End Of Year Exam Notes: Biology

Topic 3: Cellular Respiration

Definition and Details

- Cellular respiration is the oxidation of glucose, fats, and proteins (primarily glucose – fats and proteins are alternatives), with the purpose of releasing energy.
- Respiration is either aerobic (in the presence of oxygen) or anaerobic (in the absence of oxygen; in yeast or muscles).
- Cellular respiration occurs in all living cells.
- Energy released from cellular respiration is stored in the form of ATP (adenosine triphosphate).

Uses of Energy released from Cellular Respiration

- Synthesis of new living matter.
  - This requires the formation of new chemical bonds, and the formation of new chemical bonds requires energy.
  - For growth and repair
  - Example: Mitosis
- Transport
  - Transport of material by active transport or movement of materials across cell membranes
- Movement
  - Contraction of muscles
- Electrochemical Activity
  - The generation of nerve impulses
- Heat production
  - To maintain a constant body temperature in warm-blooded animals

Aerobic Respiration

- Overall equation: Glucose ($C_6H_{12}O_6$) + Oxygen ($6O_2$) → Carbon Dioxide ($6CO_2$) + Water ($6H_2O$) + Lots of Energy
- Food substances (such as glucose, fats or proteins) are broken down in the presence of oxygen, and this releases lots of energy.
- The released energy is stored in the form of ATP.
  - ADP (adenosine diphosphate) and a free phosphate group is converted to ATP in the presence of energy from breaking down of food substances (primarily glucose).
  - ATP takes part in many metabolic reactions, and delivers energy in small amounts to drive these individual reactions.
  - ATP is involved in both exergonic (energy releasing) and endergonic (energy absorbing) reactions.
  - The bond with the last phosphate group contains large amounts of energy.
- Energy produced from respiration is used to phosphorylate ADP to ATP.

  - The energy is stored in the bond (of the third phosphate group) until required.
  - The energy required for work is obtained by hydrolysing the ATP to ADP and inorganic phosphate.
- When energy is required, the ATP undergoes hydrolysis, and this produces ADP and an inorganic phosphate.
- ADP-ATP cycle: $ADP+P_i \leftrightarrow ATP$
  - Note: The "i" in P_i stands for *inorganic*.
  - If the chemical bonds in ATP are broken to convert it to ADP and a phosphate group, **energy is released**. This is why ATP acts as a universal currency for energy.
  - For ATP to form from ADP and a phosphate group, **energy is needed**. This is what happens in aerobic respiration.
  - Energy from catabolic (processes that release energy) phosphorylates ADP and an inorganic phosphate to ATP.
  - ATP and water (H_2O) release large amounts of energy for anabolic activities by means of hydrolysis, to produce ADP and an inorganic phosphate.
- 1 glucose molecule produces 38 ATP molecules worth of energy.
- Aerobic respiration takes place in the mitochondria of cells.
- 3 stages of aerobic respiration:
  - Glycolysis in cell cytosol
  - Krebs cycle
  - Electron transport chain and oxidative phosphorylation

<u>Anaerobic Respiration</u>

- Breakdown of food substances (primarily glucose) in the absence of oxygen
  - Breakdown of glucose remains incomplete because only glycolysis in the cell cytosol occurs.
  - Bulk of the unreleased energy remains in the ethanol/lactic acid
- Still releases energy, but small amounts only (2ATP).
- Overall equation of anaerobic respiration in YEAST: Glucose($C_6H_{12}O_6$) → Carbon Dioxide ($6CO_2$) + ethanol ($2C_2H_5OH$) + small amounts of energy
  - Yeast cells can respire both aerobically and anaerobically (known as fermentation).
- Overall equation of anaerobic respiration in MUSCLES: Glucose($C_6H_{12}O_6$) → lactic acid ($2CH_3CHOHCOOH$) + small amounts of energy
  - During rigorous muscular activity, insufficient oxygen is delivered to the muscles; anaerobic respiration occurs too.
  - Lactic acid builds up, resulting in fatigue
  - Note: Aerobic respiration does not stop, it continues to happen together with anaerobic respiration.
  - Only the first stage of respiration occurs (glycolysis in the cell cytosol) and thus only 2 ATP are produced per glucose molecule.
  - After a period of rest, lactic acid is transported to the liver, and some is oxidised to produce energy (oxygen debt cleared), and energy is used to convert remaining lactic acid to glucose which is then transported to the muscles for usage and storage.
  - Oxygen debt:

        - Oxygen is required to oxidize the lactic acid produced in muscles during anaerobic respiration
        - Oxygen debt occurs during the period of rest immediately after vigorous exercise (heavy, rapid breathing)
- Waste products of anaerobic respiration (lactic acid and ethanol) are harmful to organisms if they accumulate.
    - Lactic acid can be converted back to sugar to use as glucose for respiration
    - Yeast cannot metabolise ethanol

Respiration VS Photosynthesis

Respiration	Photosynthesis
- Energy is released - Oxygen is used, carbon dioxide and water are released - Catabolic process – glucose is broken down - Occurs all the time - Results in loss of dry mass	- Energy is stored in carbohydrate molecules. - Carbon dioxide and water are used, oxygen is given off - Anabolic process – glucose is formed - Occurs only in cells with chlorophyll, and in the presence of sunlight - Results in the gain of dry mass

Note

- Exergonic reaction is one that releases energy, while an endergonic reaction is one that absorbs energy.
- Catabolic processes are ones that break down complex molecular structures into simple ones, and anabolic processes are ones that are responsible for synthesis of living matter (building of complex molecular structures from simple ones).
- Catabolic processes release energy and are thus exergonic in nature.
- Anabolic processes absorb (or require) energy and are thus endergonic in nature.

Topic 4: External Respiration

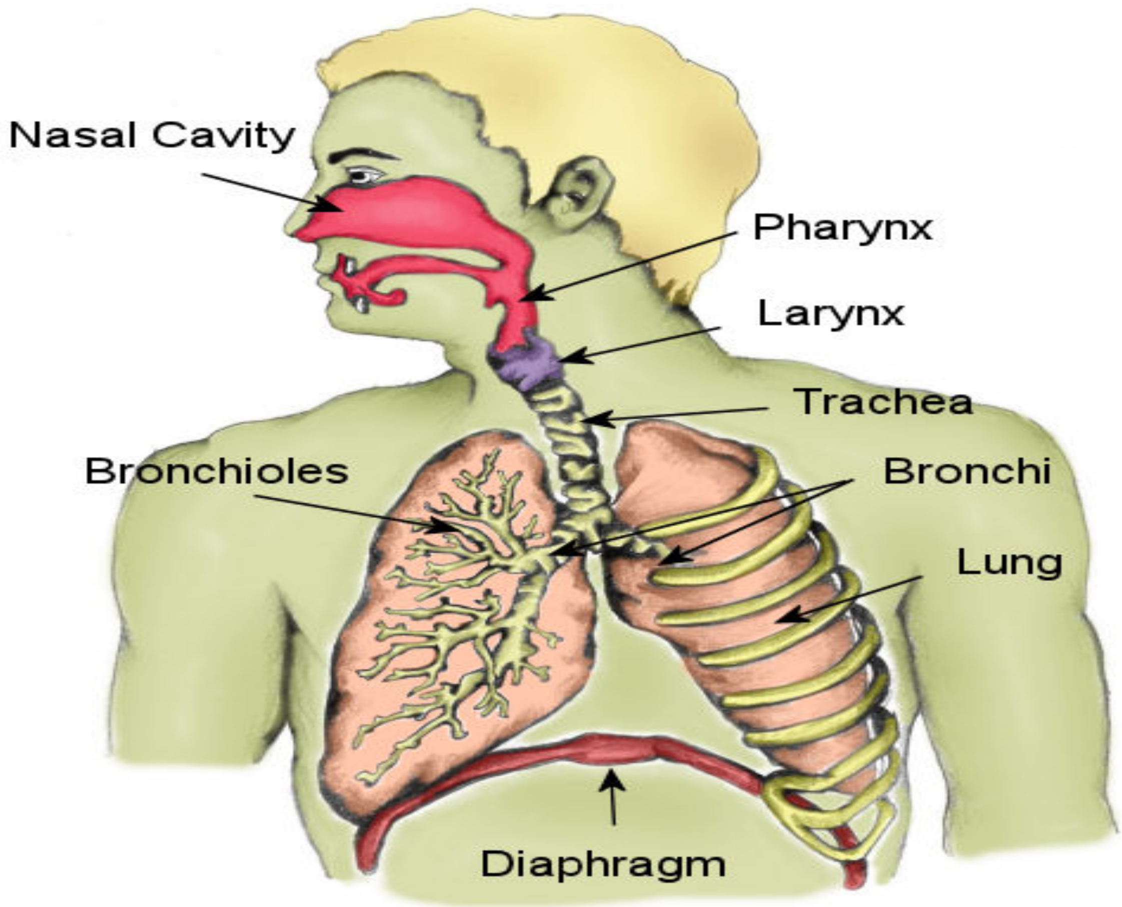
Definitions

- Gas exchange: The movement of carbon dioxide out of a living body, and the movement of oxygen into it, which occurs over a pressure gradient. The aim of gas exchange is to support the production of ATP during cellular respiration.
- Respiratory medium: The source of O_2 (air for terrestrial animals, and water for fish)
- Respiratory surface: The surface of the body which acts as the site of gas exchange with the surrounding environment (alveoli in humans, gill filaments in fish)
- Inspiration: Process in which air is taken into the body
- Expiration: Process in which air is given out from the body
- Breathing: Rhythmic inspirations and expirations (about 10-14 times a minute in humans)

External Respiration in Humans

Note: Must know how to label the respiratory system in humans. Refer to slides.

Organs in the human respiratory system:



- Note: The epiglottis is the dangling bob that prevents from food going into the trachea (windpipe), the pharynx is the throat (a passageway), the larynx is the voice box

- To get to the lungs, air travels through (nasal passage→ pharynx → larynx → trachea →bronchi →bronchioles →lung (alveoli)
- The pleura is a membrane that covers major organs such as the lungs and the heart to lubricate them and minimise friction between lungs, ribcage, and heart

Entry of Air:

- Air enters through the nose or mouth. However, breathing through the nose is more advantageous:
    - Dust and foreign particles get trapped by hair in nostrils and mucus on mucous membrane
    - The air is warmed and moistened before it enters the lungs (especially beneficial in cold or dry countries)
        - If this did not happen, dry air in the atmosphere would evaporate the layer of moisture on the alveolus (thus preventing it from absorbing dissolved oxygen).

        - The warmed air also prevents the lungs from getting a temperature shock in cold regions.
    - Harmful chemicals are detected by the chemical receptors in the mucous membrane.
- Air then passes through the nasal passage (which is lined with moist mucous membrane), and then it passes into the pharynx. At this point, it passes to the trachea through an opening known as the glottis (which leads to the larynx). From there, air goes down the trachea.
- The trachea and bronchi have C shaped cartilage rings:
    - Cartilage rings are strong and light, and provide structural support to the trachea and the bronchi, and keep them upright and prevent them from collapsing.
    - The C shaped ring is not complete, and has a stretchable membrane (to allow the trachea and bronchi to expand when necessary).
- The trachea splits up into two bronchi (left and right bronchus):
    - The left bronchus has two bronchial tubes (smaller, to make space for the heart)
    - The right bronchus has three bronchial tubes.
- The bronchi and trachea is lined by ciliated (cilia containing) epithelium which contain gland cells. These cells have cilia (hair-like structures), and they produce mucus. Thus, the epithelial lining is coated with mucus.
    - Dust and foreign particles are trapped in the mucus that is secreted by the gland cells, and this mucus (containing the dust and foreign particles) is swept up the bronchi and trachea by the cilia. This then enters the pharynx and is swallowed by the oesophagus. The highly acidic environment of the stomach can digest these substances.
- Within the lungs, the bronchial tubes repeatedly divide into smaller tubes. The smallest tubes are called bronchioles. Each bronchiole ends in a cluster of alveoli.
- The walls of the alveoli is the site of gaseous exchange through diffusion:
    - Surface Area: Alveoli are found in large numbers and are spherical in shape to maximise surface area of the respiratory surface (maximise oxygen intake and release of carbon dioxide).
    - Thin: Alveolar walls are extremely thin (1 cell thick), and the capillary wall at the lungs is one cell thick too. Thin walls allows the fastest gas exchange through diffusion (as diffusion is heavily dependent on distance as a factor for its rate).
    - Layer of moisture: The alveoli has a layer of moisture to allow gaseous oxygen to dissolve into it for diffusion through the alveolar wall. (Oxygen as a gas is not absorbed).

Associated Structures:

- Ribs:
    - The chest wall is supported by the ribs
    - The front of the ribs (10 out of 12 pairs of ribs) are attached to the sternum (chest bone) while all the back of the ribs are attached to the vertebral column.
- Intercostal muscles:
    - External intercostal muscles – Intercostal muscles on the outside of the ribcage.
    - Internal intercostal muscles – Intercostal muscles on the inside of the ribcage.

    - When one set of intercostal muscles contracts, the other set relaxes.
    - When the muscles alternatively relax and contract, they change the volume of thoratic cavity:
        - Inspiration: The external intercostal muscles contract and the internal intercostal muscles relax to make the ribcage move upwards and outwards. This increases the volume of the thoratic (chest) cavity.
        - Experiation: The reverse occurs, to make the ribcage move downwards and inwards, and this decreases the volume of the thoratic (chest) cavity.
- Diaphragm
    - The thorax and the abdomen are separated by the diaphragm, making the thorax an isolate chamber
    - The diaphragm is curved like an upside-down U. Therefore, when the diaphragm muscles contract, the diaphragm flattens downwards, and when they relax, the diaphragm arches upwards.
    - This increases/decreases the volume of the thoratic cavity.

* The thoratic cavity is an isolated chamber (enclosed by the diaphragm), and with the mouth and nose as the only openings. Thus, a pressure gradient can be created by increasing/decreasing the volume of the thoratic cavity, which is achieved by both the diaphragm muscles, and the intercostal muscles working together. (Chest expands and diaphragm contracts during inspiration, chest contracts and diaphragm relaxes during expiration). This is known as negative pressure breathing.

Inspiration:

- Volume of thoratic cavity increases:
    - Diaphragm contracts and flattens
    - Intercostal muscles make the ribcage move upwards and outwards
        - Internal muscles relax
        - External muscles contract
- The pressure of air in the lungs would be lower than atmospheric pressure
- Air rushes into the lungs

Expiration:

- Volume of thoratic cavity decreases:
    - Thoratic cavity contracts because:
    - Intercostal muscles make the ribcage move inwards and downwards:
        - Internal muscles contract
        - External muscles relax
    - Diaphragm relaxes and arches upwards
- Air pressure in thorax would be higher than atmospheric pressure
- Air rushes out of lungs

Gaseous exchange:

- Note: The pulmonary artery brings deoxygenated blood while the pulmonary vein carries oxygenated blood.

- Air entering lungs has high concentrations of oxygen and low concentrations of carbon dioxide, and air exiting the lungs has high concentrations of carbon dioxide and low concentrations of oxygen.
- Deoxygenated blood in the pulmonary artery from the heart contains high concentrations of carbon dioxide and low concentrations of oxygen.
- Thus, a diffusion gradient is present for both oxygen and carbon dioxide between the blood and the air in the lungs.
- This diffusion gradient is maintained by:
    - Continuous flow of blood through blood capillaries
    - Continuous flow of air through alveoli
- Membrane separating blood capillaries from alveolar air (alveolar wall, essentially) is permeable to both gases
- During the short pause between inspiration and expiration:
    - Oxygen dissolves in the moisture lining the alveolar walls
    - Dissolved oxygen diffuses into the blood, and combines with haemoglobin to form oxyhaemoglobin (main role: to transport oxygen)
        - Note: The loading and unloading of oxygen onto haemoglobin is reversible, to release oxygen for use
        - Equation: $Hb + 4O_2 \leftrightarrow HbO_8$
    - Carbon dioxide diffuses into the alveolar air space
- The flow of blood is similar to a conveyor belt system: Blood from the pulmonary artery enters the capillary lining the alveolus, and passes through the capillary (and at this point gaseous exchange occurs) and then exits into the pulmonary vein.

Carbon Dioxide in Blood:

- Carbon dioxide is transported in blood in three forms:
    - Dissolved carbon dioxide in the plasma (very little)
    - Bound to the amino groups of haemoglobin (very little)
    - As bicarbonate ions in the plasma (majority)
        - This is how carbon dioxide travels through the blood
        - However, when carbon dioxide concentration is low (such as in the alveolus), carbonic anhydrase (an enzyme, CA) catalyses a reaction in which hydrogen carbonates are converted to carbon dioxide and water.
        - Equation: $H_2O + CO_2 \leftrightarrow H_2CO_3$
        - This is how carbon dioxide is released in the alveolus.

