1. Cells

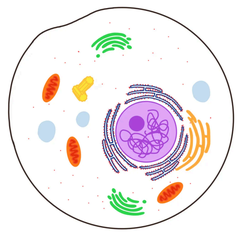
Learning Outcomes:

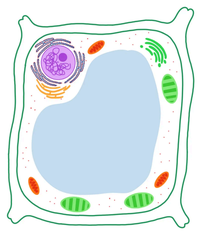
1. Identify and state the functions of plant and animal cell organelles
2. State the relationship between cell structure and function (w.r.t. RBC, root hair cell, muscle cell)
3. Compare structures of plant and animal cells

Keywords:

- Organelle, membrane, cellular activities
- Steroids, detoxification, protein synthesis
- Small and temporary, large central, cell sap
- Modifies, sorts and packages
- Partially permeable, fully permeable
- Biconcave, surface area to volume ratio, flexible, bell-shaped, long, narrow protrusion

If you're our student: Cells Crash Course Clips





1. Identifying structures

Component/Organelle	Function	Visible under Light Microscope?
Nucleus	• Contains **DNA** (in the form of chromatin) • Controls **cellular activities**	Y
Nuclear envelope	Separates nucleus from cytoplasm	Y
Rough Endoplasmic Reticulum	• Studded with **ribosomes** • Ribosomes **synthesise proteins** (for transport out of the cell)	N
Smooth Endoplasmic Reticulum	• Synthesises **fats** and **steroids** **Pro Tip:* A class of molecules, including sex hormones • Carries out **detoxification:** where harmful substances are converted to harmless ones	N
Cytoplasm	• Place where most **cellular activities** occur • Contains **organelles** • Site of **anaerobic respiration**	Y
Vacuole	Animals: • Several **small** and **temporary** vacuoles • Store food and water Plants: • Have a **large central** vacuole • Stores **cell sap** (water + dissolved substances such as: sugars, amino acids, mineral salts)	Y (plants) N (animals)
Golgi body/apparatus	• **M**odifies, **S**orts and **P**ackages substances into **vesicles** for secretion out of cell	N
Mitochondria	• Site of **aerobic respiration**, where food substances (such as glucose) are broken down to **release energy**	N
Chloroplast **(plants only)**	• Site of **photosynthesis**	Y
Cell surface membrane/plasma membrane	• **Partially permeable** • Controls movement of substances in and out of the cell	Y
Cell wall **(plants only)**	• Fully permeable • Made of **cellulose** • Gives cell its shape	Y
Ribosomes	• **Protein synthesis**	N

[Memory Hacks]

- Golgi Body:
  - When receiving vesicles from ER, says "**M**ajulah **S**inga**P**ura"
  - **M**odifies, **S**orts and **P**ackages substances into vesicles for secretion out of cell
- Rough ER:
  - Proteins --> Meat. When you bite into meat patty, has a **rough** texture
  - **Rough** ER synthesises proteins
- Smooth ER:
  - Lipids --> Oil. Oil is **smooth** and slippery.
  - **Smooth** ER synthesises lipids

2. Linking Structure to Function

Cell Structure

How it is adapted to its function

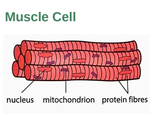
Red Blood Cell

- **Biconcave**, increases **surface area to volume ratio**, so oxygen can **diffuse** in/out of it faster
- Lacks a nucleus hence has **more space** for more **haemoglobin,** to transport more oxygen
- **Flexible**, so it can squeeze through tiny **capillaries**
- Can become **bell-shaped** in capillaries, further increasing **surface area to volume ratio**

Root Hair Cell

- Has a **long, narrow protrusion** (root hair), that increases **surface area to volume ratio**, for faster absorption of water and mineral salts
- Have **many mitochondria** to generate a lot of **energy** via **aerobic respiration**
  - As they need to pump in mineral salts from the surrounding soil into their **large central vacuoles** via **active transport**

Muscle Cell



- **Elongated**, **cylindrical** shape
- Contains many **nuclei**
- Have **many mitochondria** to generate a lot of **energy** via **aerobic respiration** for **muscular contractions**

3. Comparing Plant and Animal Cells

Comparison	Animal Cell	Plant cell
Chloroplasts	No	Yes (sometimes)
Cell wall	No	Yes (always)
Mitochondria	Yes (mostly)	Yes (mostly)
Vacuole	Small, temporary	Large, permanent

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2. Movement of Substances

Learning Outcomes:

1. Define Diffusion, Osmosis and Active Transport
2. Movement of substances in nutrient uptake and gas exchange
3. Effects of osmosis on plant and animal tissues
4. Bonus: Factors affecting rate of diffusion

Keywords:

- Diffuse, osmosis, active transport
- Water potential, down/against concentration gradient, steepness
- Partially permeable membrane
- Crenated, lyse/burst
- Plasmolysed, flaccid, turgid, turgor pressure

If you're our student: Movement of Substances Crash Course Clips

1. Definitions

1. **Diffusion:** The **net** movement of particles from a region of higher concentration to a region of lower concentration, **down a concentration gradient**.
2. **Osmosis:** The **net** movement of **water molecules** from a region of higher **water potential** to a region of lower **water potential**, through a **partially permeable** membrane.
3. **Active Transport:** The movement of particles, using **energy**, from a region of lower concentration to a region of higher concentration, **against a concentration gradient**, through a **partially permeable** membrane.

**Pro Tip: When explaining these processes in contexts of questions, replace' substances' with the molecule in the question, e.g. CO2*

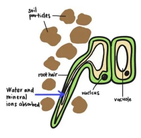
Process	Diffusion	Osmosis	Active transport
Type of molecule	Any	Water molecules	Dissolved molecules/ions
Partially permeable membrane needed?	No	Yes	Yes
Energy needed?	No	No	Yes
Direction w.r.t. Concentration gradient	Down (higher to lower)	Down (higher to lower)	Against (lower to higher)

2. Movement of substances in nutrient uptake and gas exchange

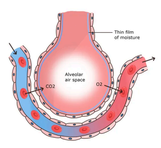
Example

How substances are moving

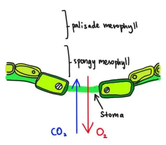
- Digested food substances such as glucose, and amino acids **diffuse** into epithelial cells of villi in the small intestine
- After **diffusion** no longer occurs, these substances are transported in via **active transport**



- Mineral salts are transported from the soil into root hair cells **via active transport**, to maintain a high concentration of mineral salts in their vacuoles
- This creates a region of lower **water potential** than the surrounding soil, so that water molecules flows in by **osmosis**

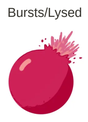


- O2 **dissolves** into the thin film of moisture lining the **alveolar air space**, then **diffuses** into the **blood plasma**
- Conversely, CO2 **diffuses** from the **blood plasma** into the **alveoli air space**



- O2 **diffuses** from the **intercellular air spaces** of the leaf to the surrounding air, through the **stomata**
- CO2 **diffuses** from the surrounding air into the **intercellular air spaces** of the leaf, through the **stomata**

3. Effects of osmosis on plant and animal tissues

Water Potential of Solution	**High**	**Low**	**Very Low**
Effect on Animal Cell	Bursts/Lysed 	Crenated 	Crenated 
Effect on Plant Cell	Turgid 	Flaccid 	Plasmolysed 

How plasmolysed is different from flaccid:

- During **plasmolysis**, as a lot of water molecules have left the **cell sap** from the **large central vacuole** to the outside of the cell by **osmosis**,
- **cytoplasm** of the plant cell **shrinks** so much that the **plasma membrane** pulls away from the **cell wall**.

**Pro Tip: Turgidity in plant cells is important as it allows the plant to remain upright and reach for sunlight, especially if it has a non-woody stem.*

4. Bonus: Factors affecting rate of diffusion

- **Surface area to volume ratio:** The higher the SA:V, the higher the diffusion rate
- **Temperature:** Higher temperature, molecules have more **kinetic energy**, hence move faster and diffuse down the concentration gradient faster
- **Steepness of concentration gradient:** The steeper the gradient, the higher the diffusion rate
- **Distance:** The shorter the distance that molecules need to travel/diffusion distance, the higher the diffusion rate
- **Molecule size:** Smaller molecules diffuse faster (e.g. glucose diffuses faster than sucrose)

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3. Biomolecules

Learning Outcomes:

1. Carbohydrates, fats, and proteins: Their chemical elements, and the smaller molecules that make them up
2. Food tests for starch, reducing sugars, fats and proteins

Keywords:

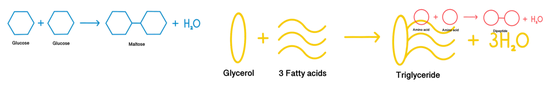
- Single sugars, double sugars, complex carbohydrates
- Amino acid, polypeptide
- Glycerol, fatty acid, triglyceride, solvent
- Carbohydrate, starch, glycogen, cellulose
- Reducing sugar, precipitate, cloudy white emulsion

If you're our student: Biomolecules Crash Course Clips

1. Elements making up carbs, fats and proteins

Type of Nutrient	Carbohydrate	Fats	Protein
Elements	C, H, O (1:2:1 ratio)	C, H, very few O	C, H, O, N, (S) **Pro Tip: Some proteins have S (the element Sulfur), but not all. If a question tells you the molecule has Sulfur, it is likely to be a protein.*
Basic unit	Single sugars • Glucose • Fructose	Glycerol, Fatty acids	Amino acid
Dimer (2 units)	Double sugars • **Maltose** (Glucose + Glucose) • **Sucrose*** (Glucose + Fructose) **Pro Tip: Sucrose is the only **non-reducing sugar** you'll learn.*	-	Dipeptide
Many units (several thousand)	Complex carbohydrates	-	Polypeptide
Functions (**bold** = most important to give in qns)	**• An immediate source of energy (glucose for aerobic respiration)** • Energy storage • Structural molecules, e.g. cellulose	• **Long-term energy storage** • **Thermal insulation** • Protects vital organs • Forms cell membranes* • Solvent for fat-soluble vitamins • Secreted as oil on the skin to reduce water loss **Pro Tip: We intentionally do not say plasma membrane here, as fats are part of membranes within cells too.*	**• Growth and repair of cells** • For the production of enzymes, antibodies and some hormones • Synthesis of new muscle fibres

Formation



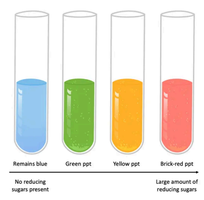
Reducing sugars

- = are able to react with **Benedict's reagent**, resulting in a **precipitate**.
- All **single** and **double** sugars in our syllabus are **reducing sugars**, except **sucrose**.

Complex carbohydrates

Complex Carbohydrate	Structure	Function	Found in
Cellulose	Thousands of glucose bonded together (FYI: straight chained)	Structural support	Plant cell walls
Starch	Thousands of glucose bonded together, bonds are different from those in cellulose (FYI: Branched)	Energy storage (plants)	Leaves/storage organs
Glycogen	More branched than starch	Energy storage (animals)	Liver/muscle cells

2. Food Tests

Test	Procedure	Results
Benedict's test [Reducing sugars]	**Liquid sample:** 1. Add 2cm3 of **Benedict's reagent** to an equal volume of the sample in a test tube and shake. 2. Heat water in a beaker for 2-3min until it starts **boiling** (bubbles vigorously). *Pro Tip: The water level in the beaker should be higher than that of the test tube. 3. Place the test tube into a beaker of **already boiling water.** 4. Observe for colour change. **Solid sample:** 1. Add 2cm3 of distilled water to a finely cut sample in a test tube and shake. 2. Add 2cm3 of **Benedict's reagent** to the test tube and shake. 3. (Remaining steps are the same as if sample were liquid.)	 (-) Solution remains blue (+) A brick-red/orange/green ppt is formed *Pro Tip: Upon heating with acid, sucrose is broken into glucose and fructose, which gives a positive result.*
Iodine test [Starch]	**Liquid sample:** 1. Place a few drops of the sample on a white tile. 2. Add a few drops of **iodine** to a sample, observe for colour change. **Solid sample:** 1. Add a few drops of **iodine** to a sample, observe for colour change.	 (-) Solution remains yellow-brown (+) Yellow-brown solution turns blue-black
Biuret test [Proteins]	**Liquid sample:** 1. Add 2cm3 of **biuret solution** solution to an equal volume of sample and shake. 2. Allow the mixture to stand for 5 minutes and observe for the colour change. **Solid sample:** 1. Add 2cm3 of **biuret solution** toa finely cut sample and shake. 2. (Remaining steps are the same as if sample were liquid.)	 (-) Remains blue (+) Turns violet/purple
Ethanol Emulsion test [Fats]	**Liquid sample:** 1. Add 2cm3 of **ethanol** to equal volume of sample and shake. 2. Add 2cm3 of **water** to the mixture, shake. **Solid sample:** 1. Add 2cm3 of **ethanol** to finely cut sample, shake and allow solids to settle. 2. Decant the ethanol into another test tube containing 2cm3 of **water**, shake.	 (-) Solution remains clear (+) Cloudy white emulsion formed

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4. Enzymes

Learning Outcomes:

1. Explain the mode of action of enzymes using 'lock and key' hypothesis, including active site, activation energy, enzyme specificity
2. Effect of pH and temperature on enzyme-catalysed reaction
3. Bonus: Benefits of using enzymes

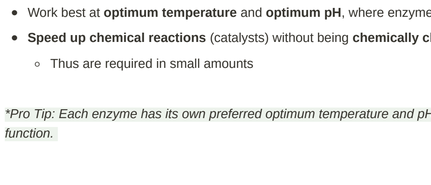
Keywords:

- Biological catalysts, alternative pathway, activation energy, chemically unchanged
- Substrates, active site, specific three-dimensional structure, complementary
- Lock and key hypothesis, enzyme-substrate complex, optimum temperature/pH
- Kinetic energy, chance of collision
- Weak bonds, denature

If you're our student: Enzymes Crash Course Clips

1. Mode of action

- **Enzymes:** A biological **catalyst** made of **protein**, that speeds up the rate of chemical reactions, and remain **chemically unchanged** at the end of the reaction.
- **Activation energy:** The energy needed to start a chemical reaction.
  - Enzymes provide an alternative pathway of lower **activation energy**.



Lock and Key hypothesis (Mode of Action)

- According to the **lock and key** hypothesis,
- A **specific** substrate (key) is **complementary** to and binds to the **active site** of the enzyme (lock), and bind,
- Forming an **enzyme-substrate complex**.
- The enzyme then **catalyses** the reaction (by breaking/forming the bond in context)*
- After reaction, products are **no longer complementary** to the **active site**, hence they leave the **active site**.
- The enzyme remains **chemically unchanged** and can accept a new substrate.

Pro Tip: If the question was on 'explain the mode of action of sucrase', state here that sucrase catalyses the reaction by breaking the bond between glucose and fructose

> 💡 ***[Memory Shortcut]***
>
> - Mode of action of enzymes [**B**e **C**areful **R**ed **L**ight **U**nchanged]
>   - enzyme and substrate **B**inds
>   - forming an enzyme-substrate **C**omplex
>   - **R**eaction is catalysed
>   - products **L**eave active site
>   - enzyme remains chemically **U**nchanged

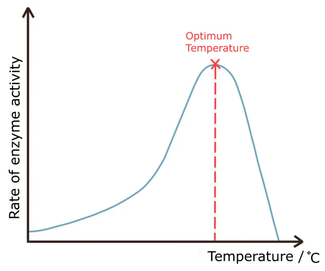
Characteristics of Enzymes

- **Protein** in nature
- Are **highly specific**, only catalyse one type of reaction
  - As they have a **specific three-dimensional (3D) structure**
  - **Active site** that the substrate is complementary to
- Work best at **optimum temperature** and **optimum pH**, where enzyme rate is highest
- **Speed up chemical reactions** (catalysts) without being **chemically changed**
  - Thus are required in small amounts

Pro Tip: Each enzyme has its own preferred optimum temperature and pH, depending on its function.

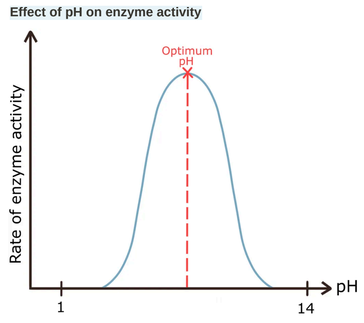
2. Effect of Temperature and pH

Effect of increasing temperature on enzyme activity



- As temperature increases from low until the **optimum temperature**, **kinetic energy** of enzyme and substrate molecules increases, increasing their **chances of collision**.
- **Enzyme-substrate complexes** form faster, and rate of reaction increases until the **optimum temperature**, where rate is highest.
- As temperature increases beyond **optimum temperature**, **weak bonds** within enzymes are broken, causing the enzyme to lose the shape of its **active site** and become **denatured**.
- The substrate can **no longer fit** into the **active site**, hence rate of reaction decreases sharply to 0.

Effect of pH on enzyme activity



- At pH 7, reaction rate is maximum as this is the enzyme's **optimum pH**.
- As pH moves further from pH 7, reaction rate decreases sharply. When pH moves too far from 7, weak bonds within the enzyme are broken,
- the enzyme loses the shape of its **active site** and becomes **denatured**.
- The substrate can **no longer fit** into the **active site**, hence rate decreases sharply until 0.

3. Bonus: Benefits of using enzymes

- As **catalysts**, they speed up reactions that would otherwise take a long time (saves time)
- Since enzymes remain **chemically unchanged** after reaction, only a small amount of them is needed (saves money/resources)
- Enzymes can **catalyse** reactions at lower temperatures than if they were to be done without enzymes (saves energy)
- Enzymes are **specific**, hence only the intended reaction will occur

Pro Tip: Each of these are actually linking a characteristic of enzymes to a benefit

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5. Nutrition in Humans

Learning Outcomes:

1. Main parts of the alimentary canal + related processes
2. Summary: Enzymes Involved in digestion
3. Peristalsis
4. Structure and function of villi
5. Liver functions and its associated blood vessels
6. Effects of excessive alcohol consumption

Keywords:

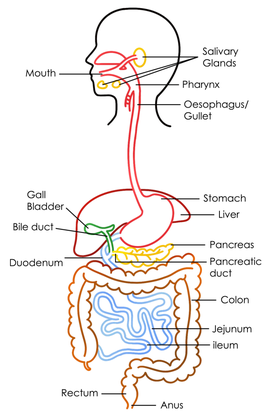
- Ingestion, digestion, absorption, assimilation, egestion
- Peristalsis, antagonistic
- Bile salts, emulsify, fat globules
- Digested food substances
- Deamination, detoxification, blood glucose concentration
- Addictive, depressant, reaction time, cirrhosis, social responsibilities, dementia, brain volume

If you're our student: Nutrition in Humans Crash Course Clips

1. Main parts of the alimentary canal

Definitions of processes

1. **Ingestion:** The intake of food through the mouth.
2. **Digestion:** The physical or chemical breakdown of larger food molecules into smaller and soluble molecules that can be absorbed by body cells.
3. **Absorption:** The uptake of digested food substances into body cells.
4. **Assimilation:** Digested food substances are used to make new cell parts or used for energy.
5. **Egestion:** The removal of undigested food waste from the body.



