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### 6.4 Gas Exchange



# IB Biology - Revision Notes

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## 6.4.1 Ventilation: Function & Structures

### Ventilation

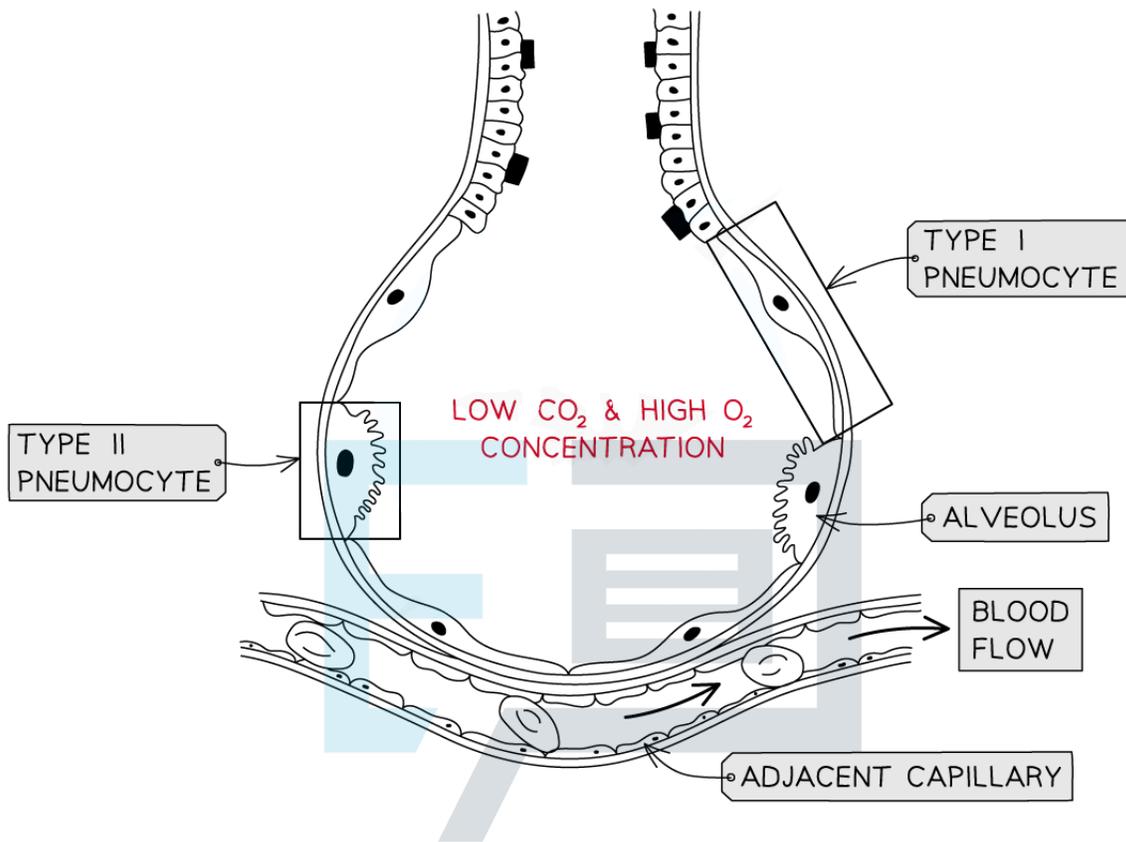
- **Ventilation** can be defined as
  - **The replacement of older air in the lungs with fresh air from the body's external environment**
- Ventilation is essential for the effective **exchange of gases** in the lungs
- The **exchange** of oxygen and carbon dioxide occurs between the alveoli and the 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**

