# Edexcel International A Level (IAL) Biology

Your notes

## Muscular Movement

### Contents

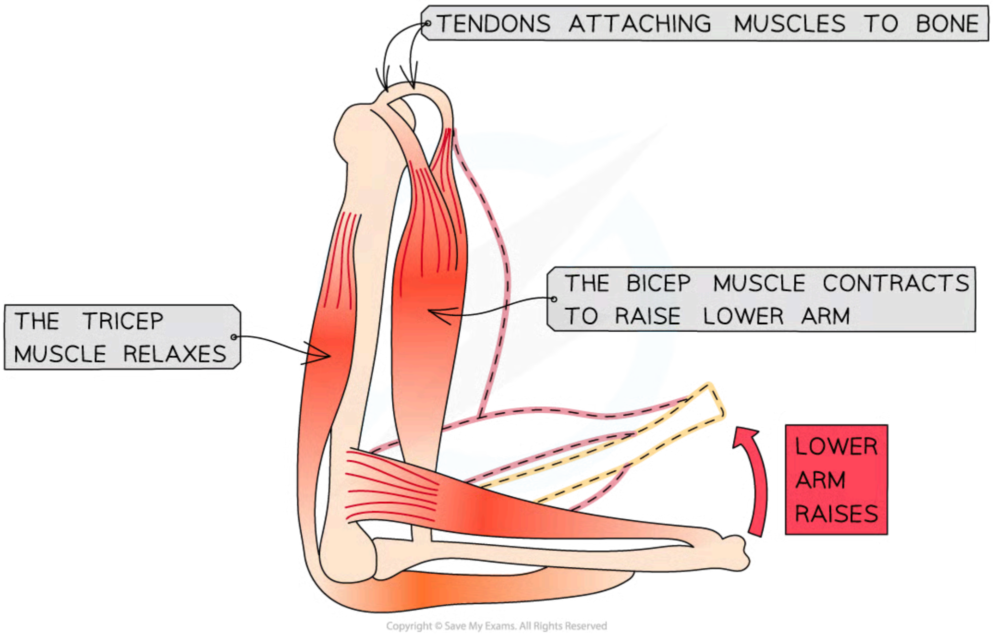
# The Musculoskeletal System

- The **effective movement** of the human body requires both **muscle** and an **incompressible skeleton**
  - This is because muscles will only produce effective movement if they **pull on a structure** that does not shorten or bend - bone
- There are over 600 skeletal muscles in the human body
- Muscles are **effectors**, stimulated by nerve impulses from motor neurones
- The muscular system is complex, with multiple muscles crossing over each other in multiple directions
- Lengths of **strong connective tissue** called **tendons, connect muscles to bones**
  - They are flexible but do not stretch when a muscle is contracting and pulling on a bone
  - There are a few muscles with very long tendons and also a few that are directly attached to the bone
- **Ligaments** are also lengths of **strong connective tissue** but they **connect bones to other bones**, which keep the skeleton intact

## Antagonistic muscle action

- Muscles are only capable of **contracting** or **pulling,** they **cannot push**
- As a result of this limitation muscles generally operate in **pairs**
- A muscle pulls in one direction **at a joint** and the other muscle **pulls in the opposite direction**
  - This is described as **antagonistic** muscle action
- An example of this can be seen in the biceps and triceps of the arm
- To raise the lower arm
  - The **bicep contracts** and the **tricep relaxes**
  - As the bone can't be stretched the arm **flexes around the joint**
  - A muscle that bends a joint during contraction is known as a **flexor** (the bicep in this case)
  - This brings the tricep into its full length so that it can contract again
- To lower the lower arm
  - The **tricep contracts** and **bicep relaxes**
  - As the bone can't be stretched the arm **flexes around the joint**

- A muscle that straightens a joint during contraction is known as an **extensor** (the tricep in this case)



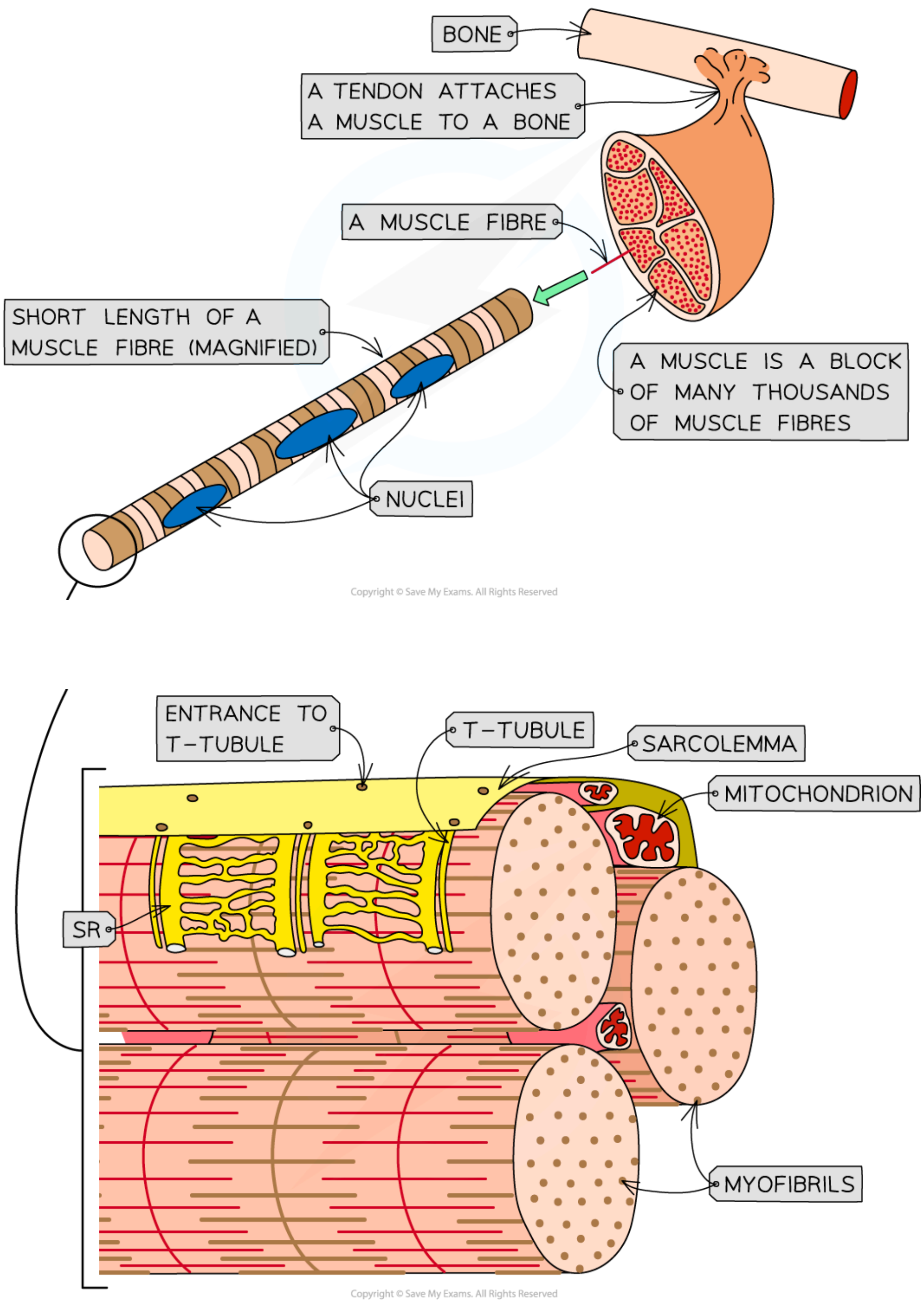

***Antagonistic muscle action: the two muscles work together by pulling in opposite directions***

Your notes

Your notes

# Muscle Fibre: Structure

- **Skeletal muscle** makes up the muscles in the body that are attached to the skeleton
- Skeletal muscle is made up of **muscle fibres**
- A muscle fibre is a **highly specialised** cell-like **unit**:
  - Each muscle fibre:
    - Contains an organised arrangement of **contractile proteins in the cytoplasm**
    - Is surrounded by a **cell surface membrane**
    - Contains **many nuclei** (**multi-nucleated**) – this is why muscle fibres are not usually referred to as cells
- The different parts of a muscle fibre have different names to the equivalent parts of a normal cell:
  - Cell surface membrane = **sarcolemma**
  - Cytoplasm = **sarcoplasm**
  - Endoplasmic reticulum = **sarcoplasmic reticulum (SR)**
- The sarcolemma has many deep tube-like projections that fold in from its outer surface:
  - These are known as transverse system tubules or **T-tubules**
  - These run **close to the SR** and help spread electrical impulses throughout muscle fibre
- The sarcoplasm contains **mitochondria** and **myofibrils**
  - The mitochondria carry out aerobic respiration to generate the ATP **required for muscle contraction**
  - Myofibrils are **bundles of actin and myosin filaments**, which slide past each other during muscle contraction
- The membranes of the SR contain **protein pumps** that transport **calcium ions** into the lumen of the SR
  - Calcium ions are needed for the contraction of muscle