Part (Processes)	**Function**	**pH**	**Digestive enzymes**
Mouth (Ingestion, Digestion)	**Teeth:** • Chews food **(mechanical digestion)** • Breaks food into smaller pieces, increasing **SA:V** for enzymes to digest it faster **Salivary glands:** • Secrete **saliva** containing **salivary amylase**, breaks down **starch** into **maltose** **Tongue:** • Rolls food into a **bolus** to be swallowed • Mixes **saliva** with food	7	Salivary amylase
Oesophagus	• Pushes food from mouth into the stomach	7	-
Stomach (Digestion)	• **Gastric glands** secrete **gastric juice** containing **hydrochloric acid** and **protease** • **Protease** breaks down **protein** into short **polypeptides** • Stomach **churns** food, breaking up food **(mechanical digestion)** and mixing it with gastric juice **Pro Tip: There are many types of protease, but for simplicity in our syllabus, they are all referred to as 'protease'*	2	Protease
Small Intestine (Digestion, Absorption, then Assimilation occurs throughout body) **Pro Tip: Absorption involves **both** diffusion + active transport*	**Small intestine** • Is **very long**, giving **more time** for digested food substances to be **absorbed** • Has many **folds**, increasing **SA:V** • Parts of the small intestine **[DJI]** ◦ **D**uodenum: Mainly digestion, some absorption ◦ ***[FYI]*** **J**ejunum: Some digestion, some absorption ◦ **I**leum: Some digestion, mainly absorption ***[Memory Hack]*** • "**D**wayne **J**ohnson and **I**" for small intestine parts ◦ **D**uodenum, **J**ejunum, **I**leum • **Epithelial cells** of the small intestine secrete **LiMP** enzymes ◦ Intestinal **Li**pase: fats -> glycerol + fatty acids ◦ **M**altase: maltose -> glucose + glucose ◦ **P**rotease: short polypeptides -> amino acids	8	(Epithelial, **LiMP**): Intestinal **Li**pase, **M**altase, **P**rotease
Small Intestine	**Gall bladder** • Stores **bile** (an alkaline yellow-green liquid) • Bile is secreted into the **duodenum** via the **bile duct** during digestion • **Bile salts** in bile **emulsify** large fat droplets into smaller ones, increasing **SA:V** for **lipase** to digest **triglycerides** into **glycerol** and **fatty acids** • **Pro Tip: This is physical digestion, not chemical digestion, since fat molecules are not being altered.* **Pancreas** • **Pancreas** secretes **pancreatic juice** (alkaline) containing **LAP** enzymes into duodenum ◦ Pancreatic **Li**pase: fats -> glycerol + fatty acids ◦ Pancreatic **A**mylase: starch -> maltose ◦ **P**rotease: Proteins -> short polypeptides	8	(Pancreas, **LAP**): Pancreatic **Li**pase, Pancreatic **A**mylase, **P**rotease
Large Intestine/Colon (Absorption)	• Has many **folds**, increasing **SA:V** • Large intestine absorbs **water** and **mineral salts** • **Undigested** food (**faeces**) are temporarily stored in the **rectum**	7	-
Anus (Egestion)	• **Faeces** is expelled	7	-

💡 ***[Memory Shortcuts]***

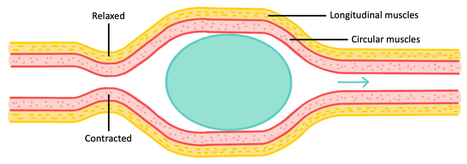
- Pancreatic enzymes [**LAP**]
  - pancreatic **Li**pase
  - pancreatic **A**mylase
  - **P**rotease
- Enzymes secreted by the small intestine's epithelial cells [**LiMP**]
  - intestinal **Li**pase
  - **M**altase
  - **P**rotease

2. Summary: Enzymes involved in digestion

Enzyme	Produced by	Digests	Found in	pH of Location
Amylase (salivary)	Salivary glands	Starch --> Maltose	Saliva (Mouth)	7
Protease	Gastric glands	Proteins --> Short Polypeptides*	Stomach	2
Lipase (pancreatic)	Pancreas	Triglycerides --> Glycerol + Fatty acids	Pancreatic juice	Alkaline (>7)
Amylase (pancreatic)		Starch --> Maltose		
Protease		Proteins --> Short Polypeptides*		
Lipase (Intestinal)	Epithelial cells	Triglycerides --> Glycerol + Fatty acids	Small intestine	8
Maltase		Maltose --> Glucose + Glucose		
Protease		Short Polypeptides* --> Amino acids		

**Pro Tip: Short polypeptides is more accurate than just 'polypeptides', since it distinguishes between the length of the polypeptide (undigested proteins are folded polypeptides, hence the ambiguity).*

3. Peristalsis



Definition (in digestion): Rhythmic, wave-like muscular contractions in the wall of the alimentary canal that moves food forward

- Peristalsis propels food forward ensuring it moves in the right direction,
- also mixes food with digestive juices

How it works:

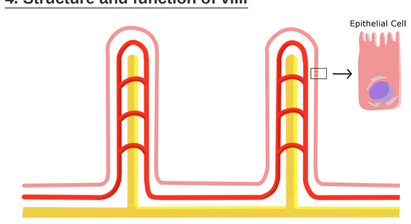
- At the region before the food mass, **circular muscles** contract while **longitudinal muscles** relax, narrowing the **lumen** and pushing food forward
- At the food mass, **circular muscles** relax while **longitudinal muscles** contract, widening the **lumen**, allowing food to pass through easily
- The above also applies for the region just in front of the food mass
- **Circular muscles** and **longitudinal muscles** are **antagonistic** (i.e. when one contracts, the other relaxes)

**Pro Tip: Peristalsis occurs throughout the alimentary canal, not just in the oesophagus*

💡 ***[Memory Hack]***

- How to remember what circular muscles are doing in peristalsis
  - Think of circular muscles as 'controlling' the lumen size. At the point where you see it squeezing (contracting), the circular muscles are therefore contracting too.
  - If lumen is widening (relaxing) at an area, circular muscles are relaxing too.

4. Structure and function of villi



Where digested substances are absorbed:

- **Glucose** and **amino acids** move by **diffusion + active transport** into **blood capillaries** (red in diagram) of **villi** to be transported to the **liver**.
- **Glycerol** and **fatty acids** move by **diffusion + active transport** into the **epithelial cells** of **villi**, where they **reform** into **triglycerides**, then enter the **lacteal** (yellow in diagram) as **fat globules**.

**Pro Tip: Villus is singular, villi is plural.*

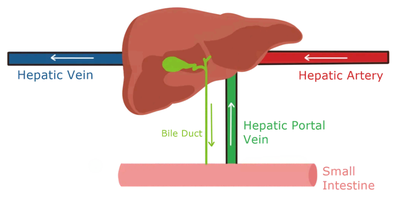
**Pro Tip: Water is also absorbed at villi by osmosis.*

Adaptations for fast absorption:

- **Villi** are **finger-like projections** in the small intestine, increasing **SA:V**
- Are lined with a **one-cell-thick** layer of **epithelial cells**, minimising **distance** digested food substances have to travel
- **Epithelial cells** have **microvilli**, further increasing **SA:V**
- Absorbed substances that enter the **lacteal** and **blood capillaries** are constantly transported away, maintaining a steep **concentration gradient** between the **lumen** and **villi** to maximise **diffusion** rate of digested substances into villi
- **Epithelial cells** have numerous **mitochondria**, releasing more **energy** for **active transport** of digested food substances from **lumen** into villi

**Pro Tip: After diffusion has reached equilibrium, active transport is needed to further absorb digested substances*

5. The Liver



What happens to absorbed digested food substances:

- **Hepatic portal vein** transports **glucose** and **amino acids** from small intestine to the **liver**
- **Glucose** is converted to **glycogen** and stored in the **liver** and **muscles**, or transported around the body for cells to uptake and use for energy
- **Amino acids** are transported around the body and taken up by cells during **assimilation**, to build new cell parts/**protoplasm**
  - **Deamination:** The process where **amino groups** are removed from **excess amino acids** and converted into **urea**, in the liver.
  - Hence **hepatic vein** has high **urea**.
- **Fats** are transported around the body to be stored/used for energy

Functions of liver	Description
Detoxification	**Detoxification** is the process where **harmful substances** (e.g. hydrogen peroxide, alcohol) are converted into **harmless** ones.
Breakdown of Hormones	**Hormones** are broken down at the liver after they have caused **target organs** to carry out the **response.**
Bile production	The liver **produces bile**, which is stored in the **gall bladder**.
Amino acids (Deamination)	The process where **amino groups** are removed from **excess amino acids** and converted into **urea**, in the liver.
Blood Glucose regulation	When **blood glucose concentration** is too high, liver converts **glucose** to **glycogen** in response to **insulin**.When **blood glucose concentration** is too low, liver converts **glycogen** to **glucose** in response to **glucagon**.

💡 ***[Memory Shortcut]***

- Functions of the liver [**D**un **H**ave **BAG**]
  - Detoxification
  - Hormone breakdown
  - Bile production
  - Amino acids --> Urea (Deamination)
  - Glucose regulation

6. Effects of excessive alcohol consumption

Short term effects:

- Alcohol is a **depressant**, meaning it slows **brain functions**, increases **reaction time**
- Reduces **self-control**, increasing tendency to make irrational decisions

Long term effects:

- **Addictive**, leading to neglect of **social responsibilities**
- Stimulates acid secretion in stomach, increasing risk of **stomach ulcers**
- Liver is overworked, cells start dying, which can lead to liver damage:
  - E.g. Liver **cirrhosis** (formation of fibrous tissue), liver **failure**
- Causes brain damage:
  - E.g. **Dementia,** high consumption during **pregnancy** may impair **foetus' brain development**

💡 ***[Memory Shortcut]***

- Effects of alcohol [**S**tudents **D**rinking, **A**lcohol **U**nleashes **C**haos **F**or **B**rains]
  - reduces **S**elf-control
  - **D**epressant
  - **A**ddictive
  - stomach **U**lcers
  - liver **C**irrhosis
  - liver **F**ailure
  - **B**rain damage

6. Transport in Humans

Learning Outcomes:

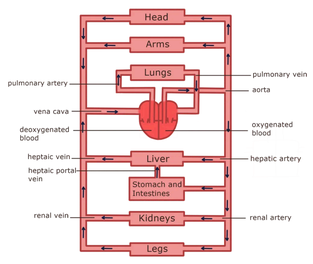
1. Main blood vessels in the body
2. The role of blood (transport, defence) and its components
3. Blood groups and their compatibilities
4. Structure and function of arteries, capillaries and veins
5. Transfer of materials between capillaries, tissue fluid and cells
6. Structure and function of heart
7. Cardiac cycle
8. Coronary artery disease

Keywords:

- Oxygenated, deoxygenated
- Insoluble, coagulation, clot, universal donor, universal recipient
- Tissue rejection, antibody, neutralises, antigen, agglutination
- Biconcave, bell-shaped
- Arteries, arterioles, capillaries, venules, veins
- Tissue fluid, one-cell-thick
- Blood pressure, backflow, atrioventricular, semi-lunar valves, systole, diastole
- Coronary, atherosclerosis, fatty deposit, lumen

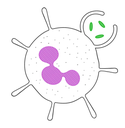
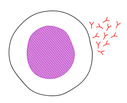
If you're our student: Transport in Humans Crash Course Clips

1. Main blood vessels in the body



**Pro Tip: Blood from the stomach and intestines does not go back to the heart directly through veins, it passes through the liver first.*

2. The role of blood (transport, defence) and its components

Component	Structure/Appearance	Function
Plasma (55%)	Made of 95% water	Carries **dissolved** substances in the blood such as glucose, amino acids, mineral salts, CO_2, waste, hormones, plasma proteins, etc.
Red Blood Cells	• O_2 binds **reversibly** to **haemoglobin** in **red blood cells** and is carried around the body • When blood passes through oxygen-poor areas, O_2 **dissociates** from **haemoglobin** and **diffuses** into body cells *FYI: Some carbon dioxide is also transported in red blood cells, brought to the lungs for removal.* **Biconcave** — Increases **SA:V** for O_2 to **diffuse** in/out of the cell faster Lacks a nucleus — More space to pack in more **haemoglobin** Flexible — To squeeze through tiny **capillaries**, in which, it can become **bell-shaped**, further increasing **SA:V**	
White Blood Cells - Phagocytes	 • Can have a lobed nucleus • Can have tendril-like protrusions	**Phagocytosis:** The process where phagocytes engulf **foreign particles** and destroy them
White Blood Cells - Lymphocytes	Have a large nucleus 	Produce antibodies, which: • Cause pathogens to clump together (agglutination), promoting phagocytosis • Bind to and neutralises harmful toxins that pathogens produce Tissue rejection: • When lymphocytes produce antibodies against a transplanted organ to destroy it
Platelets	Membrane-bound bodies (Not considered cells)	Promotes blood clotting **(coagulation)** at the site of injury, sealing the **wound** to prevent loss of **blood** and preventing the entry of harmful **microorganisms**.

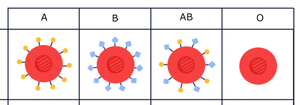
[Memory hack]

- How to remember which is coagulation and agglutination
  - **A**gglutination: Due to **A**ntibodies in the blood
  - **C**oagulation: blood **C**lotting

How blood clots (Coagulation)

- When blood vessels are damaged, **platelets** are activated, which trigger the conversion of **soluble fibrinogen** into **insoluble Fibrin**,
- Forming **long insoluble Fibrin threads** which trap **red blood cells**, forming a **clot** at the site of injury.

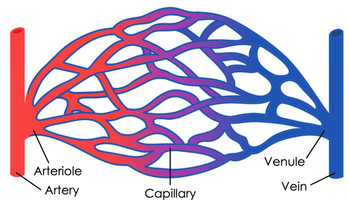
3. Blood groups and their compatibilities

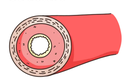
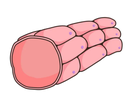
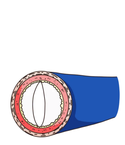
	A	B	AB	O
Red Blood Cell Type				
Antibodies in Plasma	 Anti-B	 Anti-A	None	 Anti-A and Anti-B
Antigens on Red Blood Cell	 A antigen	 B antigen	 A and B antigens	None
Who can donate to this blood group	A, O	B, O	A, B, AB, O	O

How to remember intuitively:

- The body will naturally produce **antibodies** of the other blood types, except against its own RBC's **antigens** (or it will kill its own RBCs!)
- If you transfer blood into a recipient who does not have **antibodies** against the donor's blood type, the transfusion will be safe.
  - **Pro Tip: Only the red blood cells of the donor are transferred, not the blood plasma, hence no antibodies from the donor are transferred! Hospitals separate out just the red blood cells to donate.*
- **Special blood types:**
  - AB is the **universal acceptor** - can receive from all, but can donate to AB only.
  - O is the **universal donor** - can donate to all, but can receive from O only.

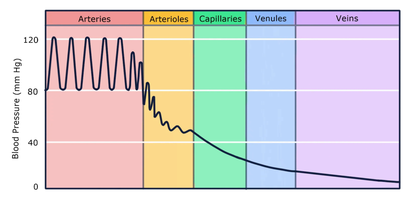
4. Structure and function of arteries, capillaries and veins



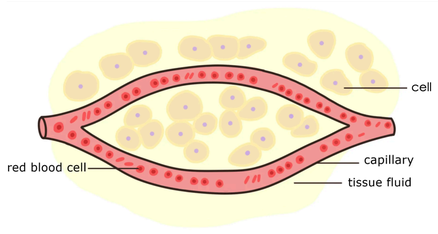
Type of Vessel	Structure	Function
Arteries		• Carries blood **away** from the heart • Usually carry **oxygenated** blood, except for **pulmonary artery** • Have thick **elastic and muscular** walls to **accommodate/withstand** and the **high blood pressure** exerted by the heart • **Elastic and muscular** walls **stretch** and **recoil**, maintaining high blood pressure and pushing blood forward in **spurts** • Arteries branch out into **arterioles,** then into capillaries
Capillaries		• Are present near almost every cell in the body • Made of a wall of **one-cell-thick** cells, minimising **diffusion distance**, increasing **diffusion** rate • Capillaries **branch repeatedly**, increasing **SA:V**, hence increasing rate of **diffusion** of substances in and out of them • High **total cross-sectional area**, lowering **blood pressure** and **slowing** blood down, giving more **time** for substances to **diffuse** in and out.
Veins		• Capillaries converge into **venules,** then into veins • Veins carry blood **back to** the heart • Usually carry **deoxygenated** blood, except for **pulmonary vein** • Have **semi-lunar valves** to prevent **backflow** of blood, which is likely due to low **blood pressure** in veins • Larger **lumen** to reduce **resistance** to bloodflow • Thin **elastic and muscular** walls as **blood pressure** is lower • Contraction of **skeletal muscles** exerts pressure on veins, moving blood along more quickly

Graph of Blood pressure against location

- The further from the **aorta**, the lower the blood pressure due to **loss of energy**
- In **arteries** and **arterioles**, blood pressure **fluctuates** as:
  - Arteries have thick **elastic** and **muscular** walls that **stretch** and **recoil**, and are directly connected to the **left ventricle**.
  - Hence, blood pressure increases during **ventricular systole** as left ventricle **contracts**, and decreases during **ventricular diastole** as left ventricle **relaxes**.

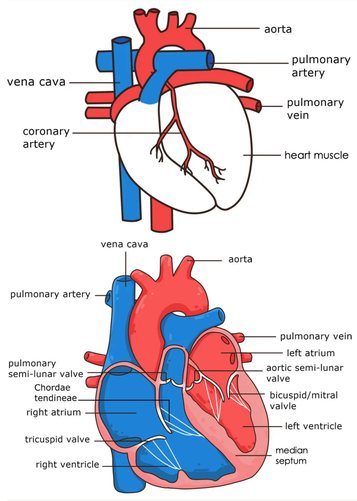


5. Transfer of materials between capillaries, tissue fluid and cells



- **Capillaries** bring **nutrients** and **O2**, which **diffuse** from the **blood plasma** to the **tissue fluid**
- These then **diffuse** from **tissue fluid** into cells
- Conversely, **waste products** and **CO2 diffuse** out of the cells into the **tissue fluid**, then into the **blood plasma** of capillaries.

6. Structure and function of the heart + types of circulation

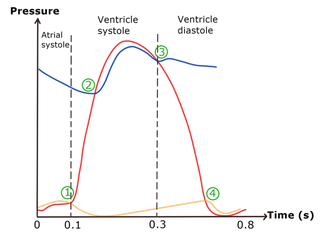


> 💡 ***[Memory hack]***
>
> - How to remember left side of heart has bicuspid valve (2 flaps), right side has tricuspid valve (3 flaps)
> - **L**eft side **L**ost, **R**ight side **R**etained
> - Left side lost a flap so only has 2 flaps, right side retained all 3 flaps.

