# DP IB Biology: SL

Your notes

## 6.4 Gas Exchange

### Contents

## 6.4.1 Ventilation: Function & Structures

Your notes

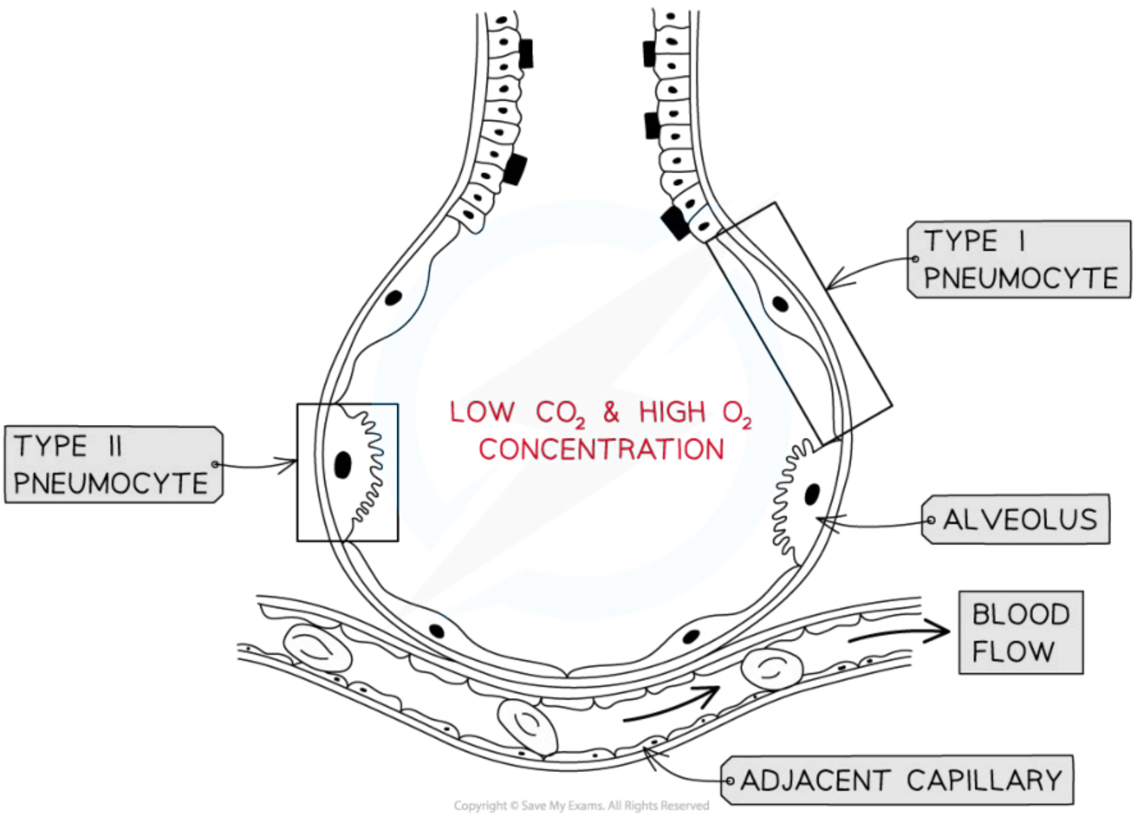
# Ventilation

- **Ventilation** can be defined as
  - **The replacement of older air in the lungs with fresh air from the body's external environment**
- Ventilation is essential for the effective **exchange of gases** in the lungs
- The **exchange** of oxygen and carbon dioxide occurs between the alveoli and the capillaries in the lungs
- Gases are exchanged by **simple** diffusion which requires a concentration gradient
- This gradient is maintained by
  - **Ventilation**
  - The **continuous flow of blood** in the capillaries

### The impact of ventilation

- Ventilation maintains **concentration gradients** of oxygen and carbon dioxide between air in the alveoli and blood flowing in adjacent capillaries
  - **Breathing in** fresh air from the surrounding environment increases the concentration of oxygen in the air inside the alveoli
  - **Breathing out** removes carbon dioxide
- This means that after ventilation, compared to the blood found in adjacent capillaries, the alveoli have
  - **Higher oxygen levels**
  - **Lower carbon dioxide levels**
- This ensures that oxygen continues to **diffuse** from the alveoli into the capillaries, while carbon dioxide continues to diffuse from the capillaries into the alveoli
  - Both gases move down their **concentration gradient**

Your notes

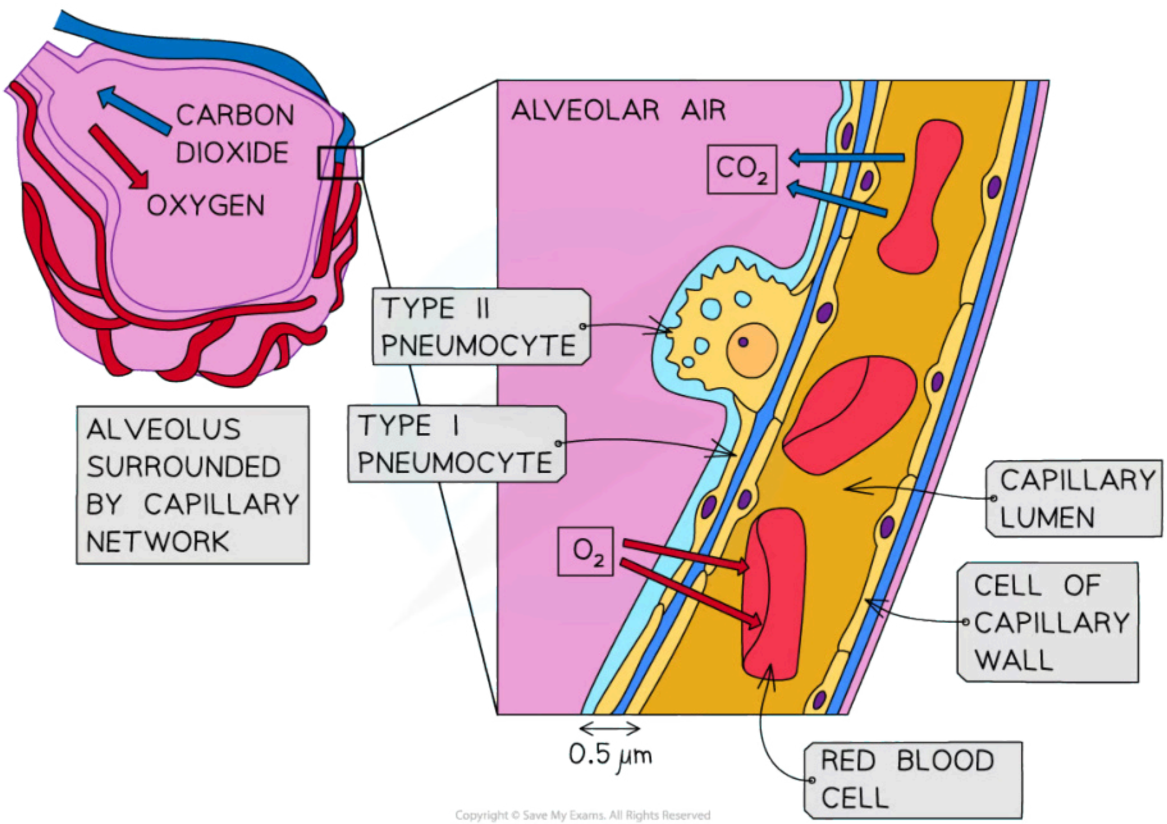



***Ventilation maintains a concentration gradient between the air in the alveolus and the blood in the adjacent capillary***

