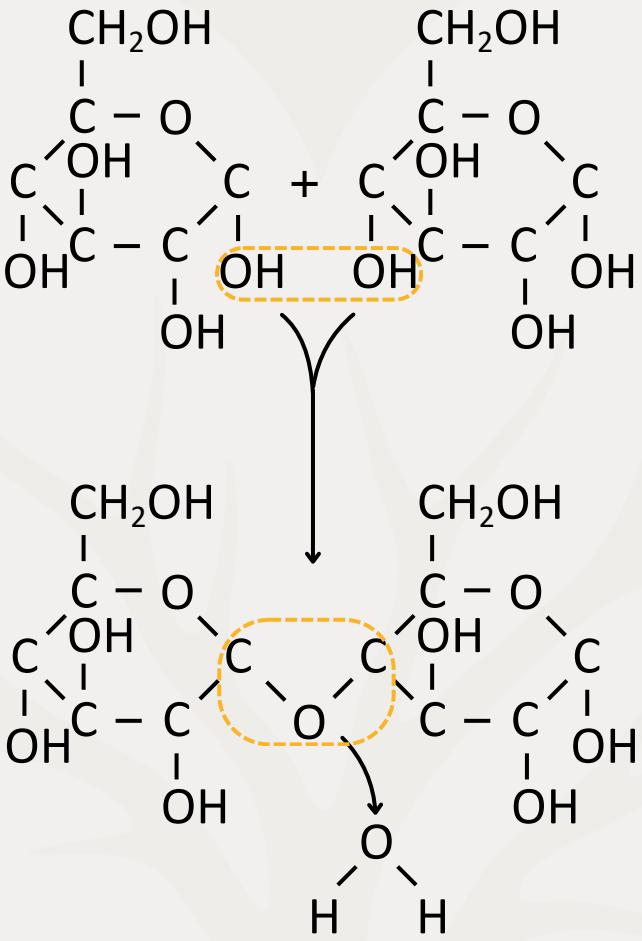
Biomolecule	Elements Present	Monomer	Polymer(s)	Examples
Carbohydrates	C, H, O	Monosaccharides	Polysaccharides	Maltose, Sucrose, Lactose, Starch, Glycogen, Cellulose
Lipids	C, H, O	Fatty acids & Glycerol	Triglycerides, Phospholipids	Phospholipids, Cholesterol, Steroids
Proteins	C, H, O, N, S**most	Amino 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**.

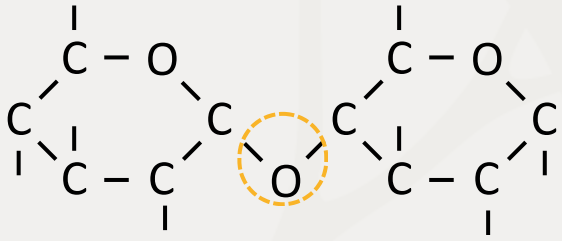
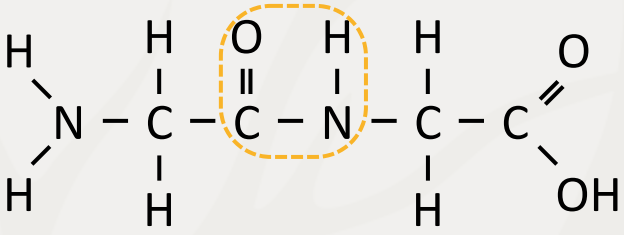
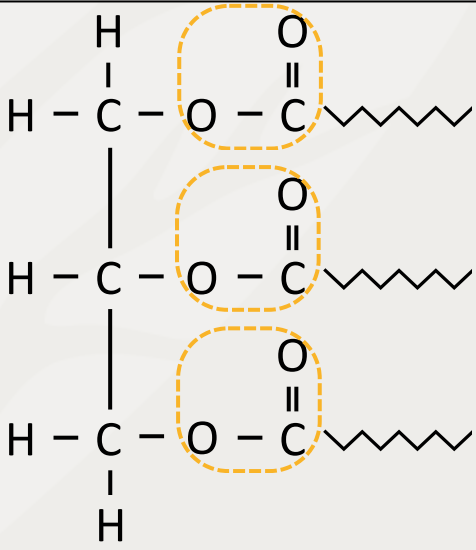
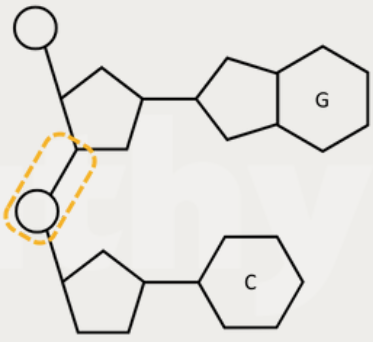
A **polymer** is a large molecule made from **many monomers** joined together in **condensation reactions**.

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:



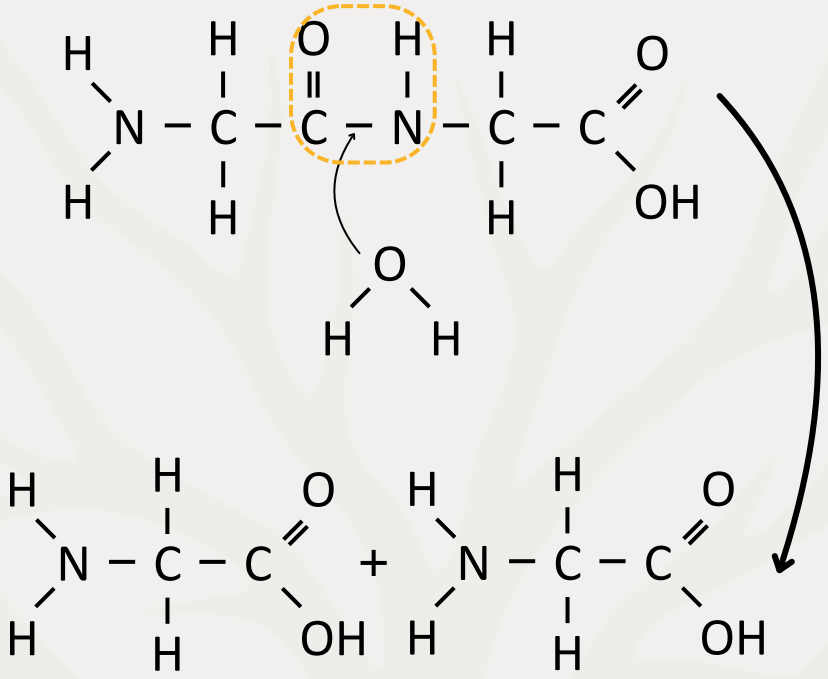
The table below gives an overview of the bonds in biological molecules formed by condensation reactions.

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**.

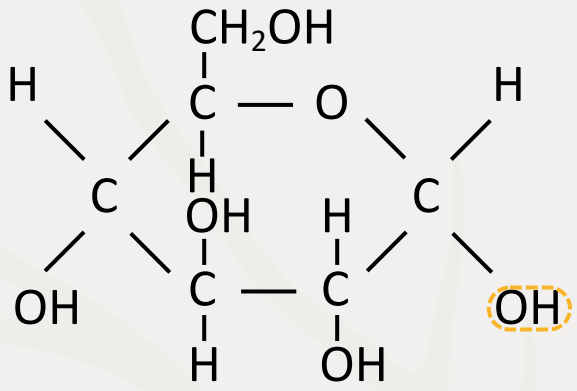
A **hydrolysis reaction** is when a water molecule is used to **break** a **covalent bond**, producing two molecules from one.

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

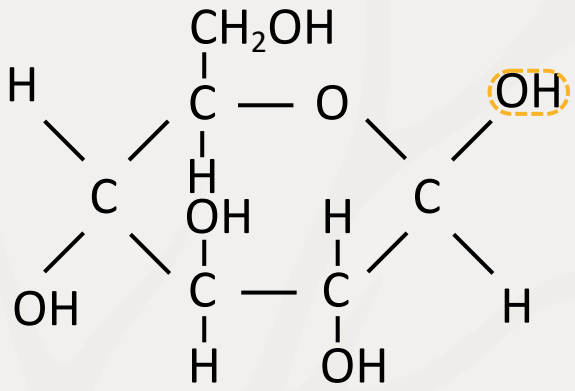


Carbohydrates

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:

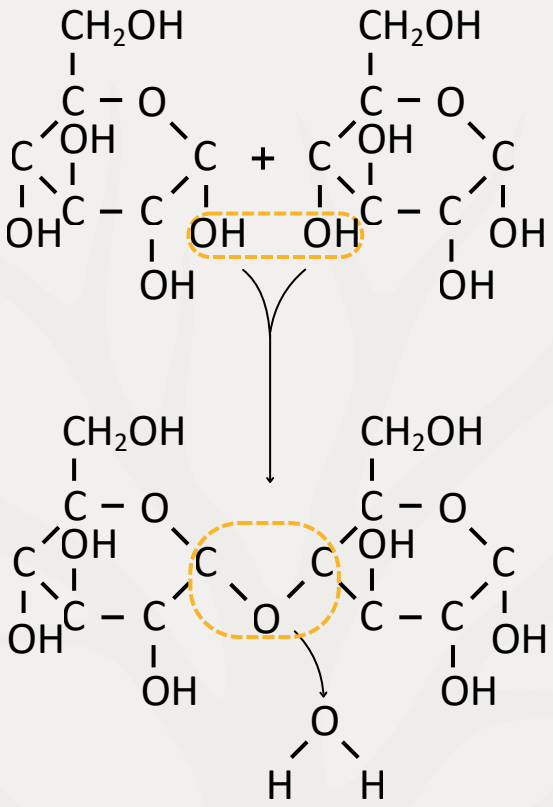
Monosaccharide	Molecular Formula	Type	Use
α-Glucose	$C_6H_{12}O_6$	Hexose	Energy source and primary respiratory substrate.
β-Glucose	$C_6H_{12}O_6$	Hexose	Energy source, a component of glycolipids and glycoproteins
Ribose	$C_5H_{10}O_5$	Pentose	A component of nucleotides (e.g. ATP, RNA)

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

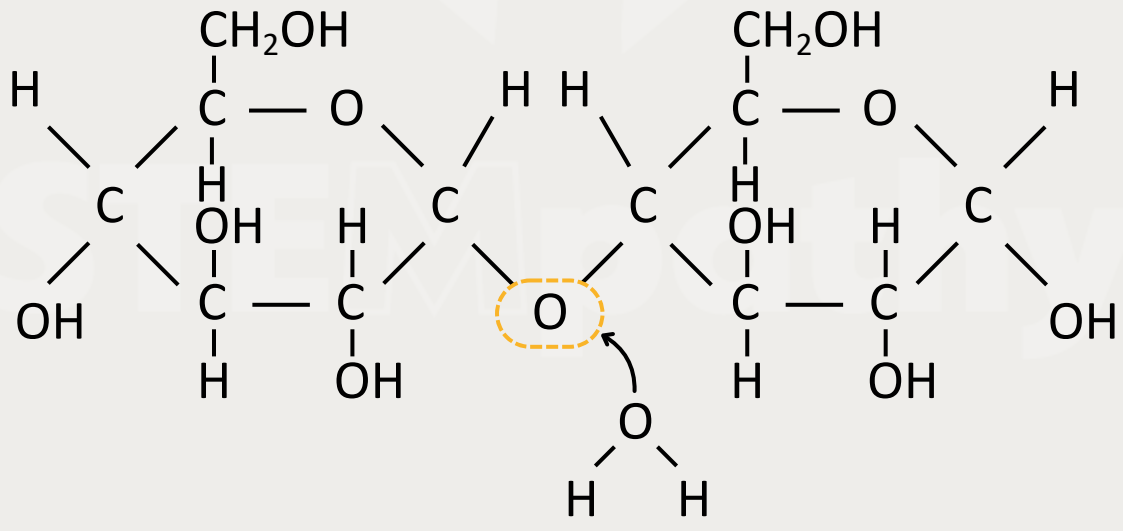
Disaccharide and Polysaccharide Formation

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:

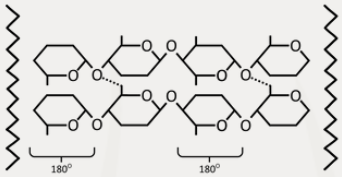
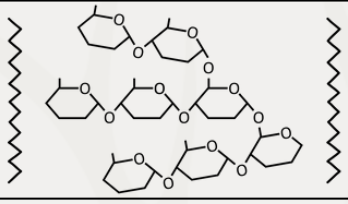
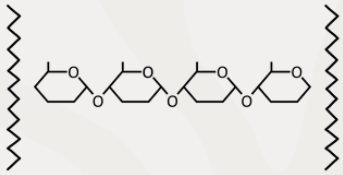
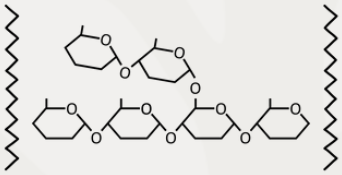
Disaccharide	Monomers joined	Use
Cellobiose	β-Glucose + β-Glucose	Intermediate in cellulose breakdown
Lactose	α-Glucose + β-Galactose	Sugar in milk and an energy store
Maltose	α-Glucose + α-Glucose	Intermediate in starch digestion
Sucrose	α-Glucose + Fructose	Transport sugar in plants

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).	✓

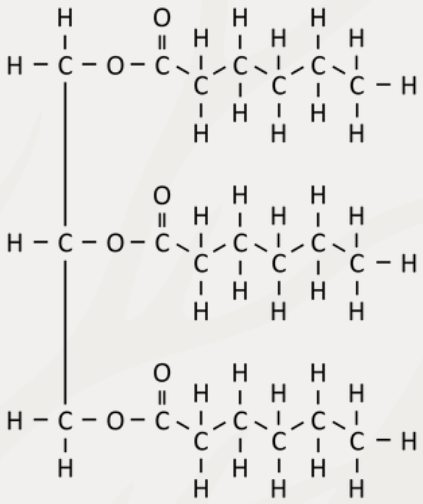
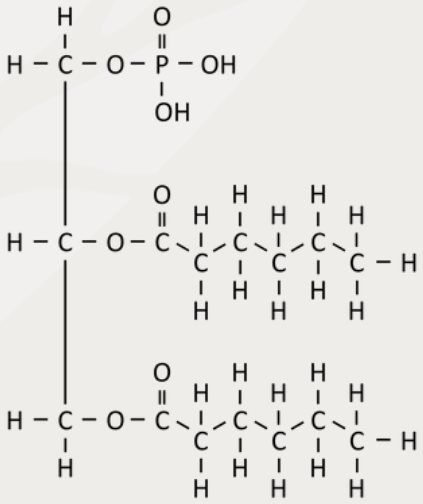
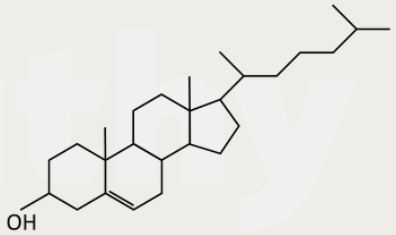
The table below outlines how structure relates to the function of each polysaccharide's use:

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.

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.

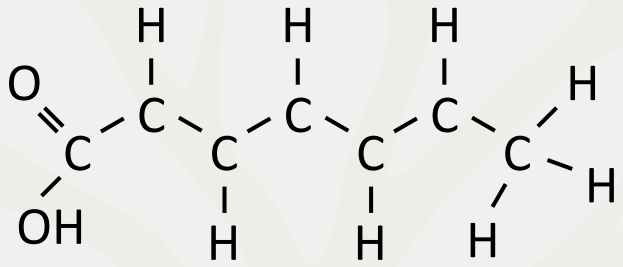
Fatty acids are **not lipids**, but are instead used to make them.

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

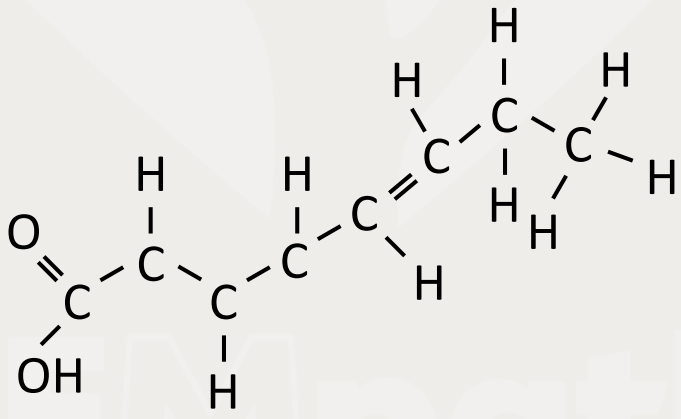
They can either be **saturated** or **unsaturated**.

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



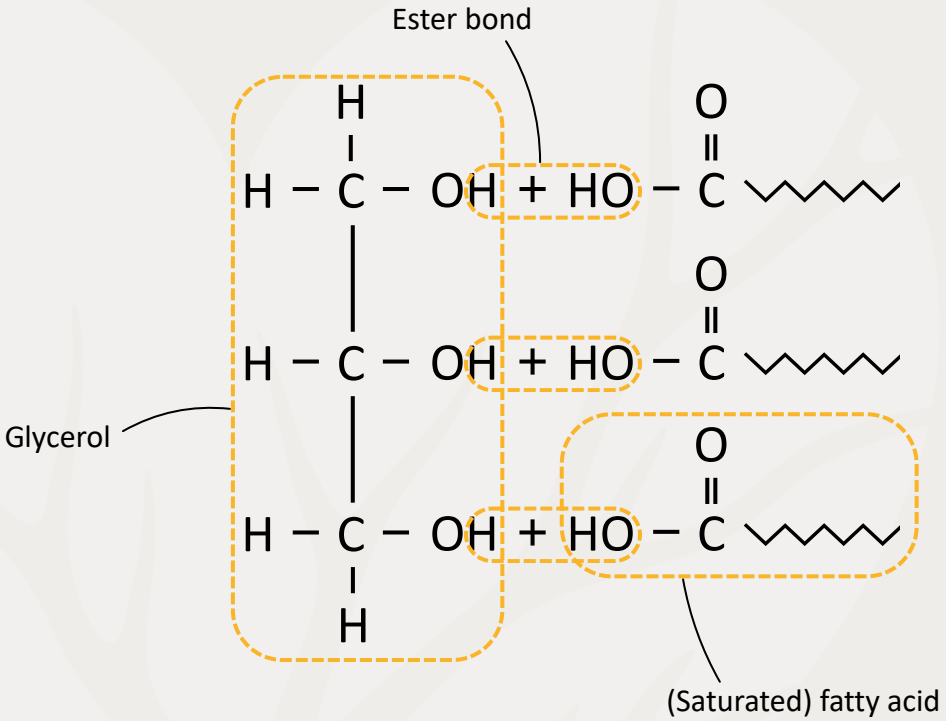
Unsaturated fatty acid

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

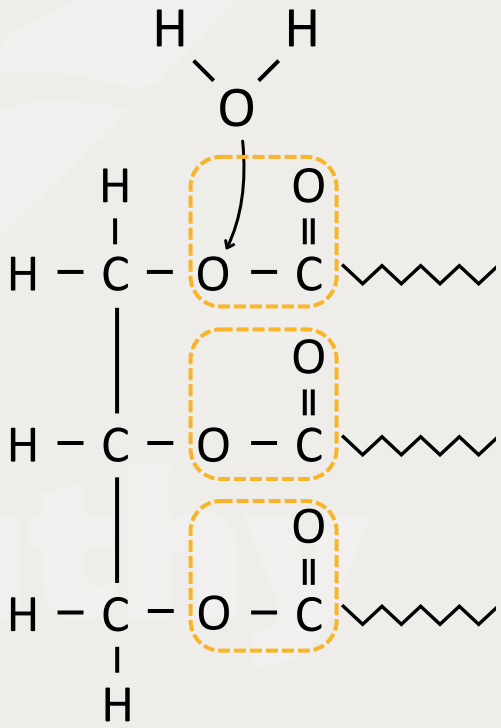
Triglyceride Synthesis

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**.



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

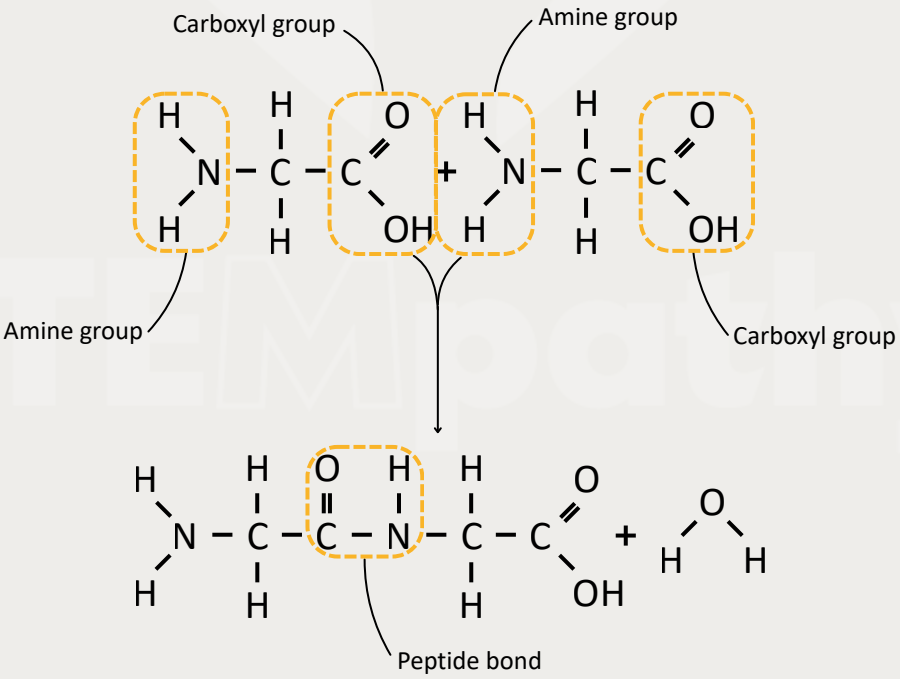
Proteins are important biological molecules with structural and metabolic roles determined by their structure. They can be **enzymes**, **hormones**, **antibodies**, structural scaffolds or transport molecules.