Parts of the heart	Function
Atria	• Have thinner walls then ventricles
Ventricles	• Left ventricle has thicker **muscular walls** as it has to generate **high pressure** to quickly pump blood around entire body • Right ventricle has **thinner muscular walls**, as it does not need to generate as high of a pressure to pump blood to **lungs** **Pro Tip: Use ventricle wall thickness to identify which side of the diagram is right/left. Usually, heart diagrams are mirror imaged, meaning the left side of the picture is the right side of the heart.*
Chordae tendineae	• Attaches valves to the heart walls
Medium septum	• Separates left and right sides, so deoxygenated and oxygenated blood stay separate

7. Cardiac Cycle

(Link for the above GIF to visualise bloodflow in heart:
https://media.tenor.com/dO9JYv5q8xsAAAAC/heart-heart-pumping.gif)



Note: Blue = Aorta, Red = Left Ventricle, Yellow = Left Atrium

From Graph:

(1) Atrioventricular valves close

(2) Semi-lunar valves open

(3) Semi-lunar valves close

(4) Atrioventricular valves open

> 💡 ***[Memory Shortcut]***
>
> - Cardiac Cycle Valves Opening/Closing [**A** **C**ool **S**cientist **O**wns **S**ick **C**ars **A**nd **O**utfits]
> - **A**V valves **C**lose
> - **S**L valves **O**pen
> - **S**L valves **C**lose
> - **A**V valves **O**pen

- **Systole** = contraction
- **Diastole** = relaxation
- RA = **Right atrium,** LA = **Left atrium,** RV = **Right ventricle,** LV = **Left ventricle**

Atrial systole (+Ventricular diastole)

- Both atria contract, pushing blood past the **atrioventricular valves** into the ventricles
  - **LA** pumps blood past the **mitral/bicuspid valve** to the **LV**
  - **RA** pumps blood past the **tricuspid valve** to the **RV**

Pro Tip: AV valves were already open before atrial systole, as they opened near the end of ventricular diastole.

Ventricular systole (+Atrial diastole)

- Ventricles contract
  - **Pulmonary semi-lunar valve** is forced open, blood moves from **RV** to the **pulmonary artery**, and is sent to the lungs.
  - **Aortic semi-lunar valve** is forced open, blood moves from **LV** to the **aorta**, and is sent to the rest of the body.
- At the same time, **atrioventricular valves** close, preventing **backflow** of blood from ventricles to the atria.
  - This causes the first '**lub**' sound.
- Meanwhile, atria relax,
  - Blood from **pulmonary vein** flows into **LA**
  - Blood from **vena cava** flows into **RA**

Ventricular diastole (+Atrial diastole)

- Ventricles relax
  - **Semi-lunar valves** close, preventing **backflow** of blood from the **pulmonary artery** and **aorta** back into the ventricles.
  - This causes the second '**dub**' sound.
- Blood fills the relaxed atria and ventricles again

- Typical duration of each cardiac cycle: 0.8s = 75 beats per min
- **Pro Tip: When the heart pumps faster, such as during exercise, the duration of each cardiac cycle will be shorter.*

8. Coronary artery disease

Atherosclerosis: The disease where fatty deposits accumulate on the inner walls of arteries, narrowing the lumen.

Coronary artery: An artery that branches out of the aorta, sending oxygen and nutrients to the heart muscles.

- **Coronary artery disease:** When atherosclerosis occurs in a coronary artery.

Heart attack

- If a **fatty deposit** ruptures in a **coronary artery**, a **blood clot** could form, blocking the **artery.**
- Blood with **oxygen** and **nutrients** cannot reach the **heart muscles** for them to release **energy** via **aerobic respiration**, hence they die, resulting in a **heart attack**.

Preventive measures

- Adopt a diet low in **saturated fats** and **cholesterol**
- Not smoking
  - **Carbon monoxide** in cigarette smoke damages the inner layer of **blood vessels**, hence increasing the rate **fatty deposits** accumulate.
  - **Nicotine** stimulates **adrenaline** release, increasing **blood pressure**, which also increases the rate **fatty deposits** accumulate
- Stress management
- Regular exercise

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7. Respiration

Learning Outcomes:

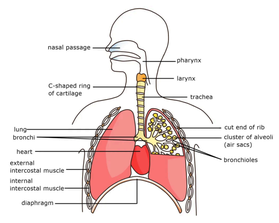
1. Parts of the respiratory system and their roles in breathing
2. Adaptations of alveoli
3. Bonus: Inspired vs Expired air
4. Harmful effects of tobacco smoke
5. Aerobic and anaerobic respiration

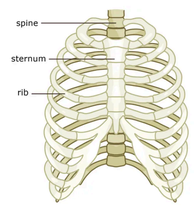
Keywords:

- Alveolar air space, one-cell-thick, film of moisture, dissolve
- Inspiration/inhalation, expiration/exhalation, thoracic volume, air pressure
- Foreign particles, pathogens, ciliated, hair-like structures
- Nicotine, addictive, social responsibilities
- Carbon monoxide, irreversibly
- Tar, carcinogen, chronic bronchitis, partition walls, emphysema, cancer
- Aerobic, oxidise, cellular respiration, release energy, cellular activities
- Anaerobic, lactic acid, additional energy, oxygen debt

If you're our student: Respiration Crash Course Clips

1. Parts of the respiratory system and their roles in breathing





Structure	Function
Ciliated cells	• Have **hair-like structures** called **cilia** • Found on inner walls of **trachea**, **bronchi** and larger **bronchioles** • Cilia sweeps mucus with the trapped particles up the **trachea** to be swallowed, **neutralising** any **pathogens** due to the stomach's **acidic pH**
Gland/Mucosal cells	Secrete mucus that traps **dust** and **foreign particles**
C-shaped rings of cartilage	Structural support: prevents collapse of the trachea, keeps the trachea open for unobstructed breathing

Breathing process

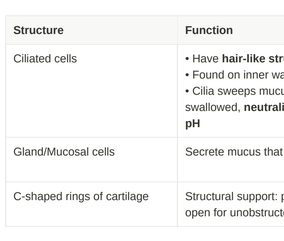
Event	Inspiration (Breathing in)	Expiration (Breathing out)
Diaphragm	Contracts and flattens downwards	Relaxes and arches upwards
Intercostal muscles		
- *Internal	Relax	Contract
- *External	Contract	Relax
Ribcage	Moves up and out	Moves down and in
Thoracic Volume	Increases	Decreases
Air pressure in lungs	Lower than surrounding air, causing air to rush in	Higher than surrounding air, causing air to rush out

Pro Tip: These muscles are antagonistic

💡 ***[Memory Shortcut]***

- Inspiration/expiration process [**DIRVA**]
  - **D**iaphragm
  - **I**ntercostal muscles (internal + external)
  - **R**ibcage
  - thoracic **V**olume
  - **A**ir pressure in lungs

2. Adaptations of alveoli



Feature	Function
One-cell-thick	Minimises distance O2 and CO2 have to travel, increasing **diffusion** rate
Small and numerous	Increases their **SA:V**, increasing **diffusion** rate
Surrounded by network of capillaries	Provides continuous blood supply, **oxygenated** blood is quickly carried away to maintain the **concentration gradients*** for O2 to **diffuse** from **alveolar air space** into blood and CO2 to **diffuse** out
Thin film of moisture lining alveolar air space	Gases **dissolve** in it before **diffusing** across

Pro Tip: Concentration gradients are also maintained by fresh air being breathed in and old air breathed out

3. Bonus: Inspired vs expired air

Component of air	Inspired air	Expired air
Oxygen	21%	16%
Carbon Dioxide	0.03%	4%
Nitrogen	78%	78%
Water Vapour	Varies	Saturated
Dust Particles	Present	Almost none
Temperature	Varies	~37°C

4. Harmful effects of tobacco smoke

Chemical in Tobacco smoke	Negative Effects
Nicotine	• **Addictive**, resulting in social problems • Increases **blood pressure*** and **heart rate** • Increases **ease of blood clotting**, increasing the risk of **heart attacks** *Pro Tip: This increases 'wear and tear' of arteries, hence increasing the rate that fatty deposits accumulate.*
Carbon Monoxide	• Binds **irreversibly** with **haemoglobin** such that it cannot transport O2 anymore, reducing the ability of blood to transport O2 • Damages the **innermost layer** of blood vessels, increasing the rate that **fatty deposits** accumulate in **arteries**, increasing the risk of **heart attacks**
Tar	Paralyses **cilia,** dust particles and **pathogens** cannot be expelled, which can result in: - **Chronic bronchitis** (where the **epithelium** lining the airways are **inflamed** + persistent coughing) - Persistent and violent coughing can lead to **Emphysema** (when **partition walls** between **alveoli** break down, making it hard to breathe. The alveoli have lost **elasticity**, resulting in the lungs being **inflated** with air.) - Tar is a **carcinogen***, increasing chances of **lung cancer** *Pro Tip: Carcinogen = something that causes cancer*

5. Aerobic and anaerobic respiration

- Living things need **cellular respiration** to **release energy** for **cellular activities**, such as:
  - Muscular contractions, cell division, active transport, etc.

- **Aerobic respiration:** The process where food substances are broken down into carbon dioxide and water, in the presence of oxygen, releasing a large amount of energy.
  - Glucose + oxygen --> carbon dioxide + water + large amount of energy
  - **C**6H12O6 + **6**O2 --> **6**CO2 + **6**H2O + large amount of energy

- **Anaerobic respiration (mammals):** The process where food substances are broken down into lactic acid, in the absence of oxygen, releasing a small amount of energy.
- Glucose --> Lactic acid + small amount of energy

- **Oxygen debt:** The amount of oxygen needed to remove lactic acid from the body.
  - During **vigorous** exercise, muscles demand more **energy** than can be generated by **aerobic respiration**.
  - **Additional energy** is generated by **anaerobic respiration**, resulting in **lactic acid** produced.
  - An **oxygen debt** is incurred.
    - **Lactic acid** is transported to the **liver**, where it is **removed**, which requires **oxygen** (this amount of oxygen = **oxygen debt**)
  - Immediately after exercise, the person continues to consume more oxygen compared to at rest, to repay the **oxygen debt**, by:
    - Fast **heart rate**: Carries **lactic acid** quickly to the liver
    - **Deeper** and **faster breathing**: Intake large amounts of oxygen quickly

***[FYI]:* Anaerobic respiration (yeasts)**

- Glucose --> carbon dioxide + ethanol + small amount of energy
- This process is also called **alcoholic fermentation**

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8. Excretion

Learning Outcomes:

1. Importance of excretion
2. Structure of kidneys and nephrons
3. Dialysis

Keywords:

- Afferent/efferent arteriole, ultrafiltration, high blood pressure
- Selective reabsorption, filtrate
- Kidney failure, partially permeable, long narrow and coiled, opposite direction

If you're our student: Excretion in Humans Crash Course Clips

1. Importance of excretion

Excretion: The removal of metabolic waste products, toxic substances and substances in excess from the body.

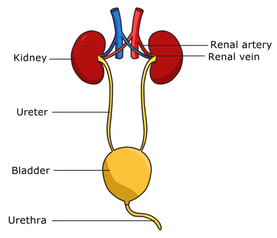
- Our **metabolism** (chemical activities within cells) results in **metabolic waste products**.
- **Importance:** They must be excreted as they can harm the body if they accumulate to high concentrations.

Examples of excretion in humans

- Unicellular organisms use **diffusion** for excretion, multicellular organisms need organs
  - **Lungs** excrete CO2 during **expiration**
  - **Urea** (product of deamination) is filtered out by **kidneys** and excreted in **urine**
  - Excess **water** excreted by **sweating**, **expiration** and in **urine**
  - Excess **mineral salts**
  - **Bile pigment** excreted through **faeces**

2. Structure of kidneys and nephrons

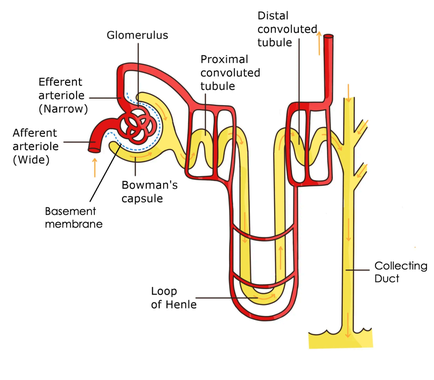
Urinary system



- **Renal artery** brings blood to kidney, **renal vein** carries blood away
- Kidneys act as filters, removing unwanted substances
- **Ureter** carries urine to **bladder** where it is temporarily stored
- **Urethra** carries urine outside of body

> 💡 ***[Memory hack]***
>
> - How not to mix up ureter and urethra
>   - When you've been holding your pee in for very long and finally go toilet, you say "**aaaaaaa**"
>   - Urethr**aaaa** is the one through which urine leaves your body

Parts of a nephron



Formation of urine

- A **nephron** is the **basic functional unit** of the kidney that filters and removes waste substances from the blood to form urine.
- The processes involved that make this possible are **ultrafiltration** and **selective reabsorption**.

Ultrafiltration: The process where most of the blood plasma and dissolved substances are forced out of the glomerulus into the bowman's capsule by high blood pressure.

- Blood enters the **glomerulus** through the **afferent arteriole** and leaves through the **efferent arteriole**
- **Lumen** of **efferent arteriole** is smaller than the **afferent arteriole**, generates **high blood pressure** which forces out most of the **blood plasma** and its **dissolved substances** (glucose, amino acids, mineral salts, urea, toxins, medicine, etc.)
- These substances enter the **Bowman's capsule**
- Large molecules such as **blood cells**, **platelets** and **proteins** cannot pass through the **basement membrane** that lines the glomerular capillaries

Selective reabsorption: The process where certain substances are reabsorbed from the filtrate back into the blood as they pass through nephrons.

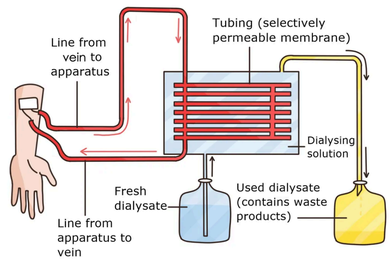
- Useful substances are **selectively reabsorbed** while unwanted substances (or substances in excess) stay in the **filtrate** and become urine
- Water molecules are reabsorbed* via **osmosis**
  - **Pro Tip: Since water is not reabsorbed using energy, do not say it is "selectively reabsorbed", only "reabsorbed".*
- Glucose, amino acids, and some mineral salts are reabsorbed via **diffusion** and **active transport**

Part of nephron	Reabsorption of substances
Proximal Convoluted Tubule	Some water, some mineral salts, all glucose and all amino acids reabsorbed
Loop of Henle	Some water and some mineral salts reabsorbed
Distal Convoluted Tubule	Some water and some mineral salts reabsorbed
Collecting Duct	Some water reabsorbed

> 💡 ***[Memory hack]***
>
> - Substances reabsorbed along nephron
>   - **P**roductive **P**roximal: Reabsorbs a lot of things - some water, some mineral salts, all glucose and all amino acids.
>   - **H**esitant **H**enle: Loop of Henle reabsorbs some things - some water, some mineral salts
>   - **D**iscerning **D**istal: DCT reabsorbs some things - some water, some mineral salts
>   - **C**onservative **C**ollecting duct: Collecting duct reabsorbs the least types of substances - only water

3. Dialysis

- Patients with **kidney failure** need to use a **dialysis machine** to filter waste products out of their blood



Procedure

- Blood is drawn from the **vein** in patient's arm into a **partially permeable** tube
  - *`*Pro Tip: Veins are safer as they are closer to the surface unlike arteries which are deeper in the arm. Veins also have low pressure making it easier to stop the bleeding after dialysis.`*
  - Tube does not allow large substances such as blood cells and platelets to pass through, but allows small substances such as waste products to diffuse out.
- Tube enters machine where it is bathed in **dialysis fluid/dialysate**.
- **`Features of machine that increase efficiency:`**
  - Dialysate contains zero waste products, hence waste products from blood **diffuse** out down their **concentration gradients**.
  - Dialysate has an equal concentration of useful substances (glucose, amino acids, mineral salts) as healthy blood, so there is no **diffusion**.
  - Tubing is **long**, **narrow** and **coiled**, increases **SA:V**, increasing **diffusion** rate.
  - Dialysate flows **opposite direction** to blood, maintaining a **concentration gradient** along the entire length of the tubing for more waste products to **diffuse** out.
- Cleaned blood is returned via the **vein** in patient's forearm.

💡 ***[Memory shortcut]***

- Dialysis machine features [**ZERO**]
  - **Z**ero waste products in fluid
  - **E**qual concentration of useful substances in fluid
  - Tubing has high surface area to volume **R**atio
  - blood and dialysate flow in **O**pposite directions

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9. Homeostasis

Learning Outcomes:

1. Homeostasis, Negative Feedback and Hormones
2. Glucose Regulation and Diabetes
3. Osmoregulation and ADH
4. Parts of skin
5. Temperature regulation

Keywords:

- Internal environment, internal temperature, negative feedback
- Stimulus, receptor, control centre, set-point/normal condition, corrective mechanism
- Endocrine, target organs, blood glucose concentration, permeability to glucose
- Persistent high blood glucose, unexpected weight loss, calories
- Osmoregulation, osmoreceptors, permeable to water
- Thermoreceptors, dilate, constrict, arterioles
- Latent heat, metabolic rate, thermoreceptors, rapid contraction

If you're our student: Homeostasis Crash Course Clips

1. Homeostasis, negative feedback and hormones

Homeostasis: The maintenance of a constant internal environment via negative feedback.

Negative feedback: A sequence of events triggered by a disturbance in the system, which counteracts the change, restoring the system to its set-point.

- There is a change in internal environment (this is the **Stimulus**)
- A **Receptor/sensor** detects the change in internal environment
- The **Control centre** receives the information and triggers corrective mechanisms
- Response is a **Corrective mechanism** that removes the stimulus
- Internal environment returns to its **Normal condition/set-point**
- Receptor detects that set-point is reached, sends signals to the **control centre** to **Stop** corrective mechanism

💡 ***[Memory Shortcut]***

- Negative feedback process [**S**neaky **R**abbit **C**hews **C**arrot **N**on **S**top]
  - **S**timulus
  - **R**eceptor
  - **C**ontrol centre
  - **C**orrective mechanism
  - **N**ormal condition/set-point restored
  - **S**top corrective mechanism once receptor detects set-point restored

Some factors controlled by homeostasis

- Temperature
- Blood water potential
- Blood pressure
- Blood pH, blood CO2 concentration
- Blood glucose concentration
- Water content in urine

Hormone: A chemical substance produced in minute quantities by an endocrine gland. It is transported in the bloodstream to one or more target organs where it exerts its effects.

- **Endocrine gland:** A ductless gland that secretes its products, hormones, directly into bloodstream.