***The ultrastructure of skeletal muscle and of a section of muscle fibre***

Your notes

## Myofibrils

- Myofibrils are located in the **sarcoplasm**
- Each myofibril is made up of **two types of protein filament:**
  - **Thick** filaments made of **myosin**
  - **Thin** filaments made of **actin**

- These two types of filaments are arranged in a particular order, creating different types of **bands** and **lines**

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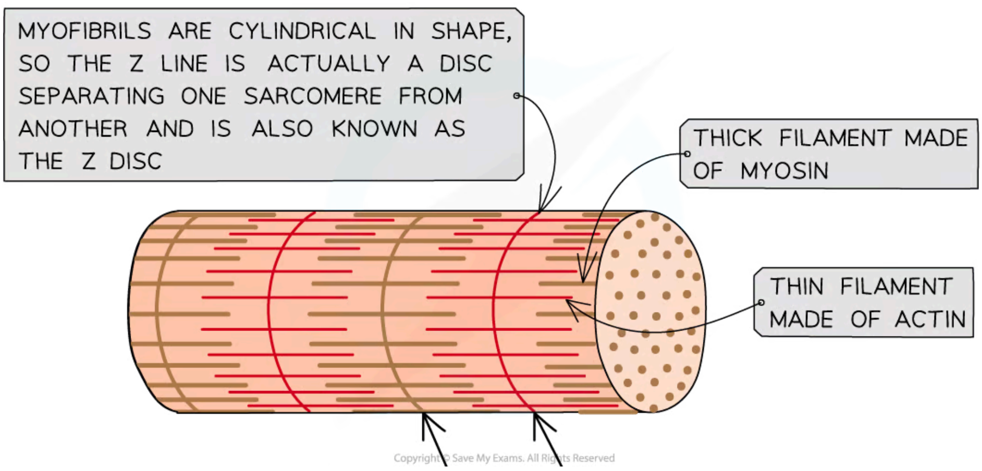
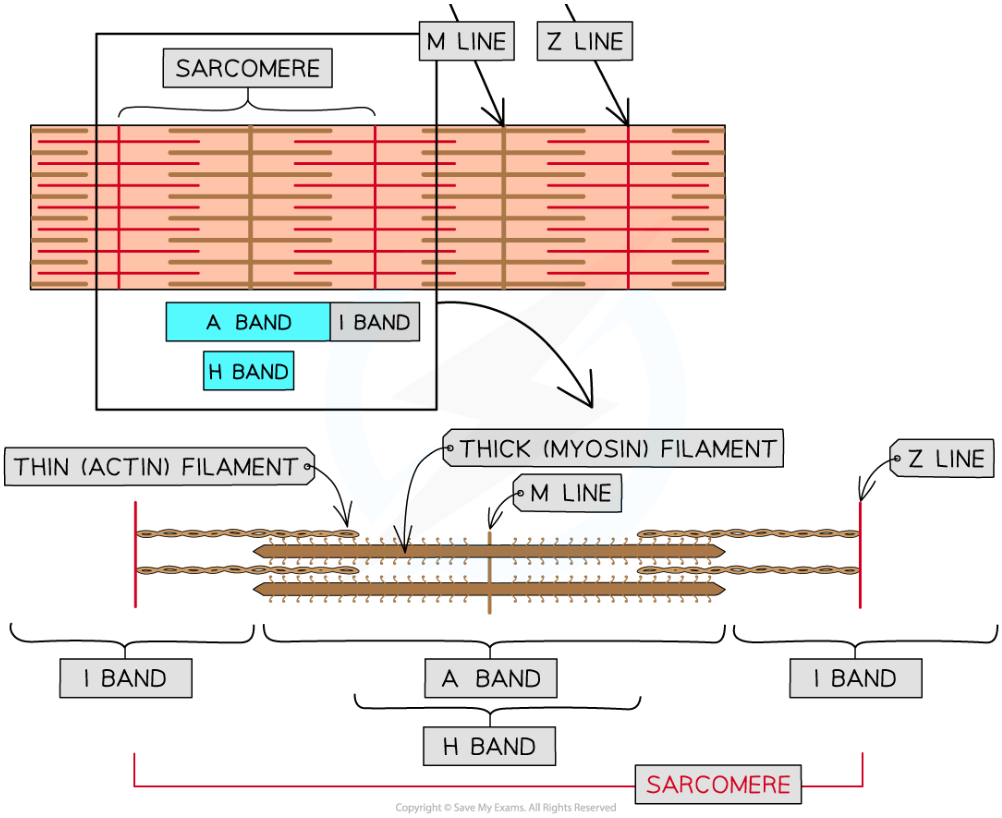
**Myofibrils Parts & Descriptions Table**

| Part of Myofibril | Description |
|---|---|
| H band | Only thick myosin filaments present |
| I band | Only thin actin filaments present |
| A band | Contains areas where only myosin filaments are present and areas where myosin and actin filaments overlap |
| M line | Attachment for myosin filaments |
| Z line | Attachment for actin filaments |
| Sarcomere | The section of myofibril between two Z lines |








*The structure of a myofibril*

# Fast & Slow Twitch Muscle Fibres

- There are two types of muscle fibres found in muscles
  - **Fast twitch** fibres
  - **Slow twitch** fibres
- Human muscles are made up of both types of muscle fibres
- Some muscles have higher proportions of a particular fibre type due to their different properties

## Fast twitch muscle fibres

- Fast twitch muscle fibres **contract rapidly**
  - The myosin heads bind and unbind from the actin-binding sites five times faster than slow twitch muscle fibres
  - Their rapid contraction-relaxation cycle means they need **large amounts of calcium ions** present to stimulate contraction
- They rely on **anaerobic respiration** for ATP supply
- They are suited to **short bursts of high-intensity activity** as they **fatigue quickly** due to the **lactate** produced from anaerobic respiration

Your notes

- These muscle fibres are often found in high proportions in the **limbs** of animals that flee a predator or hunt prey at high speeds
    - For example, the wings of a robin and legs of a cheetah
- There are high proportions of fast twitch muscle fibres in **human eyelids**
    - They contract in short bursts and do not need to sustain the rapid movement
- Fast twitch muscle fibres have **fewer capillaries**
    - Blood containing glucose and oxygen flow through the capillaries
    - This means they have quite a slow supply of oxygen and glucose for aerobic respiration
- **Low amounts of myoglobin are present** in fast twitch muscle fibres
    - Myoglobin is a red pigment molecule that is similar to haemoglobin
    - Myoglobin functions as a **store of oxygen** in muscles and increases the rate of oxygen absorption from the capillaries
- Due to this fast twitch muscle fibres appear **paler** in colour than slow muscle fibres

## Slow twitch muscle fibres

- Slow twitch muscle fibres **contract more slowly** and are suited to **sustained activities** like walking and perching
- They rely on aerobic respiration for ATP
- They **fatigue less quickly** due to less lactate production, making them ideal for **endurance**
- These muscle fibres are often found in high proportions in the **limbs** of animals that migrate or stalk prey over long distances
    - For example, the wings of geese and legs of wolves
- **Human back muscles** have a high proportion of slow twitch muscle fibres
    - These muscles have to contract for long periods of time in order to keep the skeleton erect when standing or sitting
- Slow twitch muscle fibres have **a denser network of capillaries**
    - Blood containing glucose and oxygen flows through the capillaries
    - This means they have a short diffusion distance and a good supply of oxygen and glucose for aerobic respiration
- **High amounts of myoglobin, haemoglobin and mitochondria** are present in slow twitch muscle fibres
    - This increases the rate of oxygen supply, oxygen absorption and aerobic respiration
- Due to the high amounts of red pigment, slow twitch muscle fibres appear a **dark red**

Your notes

**Fast Twitch & Slow Twitch Muscle Fibres Table**

| Fast muscle fibres | Slow muscle fibres |
|---|---|
| Short contraction–relaxation cycle | Long contraction–relaxation cycle |
| Fewer capillaries | Denser network of capillaries |
| ATP supplied mostly from anaerobic respiration | ATP supplied mostly from aerobic respiration |
| Fewer, smaller mitochondria present | Many, large mitochondria present |
| Large store of calcium ions in the sarcoplasmic reticulum | Small store of calcium ions in the sarcoplasmic reticulum |
| Large amounts of glycogen and phosphocreatine present | Small amounts of glycogen present |
| Faster rate of ATP hydrolysis in myosin heads | Slower rate of ATP hydrolysis in myosin heads |
| Fatigues rapidly due to greater lactate formation | Fatigues more slowly due to reduced lactate formation |