## Type I Pneumocytes

Your notes

- The alveoli are specifically adapted for gas exchange as they collectively have a **very large surface area** and the alveolar walls are only one cell thick which provides a **short diffusion distance**
  - The alveolar walls are also known as the alveolar epithelium
- **Type I pneumocytes** are extremely **thin alveolar cells** which make up the majority of the alveolar epithelium
  - They are adapted to maximise the rate of gas exchange by providing a **short diffusion distance**
- The capillary walls are also only **one cell thick** which means there is usually less than **0.5µm** between the air in the alveoli and the blood, this **maximises the rate of diffusion**

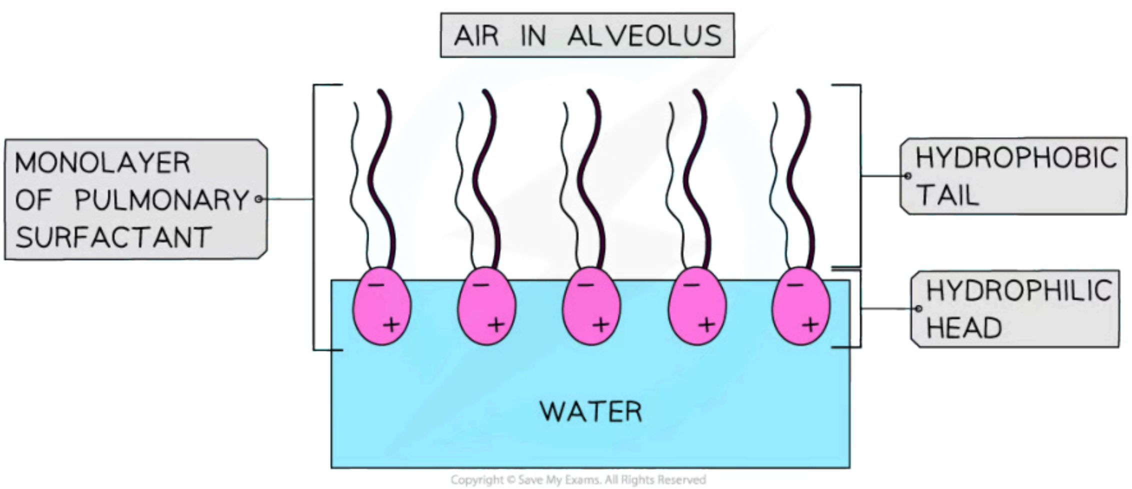



***The thin type I pneumocyte cells and the thin capillary walls provide a short diffusion distance to maximise gas exchange***

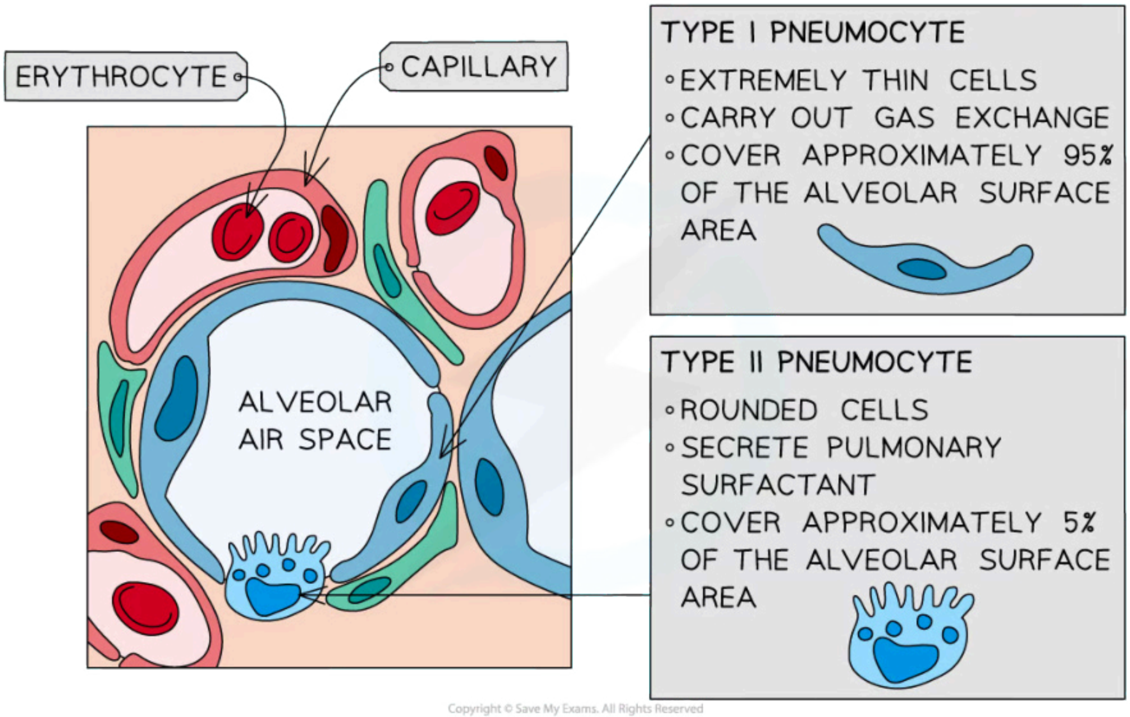
Your notes

## Type II Pneumocytes

- Type II pneumocytes are **rounded cells** which secrete a solution that coats the epithelium of the alveoli
- They occupy a much smaller proportion of the alveolar epithelium than the type I pneumocytes; around 5%
- The solution released by type II pneumocytes contains **pulmonary surfactant**
  - Pulmonary surfactant has hydrophobic **tails and** hydrophilic **heads**
  - The molecules form a monolayer with the hydrophobic tails facing the alveolar air
- Pulmonary surfactant **reduces** surface tension, maintaining alveolar **shape** and **preventing the sacs sticking** together
  - This prevents the alveoli, and therefore the lungs, from **collapsing**
- The solution also aids gas exchange
  - The layer of moisture provided by the solution allows **oxygen to dissolve** before it diffuses into the blood
  - **Carbon dioxide** diffuses from the moist surface before it is removed in exhalation




