Edexcel IAL Biology A Level

Topic 7: Respiration, Muscles and the Internal Environment

Notes

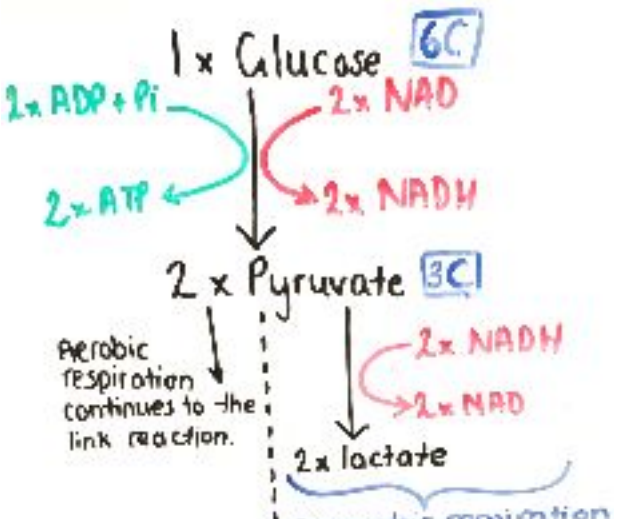
Respiration

Aerobic respiration is splitting of a **respiratory substrate**, to release carbon dioxide as a waste product and **reunite hydrogen with atmospheric oxygen,** with the release of a **large amount of energy.** Whereas anaerobic respiration occurs in the **absence of oxygen.**

Respiration is a **multi-step process** with each step controlled and catalysed by a **specific intracellular enzyme**. The reaction is aided by the **coenzymes NAD, FAD** and **co-enzyme A** that make it easier for enzymes to catalyse the reactions.

Glycolysis

Glycolysis is the first stage of both anaerobic and aerobic respiration and occurs in the **cytoplasm**. In this stage, **1 hexose sugar molecule**, commonly glucose, is **phosphorylated** (the addition of phosphate groups) and oxidised to produce **2 molecules** of **pyruvate** [3 carbons], 2 molecules of **ATP** and 2 molecules of **NADH**. ATP is synthesised in this reaction by **substrate level phosphorylation,** where phosphate groups from phosphorylated glucose directly combine with ADP to form ATP.

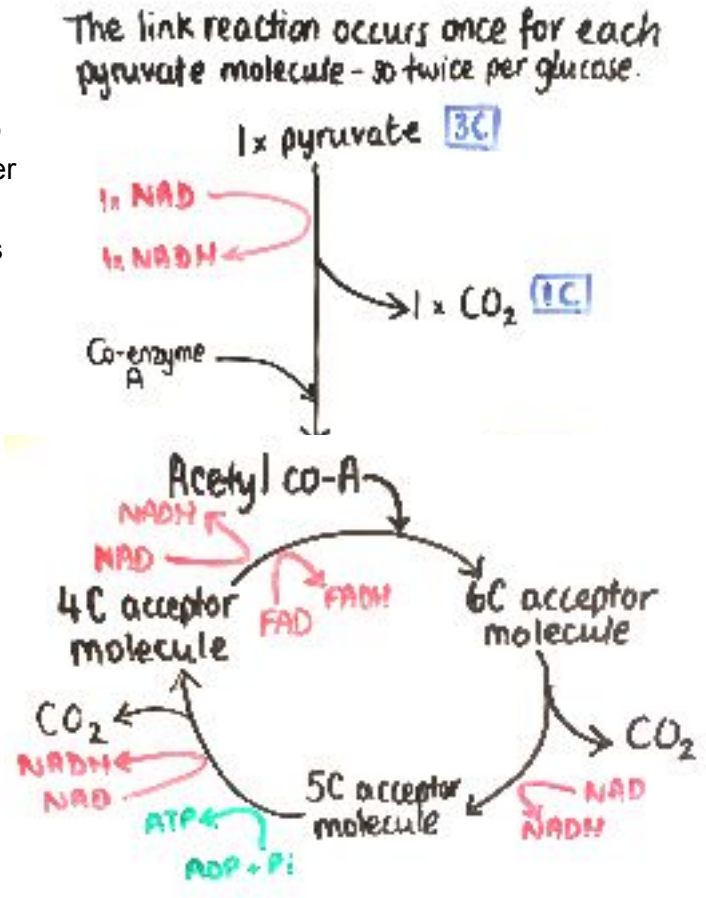


Anaerobic respiration

In **anaerobic respiration** glucose is converted into **pyruvate** by **glycolysis**; the pyruvate is then further converted into **lactate** with the help of NADH in a process known as **lactate fermentation**. Lactate is then converted back to pyruvate in the **liver**.