2. Glucose Regulation and Diabetes

Blood glucose regulation

Hormone	Insulin	Glucagon
Stimulus	High blood glucose level	Low blood glucose level
Detected by	Cells* in islets of Langerhans	Cells* in islets of Langerhans
Secreted by	Cells* in islets of Langerhans	Cells* in islets of Langerhans
Target organs	Liver and muscles	Liver only
Responses triggered	• Increases **permeability** of liver and muscle cells to glucose, more glucose **diffuses** in, decreasing blood glucose levels • **Glucose** is converted into **glycogen** in liver and muscles	• **Glycogen** is converted to **glucose** in liver (but not in muscles), and glucose is released into the **bloodstream** ***[Memory hack]*** How to remember that glucagon does not target muscle cells: • Muscles are "selfish", they only take in glucose but don't want to release glucose to the bloodstream
Overall effect	Decreases blood glucose level until set-point	Increases blood glucose level until set-point

**FYI: There are actually 2 different types of cells of the islets of Langerhans that secrete insulin and glucagon respectively.*

💡 ***[Memory hack]***

- How to remember what insulin and glucagon do:
  - **IN**sulin is released to make glucose go **IN**to the target cells when blood glucose is too high (hence reducing blood glucose)
  - Glucagon does the opposite - makes glucose come out of liver cells

💡 ***[Memory hack]***

- How to not mix up Glycogen and Glucagon
  - GlycoGEN is a very GENerous storage of glucose, when the body needs glucose it "donates" it by being broken down to release glucose into the bloodstream

Diabetes mellitus: The condition where the body is unable to maintain blood glucose level within normal range.

Type I

- **Pancreas** cannot produce insulin/enough insulin
- Develops at a young age

Type II

- **Target organs** (liver and muscles) **lose sensitivity** to insulin
- The **pancreas** initially produces more insulin to compensate, gets overworked, and eventually produces **insufficient insulin**
- Develops at an older age, linked to unhealthy lifestyle

💡 ***[Memory hack]***

- How to differentiate Type I and Type II diabetes:
  - I comes before II
  - Type I comes earlier in life, as it is genetic hence the person has issues producing insulin since young
  - Type II comes later in life, due to unhealthy lifestyle

Symptoms

- Persistent high blood glucose
- Glucose found in urine
- Frequent urination
- Frequently feeling dizzy, fatigue
- Unexpected weight loss
- Wounds take longer to heal

Risk factors

- Obesity/overweight
- Age
- Family history (diabetes can be inherited)
- Unhealthy blood lipid levels
- Sedentary lifestyle

Prevention

- Exercise regularly, maintain healthy bodyweight
- Eat a balanced, healthy diet, low in calories, high in fibre
  - Doing the above improves blood lipid levels.

Treatment

- There is currently no cure for diabetes

- Type 1: Insulin injections
- Type 2: Control blood glucose level
  - Diet lower in carbohydrates
  - Exercise regularly
  - If condition worsens, have to inject insulin/take medication to improve body's sensitivity to insulin

3. Osmoregulation and ADH

Osmoregulation: The process where the amount of water and concentrations of solutes in blood are controlled to maintain constant water potential in the body.

- **Osmoregulation** works by **negative feedback**, and attempts to restore the set-point of blood **water potential**
- **Osmoreceptors** are cells in the **hypothalamus** that detect changes in blood **water potential**
- More/less **Antidiuretic Hormone (ADH)*** is secreted by the pituitary gland in response to a change detected
  - **Pro Tip: A diuretic is something that makes you pee more. Therefore Anti-diuretic means anti-pee, so you pee less and urine becomes more concentrated.*

💡 ***[Memory Hack]***

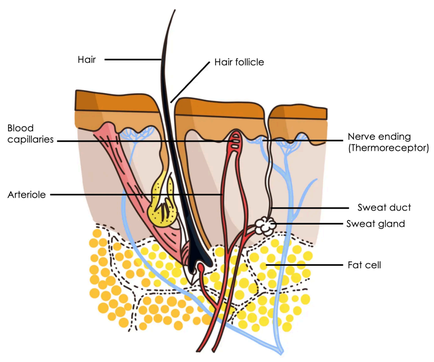
- Think of ADH as the "water conservation hormone" (I like to visualise ADH as the water wally mascot)
- When you don't have enough water, more of it is secreted to conserve water in your body

Water potential	Water potential **decreases**	Water potential **increases**
Osmoreceptors	in the **hypothalamus** detect this	in the **hypothalamus** detect this
ADH secretion	**Pituitary gland** secretes **more** ADH	**Pituitary gland** secretes **less** ADH
Collecting ducts	**Cells** in the **walls** of **collecting ducts** become	**Cells** in the **walls** of **collecting ducts** become
Permeable	**More permeable** to water hence reabsorb more water from **filtrate** back into blood	**Less permeable** to water, hence reabsorb less water from **filtrate** back into blood
Dilute	Becomes **less dilute**/more concentrated	Becomes **more dilute**/less concentrated

💡 ***[Memory shortcut]***

- ADH explanation [**W**ealthy **O**tters **A**te **C**ustard **P**udding **D**essert]
  - **W**ater potential
  - **O**smoreceptors
  - **A**DH secretion
  - **C**ollecting ducts
  - **P**ermeable
  - urine becomes more/less **D**ilute

4. Parts of skin



Sweat

- Contains water, salts (mainly sodium chloride) and small amounts of urea
- Hence sweating is a means of **excretion**

Adipose (fat) tissues

- **Adipose** cells = Fat cells
- Fat is a **poor conductor** of heat, reducing heat loss through the skin

5. Temperature regulation

Negative feedback is involved

- Changes in **internal temperature** are the **stimulus**
- Detected by **thermoreceptors** in **hypothalamus**, hypothalamus sends **nerve impulses** to **effectors** that carry out **corrective mechanisms** to counteract the change in internal temperature
  - **Pro Tip: There are also thermoreceptors in the skin, though they detect skin temperature, while hypothalamus detects internal temperature (by measuring blood temp).*
- Once **set-point** is restored, thermoreceptors detect this and send nerve impulses to hypothalamus to **stop** the **corrective mechanisms**

Responses to changes in internal temperature [MASS]

Response	Too cold	Too hot	Explanation
Metabolic Rate	Increases	Decreases	**Metabolic rate** increases by increasing rate of **aerobic respiration** by **mitochondria**, releasing more **heat energy.**
Arterioles in the skin	Constrict	Dilate	**Constriction** of arterioles in the skin reduces blood flow to capillaries at the skin surface, decreasing heat loss.
Sweat Glands	Secrete less sweat	Secrete more sweat	When sweat glands secrete more sweat, more water in sweat **evaporates,** hence more **latent heat** is lost.
Shivering	Begins	Does not occur (No need to write in answer)	**Shivering,** the **rapid contraction** of **skeletal muscles,** further increases **the rate of aerobic respiration,** releasing more **heat energy.**

💡 ***[Memory Shortcut]***

- Responses to changes in temperature [**MASS**]
  - **M**etabolic rate
  - **A**rterioles
  - **S**weat glands
  - **S**hivering

💡 ***[Memory Hack]***

- How to remember whether arterioles in skin constrict/dilate
  - When it is **co**ld, arterioles in skin **co**nstrict.

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10. Nervous System and The Eye

Learning Outcomes:

1. Central and Peripheral nervous system
2. Neurones
3. Reflex actions
4. The human eye
5. Bonus: Nervous system vs Endocrine system

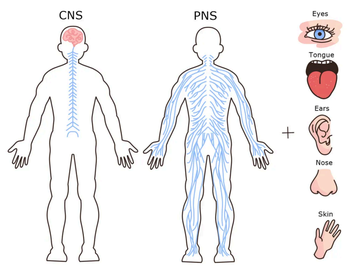
Keywords:

- Central/peripheral nervous system, cranial/spinal nerves, sense organs
- Nerve impulses, stimulus, receptor, effector, gland, transmitted, junction
- Sensory, relay, motor neurone
- Reflex arc, involuntary, conscious control, reflex centre,
- Internal reflection of light, refract
- Taut, slacken, convex, focal length, sharply focussed
- Dim, dilate, constrict

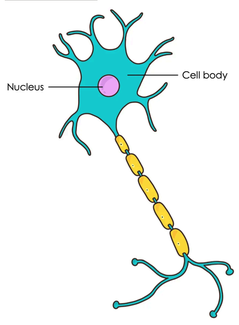
If you're our student: Nervous System and The Eye Crash Course Clips

1. Central and Peripheral nervous system

- **Central Nervous System (CNS)** consists of **Brain** and **Spinal cord**
- **Peripheral Nervous System (PNS)** consists of:
  - **Cranial nerves** (from the brain)
  - **Spinal nerves** (from spinal cord)
  - **Sense organs** (eyes, nose, tongue, ears, skin)

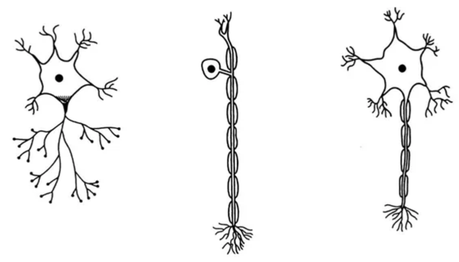


2. Neurones



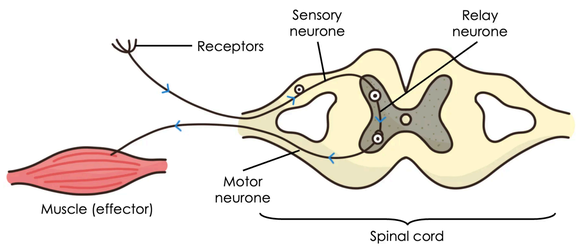
Neurone Part	Function
Cell body	Contains the **nucleus** and other **organelles**
Synapse (not a neurone part)	• The **junction** between **two neurones** OR between a **neurone** and an **effector** (muscle/gland). • **Chemicals** are released and **diffuse** across, allowing **nerve impulses** to **effector** (muscle/gland).
Nerve fibre	A strand of cytoplasm extending from the cell body **Pro Tip: Think of it as any part of the neurone other than the cell body = nerve fibre.*

Sensory, relay and motor neurones



**Pro Tip: Sensory neurones are distinct because of the position of their cell body being along the length instead of near the start.*

Neurone Type	Transmits nerve impulses from	Transmits to
Sensory (Centre)	Receptor* **Pro Tip: Receptor is part of the sensory neurone, no synapse between receptor and sensory neurone.*	Relay neurone
Relay (Left)	Sensory neurone	Motor neurone
Motor (Right)	Relay neurone	Effector



**Pro Tip: Tell apart which neurone is which by their position in the reflex arc.*

3. Reflex actions

Reflex action: An immediate response to a specific stimulus without conscious control.

- Involves a **reflex centre** (either brain or spinal cord).
  - **Spinal reflexes** use spinal cord as reflex centre, e.g. knee jerk reflex, withdrawal reflex when touching a hot object
  - **Cranial reflexes** use the brain as reflex centre, e.g. blink reflex, accommodation reflex, pupil reflex, sneezing, coughing
- **Reflex arc:** The shortest pathway for nerve impulses to travel from receptor to effector during a reflex action.

- **Examples** of reflex actions: Knee jerk reflex*, pupil reflex, touching hot/sharp object, blink reflex, grasp reflex, cough reflex, sneeze reflex, production of gastric juice, production of saliva, secretion of adrenaline
  - **Pro Tip: For the knee jerk reflex, this is a stretch reflex. When there is a tap on the tendon below the knee, stretch receptors detect this and result in the contraction of the quadriceps muscle (to prevent the muscle from overstretching and being injured)*

- **Receptors** you should be familiar with in syllabus:
  - **Pain** receptors
  - **Thermo**receptors
  - **Stretch** receptors
  - **Photo**receptors
  - **Osmo**receptors

Pathway of nerve impulses questions:

- When _____ (incident), _____ (receptors) detect this, **nerve impulses** are generated and travel along a **sensory neurone.**
- They are **transmitted** to a **relay neurone,** in the _____ (either brain/spinal cord), which is the **reflex centre.**
- **Nerve impulses** are then **transmitted** to a **motor neurone,** then to the _____ (thing that does the action), which is the **effector**,
- Triggering it to _____ (response triggered), so that _____ (where possible, the purpose for the reflex action).

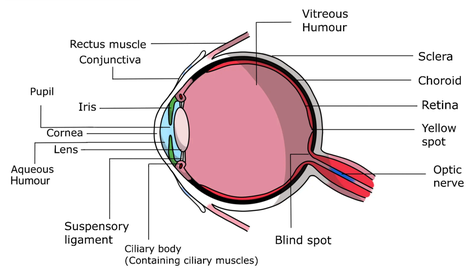
💡 ***[Memory shortcut]***

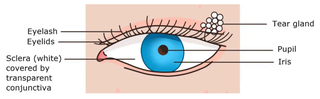
- Pathway of nerve impulses during reflex action [**I** **R**aced **S**everal **R**acing **C**ars, **M**aking **E**very **R**ace **P**erfect]
  - **I**ncident
  - **R**eceptor
  - **S**ensory neurone
- **R**elay neurone
- reflex **C**entre
- **M**otor neurone
- **E**ffector
- **R**esponse
- **P**urpose

Voluntary action: A deliberate action done under conscious control.

- E.g. when you want to raise your hand: Brain --> Relay neurone in spinal cord --> Motor neurone --> Hand muscles

4. The human eye



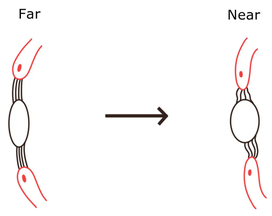


Part of eye	Description
Sclera	Protects eyeball from mechanical damage
Choroid	• Rich in blood vessels, bringing O2 and nutrients to eyeball and remove metabolic waste products • Pigmented black to prevent **internal reflection of light**
Retina	Contains **photoreceptors** that detect light and generates **nerve impulses**, which are sent to the **brain** via the **optic nerve**.
Yellow spot/Fovea	Light is mainly focussed here as the image that is produced here is the sharpest.
Blind spot	An area of the retina right above the **optic nerve**, where there are no **photoreceptors**
Cornea	**Refracts** light rays into the eye • The greatest degree of refraction is done by the cornea
Conjunctiva	• Moistens eye by secreting mucus
Eyelashes	Shield the eye from dust particles/irritants
Aqueous humour	• A watery substance found in the aqueous chamber, gives the eyeball its shape • **Refracts** light into pupil • Nourishes cornea
Iris	• Consists of **circular** and **radial** muscles, controlling amount of light entering the eye • Gives the eye its colour
Ciliary body	Contains **ciliary muscles** that pull on **suspensory ligaments**, which in turn pull on the **lens** to change its shape
Lens	• Focusses light onto the **retina** • Is flexible, thickness can be changed to focus on objects at varying distances
Vitreous humour	• A jelly-like substance found in the vitreous chamber, gives the eyeball its shape • **Refracts** light onto **retina**
Rectus muscles	Controls eye movement

How light enters the eye

- Light is refracted by the **cornea** into the eye
- The **aqueous humour** refracts light into the **pupil** (a hole)
- The **lens** refracts light towards the **retina**
- The **vitreous humour** refracts light onto the **retina**

Focusing/Accommodation reflex



Object	Far	Near
Ciliary muscles	Relax	Contract*
Suspensory ligaments	Taut	Slacken
Lens shape	Thinner and less convex	Thicker and more convex
Focussed sharply on retina	Clear image seen	Clear image seen

**Pro Tip: Think of ciliary muscles contracting towards lens, hence suspensory ligaments slacken*

**Pro Tip: Do not say lens becomes more concave, you must say less convex.*

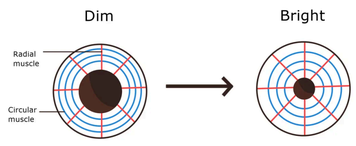
💡 ***[Memory Shortcut]***

- Accommodation reflex [**C**ats **S**cratch **L**eather **F**urniture]
  - **C**iliary muscles
  - **S**uspensory ligaments
  - **L**ens shape
  - **F**ocussed sharply on retina

💡 ***[Memory hack]***

How to remember whether ciliary muscles contract or relax

- When you focus on a near object, you are 'straining' your eyes, so ciliary muscles contract to focus on near objects.
- When you focus on a far object, you are 'relaxing' your eyes, so ciliary muscles relax to focus on far objects.



Pupil reflex

Light conditions	Bright	Dim
Radial muscles	Relax	Contract
Circular muscles	Contract	Relax
Pupil	Constricts	Dilates
Effect on eye	Allows less light in, prevents damage to retina	Allows more light in to see better

**Pro Tip: Iris contains circular and radial muscles (antagonistic), which control size of the pupil*

💡 ***[Memory Shortcut]***

- Pupil reflex [**R**eally **C**ool **P**upil **E**ffect]
  - **R**adial muscles
  - **C**ircular muscles
  - **P**upil
  - **E**ffect on eye

> 💡 ***[Memory hack]***
>
> How to remember what radial muscles are doing:
>
> - Radial muscles are "afraid of the dark", so when it's dark they tense up in fear, hence they contract.
> - When you're in a bright place, they relax

5. Bonus: Nervous system vs Endocrine system

System	Endocrine	Nervous
Signal	Hormones	Nerve impulses
Mode of transmission	Bloodstream	Neurones
Speed	Relatively slower	Relatively faster
Duration of responses	Short-lived or long-lived	Short-lived
Can be activated by conscious control?	No	Either
Affected areas	Usually more than one target organ, throughout the body	Usually localised

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11. Infectious Diseases

Learning Outcomes:

1. Infectious diseases and how they spread
2. Bacteria vs viruses
3. Treatment and prevention

Keywords:

- Pathogen, symptoms, droplets, respiratory tract, direct contact, sexually transmitted, contaminated surface, breastfeeding
- Cholera, water-borne
- Single-celled, cell membrane, membrane-bound, DNA
- DNA, RNA, protein coat, spike proteins, host
- Influenza, flu, pneumococcus, pneumococcal disease, pneumonia, close contact, antiviral drugs
- Fever, headache, vomiting, photophobia, runny nose, coughing, sore throat, muscle aches,
- Vaccine, agent, antigen, quickly produce antibodies
- Inhibit synthesis, growth
- Course of antibiotics, strain, less/more sensitive, antibiotic resistance, survive and reproduce

If you're our student: Infectious Diseases Crash Course Clips

1. Infectious diseases and how they spread

Disease: A condition that causes the body to function less effectively, and produces specific signs or symptoms.