***The type II pneumocyte cells in the alveoli produce a solution containing pulmonary surfactant which reduces surface tension***




***The alveolar epithelium is made up of type I and type II pneumocyte cells***

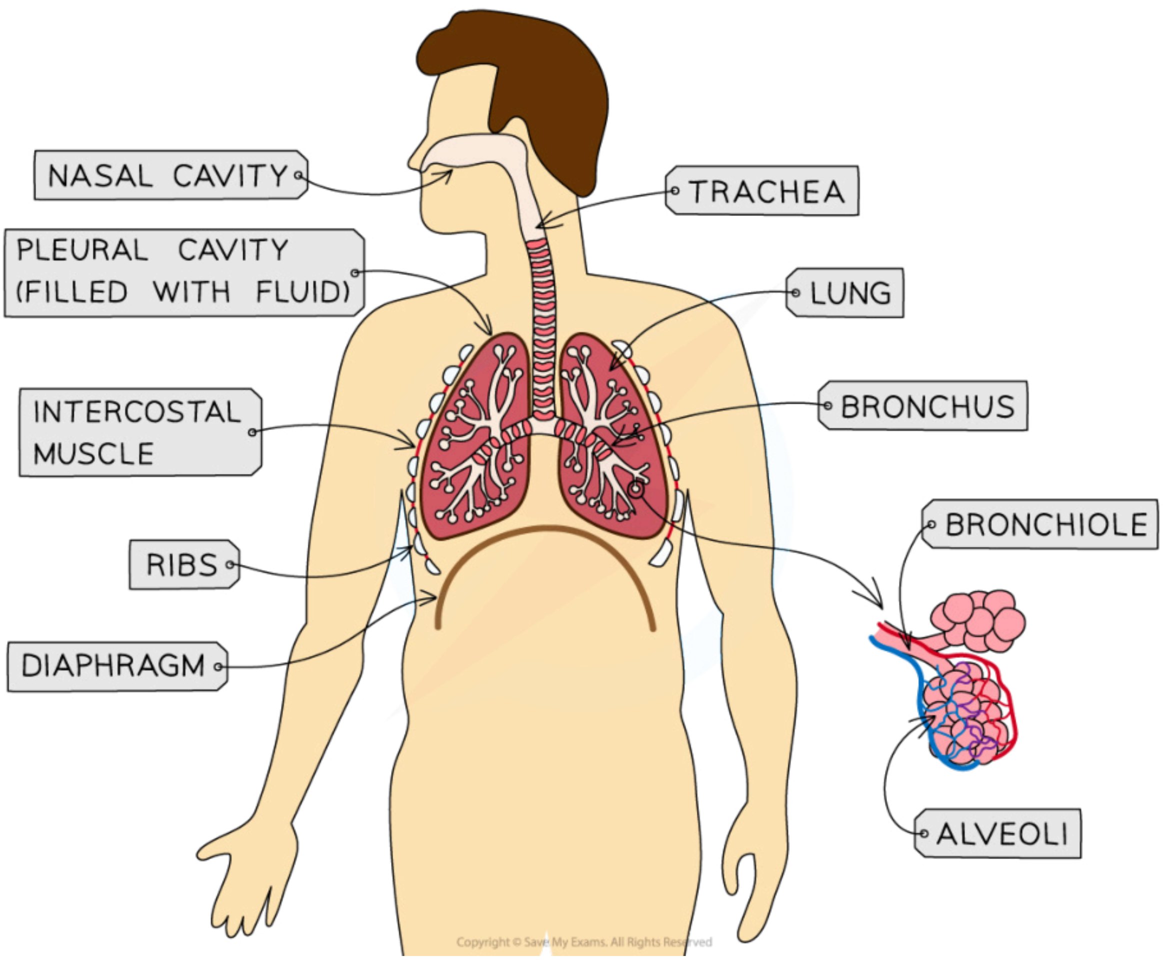
## Air Pathway

Your notes

- Air moves in through the nose and mouth before it is carried to the lungs through the **trachea**
- The **trachea** is a tube supported by **rings of cartilage** which help to support its shape and ensure it stays open, while allowing it to move and flex with the body
- The **trachea** divides to form the two **bronchi** (singular bronchus) with walls also strengthened with cartilage and has a layer of smooth muscle which can **contract** or **relax** to change the diameter of the airways.
- 
  - One bronchus leads to each lung

- **Bronchioles** branch off the two bronchi to form a network of narrow tubes
  - The walls of the bronchioles are lined with a layer of **smooth muscle** to alter the diameter of the bronchiole tubes
  - This helps to regulate the flow of air into the lungs by dilating when more air is needed and constricting when e.g. an allergen is present

- Groups of **alveoli** are found at the end of the bronchioles
- Each alveolus is surrounded by an extensive network of **capillaries** to provide a **good blood supply** for maximum gas exchange




