CAIE Biology A-level

Topic 14: Homeostasis

Notes

Communication

Communication is essential for the survival of organisms as all living organisms must be able to detect and respond to changes in both their **internal and external environments**. In multicellular organisms, changes necessary for survival are triggered by the **nervous and endocrine systems**.

Cell signalling involves communication between cells in the form of **electrical signals** carried by neurones or **chemical signals** carried by hormones. **Neuronal cell signalling** is faster and short term whereas **chemical signalling** is slower and long term. Cell signalling in the form of **endocrine signalling** can be used for long distance signalling, where the signalling molecule is carried by the circulatory system.

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.

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 and effectors.** Sensory receptors, such as temperature receptors, detect changes in internal conditions. If a change is detected, the receptors pass the message either via the nervous or hormonal system to the **effectors** such as liver or muscles which bring about a response to restore the optimum conditions.

Another example of a control pathway is **positive feedback** which does not occur as often as negative and has an opposing effect, that is it increases the original change in the conditions. An example of positive feedback is **dilation of the cervix during childbirth.**

Deamination of amino acids

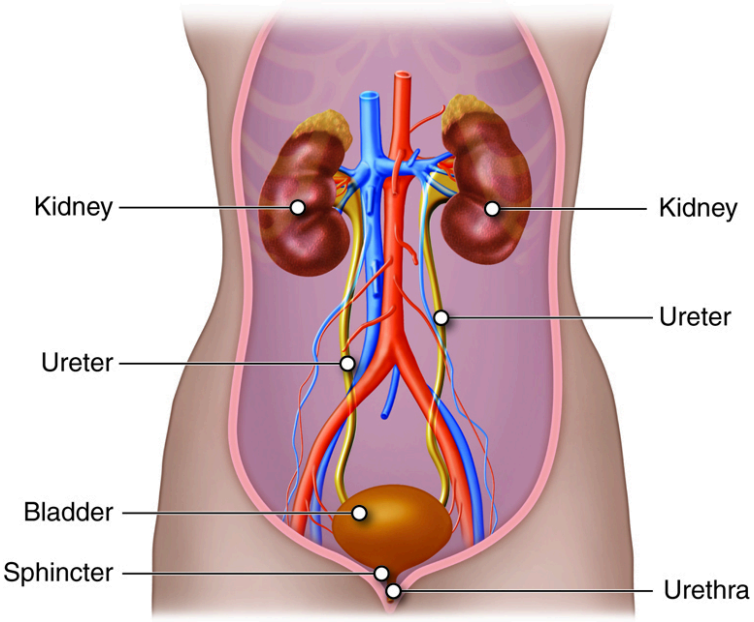
The liver is responsible for the breakdown of **excess amino acids** coming from the digestion of protein. The reason why the excess amino acids need to be excreted is because nitrogenous substances are **damaging to the body** therefore if they are not used up, they must be excreted.

