SL IB Biology

Your notes

Integration of Body Systems

Contents

Your notes

Integration in Living Organisms

System Integration

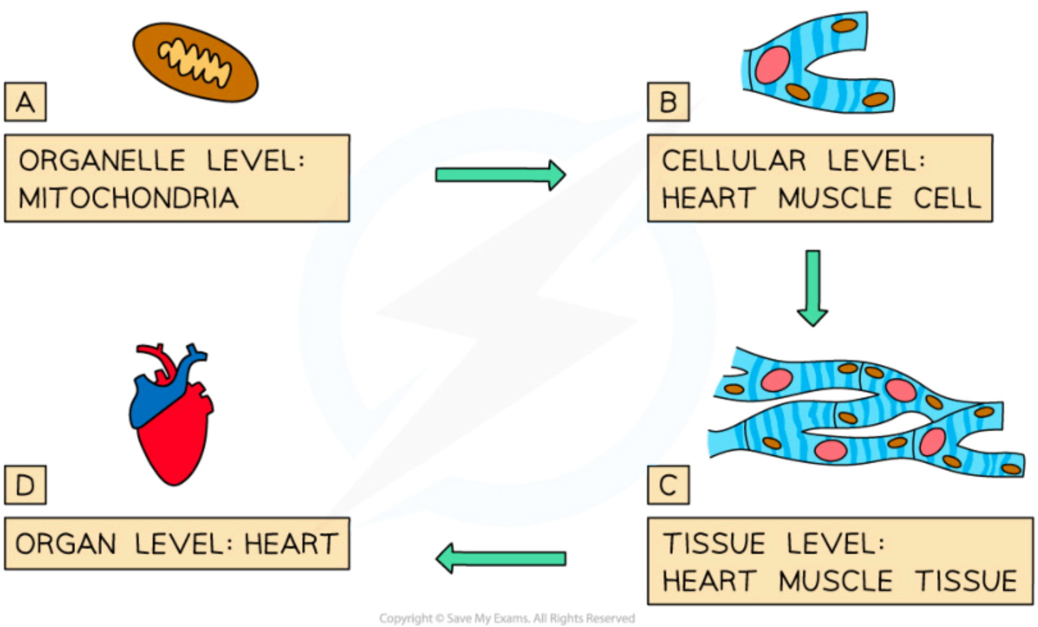
- Complex living organisms have evolved to make use of **living, or body, systems** made up of **component parts** that collectively perform an overall function
- **Coordination** of these parts is required in order for the systems to fully integrate and work together for the whole organism
- Living systems are often made up of billions of cells and so require mechanisms of cell-cell **communication** within the system and with cells in a separate system in a different part of the organism
  - An example of this, found in both plants and animals, is the use of **hormones**; these are produced within one body system (the endocrine system) but may have an effect in a different body system (the reproductive system)

System Integration: Cells, Tissues, Organs & Systems

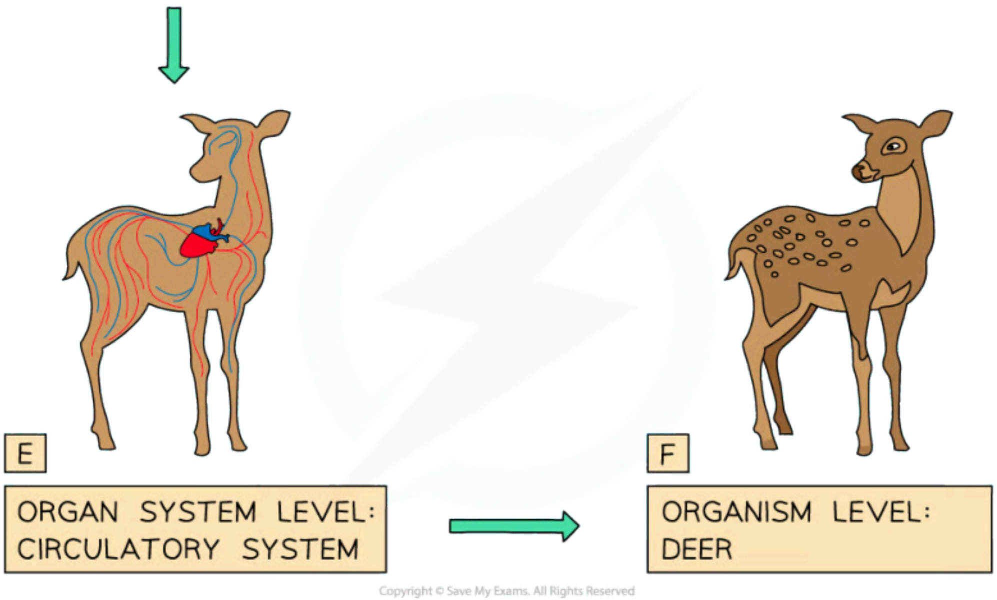
Your notes

- Multicellular organisms have developed a hierarchy of organisation that allows for effective communication and interaction with their environment
- **Specialised cells** of the **same type** group **together** to form **tissues**
- A tissue is a group of cells that **work together** to perform a **particular function**. For example:
  - Epithelial cells group together to form epithelial tissue (the function of which, in the small intestine, is to absorb food)
  - Muscle cells (another type of specialised cell) group together to form muscle tissue (the function of which is to contract in order to move parts of the body)
- Different tissues **work together** to form **organs**. For example:
  - The heart is made up of many different tissues (including cardiac muscle tissue, blood vessel tissues and connective tissue, as well as many others)
- Different organs **work together** to form **organ systems**
- Organ systems **work together** to carry out the life functions of a complete **organism**
- At each hierarchical level there is great efficiency and complexity

Example of the hierarchy of organisation diagram



Your notes



Multicellular organisms have many levels of organisation

Emergent properties

- Multicellular organisms are able to undertake functions that unicellular organisms cannot, e.g. move over vast distances and digest large macromolecules
- This is a result of properties emerging when **individual cells organise and interact** to produce living organisms
  - Scientists sometimes summarise this with the phrase "*The whole is greater than the sum of its parts*" , this phrase describes the idea that the individual systems within the organism are more effective when they work together
- Traditionally, scientists have approached the study of biology from a reductionist perspective, looking at the individual cells, however, due to **emergent properties** there is an argument that the **systems approach** should be used
  - For example a cheetah becomes an effective predator by integration of all its body systems

Integration of Organs

- Communication within the bodies of animals is primarily by the **nervous system** or the **endocrine system**
- Often these two systems are required to work together to maintain body processes such as digestion, maintaining heart rate, blood glucose levels and blood pressure
- These processes rely on transfer of **energy** and **materials** around the body of the organism
- **Transport vessels within the blood system** are at times required to move materials around the body to various tissues, for example:
  - Oxygen and glucose are transported to all cells of the body to facilitate respiration
  - Urea, produced by protein metabolism in the liver, is transported in the blood to be excreted by the kidneys
  - Hormones, such as FSH and LH, are transported via the blood from the pituitary gland in the brain to the ovaries during the menstrual cycle

The nervous system

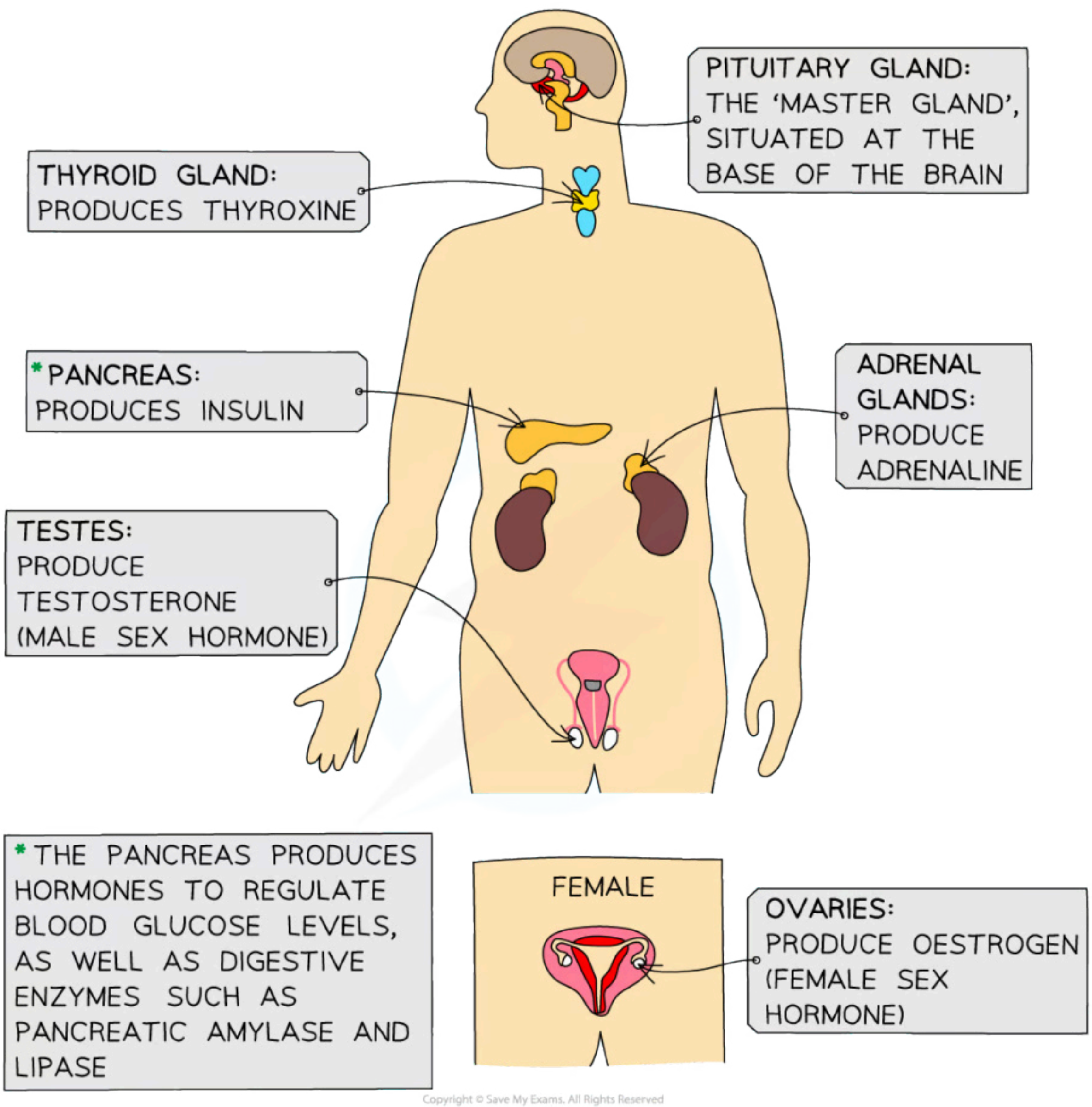
- The human nervous system consists of:
  - **Central nervous system** (CNS) – the **brain** and **spinal cord**
  - **Peripheral nervous system** (PNS) – all of the **nerves** in the body
- It allows us to make sense of our surroundings and respond to them, and to **coordinate and regulate body functions**
- Information is sent through the nervous system in the form of **electrical impulses** – these are electrical signals that pass along **nerve cells** known as neurones
  - A **bundle of neurones** is known as a **nerve**
- The nerves spread out from the central nervous system to **all other regions of the body** and importantly, to all of the **sense organs**
- More information about the structure of the nervous system can be found **here**