# The Sliding Filament Theory

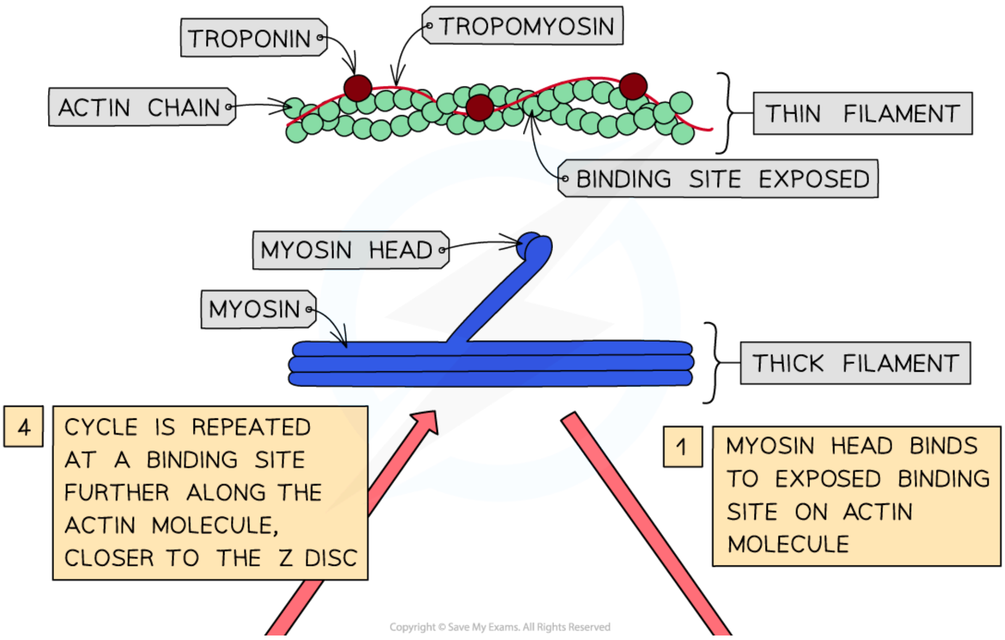
## Structure of thick & thin filaments in a myofibril

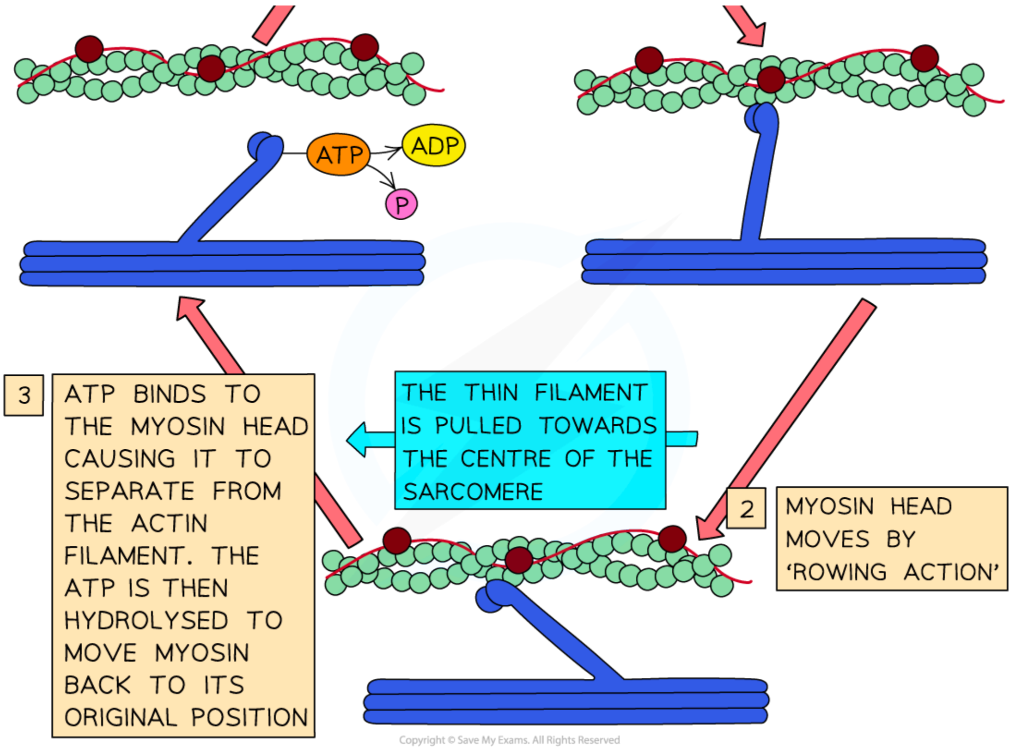
- The **thick filaments** within a myofibril are made up of **myosin molecules**
  - These are **fibrous protein molecules** with a **globular head**
  - The **fibrous part** of the myosin molecule **anchors** the molecule into the thick filament
  - In the thick filament, many myosin molecules lie next to each other with their **globular heads all pointing away** from the **M line**
- The **thin filaments** within a myofibril are made up of **actin molecules**
  - These are **globular protein molecules**
  - Many actin molecules link together to form a **chain**
  - **Two** actin chains **twist** together to form one **thin filament**
  - A **fibrous** protein known as **tropomyosin** is twisted around the two actin chains
  - Another protein known as **troponin** is attached to the actin chains at regular intervals

## How muscles contract – the sliding filament theory

- Muscles cause movement by **contracting**
- During muscle contraction, **sarcomeres** within myofibrils **shorten** as the **Z discs are pulled closer together**
- It is **not** the filaments that contract as the myosin and actin molecules remain the **same length**
- Myosin and actin filaments **slide over one another**
- This is known as the **sliding filament theory of muscle contraction** and occurs via the following process:
  - An **action potential arrives** at the **neuromuscular junction** (a specialised synapse between a motor neuron nerve terminal and its muscle fibre)
  - **Calcium ions** are **released** from the **sarcoplasmic reticulum** (SR)
    - Calcium ions **bind to troponin molecules**, stimulating them to **change shape**
    - This causes **troponin** and **tropomyosin** proteins to **change position** on the **actin (thin) filaments**
  - **Myosin binding sites are exposed** on the actin molecules

- The **globular heads of the myosin molecules bind** with these sites, forming **cross-bridges** between the two types of filaments
    - Myosin heads **bend**, **pulling the actin filaments towards the centre of the sarcomere** and causing the muscle to contract a very small distance; this bending of the myosin heads is known as the **power stroke**
- **ATP** plays an important role in this process
    - The **binding of ATP to the myosin heads** produces a **change in shape** of the myosin heads that allows them to **detach** from the actin filaments
    - The enzyme **ATPase** hydrolyses ATP into ADP and inorganic phosphate which causes the myosin heads to move back to their **original positions,** this is known as the **recovery stroke**
    - The myosin heads are then able to bind to **new binding sites** on the actin filaments, **closer to the Z disc**
    - The binding of the myosin heads to their new binding site causes the release of ADP and phosphate and results in a new power stroke
- The myosin heads move again, pulling the actin filaments **even closer to the centre of the sarcomere**, causing the sarcomere to **shorten** once more and pulling the Z discs closer together
- ATP binds to the myosin heads once more in order for them to **detach** again
- As long as troponin and tropomyosin are not blocking the myosin-binding sites and the muscle has a supply of ATP, this process **repeats** until the muscle is **fully contracted**






***The sliding filament theory of muscle contraction***

- Once muscle stimulation stops, **calcium ions leave** their binding sites on troponin molecules
  - They are **actively transported** back to the SR
- Without calcium ions bound to them, the **troponin molecules return** to their original shape
  - This pulls the **tropomyosin** molecules in a position that **blocks the actin-myosin binding sites**
- Since **no cross bridges** can form between actin and myosin, **no muscle contraction** can occur
- The **sarcomere will lengthen** again as actin filaments slide back to their relaxed position

## Examiner Tips and Tricks

There is a lot to remember here so take some time to go through it and ensure you understand the order of events.

Because muscles require a source of ATP for myosin heads to detach (and the muscle to stop contracting) this explains rigor mortis (stiffening of the joints and muscles of a body a few hours after death) as there is no ATP after death to detach the myosin heads, the muscles remain contracted!

Your notes

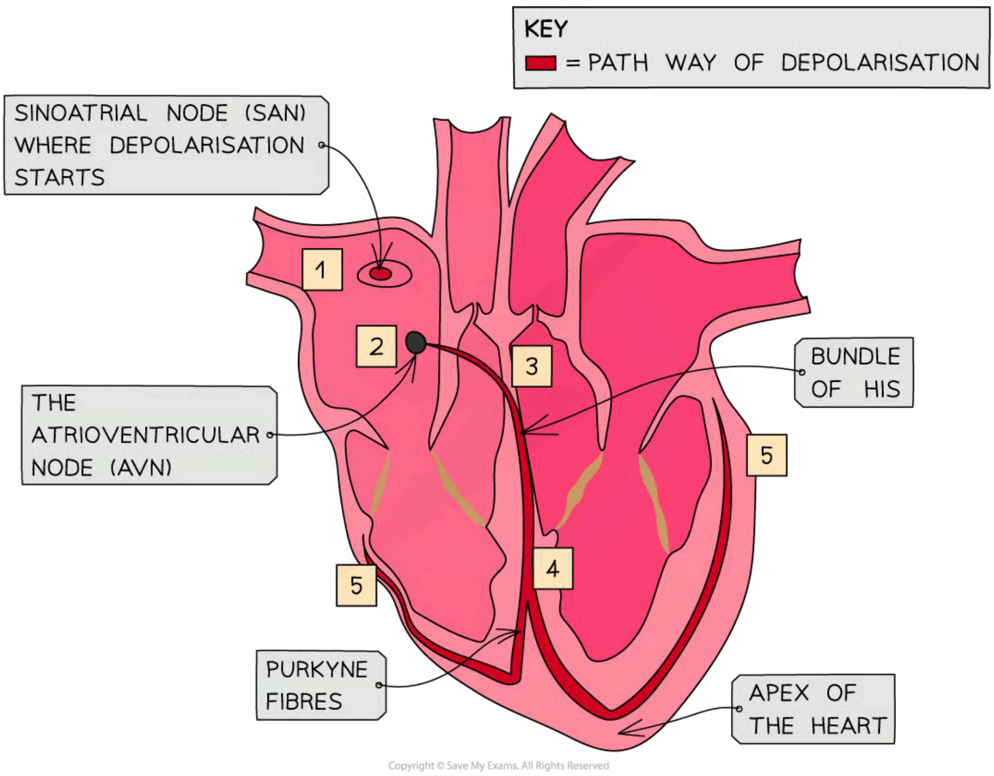
# The Role of Muscle in the Cardiac Cycle

