MEGA LECTURE

AQA Biology A-level

Topic 6: Organisms respond to changes in their internal and external environments

Notes

Survival and response

Key Words:

Stimulus - this is something that can be detected by an organism. It can either be internal in multicellular organisms or external in any organism.

Receptor - a receptor is a organ or specialised cell that can detect the change that is causing the stimulus.

Response - as a result of the stimulus that is detected by the receptor a response is caused. This may be movement of the organism or a change in behaviour.

Taxes and Kinesis

A **taxis** is a response that involves **movement in a specific direction**. Therefore positive taxis is towards the stimulus and negative taxis is away from the stimulus. An example of positive chemotaxis is **mobile bacteria** moving to an area where there is a **higher concentration of glucose**.

A **kinesis** is a response that involves **movement**, but this time in **random directions**. Both the **speed and frequency of direction change increase**. The response is carried out in order to increase the chance that the organism will enter different conditions more rapidly. An example is if you place a woodlouse in a dry area it will speed up and change direction more frequently in order to increase the chance it enters a damp region which are its favoured conditions.

Plants response to stimuli

Plants respond to **external stimuli** to increase their **chance of survival**. For instance, they exhibit **tropisms**, that is **growth responses** controlled by a **direction stimulus**. An example of a tropism is **phototropism** where the **direction of growth** is determined by the **direction of light**, that is, the shoots of the plant are **positively phototropic** and grow **towards the light** whereas roots are **negatively phototropic** and grow **away from the light**.

Plant growth is controlled by **indoleacetic acid (IAA)** which is an important **auxin** produced in the **tips and shoots** of flowering plants. The **distribution** of IAA around the plant **controls tropisms**. For instance, if IAA is **unevenly distributed**, it causes **uneven growth** of the plant to occur.

When the shoot is **illuminated from all sides**, the auxins are **distributed evenly** and move down the shoot tip thus causing **elongation of cells across the zone of elongation**. Whereas if the shoot is only illuminated from one side, the auxins move towards the **shaded part of the shoot** thus causing **elongation of the shaded side only** which results in the **bending of the shoot towards the light**.

Gravitropism in roots is the opposite. IAA will build up on the lower side of the root. In roots IAA **inhibits growth**, therefore causing the cells on the upper side to grow faster, causing the root to **bend downwards.**

Simple Reflex Arc

Reflexes are rapid automatic responses that can protect and organism from harmful stimuli and therefore can help them to survive and avoid danger. These are fast responses which bypass the brain meaning that no decision has to be made. The general path or a reflex arc is:

Stimulus —> Receptor —> Sensory Neurone —> Intermediate Neurone —> Motor Neurone —>Effector —> Response

Sensory Neurone - carries the nerve impulse from the receptor to the spinal cord.

Intermediate Neurone - this is located entirely in the spinal cord and relays the nerve impulse from the sensory neurone to the motor neurone.

Motor Neurone - carries the nerve impulse from the spinal cord to the effector which can be a muscle or gland.

Receptors

Receptors detect changes in the internal and external environment. There are many types of receptors, each specific to a particular kind of stimuli, for instance photoreceptors detect changes in light whereas mechanoreceptors such as the Pacinian Corpuscle detect mechanical stimuli in the form of pressure and vibrations.

Pacinian Corpuscle

Pacinian Corpuscles are located deep in the skin, and are mostly found on fingers, soles of the feet as well as external genitalia. They are also found in joints, tendons and ligaments. Pacinian Corpuscles have a single sensory neurone, located in the centre of connective tissue called lamellae which forms layers separated by a gel.

The Pacinian Corpuscle contains stretch mediated sodium channels in the cell surface membrane. When not under pressure these channels are closed, however under pressure these become deformed. As a result they open and allow the rapid influx of sodium ions to occur. The positive charge on the sodiums changes the membrane potential, causing the membrane to become depolarised. This results in an generator potential being created which goes on to create an action potential in the axon.