Inspired VS Expired Air:

Inspired Air	Expired Air
21% Oxygen	16% Oxygen
0.03% carbon dioxide	4% carbon dioxide
78% nitrogen	78% nitrogen
Water vapour concentration is variable	Water vapour is saturated
Temperature is variable (based on atmospheric temperatures)	Temperature is about $37^{o}C$
Dust particles might be present	Little or no dust particles

Automatic Control of Breathing:

- Breathing rate is controlled by the medulla in the brain, by means of detecting the pH value of the blood. This is because carbon dioxide is slightly acidic, and an increased concentration of carbon dioxide in the blood would change the pH value of the blood. (Thus, lower pH value → Faster breathing rate)

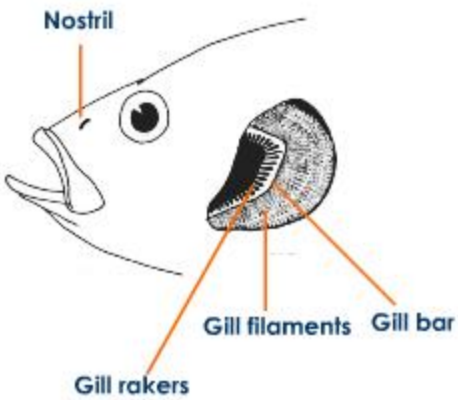
Smoking and associated health risks:

- Carbon monoxide poisoning:
  - Carbon monoxide binds to haemoglobin to form carbaminohaemoglobin. However, unlike the bond which makes oxyhaemoglobin, carbaminohaemoglobin is irreversible.
  - This reduces the oxygen transport capabilities
  - Risk of fetal underdevelopment and deformity caused by smoking when pregnant.
- Chronic bronchitis:
  - The epithelium of the bronchi and the trachea get inflamed by toxins in tobacco smoke
  - As a result, the hyper production of mucus by gland cells occurs, and this mucus accumulates and obstructs the bronchial pathway
  - The cilia would be overwhelmed by the large amounts of mucus and thus paralyzed, and they would not be able to get rid of the mucus.
  - Airway becomes blocked and breathing gets difficult, and persisting coughing occurs.
- Emphysema
  - Toxins in tobacco smoke cause the partition of walls between alveoli to disintegrate, thus greatly reducing surface area
  - Lungs also lose elasticity
  - Thus, gaseous exchange would be much slower
  - This results in breathlessness and wheezing. Emphysema is irreparable.
- Lung cancer
  - Cigarettes contain many carcinogens like tar and lead which may cause lung cancer

*Respiratory system of humans is similar to the respiratory system of amphibians (just that they have an additional respiratory surface – skin).

*Respiratory system of reptiles is similar to the respiratory system of humans. However, reptiles have a right systematic aorta from the heart which then again pumps the deoxygenated blood throughout the body to maintain body temperature (since reptiles are cold blooded) – not only because the deoxygenated blood is warm, but also because it contains oxygen that has not been used up (thus maximising aerobic respiration and producing even more heat).

External Respiration in Fish



Fish Gill Structure and Function:

- Operculum: The operculum opens and closes to assist in creating the required pressure gradients for inspiration and expiration. It also protects the gill filaments (and is commonly known as the gill cover).
- Gill arch: The gill arch is a structure that holds up the gill filaments, and has two arteries running through it. The filament blood capillary network branches out from the arteries in the gill arch.
    - Afferent & Efferent Vessel: The vessel that is going to the lamella, containing deoxygenated blood. This then makes a u-turn, and a later part of this vessel is known as the efferent vessel, which would contain oxygenated blood.
- Gill rakers: Comb like structures that are strategically positioned to filter large objects from the water and prevent them from causing damage to the gill filament (which are extremely delicate, 1 cell thick)
- Gill filaments: Site of gaseous exchange in fish
- Lamella: Similar to the microvilli on villi, lamella are small structures found on gill filaments which increase surface area of the filament to make gas exchange more efficient. The walls of the lamella are also 1 cell thick.

Unidirectional movement of water:

- The mouth of the fish opens and the mouth floor is lowered (while the gills are closed). This produces low pressure within the mouth of the fish, and thus when the mouth is opened, water rushes into the mouth. This then passes out of the gills. This process is then repeated to make intake more water through the mouth and release through the gills.

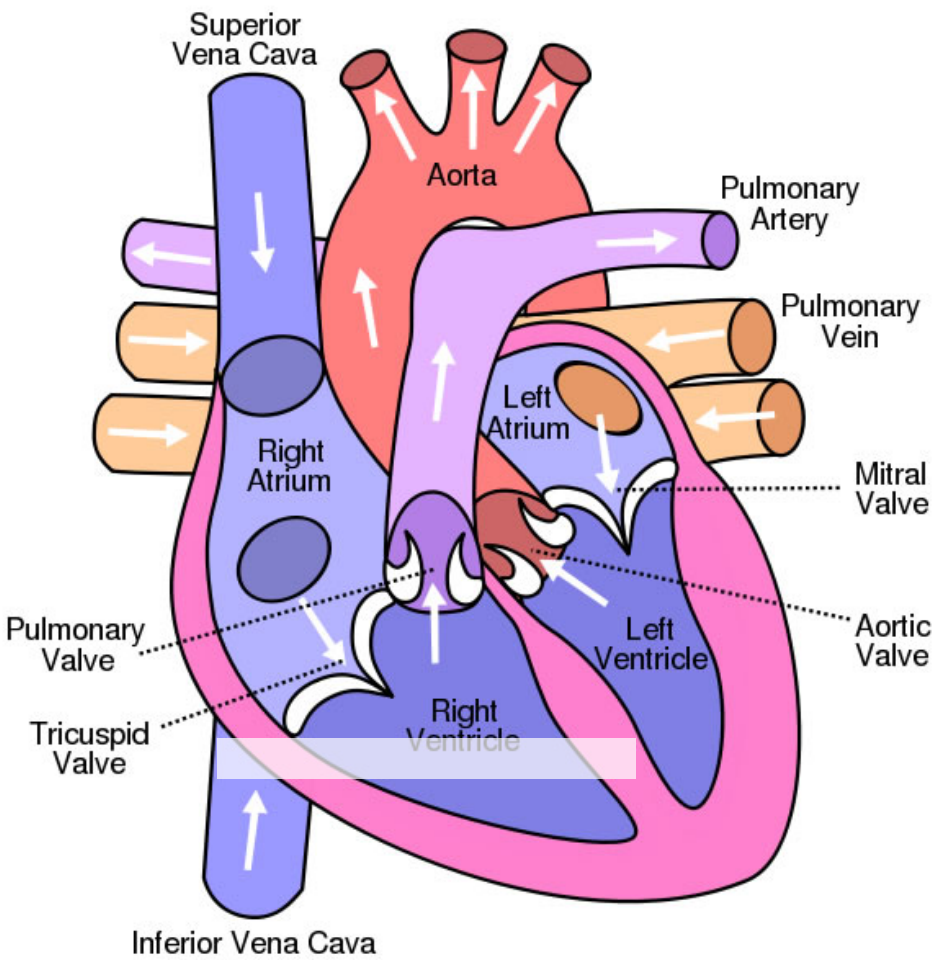
Countercurrent Exchange:

- The direction of water flow is in a direction opposite to the direction of blood flow. This is because countercurrent exchange ensures that equilibrium is not reached, such that the diffusion gradient is constantly maintained over a longer time (which resultsi n more efficient and more gaseous exchange).

Factors affecting diffusion (and rate of gaseous exchange):

- Surface Area:
    - The fish has huge numbers of gill filaments, and huge numbers of lamella on these filaments. This maximises surface area to allow for maximum fas exchange.
- Distance of diffusion:
    - The distance of diffusion is also one cell per wall in fish (very thin to allow for the fastest diffusion).
- Concentration gradient:
    - Constant blood flow to the gill filaments ensures that oxygenated blood is quickly moved away from the gill filaments to preserve the concentration gradient.
    - Constant replenishment of water to the gill filaments ensures that deoxygenated water is quickly sent away and replaced by oxygenated water to preserve the concentration gradient.
    - Countercurrent exchange ensures that equilibrium cannot be attained, and preserves a continuous concentration gradient.

Topic 5: Transport in Man



The Human Heart

Pulmonary: Between the heart and the lungs

Coronary: Arteries and veins that carry substances to and from the *heart muscles*.

Vena Cava: From the body, to the heart (de-oxygenated)

Aorta: From the heart, to the body (oxygenated)

Atrio-Ventricular Valve: Between the atria and ventricles:

- Tricuspid – right AV valve
- Bicuspid (aka Mitral) – left AV valve

Semilunar Valve (found in blood vessels away from heart):

- Aortic valve: found in the aorta
- Pulmonary valve: found in the pulmonary artery

<u>Need for a Circulatory System</u>

- Every organism needs to exchange materials and energy with its environment (note that the exchange occurs at the cellular level),

Simple Organisms	Multicellular Organisms
- In simple organisms, all cells (or almost all) are in direct contact with the environment → Exchange can occur easily, and directly with the environment, - Exchange of nutrients, gases and wastes occur via diffusion	- In multicellular organisms, not all cells are in direct contact with the environment → direct exchange is not possible as most cells are not in contact with the environment - **The amount of materials being exchanged is greatly increased,** - **The distance the materials have to travel is greatly increased,** -

The human circulatory system:

1. Provides an efficient internal transport system
2. Connects the organs of exchange with the body cells
3. Circulating fluid provides a bridge between the aqueous environment of living cells and the exchange organs (lungs) that exchange chemicals with the outside environment
4. Brings resources close enough to cells for diffusion to occur.

<u>Circulatory System – Overview</u>

- Substances diffuse in and out of the cell membranes and into the capillaries (which form part of the circulatory system)
- Direction of movement:

[Artery → Arteriole → Capillaries → Venule → Veins]

[Highest pressure → Lowest pressure]

- Main components:

- Central muscular pump – the heart
    - Vascular system – blood vessels
    - Circulating fluid – blood
    - All the above components work together to ensure a unidirectional flow of blood by including a set of valves in the blood and the heart.
- How to achieve efficient diffusion (therefore, large concentration gradient)
    - Continuous blood flow:
        - Constant pumping of the heart → Difference in pressure between the two areas → Blood flow
    - Fast diffusion:
        - Capillaries are 1 cell thick
        - Low pressure at capillary beds
        - Large surface area of capillaries (spread across the living cells, lesser distance to travel before diffusion)

Open Circulatory System VS Closed Circulatory System

Open circulatory systems

- Circulating fluid is pumped through open ended vessels
- The circulating fluid flows out into the cells (therefore it bathes the cells directly)
- Seen in many invertebrates

Closed circulatory systems:

- Circulating fluid is confined to the transport vessels
- Circulating fluid is distinct from the interstitial fluid (tissue fluid)
- Exchange occurs:
    - Circulatory fluid → Interstitial fluid
    - Interstitial fluid → Cells
- Seen in many vertebrates

Closed circulatory system in man:

- Arteries carry blood away from the heart (to capillaries)
- Veins carry blood to heart (from capillaries)
- Capillaries are the site of exchange of substances (such as nutrients, oxygen, waste products, etc) **between the blood and the interstitial fluid**.

Double Circulatory System

Called the 'Double Circulatory System' because blood passes through the heart twice in one complete circulation.

- One complete circulation consists of:
    1. Pulmonary circulation: (Heart→ Lungs→ Heart)
        a. Pulmonary arteries: Carry deoxygenated blood from the heart (right ventricle) to the lungs,
        b. Deoxygenated blood is replaced by oxygenated blood at the lungs
        c. Pulmonary veins: Carry oxygenated blood from the lungs to the heart (left atrium).

2. Systemic circulation: (Heart→ Rest of Body → Heart)
    a. Aorta: Oxygenated blood leaves the heart (left ventricle, aorta) and is sent to the rest of the body
    b. The oxygenated blood is replaced by deoxygenated blood at the rest of the body,
    c. Vena Cava: Deoxygenated blood leaves the rest of the body and enters the heart through the vena cava, and into the right atrium
3. Note:
    a. Oxygenated blood refers to blood with: oxygen and nutrients (glucose)
    b. Deoxygenated blood refers to blood with: carbon dioxide and waste products

- Right and left sides of heart are completely separated to prevent the mixing of oxygenated and de-oxygenated blood:
    - Right side receives and pumps **deoxygenated blood**
    - Left side receives and pumps **oxygenated blood**

Description of Events:

1. Deoxygenated blood (from the body) enters the right side of the heart,
2. Deoxygenated blood leaves the right side of the heart as it is pumped to the lungs,
3. Oxygenated blood (from the lungs) enters the left side of the heart,
4. Oxygenated blood leaves the left side of the heart as it is pumped to the rest of the body.

The Heart

A muscular organ that pumps blood through blood vessels in rhythmic contractions. It is approximately the size of a fist. It is located in the thorax (behind sternum), and is surrounded by the lungs. It is enclosed within a sac known as pericardium (a sac that acts as a lubricant to reduce the friction from the rhythmic contractions).

Structure:

- Two atria (the upper chambers)
- Two ventricles (the lower chambers)
    - Generate pressure (by compression/squeezing) to pump blood out of the heart to the lungs/rest of the body
    - Right ventricle (deoxygenated blood) – to the lungs
    - Left ventricle (oxygenated blood) – to the rest of the body
- Septum – separates the right and left sides (atria + ventricles)

The atria are thin walled as compared to the ventricular walls because the blood rushes in with low pressure; they receive blood returning to the heart. The ventricles pump the blood out (high pressure), and thus require thicker walls (3x thicker than atrial walls).

AV valves:

- Tricuspid valve (right side)
    - Located between right atrium and ventricle
- Bicuspid valve (left side)
    - Located between left atrium and ventricle

- AV valves prevent backflow of blood (when the systole occurs, and the ventricle contracts)
- AV valves are held in place by chordae tendineae
    - Prevents the inverting of the valves by holding them in place)

Blood vessels that bring blood into/out of the heart:

1. Vena Cava:
    - Major vein that brings deoxygenated blood from the rest of the body into the right atrium (during systemic circulation)
2. Pulmonary Artery:
    - Artery that brings deoxygenated blood out of the right ventricle and into the lungs (during pulmonary circulation)
3. Pulmonary Vein:
    - Vein that brings oxygenated blood from the lungs to the left atrium (during pulmonary circulation)
4. Aorta:
    - Major artery that brings oxygenated blood out of the left ventricle to the rest of the body (during systemic circulation)

Semilunar valves:

- Found in the arteries leaving the ventricles: They prevent backflow of blood back into the ventricles after the systole (pumping/contraction of the blood)
- Pulmonary valve – found in pulmonary artery
- Aortic valve – found in the aorta

<u>Cardiac Cycle</u>

The rhythmic cycle that the heart contracts and relaxes in is called the cardiac cycle. Comprises of **systole** and **diastole**.

- Systole: The phase of contraction (pumping)
- Diastole: The phase of relaxing (filling)

Diastole	**Atrial Systole**	**Ventricular Systole**
0.4s	0.1s	0.3s
All heart muscles relax	The atrial muscles contract	The ventricular muscles contract
Blood flows into the atria then into the ventricles	Blood flows from the atria into the ventricles	Blood flows from the ventricles into the arteries
Semilunar valves are closed (to build up pressure)	Semilunar valves are closed (to build up pressure)	Semilunar valves are open (to release the blood at high pressure)
AV valves are open (to let the blood flow between the chambers)	AV valves are open (to let the blood flow between the chambers)	AV valves are closed (to prevent backflow of blood into the atria when the blood is being sent into arteries)

Heart rate:

- AKA pulse

- Number of heart beats per minute (average 75bpm)

Cardiac output:

- Volume of blood pumped out into the systemic circulation per minute
- Heart rate X volume of blood pumped out every time

Cardiac cycle summary:

1. The atria contract. At this point, the pressure in the aorta is higher than the pressure in the ventricles, but as the atria contract and the ventricles get filled up, the pressure in the ventricles rises.
    a. AV valves are open (to let the blood flow into the ventricles)
    b. Semilunar valves are closed (to build up pressure)
2. The ventricles contract. The AV valves close to prevent backflow, and the pressure in the ventricles shoots up, higher than that in the arteries, and the blood starts flowing through the arteries.
    a. The AV valves are closed (to prevent backflow from the ventricles into the atria)
    b. The semilunar valves are open (to allow the blood to flow into the arteries)
3. All heart muscles relax, pressure in both atria and ventricles falls (now lower than that in the arteries). Since the pressure is higher in the aorta and pulmonary artery, the semilunar valves close.
4. The atria and ventricles fill up with blood (during diastole).
5. Additional Note: The ventricles are completely emptied of blood during systole, but there is always blood flowing through the aorta (thus the generally higher pressure of the aorta)

Note: Although the right and left ventricles perform similarly – the pressure in the left ventricle will be much greater than the pressure in the right ventricle, because the right ventricle only pumps to the lungs (short distance) while the left ventricle pumps to the rest of the body.

Note: For this reason, the left ventricle wall is much thicker too (to bear the higher pressure). In turn, the thicker wall (muscles) allows for stronger contractions and results in higher blood pressure.

Pacemaker:

- Some cardiac muscles are self-excitable (do not require signals from the nervous system for contraction)
- These cells are responsible for the generation of rhythmic impulses and directly control the heart rate

1. The sinoatrial node (SA node), located on the upper right atrial wall, generates impulses that travel to the atrioventricular node (AV node) – this contracts the atrial walls.
2. At the AV node, the impulses are delayed – to ensure the atria have ejected all the blood into the ventricles (before contracting the ventricles)
3. The impulses are sent from the AV node to the heart apex (Bundle of His and the Purkinje fibres); and then the impulses spread throughout the ventricles – this contracts the ventricular walls.