- The cells making up cardiac muscle are **myogenic**, which means they contract without any external stimulus
- This intrinsic rhythm means the heart beats at around 60 times per minute
- The **sinoatrial node (SAN)** is a group of cells in the wall of the right atrium
  - The SAN initiates a wave of depolarisation that causes the **atria to contract**
- There is a region of non-conducting tissue which prevents the depolarisation spreading straight to the ventricles
  - Instead, the depolarisation is carried to the **atrioventricular node (AVN)**
  - This is a region of conducting tissue between atria and ventricles
- After a slight delay, the AVN is stimulated and passes the stimulation along the **bundle of His**
  - This delay means that the ventricles contract after the atria
- The bundle of His is a collection of conducting tissue in the **septum** (middle) of the heart
  - The bundle of His divides into two conducting fibres which carry the impulse to the **Purkyne fibres**
    - Purkyne fibres are also known as Purkinje fibres
- Purkyne fibres spread around the ventricles and initiate the **depolarisation of the ventricles** from the **apex** (bottom) of the heart
- This makes the **ventricles contract from the bottom upward** and **blood is forced out** of the ventricles into the pulmonary artery and aorta

**Stages in the Cardiac Cycle Table**

| Stage in sequence | Event |
|---|---|
| 1 | Sinoatrial node sends out a wave of excitation |
| 2 | Atria contract |
| 3 | Atrioventricular node sends out a wave of excitation |
| 4 | Purkyne tissue conducts the wave of excitation |
| 5 | Ventricles contract |






*The wave of depolarisation spreads across the heart in a co-ordinated manner*

## Examiner Tips and Tricks

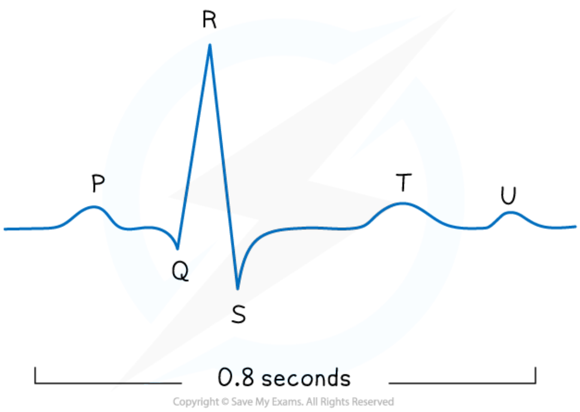
Your notes

Remember that the heart is **myogenic**, which means that the heart will generate a heartbeat by itself and without any other stimulation. Instead, the electrical activity of the heart regulates the heart rate. Be aware that you may sometimes see an alternative spelling of "Purkyne" as "Purkinje" they mean the exact same thing!

Your notes

# The Use of ECGs

- Electrocardiography can be used to monitor and investigate the electrical activity of the heart
- **Electrodes** that are capable of detecting electric signals are placed on the skin
- These electrodes produce an **electrocardiogram** (ECG)
  - An ECG shows a number of distinctive **electrical waves produced by the activity of the heart**
- A healthy heart produces a distinctive shape in an ECG




*The ECG of a healthy heart*

- **The P wave**
  - Caused by the depolarisation of the atria, which results in atrial contraction (systole)
- **The QRS complex**
  - Caused by the depolarisation of the ventricles, which results in ventricular contraction (systole)
  - This is the largest wave because the ventricles have the largest muscle mass
- **The T wave**
  - Caused by the repolarisation of the ventricles, which results in ventricular relaxation (diastole)
- **The U wave**
  - Scientists are still uncertain of the cause of the U wave, some think it is caused by the repolarisation of the Purkyne fibres

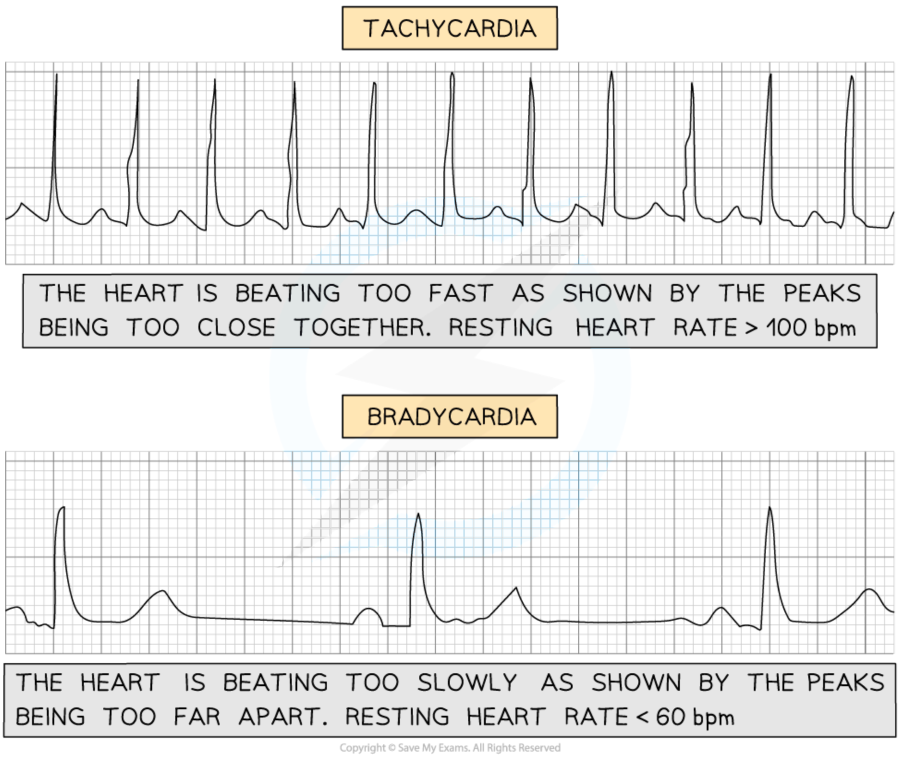
- The **bigger** the wave, the **greater** the electrical activity passing through the heart, which results in a **stronger contraction**

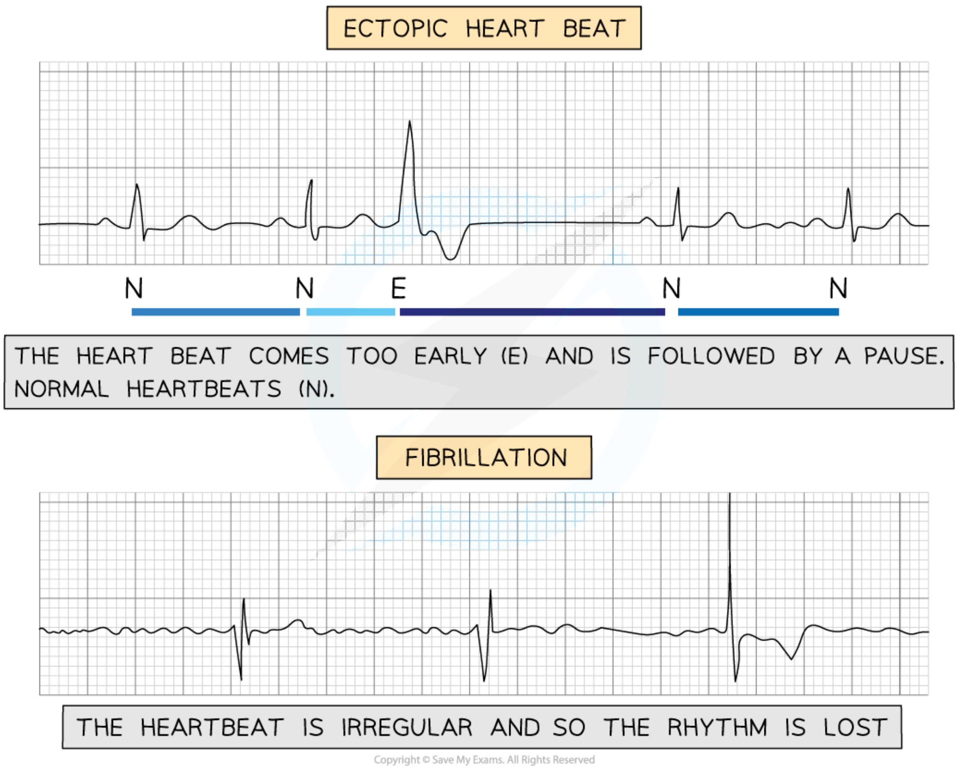
Your notes

## Using ECGs to diagnose heart problems

- If someone has a suspected heart problem a doctor will often use an ECG as a diagnostic tool
- Some heart problems produce certain shapes or waves in an ECG which allow for a diagnosis
- **Tachycardia**
  - When the **heart beats too fast** it is tachycardic
  - An individual with a resting heart rate of over 100 bpm is said to have tachycardia
- **Bradycardia**
  - When the **heart beats too slow** it is bradycardic
  - An individual with a resting heart rate below 60 bpm is said to have bradycardia
  - A lot of fit individuals or athletes tend to have lower heart rates and it is usually not dangerous
- **Ectopic heartbeat**
  - This condition is caused by an **early heartbeat followed by a pause**
  - This could be due to an earlier contraction of either the atria or ventricles
  - It is common in the population and usually requires no treatment unless very severe
- **Fibrillation**
  - An **irregular heartbeat** will disrupt the rhythm of the heart
  - The atria or ventricles stop contracting properly
  - Severe cases of fibrillation can be very dangerous, even fatal