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

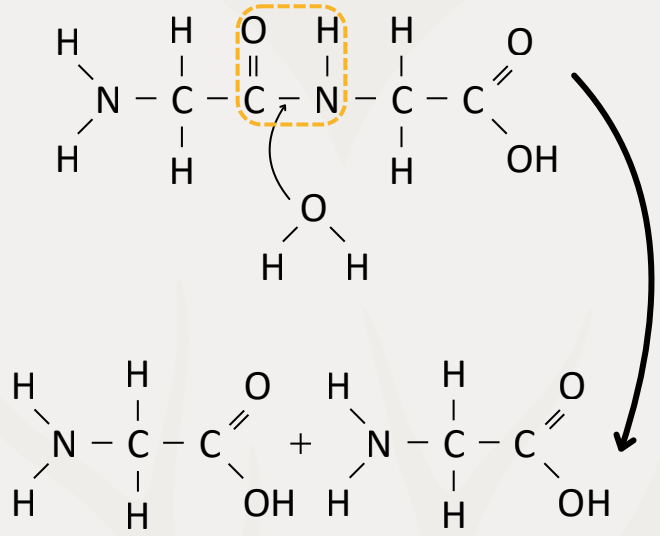
Level	Definition	Structural Bonds
Primary	Order of amino acids in a polypeptide chain	Peptide bonds
Secondary	Coiling and folding of the polypeptide chain into α-helix or β-pleated sheets (zig-zag)	Hydrogen bonds (between different amino acids' -NH and -CO groups)
Tertiary	The 3D shape of the protein, 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

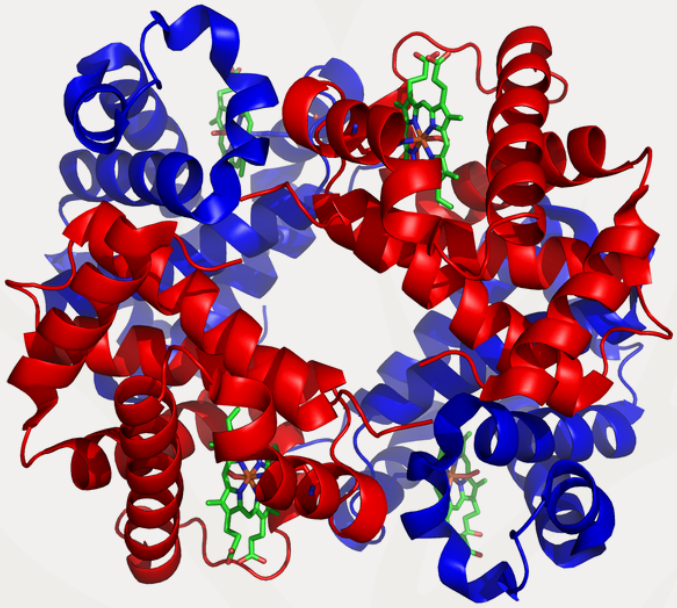
There are **2 types** of protein: **fibrous** and **globular**.

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:

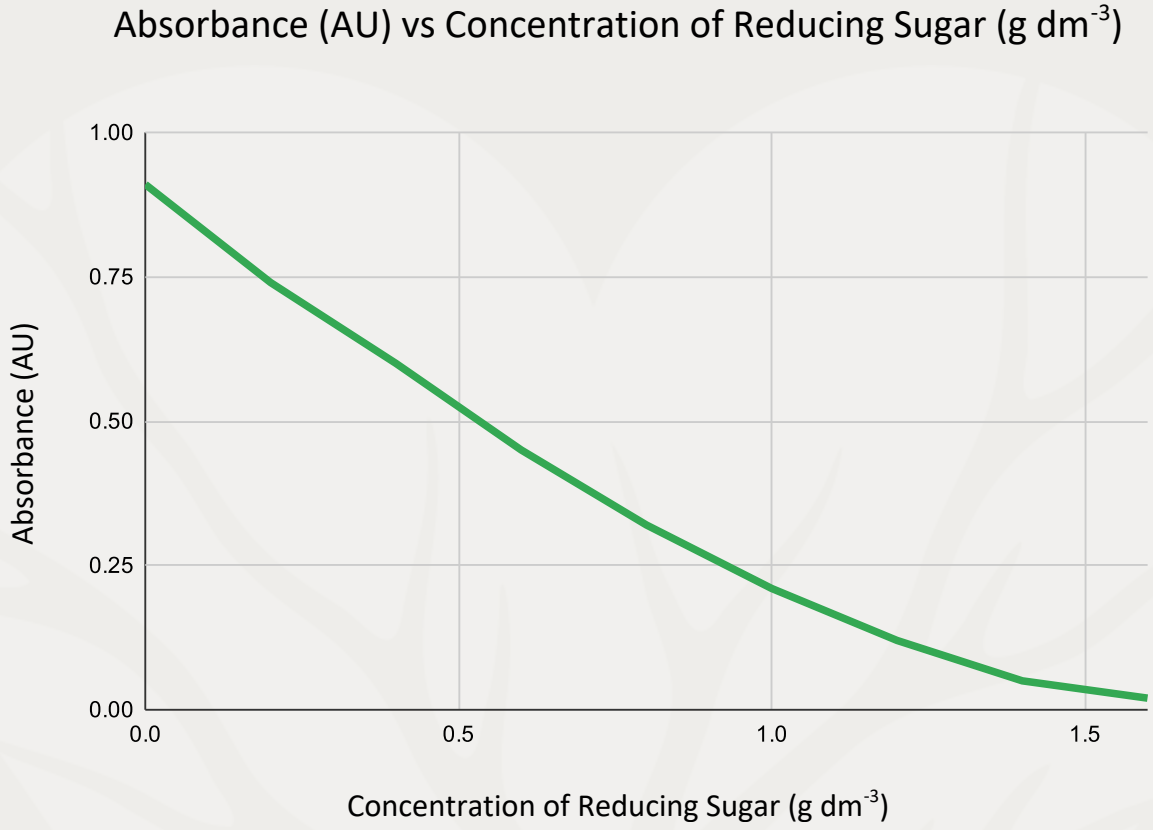
1. Add excess Benedict's reagent to your sample and heat it to 80°C.

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

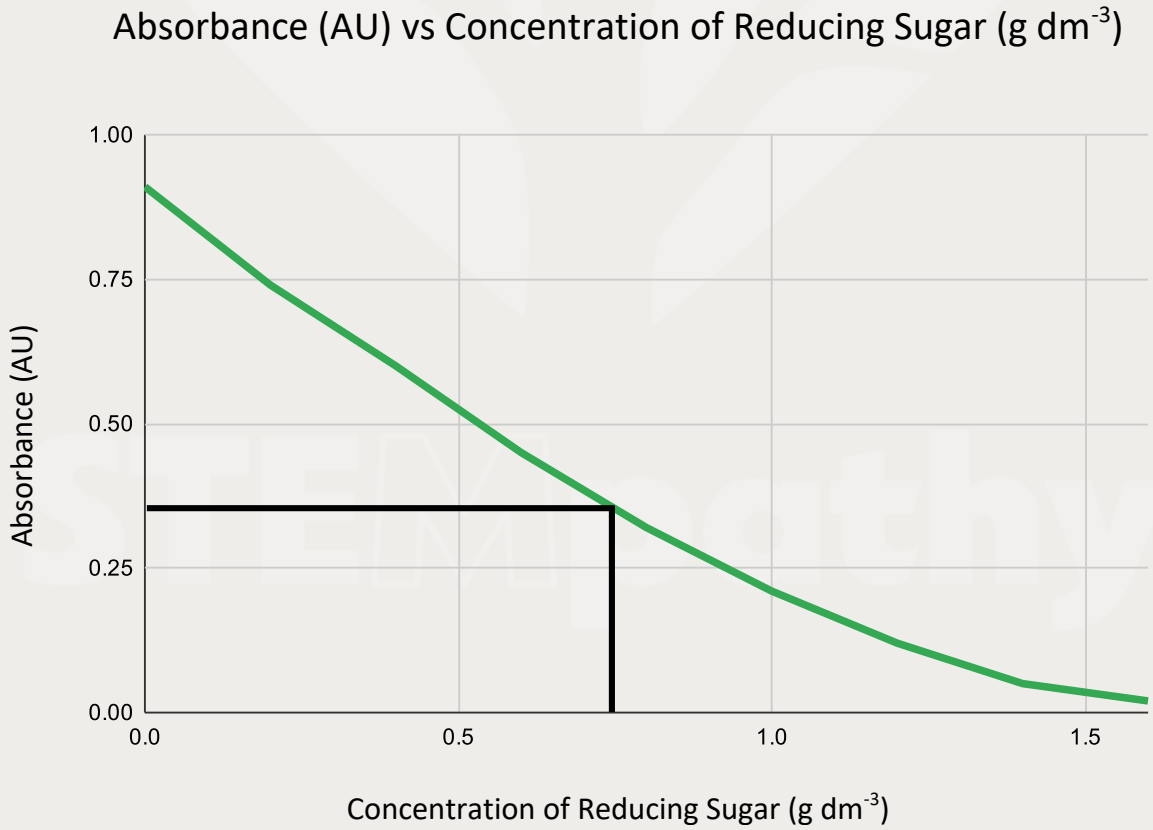
2. Centrifuge the mixture to remove the precipitate.
3. Collect the supernatant (the clear liquid) and place into a cuvette.
4. Calibrate a colorimeter with distilled water (for comparison).
5. Use a colorimeter to measure the absorbance of the supernatant.

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.



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



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

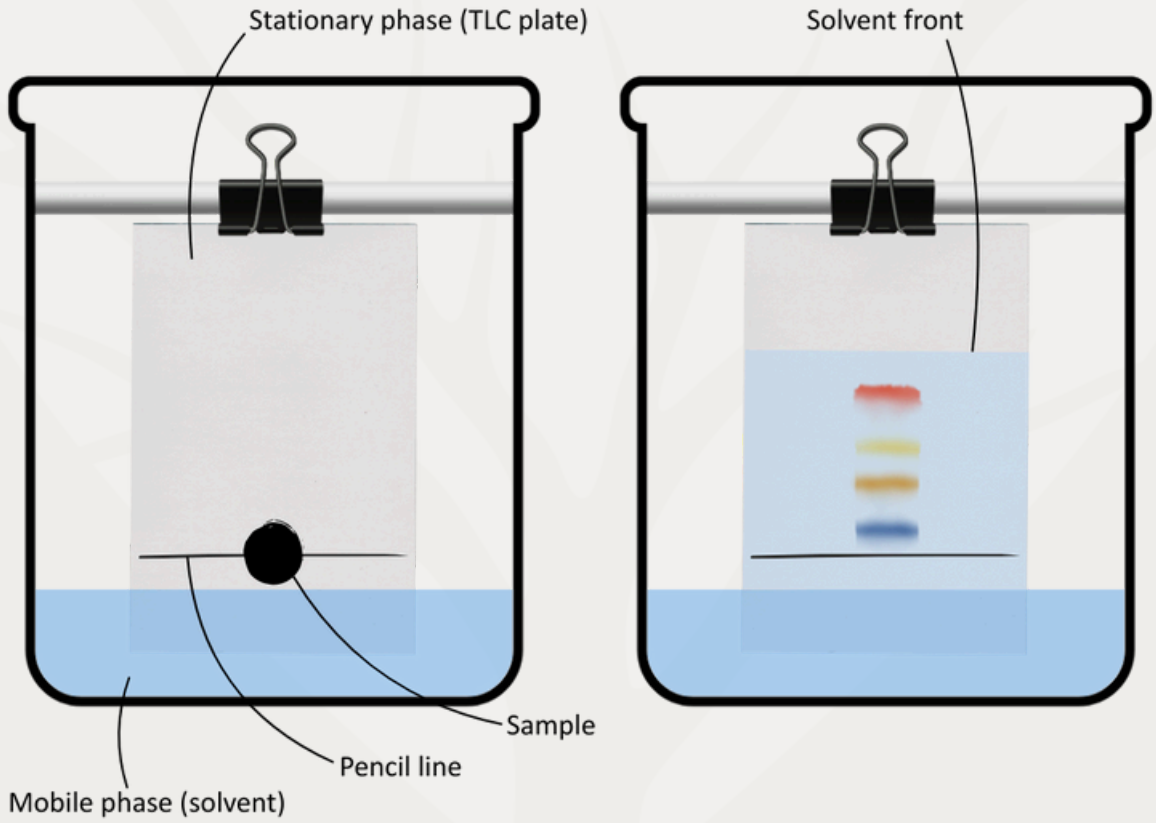
Practical method:

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**.

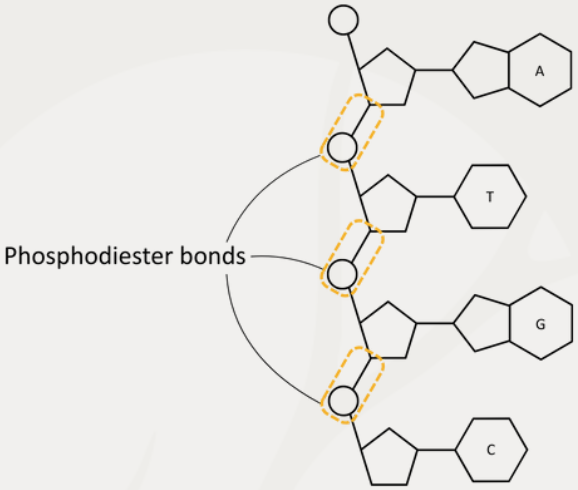
The following treatments make them **visible**:

- **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**.

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**.

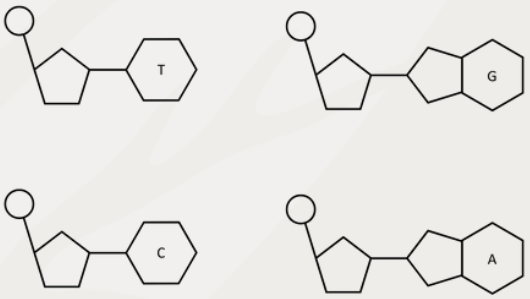


Nucleotides

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.

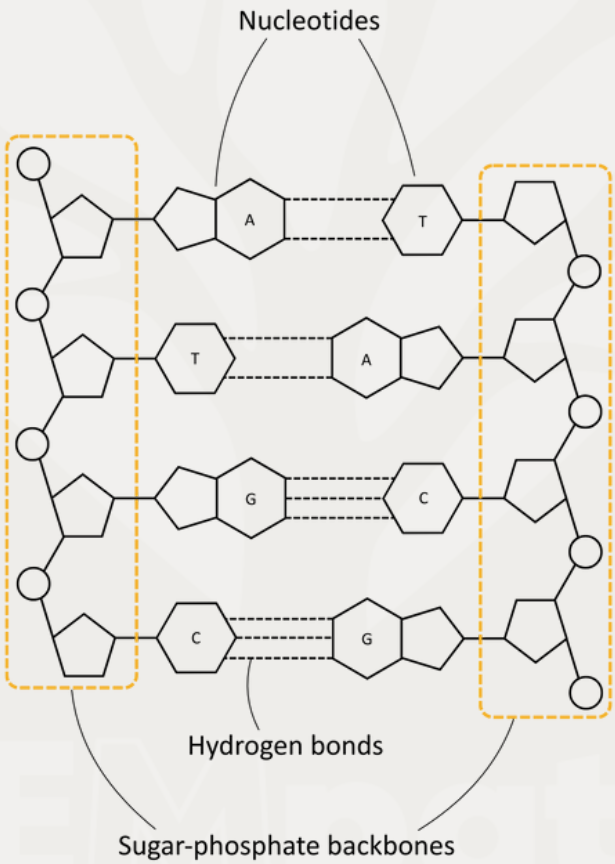
Phosphodiester Bonds

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**.

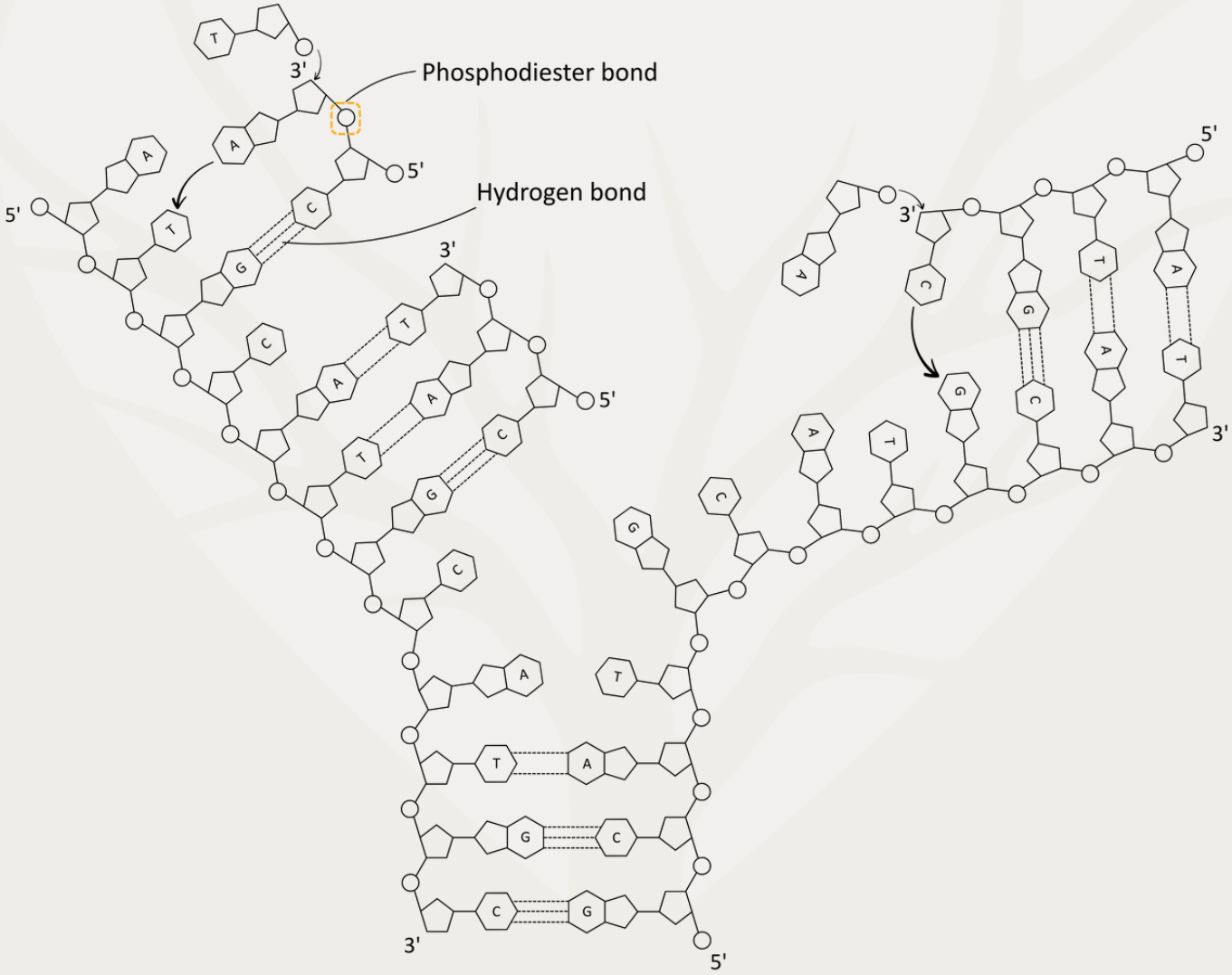
ATP → ADP + Pi + energy

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.

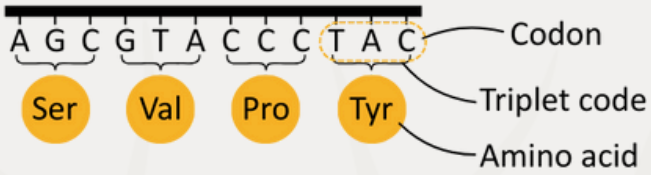
9. Semi-Conservative Replication
Each resulting DNA molecule contains one original strand and one newly synthesised strand - this is semi-conservative replication.

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**.