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

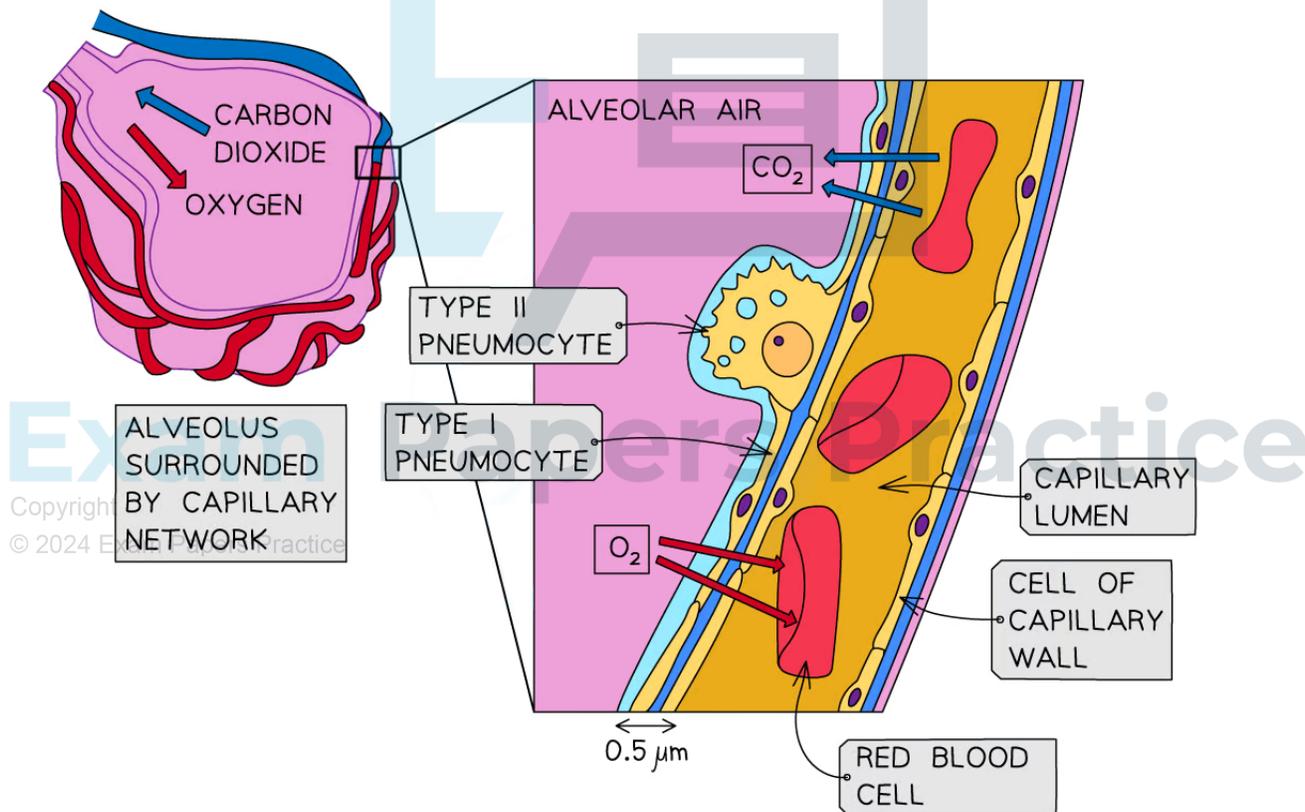
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## Type I Pneumocytes