Note: The SA node sets the timing at which the cardiac muscles contract ('paces' the heartbeat).

Blood Vessels

Description of blood vessels:

- Arteries:
  - Carry blood away from the heart
  - Branch and narrow into arterioles
  - Arterioles branch and narrow into capillaries.
- Capillaries:
  - Connect the arterioles and the venules
  - Are the site of exchange between blood and interstitial fluid
  - Join and widen to become venules
  - Venules then connect and widen further to become veins
- Veins:
  - Carry blood towards the heart

Structure of blood vessels:

- Arteries and veins:
  - Innermost layer: Endothelium
  - The endothelium is surrounded by smooth muscle and elastic fibres
  - Outermost layer: The smooth muscles and elastic fibres are surrounded by connective tissue
  - Lumen: The inside space in a blood vessel
- Capillaries (thin walled, 1 cell thick):
  - Endothelium
  - Lumen: The inside space in a blood vessel

Artery:

- Thick muscular and elastic walls (thicker than veins)
- They accommodate and maintain high pressure of blood pumped from the heart
- This high blood pressure helps to move the blood along
- No valves (except the semilunar valve at the heart – pulmonary artery)

Note: Coronary arteries supply the heart muscles with blood, and bring in substances like nutrients and oxygen.

Veins:

- Thinner muscular and elastic walls (much thinner than arteries)
- They accommodate extremely low blood pressure
- The low blood pressure is brought back to the heart with aid from the skeletal muscle pump
  - When skeletal muscles contract, the pressure exerted on the veins help push the deoxygenated blood back to the heart (the valves prevent backflow too)
- Valves are present to prevent the backflow of blood (backflow is easier to occur in low pressure veins)

Note: Coronary veins bring back blood from heart muscles (back to the heart), and thus carry waste products like carbon dioxide.

Capillaries:

- One cell thick, no smooth muscles or elastic walls – just endothelial cells
- Being one cell thick allows for rapid diffusion
- Capillaries are branched repeatedly → large surface areas of capillaries allows for faster exchange of materials between blood and tissue fluid through diffusion

Note: The only place oxygen diffuses into capillaries is at the lungs. Oxygen diffuses out of the capillaries at areas in the rest of the body.

Summary:

	Arteries	Veins	Capillaries
Endothelium	Present	Present	Present
Smooth muscles	Thick	Thin	Absent
Connective tissues	Present	Present	Absent
Valves	Absent	Present	Absent

Blood Flow Velocity & Blood Pressure

Blood flow velocity:

- Fastest in the arteries
    - High blood pressure (together with the smaller cross-sectional area)
- Slowest in the capillary beds
    - Low blood pressure (together with the large cross sectional area)
    - This allows for sufficient time for the exchange of materials between the blood in the capillaries and the interstitial fluid
    - Note: Capillaries are usually filled to capacity in major organs, but blood supply varies (depending on need) in other organs
- Law of continuity: the total volume of flow per second must be constant
    - As the total cross sectional area increases, the flow velocity decreases (such as in capillaries)
    - As the total cross sectional area decreases, the flow velocity increases (such as in arteries and veins)

Blood pressure: Refers to the hydrostatic pressure that the blood exerts against the walls of a blood pressure. It is affected by:

- Cardiac output – the volume of blood pumped by each ventricle per minute
- Peripheral resistance – the constriction of the arterioles

Systolic pressure: Refers to the pressure in the arteries during systole (and is the highest pressure in the arteries).

Diastolic pressure: Refers to the pressure in the arteries during diastole (and is much lower than systolic pressure)

Exchange of Materials

Refers to the exchange of substances between the blood and the interstitial fluid, and it occurs across the thin endothelial walls of the capillaries.

The difference between hydrostatic pressure (blood pressure) and osmotic pressure (pressure in tissue fluids):

- Drives fluid out of capillaries at the arteriole end
    - Plasma and white blood cells squeeze through the capillary walls
    - These plasma + white blood cells become part of the interstitial fluid which:
        - Bathe all living body cells
        - Contain dissolved food and oxygen from blood (which is then supplied to the cells)
        - Receives waste products of cells (which is then returned to blood in capillaries and removed)
- Drives fluids into the capillaries at the venule end

Components of Blood

Blood consists of:

- Plasma (55%) – the liquid component of the blood
- Cells (45%):
    - Erythrocytes (45%) - red blood cells
        - Transport oxygen and help transport carbon dioxide
    - Leukocytes (<1%) – white blood cells
        - Defend the body from bacteria and viruses as part of the immune system
    - Thrombocytes (<1%) – platelets
        - Fragments of cells that help in blood clotting
- Blood needs to be kept in a centrifuge to achieve this separation

Plasma:

- A pale yellowish liquid
- Main function is to serve as solvent for carrying other substances, such as:
    - Inorganic salts
    - Dissolved nutrients
    - Waste products: urea, lactic acid, carbon dioxide (which is done in 3 main ways)

Red blood cells (erythrocytes):

- No nucleus
- Iron is essential for the production of red blood cells because haemoglobin is an iron containing transport protein
- Contain haemoglobin molecules
    - Made up of 4 globular proteins
    - Can bind to oxygen to form oxyhameoglobin – oxygen requires haemoglobin to bind to as it is poorly soluble in water
    - Deoxyhaemoglobin refers to haemoglobin without the bound oxygen
- Help to transport oxygen (and occasionally carbon dioxide) throughout the body

- Elastic: can squeeze into capillaries smaller than themselves
- Produced in the bone marrow, and destroyed in the spleen and liver

White blood cells (leukocytes):

- Produced in the bone marrow
- Irregular shape: changes shape to squeeze through capillary walls
- Two main types:
  - Lymphocytes – produces antibodies to destroy foreign organisms
    - Large rounded nucleus, and small amount of cytoplasm
  - Phagocytes – engulfs and destroys foreign organisms
    - Lobed nucleus
    - Protects body by ingesting foreign particles in a process called phagocytosis

Platelets (thrombocytes):

- Not true cells (just fragments of cytoplasm from bone marrow cells)
- Help to clot blood (haemostasis) when skin is cut or when endothelium of a blood vessel is damaged:
  - To prevent blood loss
  - To prevent entry of microorganisms into the wound
  -

Carbon dioxide:

1. Dissolved in the plasma (5%)
2. Bound to the haemoglobin (15%)
3. Bicarbonate ions (80%) – majority of carbon dioxide combines with water to form carbonic acid (H_2CO_3).
   a. This reaction is catalysed by carbonic anhydrase
   b. The carbonic acid then dissociates to form bicarbonate ions (HCO_3^-)and hydrogen ions (H^+)

<u>Diseases of Cardiovascular System</u>

Atherosclerosis:

- Caused by the build-up of cholesterol within arteries
- Exacerbated by consumption of excessive amounts of trans fat and saturated fat in diet

Hypertension (high blood pressure):

- Promotes atherosclerosis and increases the risk of heart attack and stroke

Heart attack:

- Is the death of cardiac muscle tissue resulting from the blockage of one or more coronary arteries

Stroke:

- Refers to the death of nervous tissue in the brain, resulting from rupture or blockage of arteries in the head.

Topic 6A: Nervous System and Reflex Action

Nervous System Summary

The nervous system is the coordinator of body's response to stimulus.

It collects information about internal and external environment, sends this information for processing and integrates is (by relating it to previous experiences by association). Then it initiates the appropriate response to the stimulus.

Central Nervous System: Brain and spinal cord

Peripheral Nervous System: Cranial nerves from brain, spinal nerves from spinal cord and receptors (nerve endings of specialized cells in sense organs).

- Autonomic Nervous System: Involuntary actions
  - Sympathetic Nervous System: Deals with quick/immediate responses (to respond to immediate threats, for example) – heart rate, respiration, etc.
  - Parasympathetic Nervous System: Deals with slow bodily processes (for example, digestion)
- Somatic Nervous System: Conscious/Voluntary actions
- ▪ Sends impulses once from receptor to CNS, and once from CNS to effector

Stimulus: A change that is detected by receptors

Receptors: Nerve endings of specialized cells in sense organs (photoreceptors, thermoreceptors) that receive stimuli from the environment

Response: Refers to a reaction of the body due to the stimulus

Effectors: Muscles or glands that bring about the response

Process Overview:

[Detection of stimuli by receptors → Conversion of stimuli to electrical impulses → Impulses sent to CNS for analysis and integration → Impulse sent to effectors → Effectors carry out response]

Pathway of Nervous Control

1. Stimulus is detected by receptor and converted to electrical impulses
2. Information is sent via sensory nerve to Central Nervous System in the form of electrical impulses
   a. Note that a 'nerve' refers to a bundle of nerve fibres (sensory neurons in this case)
3. Central Nervous System receives the information and processes it, and decides on the appropriate response
4. Response is sent in the form of electrical impulses via a motor neuron to the effector

Structure of a Neuron

Definition: A neuron is a specialized cell for carrying information in the form of electrical impulses from the receptors to the CNS, and from the CNS to effectors.

Note that neurons are cells themselves, and thus contain normal organelles like: ribosomes (for creating proteins), endoplastic recticulum, and golgi apparatus as well.

Structural features of a neuron:

1. Soma
    a. Nucleus
    b. Cytoplasm
    c. Cell membrane
2. Dendron (transmits impulses towards **nerve** cell body)
    a. Dendron → Dendrite
    b. The dendrites receive impulses from other cells and conducts these impulses to Dendron and cell body
3. Axon (transmit impulses away from **nerve** cell body)
    a. Axon → Axon terminals
    b. Covered with a fatty layer called the myelin sheath

Note: Nerves are always found in bundles of cable-like neurons.

- Myelin sheath: A layer of lipids that covers the axon
    - Created by schwann cells
    - Provides nourishment for the nerve cell
    - Acts as an insulation substance for the nerve ("live wire")
- Node of Ranvier: Unmyelinated parts of the axon that speeds up transmission of impulses (gaps in the myelin sheet)
    - Longer to cover distance before re-transmission
- Synapse: Physical gap between two neurons, or between neuron and effector
    - Synaptic junctions ensure that impulses travel in one direction because:
        - Neurotransmitters are only released from the side of the synaptic knob
        - Receptors for these neurotransmitters are only found on post synaptic knob
- Neurotransmitter: A chemical substance released at the synapse that helps in the transmission of the impulse across the synapse
- Schwann cell: Schwann cells repeatedly roll themselves around the axon to form the myelin sheaths
    - Myelin sheaths are primarily layers of cell membranes of the schwann cells (thus mainly phospholipids)
    - Unsheathed points are called Nodes of Ranvier

Types of Neurons and their Functions

Sensory (or Afferent or Receptor) Neuron:

- Carry impulses from receptors to Central Nervous System
- Found in the Peripheral Nervous System
- **Single long dendron and short axon**
- Modified endings of sensory neurons (modified dendrites) are known as receptors
- Begin at sense organs and transmit impulses to intermediate neuron or to motor neuron

Effector (or Efferent or Motor) Neuron:

- Carry impulses from Central Nervous System to effectors (muscles or glands)
- Found in the Peripheral Nervous System
- **Single long axon with several short dendrons** that project from cell body
- Conducts impulses from Central Nervous System to effectors

Intermediate (or Relay) Neuron:

- Carry impulses from sensory neurons to motor neuron
- Found between sensory and motor neurons and in the Central Nervous System
- Note that intermediate neurons do not have a fixed structure

<u>White Matter VS Grey Matter</u>

White matter: Consists of nerve fibres

Grey matter: Consists of cell bodies

White matter	Grey matter
Nerve fibres	Cell bodies
Brain: Inside Spinal Cord: Outside	Brain: Outside Spinal Cord: Inside

<u>Spinal Cord</u>

The spinal cord passes through the vertebral column (the backbone), which protects it from damage.

Central canal:

- Narrow canal that runs through middle of spinal cord (through the middle of the grey matter)
- Carries cerebrospinal fluid, which:
    - Brings nutrients to spinal cord
    - Helps to cushion the Central Nervous System

Spinal Nerve:

- Branches into:
    - Ventral root
        - Contains only motor neurons (cell bodies of which are found in the grey matter)
    - Dorsal root
        - Contains only sensory neurons (cell bodies of which are found in the grey matter)

Dorsal Root Ganglion:

- Cell bodies of sensory neurons (which are found in the dorsal root) accumulate in a small swelling called the dorsal root ganglion.

<u>Reflex Action</u>

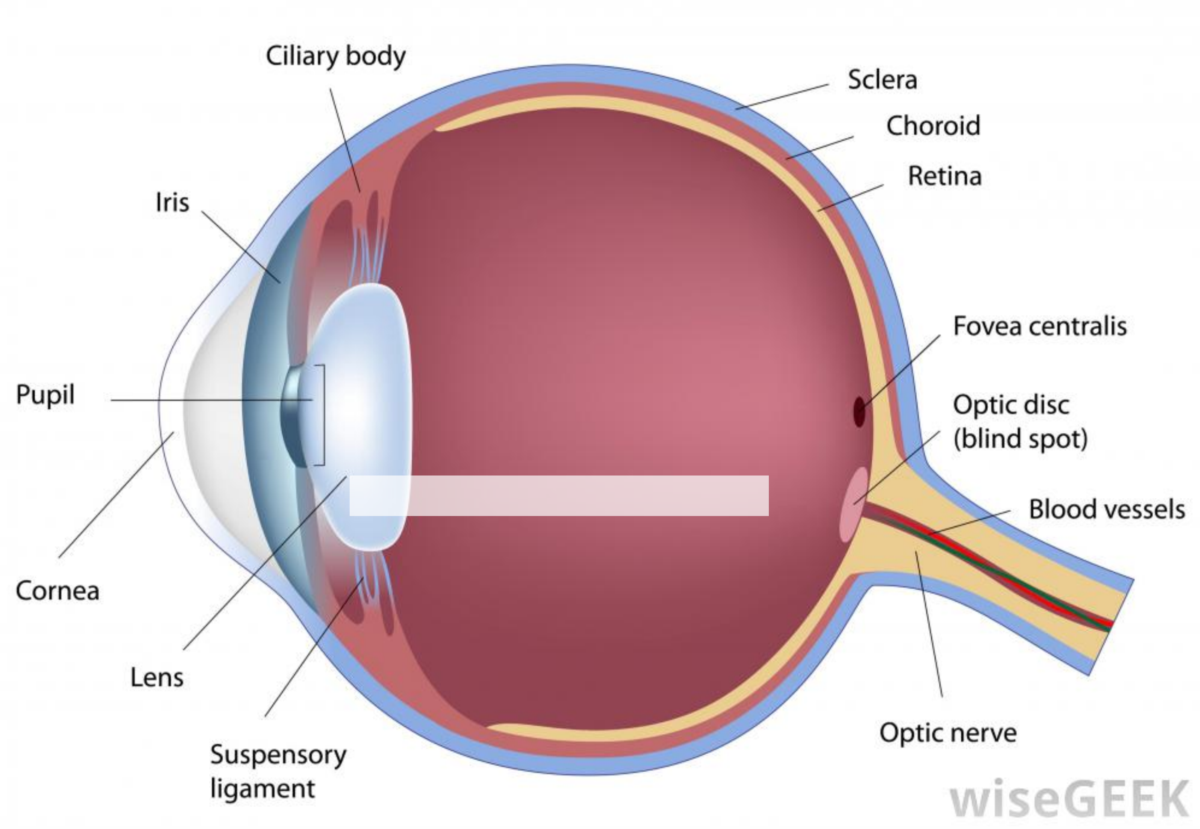
Refers to spontaneous response to a specific stimulus without conscious control (as a basic form of response in higher animals to protect them from injury).

- Shortest possible pathway is taken, and it comprises of:
    - Receptor
    - Sensory (+ intermediate) neuron – electrical impulses travel along the dendron of sensory neuron to spinal cord
    - Spinal cord (reflex centre)
    - (Intermediate +) Motor neuron – electrical impulses travel along the axon of motor neuron to effector (where neurotransmitters are released at the synapse, and received by the effector)
    - Effector
- The axon of the sensory neuron has many branches – and electrical impulses are sent across several to achieve various purposes
    - One branch may form a synapse with an intermediate neuron which then transmits impulses up to the brain (for pain to be felt)
    - One may form a synapse with a motor neuron to the voice box (producing a cry)
- Conditioned reflex action:

Reflex action acquired from past experience that was initially ineffective in producing a response (example: Pavlov's bell experiment)

Topic 6B: A Sense Organ – The Eye

Structure and Purpose



The eye is a ball filled with a clear jelly-like fluid that holds it in shape.