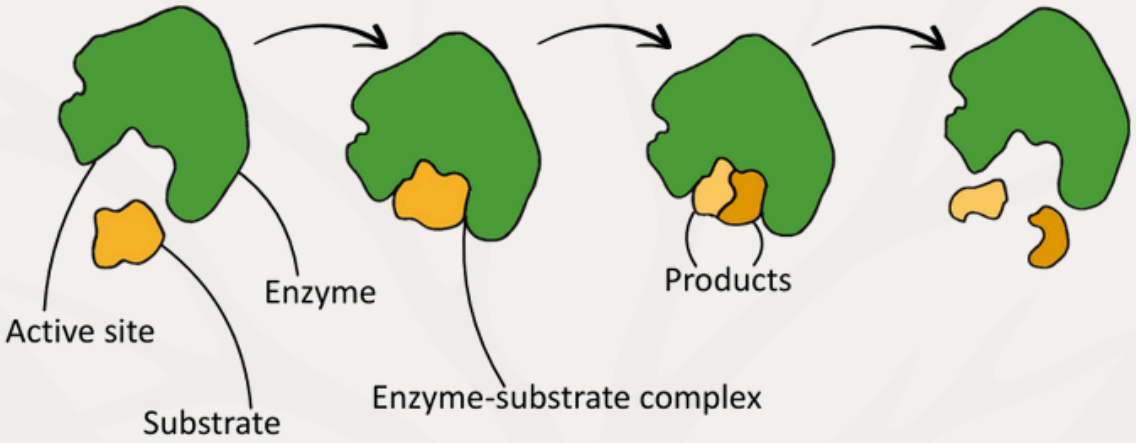
Translation

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:

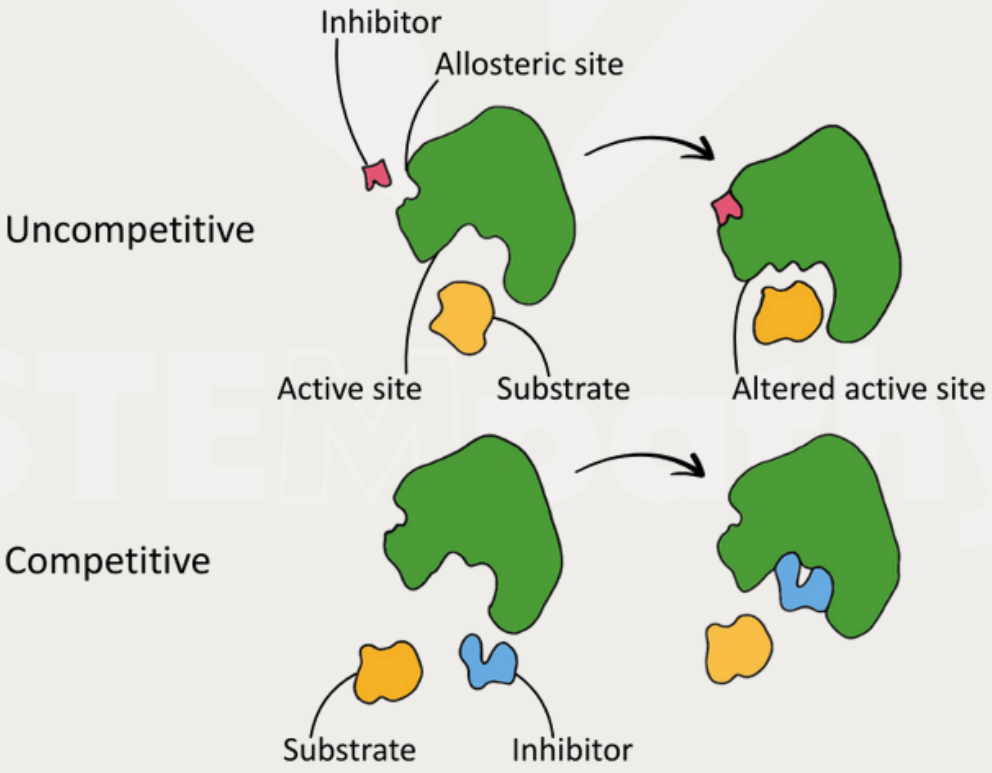
- **Reversibility** - Can the enzyme function normally 'if' the inhibitor unbinds?
- **Competition** - Does the inhibitor compete with the substrate for the active site?
- **Binding site** - Does the inhibitor bind to the active site, or the allosteric site (an external region on the enzyme)?

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**.

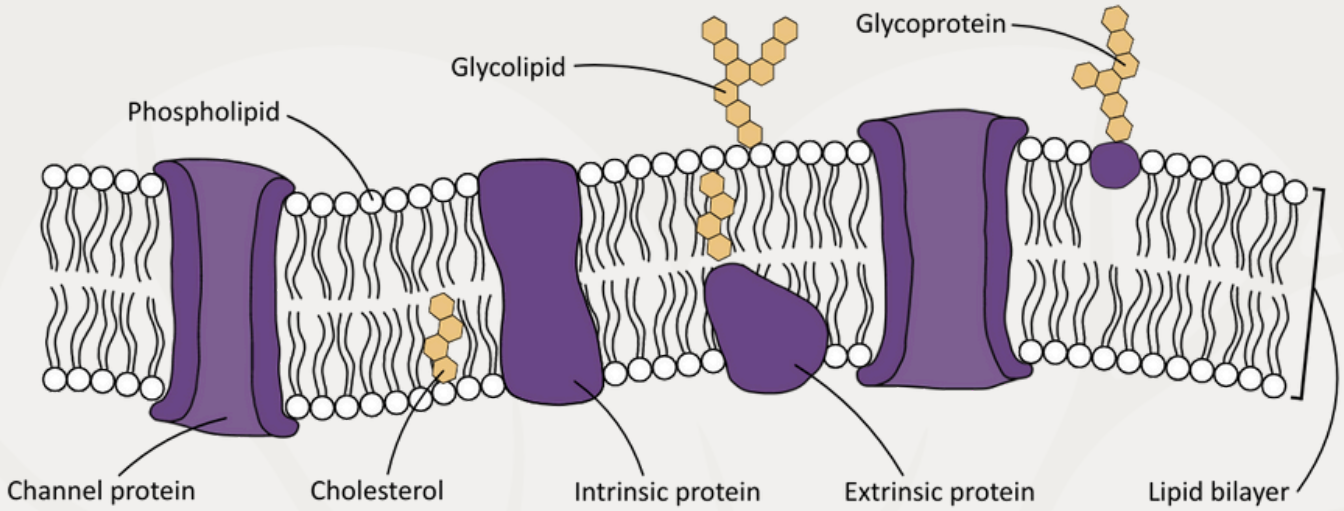
In addition to **controlling** the **movement of substances**, membranes have many more functions important to both prokaryotic and eukaryotic cells, detailed in the table below:

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.



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

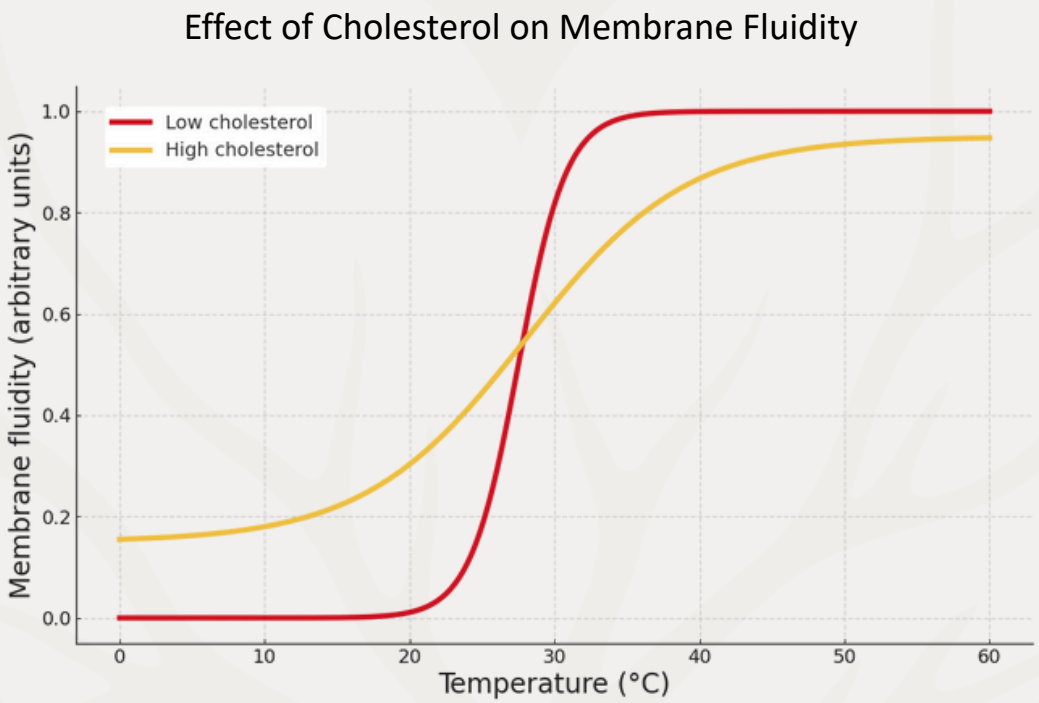
The relative abundance of each component in a plasma membrane affects its permeability to different substances, for example:

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:

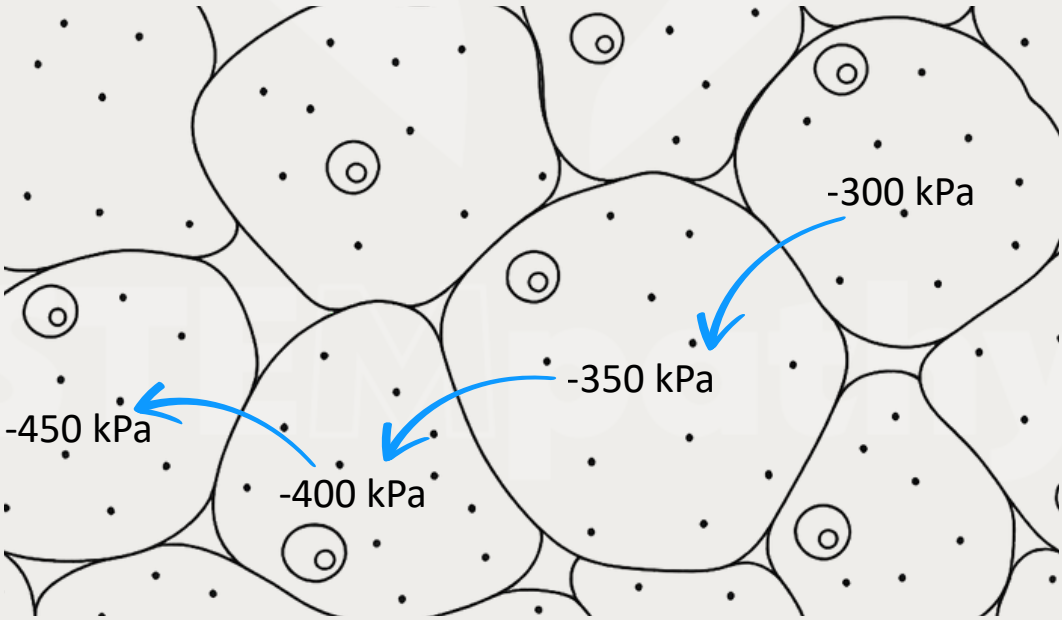
- **Solute potential** (Ψs): Solute molecules attract water, reducing **how freely** water can move.
- **Pressure potential** (Ψp): The **pressure** from the cell's contents **pressing** on the membrane or wall.

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.

Mitosis

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

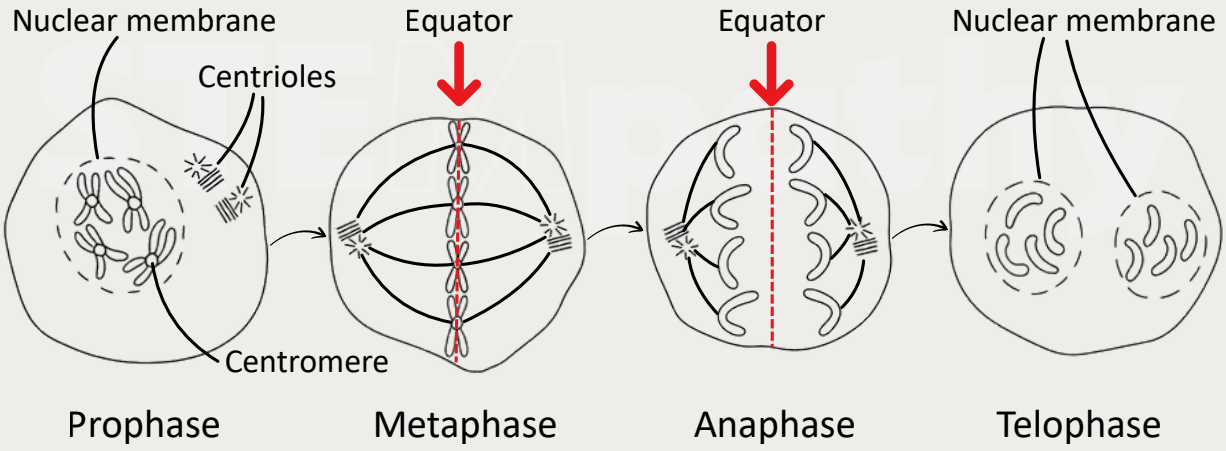
- Prophase
- Metaphase
- Anaphas
- Telophase

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.

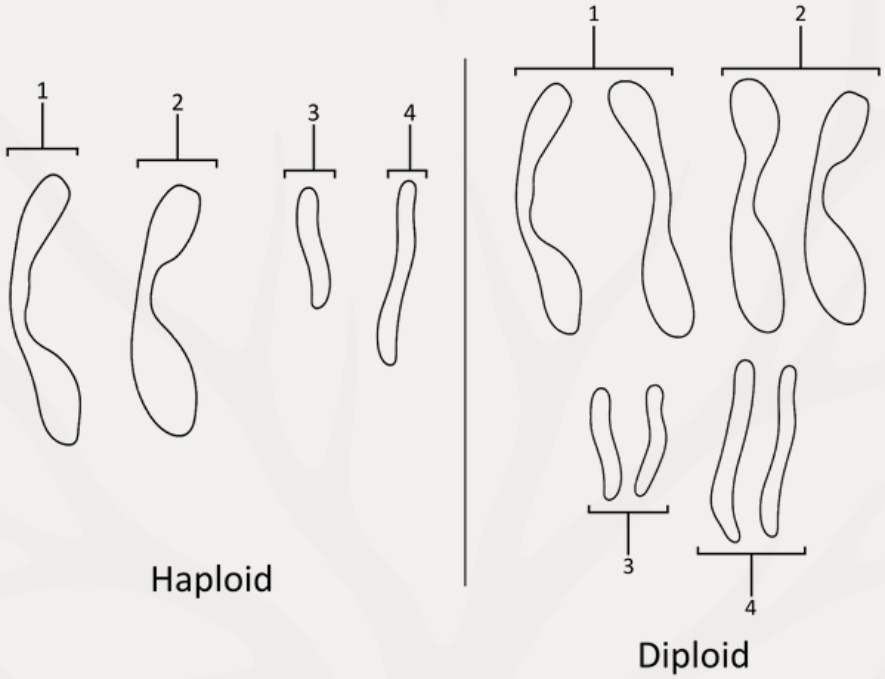
It is essential in the life cycles of multicellular eukaryotes:

- **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

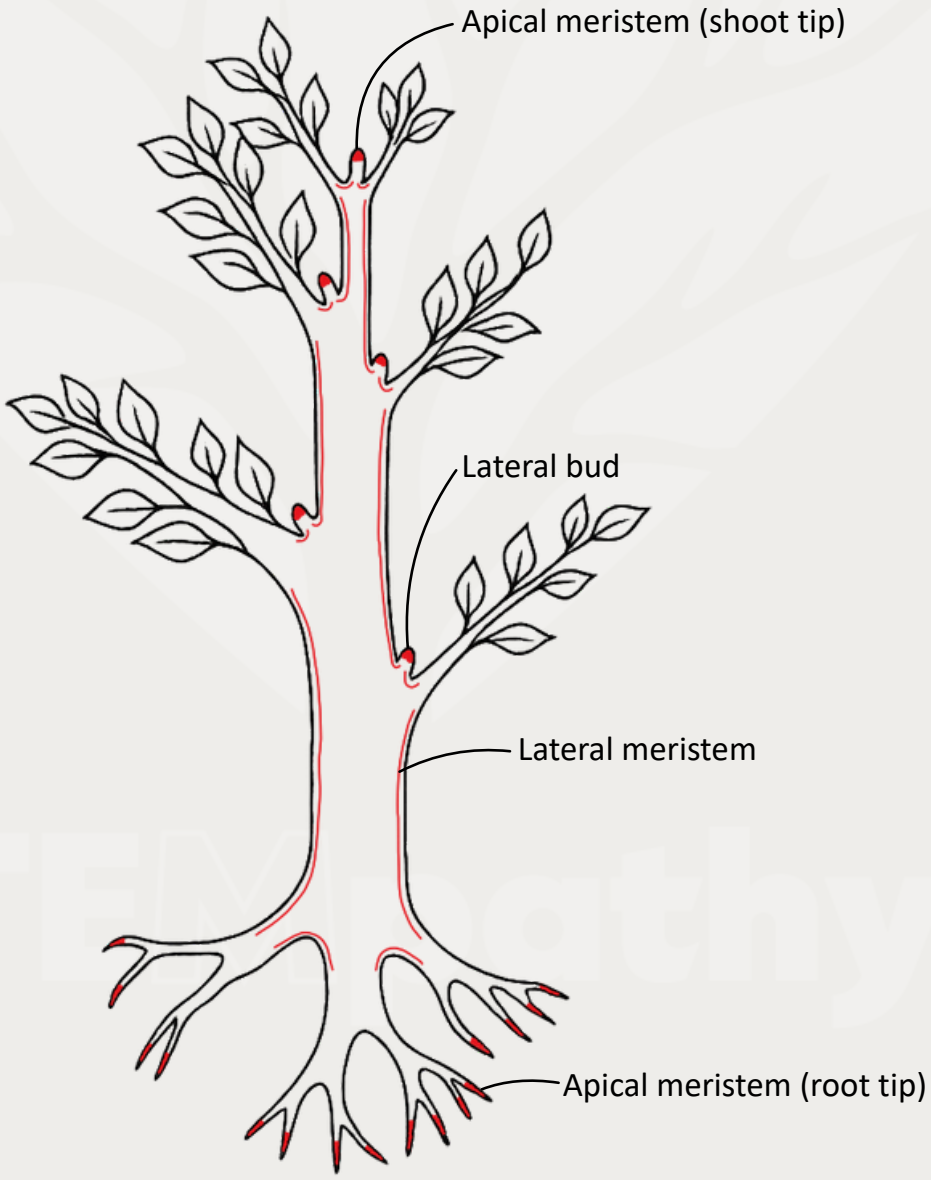
In plants, cells become **specialised** to perform specific roles more effectively.

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**.

Note: Not to scale

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.

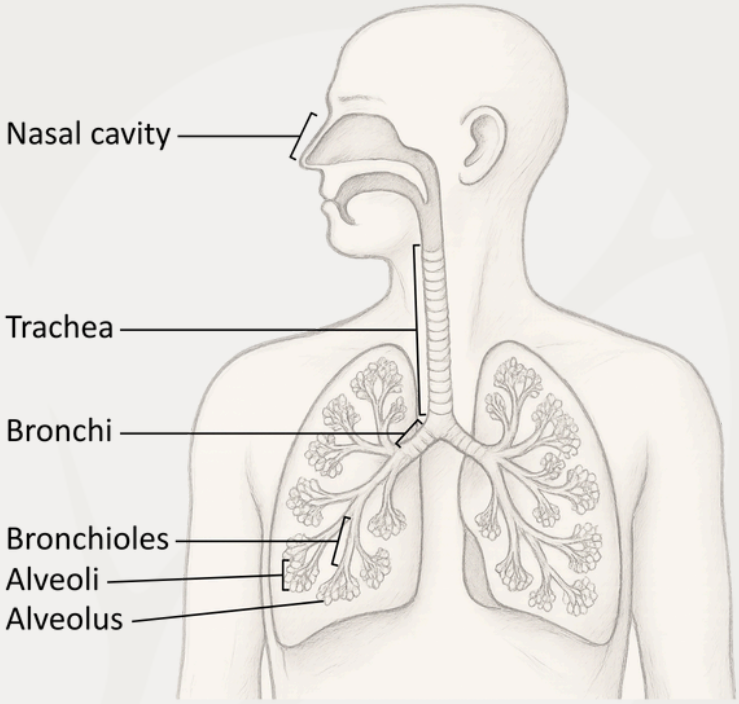
Module 3: Mammalian Gaseous Exchange System

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.

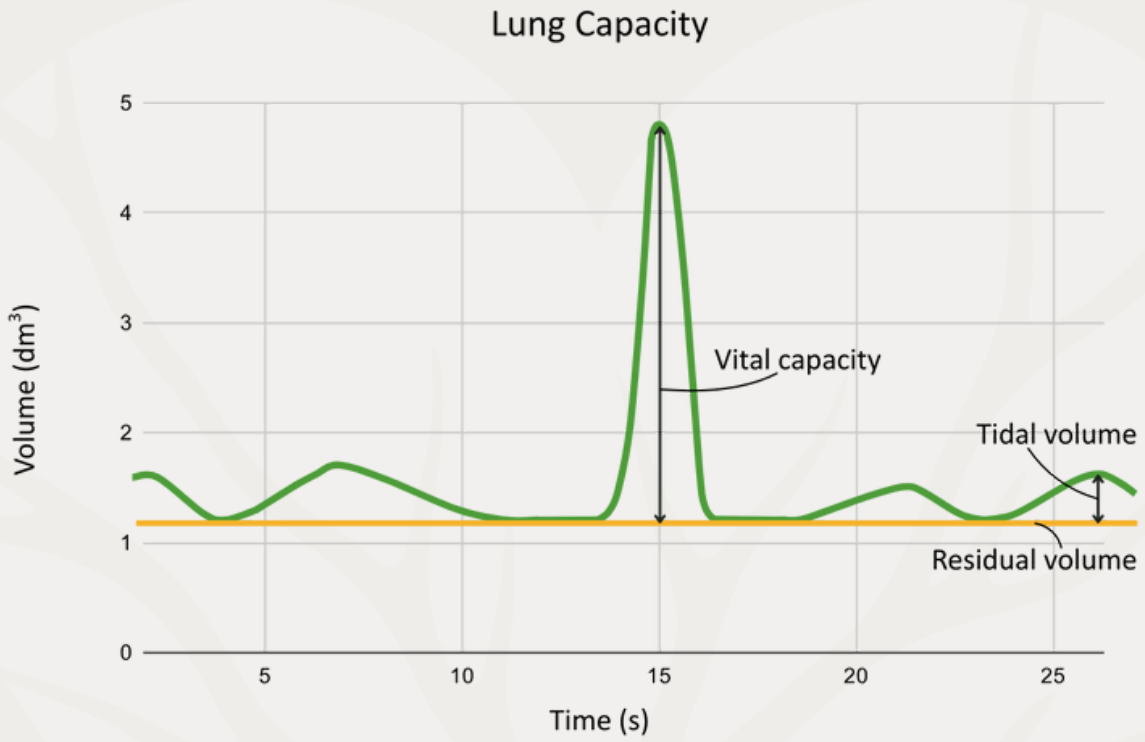
Vital capacity is the maximum volume of air that can be inhaled and exhaled during a forced breath.

