CAIE Biology A-level

Topic 14: Homeostasis

Notes

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, the change necessary for survival is triggered by nervous and endocrine systems.

Cell signalling involves the communication between cells, in the form of electrical signals which are carried by neurones or with the help of hormones. Neuronal cell signalling is faster and short term whereas chemical 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. Other examples of signalling include paracrine signalling which occurs between cells which are in close proximity to each other and occurs directly or with the help of extracellular fluid. Autocrine signalling is a form of signalling where the cell releases signals to stimulate its own receptors thus triggering a response within itself.

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, 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 liver or muscles which bring about a response to restore the optimum conditions.

Another example of a control pathway is positive feedback which doesn't 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.

Thermoregulation

An ectotherm is an organism which regulates its body temperature with the help of external source. Ectotherms are unable to increase their respiration rate to increase the internal production of heat therefore they cannot rely on internal energy sources. Therefore, they control their body temperature by exchanging heat with their surroundings, for instance by exposing their body to sun, orientating it to either minimise or maximise sun exposure, hiding away from sun or increasing breathing for heat loss via evaporation of water.

Endotherms are able to maintain a constant body temperature, independent of the external temperature. They contain thermoreceptors which monitor core body temperature changes and communicate them to the hypothalamus which in turn coordinates appropriate responses to restore the optimum temperature through either physiological or behavioural responses.

Actions taken by endotherms to control body temperature through heat gain or heat loss include:

- **Shivering** – contractions of skeletal muscles stimulated by nerve impulses sent out by the hypothalamus, lead to increase in temperature as heat is released
- **Sweat glands** – sweat production to decrease body temperature via evaporation
- **Hairs on skin** – lie flat to minimise insulation and increase heat loss, raised to provide insulation and reduce heat loss
- **Arterioles** – dilate to increase heat loss as blood flows closer to skin, constrict to reduce blood flow and therefore minimise heat loss

Deamination of amino acids

The liver is responsible for the breakdown of **excess of 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 the **deamination,** that is the removal of the amino group from excess amino acid, leading to formation **of ammonia and organic acids**. 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 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 in the form of urine.

Summary of kidney function:

- Blood enters the kidney through the **renal artery** and subsequently passes through the **capillaries in the cortex** of the kidneys.
- Blood enters the **glomerulus** through the **afferent arteriole** and exits through the **efferent arteriole**. The efferent arteriole is **narrower**, thus a **high pressure** is

created. This pushes smaller molecules (glucose, urea, water and sodium) into the Bowman's capsule from the blood. This process is known as ultrafiltration.
- Selective reabsorption occurs in the proximal convoluted tubule. Here, useful substances such as amino acids, glucose, vitamins are reabsorbed back through the tubules in the medulla. Sodium ions and glucose are cotransported back into the blood through a sodium-potassium pump. 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're disposed of as urine.
- The filtered blood passes out of the kidneys through the renal vein.

Control of water potential of the blood

In the case of dehydration, where the water content of blood is too low, not as much water is reabsorbed into the blood by osmosis from the loop of Henle, the distal convoluted tubule and collecting duct thus leading to production of more concentrated urine and vice versa in the case of water content of blood being too high. Hormones also play an important role in controlling the reabsorption of water.

Osmoreceptors in the hypothalamus control the water potential and content. In the case where the osmoreceptors detect the occurrence of low water content in the blood, the hypothalamus sends nerve impulses to posterior pituitary gland to release antidiuretic hormone (ADH) into the blood which makes walls of DCT and collecting duct more permeable to water therefore increasing the reabsorption of water from the tubules into the blood. At the same time, some concentrated urine is also produced to ensure that no water is lost from the body. The vesicles membrane 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 the kidney tubule. The opposite occurs in the case where the body is well hydrated. This controlling the balance of the water potential of 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 90mg per 100cm3 of blood 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.

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 and muscle cells
- Binding of insulin to the receptors on the plasma membrane of these cells causes adenyl cyclase to convert ATP into cyclic AMP (cAMP)
- cAMP acts as a secondary messenger and activates certain enzyme controlled reactions in the cells to stimulate the opening of glucose channels in the surface membrane, thus causing more glucose to enter the cell, which is then converted to glycogen or fats (stored in the muscle) and subsequently used for respiration

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

- Alpha cells detect 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 kinases which then leads to initiation of a cascade of enzymes
- The final enzyme that is activated is glucagon which stimulates the hepatocytes to convert glycogen to glucose

Glucose diffuses out of hepatocytes into the blood
Cells use fatty acids and amino acids for respiration instead

Second messenger model of adrenaline

If the brain perceives a threat, it stimulates the stress responses involving adrenaline which triggers a number of physiological changes that prepare the body to tackle the threat. The main physiological changes include pupil dilation, inhibition of the digestive system, increased heart rate and stroke volume, increased blood flow to brain for mental awareness, increased metabolic rate.

As adrenaline cannot cross the plasma membrane, it must interact with the cell via the receptors on its surface. The receptors that adrenaline interacts with are known as adrenergic receptors.

1. Adrenaline is released from the adrenal gland and travels to target cells
2. Adrenaline binds to the receptors on the cell-surface membrane of the target cell, activating an enzyme called adenyl cyclase inside of the cell

3. The activated enzyme converts ATP to cyclic AMP (cAMP), which acts as a second messenger.
4. cAMP activates an enzyme called protein kinase A, which triggers the breakdown of glycogen into glucose for energy.

This is called the second messenger model. Adrenaline is the primary messenger and cAMP is the secondary messenger.

Homeostasis in plants

- Stomatal aperture is regulated in response to the requirements for uptake of carbon dioxide for photosynthesis and conserving water

- Stomata have daily rhythms of opening and closing and respond to changes in environmental conditions to allow diffusion of carbon dioxide and regulate water loss by transpiration

- Guard cells control the opening and closing of the stomata by either inflating to allow water and gas exchange or deflate to prevent water loss

- Stomata inflate when turgidity caused by increase in potassium ions occurs, thus decreasing the water potential, thus causing water to enter the guard cells

- Stomata close following an excess water loss, usually in response to drop in light levels and lower rate of photosynthesis

- Abscisic acid is produced in the roots of a plant when the water potential decreases or in response to stress. The abscisic acid then activates a secondary messenger - calcium ions. Guard cells are sensitive to changes in calcium ion concentration which leads to the closing of stomata