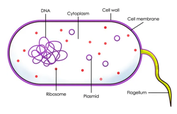
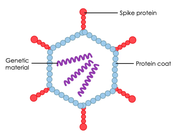
- **Pro Tip: Signs = observable/measurable, symptoms = described/felt*

- **Infectious diseases**
  - Caused by **pathogens** (disease-causing **organisms**)
  - Can spread from one person to another
- **Non-infectious diseases:**
  - Not caused by **pathogens**, cannot spread from one person to another
  - Eg: Atherosclerosis, coronary artery disease, Liver cirrhosis, diabetes, sickle-cell anaemia

How infectious diseases spread

- **Droplets**
  - When **droplets** in the air when someone **coughs/sneezes** which contain the **pathogens** are breathed into the **respiratory tract** of an uninfected person
- **Direct contact**
  - **Sexually Transmitted Infections** (STIs) through exchange of **bodily fluids** during **sexual intercourse** (e.g. **HIV**)
    - **Pro Tip: See Topic - Reproduction in humans for more on HIV*
  - Through **breastfeeding** from mother to baby
- **Contaminated surfaces**
  - Touching **surfaces contaminated** with the pathogen, then our **nose/eyes/mouth**
- **Contaminated food and water**
  - E.g. **Cholera** is a **water-borne** disease spread by consuming water contaminated with the **bacteria**
  - **Pro Tip: Food poisoning is when we consume food contaminated with the pathogen*

2. Bacteria and viruses

Feature	Bacteria	Viruses
Appearance		
Outer covering	Cell wall	Protein coat
Genetic material	DNA	DNA/RNA
Plasmids	Yes	No
Cell membrane	Yes	No
Cytoplasm	Yes	No
Ribosomes	Yes	No
Growth	Yes	No
Cellular respiration	Yes	No
Reproduction without host	Yes	No
Killed by antibiotics?	Yes	No

Bacteria

- **Single-celled** organism
- Has a **cell wall** and **cell membrane**
  - **Pro Tip: Since bacteria only have 1 cell membrane in the entire cell, we don't need to call it plasma membrane.*
- No **membrane-bound** nucleus and organelles
- Have **ribosomes** for **protein synthesis**
- **Circular DNA***
  - **Pro Tip: This is unlike the DNA in other organisms such as plants and animals, which is linear*
- Has **plasmids**
  - **Pro Tip: See Topic - Molecular genetics for plasmids*
- May have **flagella** (to move)

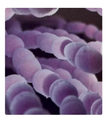
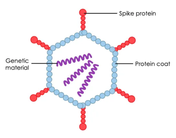
FYI: How bacteria cause disease

- *Bacteria try to 'colonise' our insides, some of them produce metabolic waste products which can be toxic to us --> thus affecting our health*
- *Not all bacteria cause disease (in fact, many are beneficial, like the 'good' bacteria in our large intestine)*

Viruses

- Has a **protein coat** (instead of cell membrane), which can have **spike proteins** on the surface
- Contains **genetic material** inside, which can be **DNA** or **RNA**
- No cellular structures like **cell membrane**, **cytoplasm**, **organelles**
- Does not **grow**, nor undergoes **cellular respiration**
- Infects **host** cells and uses the cells' **enzymes**, and **organelles** such as **ribosomes** to make more copies of itself (reproduces)

3. Treatment and prevention

Pathogen	Pneumococcus bacteria	Influenza virus
Structure	 (Refer to bacteria structure earlier)	
Illness caused	Pneumococcal disease, which can include: • Pneumonia (lung infection) • Middle ear infection • Blood infection • Inflammation of brain and spinal cord membranes (meningitis)	Influenza/Flu (respiratory tract infection)
Signs and Symptoms	• Fever, headache, vomiting • Coughing, chest pain, rapid breathing (if infects lungs) • Sensitivity to bright light/**photophobia** (if brain and spinal cord membranes inflamed)	High fever, headache, runny nose, cough, sore throat, muscle aches

Transmission	• **Droplets** in the air spread and enter an uninfected person's respiratory tract	• **Droplets** in the air spread and enter an uninfected person's respiratory tract • When someone touches a **contaminated surface** followed by their mouth/nose/eyes
Reducing transmission	• Avoid **close contact** with others who are infected/if you are infected ◦ Social distancing • *Wash hands with **soap** and water/**hand sanitiser** • *Avoid **touching** nose, eyes, mouth • Use a **mask** (prevents **droplets** from travelling/other's **droplets** from reaching you) • **Cover** nose and mouth when coughing/sneezing (prevents **droplets** from travelling) *Note: Not applicable for pneumococcal disease, since it doesn't spread via contaminated surfaces.*	
Treatment	Take **antibiotics** as prescribed by a doctor	Take **antiviral drugs** as prescribed by a doctor
Prevention	Pneumococcal **vaccination**	Influenza **vaccination**

💡 ***[Memory Shortcut]***

- Ways to reduce influenza transmission [**D**iagnose **S**ick, **T**ake **M**.**C**.]
  - social **D**istancing/avoid close contact
  - **S**oap and water/hand sanitiser
  - don't **T**ouch eyes, nose, mouth
  - use a **M**ask
  - **C**over nose and mouth when coughing/sneezing

Vaccine: Contains an agent resembling a pathogen, and prevent infectious diseases by stimulating white blood cells to quickly produce antibodies when the pathogen invades.

- Pathogens have **antigens** (substances that trigger the production of antibodies), such as the **proteins** on the pathogens' surface
- The agent in the **vaccine** have an **antigen** that the real **pathogen** has, thus resembling the pathogen
- After vaccination, **white blood cells** recognise the specific **antigen** and produce **antibodies** against it
- How vaccines protect you from the real pathogen:
  - Some of these **white blood cells** remain in the body for a long time
  - When the real **pathogen** enters the person, these white blood cells **recognise** it and **quickly** produce **large amounts** of **antibodies** to destroy the pathogen.

💡 ***[Memory Shortcut]***

- How vaccines work [**A** **S**trong **T**eam **R**eady **T**o **A**ttack]
  - **A**gent
  - **S**timulates white blood cells
  - long **T**ime
  - **R**ecognise
  - produce **A**ntibodies

How antibodies help kill pathogens:

- Cause pathogens to **clump** together **(agglutination)**, promoting **phagocytosis**
- Bind to and **neutralises** harmful **toxins** that pathogens produce

Why there might still be cases of an infection even after a vaccine is introduced:

- Not everyone may have taken the vaccine, hence were not **immune**
- The **pathogen mutated**, it is now no longer the same as the **agent** in the vaccine that the body has **immunity** against.
- Vaccine's effects may not last a lifetime, as the **white blood cells** that were trained to **recognise** the **pathogen** died after some time/became too few in number

Antibiotics: Drugs that inhibit the growth of or kill bacteria.

- Examples of how antibiotics could work:
  - Inhibiting **synthesis** of bacterial **cell wall** (cell wall weakens, water enters by osmosis, bacteria bursts)
  - Breaking up the bacterial **cell membrane**
  - Inhibiting **enzymes** in the **cytoplasm** which are required for **growth**
  - Inhibiting **protein synthesis** at **ribosomes**
- Antibiotics do not work on viruses, due to the differences between their structures
  - Viruses do not have: **cell walls**, **cell membrane**, **ribosomes**
  - Many antibiotics work by inhibiting the growth of bacteria, but viruses do not **grow**
  - Viruses cannot be directly killed, instead has to be eradicated by the person's own **immune system**
- **Antibiotic resistance**
  - Due to variation, some bacteria in a population are **less sensitive** to the antibiotic, hence lesser chance of being **killed**
  - If a **course of antibiotics** is not completed, some of the **less sensitive** bacteria may **survive and reproduce**
  - They multiply, resulting in a **strain** of **antibiotic resistant bacteria**, which are even harder to treat.
  - *Pro Tip: This is an example of natural selection (Topic: Inheritance)*

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12. Nutrition in Plants

Learning Outcomes:

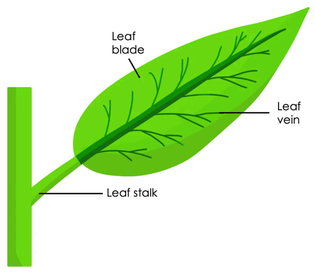
1. Leaf structure
2. Photosynthesis
3. Factors affecting photosynthesis
4. Bonus: Procedure for leaf starch test in experiment

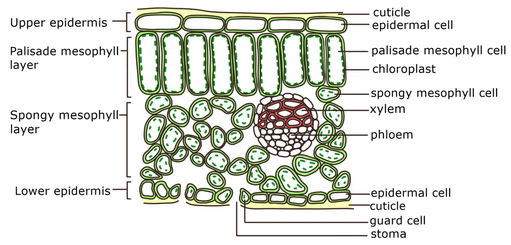
Keywords:

- Waxy cuticle, waterproof, intercellular air spaces, thin film of moisture
- Cylindrical, vertically arranged, irregularly shaped,
- Gaseous exchange, turgid
- Light energy, chlorophyll, by-product, manufactured food substances
- Light intensity, limiting factor

If you're our student: Nutrition in Plants Crash Course Clips

1. Leaf structure





Part of leaf	Structure and Function
Waxy Cuticle	• **Transparent**, allows light to reach **mesophyll cells** for **photosynthesis** to occur • **Waterproof**, reduces water loss via **evaporation** from leaf surfaces
Upper Epidermis/Lower Epidermis	• Both layers are made of closely packed **epidermal cells** and produce the **waxy cuticle** • Upper epidermis does not have any **chloroplasts** • Lower epidermis has **chloroplasts** only in the **guard cells**
Stoma *(pl. Stomata)*	• Tiny openings formed by two **guard cells**, which allow **gaseous exchange** and **transpiration** to occur • Stoma size controlled by **guard cells:** In the presence of light, **guard cells** open stomata. In the dark, **guard cells** close stomata.
Palisade Mesophyll Layer	• Just under upper epidermis, so they can receive as much **sunlight** as possible for **photosynthesis**. • Contain **many chloroplasts**, so more **photosynthesis** can be carried out per cell • **Long, cylindrical** and **vertically** arranged, so that many of them can be packed together, increasing the total amount of **photosynthesis** that is carried out by this layer.
Spongy Mesophyll Layer	• Fewer chloroplasts than **palisade mesophyll** cells • Consists of **irregularly** shaped cells that have **large intercellular air spaces** between cells
Intercellular Air spaces	• Mesophyll cells coated with a **thin film of moisture**, which allows **CO2 to dissolve** in it before **diffusing** into mesophyll cells. • **Intercellular air spaces** have large **SA:V**, for **carbon dioxide** and **oxygen** to quickly **diffuse** in and out of mesophyll cells
Vascular bundle	Consists of: • **Xylem:** Brings water and mineral salts absorbed from the soil from the roots to leaves for photosynthesis • **Phloem:** Carries manufactured food substances made by the leaves to the rest of the plant
Leaf shape	• Thin and wide **leaf blade** increases **SA:V** of the leaf, maximising light absorbed for **photosynthesis**. • Being thin decreases the **diffusion distance** for gases to reach all **mesophyll cells** quickly, • And allows light to easily **penetrate** through the leaf to reach all **mesophyll cells**.

2. Photosynthesis

Photosynthesis: The process whereby carbon dioxide and water are converted into glucose and oxygen, in the presence of light energy and chlorophyll.

- **Light energy** is absorbed by **chlorophyll** and used in converting carbon dioxide and water into **glucose**
- **Oxygen** gas is produced as a **by-product**

Word Equation:

$$\text{Carbon dioxide + Water} \xrightarrow[\text{Chlorophyll}]{\text{Light Energy}} \text{Glucose + Oxygen}$$

Chemical Equation:

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light Energy}} C_6H_{12}O_6 + 6O_2$$

Fate of glucose

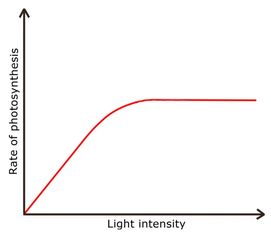
- Used in **aerobic respiration** to **release energy**
- Excess glucose stored as **starch** for **energy storage**
- Used to synthesise **cellulose** for **cell walls**
- Converted to **sucrose** to be transported in the **phloem** to other parts of the plant
- Converted to **amino acids**, which are then used to form **proteins** (to build new cell parts)
- Converted to **fats** for **energy storage** or to build new **cell parts**

3. Factors affecting photosynthesis

Limiting factor: A factor that directly affects the rate of the reaction if its quantity is increased.

Light intensity

- As light intensity increases, more **light energy** is absorbed by **chlorophyll** and converted into **chemical energy**, increasing **photosynthesis** rate.
- At very high light intensity, further increasing it has **no effect** on rate. Light intensity is **no longer a limiting factor** (some other factor is limiting).



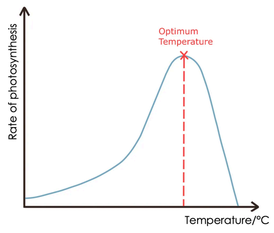
CO2 concentration

- As CO2 concentration increases, there is more CO2 available to be converted into **glucose**, increasing **photosynthesis** rate.
- At very high CO2 concentration, increasing it further has **no effect** on rate. CO2 concentration is **no longer a limiting factor** (some other factor is limiting).

Pro Tip: Atmospheric concentration is around 0.03%, while the concentration where CO2 no longer becomes limiting is **0.13% and above.*

Temperature

- Since **enzymes** are involved in photosynthesis, the photosynthesis-temperature graph looks the **same** as an enzyme-temperature graph.



4. Bonus: Procedure for leaf starch test in experiments (useful for practical)

- Place plant in dark room for 2 days, this **de-starches** the plant
- Carry out the experiment (e.g. whether photosynthesis works if leaf is placed in a sealed bag)
- Place the leaf in **boiling water** for 2min to kill the cells, **stopping further photosynthesis**.
- Place the leaf in a boiling tube with **ethanol** into boiling water bath, **removing chlorophyll** so that the green colour of chlorophyll does not affect any colour change later on
- Place leaf into **boiling water** for 1 min to **soften the leaf** (makes leaf more permeable for iodine to enter) and **remove alcohol**
- Add a few drops of **iodine** onto the leaf to **test for starch**

**Pro Tip: Variegated leaves which have a white outer layer will only have starch on the inside when tested.*

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13. Transport in Plants

Learning Outcomes:

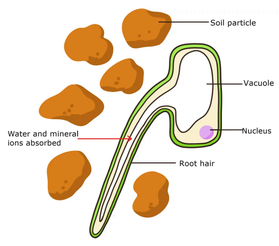
1. How plants absorb water
2. Xylem and phloem + their positions throughout a plant
3. Transpiration
4. Factors affecting transpiration
5. Wilting
6. Bonus: Adaptations to reduce transpiration rate

Keywords:

- Water potential, mineral salts
- Lignified, pits, collapse, end walls, unobstructed flow
- Translocation, manufactured food substances, sap
- Unidirectional, bidirectional, porous sieve plates
- Transpiration, transpiration pull
- Intercellular air spaces, thin film of moisture, evaporates, water vapour
- Humidity, air movement, wind, more/less steep concentration gradient
- Wilting, turgidity, non-woody stem, total leaf surface area
- Sunken stomata, pits, succulent/fleshy, spines

If you're our student: Transport in Plants Crash Course Clips

1. How plants absorb water



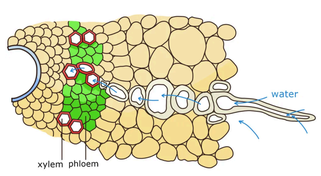
Role of root hair cells

- **Mineral salts** are transported via **active transport** from the surrounding soil into the cell.
- This results in root hair cells having lower **water potential** than the surrounding soil, hence water flows in passively via **osmosis.**

Feature of root hair cells	Function
Have a **long** and **narrow** root hair	Increases **SA:V** for faster absorption of water and mineral salts
Contain many **mitochondria**	More **aerobic respiration** to meet high **energy** demand required for **active transport** of mineral salts
Cell sap has high concentration of mineral salts	Creates a region of low **water potential** for water molecules to enter via **osmosis**

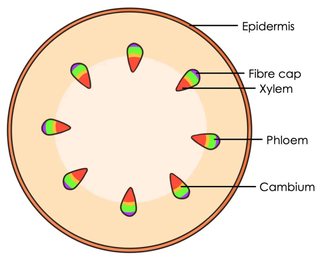
How water enters at the roots

- Water enters root hair cells via **osmosis** --> root hair cells have higher **water potential** than the inner cells, water moves via **osmosis** to inner cells
- This process of osmosis repeats until water reaches the **xylem vessels**
- Inner cells **actively transport mineral salts** into the **xylem** at roots, decreasing **water potential** of xylem so that water enters by **osmosis**.



2. Xylem and Phloem

Cross-section of stem

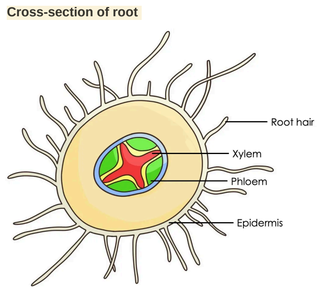


Pro Tip: Cambium differentiates into new phloem and xylem tissues

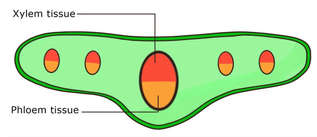
💡 ***[Memory Hack]***

- How to remember position of xylem and phloem in stem
  - Which is more crucial, food or water? Water. Since xylem carries water, it needs to be more protected, hence it's on the inside.

Cross-section of root



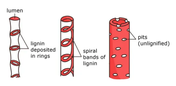
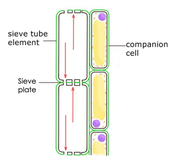
Cross-section of leaf



💡 ***[Memory Hack]***

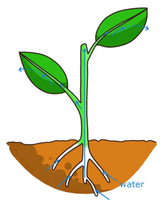
- How to remember position of xylem and phloem in leaf
  - Picture the stem's vascular bundle (you know that the xylem is on the inside), curling outwards to form the leaf's vascular bundle. That's why xylem would be on top, and phloem below

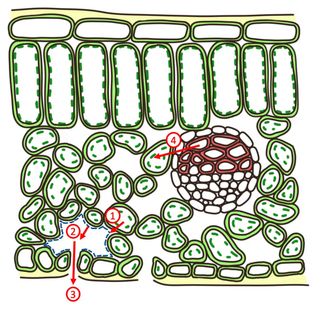
Xylem vs phloem - structure and function

Type of vascular tissue	Xylem	Phloem
Structure	 *Pro Tip: Pits allow water to flow to adjacent xylem vessels*	
Position in stem vascular bundle	Inner	Outer
Position in leaf vascular bundle	Top	Bottom
Position in root vascular bundle	Inner 'cross'	Outer 'nodules'

Transports	**Water** and **mineral salts** from roots to rest of the plant	• **Translocation:** The transport of **manufactured food substances** such as **sucrose** and **amino acids** from leaves to rest of the plant • Substance within phloem is called **sap**
Lignified walls?	• Yes, deposited in xylem walls to **strengthen** it, prevents xylem from **collapse**. • Can be deposited in **rings/spiral** bands/entire wall except for **pits**	No
Energy required?	No, substances are transported passively	Yes, **active transport** involved
Direction of transport	**Unidirectional** (upwards only)	**Bidirectional** (both up and down)
Alive?	**Dead,** and has no cell parts except **cell wall**	Yes, but **sieve tube elements** lack **nucleus, mitochondria,** and many other **organelles**
Companion cells	-	Have many **mitochondria**, to provide a lot of **energy** needed for **sieve tube elements** to transport **manufactured food substances**
End walls (a.k.a cross walls)	None, to allow **unobstructed flow** of water + min. salts	Yes - sieve plates, which are **porous**

3. Transpiration





Transpiration: The loss of water vapour from the aerial parts of a plant, mainly through the stomata in its leaves.