***The main structures of the human gas exchange system***

Your notes

# 6.4.2 Ventilation: Mechanism

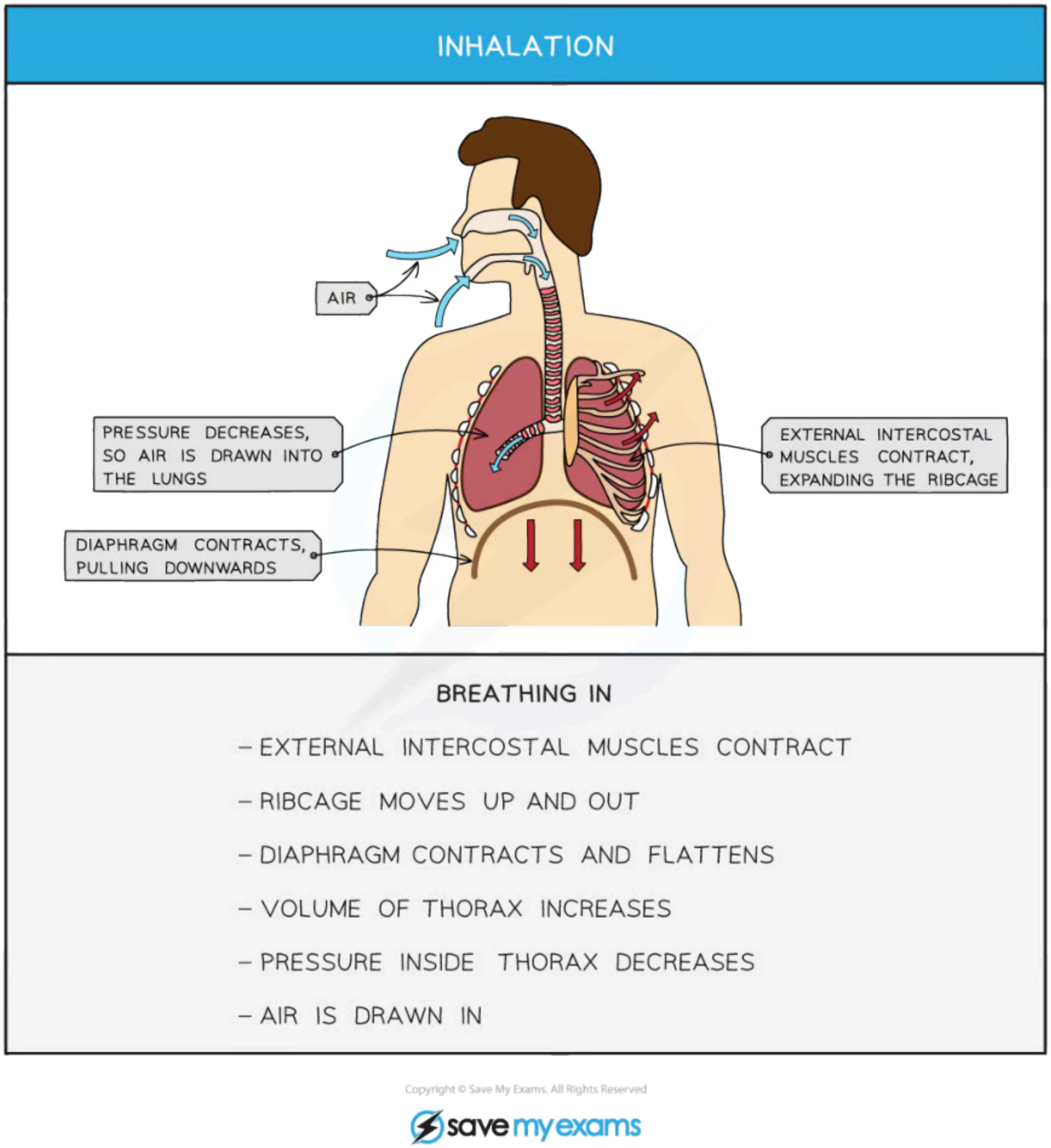
Your notes

## Inspiration & Expiration

### Breathing in

- The breathing-in, or **inspiration**, process causes the **volume of the chest to increase** and the **air pressure to decrease** until it is **lower than the atmospheric pressure**
  - When gas is in a large-volume container that allows the gas particles to spread out, the pressure exerted by the gas on the walls of the container is low
- As a result, air moves **down the pressure gradient** and rushes into the lungs
  - A gas will always move down a pressure gradient from an area of high pressure to an area of low pressure
- The inspiration process
  - The diaphragm **contracts** and **flattens**, increasing chest volume
  - In addition to the flattening of the diaphragm the **external** intercostal muscles **contract**, causing the ribcage to move **upwards** and **outwards**; this also increases chest volume

Your notes




*The process of inspiration*

## Breathing out

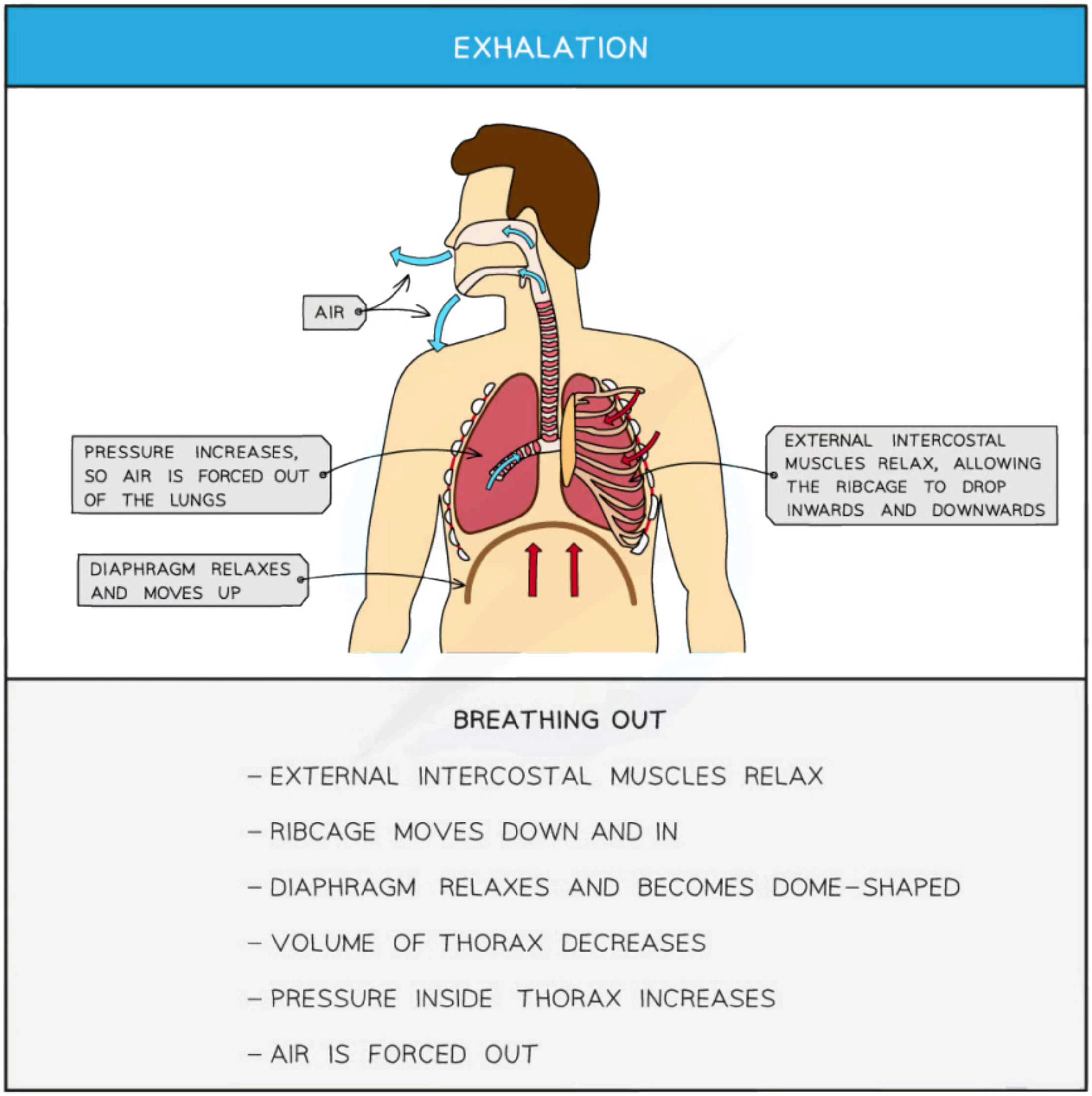
- Breathing out, or **expiration**, occurs mostly due to the recoil of the lungs after they have been stretched by the inspiration process, and is therefore a mainly passive process
- **Volume of the chest decreases** and **pressure increases**, causing air to be forced out down its **pressure gradient**