The link reaction

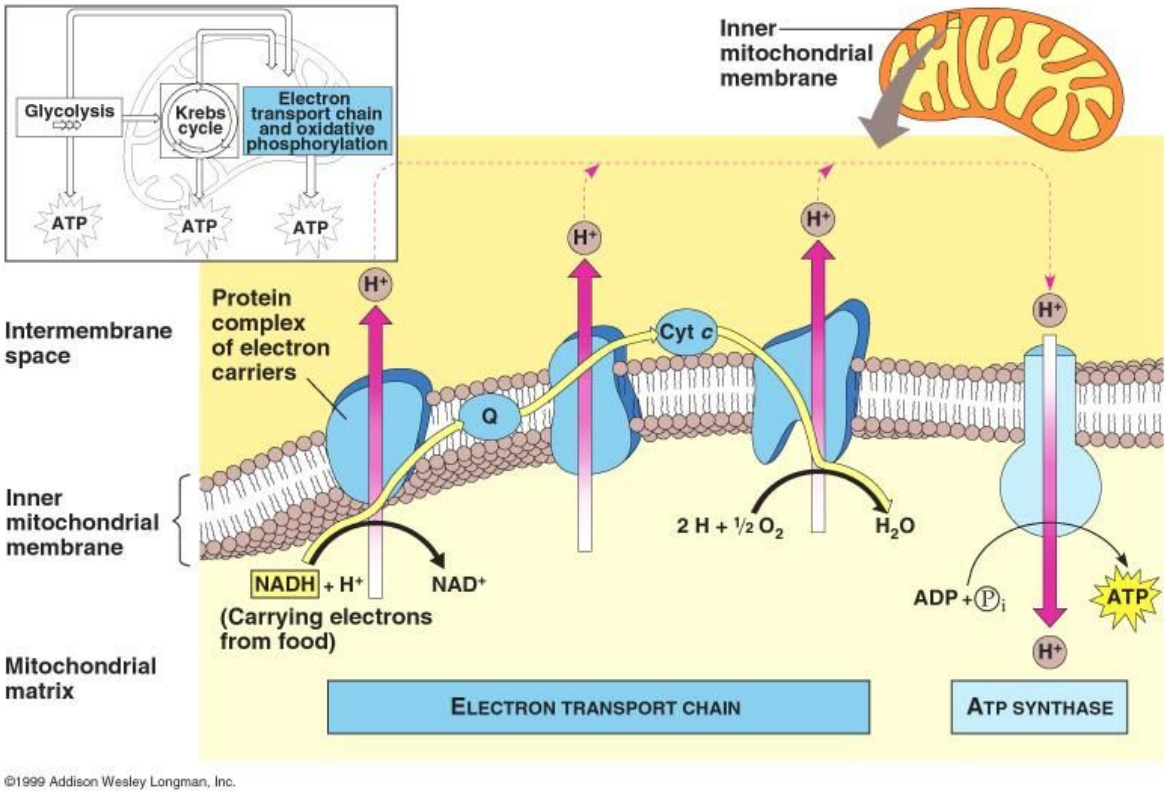
The second step of aerobic respiration is **the link reaction.** Pyruvate is **oxidised** in a redox reaction as **NAD gets reduced** to reduced NADH, it then gets **decarboxylated** as CO2 is released and finally the co-enzyme A reacts with the pyruvate to form one 2 carbon molecule of **acetyle co-enzyme A.**



Krebs cycle

Acetyl-CoA then enters the **Krebs cycle** where glucose is oxidised and **carbon dioxide, ATP, reduced NAD** and **reduced FAD** are produced which are used in the final stage of aerobic respiration - **oxidative phosphorylation**. The reduced FAD and NAD are produced during a **dehydrogenation** reaction, where hydrogen is removed from the carbon compound and added to the coenzymes, reducing them.