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:



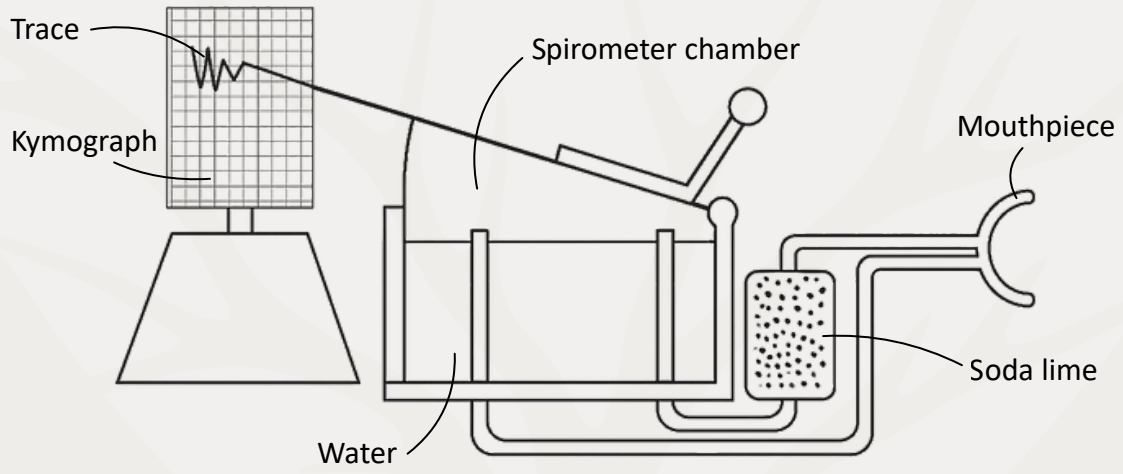
Module 3: Measuring Oxygen Uptake in Mammals

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

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 $dm^3\ min^{-1}$.

Module 3: Ventilation and Gas Exchange in Gills

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

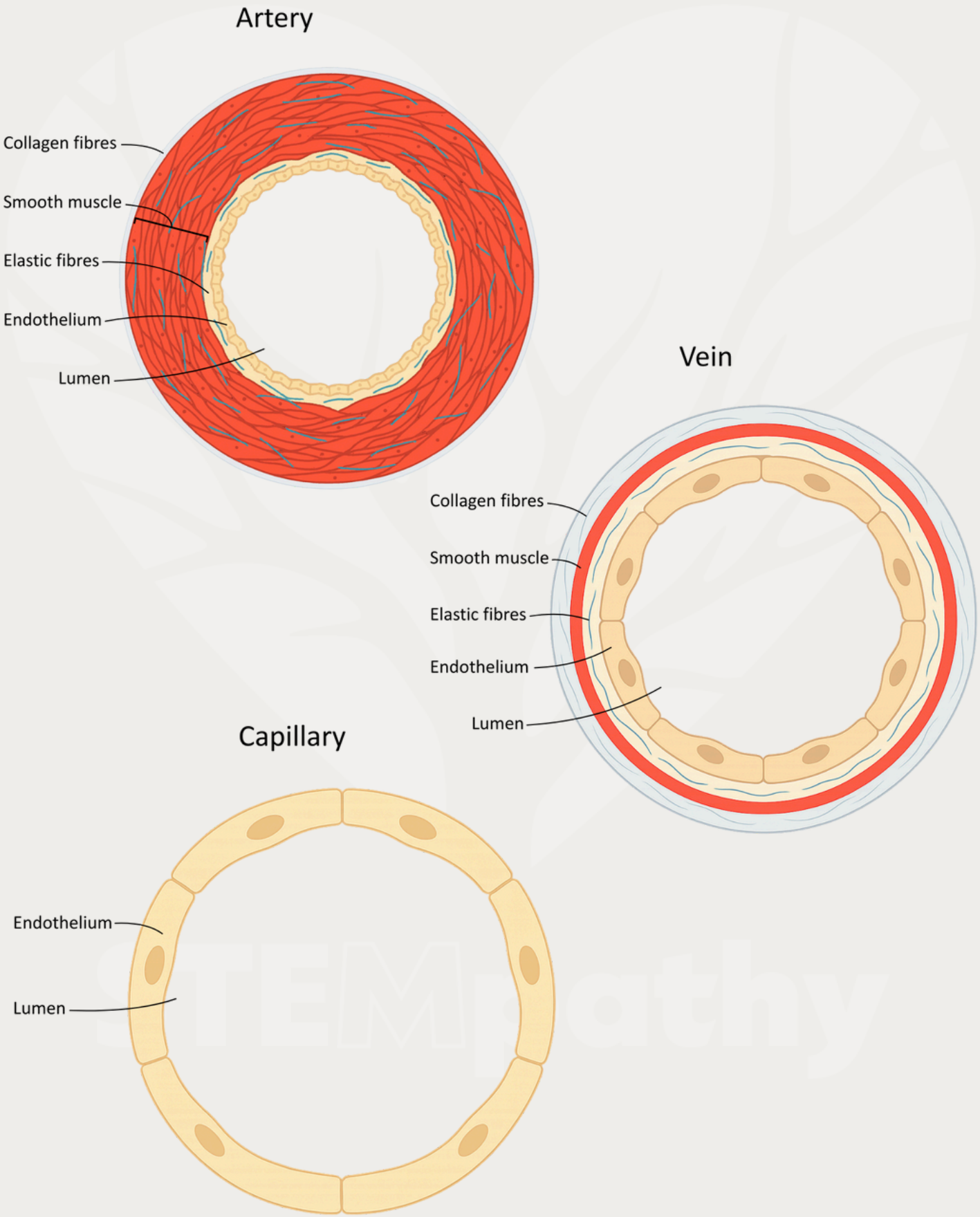
The mammalian **circulatory system** uses a network of blood vessels to transport blood throughout the body.

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:

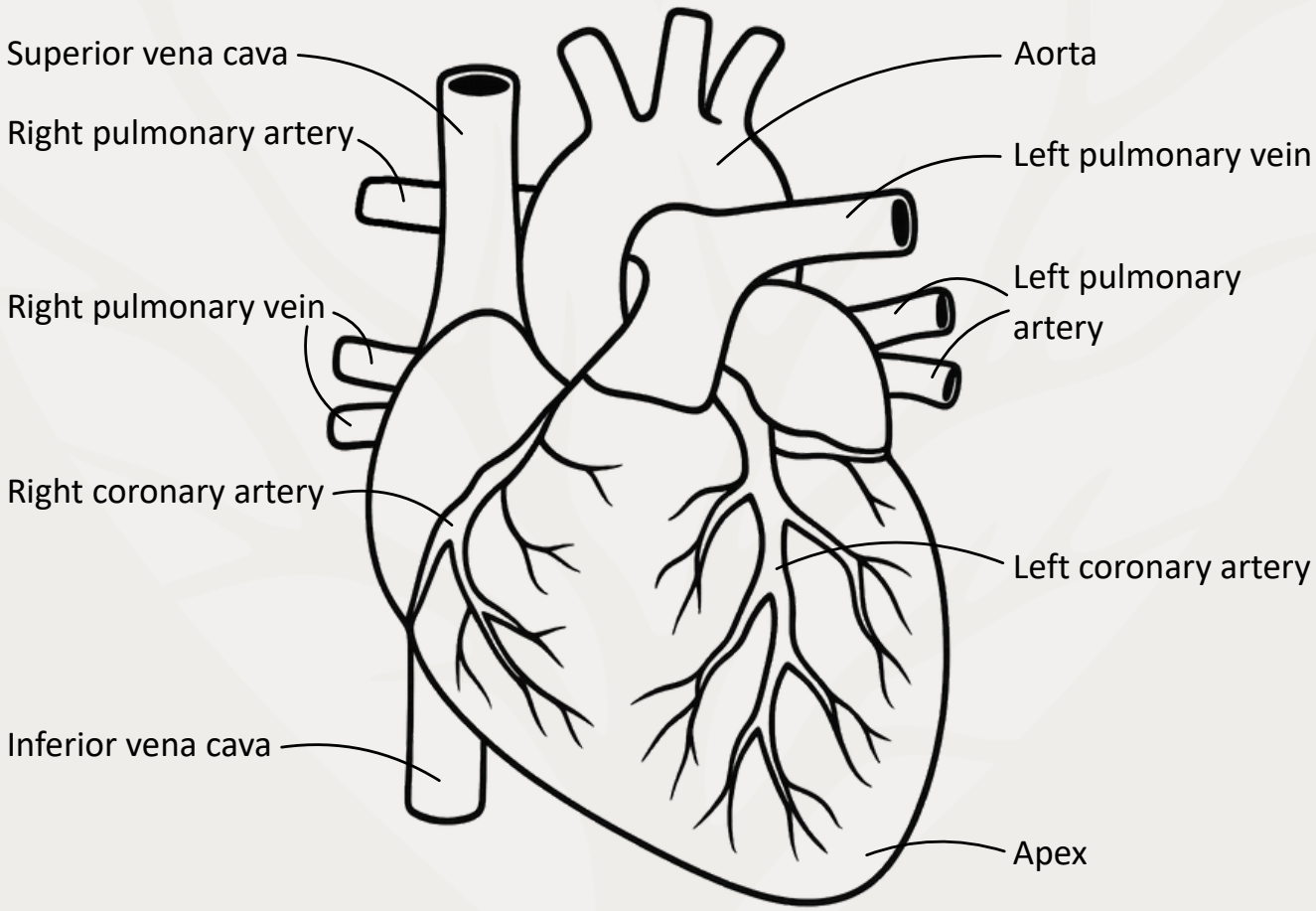
Vessel Type	Function	Structure
Arteries	Carries blood away from the heart at high pressure.	- Thick muscular walls with elastic tissue to recoil and maintain blood flow. - Narrow lumen. - No valves
Arterioles	- Carries blood into the capillaries. - Controls blood flow into the capillaries by vasoconstriction 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.

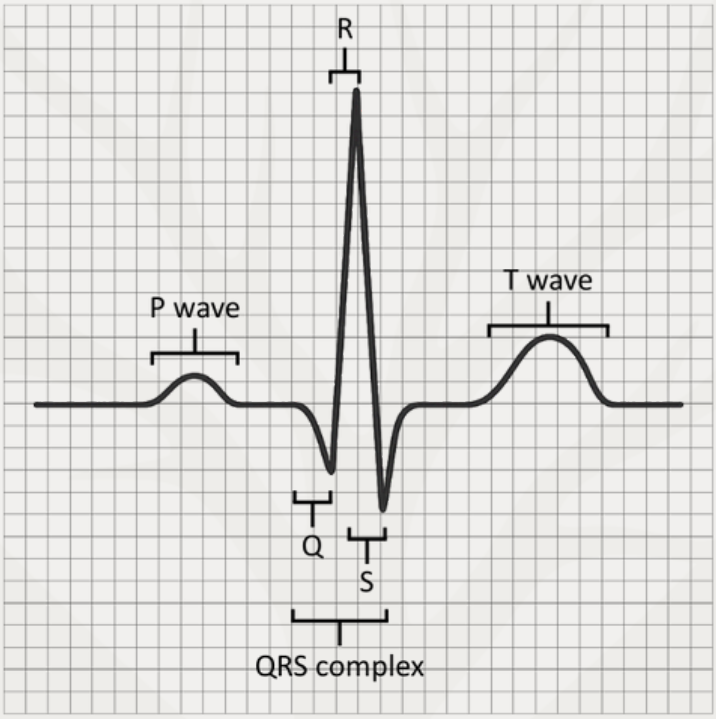
The order of events is as follows:
SAN fires → atria contract → AVN delays the impulse → Bundle of His carries the impulse to Purkyne fibres → Purkyne fibres spread the impulse → ventricles contract from apex upwards

Electrocardiograms

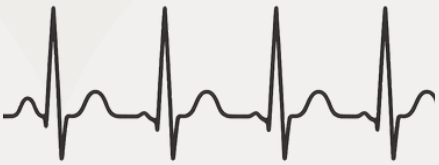
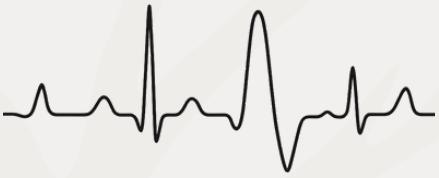
The electrical activity of these events can be recorded, measured and observed with an **ECG**.

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

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

Oxygen affinity

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

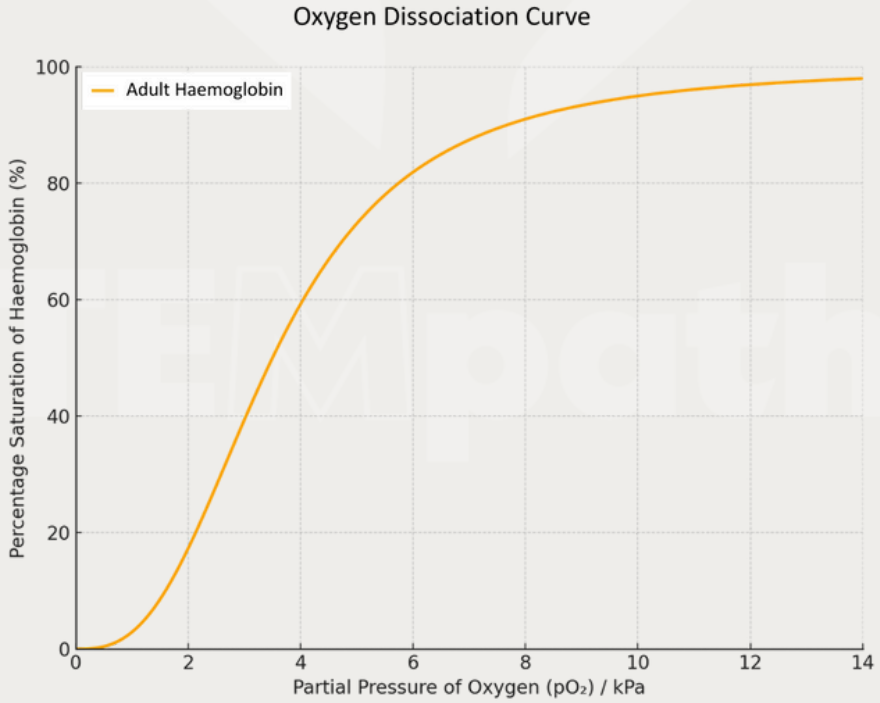
The table below outlines the different factors that can affect haemoglobin's affinity for oxygen:

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

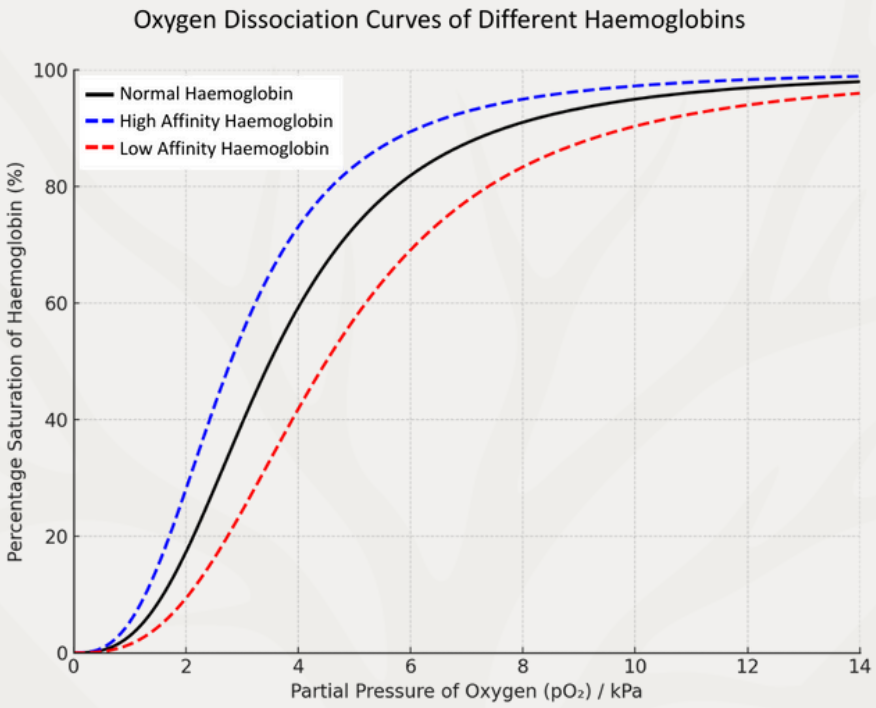
Cooperative binding is the phenomenon by which the **first** oxygen atom **binding** to haemoglobin makes it easier for **subsequent** oxygen atoms to also bind.

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



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).

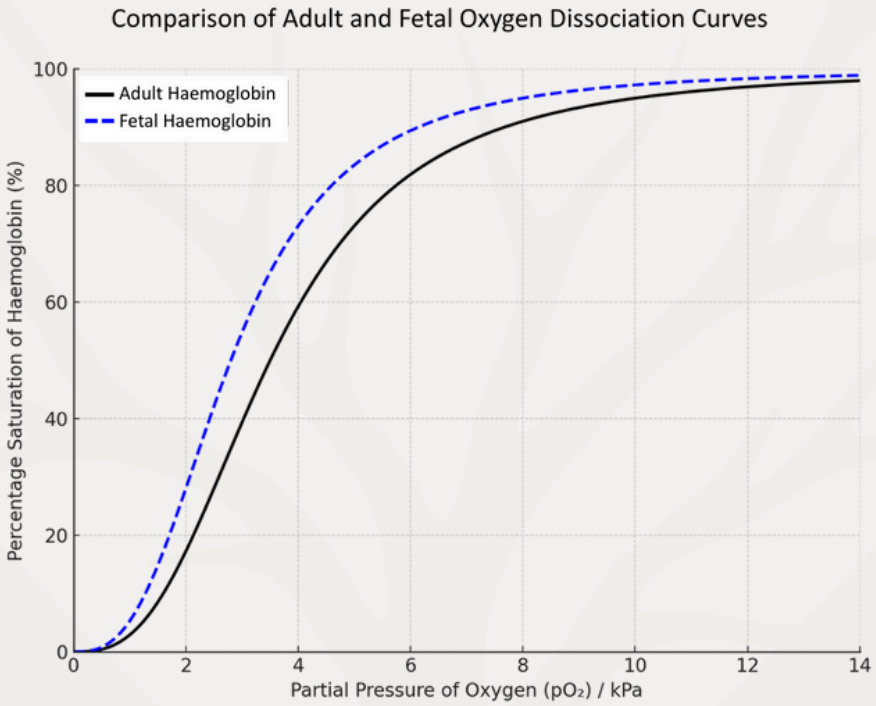
Interpreting a standard (Adult) Oxygen Dissociation Curve:

- 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.

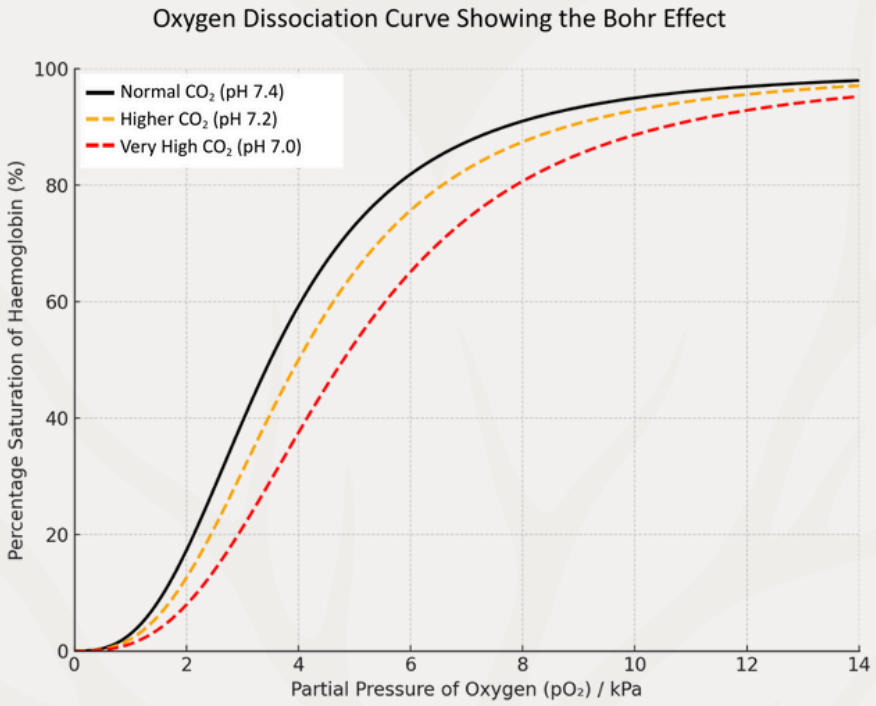
Bohr shift

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

Phloem Tissue

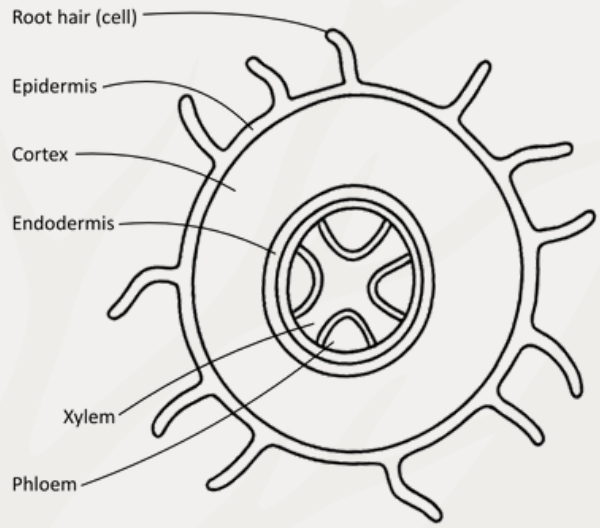
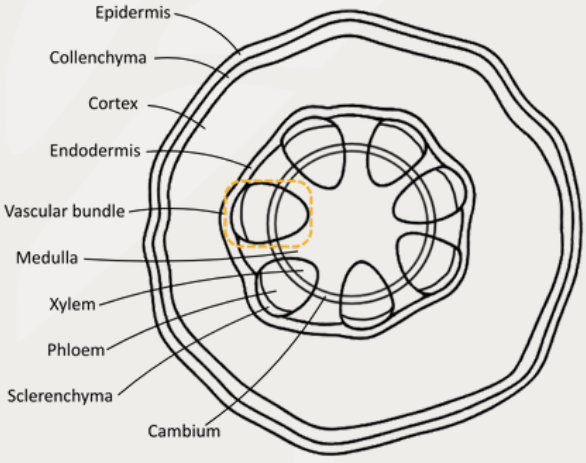
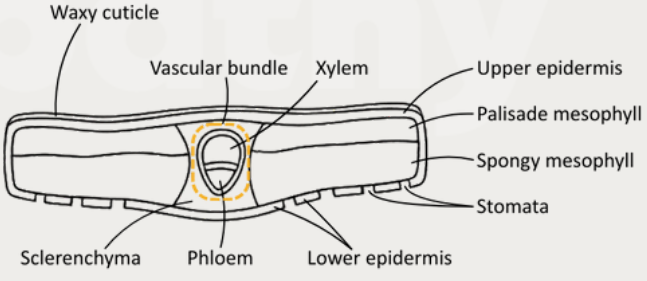
The table below outlines the structural features of **phloem tissues** and it's benefits:

Structural Feature	Benefit
Sieve tube elements	Long, thin (living) cells with sieve plates at their ends for the passage of phloem sap form tubes end to end
Sieve plates	- Specialised cellulose cell walls with perforations to allow phloem sap from one sieve tube element to another - In the event of injury or infection, the perforations are blocked with callose
No nucleus or organelles	Maximises space for phloem sap
Companion cells	- Contain many mitochondria to provide ATP for the active loading of sucrose into sieve tubes for translocation - Carry out metabolic functions for the sieve tube elements
Plasmodesmata	Connects sieve tube elements and companion cells, enables hormonal communication and the transport of substances

Vascular Tissue Arrangement

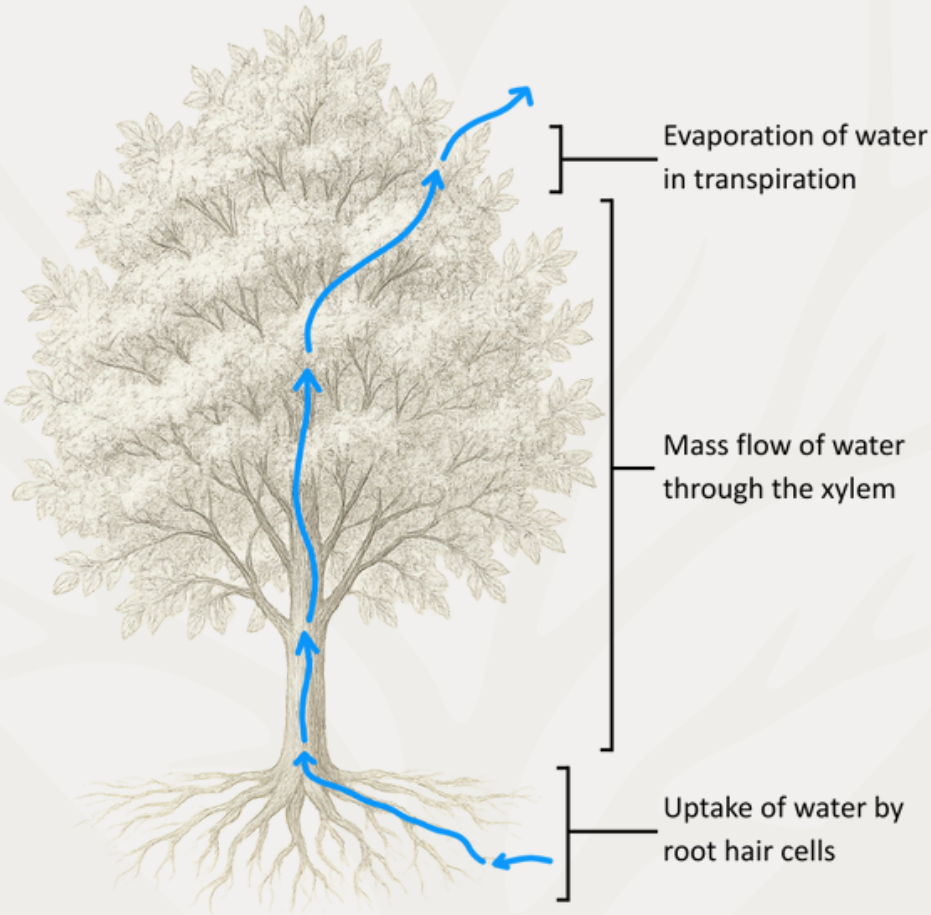
Vascular tissue is arranged differently in different plant organs, which can be used to identify them.

The table below describes the arrangement of vascular tissue in different plant organs:

Organ	Vascular Tissue Arrangement	Diagram
Root	Xylem is in an X-shape at the centre with phloem between the arms.	
Stem	Vascular bundles are arranged in a ring near the outer edge, with xylem on the inner side and phloem on the outer side.	
Leaf	Vascular tissue in the midrib and veins, with xylem above and phloem below in the bundle sheath.	

Plant Transport of Water

The **transpiration stream** is a continuous column of water that moves **upwards** through the plant from the roots to the leaves:



The Transpiration Stream

The table below provides an overview of the transpiration stream:

Location	Process	Driving Force
Soil → root hairs	Osmosis	Water potential gradient
Root cortex → xylem	Apoplast (diffusion) Symplast (osmosis) Vacuolar (osmosis)	Water potential gradient Hydrostatic pressure
Xylem	Cohesion–tension mechanism	Transpiration pull from the leaf
Leaf → atmosphere	Evaporation and diffusion via stomata	Water potential gradient and stomatal opening

Processes

The table below provides an overview of the key processes involved in the transpiration stream:

Process	Description
Evaporation	Water evaporates from the cellulose cell walls of mesophyll cells into leaf air spaces.
Diffusion	Water vapour diffuses out through open stomata, down a water vapour potential gradient.
Cohesion-Tension	A decrease in pressure caused by the loss of water molecules creates tension between hydrogen-bonded water molecules that pull more water into the mesophyll from, and up, the xylem (transpiration pull).
Adhesion	Hydrogen bonding between the water column and the xylem walls helps water move upwards against gravity.
Root pressure	The active transport of mineral ions into the medulla and xylem draws in water by osmosis, increasing water pressure that pushes the water column up the xylem.

Transpiration

Transpiration is the **evaporation** of water from the **stomata**.

1. Water moves by osmosis into the spongy mesophyll from the xylem (through cellulose cell walls) or via the apoplast pathway.
2. Some may be used for photosynthesis or maintaining cell turgidity.
3. Unused water evaporates into the air spaces.
4. Water vapour builds up in the air spaces, creating a high water vapour potential.
5. Water vapour diffuses towards the stomata, where there is a lower water vapour potential.
6. Water vapour moves out of the air spaces via the stomata, lowering the water vapour potential just inside the leaf.

Factors Affecting Transpiration Rate

The following environmental factors affect the rate of transpiration:

Factor	Factor change that increases transpiration	Mechanism
Light intensity	Increase	Opens stomata, increasing diffusion.
Temperature	Increase	Faster evaporation and diffusion.
Humidity	Decrease	Increases the water vapour potential gradient.
Air movement	Increase	Increases the water vapour potential gradient.
Leaf surface area	Increase	More surface area for more stomata.

The Importance of Transpiration

Some key examples of why transpiration is important are that it:

- Maintains water movement through the xylem (it enables the transpiration stream).
- Transports mineral ions to growing tissues.
- Enables leaf turgor for mechanical support.
- Cools the plant via the latent heat of evaporation.

Mass Flow

Mass flow is the **upward** movement of **water** and dissolved **mineral ions** through the **xylem**.

Whilst the **water column** is pulled **upwards** by **transpiration pull**, which is assisted by adhesion, upwards pressure from the root also contributes to this movement.

Root Pressure

Water enters the root through **root hair cells**, which have a **low water potential** due to dissolved mineral ions, so water enters down a water potential gradient from the soil by osmosis.

Water travels through the **cortex** to the **endodermis** via three possible pathways:

- **Apoplast**: Through the cell wall.
- **Symplast**: Through cytoplasm via plasmodesmata.
- **Vacuolar**: Through vacuoles.

At the **endodermis**, the **Casparian strip blocks** the apoplast route, so water is forced into the symplast pathway. This ensures that it enters the xylem.

Mineral ions are **actively transported** into the medulla and xylem, **lowering** the water potential there. Water moves down its water potential gradient by **osmosis** into the xylem, **increasing** the root pressure, which pushes water up into the xylem.

This pressure helps move water up the plant.

Plant Adaptations To Water

Plant species are **adapted** to the environments in which they evolved, and will have adaptations that **maximise** their chances of **survival**.

Regarding water, plants can be categorised as:

- **Xerophytes**: Adapted to **dry** environments by minimising water loss and maximising water retention
- **Hydrophytes**: Adapted to aquatic or very **wet** environments by increasing access to oxygen as well as mineral ions by maximising the transpiration stream

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Adaptations To Dry Environments

The table below outlines some adaptations found (in some) **xerophytes**:

Adaptation	Function
Thick waxy cuticle	Reduces evaporation (water loss) through the cellulose cell wall
Sunken stomata	Traps moist air to decrease the water vapour potential gradient by reducing the wind
Rolled leaves	Traps moist air to decrease the water vapour potential gradient by reducing the wind
Hairy surfaces	Traps moist air to decrease the water vapour potential gradient
Reduced leaf surface	- Spines or needle-like leaves reduce the surface area available for transpiration - Photosynthesis occurs on the fleshy plant stems instead (like a cactus)
Fleshy stems	Provides storage space for water, and can swell to accommodate more
Deep or widespread roots	Maximise water uptake by accessing deep or widespread soil moisture

Module 3: Plant Adaptations to Water

Adaptations To Wet Environments

The table below outlines some adaptations found (in some) **hydrophytes**:

Adaptation	Function
Air spaces in the tissue	Enable floating on/in water to access the air (for oxygen) and light, and to promote gas exchange
Stomata on the upper surface	So that gas exchange can occur with the atmosphere (in floating leaves)
Reduced vascular tissue	- Xylem is not required for water transport, saving resources and energy - Less mechanical support is needed
Thin, flexible stems with airspaces	- Allows flexibility with water movement to reduce breakage, so less lignin is made (saving energy and resources) - Helps the plant float, and provides a shorter diffusion pathway for oxygen to the roots

Required Examples: Marram Grass, Cactus and Water Lilies

These are the three plants whose adaptations you are expected to know for the OCR A level Biology course.

The adaptations they each have are listed in the table below:

Marram Grass(Xerophyte)	Cactus(Xerophyte)	Water Lily(Hydrophyte)
Rolled leaves	Spines instead of leaves	Stomata on the upper surface
Hairy leaf surfaces	Photosynthetic stem	Large air spaces in tissues
Sunken stomata	Fleshy stem for water storage	No waxy cuticle
Thick waxy cuticle	Thick waxy cuticle	Reduced vascular tissue
Extensive root system (deep)	Shallow, widespread root system	Thin, flexible stems
	Sunken stomata	Minimal root system

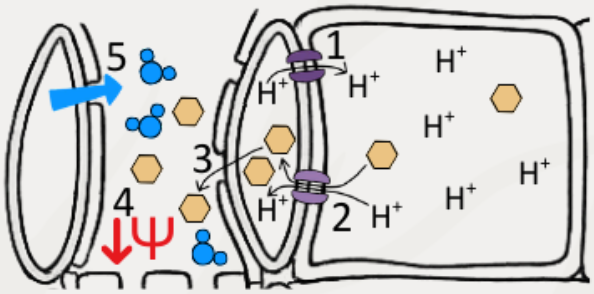
Translocation

Translocation is the movement of dissolved substances (called assimilates) in the phloem sap **from a source** (e.g. leaves, tubers) **to sinks** (e.g. roots, fruits, tubers).

Translocation: The Pressure Flow Hypothesis

Loading (at the source):

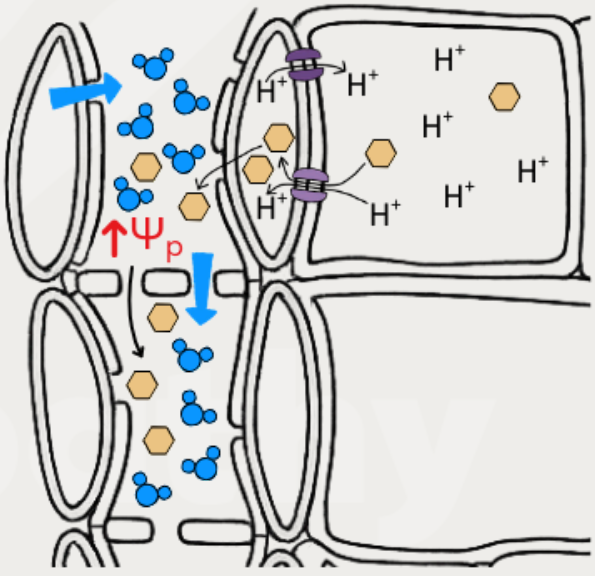
1. Companion cells use ATP to transport H+ into the surrounding source tissues.
2. H+ diffuse back into the companion cells through cotransporter proteins alongside sucrose.
3. Sucrose diffuses down its concentration gradient into the sieve tube elements via the plasmodesmata from the companion cells.
4. This lowers the water potential inside sieve tubes.



Water enters from adjacent xylem into this area down its water potential gradient by osmosis, increasing the hydrostatic pressure.

Mass flow (through phloem):

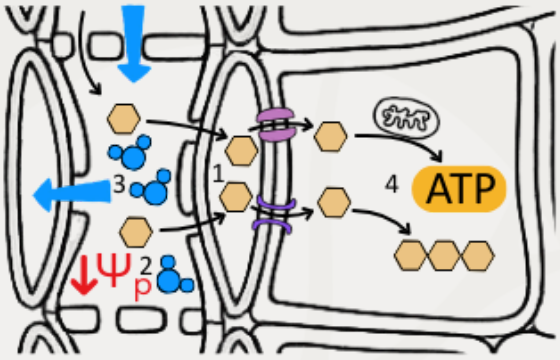
- Higher hydrostatic pressure at the source pushes the phloem sap toward the sink, where the pressure is lower.
- This is a bulk flow mechanism.



Module 3: Translocation

Unloading (at the sink):

1. Sucrose is removed from the phloem by companion cells using active transport, or through the plasmodesmata by diffusion.
2. The removal of sucrose from the phloem increases the water potential in the phloem at the sink.
3. Water moves to a lower water potential back into the xylem by osmosis, lowering the hydrostatic pressure at the sink.
4. Sucrose is used in respiration or stored.



Communicable Diseases

Communicable diseases are caused by **pathogens** which invade a host and cause **harm**; they are **infectious**.

Pathogens are **disease-causing microorganisms** that damage the host's cells and disrupt normal biological functioning.

Microorganisms can infect both animals and plants.

There are four main types of pathogenic microorganisms: **bacteria**, **fungi**, **protoctists** and **viruses**.

The table below summarises the key pathogens you need to know in OCR A level Biology, along with the diseases they cause and how they are transmitted; candidates have not been expected to recall the effects and symptoms of these different pathogens.

The table below gives two **bacterial** pathogens:

Disease	Host	Transmission
Tuberculosis (TB)	Humans	Airborne droplets
Ring Rot	Potatoes, Tomatoes	Contact with contaminated tools, soil, or infected tubers

The table below gives three **viral** pathogens:

Disease	Host	Pathogen	Transmission Method
AIDS (Acquired Immune Deficiency Syndrome)	Humans	HIV: Human Immunodeficiency Virus	- Bodily fluids (e.g. blood, semen). - Unprotected sex. - Needle sharing.
Influenza	Humans	Influenza virus	- Airborne droplets. - Contaminated surfaces.
Tobacco Mosaic Virus	Plants (Tobacco, tomatoes)	TMV: Tobacco mosaic virus	- Contact with contaminated tools, hands or other plants. - Insect vectors. - Soil.

The table below gives two **protoctista** pathogens:

Disease	Host	Transmission Method
Malaria	Humans	Vector transmission by female Anopheles mosquitoes.
Blight	Potatoes, Tomatoes	Spores: Spread by the wind, rain and contaminated soil.

The table below gives two **fungal** pathogens:

Disease	Host	Transmission Method
Athlete's Foot	Humans	Direct contact with contaminated floors, towels or communal showers.
Black Sigatoka	Bananas	Airborne spores that spread in warm and humid environments.

Transmission

Transmission is how pathogens spread, and can be **direct** or **indirect**:

- **Direct**: The pathogen is transmitted from one organism to another; there is **no intermediate** organism.
- **Indirect**: The pathogen is transmitted from one organism to another via a vector; an intermediate organism **carries the pathogen** from an infected organism to an uninfected one.

Transmission in Animals

The table below outlines some of the ways animals can be infected by direct transmission:

Method of Transmission	Description
Direct Contact	Physical contact between an infected and a healthy individual, or with contaminated surfaces.
Ingestion	Consuming food or drink contaminated by infected urine or faeces.
Droplet Infection	Pathogens are carried in droplets of mucus/saliva through the air when an infected person coughs or sneezes.
Spore Transmission	Spores in the air, soil, or on surfaces enter through cuts, inhalation, or wounds.

The table below outlines some of the ways animals can be infected by indirect transmission:

Method of Transmission	Description
Vector	Another organism (the vector) carries the pathogen between hosts.
Fomites*	Inanimate objects contaminated by pathogens which are passed between individuals (e.g. bedding, clothing, hospital equipment).

*You do not need to know this term.

Transmission in plants

The table below outlines some of the ways plants can be infected by **direct transmission**:

Method of Transmission	Description
Direct Contact	Contact between a healthy plant and an infected plant.
Soil Contamination	Pathogens in the soil infect healthy plants, and some remain viable for years.

The table below outlines some of the ways plants can be infected by **indirect transmission**:

Method of Transmission	Description
Vectors	Insects transfer pathogens between plants.
Water and Wind	Spores, bacteria, or viruses spread by the wind or movement of water (e.g. rain splashing, irrigation)
Human Activity	Pathogens spread by contaminated hands, tools, machinery, or transport of infected plant material.

Social Factors In Transmission

Social factors influence how easily pathogens spread through a population. These factors generally **increase transmission** by:

- **Increasing contact** between individuals, such as in crowded or shared environments.
- **Reducing sanitation** and **hygiene**, allowing pathogens to persist on surfaces or in water.
- **Enabling direct transmission** routes, especially through behaviours or shared equipment.
- **Delaying diagnosis** and **treatment** allows infections to spread unchecked.

Prevention strategies target these risk points by reducing exposure, promoting hygiene, limiting shared contamination routes, and improving access to healthcare.

Module 4: Plant Defences Against Pathogens

Plant Defences Against Pathogens

Plants have **two types** of defence against pathogens:

- **Chemical defences** are antibiotics, antifungals, hydrolytic enzymes, antimicrobial proteins or other metabolic products that can inhibit or kill microorganisms.
- **Physical defences** are structures that keep out microorganisms or contain their spread within the organism.

Different types of chemical and physical defences are categorised as:

- **Active Defences**: Produced in response to infection, helping to contain or destroy pathogens.
- **Passive Defences**: Always present, designed to prevent the entry of pathogens.

Active Defences

The table below outlines some of the **active chemical defences** plants have:

Examples	Description
Alkaloids, Phenols	Inhibit key metabolic processes (e.g. enzymes for digestion or protein synthesis).
Defensins, Oxidative bursts	Disrupt pathogen plasma membranes or ion transport.
Hydrolytic enzymes	Break down microbial cell walls (e.g. chitinases for fungi, lysozymes for bacteria).
Terpenoids, Phenols	Act as general antimicrobials (antibacterial and antifungal).

The table below outlines some of the **active physical defences** plants have:

Examples	Description
Cell wall thickening, Callose deposition	Strengthen cell walls and block plasmodesmata to prevent pathogen spread between cells.
Necrosis	Localised cell death to isolate infection.

Module 4: Plant Defences Against Pathogens

Passive Defences

The table below outlines some of the **passive chemical defences** plants have:

Examples	Description
Phenols, Tannins	Stored in bark and tissues, they have broad antimicrobial and antifungal properties.
Terpenoids, Alkaloids	Bitter or aromatic compounds that deter herbivores and inhibit pathogens.
Defensins	Protein-based inhibitors present in tissues act against microbial growth.
Hydrolytic enzymes	Pre-formed enzymes (e.g. chitinases, lysozymes) that degrade invading pathogen cell walls.

The table below outlines some of the **passive physical defences** plants have:

Examples	Description
Bark, Cellulose cell walls, Lignin	Physical barriers that are tough, waterproof, and contain antimicrobial compounds.
Callose, Tylose	Internal blockages that restrict pathogen movement in phloem or xylem.
Waxy cuticle, Stomatal closure	Surface defences that prevent pathogen entry.

Module 4: Non-Specific Defences in Animals

Primary Non-Specific Defences Against Pathogens

Primary nonspecific defences keep microorganisms from entering the body.

Primary defences are non-specific because they will **target** and respond to a **wide range** of pathogens.

Examples of primary defences include:

Type	Examples
Physical Barriers	Skin, mucous membranes, ear wax, and mucus plug in the cervix.
Chemical Barriers	Sebum, stomach acid, and lysozymes in tears and saliva.
Mechanical Reflexes	Coughing, sneezing, vomiting, diarrhoea.
Physiological Responses	Blood clotting, inflammation.

Physical Barriers

The Skin

The **outer layer** of the skin is the **epidermis**, a tough, waterproof layer.

The **epidermis** is mostly made up of **keratinocytes**, which specialise into **dead cells** containing **keratin**, which makes them tough and waterproof; this is known as **keratinisation**.

Because the keratinocytes are dead (and flake off), they must be continuously **replaced**.