Your notes

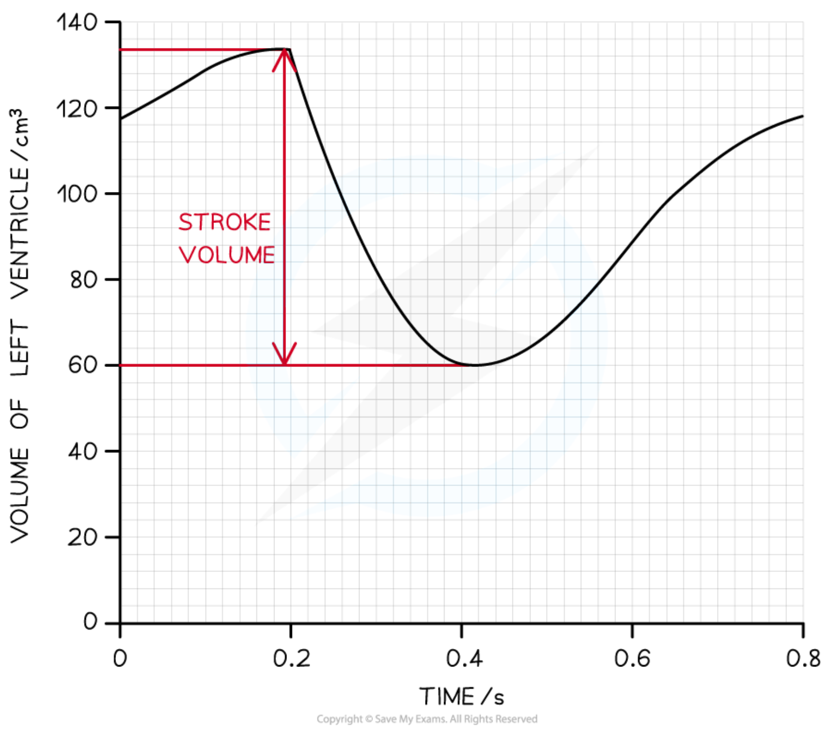



***Each of these ECGs shows different faulty heartbeats. The speed or rhythm/regularity of the heartbeat is very important***

# Calculation of Cardiac Output

- **Cardiac output** (CO) is the term used to describe the volume of blood that is pumped by the heart (the left and right ventricle) per unit of time
- An average adult has a cardiac output of roughly 4.7 litres of blood per minute when at **rest**
- Individuals who are **fitter** often have **higher cardiac outputs** due to having thicker and stronger ventricular muscles in their hearts
- Cardiac output **increases** when an individual is **exercising**
  - This is so that the blood supply can match the increased metabolic demands of the cells
- The CO of an individual can be calculated using their **heart rate** and **stroke volume**
- **Heart rate** is the **number of times a heart beats per minute**
  - This can also be described as the number of cardiac cycles per minute
- **Stroke volume** is the **volume of blood pumped out of the left ventricle during one cardiac cycle**




***Graph showing the changes in the volume of the left ventricle within one cardiac cycle; this is the stroke volume***

Your notes

## Calculating cardiac output

- Cardiac output is found by multiplying the heart rate by the stroke volume:

**Cardiac output = heart rate x stroke volume**

- The equation can be rearranged to find the heart rate and stroke volume if required:
  - Heart rate = cardiac output ÷ stroke volume
  - Stroke volume = cardiac output ÷ heart rate
- **Cardiac output** is measured in **$cm^3$ $min^{-1}$**
- **Heart rate** is measured in **beats per min** (bpm)
- **Stroke volume** is measured in **$cm^3$**

### Worked Example

A woman took 0.833 seconds to complete a single cardiac cycle. The stroke volume of her heart was measured at 75 $cm^3$. Calculate the cardiac output. Give your answer in $dm^3$.

**Answer:**

**Step 1: Find the heart rate**

One cardiac cycle (atrial systole, ventricular systole and diastole) takes 0.833 seconds

To find the number of cardiac cycles completed in a minute, divide 60 (seconds) by the time taken for one cycle, 0.833 seconds

Heart rate = 60 ÷ 0.833

= 72 bpm

**Step 2: Insert relevant figures into the equation**

Cardiac output = heart rate x stroke volume

Cardiac output = 72 x 75 = 5 400 $cm^3$

**Step 3: Convert to $dm^3$**

1 000 $cm^3$ = 1 $dm^3$

Cardiac output = 5 400 ÷ 1 000 =

**5.40 $dm^3$**

Your notes

### Worked Example

An athlete runs a 10 km race, after which his heart rate was measured at 110 bpm and his cardiac output was determined to be 9,800 $cm^3$.

Calculate the stroke volume after the race.

**Answer:**

Stroke volume = cardiac output ÷ heart rate

Stroke volume = 9,800 ÷ 110

Stroke volume = **89.1 $cm^3$**

### Examiner Tips and Tricks

1 $dm^3$ is equal to 1000 $cm^3$. It can be useful to convert all the figures found in the first question into the **same units** before starting your working out, that way you are less likely to make any mistakes!

# Effects of Variability of Cardiac Output

- During exercise, **muscle contraction** occurs **more frequently**, requiring **more energy**
- The **rate of aerobic respiration increases** to meet the increase in energy demand
- This means that cells **require more oxygen** to be delivered to them, while **producing more carbon dioxide** as a waste product of respiration
- The body will accommodate this by making the following changes:
  - **Increase the rate and depth of breathing** which will increase the amount of oxygen entering the lungs and bloodstream, while getting rid of more carbon dioxide
  - **Increase the heart rate** which will transport the oxygen (and glucose) to the muscles much faster, while removing the additional carbon dioxide produced due to the increased rate of respiration

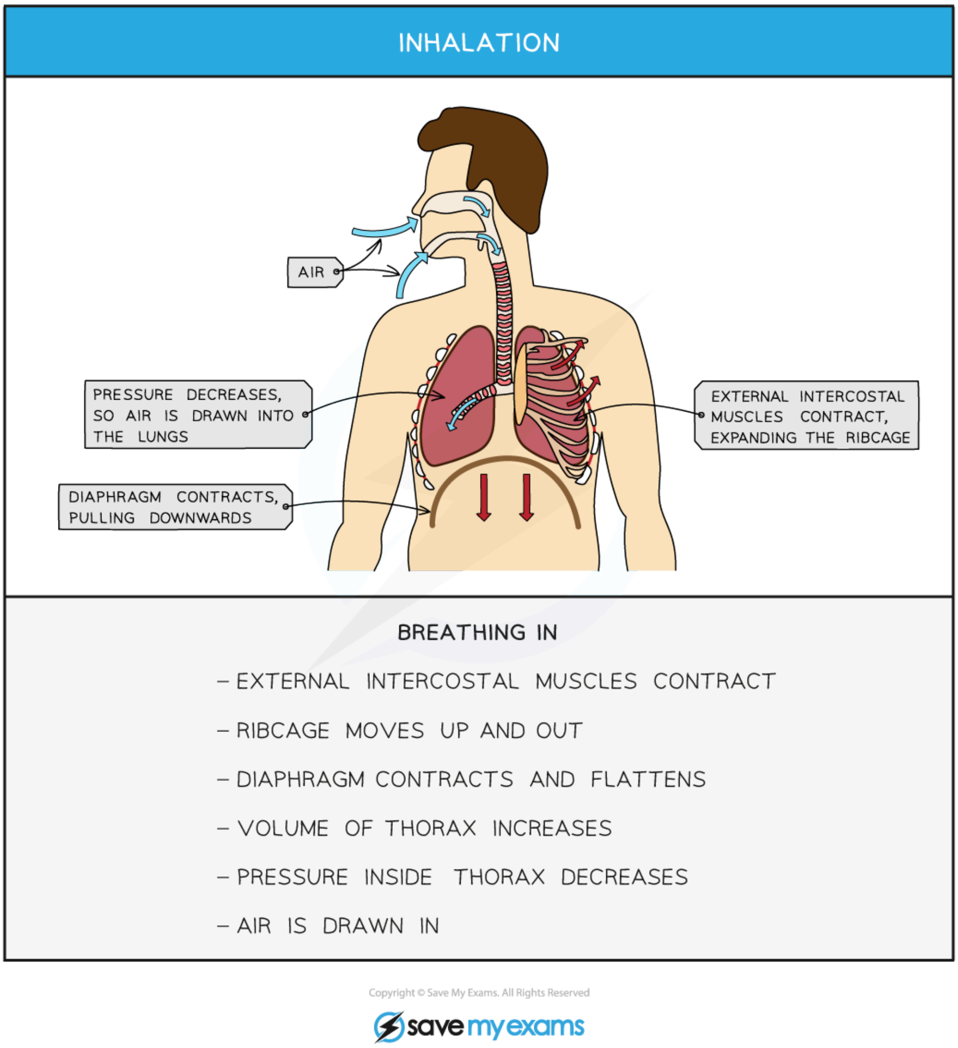
## Control of the breathing rate

- Breathing rate is controlled by the **ventilation centres** (also called respiratory centres) in the **medulla oblongata**
  - This is one of the three regions that make up the brainstem, it transfers nerve messages from the brain to the spinal cord
  - The **inspiratory centre** controls the movement of air into the lungs (inhalation)
  - The **expiratory centre** controls the movement of air out of the lungs (exhalation)
- The **inspiratory centre** in the medulla oblongata has the following effect on breathing:

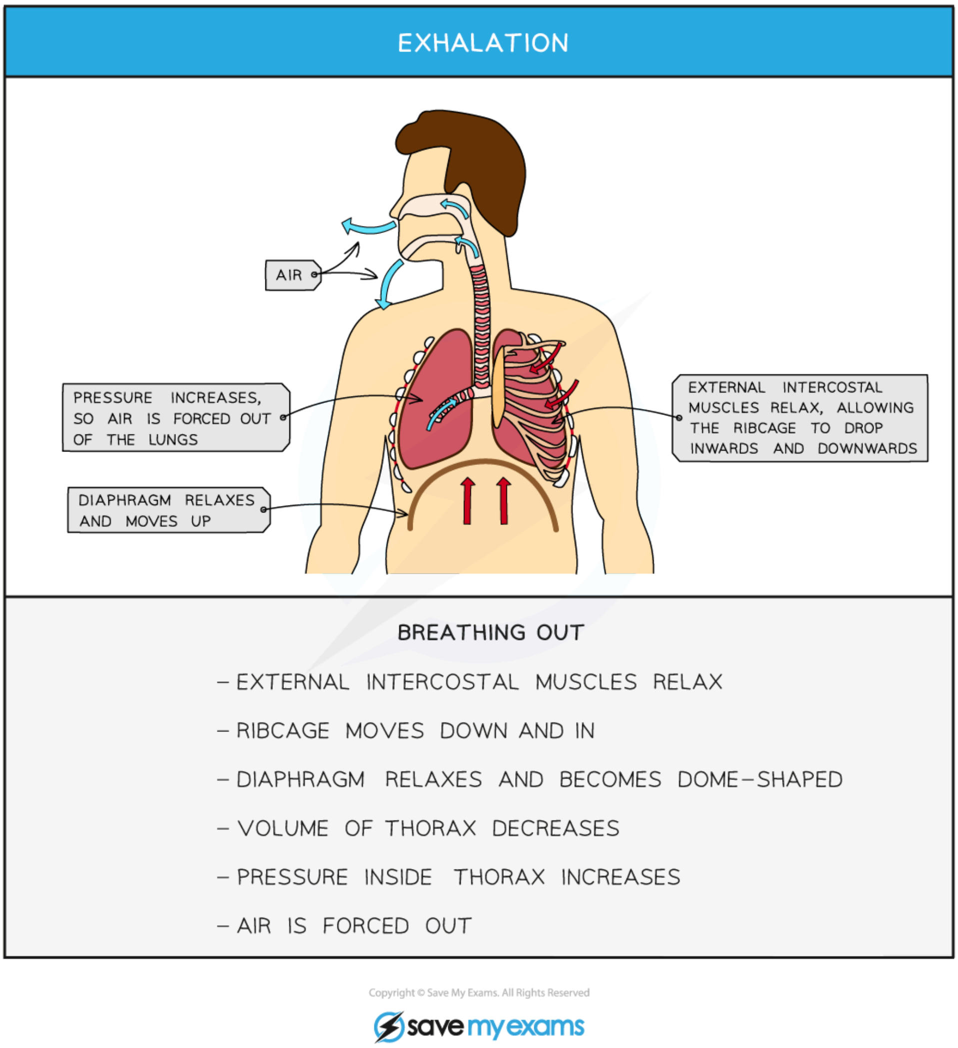
Your notes

  - It sends **nerve impulses** along motor neurons to the **intercostal muscles** of the ribs and **diaphragm muscles**
  - These muscles will **contract** and cause the **volume of the chest to increase**
    - This **lowers the air pressure in the lungs** to slightly below atmospheric pressure
  - An **impulse** is also sent to the **expiratory centre** to **inhibit** its action
  - Due to the difference in pressure between the lungs and outside air, **air will flow into** the lungs
- **Stretch receptors** in the lungs are stimulated as they inflate with air
- Nerve impulses are sent back to the medulla oblongata which will **inhibit the inspiratory centre**
- The **expiratory centre** is no longer inhibited and will bring about the following changes:
  - It sends **nerve impulses** to the **intercostal** and **diaphragm muscles**
  - These muscles will **relax** and cause the **volume of the chest to decrease**
    - This **increases the air pressure** in the lungs to slightly above atmospheric pressure
  - Due to the higher pressure in the lungs, **air will flow out** of the lungs
- As the lungs **deflate**, the **stretch receptors become inactive** which means that the inspiratory centre is **no longer inhibited** and the next breathing cycle can begin

Your notes




*The process of breathing in (inhalation)*




*The process of breathing out (exhalation)*

## Effect of exercise

- The **extra carbon dioxide** that is produced **due to the increase in the rate of respiration** during exercise dissolves in the blood to form **carbonic acid**
- This quickly **dissociates into hydrogen ions** ($H^+$) and hydrogencarbonate ions ($HCO_3^-$)
- The increase in the concentration of $H^+$ ions will **decrease the pH of the blood** (it becomes more acidic)
- The decrease in pH is **detected by receptors** sensitive to changes in the chemical composition of blood
- These are called **chemoreceptors** and they are located in several places
  - In the ventilation centre of the **medulla oblongata**
  - They are also present as clusters of cells in the aorta (**aortic bodies**) and the carotid arteries (**carotid bodies**)

Your notes

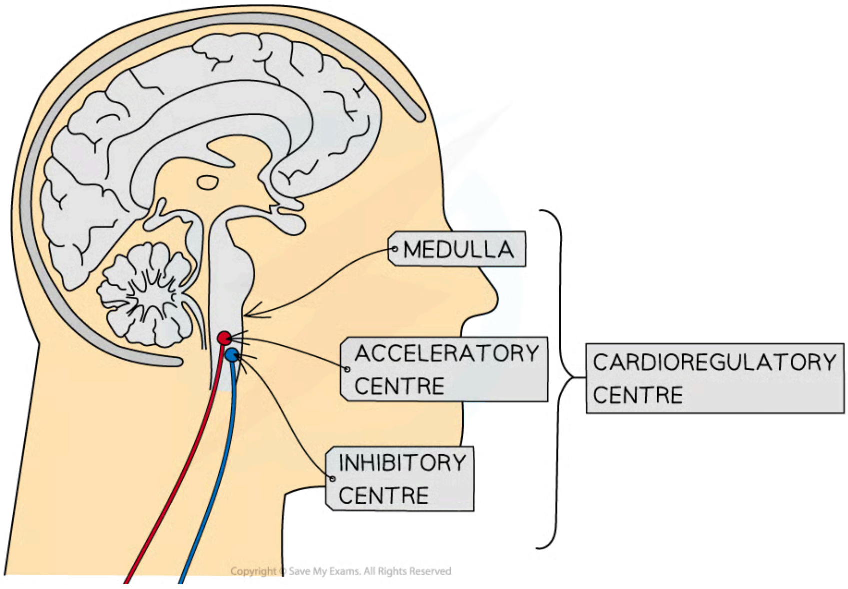
- Once they are stimulated a **nerve impulse** is sent to the **medulla oblongata**
- The medulla oblongata will then send **more frequent nerve impulses** to the intercostal and diaphragm muscles to increase the rate and strength of contractions
  - This **increases** the breathing rate and depth
- This results in **more oxygen** entering the lungs (and bloodstream), while **more carbon dioxide** can be exhaled and thus be removed from the bloodstream
  - The **decrease in carbon dioxide** levels will result in the **blood pH returning back to normal**, which leads to the breathing rate returning to normal
- The volume of air that moves in and out of the lungs during a set time period (e.g. a minute) is known as the **ventilation rate**
- The ventilation rate **increases during exercise** due to the increase in breathing rate and depth