Your notes

- When gas is in a low-volume container it is compressed, causing the gas particles to exert more pressure on the walls of the container
- The passive expiration process
  - External intercostal muscles **relax,** allowing the ribcage to move **down** and **in**
  - Diaphragm **relaxes** and becomes **dome-shaped**
  - The **recoil** of **elastic fibres** in the alveoli walls reduces the volume of the lungs

- The expiration process can be active when there is a need to expel excess air from the lungs e.g. when blowing out a candle
- The active expiration process
  - **Internal** intercostal muscles **contract** to pull the ribs **down** and **in**
  - **Abdominal muscles contract** to push organs upwards against the diaphragm, decreasing the volume of the chest cavity
  - This causes **forced exhalation**

Your notes






*The process of passive expiration*

## Antagonistic Muscle Action

Your notes

- Muscles only carry out the work of moving the body when they are **contracting**, or **pulling;** they cannot push
- As a result of this limitation muscles often operate in **pairs** when movement in two directions in required
- One muscle of the pair pulls in one direction and the other muscle **pulls in the opposite direction**
  - This is described as **antagonistic** muscle action
- Examples of antagonistic muscle action in ventilation are
  - **Internal** and **external intercostal muscles**
    - When the internal intercostal muscles contract, the rib cage moves down and in
    - When the external intercostal muscles contract, the rib cage moves up and out
  - The **diaphragm** and **abdominal muscles**
    - When the diaphragm contracts, it flattens and moves downwards
    - When the abdominal muscles contract, the internal organs of the abdomen are compressed and pushed upwards, exerting upward pressure on the diaphragm

### Examiner Tip

The intercostal muscles work in an **antagonistic** manner; as one contracts the other relaxes!Note that the internal intercostal muscles only contract to cause **forced expiration**; expiration is **passive** the majority of the timeRemember, if you learn one of either inspiration or expiration, the other is almost exactly the opposite.

# 6.4.3 Lung Diseases

Your notes

## Cancer

### NOS: Obtain evidence for theories: epidemiological studies have contributed to our understanding of the causes of lung cancer

- **Theories** are developed based on **evidence** collected through observation and where possible, scientific investigations
- Obtaining **valid** and **reliable** evidence for theories on causes and consequences of different diseases can be difficult for several reasons.
  - The sensitive nature of the data required
  - Difficulty finding volunteers with the correct specific diagnoses
  - The effect of confounding factors

- **Epidemiology** is the study of disease which includes monitoring the numbers and distribution of cases that arise, as well as building a bigger picture of the potential causes of the disease
- **Epidemiological studies** are carried out on **large numbers** of patient volunteers to give an unbiased and reliable collection of data which make it possible to draw links between certain factors and the development of a disease

### Causation and correlation

- It is very tricky to show that one particular factor is responsible for **causing** a disease, such as lung cancer, instead, data is usually used to show a **correlation** between a certain risk factor and the incidence of a disease
- **Confounding factors** which share a similar correlation and also imply causation of the disease can make it difficult to establish the actual determinant
  - Therefore it is necessary to study **several factors** simultaneously to collect enough data to carry out **statistical analysis** and develop the overall picture

- **Risk factors** contribute towards the likelihood of developing a disease
  - Therefore risk factors that are more easily controlled and measured in isolation are more likely to have a proven causal relationship, as they can be investigated in a more scientific manner
  - For example, an individual's exposure to smoking is much easier to quantify than their exposure to air pollution

- When analysing data and studies it is always important to remember that **risk factors interact with each other**
  - For example, a smoker with asthma is likely to suffer the associated negative health side effects more quickly than a smoker without asthma

- It is always important to remember that even though there is a correlation, this **does not mean** that there is a direct causal link

Your notes

    - For example, in places with higher pollution, there may be more asthmatic individuals but this does not mean that pollution caused asthma as there are many other variables at play

### Causes of lung cancer

- Of all the cancers, lung cancer is the most commonly diagnosed and results in the most deaths globally
- Cancer occurs if **mutations** affect the regulation of mitosis in cells
- This causes uncontrolled mitosis which develops into **a mass of cells** in the **lumen** of the airways
- The tumour becomes larger because it has no method of programmed cell death and survives because it develops its own blood supply (vascularisation)
- The tumour then starts to interfere with the normal working of the lungs, such as by squeezing against blood vessels or cancer cells entering into the **lymphatic system**, where they may develop another tumour
- A **causal** relationship has been **proven** for some risk factors relating to lung cancer
    - **Smoking** is a key contributor
        - **Tobacco** in cigarette smoke has been shown to have mutagenic effects on body cells due to chemicals found in the smoke
        - The effects of these **mutagenic chemicals** can lead to cancer in smokers as well as the passive smokers inhaling their second hand smoke
    - Inhalation of **air pollution** similarly, can result in lung cancer
        - In cities, average rates of lung cancer diagnoses are much higher due to high levels of vehicle exhaust fumes and smoke from burning organic matter
    - **Radon gas** is a radioactive gas which can contribute to the numbers of lung cancer in some areas more than others
        - Radon is released from rocks and buildings made from rocks containing high levels of radon gas
    - Various building materials, such as **asbestos** and **silica**, produce small dust particles which can cause lung cancer if they are inhaled
        - There are strict rules about using or working with materials, such as asbestos and silica, to minimise exposure and therefore the associated risks

### Consequences of lung cancer

- There are many symptoms associated with a lung cancer diagnosis, including:
    - Breathing difficulties
    - Coughing, sometimes coughing up blood
    - Chest pains
    - Loss of appetite and weight loss
    - Persistent fatigue
    - Tumours can form in the lungs

Your notes

- In severe cases, the **primary tumours metastasise** and lead to the formation of **secondary tumours** elsewhere in the body
- Survival rates from lung cancer are very low compared to other cancer types
  - Only 15% of patients will survive more than 5 years
- Patients that do survive may suffer from **long term symptoms** such as:
  - Pain
  - Breathing difficulties
  - Fatigue
  - Anxieties associated with a cancer diagnosis and future prognosis
- **Treatments** for lung cancer include:
  - Chemotherapy
  - Radiotherapy
  - Lung removal

Your notes

## Examiner Tip

**Scatter diagrams** are used to identify **correlations** between two variables to determine the relationships between two factors. For example, between risk factors and certain disease.Correlation can be **positive or negative**