Outer wall of eyeball:

- Sclera:
    - A white wall that is tough, and is the outer coat of the outer wall
    - Roles:
        - To protect the eyeball
        - A point of muscle attachment (allows the movement of the eyeball)
- Choroid:
    - The middle layer of the outer wall
    - Pigmented to prevent internal reflection, or cause the formation of blurry/multiple images
    - Contains lots of blood vessels for the receptors (to supply oxygen and remove waste products)
- Retina:
    - The inner layer of the outer wall
    - Contains light-sensitive neurons

Parts of the eye:

- Cornea:
    - A single transparent layer that acts as a window to the eye.
    - Helps in focussing by refracting the light rays onto the retina.
    - Does most of the refraction of entering light (~70%)
- Iris:
    - Located behind the cornea.
    - Expands and contracts to control the amount of light entering the eye, by contracting and relaxing the circular and radial (antagonistic) muscles.
- Pupil:
    - A circular opening in the iris that allows light to enter the eye
    - Appears black because the choroid is visible through the pupil
    - Controls the amount of light that can enter the eye
- Lens:
    - Located directly behind the pupil, and is held in place by suspensory ligaments
        - Suspensory ligaments connect the ciliary body to the lens
        - Ciliary body has ciliary muscles that expand and contract, and in the process slackens or tightens the suspensory ligaments, hence making the lens thicker/thinner
    - Focusses light onto the retina
- Aqueous humour:
    - A watery fluid that supports the cornea and the front chamber of the eye
- Vitreous humour:
    - Helps to adjust the shape of the lens in order to focus the eyes
- Retina:
    - The “screen” of the eye

- Light first passes through transparent layers of neurons before reaching the photoreceptors (rods and cones)

- Macula & Fovea:
  - The macula is located in the central part of the retina. As the central and highly sensitive part of the retina, it is responsible for the detailed central vision.
  - The fovea is the centre of the macula, and is the point of our central, sharpest vision. A healthy fovea is essential to tasks such as reading, watching TV, etc.
- Blind spot:
  - A general angle at which the eye cannot capture images.
  - However, as the two eyes have two blind spots that are located differently, we can still see clearly
- Photoreceptors:
  - Rods
    - Very sensitive to light, and enable us to see in dim light
    - Contribute to 'night vision'
    - Note: Rods contain a pigment that is derived from Vitamin A. Hence, vitamin A deficiency can result in night blindness.
  - Cones
    - Less sensitive to light, and are generally stimulated in bright light
    - Contribute to 'colour vision', by helping to distinguish colours
- Optic nerve:
  - Fibres from neurons in the retina join together to form the optic nerve at the back of the eye
- Nictitating membrane:
  - A form of "third eyelid" found in birds, reptiles, amphibians, fish – but not so common in mammals.
  - Allows for the moistening of the eye while maintaining vision.
  - Would normally work like an eyelid, moving to cover the entire eye to moisten it, but in humans simply remains at the side

Nervous Transmission

1. Impulses from the photoreceptors travel along neurons to the optic nerve fibres.
2. The two optic nerves (of the two eyes) carry impulses back to the visual centre of the brain, where the image is "seen".

Focussing the Eye

- Essential for clear vision, as clear vision depends primarily on the ability of the lens to focus light onto the retina
- As light rays pass through the eye, they are refracted (note: refraction occurs due to the varying optical densities) by the cornea and the lens – so that all the light rays converge onto the retina.

Note: The default position of the ciliary muscle, is one in which the suspensory ligaments are taut, and the lens is stretched. Hence, when the ciliary muscles are contracted, they move closer to the suspensory ligament, slackening it, and therefore thickening the lens.

Near vision (object is located very near to the eye):

- Note that rays from objects that are located very near to the eye are divergent. Hence, the lens needs to be thicker in order to converge the light rays more.
- Ciliary muscles contract → suspensory ligaments slacken → Less pull on the lens → Lens becomes thicker (more convex) → Greater converging effect on light rays by refraction → Light rays focus on the retina

Far vision (object is located very far away from the eye):

- Note that rays from objects that are located very far away from the eye are parallel. Hence the lens needs to be thinner in order to converge the light rays onto the retina, without 'over-converging' them.
- Ciliary muscles relax → Suspensory muscles tighten → Greater pull on lens (lens get stretched) → Lens becomes thinner (less convex) → Smaller, but sufficient converging effect on light rays by refraction → Light rays focus on the retina

Pupil Reflex

Even though the brain is involved in controlling the size of the pupil, note that the pupil reflex is without conscious control.

Pupil reflex is essential to protect the retina, and to ensure that the brain is not overwhelmed by bright lights sent as impulses by the photoreceptors.

In bright light:

- The circular muscles of the iris contract (to close up the pupil), and the radial muscles relax
- As a result, the pupil becomes smaller, and less light enters

In dim light:

- The circular muscles of the iris relax (to open up the pupil), and the radial muscles contract
- As a result, the pupil becomes larger, and more light enters

Process of pupil reflex:

- Changes in light intensity stimulates the retina (receptor)
- Nervous impulses are sent to the brain from the retina (receptor) to the brain via the optic nerve (sensory neurone)
- The brain interpret these impulses and sends impulses via a motor neurone to the circular and radial muscles in the iris (effectors)
- The circular and the radial muscles of the iris act accordingly.

Binocular Vision

Humans (and most other predators) have two eyes, located on either side of the face. As sch, the image that each eye sees is slightly different due to the different positions. This slight displacement (difference in angle) allows binocular vision (the ability to perceive three-dimensional images and the sense of depth).

Topic 6C: Muscles & Movement

Functions of the Skeleton

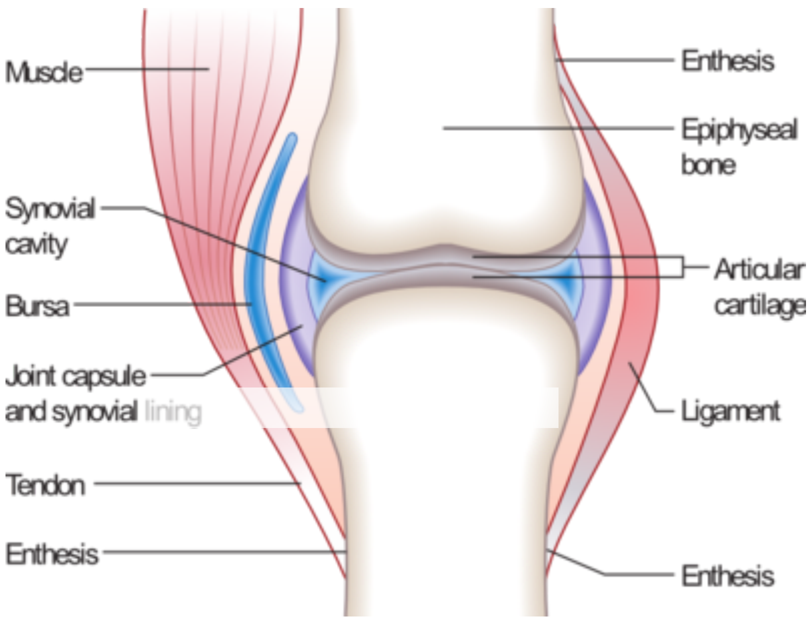
- Support
  - Skeleton provides a rigid internal framework, and helps to maintain the shape of the body
- Protection
  - Parts of the skeleton such as the skull, ribcage, and spinal cord help protect essential organs to the body
- Movement
  - Skeleton provides points of attachment for skeletal muscles
  - When muscles contract, they pull on these bones, hence producing movement
- Production of blood cells
  - Bone marrow produces red and white blood cells

Skeletal Mechanics

The skeleton of an animal (together with its muscles) act as a system of levers.

Joints come in primary 3 types:

1. Immovable
   a. Example: Cranial bones, in which skull bones are fused together
2. Partially movable
   a. Limited movement
   b. Example: Gliding joints of bones between vertebral column



3. Synovial (freely movable)

a. Parts:
    i. Ligament – a fibrous covering that joints two bones together. Designed to cope effectively with the stresses suffered by the respective joints. Ligaments are made of collagen which is elastic and flexible
    ii. Synovial membrane – secretes a mucus containing lubricant called synovial fluid, or joint fluid that is located in the synovial cavity (the part between the two sets of articular cartilage)
    iii. Articular cartilage – Prevents damage to the articulating surfaces of bones as a result of friction
b. Ball and socket joints
    i. Greatest flexibility
    ii. 360 degree movement in all planes
    iii. Examples: Shoulder joint, hip joint
c. Hinge joints
    i. 180 degrees of movement in a single plane
    ii. Examples: elbow joint, knee joint

Skeletal Muscle Control

- A skeletal muscle is usually a voluntary muscle that is under conscious control (but can be involuntary in reflex actions)
- Attached to the bone in at least 2 places – the origin (a firm, non-movable part of the skeleton), and the insertion (a freely movable part of the skeleton)
- The muscles are attached to bones by means of tendons

Antagonistic action: When one muscle group contracts, the other muscle group relaxes.

- Flexion of arm : biceps contract, triceps relax
- Extension of arm: triceps contract, biceps relax

Comparison of Muscle Cells

	Skeletal Muscles	Cardiac Muscles	Smooth Muscles (in blood vessels)
Striations	Present	Present	Absent
Control	Voluntary + Involuntary	Involuntary	Involuntary
Location	Bones across skeleton	Bulk of heart walls	Walls of internal structures like blood vessels and organs
Number of nuclei	Many per cell	One per cell	One per cell

Note: Striations refers to the repetition of the basic units of muscles.

Note: Anterior end stands for the "front end" of something, while posterior end stands for the "back end" of something.

Topic 7: Homeostasis, Temperature Control, Excretion

Overview

Metabolism is defined as the chemical reactions that take place within the body to maintain life.

Homeostasis is defined as *the maintenance of a constant internal environment despite changes in the external environment*. This internal environment must be constant to allow for two things:

1. Optimal conditions for enzymatic activities that sustain life
2. Degree of independence from external environment (to migrate, adapt, etc)

Regulator VS Conformer:

- A regulator controls its internal condition in the face of fluctuating external conditions.
- A conformer allows its internal condition to vary with external change.

Homeostasis involves 3 elements: receptors (which detect certain stimuli), messengers (to coordinate a corrective mechanism via negative feedback), and effectors (which carry out the responses to the stimuli). These responses are effected through the nervous system (electrical messengers) or the endocrine system (chemical messengers).

Blood Glucose Level Regulation

Note: Always use 'optimal blood glucose' as base reference point.

Relevant hormones:

- Insulin: Gets liver to convert glucose to glycogen
- Glucagon: Gets liver to convert glycogen to glucose

If blood glucose level rises beyond optimal blood glucose:

- The rise in blood glucose level is detected by beta cells in pancreas
- Insulin is released
- Liver cells and muscle cells start to convert excess glucose to glycogen
- Blood glucose level drops to optimal blood glucose

If blood glucose level drops below optimal blood glucose:

- The drop is blood glucose level is detected by alpha cells in pancreas
- Glucagon is released
- Stored glycogen is released as glucose by liver and muscle cells
- Blood glucose level rises to optimal blood glucose

Case Study – Lack of Insulin:

- Due to the lack of insulin, there is no trigger that gets the liver and muscles to get rid of the high blood glucose. As a result, there is always high blood glucose.
- As kidneys have a maximum reabsorption rate, when the glucose in blood exceeds this rate, glucose is expelled as waste material in urine. This condition is called **hyperglycemia**.
- As compared to a healthy body (which will not expel urine with glucose present), a diabetic (diabetes mellitus) must inject insulin into bloodstream to control blood glucose
    - Diabetes mellitus can be detected by the following symptoms:

        - Low glycogen store (as there is no insulin causing the conversion of glucose to glycogen)
        - High blood pressure (as low water potential in blood will cause more water to enter bloodstream from surrounding cells)
    - Patients of diabetes mellitus cannot exert themselves. During physical exercise, glucose is rapidly used, and as there is a low glycogen store, no glycogen can be converted to glucose. This will result in **hypoglycaemia**.

Thermoregulation

Endotherms VS Ectotherms:

- Endotherms are organisms that are 'warm-blooded' and maintain their internal temperature at a metabolically favourable temperature. Note that lots of energy is wasted in the process.
- Ectotherms are organisms that are 'cold-blooded' and depend on the external environment to maintain a metabolically favourable internal temperature. Note that lots of energy is saved in the process.

Thermoregulation is defined as the process by which animals maintain an internal temperature within a tolerable range.

- Receptors: Thermoreceptors in hypothalamus (in brain)
- Messengers: Nerve impulses from brain to effector organs
- Effectors: Sweat glands, arterioles, hair erector muscles, skeletal muscles

When body temperature rises above optimal body temperature:

- Factors that can cause the rise are: increased muscular activity, hot external environment, infections, etc
- High body temperature is detected by thermoreceptors in hypothalamus, which then sends out nerve impulses to carry out the following actions:
    - Sweat glands are stimulated, and there is an increased production of sweat. As more sweat evaporates from the surface of the skin, more **latent heat** is removed from the body.
    - Arterioles in the skin dilate (**vasodilation**), to allow more blood to flow through the skin. Excess heat is lost by conduction, convection, and radiation from the hot blood to the external surroundings
    - Hair erector muscles relax, and hairs lie close to the skin surface
    - Metabolic rate decreases
- By these actions, body temperature reduces back to optimal body temperature.

When body temperature falls below optimal body temperature:

- Factors that can cause the drop are: cold external environment, lack of muscular activity, etc
- Low body temperature is detected by thermoreceptors in hypothalamus, which sends out nerve impulses to carry out the following actions:

    - Sweat glands are not stimulated, leading to the reduced production of sweat. As less sweat evaporates from the surface of the skin, less **latent heat** is removed from the body.
    - Arterioles in the skin constrict (**vasoconstriction**), to allow less blood to flow through the skin. As such, less latent heat is lost to the surroundings by conduction, convection, or radiation
    - Hair erector muscles contract, and hairs stand on end (goosebumps). This forms an insulating layer of air between the hair – and as air is a poor conductor of heat, less latent heat is lost
    - Involuntary muscle contractions occur (shivering)
    - Metabolic rate increases
- By these actions, body temperature increases back to optimal body temperature

<u>Excretion</u>

Excretion is defined as the process by which metabolic waste products are removed from the body.

Egestion is defined as the process by which undigested food materials are removed from the body. Note that these substances have never been absorbed into the cells and are not produced as a result of metabolic changes.

Osmoregulators VS osmoconformers:

- Osmoregulators are organisms which actively control their water gain/loss. This includes all land animals, freshwater animals, and most marine vertebrates.
- Osmoconformers are organisms whose internal and external environments have similar solute concentrations. This includes saltwater animals.

Excretory products:

- Carbon dioxide
    - Excreted by lungs as gas in expired air
- Excess water
    - Excreted by kidney, skin, and lungs as a constituent of urine, sweat, and expired air
- Urea
    - Formed by deamination of proteins
    - Excreted by kidney and skin, as a constituent of urine and sweat
- Uric acid
    - A constituent of urine and sweat, and is formed by the breakdown of nuclear materials
    - Excreted by kidney and skin
- Bile pigments
    - Formed during the breakdown of haemoglobin
    - Excreted by the liver via the intestines
- Mineral salts
    - Excreted by kidney and skin as a constituent of urine and sweat

Excretory Organs:

1. Skin
    a. Excretes urea and other salts in sweat
2. Lungs
3. Liver
    a. Excretes chemical waste in bile
4. Kidneys
    a. Excrete urea and other salts

Lungs:

- Carbon dioxide and water is produced as a result of cellular respiration, and this carbon dioxide from the cells diffuse into the blood
- Carbon dioxide is carried to the lungs in the form of a hydrogen carbonate ion in red blood cells and blood plasma
- Hydrogen carbonate is changed back to carbon dioxide in the capillaries in the lungs
- Carbon dioxide then diffuses into the alveoli, and out of the lungs
- Excretes carbon dioxide

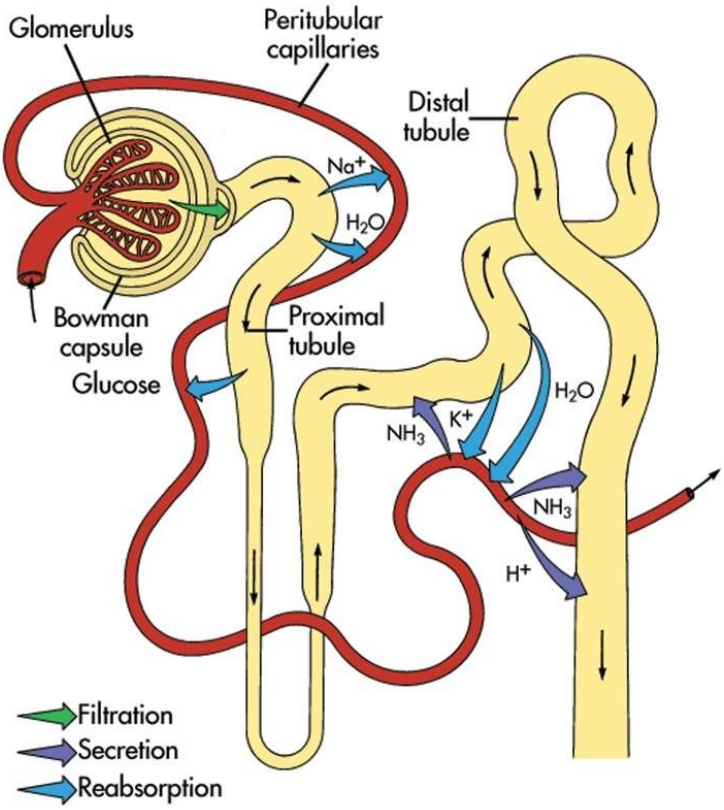
Urinary System Structure:

- Renal artery: Transports blood containing waste products to the kidney
- Renal vein: Transports 'cleaned' blood away from the kidneys
- Ureter: Transports urine from kidneys into the urinary bladder
- Urinary Bladder: Stores urine temporarily before it is discharged from the body
- Urethra: Carries urine out of the body

Kidneys:

- Position:
    - Bean shaped structures that are attached to dorsal (upper) walls of abdominal cavity
    - They lie on both sides of vertebral column
    - Left kidney is located higher than right kidney
- Function:
    - Elimination of waste substances
    - Salvage of essential ions such as sodium ions, potassium ions, and chlorine ions
    - Regulation of blood PH by removing/reabsorbing hydrogen ions (H+) and HCO_3^- ions
    - Regulation of plasma volume/blood pressure
    - Regulation of blood osmotic concentration
    - Production of hormones such as erythropoietin and renin
    - Removal of toxic substances (such as metabolites (products formed as a result of metabolism) of drugs)
- In the kidneys, a very large volume of plasma is separated from the extracellular fluid (of which 99% is reabsorbed back into the plasma), thus leaving behind excess water, salts, and urea
- A single working unit is of the kidney is a **nephron** (a system of tubes that act as a filter), which comprises of:
    - Bowman's capsule + glomerulus

- Proximal convoluted tubule
- Loope of Henle
- Distal convoluted tubule
- Collecting duct



(From Thibodeau GA, Patton KT: *Anatomy & physiology,* ed 5, St Louis, 2003, Mosby.)