The endocrine system

- A **hormone** is a chemical substance produced by an endocrine gland and **carried by the blood**
  - The endocrine glands that produce hormones in animals are known collectively as the **endocrine system**
  - A **gland** is a group of cells that produces and releases one or more substances (a process known as secretion)

Glands of the endocrine system diagram

Your notes



Hormones are produced in the glands and travel round the body in the blood

- Hormones are **chemicals** which transmit information, via the **blood**, from one part of the organism to another and that bring about a **change**
- They alter the activity of one or more **specific target organs**
  - Hormones only affect cells with **receptors** that the hormone can bind to
  - These are either found on the cell surface membrane, or inside cells
  - Receptors have to be **complementary** to hormones for there to be an effect
  - Effects can be **long lived**, as long as hormones are bound to the receptors
- Hormones are used to control functions that **do not need instant responses**
  - They **travel more slowly** in the blood compared to a nervous impulse

Your notes

Comparison of the nervous and endocrine systems table

	Nervous system	Endocrine system
Parts of the system	Brain, spinal cord, nerves / neurones	Glands
Type of message	Electrical impulse	Chemical hormone
Method of transmission	Nerves / neurones	Bloodstream
Effectors	Muscles or glands	Target cells in specific tissues
Speed of transmission	Very fast	Slower
Length of effect	Short until electrical impulses stop	Longer – until hormone is broken down

The Nervous System

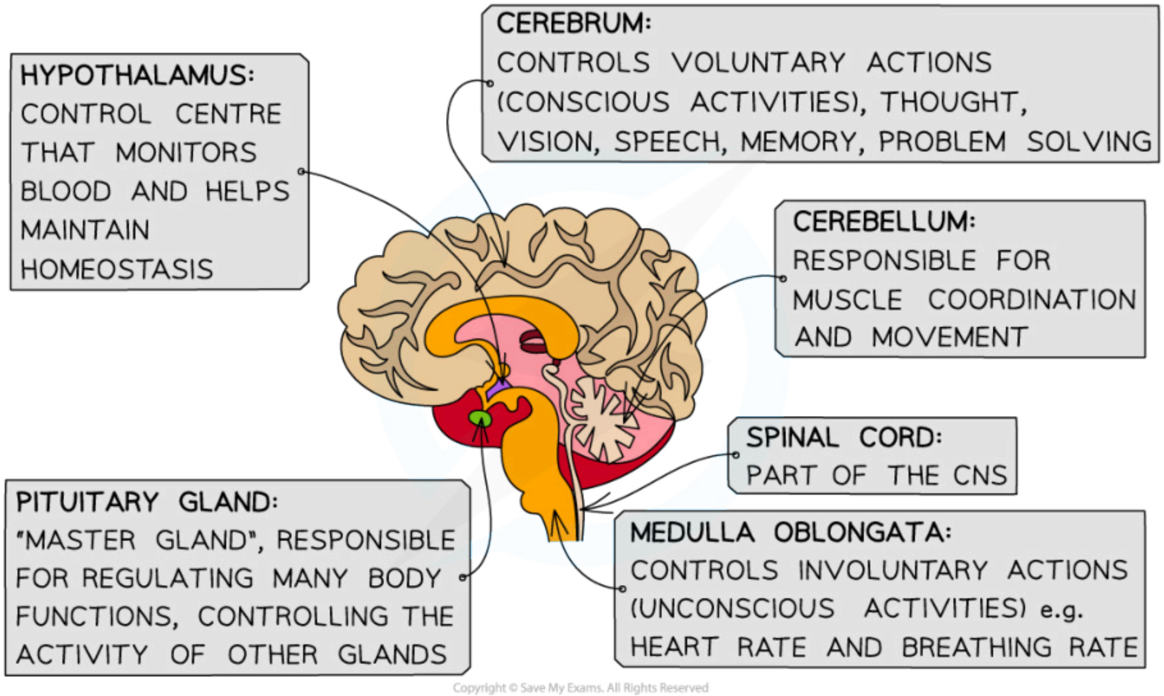
Your notes

The Brain as Integration Organ

The structure of the brain

- The brain alongside the spinal cord is part of our central nervous system
- The brain is made of **billions** of **interconnected neurones** and is responsible for controlling complex behaviours, both conscious and unconscious
- Within the brain are different regions that carry out different functions
  - **The cerebral cortex:** this is the outer layer of the brain which is divided into two hemispheres. It's highly folded and is responsible for higher-order processes such as intelligence, memory, consciousness and personality
  - **The cerebellum:** this is underneath the cerebral cortex and is responsible for balance, muscle coordination and movement
  - **The brainstem:** this relays messages between the cerebral cortex, the cerebellum and the spinal cord. A key part is the **medulla** which controls unconscious activities such as heart rate and breathing
- Two important glands of the brain that are integral the endocrine system are
  - **The pituitary gland:** This gland is responsible for producing many hormones including those involved in controlling the menstrual cycle (FSH and LH)
  - **The hypothalamus:** This region of the brain is involved in regulating body temperature, it also producing hormones which control the pituitary gland

Structures of the brain diagram



The brain is made up of several regions

The role of the brain

- The brain **coordinates** and **processes** information received
- Interactions within the brain are responsible for **learning** and **memory**
- The brains requires several **receptors** in order to receive information (this is **input** of information)
  - At a **conscious** level information is received by
    - Photoreceptors located within the retina of the eye for visual information
    - Chemoreceptors found in the tongue for tasting
    - Thermoreceptors located in the skin for detection of temperature changes
    - Mechanoreceptors located in the inner ear which are sensitive to sound vibrations
  - At **unconscious** level input of information is via
    - Osmoreceptors located in the carotid arteries and hypothalamus which detect the water content of the blood
    - Baroreceptors, also located in the carotid arteries and the aorta, these sense pressure changes of the blood
    - Proprioceptors which are located in muscles and joints and provide information on balance and movement

Your notes

Examiner Tip

You are are not required to know complex details of the brain such as the role of slow-acting neurotransmitters.

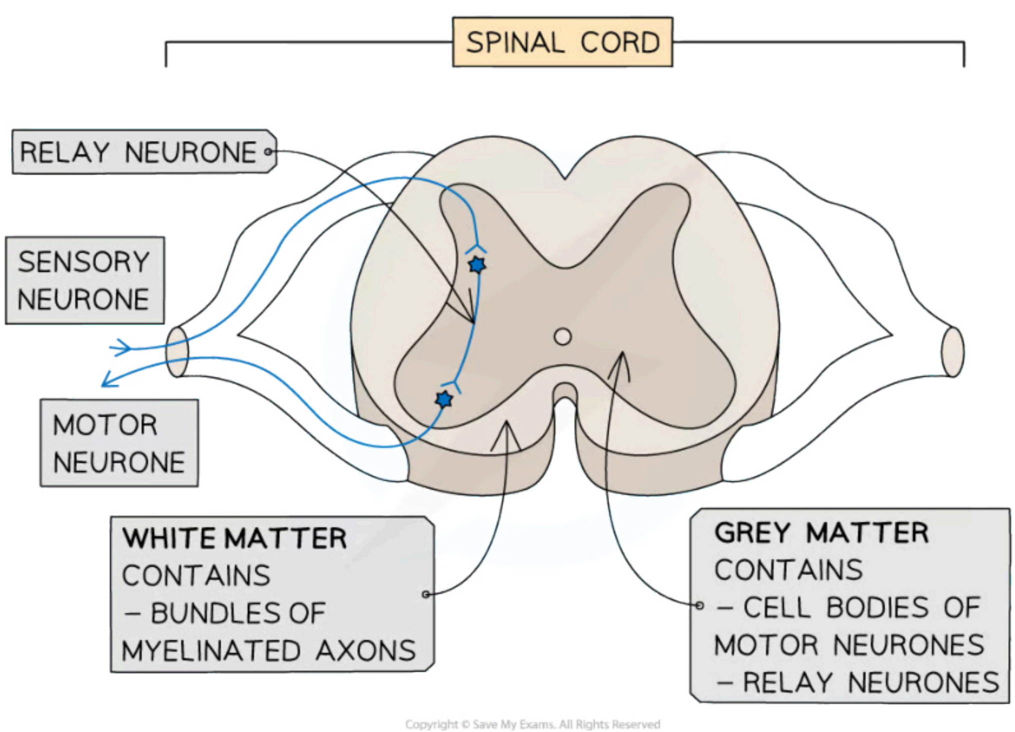
Your notes

Your notes

The Spinal Cord as Integration Centre

- The **spinal cord** is part of the central nervous system (CNS), along with the brain
- It is a neural pathway between the body and the brain, yet it can also process information independently from the brain
  - This information is processed at the **unconscious level** and involves some reflex reactions
    - The spinal cord can be described as an **integration centre** for unconscious processes
  - Note that information processed at **conscious** level means that the **cerebrum of the brain is also involved**
- The spinal cord is responsible for bringing sensory information to the CNS from the body and enables motor (muscular) information to be sent out
- There are **two** types of tissue in the spinal cord
  - **White matter** contains mainly the axons only of neurones that carry information to and from the brain
  - **Grey matter** contains the neurones and synapses involved in spinal cord integration processes which create a reflex response
    - Sensory information enters the spinal cord along **sensory neurones**, this is immediately processed and sent out as motor information along **motor neurones**; this pathway is called a **reflex arc**
    - Because the brain is not involved in this pathway this is **unconscious control directed by the spinal cord alone**