- Positive correlation: as variable A increases, variable B increases
- Negative correlation: as variable A increases, variable B decreases
- If there is **no correlation** between variables the **correlation coefficient will be 0**

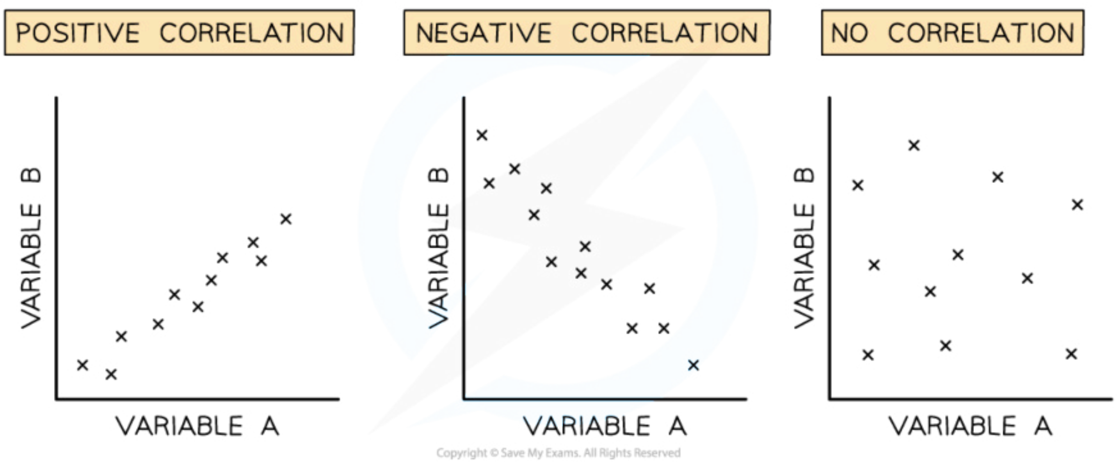



*Image showing different types of correlation in scatter graphs*

- There is a clear distinction between correlation and causation: **a correlation does not necessarily imply a causative relationship**
- **Correlation** is an association or relationship between variables
- **Causation** occurs when one variable has an influence or is influenced by another

Your notes

# Emphysema

## Causes of emphysema

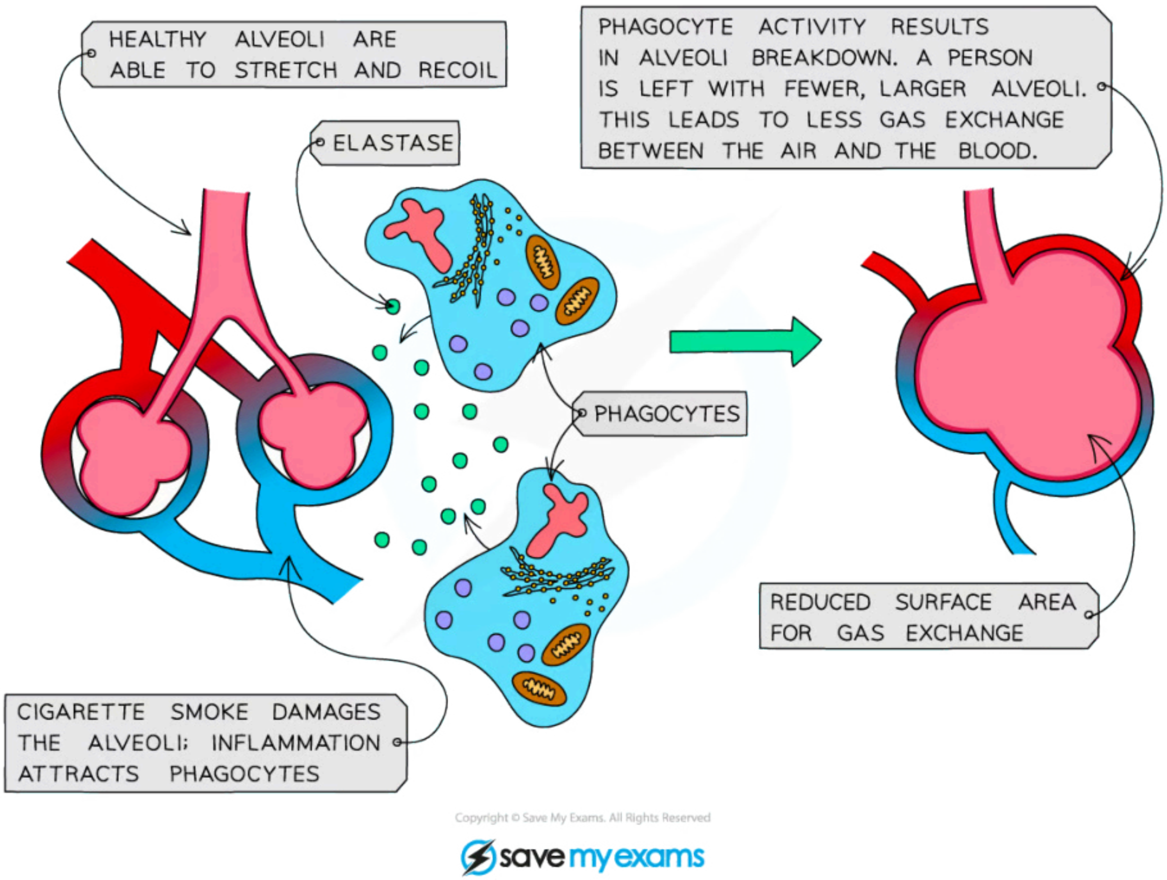
- **Emphysema** is an example of a **Chronic obstructive pulmonary disease** (COPD) which also includes lung diseases such as asthma and chronic bronchitis
- In a healthy lung, **some phagocytes** are present as part of the **non-specific** immune response to protect against bacteria found in the lungs
  - Phagocytes produce the protein digesting enzyme, **elastase** to destroy **bacteria**
  - Elastase also breaks down proteins in the cells of the lungs, including **elastin**
  - An enzyme inhibitor, **alpha 1-antitrypsin (A1AT)**, is produced by lung cells to prevent damage caused by elastase

- In **smokers**, goblet cells in the ciliated epithelium become enlarged and produce more mucus which destroys the **cilia** in the trachea and
- This prevents cilia from sweeping mucus, containing **bacteria, dust and other microorganisms** away from the lungs, this leads to infections in the lungs
- Infections attract more **phagocytes** to the lungs and the phagocytes release **elastase**
- A1AT is not effective against the increased levels of elastase and so the enzyme damages the elasticity of the **alveolar walls**
- Without enough elastin, the alveoli **break down** and may burst, creating large air spaces in the alveoli with an insufficient **surface area to volume ratio**
- **Thickening** of the alveolar walls increases the **diffusion distance** for gas exchange
- This reduces the efficiency of gas exchange, causing **emphysema** where less oxygen is carried in blood (making exercise difficult)
- Once the disease progresses, people often need a constant supply of oxygen to stay alive