Oxidative phosphorylation



Oxidative phosphorylation is the process in which ATP is synthesised in the **electron transport chain** in mitochondria. This process generates **the majority of ATP** in aerobic respiration and it occurs as following:

1. **Reduced coenzymes** carry **hydrogen ions** and **electrons** to the electron transport chain which occurs on the **inner mitochondrial membrane**
2. Electrons are carried from one electron carrier to another in a series of **redox reactions**: the electron carrier which passes the electron on is **oxidised** whereas the electron carrier which receives it is **reduced**
3. **Hydrogen ions** move across the membrane into the **intermembrane space** – as a result of that the concentration of the hydrogen ions in the intermembrane space is **high**
4. Hydrogen ions **diffuse** into the mitochondrial matrix **down the electrochemical gradient**
5. **ATP** is produced on stalked particles using **ATP synthase**

6. **Hydrogen atoms** are produced from hydrogen ions and electrons. The hydrogen atoms are then combined with **oxygen** to produce **water**.

Respiratory Quotient (RQ)

The respiratory quotient is a value given to **the ratio of CO2 released to that of oxygen consumed** in an organism. It is used in **analysing the basal metabolic rate** and is affected by the type of respiratory substrate being respired. For instance the RQ when carbohydrates are the respiratory substrate is around 1.0, whereas for lipids it's 0.7.

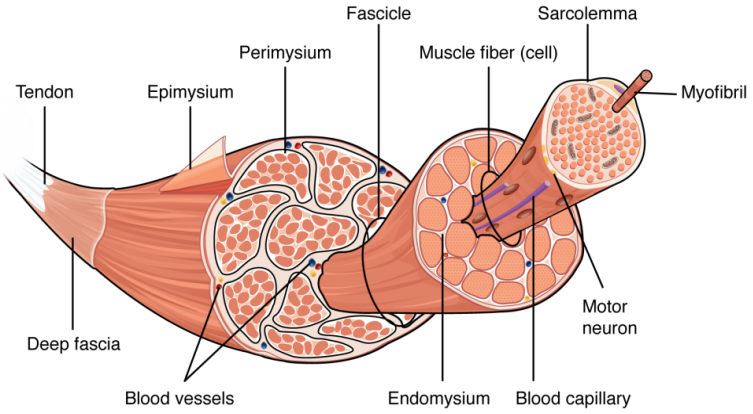
Movement

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**
- **Skeletal muscles** - **muscles attached to bones**, they are arranged in **antagonistic pairs**
- **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 relaxes, the biceps contracts to lift the arm.

Structure of a mammalian skeletal muscle fibre

Striated muscle, also known as **skeletal muscle**, makes up most of the muscles in the body and is used for **voluntary movement.** It is made up of large bundles of long muscle fibres. They contain **myofibrils**: long, cylindrical organelles that are specialised for **muscle contraction**, made of **actin and myosin**.



The cells also contain many **nuclei** and **mitochondria** to provide energy for movement. A muscle cell is called a **sarcolemma** and

contains a thick filament called **myosin** and a thin filament called **actin**, during muscle contraction the actin slides over the myosin.

Fast and slow twitch muscles

There are 2 types of skeletal muscle - **fast twitch** and **slow twitch;** they have different **physiological features** that adapt them to their use in the organism.

Fast twitch muscle fibres	**Slow twitch muscle fibres**
• Contract **quickly** • Used for **short bursts** of exercise • Used for **quick movements**, like the muscles in the eyes • **Quick energy release** from **anaerobic** respiration, using glycogen • **Tire quickly** • Few **mitochondria** or **blood vessels** • Don't have much **myoglobin** so are **whitish** in appearance	• Contract **slowly** • Used for long periods of time - have **endurance** • **Slow release of energy** from **aerobic** respiration • Many are used in **posture** • **Tire slowly** • Many **mitochondria** to release energy for muscle contraction • **Red** in colour as they contain a red pigment called **myoglobin**.

Muscle contraction

Muscles are a type of **effector** in the nervous system and so carry out **responses to stimuli,** as well as **voluntary movement** like walking. Muscles contract to make the skeleton move in a theory known as the **sliding-filament theory** which occurs as follows:

1. An impulse from a **motor neurone** arrives at a **neuromuscular junction** and depolarises the **sarcolemma** (the membrane of the sarcomere), a wave of depolarisation travels down the membrane via **T-tubules** to the **sarcoplasmic reticulum** which is also depolarised.