- In leaves, water molecules move out the **mesophyll** cells by **osmosis**, forming a **thin film of moisture** (1), which **evaporates** into **water vapour** in the **intercellular air spaces** (2)
- It **diffuses** out of leaves via **stomata**, down its **concentration gradient**. (3)
- **Water potential** of mesophyll cells has decreased, hence water molecules move from **xylem vessels** in leaves to **replace** water lost in mesophyll cells. (4)
- This causes a **whole column of water** to be pulled up xylem vessels from roots to leaves, by **transpiration pull**
  - **Transpiration pull:** The suction force created due to transpiration that pulls water and mineral salts up the xylem

💡 ***[Memory shortcut]***

- Transpiration process [**F**ake **V**ampire **D**rinks **R**ed **W**ater]
  - thin **F**ilm of moisture
  - water **V**apour
  - **D**iffuses out via stomata
  - water in xylem **R**eplaces water lost from mesophyll cells
  - causes **W**hole column of water to be pulled up

4. Factors affecting transpiration

- **Temperature**
  - As temperature increases, kinetic energy of water molecules increases
  - Water **evaporates** faster from the **thin film of moisture** into **intercellular air spaces**, more **water vapour diffuses** out of **stomata**, increasing transpiration rate

- **Light intensity**
  - As light intensity increases, **guard cells** become **turgid**, opening the **stomata**
  - ***FYI: How light causes guard cells to open stoma***
    - Light energy is absorbed by chloroplasts, they photosynthesise, forming glucose
    - Glucose is used to release energy
    - Energy is used for active transport of potassium ions into guard cells
    - Guard cells' water potential falls, water enters via osmosis, making them turgid
    - As one side of guard cells' cell wall in thicker, when guard cells expand, they curve, opening the stoma
  - This allows **water vapour** to **diffuse** out of the leaf faster, increasing transpiration rate

- **Humidity:** The concentration of water vapour in the air
  - As humidity increases, **concentration gradient** of **water vapour** between **intercellular air spaces** and surrounding air becomes **less steep**
  - Water vapour **diffuses** out slower, decreasing transpiration rate

- **Wind/air movement**
  - More wind/air movement blows **water vapour** away from air around leaves, decreasing **humidity**
  - **Concentration gradient** of **water vapour** between **intercellular air spaces** and surrounding air becomes **steeper**
  - Water vapour **diffuses** out faster, increasing transpiration rate

💡 ***[Memory hack]***

- How to remember effect of wind on transpiration rate
  - Just like a wet towel would dry faster in the wind compared to still air, plants "dry out" faster in the wind (a.k.a. higher transpiration rate)

5. Wilting

- Transpiration is a **consequence** of **gaseous exchange**, in the presence of light **stomata** open wider to allow more CO2 to enter for **photosynthesis**, however this also increases the rate that **water vapour diffuses** out

Importance of Turgidity

- Usually, **mesophyll cells** are **turgid**, keeping the leaves **firm** and **spread widely** for maximum **surface area** for higher rate of **photosynthesis**
- For plants with **non-woody** stems, **turgidity** keeps the plant **upright** to reach for sunlight

When wilting occurs

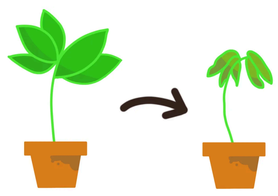
- Wilting occurs when **rate of transpiration > rate of water uptake**
- Due to a **net loss** of water to the plant, **central vacuoles** of cells shrink, **mesophyll cells** lose **turgor pressure** and become **flaccid**, resulting in the wilted look of the plant
  - **Pro Tip: Think of 'turgor pressure' as how turgid a plant cell is!*

Causes of wilting

- Too high light intensity
- Too high temperature
- Too much **fertiliser**, lowering soil **water potential** below that of root cells, resulting in water leaving the roots

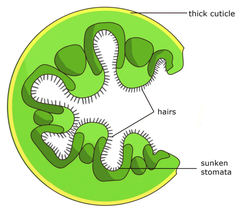
Advantages and disadvantages of wilting

- Advantages: Reduced **leaf surface area** + **flaccid** guard cells close **stomata** reduces **transpiration rate**, which helps conserve water
- Disadvantages: Due to closed **stomata**, less CO2 enters leaves. Due to reduced **total leaf surface area**, less light is captured, leading to reduced **photosynthesis** rate.
- **Pro Tip: Total leaf surface area is reduced, NOT leaf surface area to volume ratio.*



6. Bonus: Adaptations to reduce transpiration rate

- Hairs and a curled/rolled leaf structure traps water vapour around sunken stomata
  - Water vapour accumulates outside stomata + is trapped by hairs, increasing humidity, decreasing transpiration rate
- Few leaves/Small leaf surface area/Leaves reduced to spines
- Thick cuticle
- Succulent/fleshy leaves that store water



^Leaf of Marram grass, adapted to hot and dry locations

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14. Organisms and their Environment

Learning Outcomes:

1. Food chains and food webs
2. Non-cyclic energy flow
3. Ecological pyramids
4. Carbon cycle
5. Impact of Man on the Ecosystem
6. Conservation

Keywords:

- Population, Habitat, community, biotic, abiotic, ecosystem
- Food chain, food web, trophic level, producers, primary, secondary, tertiary consumers
- Herbivores, carnivores, decomposers
- Pyramid of biomass/numbers
- Growth and repair, carbon compounds, uneaten parts, egested/excreted substances, linear, non-cyclic energy flow
- Carbon cycle, fossil fuels, organic matter, combustion, decomposition
- Carbon sink, dissolves, soluble in water, buried, seabed
- Pollution, eutrophication, nitrates and phosphates, dissolved oxygen, aerobic bacteria, submerged plants
- Bioaccumulation, biomagnification, biodegradable, indigestible, landfills, leach
- Deforestation, soil erosion, flooding, desertification, biodiversity, extinction, endangered species
- Greenhouse gas, global warming, renewable energy, gene pool, cross-breeding

If you're our student: Organisms and their Environment Crash Course Clips

1. Food chains and food webs

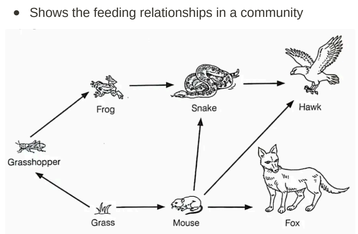
- **Population:** A group of organisms of the same species that live together in a habitat
- **Habitat:** The place an organism lives
- **Community:** Comprises all the populations living and interacting with one another in a habitat
- **Ecosystem:** A community of organisms interacting with one another and their physical environment

Food Chain: A series of organisms, beginning with the producer, through which energy and nutrients are transferred.

- Producer (1st trophic level) --> Primary Consumer --> Secondary Consumer --> Tertiary Consumer etc.
  - **Herbivores:** Only eat plants (usually, **primary consumers** are herbivores)
  - **Carnivores:** Only eat meat
  - **Omnivores:** Eat both plants and meat
- Each step in the food chain is a **trophic level** (the diagram above has 4 trophic levels)
  - **Trophic level:** The feeding position that an organism occupies in a food chain.
- **Producers:** Organisms that take up the first trophic level, and make their own food from inorganic materials through photosynthesis.
- **Consumers:** Organisms that obtain food by feeding on other organisms.

Food Webs:

- Made of interlinked food chains
- Shows the feeding relationships in a community



2. Non-cyclic energy flow

- **Producers** are **photosynthesising** plants that obtain their energy from the Sun
  - This energy is transferred up the food chain in the form of **carbon compounds** when **producers** are eaten by **consumers**
- Some energy is used by organisms for **growth** and **repair**

How energy is lost at each trophic level:

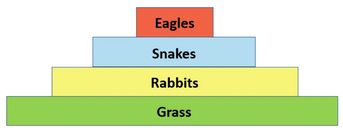
- As **heat** to the surroundings due to **cellular respiration**
- As chemical energy trapped within **excreted** and **egested** substances (eg. urine and faeces)
- As chemical energy trapped in the **uneaten parts** when an organism dies (e.g. bones)
- **Pro Tip: Decomposers will use the above substances for cellular respiration, releasing energy as heat.*

- Therefore, only **10%** of energy is actually passed on from one **trophic level** to the next
- Energy flow is thus **linear** and **non-cyclic** (energy can't be reused)
- Energy must be constantly provided by the **sun** to maintain ecosystems

3. Ecological pyramids

Pyramid of Biomass

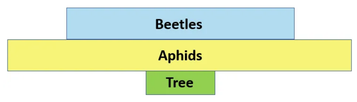
- Biomass at each trophic level = total mass of all individuals of that organism type
  - Biomass = Mass of 1 organism **X** number of that organism.



**Pro Tip: The pyramid of biomass is always this same upright shape.*

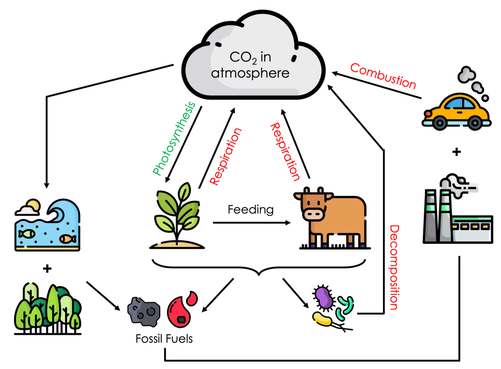
Pyramid of Numbers

- Usually, pyramid of numbers is upright (Since usually, the higher the trophic level, the fewer the number of organisms)
- However, whenever there is a parasitic relationship, the lower trophic level's organism can support many organisms of the trophic level above it (the parasite).
  - E.g. Tree/Plant --> Insects
  - E.g. Animal --> Fleas/Ticks



**Pro Tip: The pyramid of biomass is still upright for the above food chain.*

4. Carbon cycle



How carbon enters food chains

- CO2 from the atmosphere is absorbed by **plants** and converted into **glucose** during **photosynthesis**
- Glucose is also converted to other **carbon compounds** (starch, fats, proteins, etc.)
- When consumers eat plants, **carbon** is transferred up the **food chain**
  - Allowing **energy** to passed from one organism to another in the form of **carbon compounds**

How carbon enters the non-living system

- CO2 is released into atmosphere during **aerobic respiration** by producers, consumers and decomposers
  - This maintains CO2 concentration in the atmosphere, so there is a constant supply of CO2 for **photosynthesis**
- **Fossil fuels** come from dead **organic matter** buried over long periods of time. When burnt for energy (**combustion**), it releases CO2 into the atmosphere

Carbon Sink: An area which stores carbon as carbon compounds indefinitely, and releases less carbon than it takes in.

- vs **Carbon source:** Releases more carbon than it takes in

- Forests
  - Trees take in CO2 through **photosynthesis** and convert it into carbon compounds such as cellulose which they use for growth and repair
  - Trees can be buried and become **fossil fuels** after they die
- Oceans
  - During **photosynthesis, phytoplankton** take in CO2 from the air to form **carbon compounds** such as **glucose**,
    - which is transferred to other organisms in the ocean which eat them up the **food chain.**
  - As CO2 is **soluble in water**, it **dissolves** into the ocean
  - Dead organisms may be buried at the **seabed** and become **fossil fuels**

💡 ***[Memory shortcut]***

- How oceans act as carbon sinks **[PDF]**
  - **P**hotosynthesis
  - **D**issolve
  - **F**ossil fuels

5. Impact of Man on the Ecosystem

Pollution: The addition of substances to the environment that damage it, making it unfit for life.

Sewage

- Should not be discharged into water bodies like rivers/lakes as:
- It may contain harmful bacteria that would cause diseases to those who drink it (e.g. Cholera)
- Could cause **eutrophication:** The process where a body of water receives excessive nutrients, leading to excessive growth of algae and floating water plants.
  - Untreated sewage is dumped/fertilisers are washed by rain into a body of water
  - **Nutrients** (**Nitrates** and **phosphates**) in the untreated sewage/fertilisers allow **algae**/floating water plants to grow rapidly across the water surface (algae bloom)
  - They block **sunlight** from reaching below, **submerged plants** have insufficient light for **photosynthesis** and die
  - Other animals also die due to the lack of **dissolved oxygen**.
  - **Aerobic bacteria** decomposes the dead **organic matter**, further decreasing **dissolved oxygen**.
  - Hence, many organisms in the river die due to the lack of **dissolved oxygen** in area.

💡 ***[Memory shortcut]***

- Eutrophication process [**NASA**]
  - **N**utrients (Nitrates and Phosphates)
  - **A**lgae bloom
  - **S**ubmerged plants
  - **A**erobic bacteria

Plastic Pollution

- Plastic is **non-biodegradable** and **indigestible**. Wildlife that feed on plastic often die as it blocks their **stomachs** and **intestines**.
- Burning of plastic waste contributes to **global warming**
- Harmful chemicals from plastic waste in **landfills** can **leach** into rivers and seas, **poisoning** wildlife
- Plastic in the ocean can be broken into tiny pieces (**microplastics**), resulting in **bioaccumulation** and **biomagnification**.

Bioaccumulation: The process where certain substances are not excreted, and accumulate in the bodies of organisms over time.

- Toxic chemicals are taken up by organisms in contaminated water/when they eat food/prey containing these chemicals.
- Some toxic chemicals cannot be **excreted**, so they accumulate in organisms' bodies, **bioaccumulation** has occurred.
  - Why it can't be broken down by the organism: These substances non-biodegradable
    - Biodegradable = capable of being decomposed by bacteria or other living organisms
    - Common examples: Heavy metals like mercury, lead, insecticides like DDT, and microplastics.
  - Why it accumulates in their bodies: These substances are not soluble in water, and remain in the organism's fatty tissues and not excreted.

Biomagnification: The process where a substance increases in concentration higher up the food chain.

- **Consumers** in each **trophic level** have to consume many organisms of the lower trophic level (due to inefficient energy transfer).
- Hence they ingest the toxic chemicals present in multiple organisms, and toxic chemicals accumulate in high concentrations within consumers. **Biomagnification** has occurred.
- The top consumer is most affected by the toxic chemicals as they are present in the highest concentrations, and could die if present in lethal concentrations.

Deforestation

- Loss of **biodiversity**
  - Organisms lose their habitats and may become **extinct**
- Increased **global warming**
  - With fewer trees to absorb CO2 via photosynthesis, more CO2 would remain in the atmosphere
  - Cutting of trees also releases CO2 when the remains are decomposed
- **Soil erosion**
  - Tree roots hold soil together, and the forest canopy protects topsoil from force of rain
  - With less trees, soil is more likely to be washed away
- **Flooding**
  - Eroded soil may be deposited in rivers, blocking the flow of water
  - Water level rises and floods surrounding areas
- **Desertification**
  - After topsoil is eroded, barren land cannot support plant life

Global warming: The rise in global average temperatures

- Caused by increased **greenhouse gas** emissions, especially CO2
- **Greenhouse gases** trap heat in earth's atmosphere, increasing global temperature
- Common **emissions** from **human activities**: **Deforestation**, **combustion** of **fossil fuels**, **combustion** of plastic waste, emitted from **petrol-based vehicles**

How we can reduce global warming:

- Reduce use of fossil fuels, use **renewable energy** sources like wind and solar instead
- Save electricity
- Switch from petrol-based to **electric vehicles**
- Conserve forests

6. Conservation

Reasons for conservation

- To preserve **biodiversity** (the range of species found in an ecosystem)
  - **Extinction** of one species could affect the **balance** of the ecosystem
- Ecosystems have **scientific value**, as useful information can be obtained through scientific research of diverse organisms
- We rely on wild plants for certain medicines
- Economic purposes: To obtaining food and raw materials sustainably (eg. fish, timber)
- Our crops rely on natural **pollinators** to reproduce
- Conserving **biodiversity** maintains a large **gene pool**, allowing us to improve crops and livestock by **cross-breeding** different varieties of wild plants with **favourable traits**
- Preserve natural scenery, which also brings economic benefits through tourism

💡 ***[Memory shortcut]***

- Reasons for Conservation [**S**aving **R**are **B**irds **T**hrough **M**any **G**reen **P**arks]
  - **S**cientific value of ecosystems
  - obtain **R**aw materials and food
  - maintain **B**alance of ecosystems
  - **T**ourism
  - wild plants used for **M**edicines
  - large **G**ene pool for cross-breeding
  - natural **P**ollinators needed for crops

Conserving forests

- Cut trees selectively at a controlled rate
- Do not cut down young trees
- Plant seedlings to replace trees cut down
- Set up protected forest reserves

Conserving mangroves

- Plant new mangrove seedlings in mangrove swamps
- Set up protected mangrove reserves

Conserving coral reefs

- Divers should not touch coral reefs/do not anchor their boats on reefs as it may kill corals
- Avoid using sunscreen when visiting reefs as ingredients in sunscreen may harm corals
- Do not purchase corals as it will encourage people to extract live corals
- Do not pollute the sea/coastline with trash, it can be washed into the sea and harm corals

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15. Molecular Genetics

Learning Outcomes:

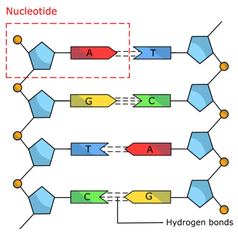
1. DNA structure
2. DNA to protein
3. Genetic Engineering
4. Implications of Genetic Engineering

Keywords:

- Deoxyribonucleic acid, nucleotide, double helix
- Deoxyribose, phosphate, nitrogenous base, Adenine, Thymine, Guanine, Cytosine
- Hydrogen bonds, complementary base pairing
- Gene, chromatin, chromosome
- Sequence of amino acids, specific polypeptide, codon, transcription, mRNA translation, folds
- Genetic engineering, donor, recipient, transgenic organism, foreign genes, target gene, anneal, vector, plasmid
- Restriction enzyme, restriction site, sticky ends, recombinant plasmid, heat/electric shock
- Social, ethical, moral, expensive, affordable, exploitation, biological warfare, allergic reactions, unwanted metabolic reactions

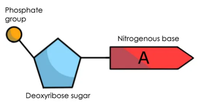
If you're our student: Molecular Genetics Crash Course Clips

1. DNA (Deoxyribonucleic Acid)



Structure of DNA

- Made from two **anti-parallel** strands (facing opposite directions), wound together in a **double helix** shape
- Each strand is made of many **nucleotides**
- Is made of **nucleotides**, which have:
  - **Deoxyribose** sugar
  - **Phosphate group**
  - **Nitrogenous**/nitrogen-containing **base** (Adenine/Thymine/Guanine/Cytosine)



- The sugar binds to a **phosphate group**, forming the **sugar-phosphate backbone** in each strand
- The strands are held together by **complementary base pairing**, with **hydrogen bonds** between:
  - **Adenine** and **Thymine**
  - **Guanine** and **Cytosine**
  - Therefore ratio of A:T and G:C must = 1:1

> 💡 ***[Memory hack]***
>
> - Remembering which nitrogenous bases pair together
>   - Apple Tree: **A**denine -- **T**hymine
>   - Car in a Garage: **C**ytosine -- **G**uanine

DNA vs Gene vs Allele vs Chromosome vs Chromatin

- **DNA**: DNA is a type of molecule, just like carbohydrates, proteins and fats are types of molecules.
  - DNA can be very short, or very long
- **Gene:** A sequence of DNA nucleotides that codes for a specific polypeptide
  - A long DNA molecule can consist of many genes along it
  - **Pro Tip: Gene has a more detailed definition in the topic Inheritance.*
- **Allele**: One of the alternative forms of a gene, that occupies the same gene locus on a pair of homologous chromosomes.
  - Alleles usually have slight **nucleotide** differences, but are otherwise very similar.
- **Chromosome**: A very long, tightly packed DNA molecule that consists of many genes.
  - In the nucleus, chromosomes are not yet condensed, and are in the loose form of chromatin. Chromosomes condense during cell division.
  - **Chromatin**: The form of DNA found in the nucleus, where DNA is loosely-packed and coiled around proteins.