Photoreceptors in the eye

Photoreceptors are light receptors in the eye. The light enters the eye through the pupil and the amount of light entering is controlled by muscles in a structure called the iris. The lens of the eye focuses the light on the retina where the photoreceptors are located, specifically the fovea. Subsequently, the nerve impulses received by the photoreceptors cells are then carried via the optic nerve to the brain. The point where the optic nerve leaves the eye is known as the blind spot as there are no photoreceptor cells located there.

There are two types of photoreceptors in the retina, these are **cones** involved in **colour vision** and **rods** involved in **monochromatic vision**. **Cones cells** are present at the **greatest density in the fovea** of the eye and contain the pigment **iodopsin**. Cone cells are **not sensitive to light** and therefore require quite **bright light** in order to work. There are three different types each sensitive to the primary colours of light (red, green or blue). Cone cells provide **good visual acuity** because each cone cell has its **own synapse via a bipolar neurone** which connects to the optic sensory neurone.
On the other hand **rod cells** are mainly concentrated in the **highest density outside of the fovea** and contain the pigment **rhodopsin**. Due to this they are **very sensitive to light** and therefore are stimulated in **low light conditions**. Rod cells provide **low visual acuity** as more than one rod cell **shares the same synapse with a bipolar cell**. As a result multiple rods need to be stimulated to cause the creation of a generator potential.

Control of heart rate

Due to the heart's ability to initiate its own contraction, it is referred to as **myogenic.** In the wall of the right atrium there is a region of **specialised fibres called the sinoatrial node** which is the **pacemaker of the heart.** This initiates a **wave of electrical stimulation** which causes the atria to **contract at roughly the same time**. The ventricles do not start contracting until the atria have finished due to the presence of **tissue at the base of the atria which is unable to conduct the wave of excitation**. The electrical wave eventually reaches the **atrioventricular node** located between the two atria which passes on the wave of excitation to ventricles, down the **bundle of His** to the **apex** of the heart. The bundle of His branches into **Purkyne fibres** which carry the wave upwards. This causes the ventricles to contract, thus emptying them.

The sinoatrial node is connected to **two nerves from the medulla oblongata** in the brain. The **accelerator nerve**, which is a part of the **sympathetic nervous system**, delivers a **higher frequency** of impulses to the **SAN** to increase the **heart rate.** Whereas the **vagus nerve** does the exact opposite – it is part of the **parasympathetic nervous system**, and delivers a **slower frequency** of impulses to slow down the heart rate.

Factors which increase the heart rate include:

- **Changes in pH** caused **by high carbon dioxide concentration**, detected by **chemoreceptors** located in **carotid arteries, aorta and the brain**. The receptors send impulses to the **medulla oblongata** more frequently as a result via the **sympathetic pathway**. As a result **more frequent impulses are sent to the SAN**, which results in an **increase in heart rate**. This consequently speeds up blood flow to the lungs where the **CO_2 can be expelled.**
- **Changes in blood pressure**, monitored by **baroreceptors in the sinus.** If blood pressure increases then an **increased frequency of impulses** are sent from the medulla oblongata via the **parasympathetic pathway** to the SAN. This causes **heart rate to decrease**, lowering blood pressure.

When changes to blood pH and pressure have been corrected, impulses to maintain heart rate continue in their normal manner.

Nerve impulses

The nerve cells called **neurones** play an important role in **coordinating communication** within the **nervous system**.

The structure of neurones is similar, as they all have a **cell body** composed of the **nucleus** as well as **organelles** such as mitochondria within the cytoplasm. Apart from the essential components, they also contain **extensions called dendrites** involved in **conducting impulses towards the cell body**, as well as **axons** which conduct them in the opposite direction, that is **away from the cell body**.

The structure of neurones, that is the length of **axons** as well as the **polarised nature of the neurone membrane in the resting state** where the **outside** of the membrane is **positively charged** and the **inside is negatively charged,** enables the neurones to carry electrical impulses called **action potentials**.