Skin Damage

When the skin is damaged, it provides an entry point for pathogens. The body **prevents infection** by sealing the wound temporarily (**blood clotting**) and permanently (**wound repair**).

Blood clotting

Blood clotting involves **platelets** releasing substances that trigger a reaction chain that produces **fibrin**, an insoluble protein. **Fibrin** forms a mesh-like network that captures extra platelets and forms a **stable clot**.

Wound repair

A clot hardens into a **scab**, creating a **temporary seal** and drawing the wound edges together. Underneath, **collagen** is laid down while **skin stem cells divide** to repair the tissue, and new blood vessels grow. Once healing is complete, the scab is shed.

Inflammation

Inflammation is **swelling** and **redness**. It occurs to help contain pathogens and encourage the action of white blood cells.

Mast cells in the skin detect microorganisms if they have entered the area, and release the cell-signalling molecule **histamine**.

Histamine mainly causes **vasodilation**, so that the capillary **dilates** and becomes more permeable to **white blood cells** and plasma proteins.

More white blood cells and blood plasma can now enter the infected area from the capillaries, forming more **tissue fluid** and causing **oedema** (swelling).

Inflammation also occurs during **allergic reactions** when mast cells mistake substances for pathogens.

Module 4: White Blood Cells and Secondary Defences

White Blood Cells

Different roles in the immune response are performed by different types of **white blood cells**, each specialised for their role.

The table below lists the different types of white blood cells named in the OCR A level Biology course, and what type they are:

White Blood Cell	Phagocyte	Antigen-Presenting Cell (APC)	Lymphocyte	Non-specific Response	Specific Immune Response
Neutrophil	✓			✓	
Monocyte / Macrophage	✓	✓		✓	✓
Plasma Cell / B effector cell			✓		✓
B Memory			✓		✓
T Helper			✓		✓
T Killer			✓		✓
T Memory			✓		✓
T Regulatory			✓		✓

Identifying white blood cells

The main types of white blood cells you need to know can be identified from a **blood smear** under a microscope:

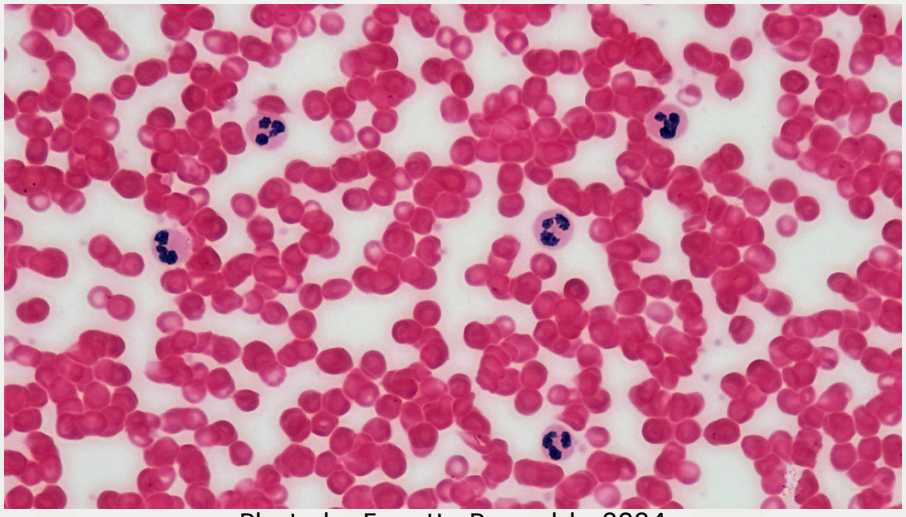


Photo by Fayette Reynolds, 2024

The table below outlines the main distinguishing features you would be expected to recognise in an exam:

Lymphocyte	Distinguishing Feature	Image
Neutrophils	Multi-lobed nucleus	
Lymphocytes	Large round nucleus	
Monocytes/Macrophages	Kidney-shaped nucleusLarger than other lymphocytes	

Module 4: White Blood Cells and Secondary Defences

Secondary Defences: Non-Specific and the Specific Immune Response

Secondary defences are for when pathogens get past primary defences and **enter the body**.

The **secondary defences** of the immune system are either:

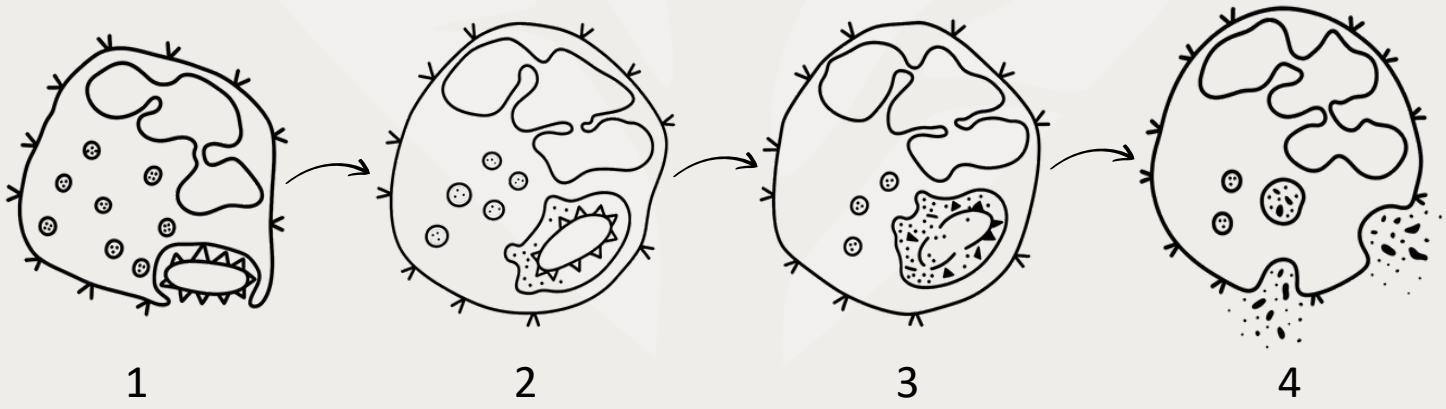
- **Non-specific**: The response of white blood cells is **indiscriminate**, targeting any 'foreign' antigens.
- **Specific**: The response of white blood cells is controlled by the presence of **particular antigens** which they **target**.

Macrophages are **non-specific** in how they approach **phagocytosis**, but their **display of antigens** involves them in the start of the specific immune response.

Only **phagocytes** are involved in the **secondary non-specific** immune response.

Phagocytes

Phagocytes are cells that **do phagocytosis**: the engulfing of a pathogen and destroying it with hydrolytic enzymes.



The process of phagocytosis is:

1. **Recognition**: The phagocyte binds to the antigen on the pathogen's surface.
2. **Engulfment**: The pathogen is engulfed by endocytosis and enclosed in a phagosome.
3. **Digestion**: Lysosomes fuse with the phagosome and release hydrolytic enzymes.
4. **Absorption or Release**: Harmless products are absorbed or expelled to be used as nutrients.

The two types of phagocyte taught in OCR A level Biology are **neutrophils** and **macrophages**.

Module 4: White Blood Cells and Secondary Defences

The table below compares the main features of neutrophils and macrophages that you need to know:

Feature	Neutrophils	Macrophages
Origin	Bone marrow	Bone marrow (as monocytes)
Maturation site	Bone marrow	Lymph nodes (and other tissues) (differentiating from monocytes)
Lifespan	Short-lived (hours to days)	Long-lived (can persist for months)
Role	Phagocytosis of pathogens	- Phagocytosis - Antigen presentation
Structure	- Multi-lobed nucleus - Many lysosomes - Many mitochondria - Many ribosomes - Chemotaxis	- Kidney-shaped nucleus* - Many lysosomes - Many mitochondria - Many ribosomes - Chemotaxis

*Monocytes have the kidney shaped nucleus, which becomes irregular as they mature into macrophages.

Non-specific immune response

In the **non-specific immune response** neutrophils and macrophages carry out **phagocytosis** on **any foreign** microorganisms they find.

Microorganisms are **recognised** as being foreign due to the **antigens** they have.

Neutrophils and macrophages are '**non-specific**' because they will respond to **any antigen**, not just certain ones (as happens in the specific immune response).

The specific immune response

The **specific immune response** identifies certain pathogens by **recognising** their **antigen marker molecules** and **targeting** them (mostly) exclusively.

This allows pathogens, or infected cells, to be destroyed more effectively. The immune system can then **make powerful antibodies** that inhibit the pathogen's function. It also **provides immunity** by recognising the same pathogen upon reinfection.

The main types of white blood cells involved are:

- **B cells**: Responsible for **making antibodies** that target specific antigens.
- **T cells**: Responsible for **attacking infected host cells** and stimulating B cells.

Both B and T lymphocytes are involved in immunity by **making memory cells**.

The actions of B and T lymphocytes in the specific immune response are driven by 4 processes:

- **Antigen presentation**: Where a cell **displays an antigen** on its cell surface membrane to **activate** specific B and T cells with a **complementary** receptor.
- **Clonal selection**: Where specific T and B lymphocytes are **activated** after binding with a complementary antigen on an antigen-presenting cell (APC).
- **Clonal expansion**: Where activated B and T lymphocytes **divide by mitosis**; each new cell is able to produce **complementary receptors** or **antibodies** to the **same antigen**.
- **Differentiation**: Where some B and T cells are produced by **clonal selection** and turn into specialised lymphocytes.

The activity of the immune system is controlled by **cell signalling**, including:

- **Antigen-presentation**: Some lymphocytes have **complementary** protein receptors to specific antigens, and binding to these, either directly on pathogens or on APCs, will activate them.
- **Cell signalling molecules**: Chemical messengers between B and T cells stimulate the immune system (e.g. cytokines and interleukins*), whilst other body cells can release substances to alert lymphocytes that they are infected (e.g. interferon for viral infections).

*Technically, interleukins are just a type of cytokine, but this is misrepresented in many educational materials.

B and T Cells

The table below outlines the roles of the lymphocytes involved in specific immunity:

Cell Type	Function
Undifferentiated lymphocyte	- Detects antigens using complementary receptors on its surface. - Activated via antigen presentation and clonal selection, then undergoes clonal expansion.
B Memory cell	- Provides long-term immunity. - Responds rapidly to known antigens by undergoing clonal expansion.
Plasma Cell / B Effector Cell	- Produces and secretes antibodies specific to one antigen.
T Memory Cell	- Provides long-term immunity. - Responds rapidly to known antigens by undergoing clonal expansion.
T Killer Cell	- Destroys infected cells that activate it with antigen presentation and interleukins. - Releases perforins and hydrolytic enzymes.
T Helper Cell	- Coordinates the immune response. - Releases interleukins to stimulate clonal selection and clonal expansion of B and T cells.

The Primary and Secondary Immune Response

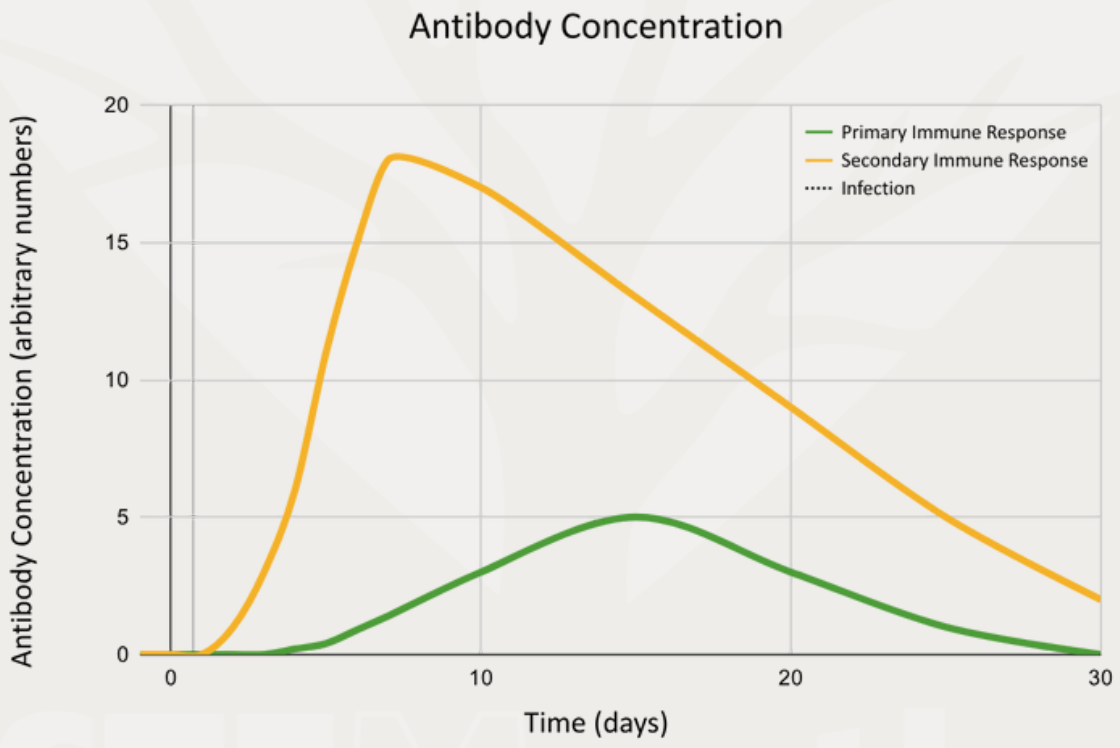
The **first exposure** to a pathogen is called the **primary response**, and **subsequent exposures** are known as a **secondary response**:

- **Primary response**: Characterised by a **delay** in, **slower rate** of, and **lower** overall total concentration of **antibody production**.
- **Secondary response**: Characterised by a **rapid**, **high rate** of, and **higher** overall total concentration of **antibody production**.

Exposure to a pathogen, or its antigens, could be from **infection** or **vaccination.**

Memory cells are produced by **T killer cells** and **plasma cells**, allowing new T killer and plasma cells to be produced **faster upon reexposure**.

The graph below visualises the difference between the primary and secondary response:



Types of Immunity

Immunity is the ability to resist infection by pathogens by **having complementary antibodies** or **memory cells** that can rapidly make them.

Immunity can be either **active** or **passive**:

- **Active**: The host's immune system **makes its own antibodies** after being exposed to a pathogen.
- **Passive**: The host receives **antibodies** from an **external source**.

Immunity can be **acquired** either **naturally** or **artificially**:

- **Natural**: A normal **biological process** confers immunity.
- **Artificial**: **Medical intervention** confers immunity.

The table below summarises these types of immunity with examples:

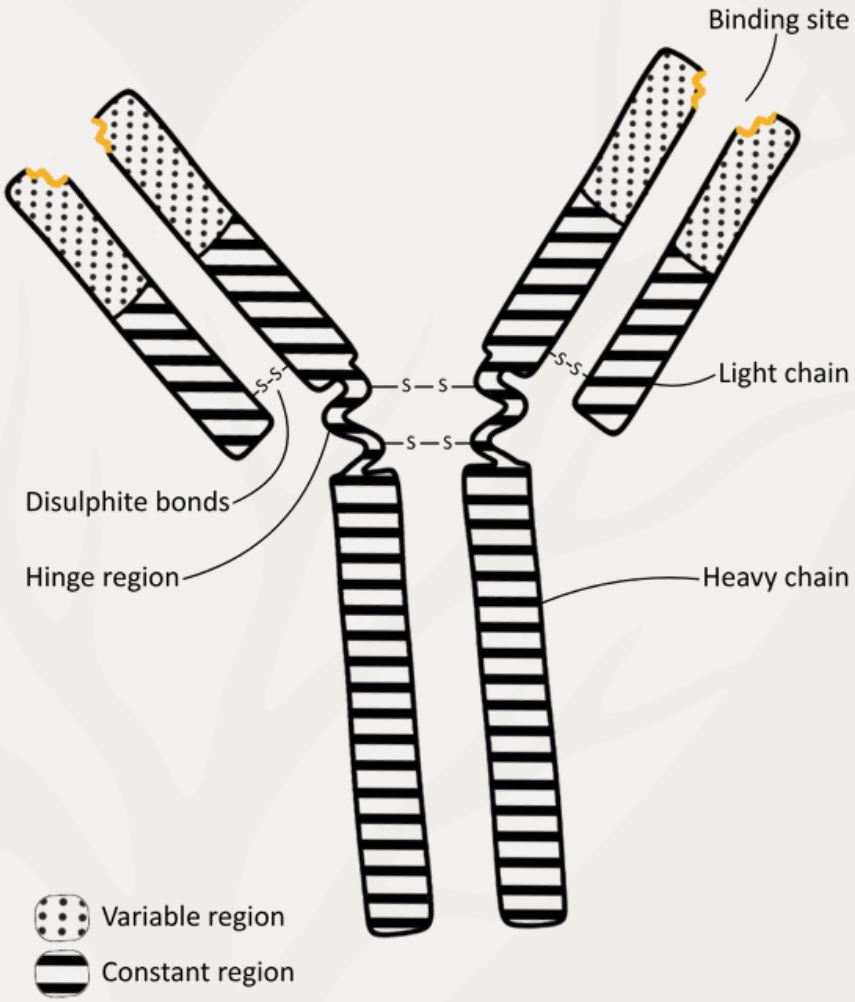
	Natural	Artificial
Active	The immune system produces antibodies after infection (e.g. chickenpox)	Antigen introduced via vaccine (e.g. MMR, TB)
Passive	Antibodies from the mother via the placenta or breast milk	Antibodies injected (e.g. antivenom, hepatitis treatment)

Antibodies

Antibodies are glycoproteins involved in the function of the immune system.

They have a quaternary structure made up of four polypeptide chains; there are **two heavy chains** and **two light chains**.

The **structure** of an antibody is **Y-shaped**, as illustrated in the diagram below:



The components labelled are:

- **Arms**: The two **branches** of an antibody.
- **Variable region**: An area at the end of the antibody arm that differs between types of antibody; the **binding site** is found here.
- **Binding site**: A **3D area** on the variable region that is **complementary** to one type of antigen.
- **Constant region**: A structure that is the **same across all antibodies**; it may have a **receptor** to help **phagocytes bind to it**.
- **Hinge region**: A **flexible** part of the antibody which allows more than one pathogen to be attached to (by each arm).
- **Disulfide bonds**: These hold the polypeptide chains together.

There are **three types** of antibodies, each with a different role:

- **Opsonins**: Bind to antigens on pathogens to make it easier for phagocytes to engulf them by **providing a binding site for phagocytosis**.
- **Agglutinins**: Bind to antigens on different pathogens so that they are **clumped together** (agglutinated), allowing **more to be engulfed** by **phagocytes**.
- **Anti-toxins**: Bind to the **toxins** made by pathogens, making them inactive and **neutralising their harmful effects**.

Autoimmune Diseases

Autoimmune diseases occur when the immune system **attacks** the body's **own tissues, mistaking self-antigens as foreign antigens**.

The causes of this are not always known, but may include **genetic** and **environmental triggers**.

Immunosuppressants are the most common **treatment**, but have side effects (e.g. vulnerability to pathogens).

Rheumatoid arthritis is the named example you are expected to know, characterised by membranes around joints being targeted, leading to **pain**, **swelling** and **inflammation**.

Vaccination

Vaccination stimulates the production of **memory cells** without causing illness.

It **exposes** the immune system to a harmless* **antigen**, stimulating the **production** of **complementary antibodies and memory cells**.

*Although it should be noted that side effects (such as allergic reactions) are possible, and in rare cases, the vaccine does not work.

Forms of antigenic material in (some) vaccines:

- **Antigens**: A selection of **antigens** from the **pathogen**, such as hepatitis B.
- **Attenuated microorganisms**: A **weakened** and **harmless pathogen**, such as the measles and TB vaccines.
- **Dead microorganisms**: **Killed** so that they are **harmless**, such as cholera.

Vaccination Programmes

Vaccination protects individuals from pathogens, but the **immunisation** of large groups of people can strategically protect **nonimmune** and **immunocompromised** people.

Two key elements are:

- **Herd Immunity**: When enough of the **population is immune**, the pathogen's spread is **highly reduced**.
- **Ring Vaccination**: All individuals who have or may be **in contact** with someone who is infected are **vaccinated** to prevent the pathogen from spreading.

Controlling epidemics

The **occurrence** of disease is monitored at both a national and an international level in both animals and humans to prepare for and prevent the possibility of an **epidemic** or a **pandemic**.

Outbreaks in animals are monitored due to their **economic importance** in the food supply (e.g. cattle), as well as their ability to spread diseases across borders (e.g. wild birds).

The table below outlines some of the key considerations when managing epidemics with vaccines:

Aspect	Consideration
Cooperation	Is a disease widespread, or transmissible enough, to require international cooperation.
Disease Traits	- Can the disease infect animals and humans. - What is its lethality. - How long does immunity last for.
Cost-effectiveness	- How cheap is the vaccine to produce. - How costly are the economic or health impacts.

Developing New Medicines

The discovery and development of new medicines are of major importance in healthcare.

New medicines can come from nature, observation, or scientific innovation, and all require **extensive testing before use**.

The need for new medicines

New drugs are constantly required because:

- **New diseases** continue to emerge (e.g. SARS, Ebola, COVID-19)
- Existing diseases still **lack effective cures** (e.g. Alzheimer's, cancer)
- Antimicrobial **resistance** makes current **treatments less effective** (e.g. MRSA)

New drugs can be discovered through different approaches:

Approach	Description
Traditional remedies	Traditionally used plants may have active ingredients.
Wildlife observation	Animals and insects utilise plants to treat and prevent infectious disease, which can be investigated for new biomolecules.
Disease mechanisms	Researching the exact mechanisms of infection and disease creates insights that can be exploited with the development of new biomolecules.
Synthetic biology	Organisms can be genetically engineered to produce medicines, or entirely new biomolecules can be designed and created.
Personalised medicine	Existing medicines can be tailored using information on an individual's genetics and metabolism, reducing side effects and increasing effectiveness.

Drug discovery is a strong argument for the conservation of biodiversity, as unexplored ecosystems may contain **undiscovered compounds with medicinal value**.

Antibiotics: Importance and Use

Antibiotics are **medicines** that either **kill** bacteria or **inhibit** their growth.