2. DNA to Protein

**Pro Tip: The following details of transcription and translation are FYI. Only a brief understanding is needed to answer questions.*

Transcription: The process where DNA is used as a template to synthesise a complementary strand of mRNA.

- The information in a **gene** is transferred onto a molecule called **messenger RNA (mRNA)**
- Every 3 **nucleotides** on the original DNA is a **codon**, and each **codon** determines an **amino acid** in the polypeptide

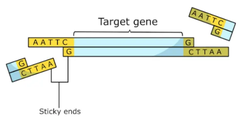
Translation: The process where mRNA is used as a template to synthesise a sequence of amino acids, forming a polypeptide.

- mRNA leaves the **nucleus** and enters the **cytoplasm**
- mRNA attaches to a **ribosome**, the ribosome **moves along** the mRNA, synthesising a **polypeptide**
- The **polypeptide** is released, and folds into a **protein**

3. Genetic Engineering

Genetic Engineering: The technique used to transfer genes from one organism to another.

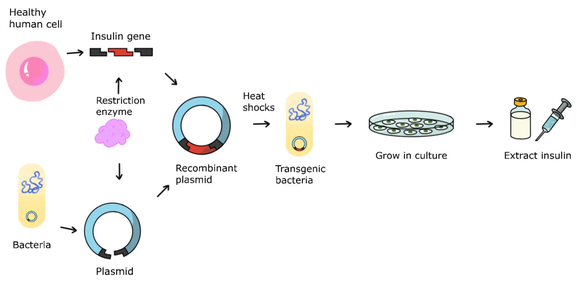
- Transferred gene can be expressed in the recipient organism
- Requires a **vector** (a vehicle that transfers genes)
- A commonly used vector is a **plasmid** (small, extrachromosomal circular DNA found in bacteria)
- **Transgenic organism:** An organism which contains **foreign genes** after gene transfer.



Restriction enzymes

- Naturally found in bacteria as defences against viruses
- Recognise a specific short nucleotide sequence, the **restriction site**
- They cut DNA there, resulting in **sticky ends** (where unpaired nucleotides can complementary base pair with another such strand to form double stranded DNA)

Genetic Engineering of bacteria to produce human insulin



Inserting gene into plasmid

- A **restriction enzyme** is used to cut a section of DNA containing the human **insulin gene**, creating **sticky ends**
- The same **restriction enzyme** is used to cut a **plasmid**, creating **sticky ends**
- **Plasmid** and **insulin gene** are mixed, allowing them to **anneal*** via **complementary base pairing** at the sticky ends
  - **Pro Tip: Writing "bind" is accepted*
- **DNA ligase** is added to **seal** them together, the result is a **recombinant plasmid** which carries the insulin gene

Inserting recombinant plasmid into bacteria

- **Heat/electric shock** treatment is applied to the bacteria that create **pores** in their **membranes** so they can uptake the **recombinant plasmids**
- Those bacteria become **transgenic** bacteria, and will produce insulin as part of their **metabolic processes**

**Pro Tip: Only a small percentage of bacteria will successfully uptake plasmids. They can be isolated by mixing with an antibiotic that the recombinant plasmids make them resistant to.*

💡 ***[Memory Shortcut]***

- Genetic engineering process [**R**eally **T**alkative **PALS**]
  - **R**estriction enzyme
  - **T**arget gene
  - **P**lasmid
  - **A**nneals via complementary base pairing
  - DNA **L**igase
  - **S**hock treatment

4. Implications of Genetic Engineering

- **Biological implications:** Impact on living things due to biological reasons
- **Social implications:** Impact on society/people (just the positive ones are needed in syllabus)
- **Ethical implications:** How genetic engineering could be morally questionable

Advantages of Genetic Engineering	How is it a benefit?
Low-cost production of medicine, such as insulin	Saves lives and is **affordable**
Can be used to treat genetic diseases	Saves lives
Crops that can grow in extreme weather conditions	Increase crop yields, avoiding **food shortages**, especially in light of climate change
Crops that have higher nutritional value, e.g. Golden rice, higher vitamin A	Decreasing **malnutrition**, especially in poorer countries
Crops produce their own **pesticide**	Less **pesticides** need to be sprayed on crops, **environmentally-friendly**.
Crops resistant to **herbicide**, e.g. soybeans	**Herbicides** can be used to efficiently kill **weeds**, increasing **crop yields,** increasing food security

**Pro Tip: Pesticide = kills pests. Insecticide = a type of pesticide, kills insects. Herbicide = kills weeds (unwanted plants that grow amongst crops, stealing nutrients)*

Disadvantages of Genetic Engineering	How is it a disadvantage?
Possibility of use for **biological warfare**	Can be used as **bioweapons** for mass destruction
Some companies *(e.g. Monsanto)* engineer GM crops to have seeds that cannot germinate, so farmers must constantly buy seeds from the companies	Financial **exploitation** of farmers
Some companies can set patents on medicines made using genetic engineering, and make medicines very **expensive**.	Medications too expensive for those who need them and **cannot afford/financial exploitation** as people have no choice but to pay the high prices
Genetic engineering involving animals may result in **unforeseen health impacts** on them.	May cause **suffering** in the animals, **morally** wrong.
Animals may be used to produce human proteins for medicinal purposes.	Morally wrong to use them as biological 'factories'.

16. Reproduction in Plants

Learning Outcomes:

1. Cell Division
2. Sexual vs Asexual Reproduction
3. Bonus: Pros and Cons of Asexual Reproduction
4. Parts of a flower
5. Pollination
6. Fertilisation

Keywords:

- Mitosis, meiosis, daughter cells, homologous chromosomes, gametes/sex cells, diploid, haploid
- Random combinations, reduction division, diploid number, zygote
- Asexual, sexual, fertilisation, fusion, nuclei of gametes
- Genetically identical, genetically different, genetic variation, offspring, favourable traits, colonise, reproductive organs
- Susceptible, wiped out, sudden environmental changes
- Male gamete, self/cross-pollination, bisexual
- Hairy back and legs, brush, odour
- Long and pendulous, large and feathery, colourful, nectar guides
- Small, smooth, light, spiky, rough, hairy back and legs
- Germinate, sugary fluid, pollen tube, micropyle, sap, male sex nucleus, fruit, seed

If you're our student: Reproduction in Plants Crash Course Clips

1. Cell Division

Mitosis: The type of cell division which produces two genetically identical daughter cells which have the same number of chromosomes as the parent cell.

- **Daughter cells** are **genetically identical** to **parent cell**
- Usually occurs in **diploid** cells.
  - **Diploid:** Having two complete sets of chromosomes, one from each parent.
  - In diploid cells, there are two of each chromosome number. Within each of these pairs, each chromosome came from one parent.
    - **Homologous chromosomes:** A pair of chromosomes, one from each parent. They have the same shape, size, length and gene loci, although they may have different alleles.
    - **Pro Tip: "Homologous" = "similar". These two chromosomes in a pair are very similar, like your left and right shoe. However there are slight differences, just like with your shoes.*

Uses:

- **Growth**: For a multicellular organism to grow, new cells are produced by mitosis
- **Repair:** Dead or damaged cells must be replaced by new cells, which are produced by mitosis
- **Asexual reproduction:** Involves the production of new cells by mitosis to form offspring

Meiosis: The type of cell division which produces four genetically different daughter cells in which chromosome number is half that of the parent cell, due to the separation of homologous chromosomes.

- One **diploid parent cell** at the start of Meiosis becomes four **haploid daughter cells** after Meiosis is complete
  - **Haploid:** Having only one complete set of chromosomes.
- **Homologous chromosomes** are separated during meiosis into different daughter cells in **random combinations**, resulting in genetic variation
- As chromosome number is halved after meiosis, meiosis is a **reduction division**
- **Importance of reduction division:**
  - Meiosis is a **reduction division**, as **gametes** produced have half the **number of chromosomes** as the **parent cell.**
  - During **fertilisation**, nuclei of the **haploid gametes** fuse, forming a **diploid zygote**, restoring the **diploid number** in the **zygote**.
  - This ensures that chromosome number stays **constant** and does not double with every successive generation.

Used in: Formation of **sex cells/gametes**

- Hence, meiosis only exists in **sexual** organisms
- **Daughter cells** are **genetically different** from **parent cell,** resulting in **variation** in the **offspring** of sexual reproduction (see section below on the advantages of sexual reproduction)

> 💡 ***[Memory hack]***
>
> - How to not mix up Mitosis and Meiosis
>   - **MI**tosis: **M**ake **I**dentical cells
>   - **ME**iosis: **M**ake **E**ggs or sperm (sex cells)

2. Sexual vs Asexual Reproduction

Asexual reproduction: The process that produces genetically identical offspring from one parent, without the fusion of nuclei of male and female gametes.

- Examples: Binary fission (bacteria), budding (yeasts), reproducing by spores, vegetative propagation*
- **Pro Tip: Vegetative propagation is when a fragment of a parent plant regrows into an entire new plant.*

Sexual reproduction: The process that involves the fusion of nuclei of male and female gametes to form a diploid zygote, producing genetically different offspring.

- Examples: Humans, flowering plants, etc.

3. Bonus: Advantages of asexual and sexual reproduction

Asexual reproduction	Sexual reproduction
Favourable traits will definitely be passed on, as **offspring** are **genetically identical** to parents	As **genetic variation** exists, the species can adapt to **sudden environmental changes** (e.g. disease/climate change) faster. Their **population** is hence are less **susceptible** to being wiped out, increasing their chances of **survival**.
No need to spend **energy** on **reproductive organs**	Offspring can **inherit favourable traits** from both parents*
No need to wait for **fertilisation,** hence reproduction is **faster**, can **colonise** an area quickly	

**Pro Tip: Think of this as getting the 'best of both worlds'.*

4. Parts of a flower

Structure	Function
Sta**men** (Remember it is male part of flower because of **men**)	Consists of the male parts of the flower
Filament	Holds the **anther** in a good position to release **pollen grains**
Anther	Produces **pollen grains**, which in turn each contain a **male gamete**
Carpel	Consists of the female parts of the flower **Pro Tip: Some flowers have multiple Carpels, and all Carpels = the Pistil*
Stigma (Remember, **stick**y)	Receives **pollen grains**
Style	Holds **stigma** in good position to receive **pollen grains**
Ovary	Produces and protects **ovules**, and becomes the **fruit** after **fertilisation**
Ovule	• Becomes a seed after **fertilisation** • Contains an **ovum**, the female gamete
Receptacle	The base of the flower where the other parts of the flower are attached **Pro Tip: It "receives" all the parts of the flower, hence its name.*
Sepal	Protects the flower during the bud stage
Petal	• Can be **colourful** to attract **pollinators** • Can have **nectar guides**

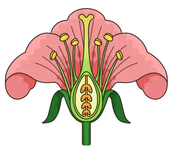
5. Pollination

- **Pollination:** The transfer of pollen grains from an anther to a stigma.

Type	Self-pollination	Cross-pollination
Difference	Occurs within the **same plant**	Occurs between **different plants** of the same species
[Memory shortcut] Features of flowers that favour self/cross pollination [MOP] **M:** Male and female parts **M**ature at same time? **O:** Flowers may not **O**pen **P:** **P**osition (anther higher/lower than stigma)	**M:** Bisexual flowers, both male and female parts mature at same time **O:** Flowers may not Open (ensuring self-pollination) **P:** Position (anther higher than stigma so pollen can fall on stigma)	**M:** Male or female parts mature at different timings/flowers only either have male or female parts **O:** Flowers open **P:** Position (anther lower than stigma)
Parent plants involved	1	2
Genetic variation	Less*, hence more **susceptible** to being **wiped out** by **sudden environmental change**	More, hence less **susceptible** to being **wiped out** by **sudden environmental change**
Chance of occurring	Higher, as **distance** to travel for pollen is short	Lower, as **distance** to travel for pollen is long
Energy expenditure	Lower, no need produce as much pollen	Higher, need to produce a lot more pollen

*Pro Tip: ***Self-pollination is NOT asexual reproduction.*** *It involves fertilisation = it is sexual reproduction, hence there is still genetic variation, just lesser variation than cross-pollination.*

Insect vs wind pollination

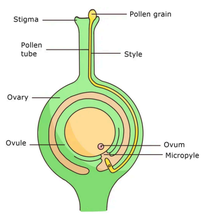
Pollinating Agent*	Insects	Wind
How it works	• Insects visit flowers to obtain **nectar** • **Anthers** brush against insects, pollen grains stick onto their **hairy** bodies/**hairy back and legs** (more suitable for bees) • Pollen grains are transferred from the insect to **stigma** of the same/different flower	• Pollen grains are picked up by wind • They land on the **stigmas** of another flower
Stigma	Small and **sticky**	Large and **feathery**
Odour/scent	Sweet-smelling	Odourless (No smell)
Anthers	Small	Large
Protruding reproductive parts?	Usually no 	Yes 
Filament	Shorter	Long and **pendulous** (hangs loosely)
pollen **G**rains	• Relatively fewer • Larger and rough/spiky 	• Very numerous • Small, light and smooth 
Nectar (and nectar guides)	Present	Absent
Colour (petals)	Bright and colourful petals to attract insects	Petals are dull/absent

💡 ***[Memory shortcut]***

- Features of insect/wind-pollinated flowers [**SOAP GNC**]
  - **S**tigma
  - **O**dour
  - **A**nthers
  - **P**rotruding reproductive parts
- Pollen **G**rains
- **N**ectar (and nectar guides)
- **C**olourful petals

6. Fertilisation

Fertilisation: The fusion of the male and female gametes' nuclei, resulting in a diploid zygote.



Process leading to fertilisation:

- After pollination, stigma produces a **sugary fluid**, stimulating pollen grain to **germinate**.
- A **pollen tube** grows from the pollen grain, secreting **enzymes** to digest a path through **stigma**, **style** and **ovary wall**.
- Pollen tube enters an **ovule** via the **micropyle**.
- The pollen tube **absorbs sap** and bursts, releasing the **male sex nucleus** which fuses with the **ovum,** forming a **diploid zygote**.
  - *Pro Tip: (FYI) The other nuclei helps form the endosperm, which will be the food reserves for the seedling.*

> 💡 ***[Memory shortcut]***
>
> - Fertilisation process in flowers [**STEMA**]
>   - **S**ugary fluid
>   - pollen **T**ube
>   - **E**nzymes secreted
>   - **M**icropyle
>   - **A**bsorbs sap and bursts, releasing male sex nucleus, fertilisation

After fertilisation

- Flower withers
- Ovary turns into a fruit
- Ovules turn into seeds
  - If fertilisation does not occur in an ovule, it degenerates when the ovary turns into a fruit
  - At least 1 ovule must be fertilised for the ovary to turn into a fruit

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17. Reproduction in Humans

Learning Outcomes:

1. Male and female reproductive system
2. Describing the menstrual cycle
3. Fertilisation
4. Foetal development
5. Human Immunodeficiency Virus (HIV)

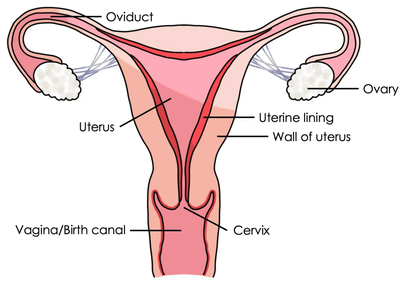
Keywords:

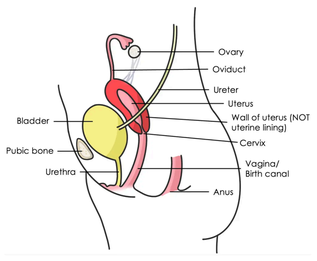
- Erectile, ejaculation, testosterone, sexual intercourse, childbirth
- Gametes, fertilisation, fusion of sex nuclei
- Menstruation, fertile period, oestrogen, progesterone, mature ovum, ovulation, repair, further thickening
- Activate, nourish, semen
- Puberty, pregnancy
- Peristaltic action, sweeping action, zygote, embryo, implantation, embeds, foetus
- Finger-like projections, immunity, antibodies
- Supports, cushions, muscular development, lubricates
- Sexually transmitted infection, human immunodeficiency virus, acquired immune deficiency syndrome
- Abstinence, physical barrier, sterilise, unprotected

If you're our student: Reproduction in Humans Crash Course Clips

1. Male and female reproductive system

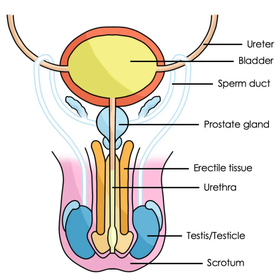
Female reproductive system

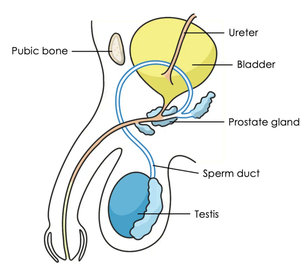




Structure	Function
Vagina (birth canal)	Where sperms are deposited during **sexual intercourse**
Cervix	The opening between the uterus and vagina(allows sperm from vagina to enter uterus, as well as menstrual blood to pass from uterus to vagina)
Uterus (womb)	• The uterine lining sheds during **menstruation** • An **embryo** embeds itself in the uterine lining during **implantation** • **Foetus** develops here during **pregnancy** • During **childbirth**, its elastic muscles contract to push out the **foetus**
Oviduct	• Where a **mature ovum** is released • Site of **fertilisation**
Ovary	• Site of where **eggs** mature • Produces **oestrogen** and **progesterone**

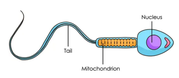
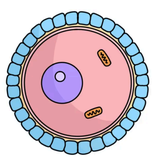
Male reproductive system





Structure	Function
Testis*/testicle (plural: testes/testicles)	Produces **sperm** and **testosterone**
Scrotum	The skin sac containing testes (which need to be outside of the body to be 2°C cooler for sperm production)
Sperm duct	Carries sperm from the testes to the urethra
Prostate gland	Mixes sperm with a fluid, which: • **Nourishes** sperm with **nutrients** • Has **enzymes** which **activate** sperm to swim actively **Semen** = Sperm + Fluid from prostate gland **Note: Semen is alkaline, to neutralise the acidic environment of the vagina to protect sperm.*
Urethra	The duct for urine/semen to exit
Penis	The male **erectile** organ, which deposits **semen** into vagina during **sexual intercourse**

Comparing male and female gametes (sex cells)

Gamete	Male (sperm)	Female (ovum)
Structure*		
Size	Smaller	Larger
Number	~250 million per ejaculation	1 released per ovulation
Motility (ability to move)	Yes, using its flagellum	No, is moved by cilia and peristalsis in the oviduct
Chromosomes	22 + X/Y chromosome	22 + X chromosome

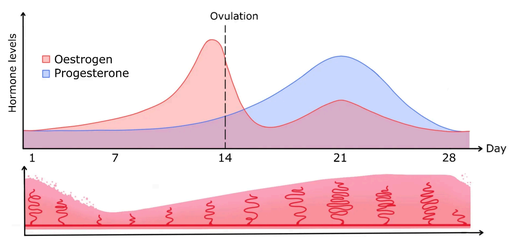
**Pro Tip: Knowing the detailed parts of the sperm and egg are not required.*

Puberty: The stage where a person becomes physically mature and capable of sexual reproduction.