Resting Potential

As previously mentioned, nerve cells are polarised in their **resting state**. This occurs as a result of an **imbalance between sodium ions and potassium ions**, thus giving the inside of the axon a negative charge in comparison to the external environment. As a result of the **polarisation**, there is a **difference in the voltage** across the axon membrane, with a value of **-70mV** known as the **resting potential.**

This **resting potential** is generated as well as maintained with the help of the **sodium-potassium pump** which moves sodium ions out of the axon thus creating an **electrochemical gradient** with a **higher concentration of sodium ions outside the axon**. This is because the **membrane is not permeable to sodium ions**. The sodium-potassium pump is also involved in transporting **potassium ions** into the axon. However, the potassium ions move back out of the axon by **facilitated diffusion** due to the presence of **potassium ion channels which are mainly open, compared to sodium ion channels which are mainly closed**. As a result of that, the outside of the axon is **positively charged** due to the **imbalance** of positively charged ions. For every **three sodium ions** that are pumped out of the axon, **two potassium ions** are pumped in. The pumping of ions requires the use of **ATP** as this is **active transport**.

Action Potential

Upon **stimulation**, the axon membrane becomes **depolarised**. This occurs as follows: firstly, the **excitation** of the neurone cell, **triggered by a stimulus,** causes the **sodium ion channels to open**, as a result making it more **permeable to sodium ions.** These subsequently diffuse into the axon **down the electrochemical gradient**, as a result making the inside **less negative**.

Upon reaching the threshold of **-55mV**, even more **sodium ion channels open** eventually giving a potential difference of **+40mV.** This is the end of **depolarisation** and now **repolarisation** starts. **Repolarisation** is achieved as a result of **sodium ion channels closing and potassium ion channels opening**. The potassium ions diffuse out of the neurone down the concentration gradient and eventually **restore the resting potential**. However, as the closing of potassium ion channels is **slightly delayed**, this leads to **hyperpolarisation** i.e. when the potential difference

becomes more negative than the resting potential. The resting potential is then achieved with the help of **sodium-potassium pump** which returns the potential difference to the value of **-70mV.**

Passage of an action potential

If an action potential travels along an **unmyelinated axon** the **wave of depolarisation** moves to the **adjacent resting region** where sodium ions go on **trigger a change in potential difference**, thus stimulating another action potential. The presence of myelin sheath speeds up the passage of an action potential down an axon. Due to the presence of myelin no action potential can be generated. Therefore the action potential has to jump between gaps in the myelin called **nodes of Ranvier**. The mechanism they do this by is called **saltatory conduction**.

Speed of the nerve impulse

The speed of an action potential is affected by three main factors:

1. **Presence or absence of myelin sheath** - if an axon is myelinated then **saltatory conduction** can occur which is much faster than generating an action potential at every point along the axon.
2. **Diameter of the axon** - the **greater the diameter of the axon the faster the conduction** e.g. the giant squids axon is 1mm in diameter compared to a humans at 22um.
3. **Temperature** - if the temperature is increased then the **ions will diffuse more rapidly**. It will also affect the **rate of respiration** and therefore the production of ATP needed in the sodium-potassium pump.

Afterwards, there is a **short period** during which **the neurone membrane** cannot be excited as the sodium channels enter a **recovery stage**. This period is known as the **refractory period** and serves an important role in ensuring that an action potential can only pass in **one direction** as **discrete** signals. Finally the **all-or-nothing principle** means that either an action potential is produced or it is not. A **threshold value** must be reached in order for an action potential to be created, with all action potentials being of the same strength.

Synaptic transmission

Synapses are **junctions** between two neurones. They have a greater role though than just transmitting signals from one neurone to another. These other roles include:

- Prevent action potentials from going in the **wrong direction**. They do this because the **neurotransmitter** is only made in the presynaptic neurone, with **receptors** only on the postsynaptic neurone.
- They can **amplify the effects of low frequency action potentials using summation**. This can be **temporal** in which a single presynaptic neurone releases neurotransmitter many times, over a short period, causing threshold potential to be reached in the post synaptic neurone. Or it can be **spatial** where multiple presynaptic neurones release neurotransmitter to reach the threshold value.
- Some synapses can be **inhibitory** and prevent the movement of action potentials. Most though are **excitatory**.