## Consequences of emphysema

- Damage to the alveoli which result in emphysema, is **irreversible**
- It leads to **low blood oxygen** levels and **high carbon dioxide** levels in patients
- The resultant **symptoms** include
  - Shortness of breath or laboured ventilation
  - A chronic or persistent cough
  - Chest tightness
  - Wheezing and difficulty breathing when exercising or during any physical activity
  - Lack of energy

Your notes




***Emphysema can lead to a reduced number of alveolar air sacs with thicker walls***

# 6.4.4 Skills: Monitoring Ventilation

Your notes

## Practical 6: Monitoring Ventilation

- The volume of air within the lungs of an individual will change depending on their level of activity
  - When at rest, breathing is shallow and slow
  - When exercising, breathing is deeper and more frequent
- The volume of air breathed in and out during normal breathing is the **tidal volume**
  - Normal breathing here refers to a breath that does not involve forced expiration
- The **ventilation rate** is the number of breaths taken per minute
- A piece of equipment called a **spirometer** can be used to create a trace to show the volume changes in the lungs

### Practical 6: Monitoring of ventilation in humans at rest and after mild and vigorous exercise

- It is possible to investigate the effect of exercise on ventilation using the following variables
- Dependent variable: The ventilation parameter that is measured
  - This could be the ventilation rate, the tidal volume, or a combination of both
  - These measurements can be taken using a variety of methods, e.g. Basic observations such as counting breaths to measure ventilation rate
  - A data logger such as an inflatable chest belt and pressure sensor to measure ventilation rate
  - A spirometer can measure both ventilation rate and tidal volume
- Independent variable: The type or intensity of exercise
  - The type of exercise could include a range from inactive e.g. lying down, to very active e.g. sprinting, and everything in between
  - E.g. the intensity of the exercise could be measured by increasing speed on a treadmill

### Apparatus

- Stop watch
- Inflatable chest belt and pressure sensor OR spirometer

### Method: Using an inflatable chest belt

1. Taking breathing measurements using an inflatable chest belt and pressure sensor
2. The person (subject) being examined breathes in and out with a **chest belt** placed around the thorax, that has had air pumped into it
3. As the subject breathes the pressure sensor logs the changes in pressure due to ventilation; the data logged can be viewed on a computer
4. From the data collected, the rate of ventilation can be deduced

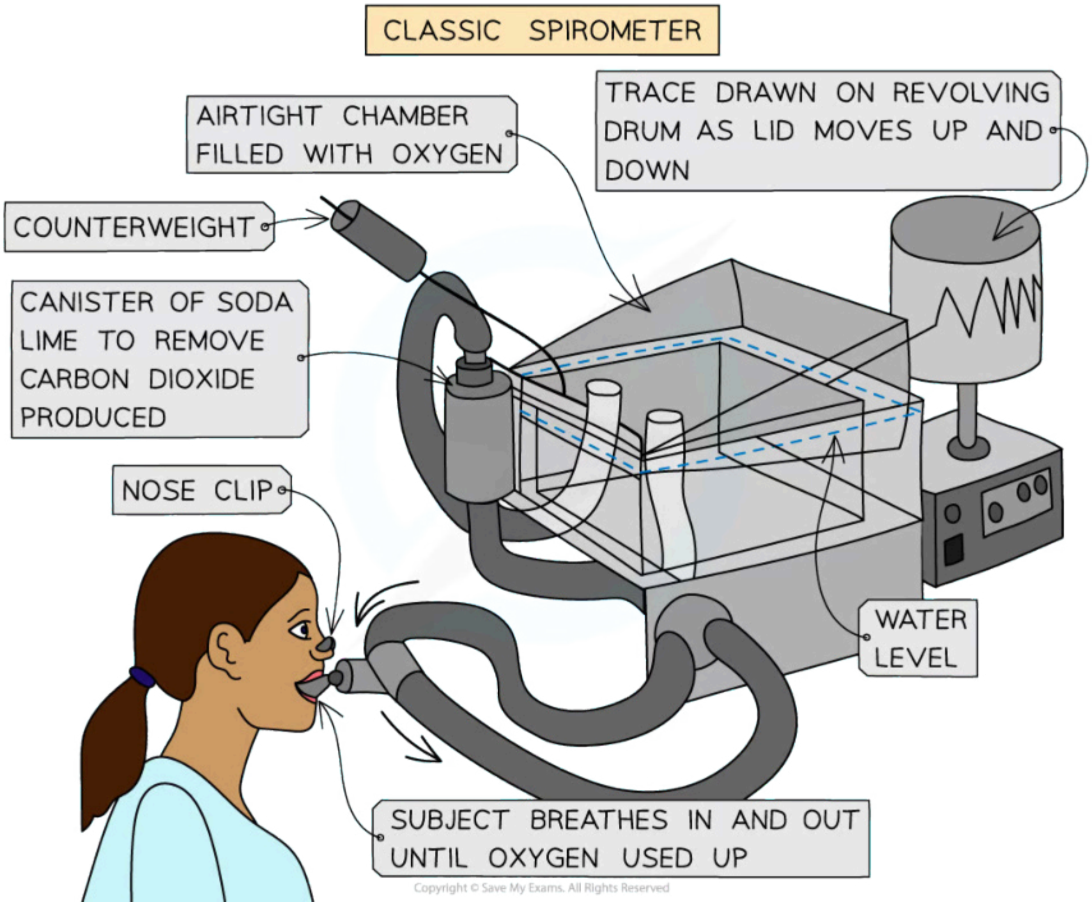
Your notes

5. The subject then repeats steps 1–4 after a period of exercise
   - The **type or intensity** of exercise should be specified
6. The subject then repeats step 5 several more times after exercise of different specified type or intensity e.g., gradually increasing in intensity
7. A **repeat** of all measurements should be taken and several subjects should be tested in order to collect **reliable results**

### Method: Using a spirometer

1. Taking breathing measurements using a **spirometer**
2. The subject being examined breathes in and out **through** the spirometer after a period of rest
3. 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
4. From this trace, the subject's **tidal volume** and **breathing rate** can all be **calculated**
5. The person then completes steps 1–4 after a period of exercise
   - The **type or intensity** of exercise should be specified
6. The subject then repeats step 5 several more times after exercise of different specified type or intensity e.g., gradually increasing in intensity
7. A **repeat** of all measurements should be taken and several subjects should be tested in order to collect **reliable results**