Penicillin, the first antibiotic, was discovered by Alexander Fleming in 1928 from the fungus *Penicillium notatum*.

Antibiotic Resistance

Antibiotic resistance occurs when bacteria **evolve** mechanisms to **survive** exposure to **antibiotics**. This poses a serious risk to public health, as it can make infections:

- Harder to treat
- More likely to spread
- More likely to cause complications or death

MRSA (methicillin-resistant Staphylococcus aureus) is a major example of a resistant "superbug" that has become prevalent in hospitals, making routine surgery more dangerous.

The factors which accelerate the evolution of antibiotic resistance include:

Factor	Explanation
Overuse of antibiotics	Increases selection pressure for resistance
Incomplete courses of treatment	Leaves behind resistant bacteria
Use in agriculture	Antibiotics given to livestock may spread resistance genes to human pathogens

Module 4: Biodiversity

Biodiversity

Biodiversity is the measurable **differences between organisms**, both as individuals and as species.

Biodiversity can be considered at **different levels**, such as:

- **Habitat biodiversity**: The number of different ecosystems or habitat types in a defined area (e.g. woodland, grassland, sand dune and streams).
- **Species biodiversity**: The number of different species in a defined area (species richness) and their relative abundance (species evenness).
- **Genetic biodiversity**: The genetic variation between individuals of the same species.

Declining Biodiversity

Biodiversity can be **reduced** by both natural and human-driven (anthropogenic) factors. Human activity is currently the largest cause of biodiversity loss worldwide.

Human Population Growth

As the **global population increases**, demand for space, food, water, and energy also rises. This leads to:

- **Habitat loss** (e.g. deforestation, urbanisation)
- **Pollution** (e.g. air, water, and soil contamination)
- **Overexploitation** of natural resources (e.g. hunting, fishing, agriculture)

Agriculture

Modern farming practices often reduce biodiversity:

- **Monoculture**: Growing a **single crop** (a monoculture) across large areas eliminates habitat variety, reduces species diversity and reduces nutrients in the soil.
- **Selective breeding: Reducing the genetic diversity** within a domesticated species to ensure only desired characteristics are expressed (genetic erosion).
- **Pesticides and herbicides: Non-target species are killed** directly, or killed indirectly through contaminated food chains (e.g. bioaccumulation).

Climate Change

Changing temperature and rainfall patterns **alter ecosystems**, such as:

- Some **species migrate** to more suitable areas (if they can), and others may go extinct.
- Coral bleaching and desertification are examples of **habitat loss** caused by climate change.

Conserving Biodiversity

Biodiversity provides essential **resources**, **services**, and **benefits** to ecosystems and human society. There are **ecological**, **economic**, and **aesthetic** reasons for protecting it.

Ecological Reasons

- **Interdependence of species** means that the loss of one species can affect **many** others.
- **Keystone species** have a **disproportionately large effect** on their ecosystem by supporting many species as a side effect of their behaviour.
- **Genetic diversity** provides **natural variation** that can be used to identify new medicines or produce new crops more resistant to drought or disease.

Economic Reasons

- **Soil depletion** caused by monoculture can lead to **lower crop yields**, requiring fertiliser and reducing long-term sustainability.
- **Biodiversity** supports **ecotourism** and recreation industries.

Aesthetic Reasons

- **Natural environments** have **cultural**, **spiritual**, and **recreational value**.
- **Landscapes** with high biodiversity are more attractive and can **improve human well-being**.

Conservation Methods: In Situ and Ex Situ

Conservation can be carried out **in situ** or **ex situ**. Each approach has **advantages** and **limitations**.

In Situ Conservation

This involves protecting species **in their natural environment**.

In situ conservation typically revolves around designating areas as a type of **wildlife reserve** to **protect habitats** and the species that live there.

The table below outlines the types of wildlife reserves:

Method	Actions
In General	
Wildlife reserves	- Designated to protect habitats and species from human interference and activity. - Preserves existing traditional use of the land (e.g. spiritual and hunting purposes). - Cooperate with local people to manage issues such as animal-human conflict over agriculture, logging and poaching.
Specific (UK) Types	
SSSI	Sites of Special Scientific Interest protect rare, vulnerable or highly biodiverse areas with an emphasis on conservation and research.
LNR	Local Nature Reserves are designated by local authorities as important areas for conservation work.
Marine conservation zone	Protect marine biodiversity by restricting fishing, oil drilling, and tourism.
National Park	Emphasise the aesthetic protection of UK landscapes for the access, enjoyment and use of everyone.
NNR	National Nature Reserves protect vulnerable environments for research and public education.

Ex Situ Conservation

This involves protecting species by **removing** part of the **population from a threatened habitat** and placing it in a controlled environment.

The table below outlines the main approaches to ex situ conservation:

Method	Actions
Zoo/Wildlife Park	- Breed endangered animals in captivity, using artificial insemination, IVF and embryo transfer. - Educate the public. - Research into endangered species.
Botanic gardens	- Grow rare or endangered plants. - Research plants and educate the public about them. - Collect and store seeds for easy long-term conservation at scale.
Seed banks	- Long-term storage and distribution of seeds for agricultural, conservation, research and humanitarian work.

Conservation Agreements

Conservation agreements help coordinate efforts to **protect endangered species and ecosystems** through shared objectives, legislation, and funding.

International agreements address conservation issues which are global and cross international borders; CITES (1973) and the CBD (1992) are two examples.

Agreement	Purpose
CITES	The **Convention on International Trade in Endangered Species** of Wild Fauna and Flora is an international agreement that regulates and monitors the trade of over 25,000 species.
CBD	The **Rio Convention on Biological Diversity** promotes the conservation of biodiversity for the sustainable use of resources and sharing of research to the benefit of the communities from which organisms originate.

*Examination materials typically provide the full name and abbreviation, and (so far) have tested candidates' knowledge and understanding of the named agreement, instead of testing their ability to identify and name it.

National and local agreements address conservation issues in an entire country, particular regions, or types of habitat. The CSS (1991), and later the ESS (2005) in the UK are two example.

Agreement	Purpose
CSS*	The **Countryside Stewardship Scheme** funds and supports farmers and landowners to promote biodiversity and heritage conservation.
ESS*	The **Environmental Stewardship Scheme** funds and supports farmers to conserve, enhance and promote the countryside.

*Examination materials typically provide the full name and abbreviation, and (so far) have tested candidates' knowledge and understanding of the named agreement, instead of testing their ability to identify and name it.

The endorsed OCR A level textbook indicates that the CSS was replaced by the ESS, whilst in reality both programs are still running.

Measuring Biodiversity

Sampling techniques allow for a reliable **estimation of biodiversity** to be made by collecting data on which species are **present** in an area and their **abundance**.

The table below outlines the different sampling methods:

Sampling Method	Description	Advantage	Disadvantage
Random	Sites are chosen randomly.	Removes bias.	Species may be missed.
Opportunistic	Locations are chosen based on availability, accessibility or knowledge.	Produces data quickly.	Inherently biased, making the data highly unreliable
Stratified	The habitat is divided into areas (strata) based on their differences, and each is sampled.	All different areas of a habitat are sampled.	Some areas may be smaller, overrepresenting some species.
Systematic	Samples are taken at regular intervals along a measurable abiotic gradient.	Provides paired data: The location and abundance of species sampled is linked with measured abiotic factors.	Species outside of the transect are missed.

Field equipment

Several standard techniques are used to collect data on different organisms:

- **Pitfall traps**: Containers sunk into the ground to catch small ground-dwelling animals.
- **Pooters**: Suck up small invertebrates into a container without harm.
- **Quadrats**: Square frames (e.g. 0.5 m × 0.5 m or 1 m × 1 m) used to estimate plant abundance. Quadrats are laid randomly or at intervals along a transect. Species may be counted directly or estimated by percentage cover.
- **Sweep nets**: Used for catching insects in tall vegetation.
- **Transects**: Lines across the habitat. A line transect records species touching the line; a belt transect involves placing quadrats along the line.

Measuring Species Richness and Species Evenness

Biodiversity within a habitat depends not only on the number of different species present, but also on how **evenly** the individuals are **distributed** among those species.

For example, the table below compares the abundance of 20 species in two habitats:

Habitat	Species Present	Richness	Evenness	Interpretation
Wildflower meadow	20 species, each with similar abundance.	High	High	High biodiversity: many species with balanced populations.
Managed lawn	20 species, dominated by 2 species.	High	Low	Lower biodiversity: same richness but reduced evenness.

Simpson's Index of Diversity

Simpson's Index of Diversity (D) provides a quantitative measure of biodiversity that takes both species richness and evenness into account.

It can be used for **comparing different habitats** or monitoring changes over time.

The Formula

$$D = 1 - \Sigma (n / N)^2$$

Where:

- **n** = number of individuals of a particular species
- **N** = total number of individuals of all species
- **Σ** = the sum of
- **D** = a value between 0 and 1.

Interpreting D

A **high D** (closer to 1) means high biodiversity; many species and/or even populations.
A **low D** (closer to 0) means low biodiversity; few species and/or dominated by one.

Example Calculation

Suppose a habitat has the following species counts:

Species	Number of Individuals (n)
Buttercup	25
Dandelion	25
Daisy	25
Dock	25
Total (N)	100

Using the formula:

$$D = 1 - \Sigma (n / N)^2$$

For convenience, data is typically processed in the following format:

Species	n	n/N	(n/N)2
Dandelion	85	0.85	0.7225
Buttercup	5	0.05	0.0025
Daisy	5	0.05	0.0025
Dock	5	0.05	0.0025
		Sum (Σ)	0.73
		D = 1 - Σ	0.27

This low Simpsons Index of Diversity value (D) indicates low species evenness and biodiversity.

Assessing Genetic Biodiversity

Measuring genetic diversity allows scientists to monitor population health, detect signs of inbreeding or bottlenecks, and **guide conservation** or breeding decisions.

Examples include:

- **Endangered wild species**, such as cheetahs or Ethiopian wolves, which may have experienced genetic bottlenecks.
- **Captive breeding programmes** in zoos, where maintaining variation is vital to avoid inbreeding.
- **Rare domestic breeds** and pedigree animals, where selective breeding can reduce genetic diversity.

Measuring Genetic Biodiversity

Genetic diversity calculations are especially useful when assessing populations at risk of low genetic variation.

The **proportion of genotypes** for an allele in a population can be **calculated** using the **Hardy–Weinberg equation**.

There are three common ways to **measure** or **estimate** genetic biodiversity:

- **Hardy–Weinberg equation***: Predicts expected genotype frequencies in a population, assuming no migration, mutation, random mating, a large population size, and no selection pressure.
- **Polymorphic gene loci**: Estimates the proportion of gene loci in a population that have more than one allele.
- **Heterozygous gene loci**: Estimates the proportion of gene loci in an individual that are heterozygous.

*A2 content only, but presented here for relevance.

The Hardy–Weinberg Equation

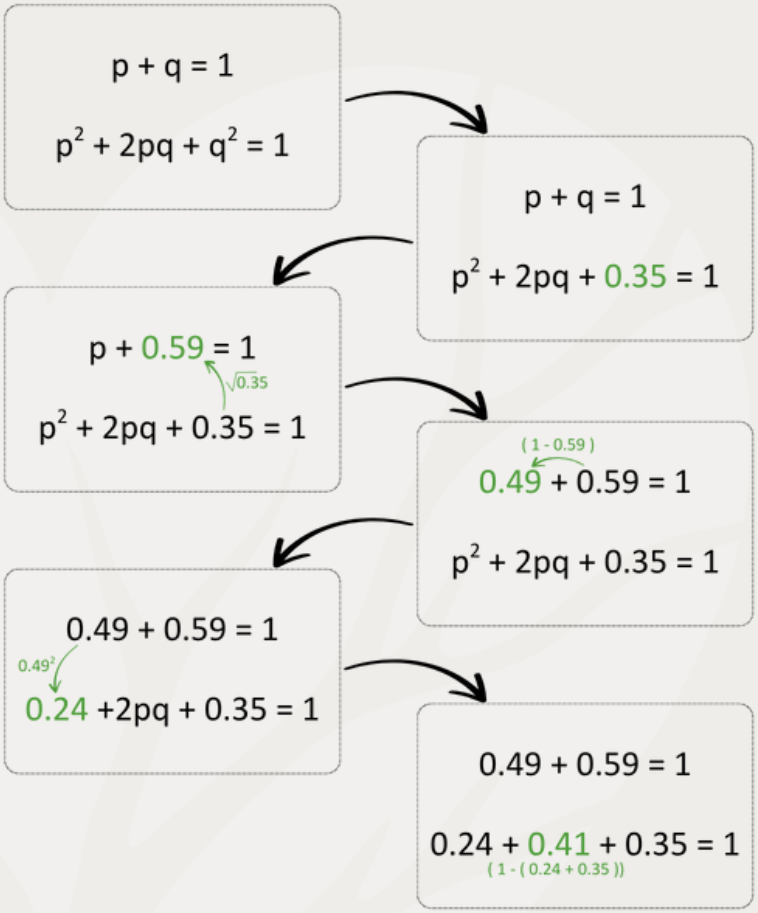
The **Hardy–Weinberg** principle **predicts** expected **genotype frequencies** within a **non-evolving population** (allele frequencies do not change across generations).

$$p^2 + 2pq + q^2 = 1$$

Where:

- **p** = frequency of the dominant allele (A)
- **q** = frequency of the recessive allele (a)
- **p²** = homozygous dominant (AA)
- **2pq** = heterozygous (Aa)
- **q²** = homozygous recessive (aa)

Because p + q = 1, knowing one allele, or genotype, frequency allows the rest to be calculated.



Determine The Percentage Polymorphic Gene Loci

You can **calculate** the **proportion** of **gene loci** in a population that are **polymorphic**.

Proportion of polymorphic loci = (Number of polymorphic loci) ÷ (Total number of loci)

To express this as a percentage:

Genetic diversity (%) = (Polymorphic loci ÷ Total loci) × 100

Determine The Number of Heterozygous Gene Loci in an Individual

An **individual's** genetic diversity can be estimated by calculating the **proportion of loci** for which it is **heterozygous**:

Heterozygosity (%) = (Number of heterozygous loci ÷ Total loci in genome) × 100

Variation

Variation is the **differences** between individual organisms.

These differences may occur and be measured within a species (**intraspecific variation**) or between species (**interspecific variation**).

Type of variation	Description	Example
Intraspecific	Variation between individuals of the same species	Eye colour in humans
Interspecific	Variation between different species	Cats and dogs have different teeth

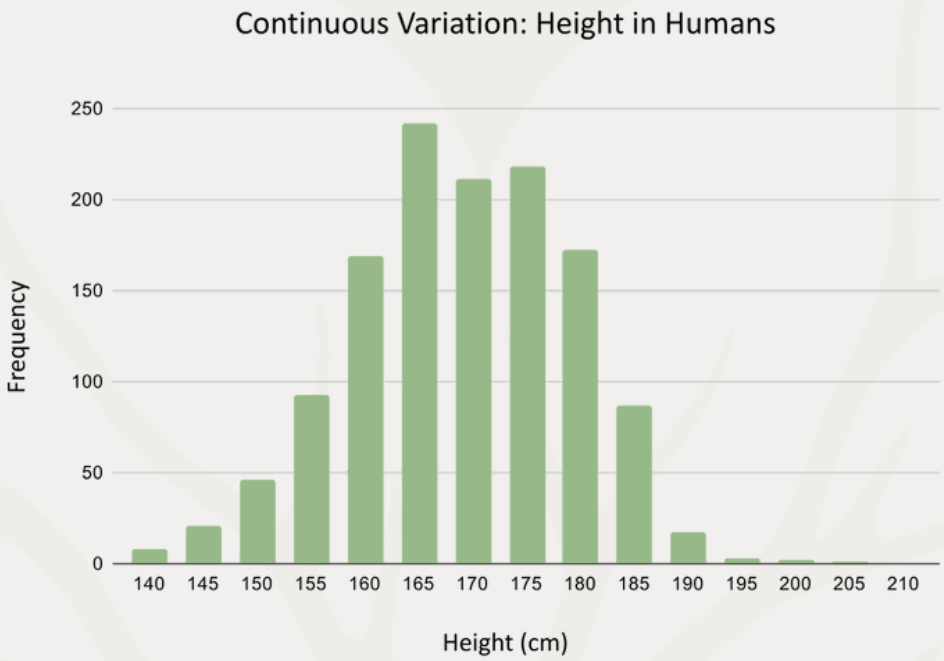
Continuous and Discontinuous Variation

Variation is either **continuous** or **discontinuous**, which affects its distribution in a population.

- **Continuous variation** is usually caused by **multiple genes** (are polygenic) and may be influenced by the environment. It shows a range of intermediate values.
- **Discontinuous variation** is usually caused by **one gene** (monogenic) and is not affected by the environment. It shows distinct categories.

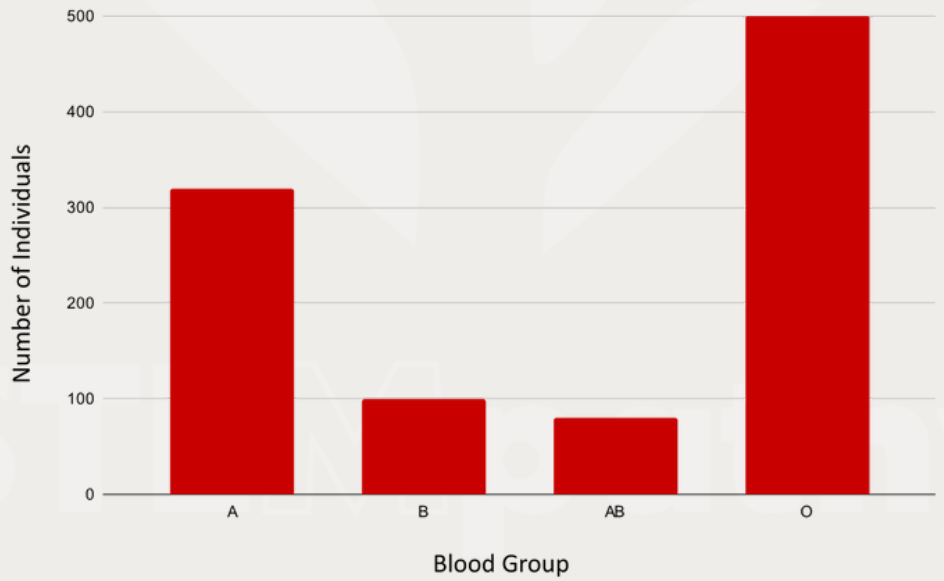
Continuous data should typically be plotted onto a **histogram**, but line graphs are commonly used.

The graph below gives an example data set of a random sample of 1000 people, presented as a histogram, showing a typical **bell-shaped curve**.



Discontinuous data is typically plotted onto a **bar chart**.

The graph below gives an example data set of a random sample of 1000 people's blood type, presented as a bar chart, showing **distinct categories** of traits.



Quantitative vs Qualitative

Measuring variation produces data that can be **quantitative** or **qualitative**.

Quantitative data involves numerical measurements and is typically associated with **continuous variation** (e.g. height, mass).

Qualitative data describes categories or characteristics and relates to **discontinuous variation** (e.g. blood group, flower colour).

Examples of Continuous and Discontinuous Variation

The table below outlines some common examples of **continuous traits**:

Trait	Description	Genetic Control
Height in humans	Varies gradually; influenced by the environment	Polygenic and environmental factors
Body mass in animals	Influenced by diet, activity, and genetics	Polygenic and environmental factors

The table below outlines some common examples of **discontinuous traits**:

Trait	Description	Genetic Control
Human blood group	A, B, AB, or O	Single gene with multiple alleles
Flower colour in peas	Distinct categories (e.g. purple or white)	Single gene

Module 4: Causes of Variation

Causes of Variation

Variation in organisms is caused by differences in their **genetic information** and **environmental conditions**.

- **Environmental**: Caused by **differences** in **external conditions** or **experiences** that affect an organism's characteristics.
- **Genetic**: Caused by **differences** or **changes** in an organism's **DNA**, including the expression of genes in its genome.
- Combined: Caused by the interaction between genetic factors and environmental influences.

Environmental Causes of Variation

Environmental variation is caused by the conditions in an organism's surroundings influencing **how genes are expressed**.

The table below outlines some environmental factors and their effect on an organism:

Environmental Factor	Effect on Organism
Diet	Affects nutrient availability; a poor childhood diet can limit growth (e.g. human height).
Predators or Disease Exposure	Triggers stress and immune responses.
Human Activity	Introduces pollutants that can disrupt normal gene function.
Light	Influences hormones that control development; causes tanning in human skin.
Temperature	Alters enzyme activity; e.g. hawthorn trees grow tall in the wild but stay bushy when trimmed.

Mutation

A **mutation** is a permanent **change in the base sequence of DNA**.

Mutations can be neutral, harmful, or (rarely) beneficial.

A mutation may:

- Change the amino acid sequence of a protein, and its structure or function.
- Affect gene regulation and expression.
- Have no effect at all.

Causes of Mutation

Mutations may occur due to cellular mishap or be induced by environmental factors (mutagens).

Genetic Causes of Mutation

Genetic mutations occur due to random errors by enzymes (e.g. DNA polymerase) or structural instability (e.g. spindle fibres failing to separate chromosomes).

Environmental Causes of Mutation

Mutations can occur due to environmental factors known as mutagens.

Mutagens increase the rate of mutation by damaging DNA or interfering with replication.

The table below outlines some mutagenic factors and the damage they cause:

Cause	Type of Damage	Examples
Ionising radiation	Breaks DNA strands	X-rays, gamma rays
UV light	Causes thymine dimers	Sunlight
Chemicals	Modify bases or interfere with DNA replication	Cigarette smoke, asbestos, benzene
Viruses	Insert viral DNA into the host genome	HPV, retroviruses

Adaptations

Adaptations are **characteristics** that improve an organism's ability to **survive** and **reproduce**, such as:

- Gain food, light, or water
- Avoid predators or disease
- Tolerate environmental stress (e.g. drought, salinity, cold)
- Reproduce successfully
- Respond to environmental changes

There are **three** main categories of **adaptation**:

- Anatomical
- Behavioural
- Physiological

Anatomical Adaptations

Anatomical adaptations are the **structural features** of an organism's body.