An action potential moves across a synapse in the following way:

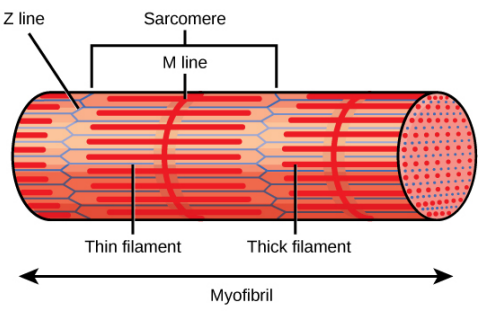
1. Upon the arrival of an action potential, the **presynaptic membrane depolarises** therefore causing **calcium ion channels to open** subsequently allowing calcium ions to enter the presynaptic neurone.
2. The presence of calcium ions in the neurone causes the **fusion of synaptic vesicles,** filled with a particular **neurotransmitter** such as **acetylcholine,** with the presynaptic membrane.
3. The neurotransmitter is then released into the **synaptic cleft**, that is the gap between the two neurones.
4. The neurotransmitter then diffuses across the synaptic cleft towards the post synaptic neurone. Here the neurotransmitter **binds to the receptors located on the postsynaptic membrane** therefore stimulating the **opening of sodium ion channels** which enable **sodium ions** to enter the neurone down their concentration gradient by diffusion.
5. After the new action potential has been created the enzyme **acetylcholinesterase hydrolyses** acetylcholine into **choline and ethanoic acid (acetyl)** which diffuses back across the synaptic cleft and back into the presynaptic neurone where it can be **reassembled and reused**. The benefit of this is both the recycling of the neurotransmitter as well as it **prevents continuous generation** of an action potential in the post synaptic neurone.

Skeletal muscles

Key words:

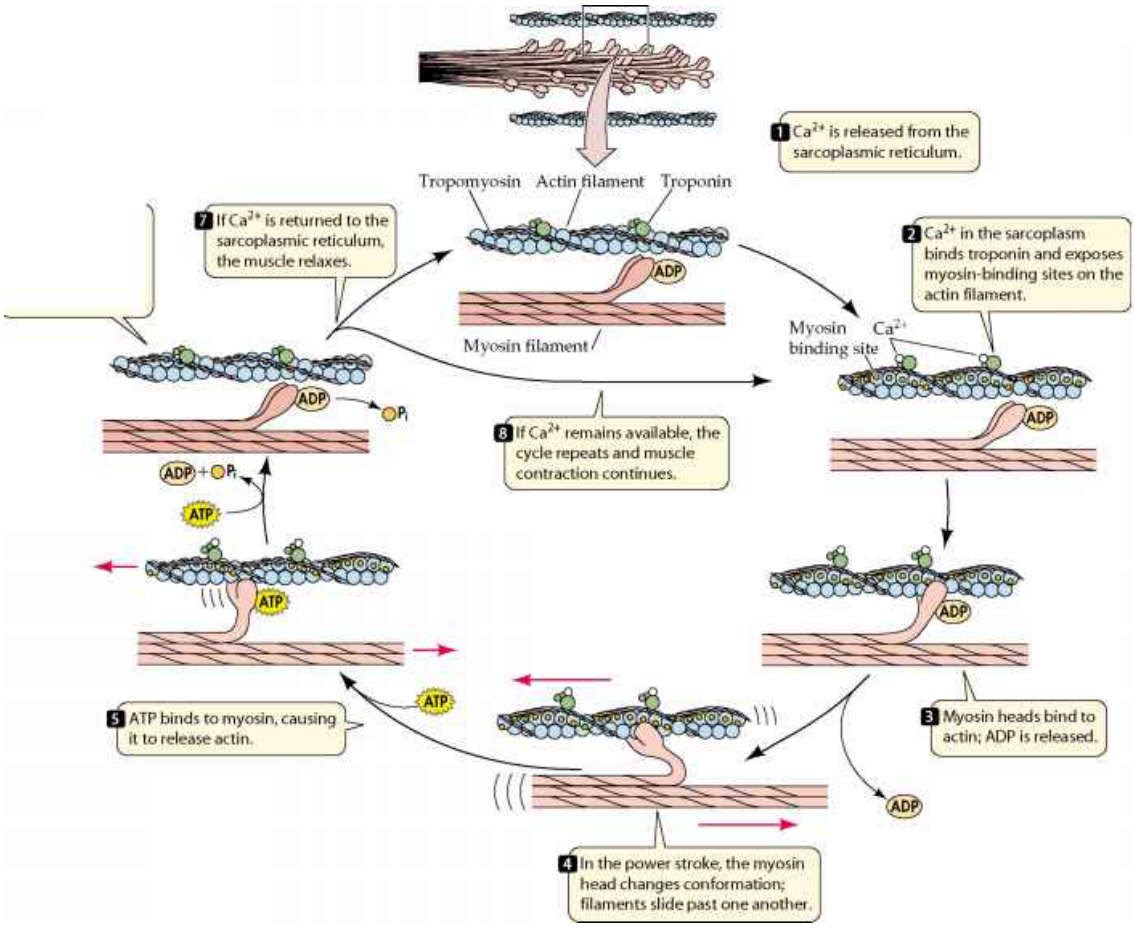
- **Tendons** - non-elastic tissue which connects muscles to bones.
- **Ligaments** - elastic tissue that joins bones together and determines the amount of movement possible at a joint.
- **Joints** - the area where two bones are attached for the purpose of permitting body parts to move, they're made of fibrous connective tissue and cartilage.
- **Antagonistic muscle pairs** - pairs of muscles which pull in opposite directions – as one muscle contracts, the other relaxes. **Flexors and extensors** are an antagonistic muscle pair such as triceps and biceps. When the triceps relax, biceps contract to lift the arm.

Skeletal muscles are under **voluntary control** and are attached to bones by ligaments and tendons. Muscle cells are grouped together to make a larger, stronger structure than can contract efficiently. Protein fibres called **myofibrils** run through these cells increasing their strength.



Myofibrils are made from **thick and thin filaments** which overlap in places to give a banded appearance. Within these the thick filaments are made of **myosin** and the thin filaments are made of **actin**. **Two actin molecules are twisted together** to make the filament. The myosin has **heads** which can attach to specific binding sites on the actin when the muscle is contracting.

Muscle contraction occurs as following:



Muscle contraction requires an **extremely large amount of ATP** in order to occur. A molecule of **ATP is hydrolysed** every time a **myosin head moves** and every time a **calcium ion is pumped** back into the endoplasmic reticulum where there is a high concentration of calcium ions.

Most of the ATP needed is produced through **aerobic respiration**, with the molecule **myoglobin** helping to keep a good supply of oxygen flowing. **Phosphocreatine** is a molecule that can be used to supply the phosphate for ADP phosphorylation so that ATP can continue to be made.

Muscles are either slow or fast twitch, these are summarised below:

- **Slow twitch fibres** are specialised for **slow contractions** and are adapted to long periods of exercise such as marathon running therefore they do not fatigue quickly. They are adapted to aerobic exercise by having a **large store of myoglobin, a rich supply of blood vessels and numerous mitochondria.**
- **Fast twitch fibres** on the other hand are adapted for **rapid release of energy** during intense exercise such as sprinting – the contractions are intense and in short bursts. As a result they are adapted to this role by having **thick and numerous myosin filaments, a high concentration of glycogen, a high concentration of enzymes needed for anaerobic respiration and finally a store of phosphocreatine** so that ATP can be rapidly generated to provide energy.