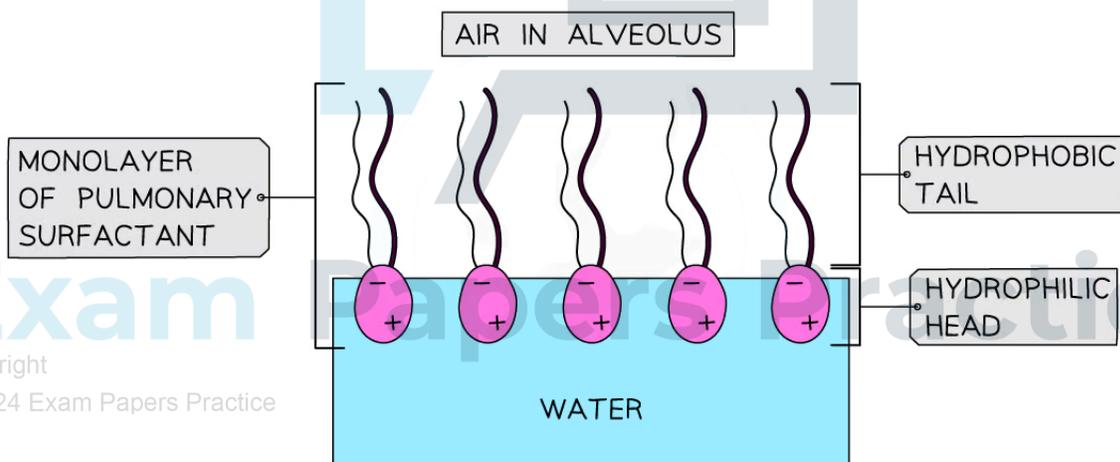
- The alveoli are specifically adapted for gas exchange as they collectively have a **very large surface area** and the alveolar walls are only one cell thick which provides a **short diffusion distance**
  - The alveolar walls are also known as the alveolar epithelium
- **Type I pneumocytes** are extremely **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*