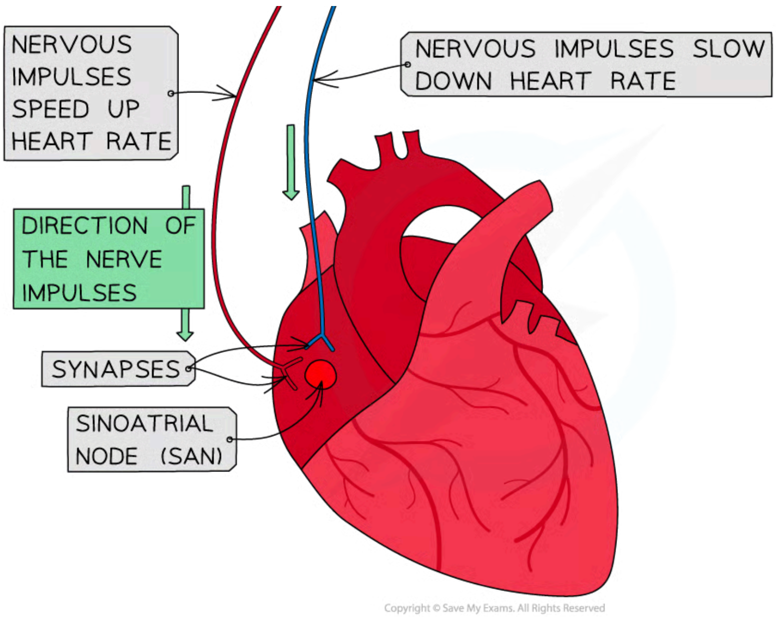
## Control of the heart rate

- The **cardiovascular control centre** in the **medulla oblongata** unconsciously **controls the heart rate** by controlling the rate at which the **sinoatrial node** (SAN) generates electrical impulses
  - These electrical impulses cause the atria to contract and therefore **determines the rhythm of a heartbeat**
- Changes in the internal environment of the body (e.g. blood pressure, oxygen levels) can result in a change in the heart rate
- These changes act as **stimuli** which is detected by **baroreceptors** and **chemoreceptors**
  - **Baroreceptors** are found in the **aortic** and **carotid bodies** and they are stimulated by **high and low blood pressure**
  - **Chemoreceptors** are found in the **medulla oblongata**, as well as in the **aortic** and **carotid bodies**
  - They are stimulated by changes in the **levels of carbon dioxide** and **oxygen** in the blood, as well as **blood pH**
- Once stimulated, these receptors will **send electrical impulses** to the medulla oblongata
- The cardiovascular control centre in the medulla oblongata will respond by sending impulses to the SAN along **sympathetic** or **parasympathetic neurones**
- Each of these neurones release different **neurotransmitters** which will affect the SAN in a different way
  - **Sympathetic neurones** will increase the rate at which the SAN generates electrical impulses, thus **speeding up** the heart rate
    - These neurones form part of the **sympathetic nervous system** which prepares the body for **action** ('fight or flight' response) and **increases the heart rate** during exercise

Your notes

- **Parasympathetic neurones** will decrease the rate at which the SAN fires, thus **slowing down** the heart rate
    - These neurones form part of the **parasympathetic nervous system** which **calms** the body down after action ('rest and digest' response) and **decreases the heart rate** after exercise




*Nervous control of the heart rate by the cardioregulatory centre (also known as the cardiovascular control centre). Sympathetic neurones (indicated in red) will speed up the heart rate while parasympathetic neurones (indicated in blue) will slow the heart rate down*

## Changes in heart rate

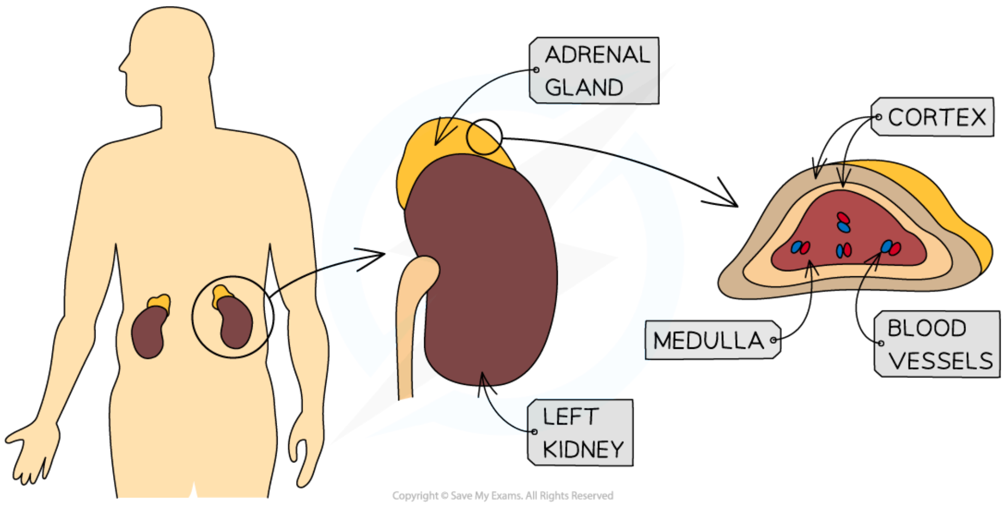
- The heart will respond in different way depending on the stimulus that it receives
- **High blood pressure**
  - Detected by **baroreceptors** which send impulses to **cardiovascular control centre**
  - It sends impulses along **parasympathetic** neurones which secrete the neurotransmitter **acetylcholine**
    - Acetylcholine binds to receptors on **SAN** causing it to fire **less frequently**
  - Heart rate **slows down** and blood pressure decreases back to normal
- **Low blood pressure**
  - Detected by **baroreceptors** which send impulses to **cardiovascular control centre**
  - It sends impulses along **sympathetic** neurones which secrete the neurotransmitter **noradrenaline**
    - Noradrenaline binds to receptors on **SAN** causing it to fire **more frequently**
  - Heart rate **speeds up** and blood pressure increases back to normal
- **High blood $O_2$ / Low $CO_2$ / high pH levels**
  - Detected by **chemoreceptors** which send impulses to **cardiovascular control centre**
  - It sends impulses along **parasympathetic** neurones which secrete the neurotransmitter **acetylcholine**
    - Acetylcholine binds to receptors on **SAN** causing it to fire **less frequently**
  - Heart rate **slows down** and $O_2$ / $CO_2$ and pH levels return to normal
- **Low blood $O_2$ / High $CO_2$ / low pH levels** (during **exercise**)
  - Detected by **chemoreceptors** which send impulses to **cardiovascular control centre**
  - It sends impulses along **sympathetic** neurones which secrete the neurotransmitter **noradrenaline**
    - Noradrenaline binds to receptors on **SAN** causing it to fire **more frequently**
  - Heart rate **speeds up** and $O_2$ / $CO_2$ and pH levels return to normal

Your notes

## The Role of Adrenaline

# The Fight or Flight Response

- 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 **adrenaline**
  - Adrenaline 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 adrenaline** that lead to the typical symptoms we experience during stressful situations such as increased heart rate, dry mouth, increased sweating etc.




***The adrenal medulla is responsible for releasing the hormone adrenaline into the bloodstream to prepare the body for the "fight or flight" response***

- Since adrenaline 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 adrenaline 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 or dangerous situation

