Edexcel (B) Biology A-level

Topic 9: Control Systems

Notes

Homeostasis

Homeostasis is the maintenance of a state of internal dynamic equilibrium. It serves to ensure that **a constant internal environment** consisting of factors such as **temperature, water potential, and pH** is maintained, despite changes in the external environment of the organism. Temperature and pH are controlled to maintain optimum enzyme activity and cell membrane integrity. Water potential is controlled to avoid negative osmotic effects which could damage a cell.

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**. Another example of a control pathway is **positive feedback,** which doesn't occur as often as negative, and acts in the same direction as the original disturbance, therefore reinforcing the original stimulus. Examples of positive feedback include **dilation of the cervix during childbirth, blood clotting** and **urination.**

Chemical Control in Mammals

Hormones are signalling proteins secreted by **endocrine glands** directly into the bloodstream. Hormones only affect target organs and cells which contain complementary receptors on their plasma membrane, thus **making them very specific**.

There are two modes of hormone action.

1. Hormones (e.g. adrenaline) **bind to a receptor** on the target cell membrane. This triggers a series of intracellular **membrane-bound reactions** which stimulates the release of a **second messenger** e.g. cAMP. The second messenger activates enzymes to alter the metabolism of the cell e.g. cAMP increases cellular respiration, contraction of muscle cells, relaxation of smooth muscle etc.
2. Hormones (e.g. oestrogen) pass through the cell membrane and **bind to a receptor inside the cell**. They form a hormone-receptor complex which passes into the nucleus and acts as a transcription factor to regulate gene expression.

Chemical Control in Plants

Auxins

- **Growth stimulants** e.g. IAA
- Maintain **apical dominance** and suppress the growth of lateral buds
- Promote root growth
- Promote **trophic responses** to unilateral light (directional growth responses e.g. phototropism, geotropism)

- Functions include rooting powder and weed killers

Auxins cause cell elongation via the active transport of **hydrogen ions** into cell walls, which as a result lowers the pH of the walls. Low pH makes cell walls flexible - this makes cell walls **stretch to accommodate more water**- thus enabling the expansion and growth of cells.

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.
When 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 bending of the shoot towards the light.

Gibberellins

- Stimulate **elongation at cell internodes**
- Stimulate growth of fruit
- Stimulate **germination**
- Stimulate 'bolting' - rapid growth and/or flowering

To stimulate germination, the seed absorbs water, which activates the embryo. The activated embryo secretes **gibberellins**. Gibberellins diffuse to the **aleurone** layer. The Aleurone layer produces **amylase**. Amylase diffuses to the **endosperm** layer and **breaks down starch** into glucose.

Cytokinins

- Promote cell division in **apical meristems/lateral bud development**
- Work synergistically with ethene to promote abscission of leaves

Plant hormones often interact with each other. This can be **synergistically** (for the same effect e.g. auxins and gibberellins) or **antagonistically** (for inverse effects e.g. auxins and cytokinins on apical dominance).

Phytochrome = a plant pigment that exists as two interconvertible forms:

- **Pr** = the biologically inactive form, absorbs red light (like sunlight).
- **Pfr** = the biologically active form, absorbs far red light.

When phytochrome absorbs one of the two respective types of light, it is converted to the other form (or in darkness, it is converted to Pr) at a rate dependent on light intensity.

- In long-day plants, Pfr **stimulates flowering**.
- In short-day plants, Pfr **inhibits flowering**.
- Day-neutral plants have different flowering triggers.

Plants grown in the dark (where all phytochrome is in the form Pr) are **etiolated**:

- Tall and thin
- Fragile stems with long internodes
- Small yellowed leaves
- Little root growth

This is reversed when the stem breaks through the soil because **Pfr acts as a transcription factor** - it moves through nuclear pores and binds to a nuclear protein. The complex activates transcription and controls aspects of growth and development.

Structure and Function of the Mammalian Nervous System

- **Central Nervous System** (a specialised concentration of nerve cells that processes incoming information, sends impulses through motor neurons and carries impulses to effectors).
  - Brain
  - Spinal Cord
- **Peripheral Nervous System** (neurons not in the CNS that spread throughout the body).
  - **Autonomic** (not under conscious control)
    A. **Sympathetic** - ganglia close to CNS, neurotransmitter is noradrenaline, coordinates the fight/flight response
    B. **Parasympathetic** - ganglia far from CNS, neurotransmitter is acetylcholine, coordinates the rest/digest response
  - **Voluntary** (under conscious control)

Sympathetic and parasympathetic nervous systems work antagonistically.

- **Hypothalamus**: thermoregulation, osmoregulation, hormone secretions, basic drives.
- **Cerebellum**: smooth movements, balance/posture.
- **Cerebrum**: voluntary behaviour - personality etc.
- **Medulla Oblongata**: reflex centres - breathing, heart rate, peristalsis etc.