Reflex arc diagram



The spinal cord of the central nervous system acts as an integration centre for unconscious processes

Your notes

Input Through Sensory Neurones

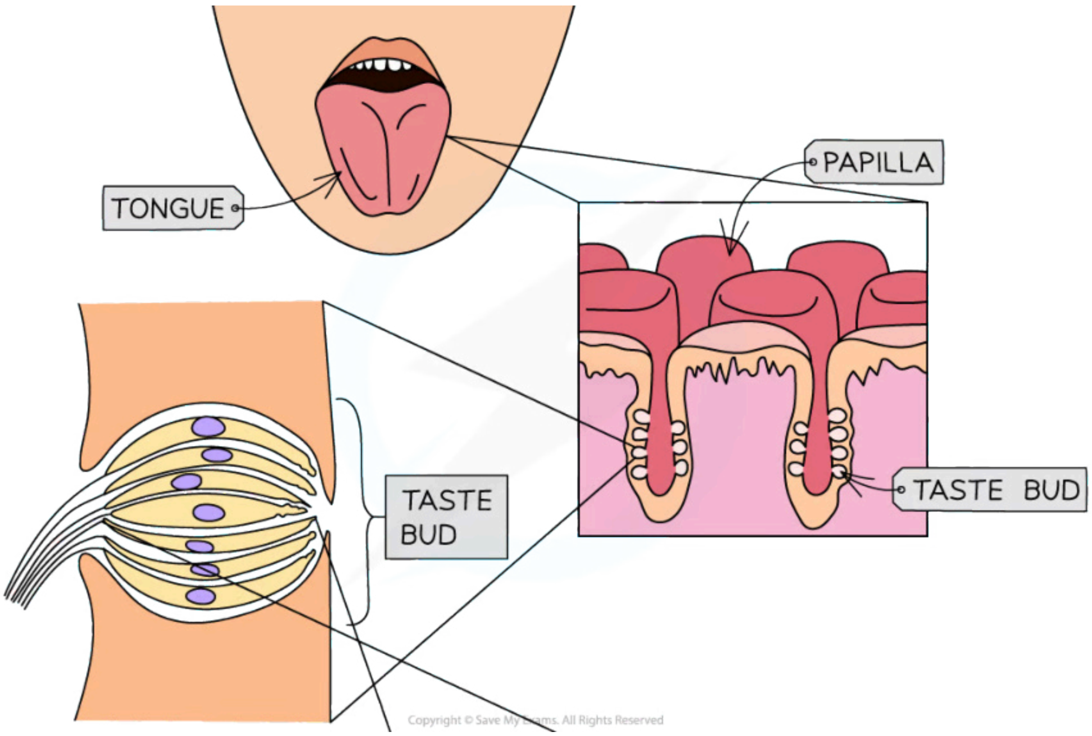
Your notes

- A neural pathway begins with a **receptor**
- A receptor is a specialised cell that can detect changes in the environment that cause a stimulus
- Receptor cells are **transducers** – they **convert energy** in one form (such as light, heat or sound) into energy in an **electrical impulse** within a **sensory neurone**
- Receptor cells are often found in **sense organs** (e.g. light receptor cells are found in the eye)
  - Some receptors, such as light receptors in the eye and chemoreceptors in the taste buds, are specialised cells that detect a specific type of stimulus and influence the electrical activity of a sensory neurone
  - Other receptors, such as some kinds of touch receptors, are just the ends of the sensory neurones themselves
- When receptors cells are stimulated they are **depolarised**
  - If the **stimulus** is very **weak**, the cells are **not sufficiently depolarised** and the sensory neurone is not activated to send impulses
  - If the **stimulus** is **strong** enough, an **action potential is initiated** in the sensory neurone and the impulse is transmitted to the CNS, specifically the **spinal cord** and the **cerebral hemispheres**

An example of the sequence of events that results in an action potential in a sensory neurone

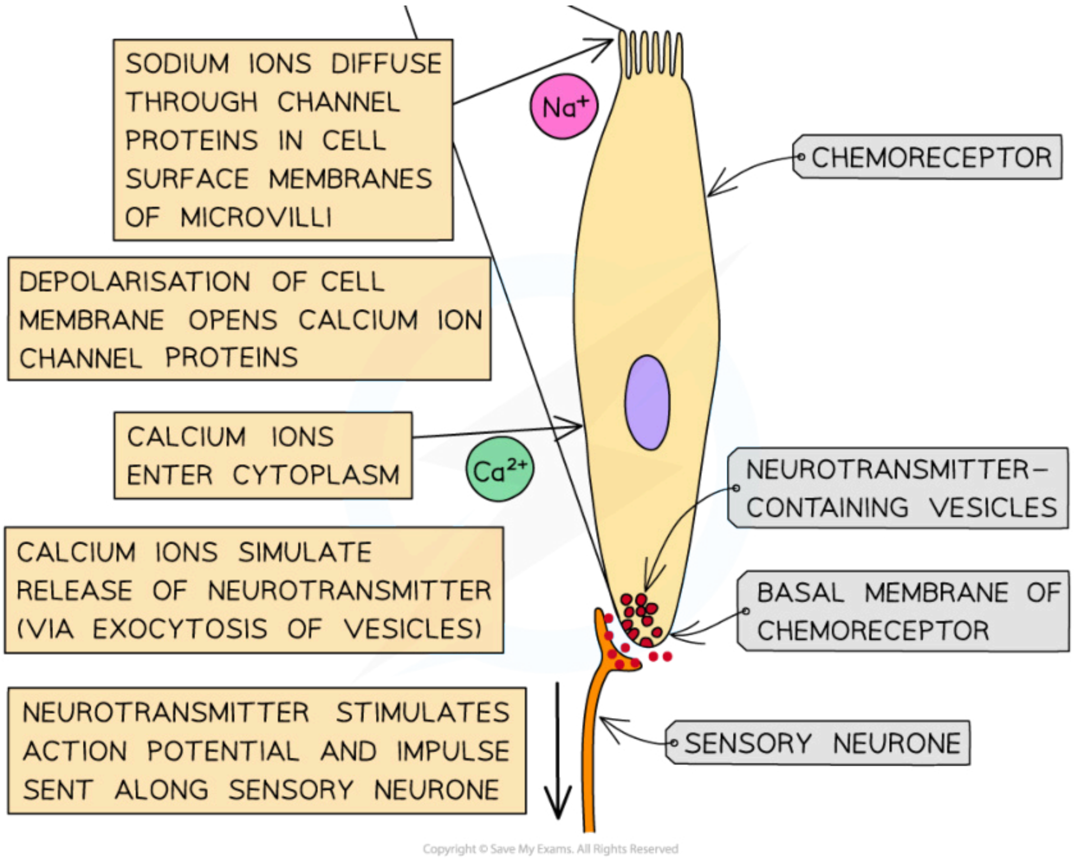
- The **surface** of the **tongue** is covered in many small bumps known as **papillae**
- The surface of each papilla is covered in many **taste buds**
- Each taste bud contains many receptor cells known as **chemoreceptors**
  - These chemoreceptors are sensitive to **chemicals** in food and drinks
- Each chemoreceptor is covered with **receptor proteins**
  - Different receptor proteins detect different chemicals
- Chemoreceptors in the taste buds that detect **salt** (sodium chloride) respond directly to **sodium ions**
- If salt is present in the food (dissolved in saliva) being eaten or the liquid being drunk:
  - Sodium ions **diffuse** through **highly selective channel proteins** in the cell surface membranes of the **microvilli** of the **chemoreceptor cells**
  - This leads to **depolarisation** of the chemoreceptor **cell membrane**
  - The **increase** in **positive charge** inside the cell is known as the **receptor potential**
  - If there is **sufficient stimulation** by sodium ions and sufficient depolarisation of the membrane, the receptor potential becomes large enough to stimulate **voltage-gated calcium ion channel proteins** to **open**
  - As a result, **calcium ions enter the cytoplasm** of the chemoreceptor cell and **stimulate exocytosis of vesicles containing neurotransmitter** from the basal membrane of the chemoreceptor
  - The neurotransmitter stimulates an **action potential** in the **sensory neurone**
  - The sensory neurone then transmits an **impulse** to the brain

Diagram to show the sequence of events initiated by activated chemoreceptors in the taste buds


TONGUE
PAPILLA
TASTE BUD
TASTE BUD
Copyright © Save My Exams. All Rights Reserved

Your notes

Your notes



Sensory neurons convey messages from receptor cells to the CNS

Your notes

Output Through Motor Neurones

- Once an action potential has been transmitted from a sensory neurone to the CNS
- The cerebrum within the brain uses the information to **process movements within the body** as needed; the part of the cerebrum responsible for this is called the **motor cortex**

The role of motor neurones

- **Motor neurones** are used to carry action potentials to **muscles** to initiate the movement required
- Motor neurones terminate within a muscle within a **neuromuscular junction** (also known as motor end plates)
  - There are multiple neuromuscular junctions spread across several muscle fibres within the muscle
    - Neuromuscular junctions work in a very similar way to synapses
    - They are located **between the terminal branches of a motor neurone and a muscle cell**