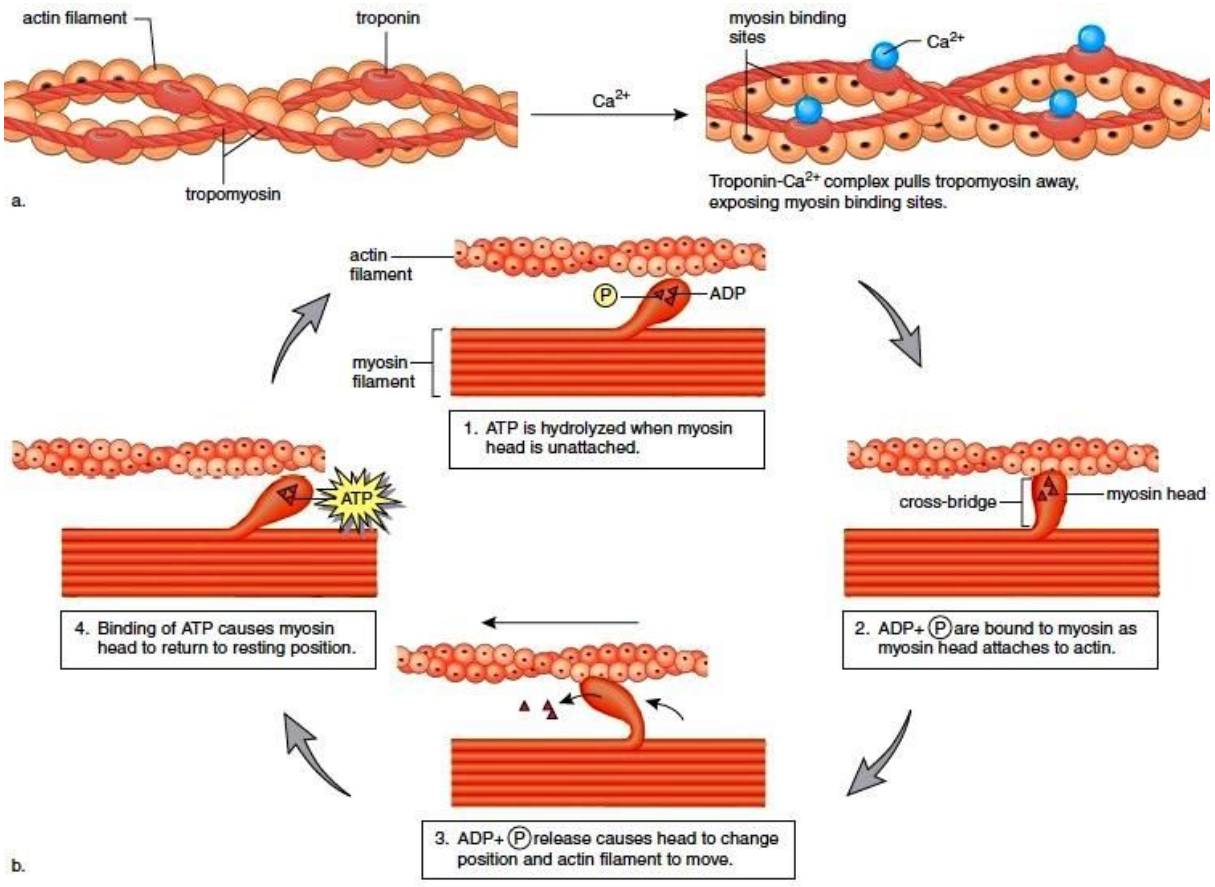
2. This triggers the release of **calcium ions (Ca 2+)** from the sarcoplasmic reticulum.

3. The Ca2+ ions bind to **troponin**, causing a change in shape which moves the **tropomyosin** out of the binding sites.

4. Calcium ions also activate the enzyme **ATPase** that converts **ATP into ADP** to release energy needed for contraction.

5. The **myosin head** binds to the **actin filament**, energy released from ATP causes the myosin head to **bend** in a **power stroke.**

6. ATP binds, causing the myosin head to **detach** allowing it to **reattach** further along the actin filament. Many **cross bridges** are formed and broken simultaneously, making the actin filament slide and causing the **shortening of the muscle** and thus creating the contraction.



When the motor neurone stops sending impulses the Ca2+ ions are **reabsorbed**, **troponin** moves back to its original shape and **tropomyosin** re-covers the binding sites. Thus **ending the contraction** and moving the muscle back to its relaxed position.