Your notes


CLASSIC SPIROMETER
AIRTIGHT CHAMBER FILLED WITH OXYGEN
TRACE DRAWN ON REVOLVING DRUM AS LID MOVES UP AND DOWN
COUNTERWEIGHT
CANISTER OF SODA LIME TO REMOVE CARBON DIOXIDE PRODUCED
NOSE CLIP
WATER LEVEL
SUBJECT BREATHES IN AND OUT UNTIL OXYGEN USED UP
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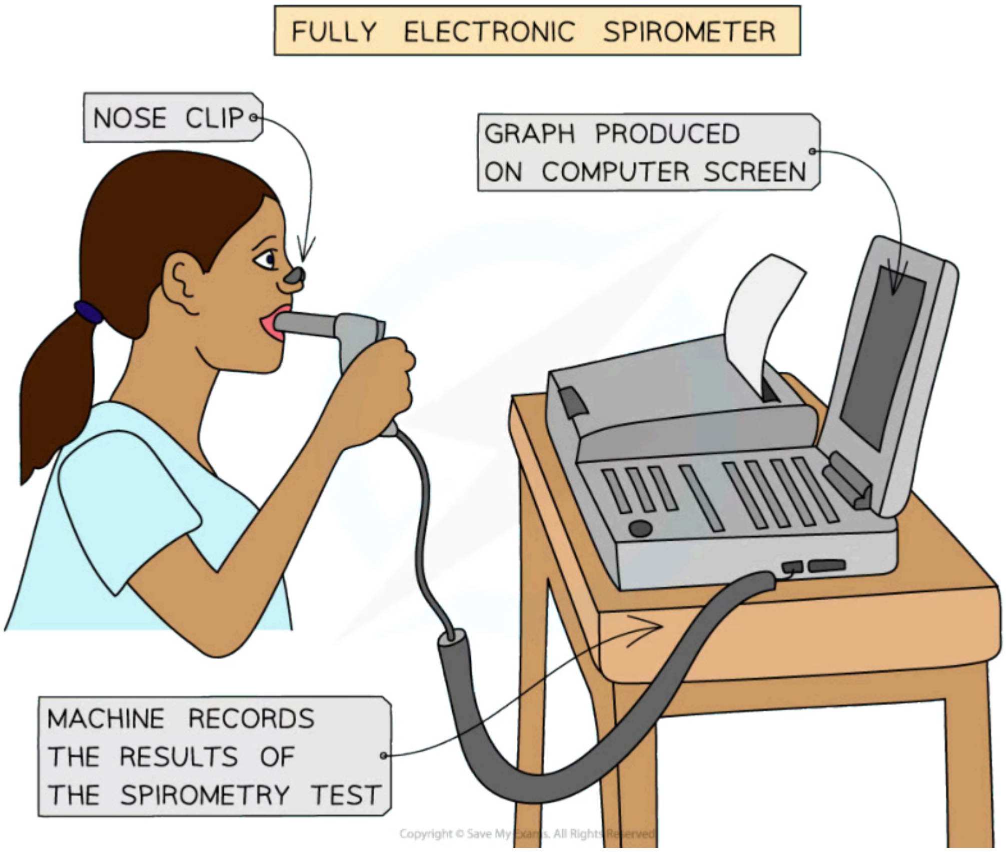
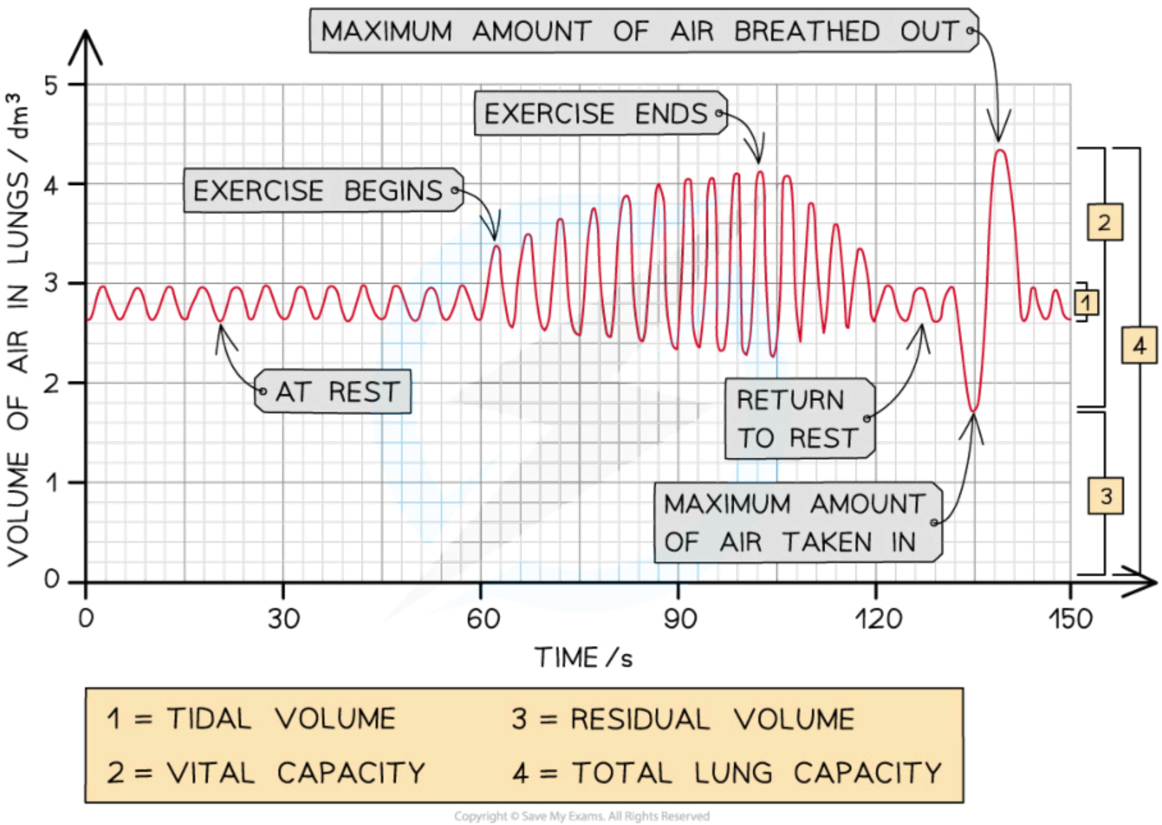



*Using a spirometer to monitor ventilation*

### Analysis

- The effect of exercise on ventilation can be seen in the spirometer trace below

Your notes




- Exercise can be seen to increase the rate of ventilation resulting in **more breaths taken per minute**
- It is also evident that after exercise the tidal volume of the person has increased, which means **more air** is breathed in and out in each breath
- After exercise, both tidal volume and ventilation rate eventually return to **resting values**