Transmission across the neuromuscular junction

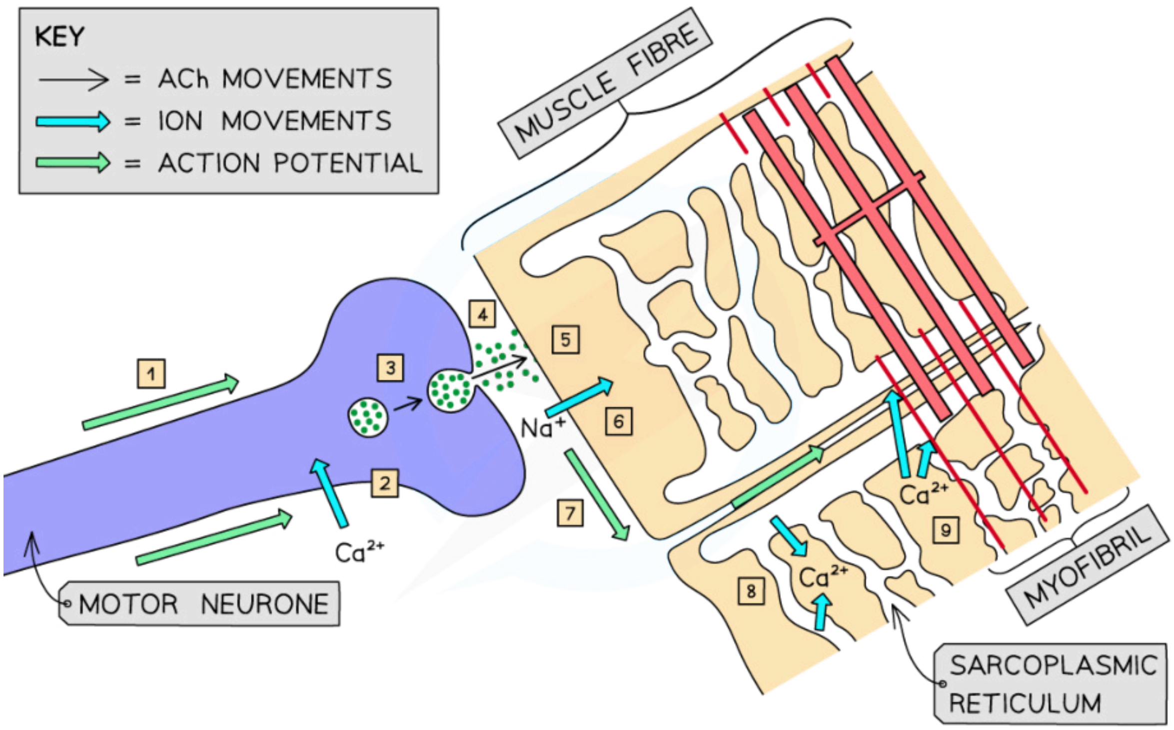
- When an impulse travelling along the axon of a motor neurone arrives at the **presynaptic membrane**, the action potential causes **calcium ions to diffuse** into the neurone
- This stimulates **vesicles** containing the neurotransmitter **acetylcholine** (ACh) to **fuse** with the presynaptic membrane
- The ACh that is released diffuses across the neuromuscular junction and **binds to receptor proteins** on the **sarcolemma** (surface membrane of the muscle fibre cell)
- This stimulates **ion channels** in the sarcolemma to **open**, allowing **sodium ions** to **diffuse in**
- Influx of sodium ions **depolarises the sarcolemma,** generating an **action potential** that passes down the **T-tubules** towards the centre of the muscle fibre

Action potentials stimulate muscle contraction

- Action potentials travel down the T-tubules and trigger the opening of **voltage-gated calcium ion channel proteins** in the membranes of the **sarcoplasmic reticulum**
- **Calcium ions** diffuse **out of the sarcoplasmic reticulum** (SR) and **into the sarcoplasm** surrounding the myofibrils
- Calcium ions **bind to troponin molecules**, stimulating them to **change shape**
- This causes the **troponin** and **tropomyosin** proteins to **change position** on the thin (actin) filaments
- The **myosin-binding sites are exposed** to the actin molecules
- The process of muscle contraction (known as the sliding filament model) can now begin

Muscle contraction diagram

Your notes



1	ACTION POTENTIAL
2	CALCIUM IONS DIFFUSE INTO NEURONE
3	ACh-CONTAINING VESICLES FUSE WITH PRESYNAPTIC MEMBRANE
4	ACh DIFFUSES ACROSS NEUROMUSCULAR JUNCTION
5	ACh BINDS TO SARCOLEMMA RECEPTOR PROTEINS
6	SODIUM IONS DIFFUSE INTO SARCOLEMMA
7	ACTION POTENTIAL PASSES ALONG SARCOLEMMA AND DOWN T-TUBULES
8	CALCIUM IONS DIFFUSE OUT OF SR AND INTO SARCOPLASM
9	CALCIUM IONS BIND WITH TROPONIN MOLECULES, STARTING THE PROCESS OF MUSCLE CONTRACTION

Action potentials from the motor neurone cross the neuromuscular junction to trigger the events leading to muscle contraction

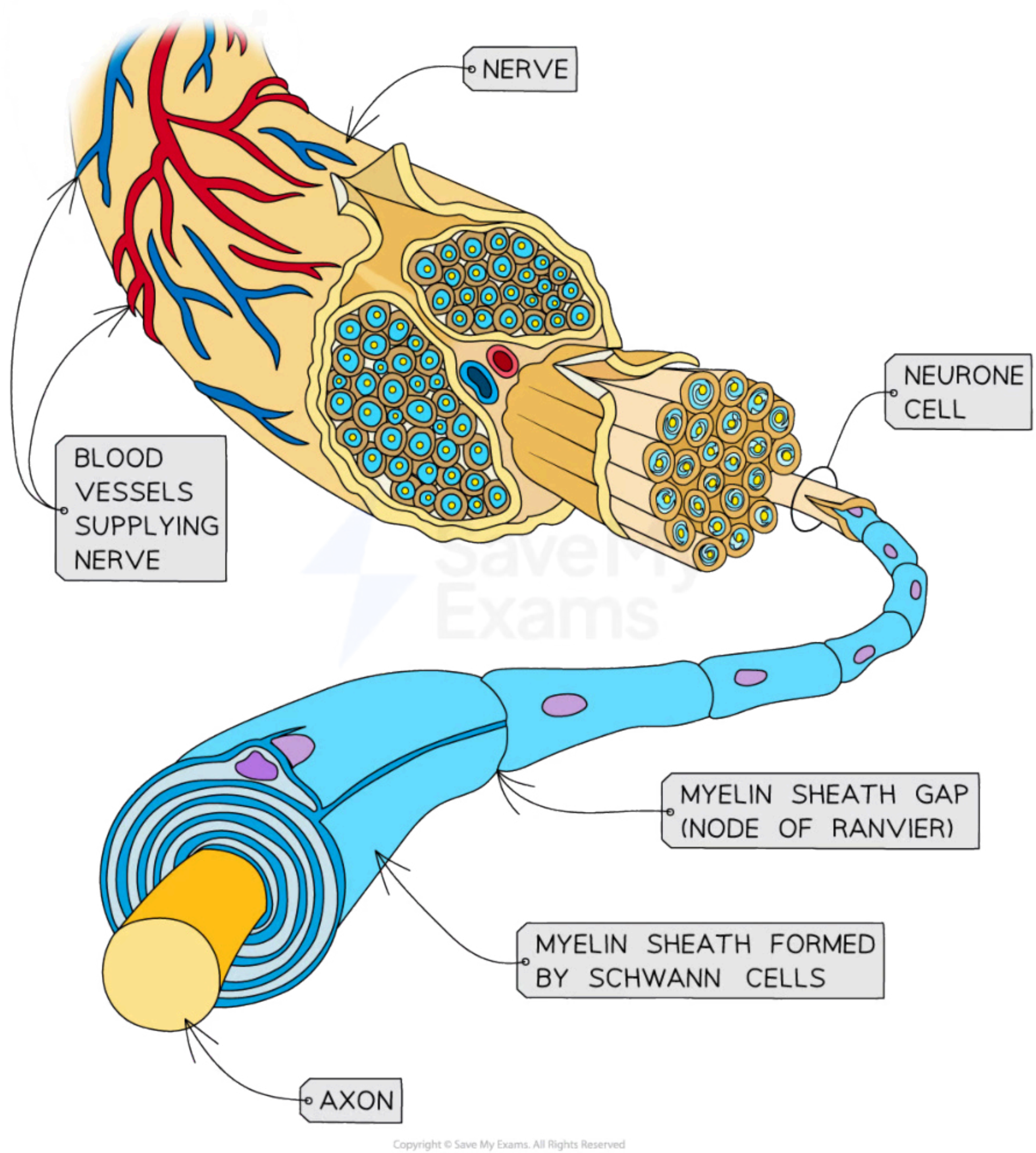
The Structure of Nerves

Your notes

- Information is sent through the nervous system as **nerve impulses** – electrical signals that pass along nerve cells known as **neurones**
- Nerves are made up of **bundles of sensory neurones or motor neurones**
  - These may be **myelinated or unmyelinated**
- The different structures of these neurones are considered in more detail here
- Myelination is covered in more detail here