There are three types of neurons, **sensory, motor and relay,** with different functions which differ by the position of the cell body within the neuron.

Motor neurons are involved in transmitting electrical signals from the central nervous system to muscles and glands in the body.

Sensory neurons transmit impulses from receptors to the central nervous system whereas **relay neurons,** which are located within the central nervous system, are involved in transmitting the electrical impulses from sensory neurons to motor neurons.

Nervous Transmission

Nerve cells are **polarised in their resting state**. As a result of the polarisation, there is a difference in the voltage across the neuron membrane, with a value of -70mV known as the **resting potential**.

This resting potential is generated as well as maintained with the help of a **sodium-potassium pump** which moves **sodium ions** out of the neuron and **potassium ions** into the neuron. This creates an electrochemical gradient as the **concentration of sodium ions is higher outside the cell** because the **membrane is not permeable to sodium ions**. However, the **potassium ions diffuse back out** due to the presence of **potassium ion channels**. As a result, the **outside of the cell is positively charged** due to the imbalance of positively charged ions.

Upon stimulation, the neuron cell membrane becomes **depolarised**. This occurs as follows:

1. The excitation of a neuron cell triggered by a stimulus **causes the sodium channels to open, making it more permeable to sodium ions** which subsequently **diffuse into the neuron** down the electrochemical gradient, as a result **making the inside less negative**.
2. Upon reaching the threshold of **-55mV**, even **more sodium channels open**, eventually giving a potential difference of **+30mV** which is the end of the depolarisation and start of **repolarisation**. This is achieved as a result of **sodium ion channels closing and potassium ion channels opening**.
3. The **potassium ions diffuse out of the neuron** 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 greater than the resting potential.
4. The resting potential is then achieved with the help of the sodium-potassium pump which returns the potential difference to the value of -70mV.

The action potential travels along the neuron as a **wave of depolarisation** where the **sodium ions move to the adjacent resting region** where they **trigger a change in potential difference**, thus **stimulating another action potential**.

During the **absolute refractory period,** sodium ion channels are blocked and it is impossible for another action potential to be generated.
During the **relative refractory period,** sodium ion channels are not blocked, but potassium ion channels are still open and effectively the threshold is raised.

The speed at which the electrical potential is carried can be increased with the help of the **myelin sheath** which serves as an insulator of axons and dendrons, produced by **Schwann cells**. The mechanism by which the speed is increased is known as **saltatory conduction,** where the action potential jumps between gaps in the cells of the myelin sheath (Schwann cells), called **nodes of Ranvier.** This is because the myelin sheath is impermeable.

Synapses are junctions between two neurons. Upon the arrival of an action potential, the **presynaptic membrane** depolarises, therefore **causing the calcium channels to open,** which subsequently **allow calcium ions to enter the neuron**. The presence of calcium ions in the neuron causes **the fusion of synaptic vesicles** filled with a particular neurotransmitter such as **acetylcholine** with the **presynaptic membrane,** thus causing the release of neurotransmitter into the **synaptic cleft**. Afterwards, the **neurotransmitter binds to the receptors** located on the postsynaptic membrane and either:

- **Stimulates the opening of cation channels,** which enable sodium ions to enter the neuron. As a result, the membrane depolarises, therefore **triggering another action potential.** This is an **Excitatory Post-Synaptic Potential.**
- **Stimulates the opening of anion channels**, which enable chloride ions to enter the neuron, thus causing hyperpolarisation of the post-synaptic membrane. This makes triggering a **new action potential more difficult**. This is an **Inhibitory Post-Synaptic Potential**.

Effect of Drugs on the Nervous System

Nicotine mimics the effects of acetylcholine and triggers the release of dopamine, and at high doses binds to and blocks acetylcholine receptors. **Lidocaine** blocks voltage-gated sodium ion channels. **Cobra Venom** binds to and blocks acetylcholine receptors.

Detection of Light by Mammals

Cells specialised for detection of stimuli are known as **receptors**. Sense organs such as the eye are composed of groups of receptors.

The **two types of photoreceptors** in the retina are **cones,** involved in colour vision, and **rods**, which produce monochromatic vision. Apart from the type of vision they provide, the two photoreceptors differ in their level of sensitivity – **cones can only work in bright conditions whereas rods are much more sensitive and dim light is sufficient for them to work.**

Rods contain a light-sensitive pigment called **rhodopsin,** which absorbs light energy and subsequently **splits into retinal and opsin**.