Formation of urine:

- Renal artery divides to form a mass of capillaries (glomerulus). These blood capillaries are in the Bowman's capsule of the nephron.
- Two process occur to remove waste products (such as urea) from the contents of the renal artery:
  - Ultrafiltration
    - Diameter of afferent arteriole (the arteriole that brings blood to the glomerulus) is larger than diameter of efferent arteriole (the arteriole that takes blood away from it)
    - Hydrostatic pressure created as a result of this difference in diameter forces fluid out of the artery to the Bowman's capsule
    - Small particles (plasma containing glucose molecules, amino acid molecules, etc) are filtered into the Bowman's capsule, while large particles (RBC, WBC, proteins) remain in the renal artery
    - Resultant fluid is known as glomerular filtrate
  - Selective Reabsorption

        - Occurs in the proximal convoluted tubule
        - As filtrate passes through the tubule, selective reabsorption of useful molecules will occur, in which most of the water, glucose, amino acids, and some minerals are reabsorbed through the tubule walls into the surrounding capillaries.
        - This selective reabsorption occurs through active transport (movement of molecules against a concentration gradient with ATP) or passive transport (movement of molecules with the concentration gradient, from high concentration to low concentration)
        - The remaining water, mineral salts, and nitrogenous wastes pass through the tubule and out to the ureter and urinary bladder in the form of urine
- The substances then move on into the:
    - Loop of Henle (descending limb)
        - The descending limb descends into the renal medulla
        - High concentration of interstitial fluid (tissue fluid) in renal medulla causes water to move out of the loop of henle, and into the surrounding cells
        - Results in more concentrated urine
    - Loop of Henle (ascending limb)
        - The ascending limb is completely impermeable to water
        - Sodium and potassium ions are transported into the interstitial fluid of the medulla by active transport
        - This causes anions to follow, thus increasing the concentration of the interstitial fluid in the medulla
    - Distal convoluted tubule
        - Reabsorbs water to make urine more concentrated
        - The permeability of its walls to water is controlled by antidiuretic hormone
    - Collecting duct
        - Collects the urine

Urine (100g):

- Water (96g)
- Mineral salts (1.8g)
- Urea (2g)
- Other nitrogenous substances (0.2g)
- Note that the composition also varies according to diet

<u>Osmoregulation</u>

Osmoregulation is defined as the process of regulating blood osmolarity (solute concentration), and this controls the amount of water available for cells to absorb.

Osmotic pressure is defined as the pressure required to prevent osmosis into the solution. As a result, solutions with high osmolarity (solute concentration) have high osmotic pressure.

- Receptor: Osmoreceptors that are situated in the hypothalamus, and are capable of detecting osmoic pressure

- Messengers: The hypothalamus sends chemical messages to the pituitary gland that is located next to it in the brain. The pituitary gland then secretes anti-diuretic hormone which targets the kidneys.
- Effectors: Kidneys

If there is a lack of water in the bloodstream (more water required):

- High concentrations of anti-diuretic hormones are released
- At the target site (the kidneys), the walls of the distal convoluted tubule become more permeable
- More water is reabsorbed by the kidneys and less water is expelled with urine

If there is an excess of water in the bloodstream (less water is required):

- Low concentrations of anti-diuretic hormones are released
- At the target site, the walls of the distal convoluted tubule become less permeable
- Less water is reabsorbed by the kidneys, and more water is expelled with urine

Haemodialysis

When both kidneys fail, a patient will be treated with a dialysis machine.

- Blood is drawn from a radial artery (the largest and main artery) in the patient's arm
- The blood flows through a coiled tubing (coiled to increase surface area) in the machine, bathed in specially controlled dialysis fluid (which is an isotonic solution)
- As the walls of the coiled tubing are partially permeable, urea and other waste products diffuse through them, while proteins and blood cells stay in the tubing
- As the isotonic dialysis fluid contains essential salts for the body, such salts do not diffuse out of the blood.
- The filtered blood then returns to the vein.

This process is repeated three times a week, for several hours each time

Topic 8: Hormones, and the Endocrine System

The endocrine system is a system made up of small endocrine glands which secrete chemical messengers known as hormones. An example of an endocrine gland is the pituitary gland, the thyroid gland, or the gonad.

Endocrine glands VS exocrine glands:

- Endocrine glands are ductless, and as such, secretions directly enter the bloodstream
- Exocrine glands have ducts to carry their secretions (eg, salivary gland that has a salivary duct)
- Note that a duct is a passage/channel used to convey substances

Hormones:

- Hormones are chemical messengers carried by the blood.

- Their effect on target cells is slow (due to time taken for production, and time taken for transport through the bloodstream)
- They are produced in minute amounts, as such minutes amounts are sufficient to trigger the necessary changes
- They alter the activity of one or more target organs (example: insulin triggers liver and muscle cells), and are specific (do not affect any other cells)
- They are removed in 2 ways:
  - Destroyed by the liver
  - Excreted in the urine by the kidneys
- They are made from:
  - Proteins – insulin, glucagon
  - Lipids/steroids – testosterone, oestrogen

The 3 major functions of hormones:

1. To control growth/metabolism
   a. Growth hormones
2. To maintain a constant internal environment (homeostasis)
   a. Anti-diuretic hormone for osmoregulation, insulin for blood glucose level regulation, etc
3. Regulate activities of different systems so that they are coordinated
   a. Hormones that are secreted by the pituitary gland

Pituitary gland:

- Consists of two distinct parts:
  - Anterior lobe
    - Synthesizes and releases its own hormones
    - Synthesizes and secretes **growth hormones** which stimulate growth
      - Dwarfism occurs when too little growth hormone is secreted, and requires the administration of synthetically produced growth hormone to children with GH deficiency to prevent dwarfism
      - Gigantism occurs when too much growth hormone is secreted during childhood
      - Acromegaly occurs when too much growth hormone is secreted during adulthood, after growth has completed
  - Posterior lobe
    - Stores hormones made by the hypothalamus
    - Secretes **anti-diuretic hormone** which controls the volume of urine produced by the kidney
    - Secretes **oxytocin** which regulates milk release during child-birth and nursing

Thyroid Gland:

- Located in the neck, just under the larynx (voice box)

- Produces thyroxine and triiodothyronine, which regulate metabolic rate, ensure normal growth and mental development
    - Undersecretion: weight gain, lethargy, simple goitre (thyroid gland becomes larger)
    - Oversecretion: high body temperature, profuse sweting, weight loss, irritability, high blood pressure, protruding eyes

Gonads (an organ that produces a gamete, a testis or an ovary):

- Gonads produce hormones that control development of male or female sexual characteristics
- Testes of male produce testosterone
- Ovaries of females produce oestrogen and progesterone

Adrenal glands:

- Located on the top of each kidney
- Each adrenal gland has two portions:
    - Adrenal cortex
    - Adrenal medulla
        - Adrenal medulla produces adrenaline under conditions of fear, anger, and anxiety
        - Adrenaline increases metabolic rate, and more energy is released
        - Heart rate and blood pressure increase, and as a result, oxygen and glucose are carried faster to muscles
        - Vasoconstriction of blood vessels in the skin, and vasodilation of blood vessels in the brain and skeletal muscles – hence more blood is sent to brain and skeletal muscles, and a pale skin is observed
        - Blood clot rate increases
        - Enzymes that break down glycogen into glucose are activated
        - Pupils dilate, and hair erector muscles contract (goosebumps)

Pancreas, and the Islets of Langerhans:

- Endocrine cells are found in specialized regions of the pancreas known as the Islets of Langerhans
- The Islets of Langerhans produce two antagonistic (complementary) hormones known that regulate blood glucose levels:
    - Insulin
        - Binds to receptors on liver/muscle cell surfaces, and moderates various enzymes to:
            - Increase uptake of glucose into the cells
            - Convert excess glucose to glycogen for storage in the liver/muscles (known as glycogenesis)
            - Inhibit the breakdown of glycogen to glucose in the liver and skeletal muscle cells
        - Overall effect: Blood glucose concentration reduces
    - Glucagon

        - Binds to receptors on liver/muscle cell surfaces, and moderates various enzymes to:
            - Stimulate the breakdown (by hydrolysis) of glycogen to glucose in the liver (known as glycogenolysis)
            - Inhibit the synthesis of glycogen from glucose in liver and skeletal muscle cells
            - Produce glucose from other sources like amino acids (gluconeogenesis)
        - Overall effect: Blood glucose concentration increases

<u>Diabetes Mellitus</u>

Diabetes mellitus is a hormonal disease caused by a deficiency of insulin or a decreased response to insulin in target tissues. It is characterized by persistent hyperglycemia, where blood glucose concentration is higher than the norm

Type 1 (insulin dependent diabetes):

- Autoimmune disease, where more than 90% of beta cells of beta cells of the Islets of Langerhans are destroyed by the immune system, and are thus unable to produce insulin
- Can be controlled via insulin injection, regulation of diet, and regular exercise to control blood glucose levels
- Generally begins and is detected at an early age

Type 2 (non-insulin dependent diabetes):

- Although pancreas produces insulin normally, body cells gradually become unresponsive to insulin, or become insulin-resistant
- As a result, there is a lower conversion of glucose into glycogen, causing high glucose levels
- Can be controlled via the regulation of diet, regular exercise, and possibly insulin injections if the condition worsens
- Generally appears after the age of 40, but is also seen in younger people who are overweight and sedentary

Symptoms of Diabetes Mellitus:

- Symptoms include weakness, frequent urination (polyuria), excess thirst (polydipsia), increased incidence of infections, slower healing of wounds

Long term complications of Diabetes Mellitus:

- Damange to blood vessels affecting the eye, kidney, and cardiovascular system (due to high blood pressure)
- Kidney diseases
- Foot/leg amputations resulting from infections

Prevention of Diabetes Mellitus:

- Regular exercise

- Healthy diet to control blood glucose levels

Treatment (insulin injections):

- The amount of insulin to be injected into patients has to be properly calibrated, as small amounts of hormones such as insulin can cause large changes.
- Factors include, severity of condition, carbohydrate intake, lifestyle, and type of insulin used

Genetic Engineering of Hormones

- Animal derived insulin (porcine and/or bovine) was widely used to treat diabetes mellitus
- Synthetic insulin was first introduced commercially in the early 1980s
- Other hormones (growth hormones, adrenaline, glucagon, gonadal sex hormones, etc) can also be synthetically produced to treat various conditions

Abuse of Hormones

Growth hormone abuse:

- Some athletes inject themselves with growth hormones to improve performance
- May result is side effects that mirror acromegaly

Anabolic steroid abuse:

- Some athletes use anabolic steroids to gain muscle mass and lose body fat
- May result in side effects such as behavioural, emotional, and physical changes (such as baldness, severe acne, liver abnormalities, heart disease, etc)

Summary (Difference between nervous system and endocrine system)

Nervous system:

- Involves nerve impulses (electrical messengers)
- Impulses are transmitted by neurons
- Quick, but short-lived response
- May be voluntary or involuntary
- Usually localized

Endocrine system:

- Involves hormones (chemical messengers)
- Hormones are transmitted by blood
- Slow response, but response may be short-lived or long-lived
- Always involuntary
- May affect more than one target organ, and target organs need not be located near one another

Topic 1: Cell Reproduction

Cell Division

Functions of cell reproduction:

- Replacement for damaged or dying cells (mitosis)
    - Skin renewal (cheek cells are replaced every 48 hours)
- Growth (mitosis)
    - A single fertilized egg undergoes repeated cell division to grow and form a complete animal
- Asexual reproduction (mitosis)
    - Offspring have the same genotype as their parents, with 2n chromosomes (2n), the same as their parents
- Sexual reproduction (meiosis)
    - Haploid gametes with n chromosomes (half the number as their parents) are produced via meiosis

Mitosis

Definitions:

- Chromatin – the thin, threadlike material which chromosomes are made of
    - Note: when it is short, thick and coiled, it is referred to as a chromosome, but when it is long thin and threadlike then it is referred to as chromatin
- Chromatid – each of the two strands into which a chromosome divides longitudinally during cell division. Note that the chromosome now is made up of two sister chromatids attached together by the centromere
- Centromere – the central point of a chromosome by which it will be attached to a spindle fibre during cell division
- Centriole – the organelle that produces spindle fibres
- Spindle fibre – each short microtubule formed by the centrioles that collectively make up the spindle

Essential Features:

- The cell cycle consists of 3 stages: interphase, mitotic phase, and cytokinesis. This is known as the **cell cycle**.
- The daughter cells receive the same number and types of chromosomes as the parent cell
- The diploid condition (2n chromosomes) is maintained from one generation to the next

1) Interphase:

- Purpose: cell grows and prepares for mitosis
- Has 3 sub-phases:
    - G1: Immediately after cytokinesis and can last months to years in which the cell builds up large stores of energy and manufactures proteins and organelles
    - S: DNA replication occurs, so DNA content in the cell is doubled, but cannot be seen clearly because the DNA material is still in loosely packed chromatin threads
    - G2: The cell continues to build stores of energy and manufactures proteins and synthesizes organelles

2) Mitotic Phase:

- Has 4 distinguishable stages:
  - Prophase
    - Chromatin threads condense, they become shorter and thicker, to form distinct chromosomes
    - Nucleolus disappears
    - Each chromosome is made up of two identical sister chromatids (note that they are identical as DNA replication occurred earlier during S-phase of interphase) which are joined at the centromere
    - Centrioles move to opposite poles of the cell, and short microtubules (known as spindle fibres) develop from each centriole to form the spindle
    - Nuclear membrane breaks down
  - Metaphase
    - The microtubules attach to the centromeres of the chromosomes, and move the chromosomes towards the centre of the cell
    - The mitotic spindle is fully formed, and the chromosomes are lined up at the equator of the spindle
  - Anaphase
    - The sister chromatids are pulled apart at the centromere by the spindle
    - Each sister chromatid moves to the opposite pole of the spindle
  - Telophase (reverse of prophase)
    - Nucleolus reappears, and nuclear membrane reforms
    - Chromosomes uncoil to become long and thin chromatin threads
    - Spindle fibres disintegrate

3) Cytokinesis (division of the cytoplasm):

- Animal cells:
  - A cleavage furrow (an indentation of the cell membrane) pinches the cell into two, producing two identical daughter cells
- Plant cells:
  - A cell plate forms (kind of like a cell wall) in the middle of the cell and grows outwards until it touches the parental walls forming 2 separate cells

Cancer

Uncontrolled cell division (cancer):

- Genes are responsible for normal growth and division, and they produce proteins that act as ‘stop’ and ‘go-ahead’ signals
- When mutations in the genes occur, cancerous cells form
- The cells division goes out of control and the cells divide excessively, forming masses of cancerous cells known as tumours
- Malignant tumours spread to other parts of the body through metastasis, while benign tumours remain at the original site and do not spread

Causes of cancer:

- Age
- Carcinogenic chemicals

- Tar in cigarette smoke
- Radiation
    - Too much exposure to UV in sunlight can cause skin cancer
- Viruses
    - Human papilloma virus can cause cancer of the cervix
- Genetic factor:
    - Cancers such as breast cancer can run in some families

Prevention & Survival:

- Refrain from smoking
- Regular exercise and a high-fibre, low-fat diet
- Avoiding overexposure to sunlight
- Regular health screenings and self examinations

Homologous Chromosomes, Haploids, Diploids

Homologous Chromosomes:

- A diploid cell has two sets of chromosomes, one derived from each parent
- Any two chromosomes that determine the same characteristics are called homologous chromosomes (one chromosome from each parent that determines the same characteristics are called homologous)
- Note that homologous chromosomes only determine the same characteristics, but need not be identical (as the two chromosomes may contain different alleles of the same gene from the two parents)
- There are 22 pairs of autosomes and 1 pair of sex chromosomes (XX in female, XY in male)

Nature of cells:

- Diploid organisms contain a pair of homologous chromosomes of all body cells (autosomes) but not sex cells
- Haploid cells have only one member of each pair of homologous chromosomes, and these cells are sex cells which are a result of meiosis
- During fertilization, a haploid male sex cell fuses with a haploid female sex cell, resulting in a diploid zygote
- The diploid zygote grows via mitosis resulting in a mature adult

Meiosis

Definitions:

- Chiasmata – point of contact between non-sister chromatids of homologous chromosomes
- Bivalent/Tetrad – homologous chromosomes when associated in pairs
-

General information:

- Meiosis results in the formation of gametes, and results in haploid cells that fuse during fertilization to restore the diploid number of chromosomes
- Like mitosis, meiosis has a large interphase period, and in this interphase, replication of DNA occurs
- After the interphase, two phases of meiosis occur: meiosis 1 (prophase 1, metaphase 1, anaphase 1, telophase 1) and meiosis 2 (prophase 2, metaphase 2, anaphase 2, telophase 2)

Interphase (this is largely the same as the interphase of mitosis)

Prophase 1:

- Chromatin threads become shorter and thicker and form distinct chromosomes
- Nucleolus disappears
- Each chromosome is made up of 2 sister chromatids which are joined at the centromere
- Special proteins cause homologous chromosomes to pair up in a process called synapsis, and each pair of homologous chromosomes (each chromosome with its two sister chromatids) forms a bivalent/tetrad
- Chiasmata from between non-sister chromatids, and this is the site of crossing over, which results in the formation of new combinations of alleles on the chromosomes
- Nuclear membrane disintegrates
- Centrioles move to opposite ends of the cell, and short microtubules (known as spindle fibres) develop from each centriole to form the spindle

Metaphase 1:

- Centromeres of chromosomes become attached to individual spindle fibres
- The bivalents arrange themselves at the equator of the spindle
- Note that the arrangement of chromosomes of each bivalent is completely independent of the orientation of other bivalents

Anaphase 1:

- Homologous chromosomes are separated as they are pulled to opposite poles due to the shortening of the spindle fibres

Telophase 1:

- Chromosomes reach opposite poles
- Note that each chromosome is still in duplicate form, with two sister chromatids
- Spindle fibres disintegrate
- Nuclear membrane and nucleolus reform

Cytokinesis:

- Two haploid daughter cells are formed
- Note that meiosis 1 ended resulting in the homologous chromosomes separating into two cells (2n → n)

Note that meiosis 2 is essentially the same as mitosis, just that meiosis 2 starts with a haploid cell that has not gone through chromosome replication during the preceeding interphase.

Prophase 2

Metaphase 2:

- Centromere of each chromosome is attached to the spindle fire, and chromosomes arrange themselves at the equator of the new spindle

Anaphase 2:

- Centromeres divide and are pulled by spindle fibres to opposite poles, carrying the chromatids with them
- Chromatids become the chromosomes of the daughter cells

Telophase 2:

- Sister chromatids reach the opposite poles, and the spindle fibres disintegrate
- Chromatids uncoil and become indistinct chromatin
- Nucleolus and nuclear membrane reform

Cytokinesis:

- Cytokinesis occurs resulting in 4 haploid daughter cells

Note that meiosis 2 has resulted in the separation of sister chromatids

Genetic Variation

- Meiosis results in genetic variation essential for evolution, however plays a small role in evolution as compared to gene mutation
- Genetic variation allows natural selection to occur, and individuals best adapted to the environment survive to reproduce offspring
- Genetic variation allows species to change constantly and adapt when the environment changes

Via **crossing over**

- The formation of chiasma leads to crossing over of segments between non-sister chromatids of homologous chromosomes
- This leads to varied combinations of alleles on the chromosomes of the gametes

Via **independent assortment of chromosomes**

- As the arrangement of bivalents is independent of the arrangement of other bivalents in metaphase 1 (and the subsequent separation in anaphase 1), independent assortment occurs
- With 2 pairs of homologous chromosomes, 2^2 possible combinations are seen in the gametes, and with n pairs of homologous chromosomes, 2^n possible combinations of gametes can be produced (2^{23} in humans)

Via **separation of chromatids**

- The independent arrangement of chromosomes at the equator of the spindle during metaphase 2 and the separation of the chromatids in anaphase 2 results in genetic variation (as either sister chromatid could go to either side)

Via **random fertilisation**

- As a random gamete of the male and a random gamete of the female fuse together, genetic variation occurs
- 64 trillion combinations of chromosomes in humans

Topic 2: Reproduction in flowering plants

Note that asexual reproduction has been omitted, for the purpose of the practical test of T2W2.

Definitions:

- Integuments – tough outer layer of ovule
- Endosperm – the part of the seed which acts as a food store for the developing plant embryo
- Funicle – The seed stalk
- Cotyledon – seed leaves
- Plumule – embryonic shoot
- Radicle – embryonic root
- Calyx – the sepals of the flower, collectively

General information:

- A flower contains reproductive structures, and is either bisexual (has both male and female parts) or unisexual (only male or female parts)

Parts of a flower:

- Pedicle – the flower stalk, and plants with no pedicles are called 'sessile flowers'
- Receptacle – the enlarged end of the pedicle on which the flower structures are attached
- Petals – brightly coloured, sometimes are scented, and are arranged in a circle, and serve to attract insects
- Sepals – modified petals (often green) which protect flowers when in the bud stage. All the sepals together collectively make up the 'calyx'
- Stamen (male reproductive organ)
    - Filament – the structure that holds up the anther in a suitable position to release pollen
    - Anther – located at the top of the filament, it is the source of pollen. It contains 2 lobes, each lobe having 2 pollen sacs
        - When anther matures, the lobes split
        - Pollen is then released
    - Note that all the stamen collectively make up the 'androecium'
- Carpel (female reproductive organ)
    - Ovary
        - Contains one or more ovules
        - Ovule contains female gametes called ovum (plural: ova)
        - Ovary will become the fruit while the ovule will become the seed
        - The region where the ovule is attached to the ovary is called the placenta
    - Style – structure that holds the stigma out
    - Stigma – receives the pollen grain
    - Note that all the carpels collectively make up the pistil or 'gynoecium'

Pollination:

- Refers to the transfer of pollen grains from anthers to stigma
- When the anther splits open, the pollen grains are exposed, and are carried by either wind or insets to the stigmas

Self-pollination:

- Transfer of pollen grain from anther to stigma of the same flower or other flower in the same plant
- As long as pollination occurs within the same plant
- Advantages:
    - Only one parent plant is needed
    - Beneficial qualities are likely to be inherited by offspring
    - Does not depend on external factors for success
    - Less pollen needed for pollination to successfully occur, less energy is wasted
- Disadvantages:
    - Offspring has less genetic variation, and is less adapted to environmental changes
    - Weaker, smaller, and less resistant offspring are formed
- Features favouring self pollination:
    - Bisexual flowers
    - Same maturation times of anthers and stigmas

- Anthers situated just above the stigmas on the same flower
- Cleistogamous flowers (closed flowers) – as flower is closed, self pollination is unavoidable

Cross-pollination:

- Transfer of pollen grains from anther of one plant to stigma of another plant (but of the same species)
- Advantages:
    - Can inherit beneficial qualities from both parents
    - Greater genetic variation, better adapted to changes in the environment
    - More viable seeds, longer dormancy possible (seeds do not die off very easily)
- Disadvantages:
    - Two parent plants are needed
    - Dependence on external factors (wind/insects)
    - More pollen required for successful pollination, more energy wasted in production
- Features favouring cross pollination
    - Dioecious plants – male flowers on one plant, female flowers on another plant (cross pollination would be unavoidable)
    - Different maturation times of anthers and stigmas of the same plant
    - Anthers and stigmas are situated further apart

Wind & Insect Pollination:

Feature	**Wind**	**Insect**
Petals	Small, dull, or absent	Large, brightly coloured
Nectar	Absent	Present (nectar guides may be present on petals)
Scent	Absent	Present
Stigma	Large and feathery, protrudes out of flower to collect pollen	Small and compact, does not protrude out of flower
Stamen	Long and pendulous filaments (with protruding anthers and filaments)	Not pendulous, does not protrude out of flower
Pollen	More abundant, tiny and light with smooth surfaces so they don't stick to each other	Fairly abundant, and larger with rougher surfaces

(Double) Fertilization:

- The pollen grain lands on the stigma, and forms a pollen tube (where the cytoplasm in pollen grain grows out as the tube)
- Each pollen grain has 2 nuclei:
    - Vegetative/pollen nucleus (which moves in front, in the pollen tube)
    - Generative nucleus
- Pollen nucleus secretes enzymes to soften and digest stigma and style tissue to make space for the pollen tube to grow
- Tip of pollen tube grows towards micropyle (a small pore in ovule wall), in response to chemicals secreted by the ovary

- As the pollen tube grows, the generative nucleus (behind the pollen nucleus) divides by meiosis to form 2 gametes
- The tip of the pollen tube, when at the micropyle, absorbs sap and bursts, releasing the 2 male gametes
- One haploid gamete fuses with the haploid ovum to form a diploid zygote, while the other haploid gamete fuses with the definitive/endosperm nucleus to form the endosperm nucleus (3n)
- Hence, termed double fertilization

Post Fertilization Changes:

Flower Part	Change
Ovule	Seed
Zygote	Embryo consisting of plumule (embryonic shoot), radicle (embryonic root) and cotyledons (seed leaves)
Endosperm nucleus	Endospermic plants: endosperm (stores food for growing plant) Non endospermic plants: endosperm which is absorbed by the embryo (food is eventually stored in cotyledons instead)
Integuments	Testa (seed coats)
Ovule stalk	Funicle (seed stalk)
Ovary	Fruit
Ovary wall	Pericarp (fruit wall)
Stigma and style	Wither, but may persist to help in fruit dispersal
Stamen and Petals	Wither
Sepals	Wither, but may persist to help in fruit dispersal

Fruit Anatomy:

- Pedicle – the pedicle of the flower remains as the pedicle of the fruit
  - In some cases, the pedicle may not be present in which case there would be a scar left behind from attachment to the receptacle
- Funicle (seed stalk) – attaches seed to placenta
- Fruit chambers (loculi)
  - May be filled with juicy pulp (example: tomato)
  - May remain as empty spaces (example: pea)
  - Note that the arrangement of ovules in the fruit chambers determine how the seeds are arranged in the fruit
- Pericarp – outer covering of fruit (either dry, such as in peanuts, or fleshy, such as in tomatoes and pumkins)
  - Exocarp (outermost layer)
  - Mesocarp (middle layer)
  - Endocarp (innermost layer surrounding seed)

Function of fruit:

- To protect the seeds and embryo within it
- To help in seed dispersal

Seed Anatomy:

- Testa – seed coats
- Embryo – consisting of the radicle, plumule, cotyledon
- Micropyle – pore where the pollen tube enters, and serves to allow water and air to enter for germination
- Hilum – a scar that indicates the original position of the funicle (seed stalk)

Dicotyledonous Seeds:

- Have 2 cotyledons
- Have little or no endosperm, as food reserves are stored in the cotyledons
- They contain the immature plant (embryo) surrounded by the seed coat (testa)

Monocotyledonous Seeds:

- Have 1 cotyledon
- Store food reserves in the endosperm

Dispersal

Importance:

- To avoid overcrowding or competition for resources (like light, water, and food) with parent plants
- Enable plants to colonize new favourable habitats
- Reduce the spread of diseases due to proximity of plants

Explosion:

- The pericarp dries and contracts or twists suddenly, and as a result splits open with great force to throw out seeds
- Examples: balsam, clitoria legume

Wind:

- Have wings or hairs that aid in carrying the seed through wind
- Dry, so as to reduce weight
- Enlarged surface area (to be easily carried by the wind)
- Small, light seeds
- Examples: angsana fruit, tecoma seed

Animals (through droppings):

- Usually edible, and are sweet smelling to attract animals
- Tough seed coats in order to withstand action of digestive enzymes
- Seeds eventually pass out of animal droppings
- Examples: papaya, kiwi,

Animals (through body attachment):

- Have attachments (hooks or hairs) on seed coats or fruit wall
- Fruits or seeds cling on to animal bodies and are dispersed at a later location
- Examples: spear grass fruit, urena fruit

Water:

- Waterproof fruit surfaces
- Light (to ensure that fruit/seed floats) and contains aerated or spongy parts (to aid floating)
- Examples: coconut fruit, lotus seed

Post Dispersal:

- Pericarp (fruit wall) breaks down
- Seeds are released
- Seeds germinate if favourable conditions are present, and the embryo will grow and develop into new plants

Asexual Reproduction

Note: In asexual reproduction, mitosis occurs (not meiosis), so the parent plant and the daughter plant are not genetically different.

Sexual VS Asexual reproduction:

Asexual	Sexual
One parent (no fertilization)	Two parents (fertilization required)
Daughter cell has identical genetic make up as parent	Daughter cell has different genetic makeup as parent
Mitosis	Meiosis
Examples: Hydra (budding), planarians (fragmentation)	Examples: Humans, flowering plants

Forms of asexual reproduction:

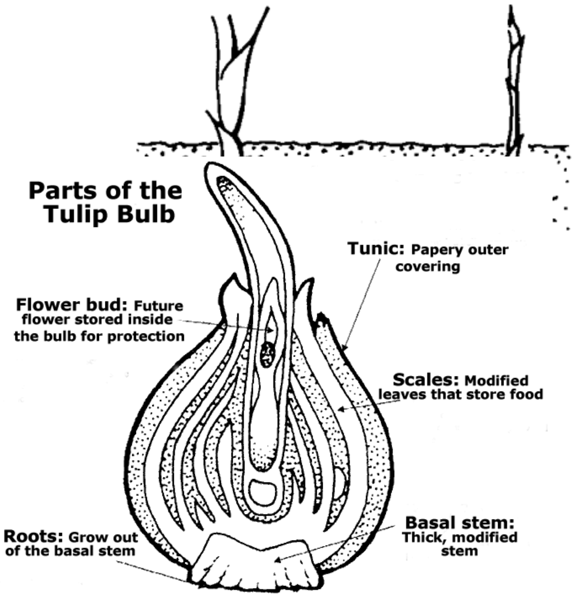
- In simple organisms:
    - Binary fission (unicellular organisms, which split into two)
    - Spore formation
    - Budding (where an outgrowth occurs at one site of the parent organism, which remains attached as it grows and only detaches from parent organism when fully developed)
    - Fragmentation (one organism is split into fragments, and each of these fragments develops into a new daughter organism)
- In flowering plants: vegetative propagation

Vegetative propagation:

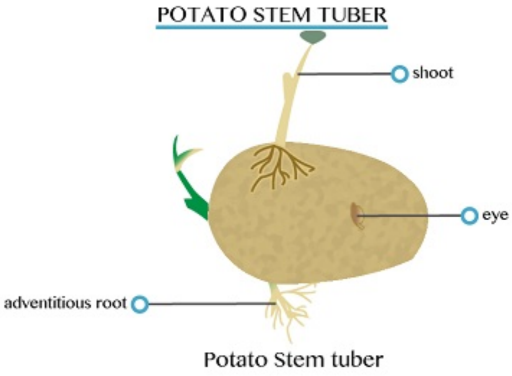
- The process by which new flowering plant individuals arise without the production of seeds, where part of the parent plant is used to form the new plant
- (Which ultimately detaches from the parent plant upon maturity)
- Include the use of underground storage organs (like rhizomes, bulbs, tubers, corms) or even runners and leaves

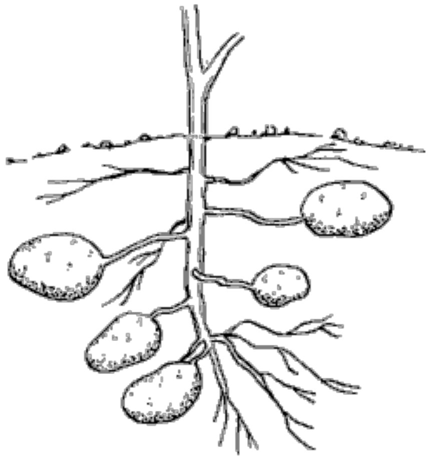
Underground storage organs:

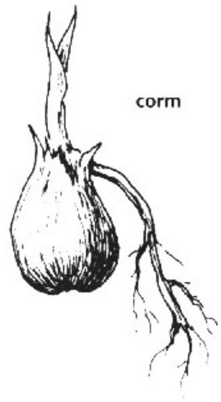
- Act as perennating organs (organs used to survive harsh, adverse conditions)
    - Underground storage organs lie dormant under the soil while the plant above ground may die off
    - When favorable conditions return, new shoots regenerate from storage organs to form new plants
    - Newly formed leaves photosynthesize to produce more food that is stored in newly formed storage organs
    - This process repeats, allowing plants to survive from one growing season to the next
- Rhizome
    - Horizontal underground stems
    - Examples: Ginger, asparagus, turmeric
    - Contains scale leaves, buds, and roots (therefore potential for propagation)
    - Note: if separated into pieces and replanted into soil, each piece may give rise to new plant