Structure of a Nerve Diagram

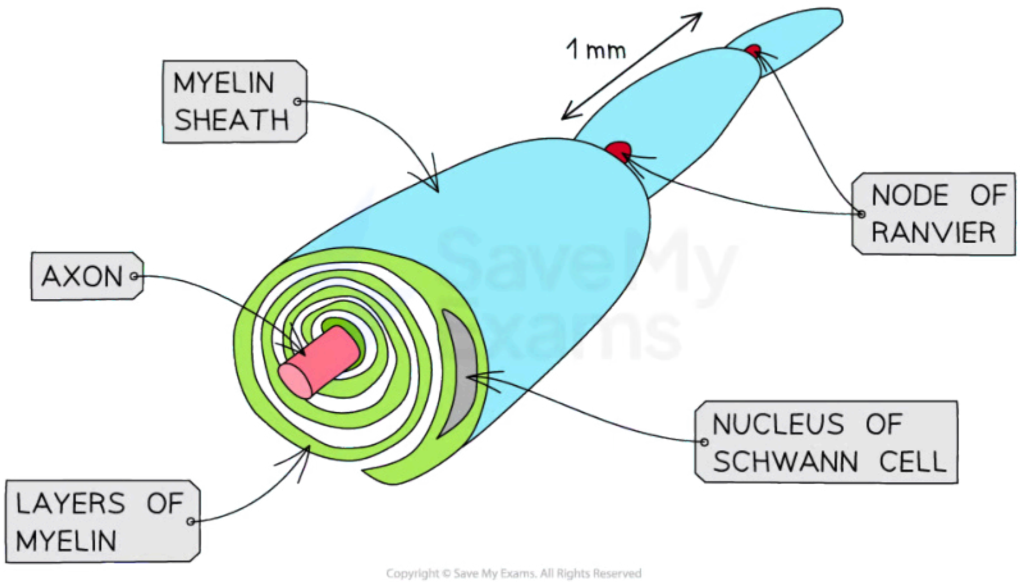
Your notes



A nerve is made up of a bundle of individual neurone cells

Transverse and Cross Section of Myelinated Neurone Diagram

Your notes



Each Schwann cell wraps its plasma membrane concentrically around the axon to form a segment of myelin sheath about 1mm long

Your notes

Reflex Arc & Movement Control

The Pain Reflex Arc

Reflexes

- **Reflex responses** are actions of the body that occur **without conscious thought**
  - Reflexes are **automatic** and **rapid, minimising damage** to the body and therefore **aiding survival**
  - Awareness of a reflex response occurs **after it has been carried out**; this is because the information takes longer to reach the conscious parts of the brain
- Examples of reflexes include blinking, coughing, and the pupil and knee reflexes
  - Blinking prevents the outer surface of the eye from drying out as well as protecting it from foreign objects
  - Coughing prevents food from entering the airways and removes mucus from the airways during infection or an allergic reaction
  - The pupil reflex prevents damage to the eye from bright light
  - The knee reflex aids balance when standing upright

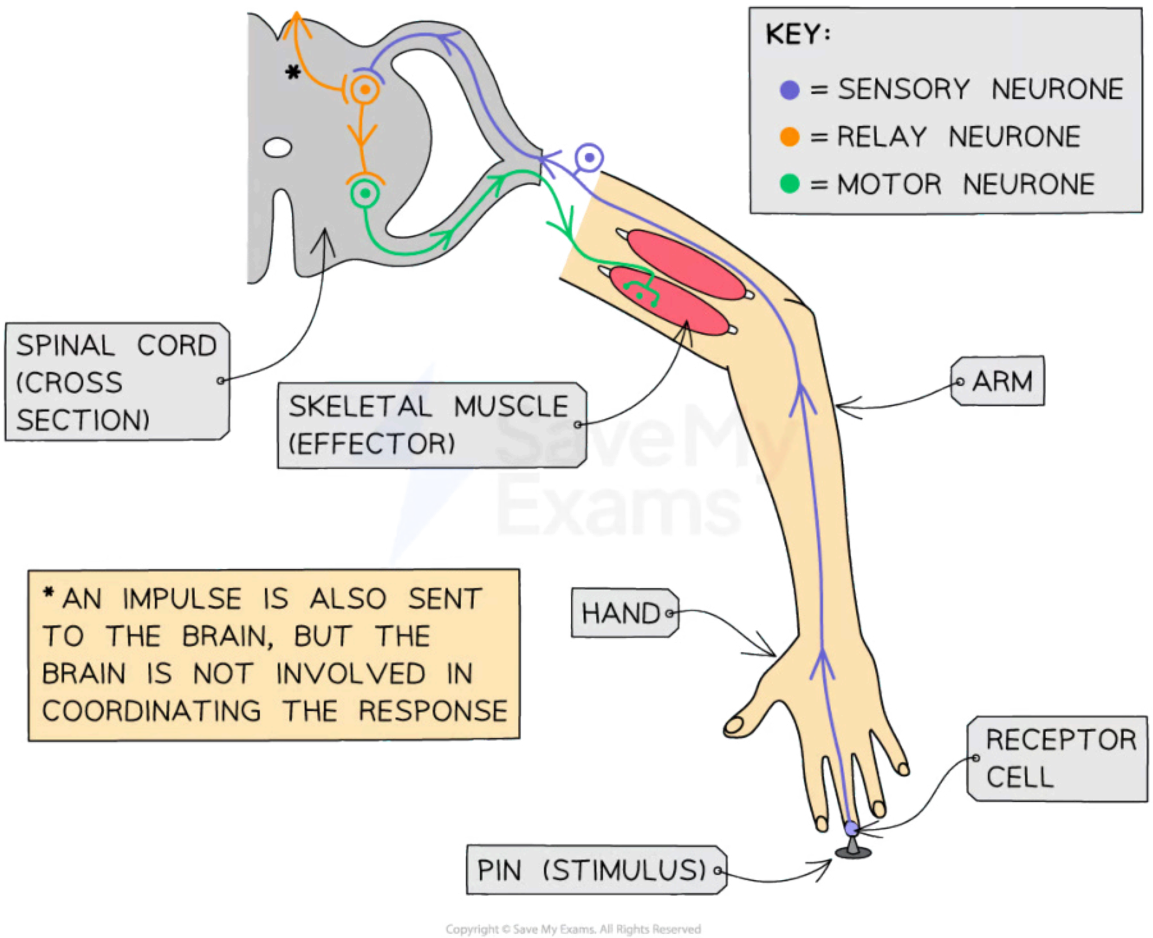
What is a reflex arc

- A **reflex arc** is a **pathway** along which impulses are transmitted from a receptor to an effector **without involving conscious regions of the brain**
  - A reflex arc therefore brings about a reflex response
  - **Sensory neurones, relay neurones and motor neurones** work together in a reflex arc

Order of a reflex arc

- A **pain reflex arc** is another example of a reflex response
- The skin has receptors for pressure, touch, and pain
  - The **receptor** involved is the pain receptor called a **nocireceptor**
    - The **stimulus** may be a sharp pin or hot flame which is detected by the nocireceptor in the skin of the hand
    - An afferent (sensory) action potential is sent along a **sensory neurone** to the CNS
    - An electrical impulse is passed to a **relay neurone** in the **spinal cord**
      - Relay neurones are found entirely within grey matter of the spinal cord
    - A relay neurone **synapses** with a motor neurone
      - A synapse is the junction between neurones; nerve impulses cross synapses by diffusion of a chemical called a neurotransmitter
    - A **motor** neurone carries an impulse to an **effector** muscle in the hand
    - When stimulated by the motor neurone the muscle will contract and pull the hand away from the sharp object or heat; this is the **reflex response**
- The reflex arc for a **spinal reflex** is as follows:

A Reflex Arc Diagram



Spinal reflexes involve relay neurones in the spinal cord as part of a pain reflex

Role of the Cerebellum

Your notes

- The cerebellum **coordinates movement**
  - This includes **balance;** a highly complex function that requires coordination between multiple parts, including the eyes, semicircular canals in the ears, and many muscles
  - Other movements coordinated by the cerebellum are
    - Posture
    - Walking
    - Hand and finger movements
    - Eye movements
    - Speech
- The cerebellum does not initiate movement, the **motor cortex of the cerebrum is responsible for initiating muscle contractions** and therefore movement
- Once the movement begins the cerebellum receives feedback signals from the area of the body that is moving and different sense organs, it then sends signals to **coordinate and control the movement**
- The structure and function of the brain as an organ is covered in more detail here

Your notes

Epinephrine & Melatonin

Melatonin

Circadian rhythms

- Many **physiological processes** and **behavioural patterns** occur in **regular, daily rhythms** in organisms throughout the plant and animal kingdoms
  - Many animal species are only active for a **specific part of the 24-hour cycle** e.g. nocturnal animals are only active at night
  - Humans are **diurnal** meaning that we are more awake during daylight hours
- Humans are **adapted** to live in a 24-hour cycle and many aspects of our physiology and behaviour, including **physical activity**, **sleep**, **body temperature,** and **secretion of hormones,** follow specific and regular cycles throughout the 24-hour period
  - These daily cycles are known as **circadian rhythms**
- In humans, many circadian rhythms are influenced by the hormone **melatonin**
  - Melatonin is **secreted** by the **pineal gland**, which is located in the **brain**
  - Melatonin secretion **increases in the evening** in response to **darkness** and **decreases at dawn** in response to **light**, leading to our diurnal behaviour patterns