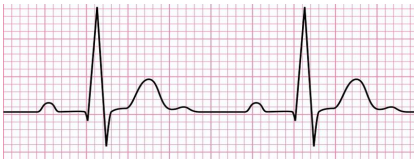
The cardiac cycle

The heart muscle is described as being **myogenic** meaning it can **contract without receiving an impulse** from the nervous system. In the wall of the right atrium there is a region of specialised fibres called the **sinoatrial node (SAN)** which is the **pacemaker** of the heart, as it initiates a **wave of electrical stimulation** which causes the heart to beat:

1. The **SAN** sends out an **electrical impulse** to the **atrial wall** causing both the left and right atria to contract. **(Atrial systole)**
2. A band of **non-conducting collagen tissue** prevents the electrical impulse from being passed straight on to the ventricles causing a short time delay, which allows the atria to empty.
3. The electrical wave eventually reaches the **atrioventricular node (AVN)** located between the two atria which passes on the excitation to the **ventricles**, down the **bundle of His** to the **apex** of the heart.

4. The bundle of His branches into the **Purkyne fibres** which carry the wave upwards. This causes the **ventricles to contract**, emptying them. **(Ventricular systole)**
5. The muscles of the atria and ventricles **relax**, allowing the atria to **refill**. **(Diastole)**

Electrocardiograms (ECGs)



Electrocardiograms are a test used to help **diagnose abnormal heart rhythms** where your heart beats too slowly or too quickly, known as **arrhythmias**. The machine works by attaching sensors across your body which detect the **electrical signals** sent out by the SAN that stimulate the heart beat. The sensors attach to the **ECG recording machine** which produces a **graph** showing the **heart rhythm** and **electrical activity**. An ECG is used most commonly with other tests to help diagnose problems such as arrhythmias.

Cardiac output

Cardiac output can be calculated using the following formula:

$$\underset{(ml/min)}{\text{Cardiac output}} = \underset{(ml/beat)}{\text{stroke volume}} \times \underset{(beats/min)}{\text{heart rate}}$$

Cardiac output - the volume of blood leaving the heart per minute
Stroke volume - the volume of blood leaving the heart per stroke
Heart rate - the number of heart beats per minute

Control of cardiac output and ventilation rate

The **heart rate** and **ventilation rate** need to be controlled to suit the situation the organism is in. For instance, when **exercising** the muscles contract more, so require **more ATP** which is produced during **respiration**; therefore the muscle cells must be supplied with **more oxygen and glucose** than normal - so the ventilation rate increases to increase intake of oxygen and the heart rate increases to increase the supply of glucose and oxygen.

The heart rate and ventilation can be controlled both by the **nervous system** and the **endocrine system:**

- Control of heart rate through the nervous system - **chemoreceptors** and **baroreceptors** detect changes in levels of chemicals such as **O2, CO2 and pH** and **pressure** respectively. When blood pressure is too high, electrical impulses are sent from the receptor cells to the cardiovascular centre - the **medulla oblongata** - which sends its own electrical impulse via the **parasympathetic nervous system** to the **SAN,** to slow the heart rate. Conversely, when blood pressure is too low or O2 levels are too low, the receptors again send signals to the medulla oblongata which this time sends signals via the **sympathetic nervous system** to the **SAN** which cause the heart rate to increase.

- Control of heart rate through the hormonal system - the hormone **adrenaline** is released during the **'fight or flight response'** which gets the body ready for action and so causes the heart rate to increase.

- Control of **ventilation** - the medulla oblongata also controls ventilation by sending impulses to the **intercostal muscles** and **diaphragm** during inhalation and causing them to contract, so increasing the volume of the thorax and **drawing air in** down the pressure gradient. As the lungs inflate **stretch receptors** become stimulated, sending an impulse to the medulla oblongata which **inhibits** the signals being sent to the muscles, causing them to **relax** and the lungs to **deflate**.

  Rate of ventilation is affected by the **concentration of CO2** in the blood; in the blood CO2 dissolves to form **carbonic acid** which is acidic and **lowers the pH.** This is detected by **chemoreceptors** in the ventilation centre that are sensitive to the concentration of hydrogen ions (H+). These can send signals to the **medulla oblongata** that cause ventilation rate to increase if CO2 levels are too high or decrease if the levels are too low.