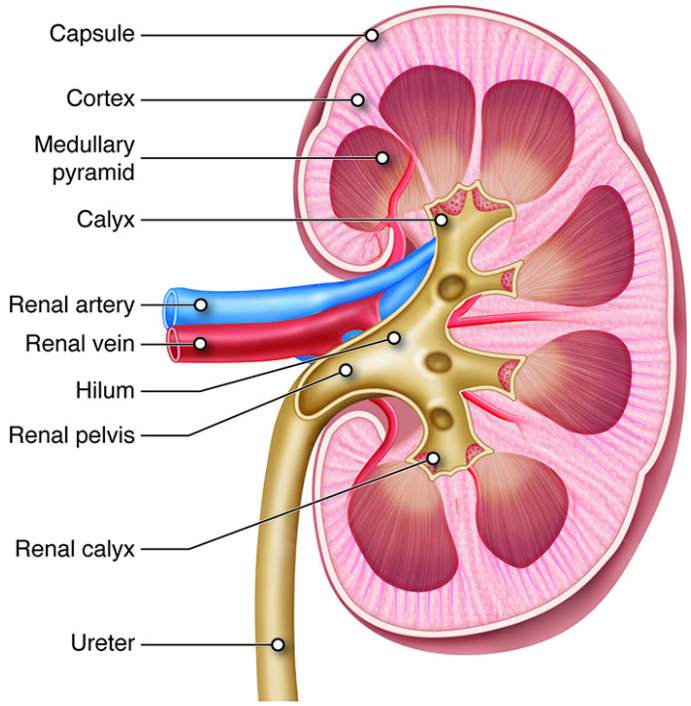
The first step of amino acid excretion is **deamination,** that is the removal of the amino group from an excess amino acid, leading to formation **of ammonia and organic acids (carbon skeletons)**. In the next step, respiration of the acids occurs to produce ATP or alternatively, the acids are converted to carbohydrates and stored as glycogen. Ammonia is converted to **urea** by the addition of carbon dioxide in the **ornithine cycle**. Finally, the urea is released from the liver into the blood and subsequently filtered out by the kidneys to produce **urine**.

Kidneys

The main role of the kidneys is **excretion of waste products**, such as urea, and reabsorption of potentially useful products, such as glucose and water.

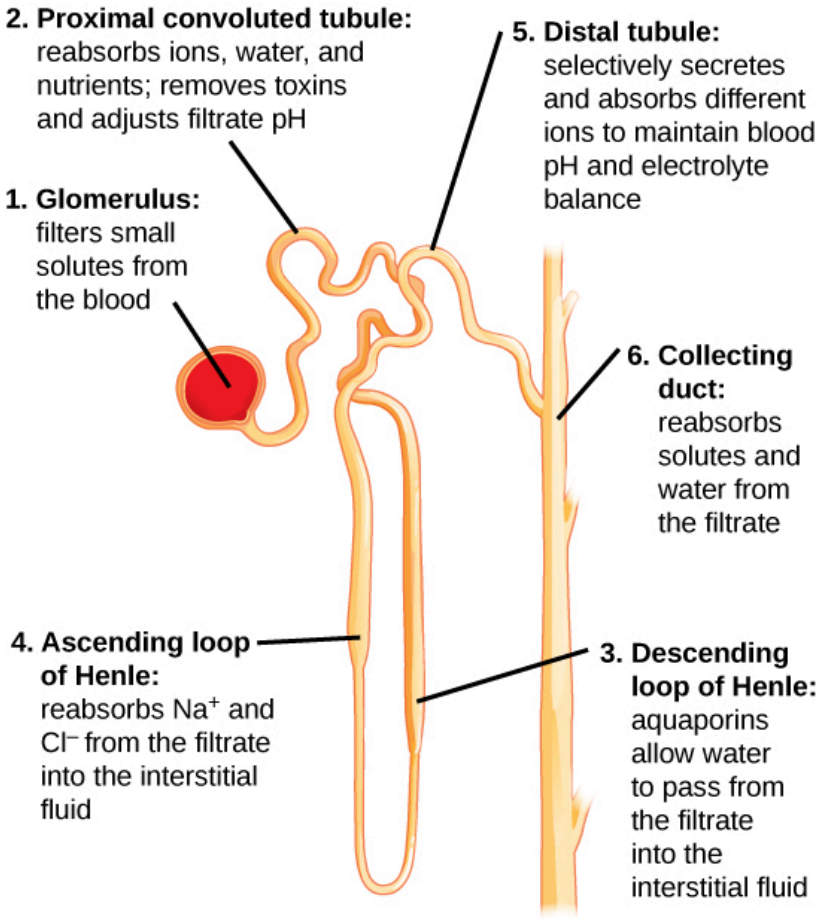
Structure of the kidney:





Summary of kidney function:

- Blood enters the kidney through the **renal artery** and subsequently passes through the **capillaries in the cortex** of the kidney.
- Blood enters the **glomerulus** through the **afferent arteriole** and exits through the **efferent arteriole**. The efferent arteriole is **narrower**, thus a **high hydrostatic pressure** is created. This pushes small molecules such as glucose, urea, water and sodium ions into Bowman's capsule. This process is known as **ultrafiltration**.
- **Selective reabsorption** occurs in the **proximal convoluted tubule**. Here, useful substances such as **amino acids, glucose, and vitamins** are reabsorbed through the tubules in the medulla. Sodium ions and glucose are **co-transported** into epithelial cells of the proximal convoluted tubule. Sodium ions are then pumped out into the blood by the **sodium–potassium pump**, allowing glucose to diffuse into the blood. Water moves down a water potential gradient into the blood.
- The substances to be excreted pass along the **tubules and ureter** and finally reach the bladder where they are disposed of as urine.
- The filtered blood passes out of the kidneys through the **renal vein**.

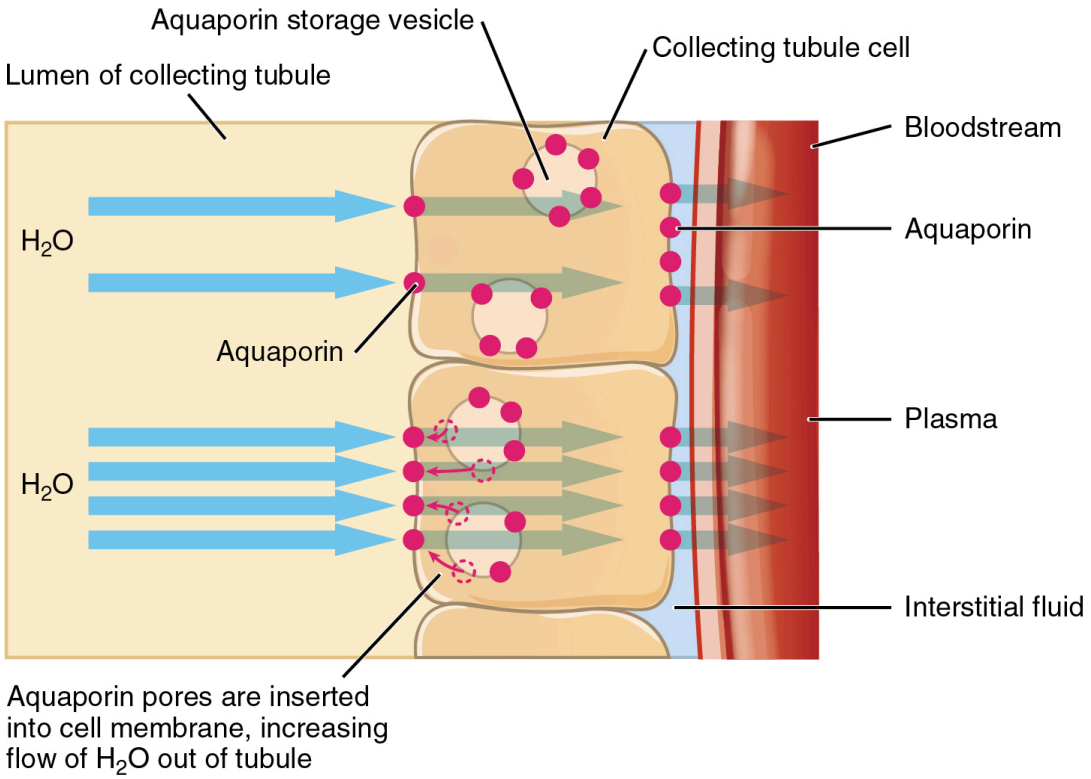


Control of water potential of the blood

In **dehydration**, when the water potential of the blood is too low, more water is **reabsorbed into the blood by osmosis from the loop of Henle, the distal convoluted tubule and collecting duct,** leading to the production of more concentrated urine, and the opposite occurs when water content is too high. **Hormones** also play an important role in controlling the reabsorption of water.