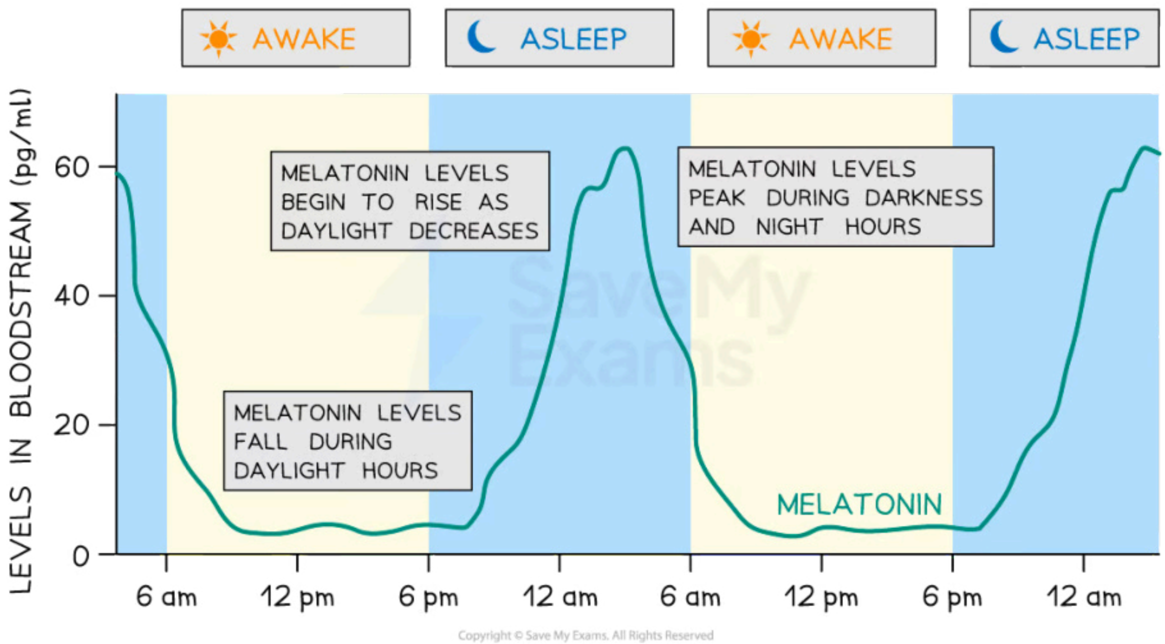
Melatonin and sleep patterns

- Although melatonin affects **many aspects of human physiology and behaviour**, one of the main circadian rhythms it controls is our **sleep-wake cycle**
  - The pineal gland **secretes melatonin into the blood**
    - Production is influenced by the detection of light and dark by the **retina** of the eye
    - Signals are then transmitted to the pineal gland according to the amount of daylight a person is exposed to and varies with changes in day length (this is why the pineal gland is sometimes referred to as both an endocrine clock and an endocrine calendar)
  - Melatonin's **target sites** are found in many areas of the brain including the hypothalamus and pituitary glands, and also in the cells of the immune system, gonads, kidney, and the cardiovascular system, blood vessels, and intestinal tract
  - **Increasing melatonin** levels lead to feelings of **tiredness** and **promote sleep**
  - **Decreasing melatonin** levels lead to the body's preparation for **waking up** and **staying awake during the day**

- Experiments have also suggested that
  - Increased melatonin at night contributes to the **night-time drop in core body temperature** in humans
  - Melatonin receptors in the kidney enable melatonin produced at night to cause the **night-time decrease in urine production** in humans
  - Melatonin is **still released in the absence of light and dark signals**, but on a slightly longer cycle than the usual 24 hours
    - Subjects living in the dark with no access to natural daylight still release melatonin on a roughly 24 hour cycle

- This suggests that the role of light is to **reset the melatonin system** every day to keep the circadian rhythm in line with daylight hours

Secretion of melatonin graph



The production of melatonin is influenced by the amount of daylight a person is exposed to: melatonin levels peak during

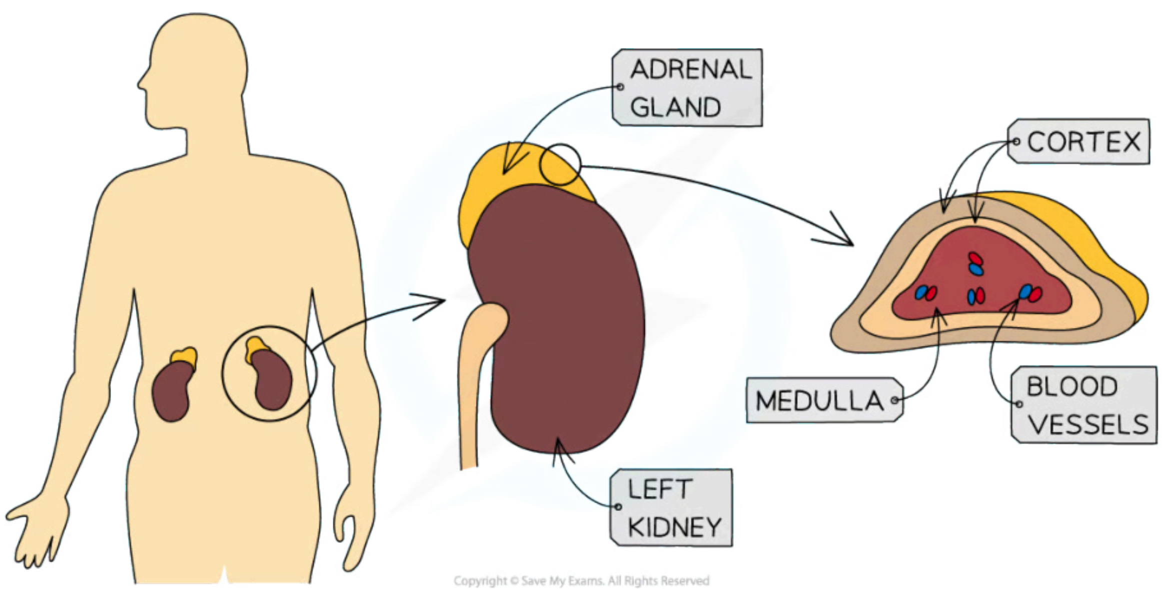
Your notes

Epinephrine

Your notes

- During situations that creates stress, fear or excitement, the neurones of the **sympathetic nervous system** will stimulate the **adrenal medulla** (of the adrenal gland) to secrete **epinephrine** (also called adrenaline)
  - Epinephrine is a **hormone** that will prepare your body for reacting to a stressful situation
  - This reaction is often called the "**fight or flight**" response
    - It is the **effects of epinephrine** that lead to the typical symptoms we experience during stressful situations such as increased heart rate, dry mouth, increased sweating etc

The adrenal gland diagram



The adrenal glands secrete the hormone epinephrine and prepare the body for vigorous activity

- Since epinephrine is a hormone, it is transported around the body in the **bloodstream**
- It will bind to receptors on its target organs
- One of the targets of epinephrine is the SAN, leading to an increase in the frequency of excitations
  - This in turn, will **increase the heart rate** to supply blood to the **muscle cells** at a faster rate
  - More blood means more oxygen and glucose that reaches the muscle cells, which in turn, **increases** the **rate of aerobic respiration**
  - This releases **more energy** that will be used during the response to the stressful, vigorous or dangerous situation
- Epinephrine will also **stimulate** the **cardiovascular control centre** in the medulla oblongata
  - This **increases** the impulses travelling along the sympathetic neurones affecting the heart, further speeding up the **heart rate**
- Blood vessels to **less important** organs (such as the digestive system and skin) **constrict** so that **more blood** can be **diverted** to organs that will be involved in the "fight or flight" response

- Note that blood flow to the **brain remains constant**, regardless of whether the body is in a state of stress or relaxation
  - The brain is one of the most important organs in the body and needs a constant blood supply in order to function properly
- The changes experienced by the body during the "fight or flight" response are controlled by a combination of nervous and hormonal responses
- Epinephrine is also covered in the course with reference to the second messenger model, this can be found here

Your notes

Your notes

Control Mechanisms

Control of the Endocrine System

- A **hormone** is a **chemical messenger** produced by an **endocrine gland** and carried by the **blood**
  - They are chemicals which **transmit information from one part of the organism to another** and bring about a **change**
  - They **alter** the **activity** of one or more specific **target organs**
- Hormones are used to control functions that **do not need instant responses**
- The endocrine glands that produce hormones in animals are known collectively as the **endocrine system**
  - A **gland** is a **group of cells** that produces and releases one or more substances (a process known as **secretion**)
- Control of the endocrine system is primarily by the **hypothalamus** and the **pituitary gland**

The hypothalamus

- The hypothalamus monitors **the blood** as it flows through the brain and, in response, **releases hormones** or stimulates the neighbouring **pituitary gland** to release hormones
  - The hypothalamus plays an important role in some **homeostatic mechanisms**
- Hypothalamus functions include
  - **Regulating body temperature**
    - The hypothalamus **monitors blood temperature** and initiates a homeostatic response if this temperature gets too high or too low
  - **Osmoregulation**
    - Cells in the hypothalamus **monitor the water balance of the blood** and releases the hormone ADH if the blood becomes too concentrated
      - ADH increases absorption of water in the kidneys
  - **Regulating digestive activity**
    - The hypothalamus regulates the hormones that control appetite as well as the secretion of digestive enzymes
  - **Controlling endocrine functions**
    - The hypothalamus causes the pituitary gland to release hormones that control a variety of processes e.g. metabolism, growth and development, puberty, sexual functions, sleep, and mood

The pituitary gland

- The pituitary gland is located **below the hypothalamus**
- Its role is to produce a **range of hormones**
  - Some of these directly influence and regulate processes in the body while some stimulate the release of further hormones from other **endocrine glands**
- The pituitary gland is divided into two sections; the **anterior pituitary** and **posterior pituitary**
  - The anterior pituitary produces and releases hormones

- The posterior pituitary stores and releases hormones produced by the hypothalamus e.g. ADH and oxytocin