- Adrenaline 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

Your notes

# The Effects of Exercise

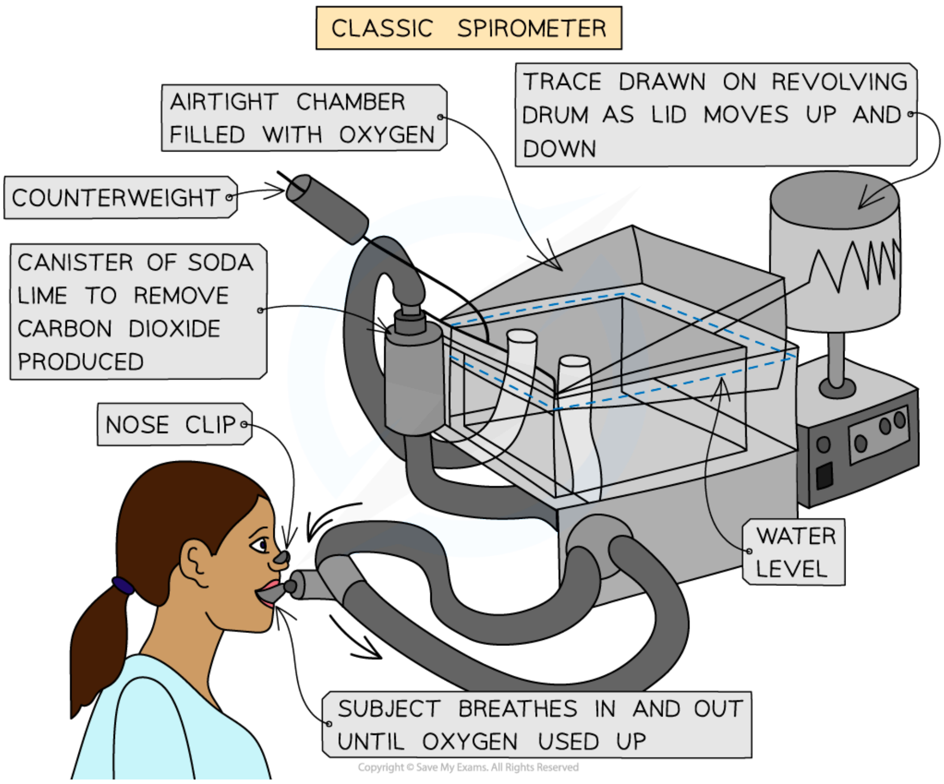
## Measuring breathing

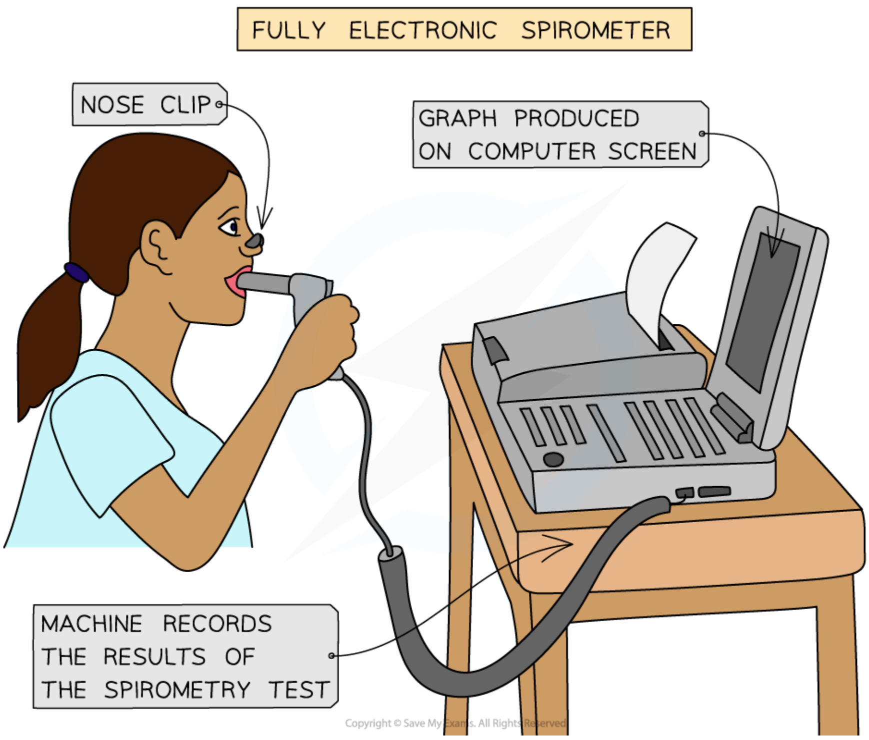
- There are **four** main ways that breathing can be **scientifically measured**. These include:
  - **Tidal volume** - this is the **volume of air that is breathed in or out** during **normal breathing** (at rest)
  - **Breathing rate** - this is the **number of breaths taken in one minute** (one breath = taking air in and breathing it back out again)
  - **Oxygen consumption** - this is the **volume of oxygen** used up by someone **in a given time**
  - **Respiratory minute ventilation** - this is the **volume of air** that can be breathed **in** or **out** in a minute and can be calculated by means of the following formula:

**Respiratory minute ventilation = tidal volume x breathing rate** (breaths per minute)

## Spirometers

- The breathing measurements described above can all be taken using a piece of apparatus known as a **spirometer**
- The person (subject) being examined breathes in and out **through** the spirometer
- **Carbon dioxide** is **absorbed** from the **exhaled air** by soda lime in order to stop the concentration of carbon dioxide in the rebreathed air from getting too high, as this can cause respiratory distress
- As the subject breathes through the spirometer, a **trace** is drawn on a rotating drum of paper or a **graph** is formed digitally, which can be viewed on a computer
- From this trace, the subject's **respiratory minute ventilation**, **tidal volume** and **breathing rate** can all be **calculated**




*Spirometers are used to measure different aspects of breathing. There are different types of spirometers*

## Investigating the effects of exercise

Your notes

- Exercise can cause an increase in breathing rate and tidal volume, including an increase in oxygen consumption and ventilation rates.

Your notes

## Apparatus

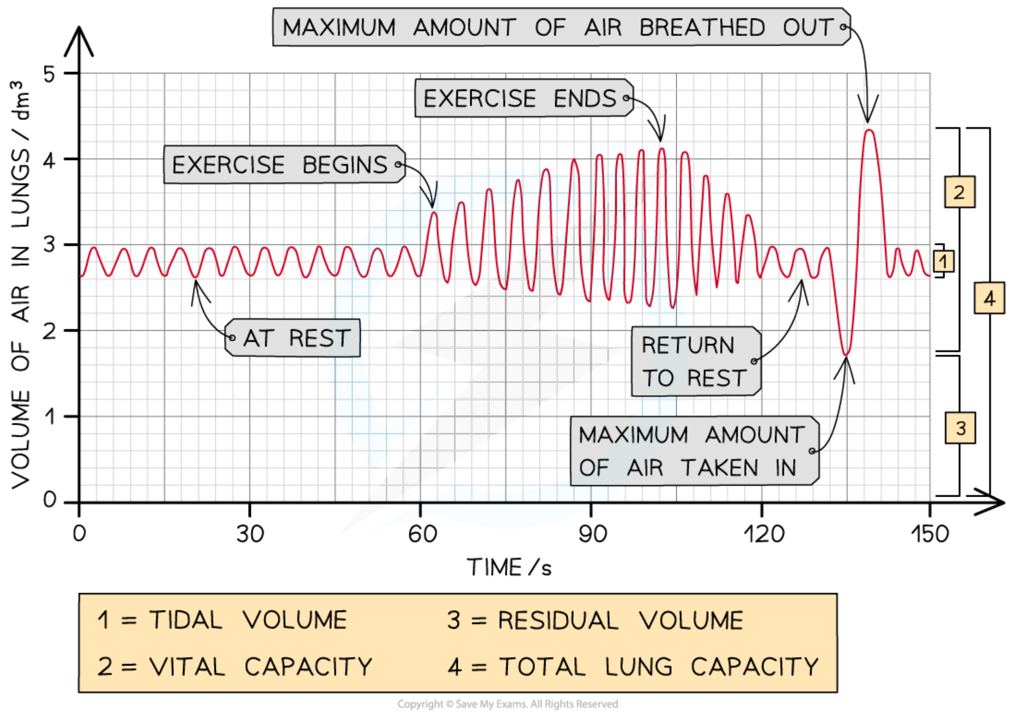
- Spirometer
- Treadmill
- Stopwatch

## Method

1. A person at rest will breathe into the spirometer for one minute
2. Record the results
3. The person will then exercise for two minutes while the spirometer chamber is refilled with oxygen
4. After they stop exercising, they will immediately breathe into the spirometer for one minute
5. Record the results
6. Compare the recordings taken before and after exercise

## Analysing data from a spirometer

- The results from a spirometer (either in the form of a trace drawn on graph paper or a digital graph created by a computer) can be used to **calculate respiratory minute ventilation, tidal volume and breathing rate**
  - A small amount of air, known as the **residual volume**, is always retained in the lungs
- The following readings and calculations can be made:
  - To calculate the **breathing rate,** count the number of peaks on the trace in a minute
  - **Tidal volume** can be determined by calculating the average difference in the volume of gas between each peak and trough
  - **Oxygen consumption** can also be calculated using a spirometer
    - Carbon dioxide is removed from the exhaled air, meaning that the total volume of air available in the spirometer gradually **decreases**, as oxygen is extracted from it by the subject's breathing
    - This change in volume is used as a measure of oxygen consumption




***The changes in the volume of air present in the lungs are shown here. Note the vital capacity; this is the maximum volume of air that can be breathed in or out in one breath***

## Worked Example

From the spirometer data in the image above, calculate the breathing rate during the first minute and then calculate the breathing rate during the second minute.

**Answer:**

**Step 1: Count the number of breaths in the first 60 seconds**

One breath is shown by the trace going up and then down, so there are 12 breaths in the first 60 seconds.

**Step 2: Give appropriate units**

Breathing rate should be given in breaths min$^{-1}$ (breaths per minute), so the breathing rate during the first minute

= 12 breaths min$^{-1}$

**Step 3: Count the number of breaths in the second 60 seconds**

There are 14 breaths in the second 60 seconds

**Step 4: Give appropriate units**

The breathing rate during the second minute = **14 breaths min$^{-1}$**

Your notes

Your notes

### Worked Example

Calculate the tidal volume during rest and the peak tidal volume during exercise.

**Answer:**

**Step 1: For the 'at rest' phase of the trace, measure the difference between the top and bottom of the trace in terms of the volume of air in the lungs**

During rest, the tidal volume = 3 $dm^3$ - 2.6 $dm^3$

= 0.4 $dm^3$

**Step 2: At the peak tidal volume during exercise, measure the difference between the top and bottom of the trace in terms of the volume of air in the lungs**

The peak tidal volume during exercise occurs right at the end of the exercise period (at around 100 seconds):

= 4.1 $dm^3$ - 2.3 $dm^3$

= **1.8 $dm^3$**

### Worked Example

Calculate the respiratory minute ventilation during the first minute.

**Answer:**

**Step 1: Use the formula**

Respiratory minute ventilation = tidal volume x breathing rate

**Step 2: Substitute the values calculated from the first minute**

Respiratory minute ventilation = 0.4 x 12

= **4.8 $dm^3$ $min^{-1}$**