Homeostasis and feedback mechanisms

Homeostasis serves to ensure that a **constant internal environment** consisting of factors such as **temperature, water potential, pH and blood glucose level** is maintained, despite changes in the **external environment** of the organism. Homeostasis is especially important in **body temperature** and **blood pH** because if these change too much then **enzymes** will become **denatured** e.g. if body temperature rises above 37°C.

This is achieved with the help of **negative feedback** which counteracts any change in internal conditions. This means that all changes are reversed to restore the **optimum conditions**. In order for the negative feedback pathway to work, the following elements need to be present: **sensory receptors** such as **temperature receptors** to detect **changes in internal conditions**, in a case where a change is detected, the receptors pass the message either via the **nervous or hormonal system** to the **effectors** such as the **liver or muscles** bringing about a response to restore the optimum conditions. An example is if **blood glucose** begins to fall then hormones are released to convert glycogen to glucose to bring it back to normal levels.

Another example of a control pathway is **positive feedback** which doesn't occur as often as negative and has an opposing effect. It **increases the original change in the conditions**. An example of positive feedback is the **dilation of the cervix during childbirth.**

Control of blood glucose concentration

The **concentration of glucose in blood** varies depending on food intake and **energy requirements**. It is important to keep the blood glucose concentration in the correct range of about **70-99mg/dl** to ensure that all the essential processes such as **respiration** of brain cells is maintained. However, if the concentration of blood glucose is too high, it is **excreted in urine** thus meaning it is of no use to the body as it **cannot be stored in the form of either glycogen or fat.**

The liver carries out three process in regulation of blood glucose:

1. **Glycogenesis** – making glycogen from glucose removed from the blood.
2. **Glycongenolysis** – breaking down stored glycogen into glucose, which can be released into the blood.
3. **Gluconeogenesis** – synthesis of glucose from other molecules such as amino acids.

In a case where blood glucose concentration is too high, for instance after a meal high in carbohydrates, the following actions take place:

- The **rise** in glucose concentration is detected by **beta cells** that are found in the **islets of Langerhans** in the **pancreas**.
- **Insulin** is **secreted by beta cells**, thus **inhibiting the action of alpha cells.**
- Insulin travels in the blood to **target cells** known as **hepatocytes in the liver, fat and muscle cells.**
- **Binding of insulin to the receptors** on the plasma membrane of these cells causes **adenyl cyclase to convert ATP into cAMP.**

- cAMP activates certain enzyme controlled reactions in the cells to stimulate the opening of glucose channels in the cell surface membrane, thus causing more glucose to enter the cell, which is then converted to glycogen or fats and subsequently used for respiration.

In a case where blood glucose concentration is too low:

- Alpha cells in the islets of Langerhans in the pancreas detect a fall in blood glucose and secrete the hormone glucagon.
- Glucagon secretion inhibits beta cell action.
- Glucagon stimulates hepatocytes to convert glycogen into glucose.
- Glucose diffuses out of hepatocytes into the blood.
- Cells use fatty acids and amino acids for respiration instead.

Another way in which glycogen can be broken down into glucose to raise blood glucose levels is using the secondary messenger adrenaline. The process is outlined below:

1. Adrenaline fuses to a receptor on the cell surface membrane of liver cell and causes the receptor to change shape on the inside the membrane.
2. The changing of the shape on the inside of the membrane activates the enzyme adenyl cyclase which converts ATP to cyclic AMP (cAMP). This acts as a second messenger.
3. The cAMP then changes shape and activates protein kinase enzyme which catalyses the conversion of glycogen into glucose.