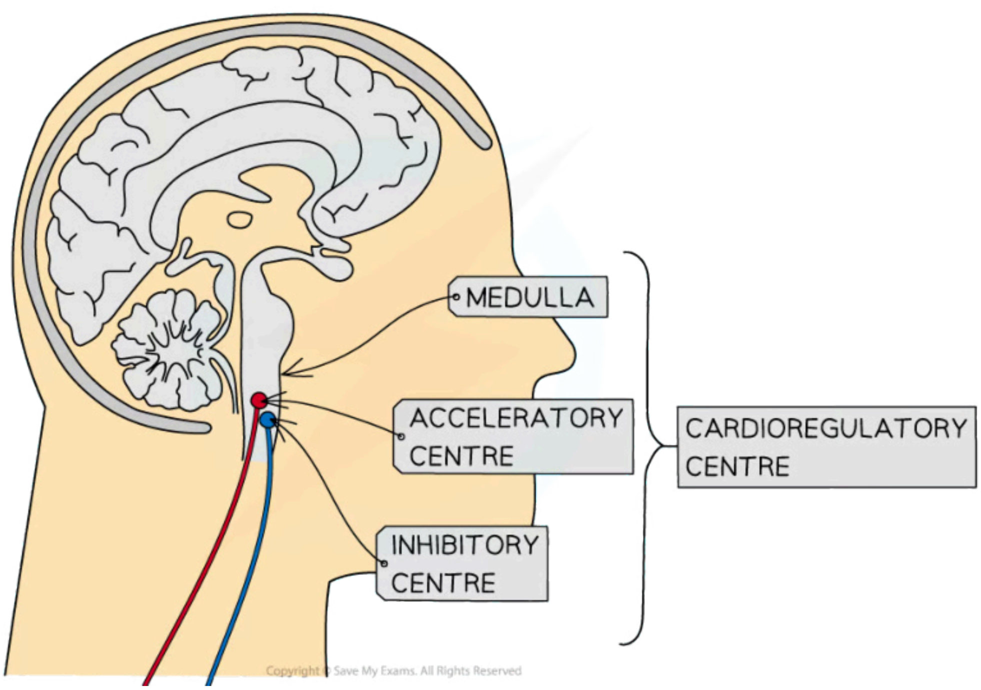
Your notes

Feedback Control of Heart Rate

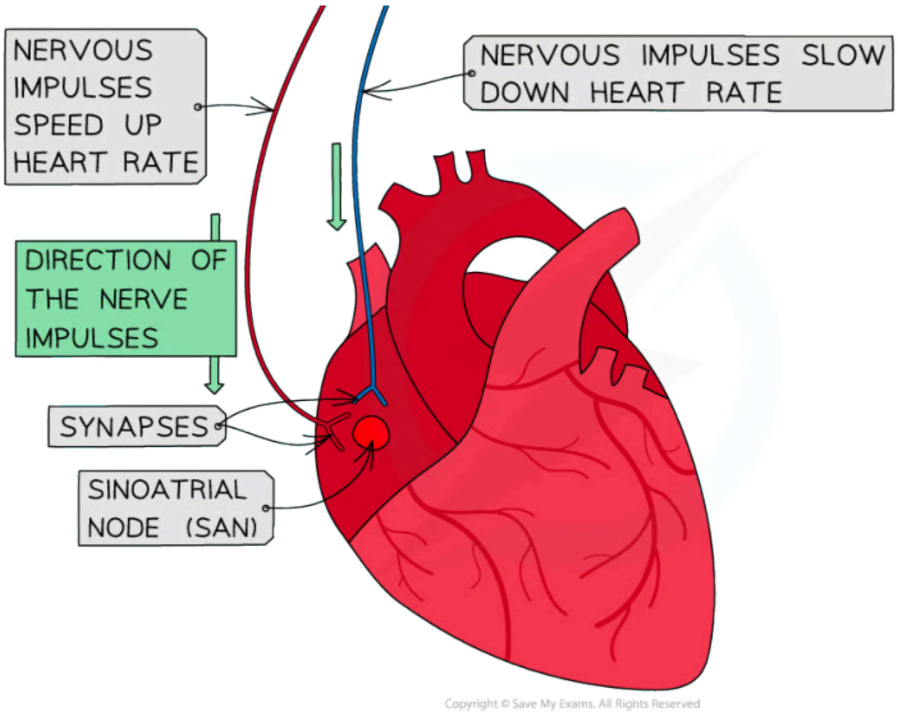
Your notes

- There are several circumstances that can cause an individual's heart rate to increase, such as during exercise
- The **brain** is involved in this response of the heart however it does not require any thinking and is under unconscious control
- There is a specific region of the brain that plays a vital role in controlling the heart rate
  - This **cardioregulatory centre** in the brain is called the **medulla**
- The medulla is found at the base of the brain near the top of the spinal cord
- The medulla is made up of two distinct parts:
  - The **acceleratory centre**, which causes the heart to **speed up**
  - The **inhibitory centre**, which causes the heart to **slow down**
- Both centres are **connected to the sinoatrial node** (SAN) by nerves
- These specific nerves are different from the nerves that control conscious activities. They make up the **autonomic nervous system**
- The autonomic nervous system is **self-controlling**

Control of heart rate diagram



Your notes



The location of the medulla helps to keep it protected from harm. It has an essential function as a cardioregulatory centre.

Increasing heart rate

- Once the acceleratory centre has been activated impulses are sent along the **sympathetic neurones to the SAN**
- Norepinephrine is secreted at the synapse with the SAN
- Noradrenaline causes the SAN to **increase the frequency** of the electrical waves that it produces
- This results in an **increased heart rate**

Decreasing heart rate

- Once the inhibitory centre has been activated impulses are sent along the **parasympathetic neurones to the SAN**
- Acetylcholine is secreted at the synapse with the SAN
- This neurotransmitter causes the SAN to **reduce the frequency** of the electrical waves that it produces
- This reduces the elevated heart rate towards the **resting rate**

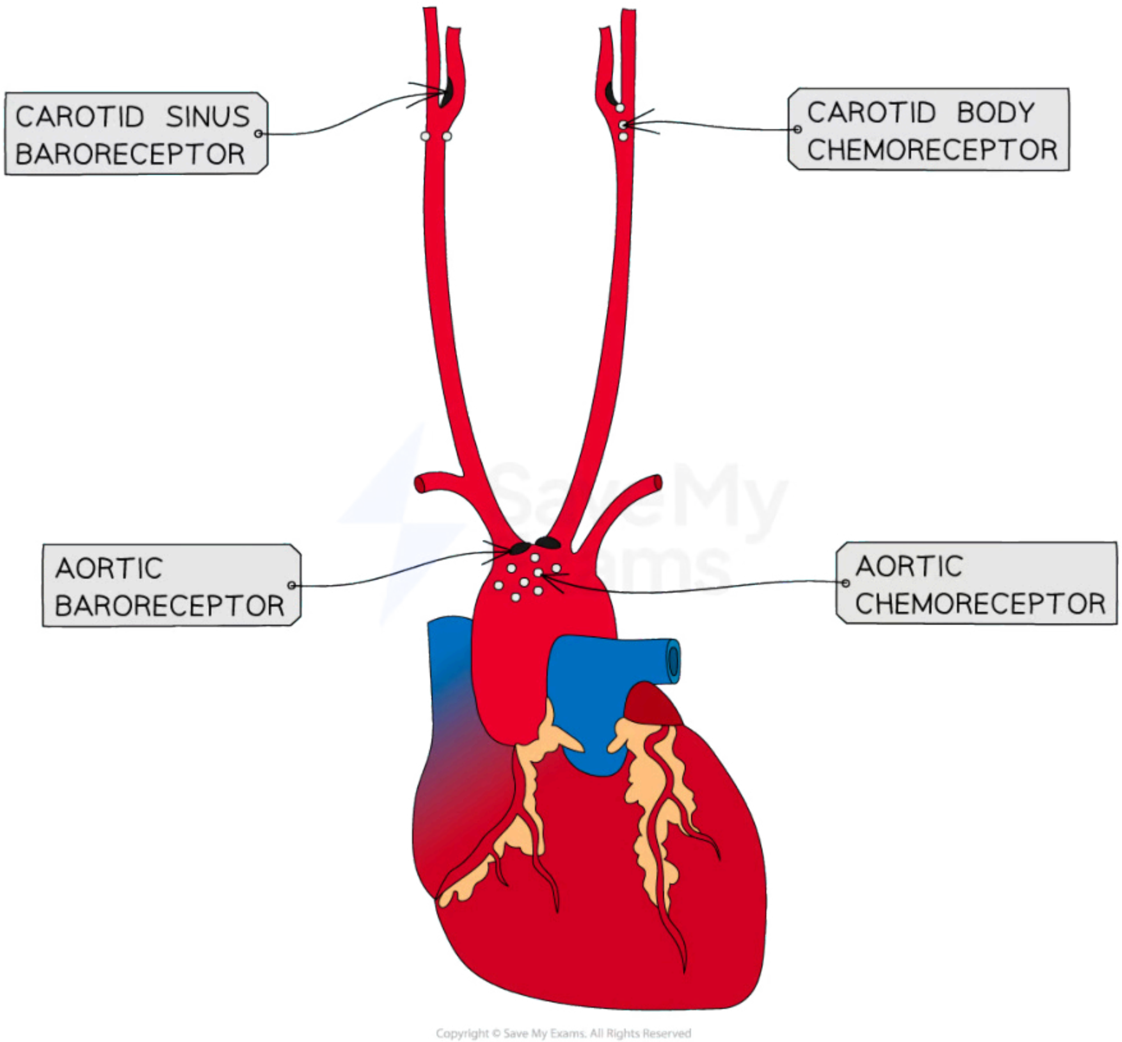
Chemoreceptors and baroreceptors

- Exercise causes several internal conditions to change, creating internal stimuli:
  - **Carbon dioxide** concentration in the blood **increases**
  - There is an **initial fall in blood pressure** caused by the dilation of muscle arterioles
- These internal stimuli can be detected by **chemoreceptors** and **baroreceptors** (pressure) **receptors** located in the **aorta** (close to the heart) and in the **carotid arteries** (they supply the head with

oxygenated blood)

- Chemoreceptors detect changes in blood pH and oxygen and carbon dioxide levels
- Baroreceptors monitor changes in blood pressure