- Bulbs
    - Vertical underground shoots with flattened disc-like stems
    - Example: shallots
    - Closely set fleshy scale leaves
    - Roots at the base of bulb
    - Note: bulbs may be dug up and replanted elsewhere to form new plants
- Tubers
    - Perennating organs to allow plants to survive to the next growing season
    - Either stem tubers or root tubers
    - Examples: potato (stem tuber), yam (root tubers)
    - How they work:
        - Food storage organs with the presence of buds
        - Every plant will develop a few new tubers (stem or root) before the end of the survival season
        - Plant will die off, but tuber will remain dormant underground
        - Each tuber has a bud end and a stem end
        - When new survival season arrives, then new plant grows out of tuber (through the bud end)
    - Note: if dub up and replanted, they can be artificially propagated







- Corms:
  - Swollen short vertical stem, that serves to store food
  - Example: taro
  - Has scale leaves and buds (therefore potential for vegetative propagation)
  - Can be replanted giving rise to new plants

Runner:

- Stems that grow horizontally above ground
- Example: strawberry
- At nodes, buds form which can grow into new plants

Leaves:

- New individual plantlets develop along the parent leaf margin
- Example: bryophyllum
- Plantlets eventually detach themselves and take root themselves, forming a new plant

Advantages of vegetative propagation:

- Offspring are genetically identical (advantageous traits can be kept)
- Only 1 parent plant is required (eliminates necessity for pollination/fertilization)
- Much faster than sexual reproduction
- Perennating organs allow plants to survive and thrive despite unfavorable conditions

Disadvantages of vegetative propagation:

- Lack of genetic variation makes plants more prone to diseases that can wipe out entire crop
- Many plants are produced in a short amount of time → may lead to overcrowding and competition for resources

<u>Germination</u>

Germination: Process by which a plant develops from a seed

Embryo (miniature plant)

- Plumule: embryonic shoot
- Radicle: embryonic root
- Cotyledons: seed leaves that are attached to the shoot and store food to nourish the germinating seed
- Testa: seed coat that the embryo and cotyledon are enclosed in

Germination process:

- Seed absorbs water through the micropyle and swells to the point the testa rupture

- Hydration activates enzymes in the cotyledon which begin to digest food stroed in the cotyledons and endosperm
- Digested food is translocated to plumule and radicle, and is used to:
    - Provide energy
    - Synthesize new plant parts (like the cell wall)
    - Produce new enzymes
- Radicle grows out of split testa and grows downwards forming lateral roots to absorb water and mineral salts
- Plumule emerges between cotyledons and grows upwards out of the soil, leaving the testa in the soil

- Over time, food tissue (cotyledons/endosperm) shrink as food supply is used up by respiration (dry mass decreases)
- Plumule starts to produce green leaves, at which point it can photosynthesize and produce its own food (dry mass starts to increase) → at this point it is known as a seedling

Conditions for germination:

- Water
    - Soften testa to allow it to rupture easily
        - Allows for carbon dioxide and oxygen to diffuse in and out easily,
        - Allows the radicle and plumule to emerge from seed
    - Acts as medium for metabolic reactions like photosynthesis and digestion
    - Required to activate and produce enzymes
    - Transports nutrients to various regions of embryo
    - Expands vacuole of newly formed cells (allowing for the roots, shoots and leaves to grow and expand)
    - Maintains turgor of cells → helps keep the shoot upright, leaves expanded, allows for the radicle and plumule to be tough enough to move through soil, etc.
- Oxygen
    - Oxygen is used for aerobic respiration and other metabolic processes
- Temperature
    - Optimum temperature required for chemical reactions
    - Note that this should not exceed 45^{o}C to ensure that enzymes are not denatured (otherwise, seedling will get killed off)

Artificial Selection

Artificial Selection: Process by which humans breed other organisms for particular traits, by carefully planting seeds with better genetic combinations, allowing for higher yield, shorter growth time, pest resistance, drought resistance, etc.

Process:

- Genetic variation occurs in the wild population
- Seeds for next generation are chosen only from individuals with the most desirable traits

- If this process is repeated for several generations, over time the quality of crops increases

Hybridization: The crossing of different varieties of plants to produce better varieties

- Example: sugar cane
    - Javanese sugar cane is high in sugar content but susceptible to pests and diseases while Wild sugar cane is low in sugar content but resistant to diseases and pests
    - Crossing these 2 strains can produce a hybrid that yields high sugar and is resistant to drought and pests

Hybridization process:

- Farmers transfer pollen from flowers of one desired plant to flowers of other desired plant manually
- Hybrid offspring are produced as a result, and the process may be repeated for better results

Molecular Genetics

Chromosomes:

- Histones are proteins used to package DNA in eukaryotes
- A nucleosome is essentially just DNA wound around histone molecules
- A chromosome is essentially nucleosomes wound around and further coiled and folded

Nucleic Acids:

- 2 types: DNA and RNA
- Consist of subunits called nucleotides, which consist of three substances combined together:
    - Nitrogenous base
        - DNA nitrogenous bases: A (adenine), G (guanine), C (cytosine), T (thymine)
        - RNA nitrogenous bases: A (adenine), G (guanine), C (cytosine), U (uracil)
        - G pairs with C → 3 hydrogen bonds
        - A pairs with T (in DNA), A pairs with U (in RNA) → 2 hydrogen bonds
    - Pentose sugar
    - Phosphate groups
    - Note: Sugar-phosphate groups form the backbone of the nucleic acid, and the nitrogenous bases are attached to each sugar along the strand
- A nucleotide is a monomer, its polymer being called a polynucleotide

DNA:

- Purines & pyrimidines:
    - Purine bases: A & G
    - Pyrimidine bases: C & T (and U)
    - Note: it is always 1 purine and 1 pyrimidine that bind together

- Rosalind Franklin, through X-ray diffraction found that DNA is long and thin
- Chargaff's ratio:
    - Number of A = Number of T
    - Number of G = Number of C
    - Named after the scientist who discovered this ratio – Edwin Chargaff
- Double Helix:
    - Analogous to a rope ladder
        - Ropes at sides represent sugar-phosphate backbones
        - Each ladder rung represent a pair of complementary bases connected by hydrogen bonds
    - Discovered by Watson and Crick
- Sugar-phosphate backbone:
    - Consists of 1 pentose sugar and 1 phosphate group
    - Alternate
        - Every 1 pentose sugar is connected to 2 phosphate groups
        - Every 1 phosphate group is connected to 2 pentose sugars
        - Nitrogenous bases are connected to pentose sugars
    - Note that 1 nucleotide has 1 pentose sugar, 1 phosphate group, 1 nitrogenous base

DNA vs RNA:

DNA	**RNA**
Long strands (millions of nucleotides long)	Short strands (100-1000 nucleotides long)
Pentose sugar is deoxyribose	Pentose sugar is ribose
Bases: A,G,C,T	Bases: A,G,C,U
2 polynucleotide strands of complementary base pairs held together by hydrogen bonds in a double helix	1 polynucleotide strand in 3 forms: mRNA, tRNA, rRNA
Found mostly in nucleus (but also in mitochondria and chloroplasts)	Synthesized in nucleus but found mainly in cytoplasm

DNA Replication:

- The process of producing a complete copy of DNA
- Semi-conservative hypothesis:
    - DNA helicase unzips the double helix DNA into 2 strands and by separating the nitrogenous bases at the hydrogen bonds → both strands of DNA separate and act as templates for the synthesis of 2 new strands
        - Note that the point of separation is called the 'replication fork'
    - DNA polymerase assembles free floating nucleotides to each of the single strands of the parental DNA molecule
    - Hydrogen bonds form between bases of one old and one new strand to form 2 DNA molecules
    - Each daughter cell inherits 1 DNA molecule
    - DNA molecule is hybrid – consisting of one old and one new strand

Why Produce RNA:

1. The production of RNA reduces damage to the DNA by producing a temporary copy

a. An error or mutation in the RNA would not result in major consequences for the organism, as compared to an error or mutation in the template DNA

2. Multiple copies of RNA can be produced from a single copy of DNA (which acts as a template), and as such huge numbers of polypeptides can be produced from 1 copy of DNA

Genotype-Phenotype Relationship:

- Genotype: An organism's genetic makeup (in other words, the sequence of nucleotide bases in its DNA)
- Phenotype: An organism's physically observable traits, which arise from the actions of a variety of proteins
- Archibald Garrod suggested that:
    - Genes dictate phenotypes through enzymes
    - Inherited diseases reflect a person's inability to make a particular enzymes, due to similarity in genes passed down
- Beadle and Tatum suggested that:
    - The function of an individual gene is to dictate the production of a specific enzyme
    - Each mutant is defective in a single gene
- 1 gene – 1 polypeptide hypothesis:
    - Function of a gene is to dictate the production of a polypeptide
    - A protein consists of 2 or more polypeptides (for example, haemoglobin which is made up of 2 alpha and 2 beta polypeptide chains)
- DNA specifies the synthesis of proteins in 2 stages:
    - Transcription: The transfer of genetic information from DNA into an mRNA molecule (occurs in the nucleus, but the mRNA then moves out into the cytoplasm)
    - Translation: The transfer of information from mRNA into proteins (occurs in cytoplasm)
- Overview: DNA strand → RNA → Polypeptide
    - 1st arrow: Transcription
    - 2nd arrow: Translation

Genetic Code:

- Codon: A triplet of bases on the mRNA that codes for a single amino acid
- Genetic code: A set of rules that convert a series of nucleotides in the mRNA to a sequence of amino acids
- Start codon is AUG (as such, first amino acid is always MET)
- Three stop codons (UAA, UAG, UGA)

Transcription:

- Initiation:
    - RNA polymerase finds the promoter (the binding site for RNA polymerase onto the DNA)
- Elongation:
    - The 2 DNA strands are separated at the site of the RNA polymerase
    - As RNA nucleotides base pair one by one with the DNA bases on the DNA template strand, RNA polymerase links the RNA nucleotides into a single RNA chain
    - The RNA strand grows longer and peels away from the DNA template

- Termination:
  - When RNA polymerase reaches the terminator (the site where RNA polymerase will detach from the DNA), RNA molecule detaches from DNA
  - DNA strands rejoin
- Processing RNA in the nucleus:
  - Additional nucleotides are added at the ends of the RNA transcript to form the cap and tail
    - The cap and tail protect the RNA transcript from other enzymes
    - They also help ribosomes recognize the RNA as mRNA
  - Introns (no-coding regions) are removed, and extrons (coding regions) are spliced together
    - Note: When the mRNA moves out of the nucleus, there should be no introns
  - The final mRNA, now, moves out of the nucleus into the cytoplasm

Translation:

- tRNA:
  - The function of tRNA is to match amino acids to the appropriate codons on the mRNA to form a polypeptide
  - tRNAs have a generally similar structure, but are slightly different from one another for each amino acid
  - tRNA is a strand of RNA that twists and folds upon itself, and some of its bases undergo pairing (via hydrogen bonding)
  - On one end, the tRNA has an anticodon and on the other end has an amino acid attachment site
- Ribosomes:
  - The function of ribosomes is to coordinate the functioning of mRNA and tRNA
  - Ribosomes have two subunits, made of proteins and rRNA:
    - Smaller unit: Binds to mRNA
    - Larger unit: Has 2 tRNA sites
      - P site: Holds the tRNA carrying the growing polypeptide chain
      - A site: Holds the tRNA carrying the next amino acid that is to be added to the chain
  - When the anticodon on the tRNA base pairs with the codon on the mRNA, the ribosomes hold the mRNA and tRNA together
  - Ribosomes then connect a new amino acid from the tRNA in the A site to the growing polypeptide chain in the P site

Translation:

- Initiation:
  - An mRNA molecule binds to the smaller ribosome subunit
  - Initiator tRNA binds to the start codon on the mRNA (as the start codon is AUG, the amino acid attached is methionine)
  - A larger ribosome subunit will attach to the small subunit to form a fully functional ribosome
    - The initiator tRNA fits into the P site of the ribosome
- Elongation:
  - The anticodon of the next tRNA pairs with the mRNA codon on the A site of the ribosome

  - The polypeptide in the P site attaches to the amino acid in the A site, then leaves the tRNA (in the P site)
  - The P site tRNA leaves the ribosome
  - The ribosome moves the remaining tRNA carrying the polypeptide from the A site to the P site
  - The cycle continues
- Termination:
  - Translation stops when the stop codon is reached
  - The polypeptide is released from the tRNA
  - The ribosome splits back into its two subunits

Mutations:

- A mutation is the change in the chromosome number:
  - A change in the chromosome number occurs when there is non-disjunction (failure to separate) in meiosis
    - Either in meiosis 1, where homologous chromosomes fail to separate, resulting in 2 cells with n+1 chromosomes and 2 cells with n-1 chromosomes
    - Or in meiosis 2, where sister chromatids fail to separate, resulting in 2 cells with n chromosomes, 1 cell with n+1 chromosomes and 1 cell with n-1 chromosomes
  - An extra chromosome 21 results in Down's Syndrome (Trisomy 21)
    - Characteristics of Down's Syndrome are: folded skin in inner corner of eye, round face, flat nose, short height, heart defects, etc.
  - Abnormal number of sex chromosomes
    - XXY – Klinefelter's Syndrome, non-disjunction of egg (XX) or sperm formation (XY)
    - XYY – Normal male, non disjunction in sperm formation (YY)
    - XXX – Normal female, non-disjunction in egg (XX) or sperm formation (XX)
    - X_ - Turner Syndrome, non disjunction in egg (--) or sperm (--) formation
  - Polyploidy – the heritable condition of having more than 2 sets of chromosomes
    - May happen in humans due to polyspermy (where 2 or more sperms fertilize 1 egg)
    - Occurs commonly in plants
- A mutation is also the change in the structure of a gene:
  - Gene mutation arises as a result of chemical changes in a gene, involving a change in one or more bases
  - An alteration in the sequence of nucleotides affects the sequence of amino acids in a polypeptide, and eventually the phenotype of an organism. As such, gene mutation can result in heritable diseases
  - A point mutation involves the change in only 1 nitrogenous base
  - Frame-shift mutations (deletion or insertion of one or more nucleotides):
    - Ribosomes will begin to read incorrect triplets from the point of deletion/insertion and onwards
    - Non functional proteins can be produced, drastically affecting the phenotype of the organism
    - Deletion or addition of 3 nucleotides may not be as serious as 1 or 2 nucleotides as now only 1 extra/less amino acid will be present, but the rest of the amino acid sequence in the polypeptide remains the same
  - Substitution is where one base is replaced by another:
    - Sickle cell anaemia is the result of point mutation (substitution) in the gene for beta haemoglobin

        - Glutamic acid is substituted with valine as the second base in the GAA codon is changed to GUA
        - While healthy haemoglobin is globular, sickle-cell haemoglobin is fibrous and a s such the cell becomes sickle-shaped and is ineffective in carrying oxygen and may obstruct blood vessels, leading to certain organs being deprived of oxygen. Also, the red blood cells accumulate easily in the spleen for destruction, resulting in an enlarged spleen
        - It is a homozygous recessive disorder
            - Sufferers have 2 copies of defective allele
            - Both parents must carry defective allele
        - Heterozygous people suffer from the trait too – as both alleles are expressed (co-dominance), their blood contains both healthy and abnormal haemoglobin, but are generally healthy
        - Heterozygotes have an advantage because the malaria parasite cannot complete its life cycle in a sickle-shaped cell. As such, they are generally healthy, and also have immunity from malaria.
    - Inversion:
        - A sequence of nucleotides is inverted
        - The sequence of this portion is reversed (resulting in the production of a different sequence of amino acid in the polypeptide)
- Causes:
    - Spontaneous mutations result from errors during DNA replication or recombination
    - Mutagens are agents that cause mutations
        - Physical mutagens: UV light, X-rays, etc.
        - Chemical mutagens: Some may be carcinogenic and result in cancer

Patterns of Inheritance

Definitions:

- Gene: A unit of inheritance made up of a heritable sequence of nucleotides along a DNA molecule which codes for a polypeptide
- Locus: The position on a chromosome where a gene resides
- Allele: An alternative form of one gene which occupies the same locus on a pair of homologous chromosomes
- Phenotype: The expressed or observable characteristics of an individual, usually resulting from the interaction between the genotype and the environment in which development occurs
- Genotype: The genetic makeup of an organism with respect to the alleles under consideration
- Dominant allele: The allele that shows its phenotype in a homozygote or a heterozygote
- Recessive allele: The allele that shows its phenotype only in the presence of another identical recessive allele
- Co-dominance: The state in which both alleles are equally expressed in the phenotype in the heterozygote condition
- Incomplete dominance: The state in which the heterozygote expresses a phenotype that is intermediate between the two homozygous forms (eg. A pink flower arising from the cross between homozygous white and homozygous red)
- Homozygous: The diploid condition in which the alleles at a given locus are identical (AA or aa)

  - An organism is considered pure bred if it is homozygous for the trait concerned
- Heterozygous: The diploid condition in which the alleles at a given locus are different (Aa)

Monohybrid inheritance:

- A monohybrid cross is a cross between purebred parents that differ in only 1 character
  - Crossing over of two such varieties is called hybridization
- When pure bred plants with different traits are crossed:
  - P generation: AA x aa
  - F1 generation: Aa
  - F2 generation: AA, Aa, Aa, aa
- Thus, 3:1 is considered the monohybrid ratio

Mendel's Law of Segregation: Allele pairs segregate during gamete formation (out of two alleles a parent has, each gamete only has 1 of these alleles)

Test Cross:

- The purpose of a test cross is to reveal the genotype of an organism that exhibits the dominant trait (and might thus either be homozygous dominant or heterozygous)
- The organism concerned is crossed with an individual expressing the homozygous recessive trait
- Results:
  - All show the dominant trait – the organism was homozygous dominant
  - Half show dominant trait, half show recessive trait – the organism was heterozygous

Dihybrid Inheritance:

- The inheritance of two pairs of contrasted characteristics
- The dihybrid inheritance ratio for the F2 generation is 9:3:3:1
- Note that observed ratio and expected ratio will be close when:
  - Fertilization is random
  - The offspring have equal chance of survival
  - Large numbers of offspring are produced

Independent Assortment: Alleles for certain traits are assorted independently of alleles for other traits.