In the dark, the rods aren't stimulated as the sodium ions diffuse into the cell through open sodium ion channels, whilst being actively pumped out of the cell by active transport. As a result, the **inside of the cell is only slightly more negative compared to the outside**, thus causing the **membrane to be slightly depolarised**. Therefore, the release of a neurotransmitter called **glutamate** is stimulated. Glutamate serves **to inhibit the neurons which connect the rod cells to the optic nerve**, and so **no information is transmitted to the brain.**

In the presence of light, the rhodopsin **splits into retinal and opsin**. This process is called **bleaching**. **Opsin** binds to the membrane of the cells thus **causing the sodium ion channels to close** without affecting the transport of sodium ions out of the cell via active transport, therefore the **membrane becomes hyperpolarised** meaning neurotransmitter is released into the synaptic cleft. Thus, an action potential forms and is transmitted to the brain via the optic nerve and subsequently processed by the brain.

Control of Heart Rate in Mammals

Factors which increase the heart rate include:

- **Low 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 where the cardiovascular centre is located.
- **Stretch receptors (baroreceptors)** respond to muscle movement, for instance during exercise.
- **Decrease** in blood pressure, monitored by baroreceptors in the sinus.
- **Adrenaline** is a hormone released to stimulate the fight or flight response.

The relevant receptor sends an impulse to the **Cardiac Control Centre in the medulla oblongata**. An impulse is then sent to the **Sinoatrial Node** along a **sympathetic neuron**, depolarisation occurs and **noradrenaline is released** at the SAN. This results in an increased heart rate.

Heart rate is decreased when the opposite of the above occurs, that is – when the pH increases as a result of a decrease in carbon dioxide concentration and increase in blood pressure.

Osmoregulation and Temperature Regulation

1. **Deamination**
   - Liver - hepatocytes.
   - **Excess amino acids are converted into urea**. The amine group is removed to form ammonia. Ammonia is converted into less toxic urea through a series of reactions called the **Ornithine cycle.**
2. Malpighian Body = Glomerulus + Bowman's Capsule: **Ultrafiltration**
   - Small molecules are forced out of the blood from the glomerulus into the Bowman's Capsule because blood is under **high pressure** in the glomerulus as the afferent arteriole (entering) is wider than the efferent arteriole (leaving).
3. Proximal Convoluted Tubule: **Selective Reabsorption**

- Ultrafiltration filters anything small enough - everything except large plasma proteins and blood cells. Many necessary substances (80% of glomerular filtrate) need to be **reabsorbed**.
- Glucose, amino acids, proteins, vitamins and hormones are taken up by active transport. Sodium ions are actively reabsorbed.
- Water moves by osmosis and other ions by diffusion down the concentration gradient.

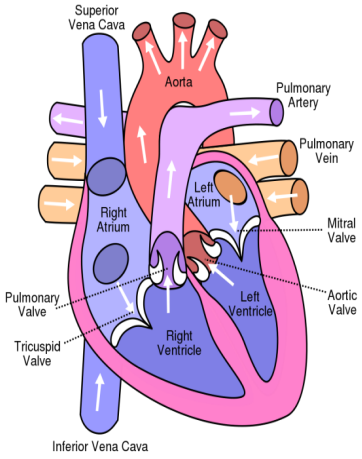

Figure 1 Wikipedia

4. Loop of Henle

- In close contact with a network of capillaries - blood and filtrate run in a **countercurrent multiplier**.
- Descending Limb:
  - Permeable to water.
  - Water moves by osmosis out of the loop down the water potential gradient.
- Ascending Limb:
  - Permeable to ions
  - In the lower, thinner part, ions move out by diffusion (maintains water potential gradient in the descending limb).
  - In the higher parts, ions move out by active transport.

5. Distal Convoluted Tubule:

- Secretes waste chemicals like creatine into the filtrate.
- Actively transports sodium/chloride ions.
- Helps control blood volume.

6. Collecting Duct

- The water potential of the plasma is detected by osmoreceptors in the hypothalamus. This then controls how much **Antidiuretic Hormone (ADH)** is released by the pituitary gland. This is a negative feedback mechanism.
- ADH binds to receptors and triggers a series of membrane-bound reactions which lead to the formation of cAMP as the second messenger. Vesicles containing water channels fuse with the cell membrane which makes the membrane more permeable to water.
- Permeability is controlled by antidiuretic hormone. More ADH = more permeable = more water reabsorbed = urine is more hypertonic (higher concentration of solutes).

An **ectotherm** is an organism which regulates its body temperature with the help of **external sources.** 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 the 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, leading to an increase in temperature as heat is released.
- **Sweat glands** – sweat production to decrease body temperature via evaporation from the skin surface.
- **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 the skin, constrict to reduce blood flow and therefore minimise heat loss.

Kangaroo rats live in **very dry environments** but still need to produce urine to get rid of toxic waste substances, e.g. urea. Their kidneys are adapted to produce a tiny amount of **very concentrated urine.** Other adaptations include:

- **Behavioural:** live in burrows (lower and stable temperature)
- **Physiological:** obtain 80% of their water from oxidation reactions
- **Anatomical:** many juxtamedullary nephrons, long loops of Henle with long descending limbs (for a low water potential in the medulla), many microvilli, many mitochondria (for efficient respiration)