Osmoreceptors in the **hypothalamus** control the water potential and content.

When osmoreceptors detect low water content in the blood, the hypothalamus sends nerve impulses **to the posterior pituitary gland** to release **antidiuretic hormone (ADH)** into the blood which makes the walls of the **distal convoluted tubule and collecting duct** more permeable to water, therefore, increasing the reabsorption of water from the tubules into the blood. At the same time, a **concentrated urine** is also produced to ensure that less water is lost from the body. The vesicle membranes contain **aquaporins,** protein-based water channels. When these are inserted into the cell surface membrane, they increase the membrane permeability to water, allowing water to move out of the kidney tubule. The opposite occurs in the case where the body is well hydrated. The control of water potential in the blood is called **osmoregulation**.



Blood glucose regulation

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 **90 mg per 100 cm^3 of blood (≈5 mmol dm^{-3})** of blood to ensure that essential processes such as respiration of brain cells are maintained. If blood glucose concentration is too high, excess glucose is normally converted to glycogen or fat for storage. Glucose is only excreted in urine when blood glucose exceeds the renal threshold, as in diabetes.

In a case where the 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 the **beta cells** in the pancreas.
- **Insulin**, a hormone, is secreted by beta cells, inhibiting the action of **alpha cells.**
- Insulin travels to target cells known as **hepatocytes** in the liver, fat cells and muscle cells.
- Binding of insulin to the receptors on the plasma membrane of these cells causes **vesicles containing glucose transport proteins** to fuse with the cell membrane.
- This **increases the permeability of the cells** to glucose, increasing the rate of glucose uptake into the cell. The glucose is then converted to **glycogen** (in the liver and muscles) or to **fat** (in adipose tissue).

In a case where the blood glucose concentration is too low:

- Alpha cells detect a change and secrete a hormone called **glucagon.**
- Glucagon secretion **inhibits beta cell action.**
- Glucagon binds to the receptors on the cell surface membrane which causes a **conformational change.**
- This activates **G-proteins** which activates **adenylyl cyclase** enzymes.
- **cAMP** (a secondary messenger) formation is initiated.
- This activates **protein kinase A** which then leads to initiation of a cascade of enzymes, which are activated by phosphorylation.
- The final enzyme, **glycogen phosphorylase** is activated, causing glycogen to be broken down into **glucose**, which diffuses out of **hepatocytes** into the blood. Cells may use **fatty acids and amino acids for respiration** instead.

Test strips and biosensors

Using test strips to measure urine glucose concentration:

- **Glucose test strips** can be used to test for the **presence and concentration of glucose** in the urine. This is important as **glucose in the urine** can indicate that a person **may have diabetes** due to the blood glucose concentration exceeding the **renal threshold**, and thus not all of the **glucose in the glomerular filtrate** in the **proximal convoluted tubule** is **reabsorbed** into the bloodstream.
    - Two enzymes (**glucose oxidase and peroxidase**) are **immobilised** on a small pad at **one end of the test strip.** The pad is **immersed** into the urine sample.
    - If glucose is present, it is **oxidised to form gluconic acid and hydrogen peroxide**. This reaction is **catalysed by glucose oxidase**. The hydrogen peroxide then **reacts with a colourless chemical in the pad** (chromogen) to form a **brown compound and water**. This reaction is **catalysed by peroxidase**.
    - The **colour of the pad is compared to a colour chart - different colours represent different concentrations of urine glucose** (i.e. the darker the colour, the higher the concentration of glucose present).