Diabetes

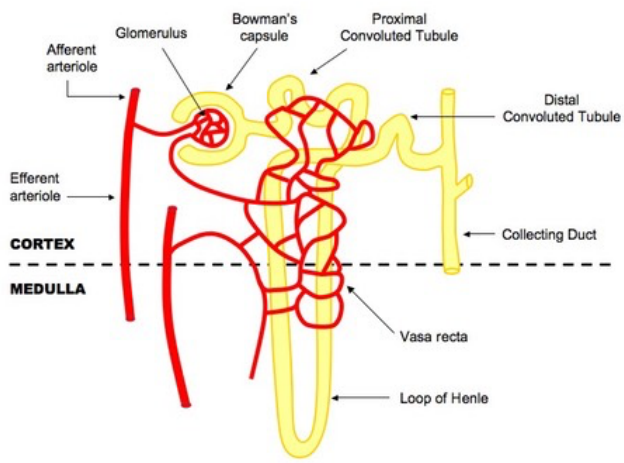
There are two types of diabetes both with different causes, these are:
Type 1 - type 1 is insulin dependent diabetes and occurs early in life and results in loss of insulin production. In some cases the immune system destroys beta cells in the pancreas. As a result people with type 1 diabetes have to control their blood sugar level by self injecting insulin, with the dose matched to diet and exercise.

Type 2 - type 2 diabetes is not insulin dependent and often appears later on in life. It can be caused by decreased insulin production or by glycoprotein receptors on target cells becoming unresponsive to insulin. This is often caused by obesity and diet. This can be controlled by diet manipulation and exercise.

Control of blood water potential

The human kidney has the following general structure:

- An outer fibrous capsule that protects the kidney.
- A layer called the cortex made up of the Bowman's capsules, convoluted tubules and blood vessels.



- Layer called the **medulla** made up of loops of Henle, collecting ducts and blood vessels.
- The **renal pelvis**, which collects urine into the ureter.

There is a 4 step process by which water is reabsorbed by the kidneys, these stages are described below:

1. **Ultrafiltration** - the blood enters the kidney via the **renal artery** which is under pressure from the heart. This then divides into the **afferent arteriole** and then a **complex network of capillaries** called the **glomerulus**. **Water and all soluble plasma components are forced out** of the **glomerulus**, however **large proteins** are too big to fit. The pressure to do this is aided by the **efferent arteriole** leaving the glomerulus being narrower than the **afferent arteriole** entering.

2. **Selective Reabsorption** - **all glucose in the glomerular filtrate must be reabsorbed** into the blood, however waste products like urea don't need to be. Glucose is reabsorbed in the process of **co-transport** from the epithelial cells of the proximal convoluted tubule to blood capillaries. It is carried out by **actively transporting sodium ions** from the epithelial cells to the blood, creating a **low concentration of sodium ions in the epithelial cells**. Sodium ions therefore consequently move in from the lumen of the proximal convoluted tubule by **facilitated diffusion** bringing in glucose. The glucose then **diffuses** into blood capillaries.

3. **Loop of Henle** - The loop of Henle acts as a **counter-current multiplier**. It works to reabsorb water by a multi step process. To begin with **sodium ions are activity transported out of the ascending limb using ATP**. This therefore creates a **low water potential** between the two limbs (called the **interstitial space**). The ascending limb is **impermeable** to water and therefore this means that water only moves out of the descending limb by **osmosis** into the area of low water potential. The water then enters the blood capillaries in this region by **osmosis**. At the hairpin of the loop the water potential is at its lowest, where sodium ions are naturally diffusing out.

4. **Distal Convoluted Tubule and the Collecting Duct** - Water naturally **moves out of the distal convoluted tubule and collecting duct by osmosis**. The collecting duct runs parallel to the loop of Henle and therefore as you move down into the **medulla ion concentration increases**.

The permeability of the collecting duct can also be altered by hormones. **Osmoreceptors** in the **hypothalamus** in the brain detect changes in blood water potential. When this falls the receptor **shrinks**, therefore causing the hormone called **antidiuretic hormone (ADH)** to be released. This passes to the **posterior pituitary gland** from where it is secreted into the blood. When it arrives at the kidney it binds to receptors on the surface of the collecting duct and activates the enzyme **phosphorylase**. This causes vesicles containing **aquaporins** to be embedded in to cell surface membrane. This **increases water permeability** as well as **urea permeability**. As a result urea leaves the collecting duct, causing water to leave and be reabsorbed in the blood.