Plant examples include:

Organism	Adaptation	Function
Marram grass	Long and/or deep roots	Stabilise dunes and absorb more water
Marram grass	Curled leaves	Reduce wind exposure
Marram grass	Hairy lower epidermis	Reduce airflow → trap moist air
Marram grass	Sunken and sunken stomata	Reduce air flow and water loss → reduce transpiration
Marram grass	Thick waxy cuticle	Prevent evaporation from leaf surfaces
Water lily	Stomata on the upper surface	Allow gas exchange while floating on water
Water lily	Air spaces in leaf tissues	Aid buoyancy and flotation
Water lily	Flexible leaf stalks	Allow movement with water currents

Animal examples include:

Organism	Adaptation	Function
Arctic fox	Small ears, thick fur	Reduce heat loss in cold climates
Camel	Wide calloused feet	Distribute surface area for walking on hot sand

Behavioural Adaptations

Behavioural adaptations are actions or **responses** that improve survival or reproduction.

Plant examples include:

Organism	Behaviour	Purpose
Marram grass	Leaves roll up tighter when dry	Reduces surface area and conserves water
Marram grass	Close stomata when water is low	Limit water loss through transpiration
Marram grass	Grows upwards when buried	Reaches sunlight after sand deposition

Animal examples include:

Organism	Behaviour	Purpose
Earthworm	Retreats into a burrow when touched	Avoids predation
Swallow	Migrates in winter	Avoids cold and food shortages
Sea cucumber	Ejects guts and fluids when threatened	Startles predators/aids escape

Physiological Adaptations

Physiological adaptations involve **internal processes** or chemical changes.

Plant examples include:

Organism	Adaptation	Function
Marram grass	Low water potential in cells	Allows water uptake in salty or dry soils
Marram grass	Turgor changes roll/unroll leaf	Minimises water loss from transpiration

Animal examples include:

Organism	Adaptation	Function
Desert animals	Produce very concentrated urine	Conserve water
Antarctic fish	Produce antifreeze proteins	Prevent blood from freezing
Humans	Sweating	Thermoregulation

Module 4: Natural Selection

Natural selection is a process by which those individuals who are **best adapted** to their environment **survive and reproduce more successfully** than those who are not, passing on their **alleles** to the next generation.

Over many generations, these **alleles**, and the characteristics they code for, **increase in frequency** in the population.

Evolution is when the **characteristics** in a species **change** due to significant **changes in allele frequencies**.

Speciation is when a **new species evolves**; the population becomes distinct enough from the ancestral precursor species that they can **no longer interbreed** to produce fertile offspring.

Natural Selection

The process of natural selection can be simplified into the following stages:

1. There is variation within a population caused by alleles which arise from mutation.
2. Some individuals will be better adapted (fitter) than others.
3. Selection pressures allow only the fitter individuals to survive and reproduce.
4. These individuals pass on their alleles for their traits to their offspring.
5. These characteristics, and their alleles, become more common in the next generation.
6. If enough time passes, as this process repeats over time genetic differences will accumulate within the population that it may be considered a new species from it's ancestral one.

Natural Selection Example: Peppered Moths

Peppered moths are a historical example that occurred in England during the Industrial Revolution, as the burning of coal created soot that **darkened** the surfaces of **trees**. The **white and speckled** peppered moth, camouflaged to blend in with tree bark, now **stood out** and was easily **hunted** and eaten by predators. However, some individuals carried a **mutated allele that caused melanism** (black pigment). This trait was previously selected against and remained uncommon in the population, but now conferred a distinct **survival advantage** in the new environment, over time becoming the dominant characteristic in the population.

Once England's air pollution was resolved, a reversal occurred in the population's occurrence of phenotypes, and now the white speckled peppered moth is the most common form.

The natural selection process at work is:

1. There is variation within a population of peppered moths.
2. Some individuals have preexisting alleles, or a new mutation, that confers darker colouring (melanism).
3. The population is exposed to the selection pressure of industrial soot pollution, which darkens tree bark and makes pale moths more visible to predators, whilst darker moths are better camouflaged and less likely to be seen and eaten.
4. Those with the beneficial allele for melanism survive and reproduce, passing on the allele to their offspring.
5. The allele for dark colouring increases in frequency in the next generation, and so this new population is more likely to survive in polluted environments.
6. This process repeats over many generations, leading to the evolution of a population adapted to urban, soot-covered habitats.

Speciation

Speciation is when an **isolated population** of a species **evolves** to become different enough that it can **no longer reproduce** with the original species' population to produce fertile offspring.

Populations become isolated - either **geographically** or **reproductively** - and stop interbreeding. Once isolated, the populations experience **different selection pressures** and, over time, **accumulate genetic differences**.

Types Of Speciation

There are two main types of **speciation**:

Allopatric: Occurs when populations are **geographically separated**.
Sympatric: Occurs when populations are **reproductively isolated**.

Allopatric and sympatric speciation do have their own technical terms, which are not required for OCR A level Biology, and are not explored here.

Examples of Allopatric Speciation

The table below outlines some situations that result in geographical isolation:

Description	Example
Continental or sea-level changes separate populations	Ostriches and emus are evolving separately
Ice sheets isolate species during glaciation	Sticklebacks in isolated post-glacial lakes
Separated populations adapt to contrasting local conditions	Lizards on either side of a canyon

Examples of Sympatric Speciation

The table below outlines some processes that result in reproductive isolation:

Process	Description	Example
Habitat Differentiation	Populations evolve to be adapted to different resources in the same area	Apple vs hawthorn maggot flies
Sexual Selection	Preferences for certain traits isolate groups (mate choice divergence)	African cichlid fish
Temporal Isolation	Groups reproduce at different times of year or day	13-year vs 17-year cicadas

Convergent Evolution

Convergent evolution is when **unrelated** species independently evolve **similar traits** or adaptations in response to **similar selection pressures**, even though they are **not closely related**.

The **key features** of convergent evolution is that it:

- Occurs in **unrelated species** living in similar environments
- Driven by **similar selection pressures**, not shared ancestry
- Results in **analogous structures** (same function, different origin)

The table below outlines some common examples of convergent evolution:

Species 1	Species 2	Shared Adaptation(s)	Reason for Convergence
Marsupial mole	Placental mole	- Streamlined body - Strong forelimbs - Reduced eyes	Adaptation for life underground (burrowing)
Shark	Dolphin	- Fins - Streamlined body - Powerful tail	Fast swimming in aquatic environments
Cactus	Euphorbia	- Thick - Fleshy stems - Spines	Water storage and herbivore protection in desert environments

The image below compares the typical anatomical profile of sharks (fish), ichthyosaurs (reptiles) and dolphins (mammals), which became similar through convergent evolution:

Shark

Ichthyosaur

Dolphin

Evidence for Natural Selection and Evolution

Anatomy, DNA, fossils, biomolecules and real-time observations provide **evidence** and **examples** for species **evolving by natural selection**.

Fossil Evidence

Fossils are the **preserved remains or traces** of organisms from the past.

The fossil record provides direct evidence of:

- Extinct species that once existed
- New species which resemble older ones
- Transitional fossils which show intermediate changes

Anatomical Evidence

Similarities and differences in the anatomical structures of different species offer insight into **evolutionary relationships**.

Homologous structures are anatomical features which are present in different species, but have adapted over time to **serve different functions**, such as the bones found in a human hand vs the same bones found in a bat's wing.

Genetic Evidence for Evolution

The discovery of DNA and the development of techniques to sequence and compare different genes and genomes allow for evolutionary changes and relationships to be accurately explored.

The table below outlines some of the different types of genetic material that can be investigated:

Evidence	What It Shows
DNA sequence similarity	Closely related species have more similar base sequences.
% of shared genes/conserved genes	Homologous (matching) genes appear in many species, indicating descent from a common ancestor and the genes' importance in being selected for.
Genetic markers/mutations	Shared mutations or marker sequences indicate common ancestry.

Biomolecular Evidence

The **biomolecules** synthesised in organisms are **determined** by their underlying **genetic code**. In some situations it may be easier, or more informative, to examine and compare these, particularly proteins, to determine evolutionary relationships.

The table below outlines the different biomolecules which can be investigated:

Evidence	What It Shows
Shared amino acid sequences in proteins	Closely related species have similar or identical amino acid sequences.
Differences in protein primary structure	Distantly related species have more differences.
Shared non-coding DNA	Identical sequence insertions passed down from a common ancestor.
Mutated DNA repeat regions	Some mutations have harmful effects, but may still be passed on.

Observing Evolution Today

While most **evolutionary changes** take place over **long periods**, some examples of natural selection can be seen happening within just a few generations. These examples often arise in response to strong selection pressures such as drugs, pollution, or pesticides.

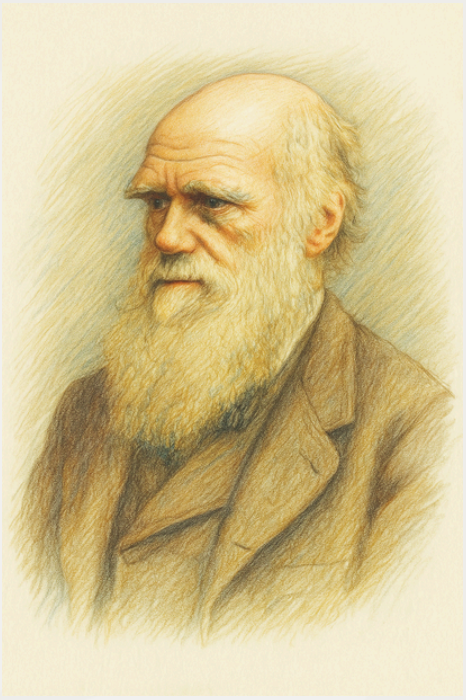
They demonstrate how beneficial traits can become more common over time.

The table below outlines some important examples of modern evolution in action:

Example	What It Shows
Antibiotic resistance	Random mutations made some bacteria resistant, and these resistant strains became more common.
Peppered moths	Changes in pollution affected camouflage success, so darker or lighter morphs were selected.
Mosquitoes and DDT	Insecticide use favoured resistant mosquitoes, so the population became resistant over time.

Module 4: Charles Darwin and Alfred Russell Wallace

Charles Darwin's Evidence for Natural Selection



Charles Darwin travelled around the world on HMS Beagle between 1831 and 1836.

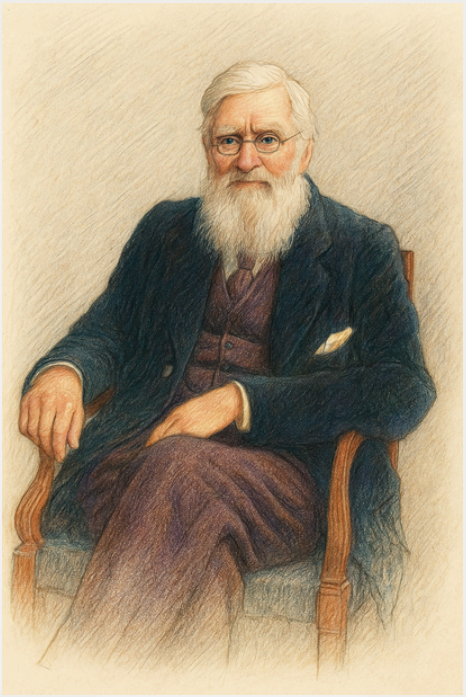
The observations Darwin made during this time gave him the idea that all **species** were **descended from other**, earlier species, and that all species **may be related**.

This became the basis of Darwin's theory of **evolution by natural selection**, a scientifically supported explanation for **how species change over time**.

The table below outlines **Darwin's** key observations and the subsequent hypotheses and theories:

Observation	Hypothesis	Theory
Fossils of extinct animals resembled living species in the same region	Extinct and extant species may be related	Species change over time and may evolve from earlier forms
Variation existed between individuals of the same species	Some individuals are better adapted to survive and reproduce	Variation means some individuals will pass on their traits more successfully than others: natural selection
Offspring resembled their parents more than others, yet still varied	Advantageous traits are often inherited and passed to offspring	Traits that increase survival and reproduction become more common over time
Different species lived in similar habitats but shared similar features	The environment determines which traits are useful	Different species can evolve similar traits under the same selection pressures
Different finches and tortoises on each Galápagos island	Populations adapt to local environments over time	Isolation and natural selection can lead to new species evolving

Alfred Russell Wallace's Evidence for Natural Selection



Alfred Russel Wallace was a British naturalist, collector, and explorer who **independently** developed a **theory of evolution by natural selection** at the same time as Charles Darwin.

The table below outlines **Russell Wallace's** key observations and the subsequent hypotheses and theories:

Observation	Hypothesis	Theory
Species on either side of a geographical divide were completely different.	Long-term geographical separation prevents populations from mixing.	Isolation leads to gradual divergence and the formation of distinct species.
Animal species had traits suited to where they lived.	Species evolve over time in response to selection pressures caused by their environment.	Natural selection causes populations to become adapted to their environment.
Variation existed between individuals of the same species.	Some individuals are better adapted to survive and reproduce.	Variation means some individuals will pass on their traits more successfully than others.
Tropical islands had high numbers of unique species.	Isolated, or diverse habitats accelerate the development of new species	Evolution occurs rapidly where populations are both separated and ecologically varied, driving speciation.

Classification

Classification is the process of placing organisms into **groups**.

Classification helps scientists to:

- Identify and name organisms
- Predict shared characteristics
- Organise biological knowledge
- Understand evolutionary relationships

Organisms can be classified by:

- **Observable characteristics** such as limbs or flower colour.
- **Cellular features** such as the presence of a nucleus.
- **Molecular traits** such as DNA and RNA sequences.
- **Physiological processes** (e.g. respiration type)

Artificial vs Natural Classification

The table below outlines the characteristics of artificial and natural selection:

Feature	Artificial Classification	Natural Classification
Based on	A selection of observable traits	A wide range of characteristics with a focus on genetic evidence
Reflects evolutionary history?	❌ No	✅ Yes
Stability	Relatively constant	Changes with new molecular data
Example	Grouping plants by leaf shape	Grouping by DNA sequence similarity

Natural Classification: Molecular Evidence

Natural classification emphasises the classification of organisms based on their evolutionary relationships and common ancestry using the following molecules:

Molecule	Use in Classification	Example Use
DNA	Compares gene sequences to reveal evolutionary relationships	Comparing conserved genes like Hox or 16S rRNA
RNA	- rRNA used for ancient divergence - mRNA to study gene expression	- 18S rRNA for eukaryotes, 16S for prokaryotes - mRNA profiles in related species
Protein	Compares amino acid sequences for functional similarity	Cytochrome c (respiratory protein) sequence comparison in animals

The Taxonomic Hierarchy

Taxonomic ranks (also known as taxonomic levels) are **hierarchical groups** into which organisms are **sorted** (hierarchical classification) to reflect their relative '**closeness**' to each other.

Binomial nomenclature (also known as the binomial system) is a **two-part naming** system that uses the **genus** and **species names** from the taxonomic hierarchy to produce a unique two-part name for **identifying** a species.

Each organism is given a two-part Latin name:

Genus (capitalised) + species (lowercase)
e.g. *Homo sapiens*

The **binomial name** is traditionally written in **italics**, but is commonly underlined when handwritten.

The **advantages** of the binomial naming system included:

- **Universality**: Latin was the common language (of the time), avoiding confusion **across different languages**, and even within different regions of the same country.
- **Precision**: Identifies a single species **without ambiguity**.
- **Relationships**: Including the genus shows the **evolutionary relationships** between species.

The table below outlines the groups you need to recall at each taxonomic level:

Rank	Groups
Domain	- Bacteria (Kingdom: Eubacteria) - Archaea (Kingdom: Archaebacteria) - Eukarya (Kingdoms: animals, plants, fungi, protists)
Kingdom	- Animalia (animals) - Plantae (plants) - Fungi (mushrooms, yeasts) - Protoctista (also known as Protista or protists) (unicellular eukaryotes) - Eubacteria ('true' bacteria) - Archaebacteria ('ancient' bacteria)*
Phylum	Not expected to recall, but hopefully familiar with: - Chordata (vertebrates) - Arthropoda (insects, spiders, crustaceans)
Class	Not expected to recall, but hopefully familiar with: - Mammalia (mammals) - Insecta (insects) - Reptilia (reptiles) - Aves (birds) - Amphibia (amphibians)
Order	Not expected to recall, but hopefully familiar with: - Primates (apes, humans) - Carnivora (dogs, cats, bears)
Family	Not expected to recall, but hopefully familiar with: - Hominidae (great apes) - Felidae (cats) - Canidae (dogs) - Muridae (mice)
Genus	Not expected to recall, but hopefully familiar with: - Homo (humans) - Canis (dogs, wolves) - Felis (cats)
Species	Not expected to recall, but hopefully familiar with: - Homo sapiens (humans) - Canis lupus (grey wolf) - Felis catus (domestic cat)

*Archaebacteria is a misleading name, as Eubacteria appear to be the older evolutionary lineage.

You are expected to know and place organisms in the correct **Domain** and **Kingdom** with some provided information, but you do not need to recall the groups of the lower ranks beyond expected general knowledge (which has been included in the table for convenience).

A commonly used **mnemonic** to recall the order of these ranks is:

Dear King Philip Came Over For Good Soup

The Five Kingdoms System

The **5 Kingdoms system** was the 1960s taxonomic system that arose from centuries of research:

Kingdom	Features
Animalia	No cell wall, heterotrophic, motile, multicellular
Fungi	Chitin cell wall, saprophytic, extracellular digestion
Plantae	Cellulose cell wall, autotrophic, multicellular
Protoctista	Mostly unicellular, some plant-like or animal-like
Prokaryotae*	No nucleus, unicellular, peptidoglycan cell wall

*Not to be confused with the term prokaryote/prokaryotic, which describes a cell without membrane-bound organelles, not what kingdom it belongs to.

At this point in time, archaea had not been discovered/recognised yet, and the domain level of classification had not been invented.

The features used to classify organisms into the 'correct' Kingdom are outlined in the table below:

Feature	Animalia	Plantae	Fungi	Protoctista	Prokaryotae*
Cell type	Eukaryotic				Prokaryotic
Nucleus	Present				Absent
DNA	Linear chromosomes with histones				Loop of naked DNA
Membrane-bound organelles	Present				Absent
Ribosomes	80s				75s
Reproduction	Sexual and/or asexual				Asexual
Unicellular or multicellular	Multicellular		Unicellular (e.g. yeasts) or multicellular (e.g. mycelium)	Mostly unicellular (some multicellular algae)	Unicellular
Cell wall	None	Yes (cellulose)	Yes (chitin)	Some (peptidoglycan)	
Nutrition	Heterotrophic	Autotrophic	Heterotrophic	Autotrophic or heterotrophic	
Mobility	Most can	Can't		Some can	

*These features do not apply to the archaea, whose discovery ended the 5 Kingdoms system.

The Three-Domain System

By 1990 **Carl Woese's** research had revealed significant differences between organisms within the 5 Kingdom's prokaryotae group.

Structural **differences** between the **bacteria** and **archaea** can be found in their:

- Cell membrane
- Cell wall
- DNA replication
- Flagella
- Genetic material (bacteria lack histone-like proteins)
- RNA synthesis (they have different enzymes)

The structural **similarities** between the archaea and eukarya include:

- DNA replication (similar mechanisms and enzymes)
- Genetic material (both have histone-like proteins)
- RNA synthesis (similar enzymes/RNA polymerase)

The differences observed between bacterial and archaea cells, and the similarities shared between the archaea and eukaryotes, provided substantial evidence that the archaea were more **closely related** to the eukaryotes than bacteria are. This insight led Woese to propose the **3 domain system** above the traditional kingdom ranks which, after initial opposition, was widely accepted.

Phylogeny

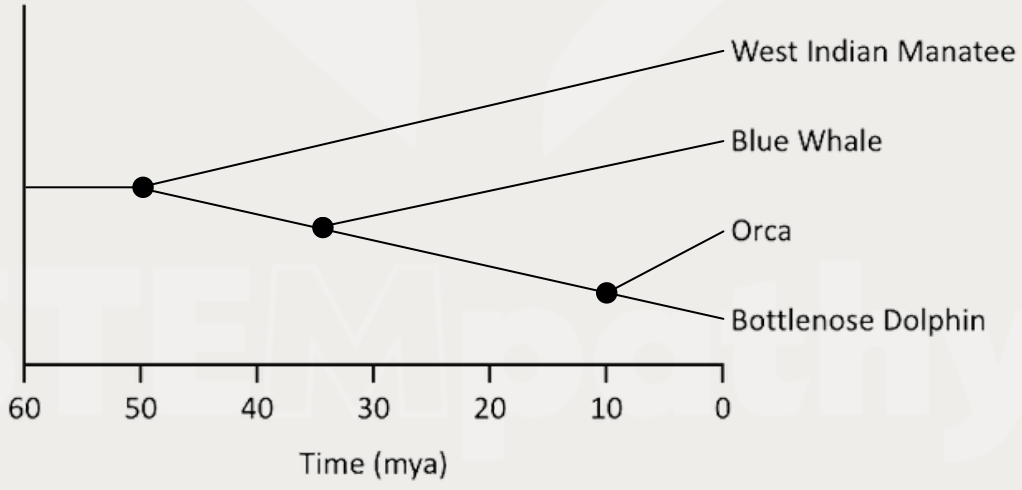
Phylogeny is the study of **evolutionary relationships** between organisms.

Phylogeny defines a species as a group of organisms that are very similar genetically (and subsequently), metabolically, physiologically and anatomically.

This definition avoids many of the problems with the traditional definition of a species, which does not apply to asexually reproducing organisms.

Phylogenetics is a scientific field of research that determines and reconstructs the evolutionary relationships between organisms.

These relationships are often shown as phylogenetic trees:



- Tips: present-day species
- Nodes: common ancestors
- Closer branches: more recent common ancestor

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