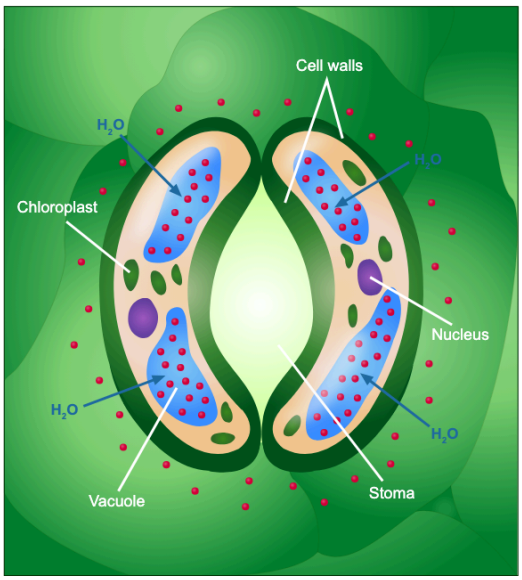
Using biosensors to measure blood glucose concentration:

- **Biosensors** are machines that can be used to show **current blood glucose levels.**
    - **Glucose oxidase enzyme** is **immobilised** on a **recognition layer.**
    - A **partially permeable membrane**, that only allows **small molecules** from the blood to pass through, **covers the recognition layer.**
    - When a **small blood sample** is tested, **glucose oxidase catalyses a reaction** in which **glucose is oxidised to make gluconic acid and hydrogen peroxide**.
    - The **hydrogen peroxide is oxidised at an electrode**. The **electron flow** at the electrode is **proportional to the blood glucose concentration**. The biosensor **amplifies the current**, which is read by a **processor to give a reading**.

Homeostasis in plants

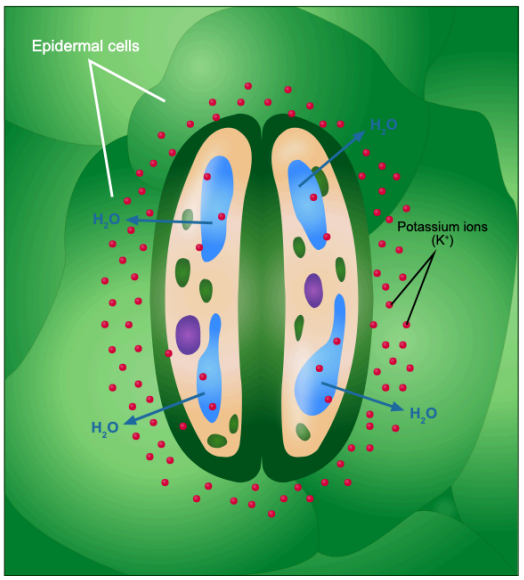
- **Stomatal aperture** is regulated in response to the requirements in the uptake of carbon dioxide for photosynthesis and conserving water.
- Stomata have **daily rhythms** of opening and closing in response to changes in environmental conditions. This allows them to regulate the rate of diffusion of carbon dioxide and water loss by **transpiration.**
- **Guard cells** control the opening and closing of the stomata by either inflating to allow water and gas exchange, or deflating to prevent water loss.
- Stomata **open** when an influx of potassium ions into the guard cells lowers their water potential. This creates a water potential gradient that causes water to enter the guard cells by osmosis, increasing their turgidity and causing the guard cells to expand and curve outward.
- Stomata **close** following an **excess water loss** in the guard cells, usually in response to a drop in their potassium levels. Stomata close when the rate of photosynthesis is lower.
- **Abscisic acid** is produced in the roots of a plant when the water potential decreases or in response to stress. The abscisic acid stimulates the opening of calcium channels in the cell membrane and the release of calcium ions from internal stores (like the vacuole) into the cytoplasm. The resulting increase in calcium ion concentration acts as a **secondary messenger**. The calcium ions cause potassium ions and other anions such as nitrate and chloride to leave the guard cells, followed by water, which eventually leads to the closing of stomata.

Guard cells (swollen)



Stoma opening

Guard cells (shrunken)



Stoma closing