Homeostasis

Homeostasis is the maintenance of a constant internal environment.

Homeostasis is needed to maintain the **optimum temperature for enzyme activity** and also to regulate and control **blood glucose concentration,** which affects the water potential of the blood, so can cause cells to shrivel or burst if not carefully controlled. A homeostatic system consists of **receptors, a control mechanism and effectors** which interact together. Homeostasis maintains the body in a state of dynamic equilibrium during exercise, the process occurs as following:

1. Firstly the changes in temperature are detected by **thermoreceptors** in the **skin** or thermoreceptors in the **hypothalamus**.

2. Hypothalamus either stimulates **effectors** to decrease or increase the body temperature.

If temperature is **too high:**

- **Vasodilation** of blood vessels **increases blood flow** near skin so **more heat is lost** to the surroundings
- **Sweating** - as water **evaporates** it takes a lot of energy from the skin with it
- Hairs on the skin lie **flat**
- The **metabolic rate decreases**

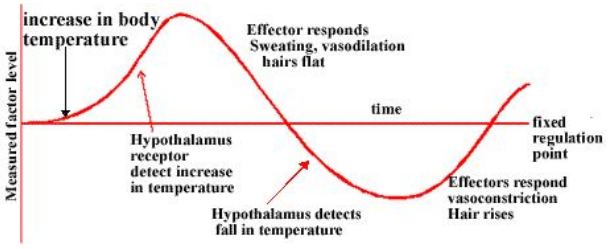
If temperature is **too low:**

- **Vasoconstriction** of blood vessels so **less blood flows** near the surface of the skin, so **less heat lost** to the surroundings

- **Shivering** - small muscle **contractions**, some of the energy released from respiration for muscle contractions is released as heat
- Hairs stand up giving a layer of **insulating air** around the skin
- The **metabolic rate increases**
- **Adrenaline** is released

Negative and positive feedback

Negative feedback – a regulatory mechanism in which a stimulus causes an **opposite output** in order to maintain an ideal level of whatever is being regulated, it keeps the **internal environment constant** within **narrow limits.**

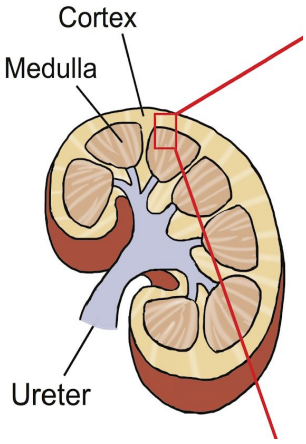


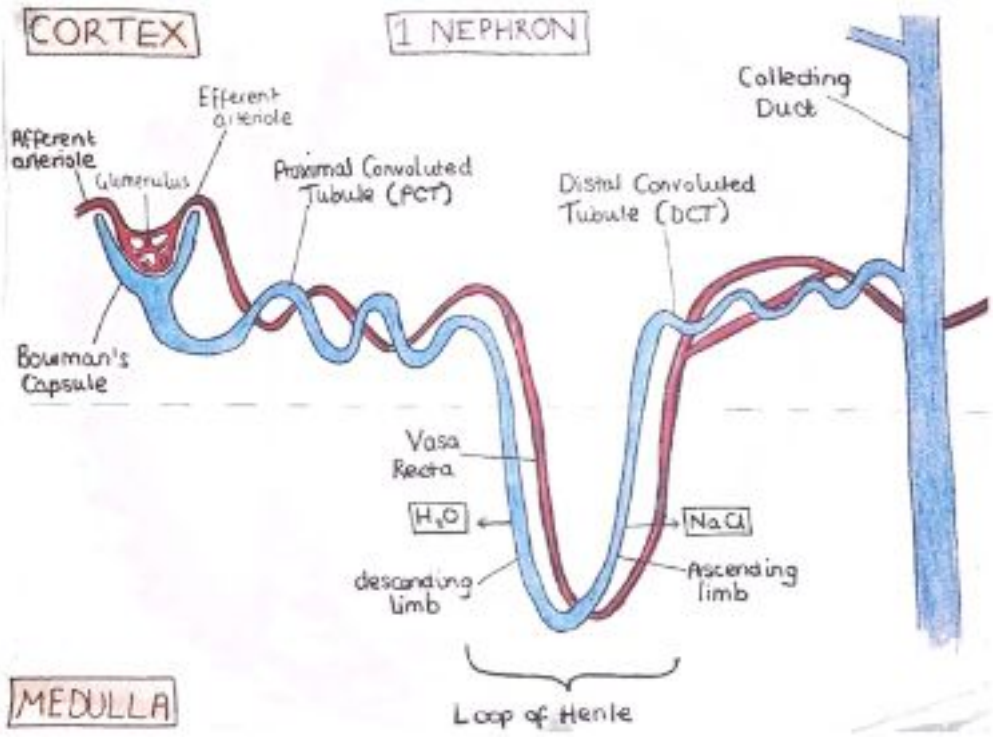
For instance, body temperature is controlled to be around 37 °C, but it constantly **fluctuates** between the upper limit, which stimulates a decrease in temperature, and the lower limit which stimulates an increase in temperature.