Multiple alleles:

- If a gene controlling a particular characteristic has more than 2 alleles, the alleles are called multiple alleles, but note that at most 2 alleles are present in any one individual
- Example: A, B, and O alleles for inheritance of blood group in humans
  - Both I^A and I^B are dominant to I^O

- As such, in the $I^A I^B$ heterozygote, they are expressed equally in the phenotype (blood group AB)

Sex Linkage:

- Sex linkage refers to the carrying of the genes on the sex chromosomes
- The genes are mostly located on the X chromosome (as the Y chromosome is far shorter)
- Sex-linked characteristics are non-sexual characteristics controlled by genes found on the sex chromosomes (such as haemophilia and red-green color blindness in humans)

Family Pedigree

Continuous and Discontinuous Variation:

- Discontinuous variation refers to traits that can be classified as an either-or basis
  - Controlled by one gene
- Continuous variation vary along a continuum and across a range of observable traits
  - Controlled by more than one gene (known as polygenic inheritance)

Effect of Environment on Phenotype:

- For traits determined by continuous variation, environmental factors (such as nutrition, exercise, etc. for height) affect the phenotype
- However, effects of the environment are not passed on from one generation to the next, and only genetic influences are inherited.

Genetic Engineering

Definitions, Overview, Methods, Process

Genetic Engineering: The direct manipulation of genes for practical purposes (such as medicine, agriculture, industries, and research)

Chimera: An organism containing a mixture of genetically different tissues

Genetic Engineering:

- Involves transferring genetic material from one cell to another
  - Between same species
  - Or between different specie → results in a transgenic organism (eg. GloFish)
- An organism is called genetically modified if its genome is changed via genetic engineering

DNA Cloning (using bacterial plasmids):

- A set of experimental methods to create multiple copies of an **isolated** DNA fragment
  - To enable manipulation of specific regions of the genome
  - To produce large amounts of target DNA
- Plasmid: Pieces of DNA material exchanged between bacteria
  - Extrachromosomal molecules that are small, double stranded and circular
  - Contain genes coding for enzymes that are beneficial to the bacteria
  - Can self replicate (independently of chromosomal DNA)
- DNA molecule is cut with a restriction enzyme to obtain the chromosomal DNA fragment while the vector DNA is also cut with the same restriction enzyme to generate complementary base sequences
- Vector (a virus, plasmid, etc.) and chromosomal DNA fragments are joined using DNA ligase
- Recombinant DNA molecule (plasmid) is introduced into DNA molecule (then called 'recombinant DNA molecule')
- Recombinant plasmid self-replicates to produce multiple copies in same host bacterium
- When bacterium divides, recombinant plasmid also replicates and passes onto its descendants
- Rapid reproduction of recombinant bacteria produces even more copies of target DNA
- Note: After plasmids are introduced in to the bacteria, they are grown on an agar plate in isolated colonies → after large colonies have formed, the colonies will be each tested and the appropriate ones will be used

Restriction Enzymes: Enzymes found naturally in bacteria to digest foreign (viral) DNA

- Each restriction enzyme only recognizes a specific DNA sequence (restriction site) that is palindromic (identical in reverse), example:
  - (5') GGGATCC (3')
  - (3') CCTAGGG (5')
- The restriction enzyme will then cut both DNA strands at the exact same precise point in the restriction site, while also cleaving the sugar phosphate backbone
- Note: the restriction site is like a general site of binding, but the cut will be made after a precise nucleotide (example: EcoRI will cut GAATTC after the 'G' nucleotide)
- Blunt ends: double sided ends
- Sticky ends: single stranded overhangs
- Two molecules of DNA digested using the same restriction enzyme will have complementary sticky ends (as both DNAs will have exposed nucleotides that can undergo complementary base pairing by hydrogen bonding)

Use of restriction enzymes:

- Restriction enzymes are used on both chromosomal DNA and the plasmid:
  - On the chromosomal DNA – to isolate target DNA from the genome (to only use what is necessary)
  - On the plasmid – to cut the plasmid such that the foreign target DNA can be inserted

Selection of restriction enzyme:

- Rule 1: Both plasmid and target DNA must be cut with same restriction enzyme (to produce complementary sticky ends)
    - This rule can be ignored if restriction enzyme produces blunt ends – then any two blunt end restriction enzymes can be used
- Rule 2: Target DNA sequence must not have restriction sites of the restriction enzyme within it (this will result in cutting DNA sequences within the target DNA)

Multiple cloning site:

- Plasmids used in DNA cloning are engineered to have a multiple cloning site (polylinker)
- Multiple cloning site: A short DNA segment containing several restriction sites
- Note that all restriction sites in the MCS must be **unique** (must only occur once)
- A MCS provides a wider choice of restriction enzymes to cut the plasmid → even if some of the restriction sites appear in the target DNA sequence, the other restriction enzymes can still be used
- Target DNA sequence is inserted at the MCS
- A promoter sequence before the MCS enables the inserted target DNA fragment to be transcribed

DNA Ligase: Joins DNA fragments by repairing the sugar phosphate backbones

- Note: The complementary base pairing occurs through hydrogen bonding, but this does not fix the sugar phosphate backbone → this is fixed via DNA ligase

Reaction conditions:

- Digestion of plasmid (use of restriction enzymes) is performed at 37^{o}C while ligation (use of DNA ligase) is performed at 16^{o}C
    - These enzymes denature at temperatures higher than their optimal temperatures, and become inactive at cooler temperatures

Bacteria transformation: Process by which foreign DNA is introduced into a cell

- Heat shock transformation:
    - Bacteria and plasmid are both first exposed to a Ca^{2+} rich environment under cold conditions (for 0.5h)
        - The Ca2+ ions neutralize negative charges on the bacterial cell wall and the sugar phosphate backbone of the plasmid
        - Reduced electrostatic repulsion occurs, as a result, and the bacteria cell wall is weakened
        - This makes the bacteria more competent to take up foreign DNA
        - Cold temperature reduces kinetic motion of the bacteria so the bacteria and plasmid can adhere
    - The mixture of the bacteria and plasmid is then exposed to a heatshock (at 42^{o}C) for 0.5 – 2.5 min
        - The high temperature increases the fluidity of the bacterial cell membrane and may induce the formation of pores
        - As such, plasmid DNA can enter easily
    - Incubate the mixture on ice for 1-2 mins
    - Add nutrient medium and incubate at 37^{o}C for 1h

        - This would allow surviving bacteria to recover
    - Grow bacteria on agar plate containing antibiotic overnight
- Electroporation
- Sonication

Selection of transformed bacteria:

- Not all the bacteria will take up the plasmid (therefore, not all the bacteria will be *transformed bacteria*)
- Plasmids have a marker (antibiotic resistance) which will help identify the transformed bacteria
- As the growth medium (agar plates) have antibiotics, all non-transformed bacteria will die off, while transformed bacteria will form colonies on the agar plate

Notes:

- Apart from the target DNA sequence, a gene marker must also be selected to allow for the identification of transformed bacteria
- A plasmid with a multiple cloning site should be used

Applications and Ethics of Genetic Engineering

Large scale production of recombinant protein:

- Human insulin, growth hormones and other proteins are produced by producing recombinant bacteria which is then fermented for mass production
- Case Study: Hep B vaccine
    - Gene for Hep B virus coat protein is cloned into a vector and introduced into yeast
    - Transformed yeast cell divides rapidly to produce large amounts of viral protein in fermenter
    - Protein is given as a vaccine to cause production of antibodies against Hep B

Gene Therapy: The use of DNA as a drug to treat disease by introducing therapeutic DNA into a patient's cells

- Overview:
    - The gene of interest is isolated and cloned
    - The gene is inserted into a vector to produce a chimera (an organism containing a mixture of genetically different tissues)
    - The chimera is introduced via one of two approaches:
        - Ex vivo approach:
            - The human body cells are harvested, and the chimera is then introduced into those cells
            - The transfected cells are reintroduced into the body
        - In vivo approach:
            - The chimera is directly introduced into the human body
- Viral vectors (modified vectors that cannot replicate in humans):

- Pros:
  - More efficient at entering human cells
  - Can be modified to be specific for certain cell types
  - Delivered gene may integrate into the genome and be replicated as the patient's cells undergo mitosis
- Cons:
  - Cannot carry too much genetic material
  - May induce an immune response

- Non-viral vectors (naked plasmid DNA, which are introduced into *liposomes* (microscopic oil drops))
  - Pros:
    - Large genes can be cloned into plasmids
    - More suited for the ex vivo approach
  - Cons:
    - Low efficiency in integrating into the patient's genome
    - Non-specific for cell types
    - Liposomes may be toxic
- Case study: Cystic Fibrosis
  - Cystic fibrosis results from a defective gene for a cell membrane protein, resulting in the production of thick sticky mucus in airways (patient is susceptible to infections)
  - Viral vector treatment:
    - Normal gene is inserted into viral genome
    - Virus is sprayed into nose/lungs
    - Virus triggers an immune response → low rate of entry into cell
  - Non-viral vector treatment:
    - Gene is placed in liposomes (microscopic oil drops) and sprayed into nose/lungs
    - Liposome is toxic → low rate of entry into cell
  - As all methods of gene therapy are largely ineffective, research is still ongoing
- Case study: Severe Combined Immune Deficiency (SCID)
  - A genetic disorder affecting lymphocytes
  - Stem cells are isolated from bone marrow harvested from a baby's hip
  - The normal gene is inserted into the stem cells externally, in a lab
  - The corrected cells are then transfused back into the baby and populate over time, repairing the baby's faulty immune system

Genetically Modified Organisms (GMOs):

- Genetically modified plants:
  - Plants with traits such as pest resistance, herbicide resistance, improved quality, medical properties (such as the production of a viral vaccine using bananas) or for plant material factories
  - Agrobacterium mediated transformation (where genes of interest are introduced into the DNA of plants)
    - Example: Bt gene is engineered into corn plants to produce toxins that kill caterpillars
- Process (agrobacterium mediated transformation):
  - Plasmid is removed from bacterium, and the DNA is cut by restriction enzyme
  - Foreign DNA is cut by same enzyme
  - Foreign DNA is inserted into DNA of the plasmid, and ligated
  - Plasmid is reintroduced into bacterium

  - Bacterium is used to insert target DNA carrying gene into the chromosome of extracted plant cells
  - Extracted plant cells (now with target DNA) are grown in a culture, and are now called explants
  - A plantlet is generated from each explant, and all of its cells carry the foreign gene (also note that all explants are genetically identical, due to the use of genetic markers that kill of non transformed cells)

Genetically modified animals:

- Case Study: Production of human anticoagulant milk
  - Target DNA is inserted into vector
  - Vector is microinjected into embryo, which is transferred into recipient females
  - Offspring produces anticoagulant milk

Biomedical Research (genome sequencing):

- Process:
  - Cut DNA from many copies an entire chromosome into overlapping fragments short enough for sequencing
  - Clone the fragments in plasmids
  - Sequence each fragment, and use computer software to order the sequences into one overall sequence
- Human genome project: aims to sequence the entire human genome, allowing for:
  - Understanding of diseases, personalized medicines, further research
  - Development of genome libraries that allows us to compare human genome with other genomes to deduce gene function and evolutionary relationships

Risks and ethical issues:

- Environmental issues:
  - Nontarget creatures could be hurt due to the genetic modification of crops to include insecticides, etc.
  - Production of 'superweeds' as genes with ability to resist pests get found in weeds
  - Failure of GM crops due to evolution (reduced effectiveness of pesticides)
- Human health:
  - Allergy to transgenic food
  - Spread of antibiotic resistance to pathogenic bacteria
- Ethical issues:
  - Animals are used as means to ends (property of humans)
  - Painful side effects to animals
  - Altering the natural order of the universe, by means of producing transgenic animals (and as a result, even producing entire species)
  - Patents on GM food may affect people on varying ends of the socioeconomic scale differently

Evolution and Natural Selection

Lamarck's Hypothesis of Evolution:

- Use and Disuse:
    - Parts of the body that are used extensively become larger and stronger while those that are not used deteriorate
- Inheritance of acquired characteristics:
    - An organism can pass on these modifications to its offspring
- Example:
    - Giraffes stretching their necks to reach leaves high in trees strengthened and gradually made their necks longer and stronger
    - These giraffes have offspring that have slightly longer necks
- Disproved by germplast theory:
    - Inheritance only takes place by means of gametes (such as ovum and sperm)
    - As such, even if neck muscles strengthen, such characteristics are not passed on through heredity as such cells are not agents of heredity

Darwin's theory of natural selection (published in his work '*On the Origin of Species by Natural Selection*'):

1. Overproduction of offspring
    a. Successful species produce more offspring than necessary per generation (more than needed to replace adults)
2. Constancy of numbers
    a. In a stable environment, population size will generally stay steady
3. Struggle for existence
    a. As a greater number of offspring are produced, offspring will compete with one another to exist (eventually meeting constancy of numbers)
    b. Factors like climate, disease, predators, etc. affect their chances of survival (aka 'tests of survival')
4. Variation among offspring
    a. Individuals are not born in identical body form, physiology or behavior (variation)
    b. Variation essentially stems from:
        i. Genetic variation via sexual reproduction
        ii. Genetic variation via mutations (new genes produced)
5. Survival of the fittest
    a. Some individuals with certain variation are more likely to survive than others, as "nature selects fitter individuals with variations which are adapted to the environment"
6. Like produces like
    a. Fitter individuals survive to breed, passing the genes for the selected variations to their offspring
    b. As a result, over time, the proportion of individuals with the advantageous population will increase
    c. Therefore, the overall characteristics of a population changes (evolution)

Factors affecting natural selection:

- Chance events
    - Example: mutation (good or bad)
- Selective advantage

  - Small advantage that tends to increase survivability and is passed down generations
  - Small change that leads to big differences

Speciation:

- Species: A group of organisms which can breed successfully to produce offspring which are fertile
- Note: Hybrids like mules (donkey and horse) are not considered species
- Speciation (formation of a new species):
  - If a barrier splits a population in two different environments, the populations could become different due to differences in selection pressures
  - Differences in the form of behavior prevent further interbreeding → new species is formed

Evidence behind natural selection:

- Genetics
  - The study of inheritance, sexual recombination and mutation served as scientific backing for Darwin's claims
- Population genetics
  - Viewing populations of organisms of the same species as "pools of genes" allowed them to apply statistical methods to measure number of genes in certain population and allowed them to study how populations change over generations
- Geographical separation
  - Scientists observed how geographically isolating a small pool of genes allowed for the development of a new species
- Chemical relatedness
  - Scientists can determine how closely related two species are by comparing their anatomy and examining fossil remains
  - Corroborated by examining the sequences of amino acids in gene pools , this allows scientists to prove natural selection
- Examples:
  - Darwin's finches on the Galapagos Islands (Peter & Rosemary Grant)
  - Industrial melanism in peppered moths
  - Insecticide resistance in insects

Tracing evolution:

- Anatomy (comparing the anatomy of different organisms)
- Fossils (fossils help in showing common ancestors, allowing us to track the path of evolution)
- Biochemistry and molecular biology (with genetic sequences)
- Ecology and behavior (through observable patterns)

General Notes & Misconceptions

Tendon VS Ligament

Tendon:

- A tendon is a fibrous tissue that joins muscle to bone (or other structures such as the eyeball).
- The purpose of a tendon is to move the general structure.

Ligament:

- A ligament is a fibrous tissue that joins bone to bone.
- The purpose of a ligament is to keep the general structure stable.
- Also note that ligaments and muscles can work together to cause a stretching/tightening action (as in the eye, with the ciliary muscles and suspensory ligaments to tighten/loosen the lens)

Case study:

- In the eye, the tendon is the one that moves the eyeball, while the ligaments are the ones that hold the lens in place.