- Secondary sexual characteristics appear due to sex hormones (testosterone in males, oestrogen + progesterone in females):
  - Sexual organs enlarge, and the person begins to produce **gametes**
  - In females, menstrual cycles begin
  - Pubic and armpit hair appears
  - Includes other physical changes, e.g. Voice deepening in men, hips broaden in women.

2. Menstrual cycle

- Typical menstrual cycle = 28 days, but it varies. It could vary more or stop completely if the person is experiencing high stress/poor diet/poor sleep, etc.



**Pro Tip: You must be familiar with the hormone graph*

💡 ***[Memory shortcut]***

- Stages of menstrual cycle [**M**other **O**rders **R**estaurant, **F**ather **P**ays **B**ill]
  - **M**enstruation (Day 1-5)
  - **O**estrogen is the dominant hormone in the 1st half
  - which **R**epairs and thickens uterine lining
  - **F**ertile period (Day 10-15) surrounds ovulation (Day 14)
  - **P**rogesterone is the dominant hormone in the 2nd half
  - which causes growth of more **B**lood vessels within lining

Day	Stage	Events
1-5	Menstruation	The **uterine lining** and **unfertilised egg** are broken down and discharged out of the vagina as **menses** ("period blood")
6-13	Repair + Growth	• **Oestrogen** levels increase • Uterine lining **repairs** and **thickens**
10-15	Fertile period + Ovulation (Day 14)	• Upon **ovulation** on day 14, one **ovary** releases **mature ovum** into the **oviduct** • Ova survive up to 1 day* unless **fertilised**, sperm survive up to 4 days* • **Pro Tip: If you see questions giving different numbers, then adjust the fertile period according to the question* • **Sexual intercourse** during this period (fertile period) has highest chance of **pregnancy**
15-28	Growth + Maintenance	• **Progesterone** levels increase • Uterine lining thickens further and more blood vessels grow within it, preparing for possible **implantation** • Nearing the end of the menstrual cycle, **oestrogen** and **progesterone** levels fall, causing the **uterine lining** to shed, starting the next menstrual cycle

Hormones involved in menstruation

- **Oestrogen**
  - Stimulates **repair** and **thickening** of uterine lining
  - High levels of oestrogen near day 14 result in **ovulation**

- **Progesterone**
  - **Maintains** thickness and stimulates **further thickening** of uterine lining
  - Stimulates **growth of more blood vessels** in uterine lining
  - High levels of progesterone inhibit another **ovulation** during second half of the menstrual cycle* (as well as during pregnancy)

3. Fertilisation

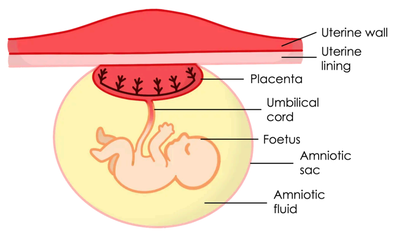
Fertilisation: The fusion of nuclei of a sperm and ovum, forming a diploid zygote.

- Occurs in the oviduct/fallopian tube

Implantation: The process whereby the embryo embeds itself in the uterine lining.

- **Zygote** travels toward uterus via **peristaltic action** of the **oviduct** walls and **sweeping action** of **cilia**
- The zygote undergoes **mitosis**, forming an **embryo** (a ball of cells)
- Embryo reaches uterus 5 days after fertilisation, floats around for 2 days. On Day 7, **embeds** itself into uterine lining during **implantation**.
- The placenta, amniotic sac and foetus then develops.

4. Foetal development



Placenta

- After implantation, **finger-like projections** called **villi**, containing **blood vessels** from the **embryo**, grow into the uterine lining, forming the **placenta**.
- Placenta secretes **progesterone** to maintain thickness of the uterine lining, supporting pregnancy.
- **Oxygen** and **nutrients** such as glucose, amino acids **diffuse** from maternal to foetal capillaries
- **Metabolic waste products** such as urea and carbon dioxide **diffuse** from foetal to maternal capillaries
- Some **antibodies** diffuse from maternal to foetal capillaries, giving the foetus **immunity** against some diseases
- Maternal and foetal blood do not mix, because:
  - Mother's blood pressure > foetus, would kill foetus
  - Mother and foetus may have incompatible **blood types**

Amniotic sac

- Contains amniotic fluid and the foetus
- Amniotic fluid
  - **Supports** and **cushions** foetus by absorbing shock
  - Allows some movement, promoting **muscular development**
  - **Lubricates** birth canal during childbirth
  - maintains a steady **temperature** around foetus

**Pro Tip: When a pregnant woman's 'water bag' bursts nearing labour, it means the amniotic sac broke, and childbirth is beginning soon.*

💡 ***[Memory Shortcut]***

- **SALT** for functions of amniotic fluid
  - **S**hock absorption
  - **A**llows some movement for muscular development
  - **L**ubricates birth canal during childbirth
  - maintains a steady **T**emperature around foetus

Umbilical cord

- Carries nutrients and oxygen from **placenta** to **foetus**
- Carries **metabolic waste products** from foetus to placenta
- Umbilical cord has 2 arteries *(from foetus to placenta) and 1 vein (toward foetus)

**Pro Tip: Umbilical arteries carry deoxygenated blood, because artery carries blood away from foetus' heart, to placenta*

5. Human Immunodeficiency Virus (HIV)

- HIV is a sexually transmitted infection (STI)
- HIV attacks a certain type of white blood cells, decreasing their number
- The resulting condition = **Acquired Immune Deficiency Syndrome** (AIDS) as the immune system is weakened, and body is susceptible to common infections that would otherwise not be as severe.

Modes of HIV transmission:

- Unprotected sexual intercourse with infected individual
- Sharing of contaminated hypodermic needles
- **Blood transfusions** where the donor's blood has the virus

  **Pro Tip: This is why in professional/public health services, donated blood is always screened.*
- Passed from mother to foetus during **pregnancy**

STIs can be prevented by:

- Abstinence (no sexual intercourse)
- Have only 1 sexual partner
- Using condoms (physical barrier prevents transmission)
- Not sharing hypodermic needles/sterilising hypodermic needles whenever used
- Do not share instruments that are likely to break the skin and be contaminated with blood (e.g. razors, toothbrushes)

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18. Inheritance

Learning Outcomes:

1. Inheritance terms and concepts
2. Monohybrid cross
3. Bonus: All monohybrid cross combinations
4. Sex determination
5. Mutation
6. Discontinuous vs continuous variation
7. Natural Selection

Keywords:

- Gene, allele, gene locus, dominant, recessive, genotype, phenotype
- Homozygous, heterozygous, co-dominance, incomplete dominance, multiple alleles
- Monohybrid, expected/observed offspring ratio, chance, discrepancy, sample size
- Mutation, mutagens, ionising radiation, single-base substitution, sickle-cell anaemia, spleen, malaria, down syndrome, chromosomal mutation
- Continuous/discontinuous variation, additive effect, multiple genes, intermediates, range of phenotypes, few and distinct
- Natural selection, random fertilisation, selection pressure, favourable alleles, selective advantage, survive and reproduce, evolution, antibiotic resistance

If you're our student: Inheritance Crash Course Clips

1. Inheritance terms and concepts

Gene: A unit of inheritance that determines a specific trait in an organism. It is a sequence of DNA nucleotides that codes for specific polypeptide, and has a particular gene locus.

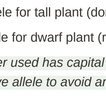
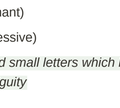
- **Gene locus:** The location of a gene along a chromosome

Genotype: The combination of alleles an individual has for a trait

Phenotype: The trait that is expressed as a result of genotype

Allele: One of the alternative forms of a gene, that occupies the same gene locus on a pair of homologous chromosomes.

- **Homozygous:** Having two identical alleles of a particular gene
- **Heterozygous:** Having two different alleles of a particular gene
  - **Pro Tip: AA = homozygous dominant. aa = homozygous recessive. Aa = heterozygous, there is no such thing as heterozygous dominant/heterozygous recessive.*
- **Dominant allele:** Always expressed regardless whether the individual is homozygous or heterozygous for the trait
  - The dominant allele **masks the effect** of the recessive allele in heterozygous individuals.
- **Recessive allele:** Only expressed if the individual is homozygous recessive for the trait

Genotype	I^RI^R	I^WI^W	I^RI^W **Codominance**	I^RI^W ***[FYI]: Incomplete dominance****
Phenotype				

Codominance: When two different alleles for a particular trait are both expressed in a heterozygote, and the resulting phenotype is an intermediate between the two alleles.

- Let allele for red flower be IR
- Let allele for white flower be IW
- In a **heterozygous** individual (I^R I^W), if the phenotype turns out to be flowers with both red and white petals, these alleles are **codominant**.

***[FYI]** Incomplete dominance:* When phenotype is 'halfway' between both alleles.

- In a **heterozygous** individual (I^R I^W), if the phenotype turns out to be pink flowers, these alleles show **incomplete dominance**.

Multiple alleles: When three or more alleles exist for a gene.

- e.g. for blood type there are the alleles: IA IB IO
- IA IB are co-dominant
- IO is recessive to IA and IB

**Pro Tip: For co-dominance, incomplete dominance, multiple alleles and sex-linked inheritance, we represent alleles with superscripts, such as IR, IW.*

2. Monohybrid cross

- Monohybrid cross involves 1 trait, with 2 alleles
- Genetic crosses can predict expected offspring ratios

Discrepancy between observed and expected ratios

- As **fertilisation** is a **random** process, the **genotype** of each offspring is based on **chance**
- The smaller the **sample size** of offspring, the greater the **discrepancy** would be

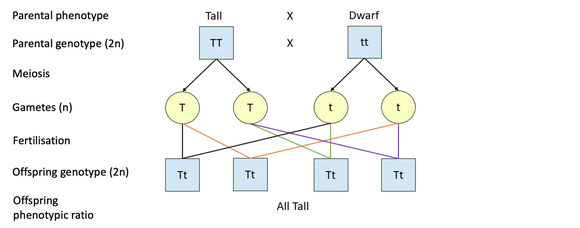
Cross #1: 2 homozygous parents (pure-bred) with different alleles

- **Pro Tip: Pure-bred means offspring are homozygous for certain traits*

Let T represent allele for tall plant (dominant)

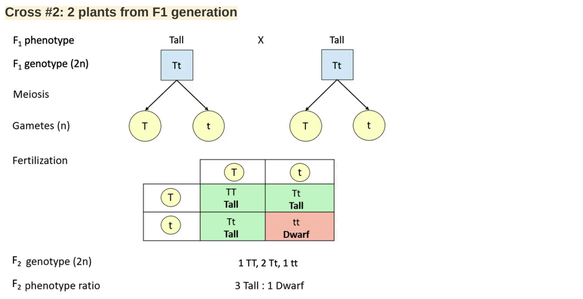
Let t represent allele for dwarf plant (recessive)

- **Pro Tip: If letter used has capital and small letters which look very similar, (e.g. c and C), use c' for the recessive allele to avoid ambiguity*



**Pro Tip: F1 and F2 are used when there is an initial cross, followed by a second cross between the offspring from the first cross. Otherwise, then in the last rows, replace F1 with 'offspring'.*

Cross #2: 2 plants from F1 generation



> 💡 ***[Memory shortcut]***
>
> - Full genetic diagram steps [**L**ockdown **P**eriod, **G**rab **F**ood **O**nly]
>   - **L**et... (define your alleles, unless question already did)
>   - **P**arents phenotype and genotype
>   - **G**ametes are formed from parents
>   - **F**ertilisation
>   - **O**ffspring genotype and phenotypic ratio

Test Cross

- Used to determine the **genotype** of an individual, as **heterozygous** and **homozygous dominant** individuals appear the same
- The individual is crossed with a **homozygous recessive** individual, eg **??** X **tt**
  - If individual is **homozygous dominant**, offspring would all express the dominant phenotype
  - If individual is **heterozygous**, offspring ratio would be 1:1
  - If individual is **homozygous recessive**, offspring would all express the recessive phenotype

3. Bonus: All monohybrid cross combinations (O levels)

- *Let A be the allele for Tall plant*
- *Let a be the allele for dwarf plant*

Parents Crossed	Offspring Genotypes	Offspring Phenotypic Ratio
AA x AA	All AA	All Tall
aa x aa	All aa	All Dwarf
AA x aa	All Aa	All Tall
Aa x Aa	1 AA, 2 Aa, 1 aa	3 Tall : 1 Dwarf
Aa x aa	2 Aa, 2 aa	1 Tall: 1 Dwarf
Aa x AA	2 Aa, 2 AA	All Tall

4. Sex determination

Sex determination

- Sex chromosomes are either X or Y
  - XX is female
  - XY is male*
- Each chromosome comes from each parent
  - The mother's ovum definitely contains an X chromosome, as the mother's diploid cells have XX
  - The father's sperm can contain either an X or Y chromosomes, as the father's diploid cells have XY
  - Therefore sex of the zygote formed depends on the sperm, and there is a 50% chance of the zygote being a boy or a girl.

5. Mutations

Mutation: A sudden change in the structure of a gene or chromosome number

- Mutations that occur in an individual can be passed down to **offspring**

Mutagen: An environmental agent that increases mutation rate

- **Ionising radiation:** e.g. ultraviolet **radiation**, nuclear **radiation**, gamma rays
- Certain toxic **chemicals:** e.g. **tar** in cigarette smoke
- **Pro Tip: Mutagens simply cause more mutations in DNA. **Carcinogens** are a group of mutagens which cause mutations that increase chances of cancer.*

Sickle-cell anaemia

- Due to a **single-base substitution** in the **haemoglobin gene,** the **codon** is changed
  - A different **nucleotide** will be coded for in **mRNA** after **transcription**
  - A different **amino acid** is coded for after **translation**
  - Instead of normal **haemoglobin**, results in abnormal **haemoglobin**
- **Homozygous recessive** individuals:
  - At **low oxygen concentrations**, abnormal haemoglobin **clumps** together, causing the cell to become **sickle-shaped**
  - Sickle-shaped RBCs can get stuck in narrow **blood vessels**, obstructing bloodflow to tissues.
  - Results in **anaemia** (body cells get insufficient **oxygen**) because:
    - Sickled RBCs are more **fragile**, break easily
    - Cannot carry O2 as efficiently as normal RBCs
    - Are actively destroyed by the **spleen**, leading to low RBC count
- Benefit to **heterozygous** individuals
  - Do not suffer the disease
  - Are more resistant to **malaria***
  - **Pro Tip: Not in syllabus - when the malaria parasite infects their RBCs to reproduce, it causes the RBC to sickle, killing both the RBC and malaria.*
  - Hence they **survive** and **reproduce** better (passing on the sickle-cell allele)
  - Thus the **allele** is most abundant in malaria-stricken regions (e.g. sub-Saharan Africa)

Down Syndrome

- During formation of sperm/egg, a **chromosomal mutation** results in the **gamete** having two copies of chromosome 21
  - This can happen in either the mother or father, although most of the time in the mother*.
  - **Pro Tip: The older the mother, the higher the chance of this happening.*
- **Fertilisation** with a normal **gamete** will result in **zygote** having three copies of chromosome 21 (trisomy 21), causing Down Syndrome.
  - The person has total 47 chromosomes instead of 46

6. Discontinuous vs continuous variation

Variation: The differences in traits between individuals of the same species.

Type of variation	Discontinuous	Continuous
Phenotypes	**Few** and **distinct** phenotypes	A **range** of phenotypes, with many intermediate forms
Number of genes involved	1 or few	**Multiple genes**, which have an **additive effect**
Environment	No effect on phenotype	Affects phenotype
Examples	Sex, blood type, ability to roll tongue, lobed or attached ears, **eye colour**	Skin/hair colour, height, weight

7. Natural Selection

Natural selection: The process whereby organisms better adapted to their environment tend to survive and pass on their favourable genes to their offspring.

- **V**ariation exists between individuals
  - Due to: **Mutation**, **meiosis**, **random fertilisation** (as each parent produces **genetically different** gametes, fertilisation of a random sperm and a random egg increases the number of possible **zygote** variants)
- Organisms face **selection pressures**
  - eg. competition for limited resources, predators, disease outbreaks
- Individuals with favourable traits have a **selective A**dvantage
- And are more likely to **S**urvive and reproduce
- Hence passing on their **favourable alleles** to their **offspring**
- Over **T**ime, more and more of the population have the favourable trait
  - [OR, if question says **evolution** occurred, replace the above statement with this]: Accumulation of new genes by **mutation** and **natural selection** resulted in the evolution of the **species**.
  - **Pro Tip: Natural selection is needed for evolution to occur, but natural selection can occur without evolution.*

💡 ***[Memory shortcut]***

- Explaining natural selection process [**VAST**]
  - **V**ariation exists between individuals
  - selective **A**dvantage
  - **S**urvive and reproduce, passing favourable alleles to offspring
  - over **T**ime, more and more of the population has the favourable trait

Examples

- Dark peppered moths in England, 1900: due to industrial revolution, soot coated trees, giving dark moths a **selective advantage** (camouflage) over white moths.
- **Antibiotic-resistant bacteria:** Those with resistance survive and reproduce, resulting in a strain of antibiotic-resistant **strain**
- Darwin's finches of the Galapagos islands: Have different beak shapes due to the type of diet they are suited for, e.g. nuts, insects, fruit, etc.

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