Positive feedback – the enhancing or **amplification** of an effect by its **own influence** on the process which gives rise to it. For instance this occurs when someone has **hypothermia**, as their temperature decreases away from the normal level.

The kidneys

Structure of the mammalian kidney





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 during **ultrafiltration** to produce urine.

Ultrafiltration and selective reabsorption

The main role of the kidneys is **excretion of waste products**, such as urea, in the form of **urine**. The kidneys produce urine the following way:

1. Blood enters the kidney through the **renal artery** and passes through the **capillaries** in the **cortex** of the kidneys.

2. The blood passes through the kidneys at **high pressure** which causes **small molecules** such as urea, glucose and water to pass out of the blood and into the **long tubules** called **nephrons** which surround the capillaries. This process is known as **ultrafiltration**.

3. **Selective reabsorption** is the name of a process where **useful substances** such as amino acids, glucose, vitamins are **reabsorbed** back into the capillaries from the tubules in the medulla. A large amount of selective reabsorption occurs in the first part of the tubule - the **proximal convoluted tubule.**

4. The substances to be excreted (mainly urea and excess water and ions) pass along the tubules and **ureter** and finally reach the **bladder** where they're disposed of as urine.

5. The filtered blood containing the reabsorbed substances, like glucose, then passes out of the kidneys through the **renal vein.**

The loop of henle

The loop of henle acts as **a counter-current multiplier** and aids the **reabsorption of water:**

1. In the **ascending limb sodium ions (Na+) are actively transported out** of the nephron and into the surrounding **medulla**. This limb is **impermeable to water,** therefore no water leaves the tubule and **the water potential of the medulla decreases.**

2. Then in the **descending limb**, which is **permeable to water**, water now leaves the tubule into the medulla, by osmosis, down the steep **water potential gradient** created by the pumping of **sodium ions** by the ascending limb. This means more water enters the medulla, so more is **reabsorbed** into the capillaries.
3. In the **distal convoluted tubule** and **collecting duct** more water moves into the medulla to be reabsorbed into the blood.

Control of water potential of the blood

The **pituitary gland** and **osmoreceptors** in the **hypothalamus**, combined with the action of **antidiuretic hormone (ADH)** control and regulate concentration of solutes in the blood and its volume.

In the case of **dehydration**, where the water content of 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 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** detect and control the water potential and content of the blood. When there is low water content in the blood the osmoreceptors **shrivel** as they lose water by osmosis; this change is detected by the hypothalamus which sends nerve impulses the to **posterior pituitary gland** to release **antidiuretic hormone (ADH)** into the blood. ADH makes the walls of DCT and collecting duct **more permeable to water** therefore increasing the reabsorption of water from the tubules into the blood. This means a **smaller volume of concentrated urine** is produced, reducing the volume of water lost from the body.

The opposite occurs in the case where the body is well hydrated, as **less ADH is released** so less water leaves the tubules and more goes on to form urine. When well hydrated a **larger volume of less concentrated urine** is produced.

Transcription factors

Transcription factors are **proteins** involved in the process of **transcribing DNA into RNA**. They include a large number of proteins that **initiate and regulate** the transcription of genes by switching them **on and off.** The transcription factors can bind to specific sections of DNA called **enhancer or promoter sequences** and thus initiate transcription followed by protein synthesis. There are 2 types of hormones - peptide and steroid hormones; **peptide hormones** act **extracellularly** and **steroid hormones** act **intracellularly.**