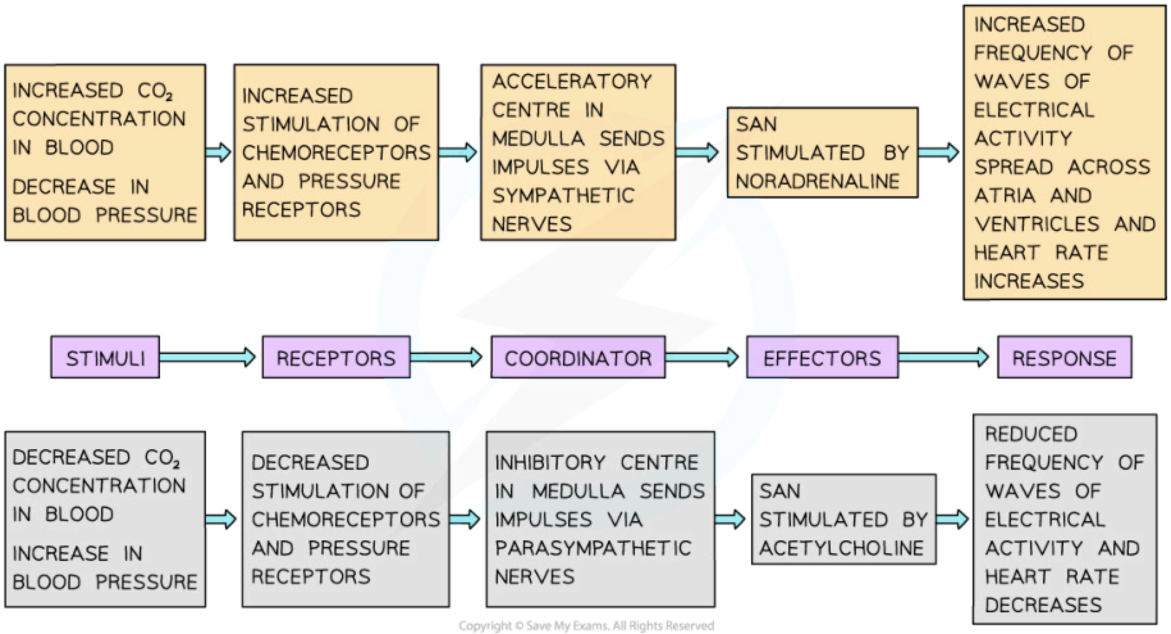
Location of the baroreceptors and chemoreceptors



Baroreceptors are located on the arch of the aorta and on the enlargement of the carotid arteries called the sinus. Chemoreceptors are located near the baroreceptors but on the outside of the aorta and carotid arteries

- These receptors release **nerve impulses that are sent to the acceleratory and inhibitory centres** (coordinators)
- The frequency of the nerve impulses increases or decreases depending on how stimulated the receptors are:
  - **Lower frequency** impulses activate the inhibitory centre to **slow down** the heart rate and stroke volume

- **Higher frequency** impulses activate the acceleratory centre to **speed up** the heart rate and stroke volume



The processes involved in the control of the heart rate. The internal stimuli are detected by chemoreceptors and baroreceptors that send impulses to coordinators (accelerator centre or inhibitory centre). The coordinators send signals to the effector (SAN) which produces a specific response.

Your notes

Your notes

Feedback Control of Ventilation Rate

- **Ventilation rates** in the body are controlled by cells called **respiratory centres** which are located in the **medulla** of the brain
- At **rest,** action potentials, produced at random, travel to the diaphragm and intercostal muscles to initiate contraction and therefore ventilation; this occurs at a stable and slow pace
- During **exercise**, higher levels of **carbon dioxide** are produced due to an increase in respiration
- Waste carbon dioxide produced during respiration diffuses from the tissues into the blood
- This waste carbon dioxide is transported around the body in different ways
  - In the blood plasma in the form of **hydrogen carbonate ions (HCO^{3-})**; around 85 % of carbon dioxide is transported in this way
  - Around 5 % of carbon dioxide dissolves directly in the blood plasma
  - Bound to haemoglobin as **carbaminohaemoglobin;** this accounts for around 10 % of carbon dioxide transport in the blood

pH changes in the blood

- Carbon dioxide released as a waste product from respiring cells **diffuses into the cytoplasm of red blood cells**
- Inside red blood cells, carbon dioxide **combines with water** to form carbonic acid (H_2CO_3)

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

  - Red blood cells contain the enzyme **carbonic anhydrase** which catalyses the reaction between carbon dioxide and water
  - Without carbonic anhydrase, this reaction proceeds very slowly
  - The plasma contains very little carbonic anhydrase hence H_2CO_3 forms **more slowly in plasma** than in the cytoplasm of red blood cells
- Carbonic acid dissociates readily into **hydrogen ions (H^+)** and **hydrogen carbonate ions (HCO^{3-})**

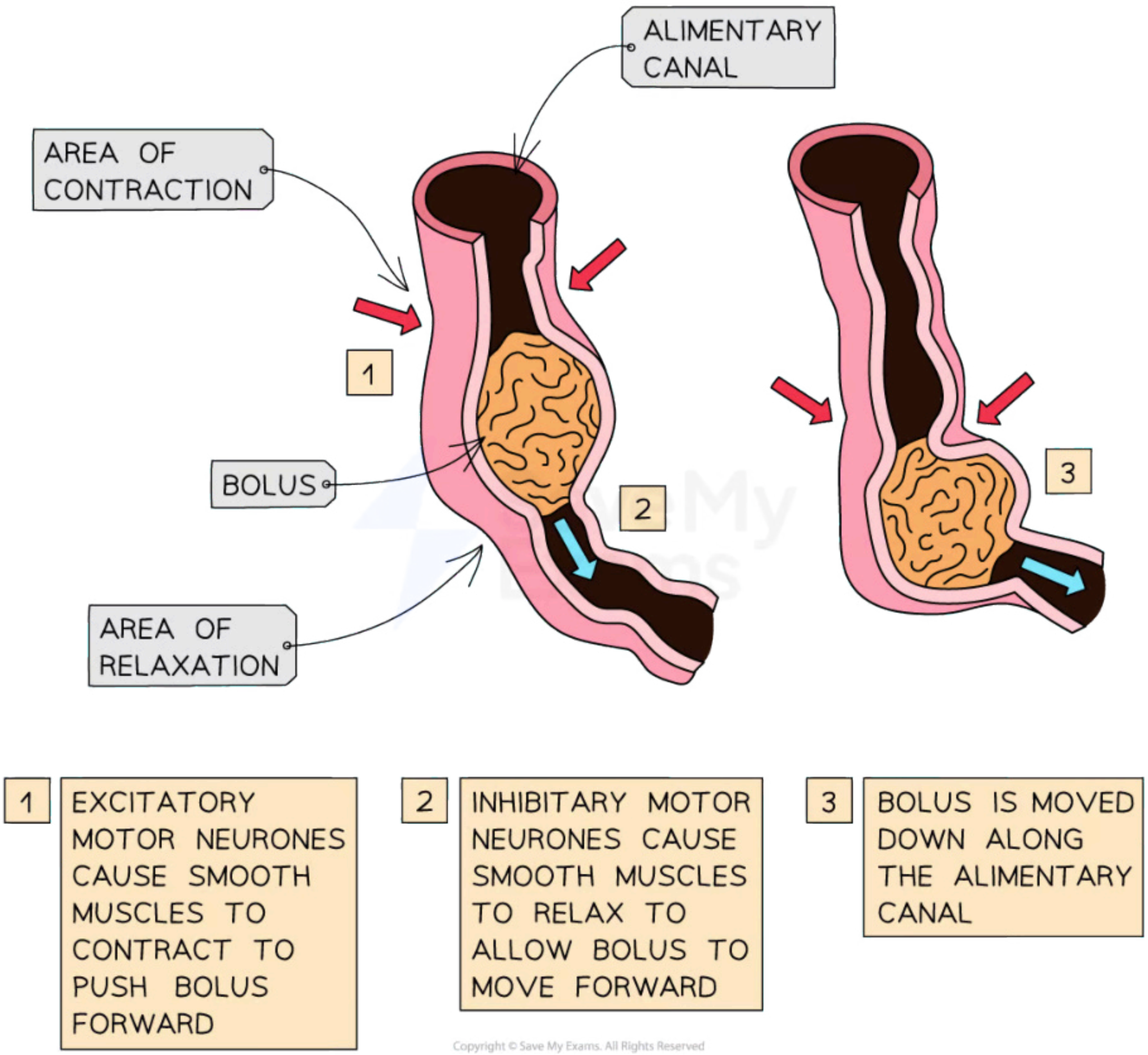
$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

- Hydrogen ions can lower the pH of the blood so their presence is **detected by chemoreceptors** in the medulla
- Action potentials are sent at a higher rate to the **diaphragm and intercostal muscles** of the lungs to increase ventilation rates and the volume of air being moved into and out of the lungs
- The pH of the blood can then return to normal and respiratory centres will stop sending action potentials to the diaphragm and the intercostal muscles, ventilation rates will return to normal resting rates
- This is an example of negative feedback

Control of Peristalsis in Digestive System

- Peristalsis is **series of muscle contractions** in the **walls of the oesophagus** or **small intestine** that pass like a **wave** along the alimentary canal
  - This wave forces the bolusof food along the alimentary canal
  - These contractions are controlled **unconsciously** by the autonomic nervous system, specifically the **enteric nervous system (ENS)**
    - The ENS consists a web of sensory neurones, relay neurones and motor neurones embedded in the tissues of the alimentary canal
- Peristalsis is controlled by **circular** and **longitudinal** muscles which initiate a mechanism called the **peristaltic reflex**
  - These muscles are smooth muscle (not striated)
- The bolus of food is detected by stretch receptors (sensory neurones of the ENS) as the alimentary canal becomes distended
- An action potential is passed to relay neurones of the ENS which synapse with two different motor neurones
  - One motor neurone releases an **excitatory neurotransmitter** which stimulates
    - **Longitudinal muscles to contract behind the bolus** to reduce the **length** of that section the oesophagus or the small intestine
      - This **forces the food forwards** through the alimentary canal
    - **Circular muscles contract** to reduce the **diameter** of the lumen of the oesophagus or small intestine
      - This **prevents the food moving backwards** towards the mouth
  - A second motor neurone releases an **inhibitory neurotransmitter** which stimulates smooth muscle **ahead** of the bolus to **relax and open the lumen of the alimentary canal**

Control of peristalsis diagram



The control of peristalsis is initiated by the bolus and is carried out by two different motor neurones