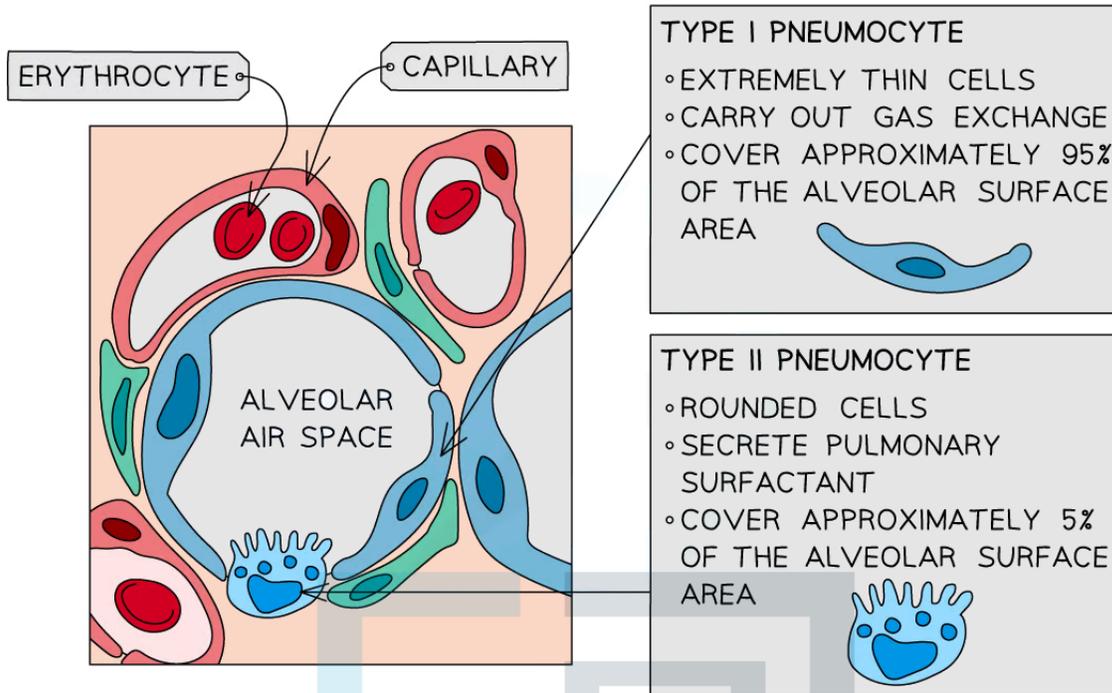
## Type II Pneumocytes

- 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



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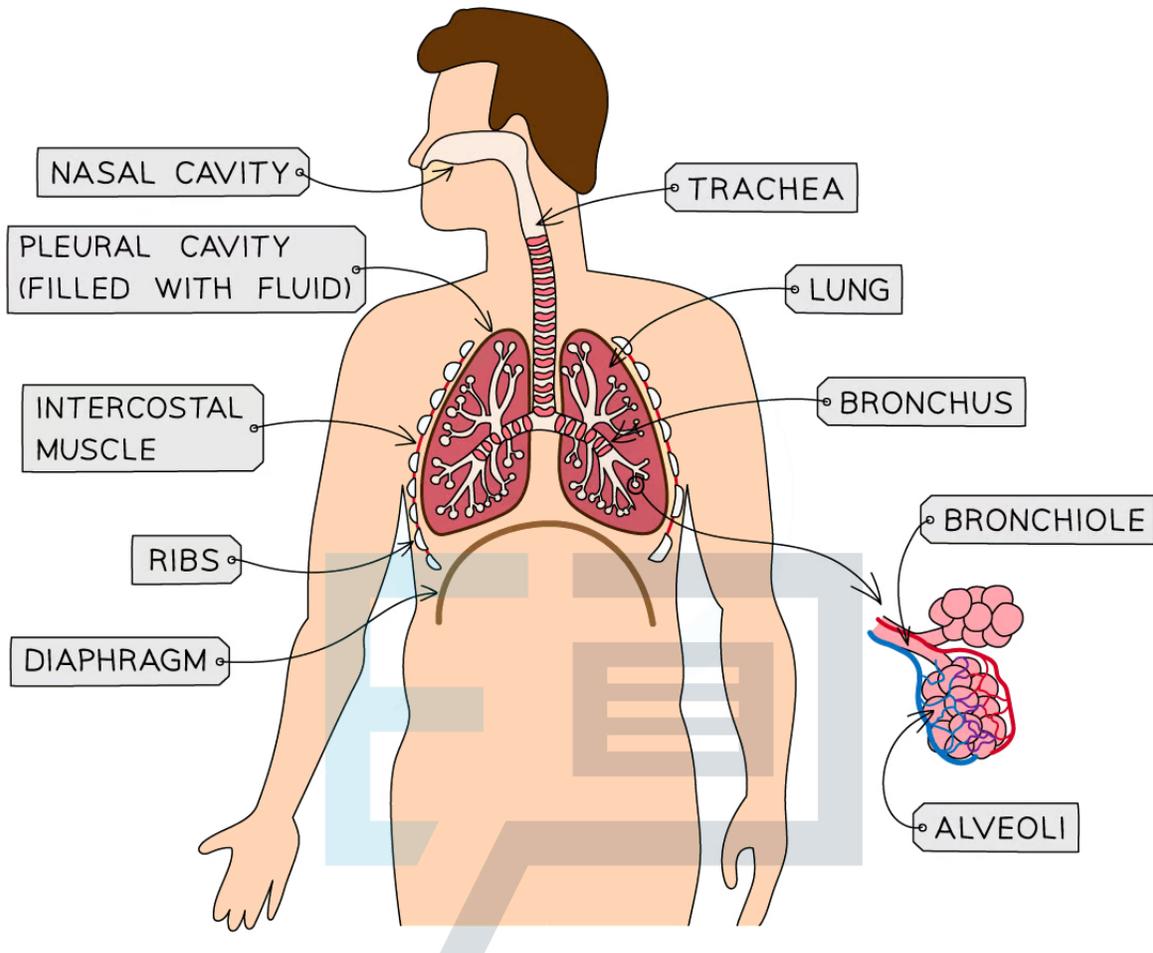
*The type II pneumocyte cells in the alveoli produce a solution containing pulmonary surfactant which reduces surface tension*



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

## Air Pathway

- 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*

6.4.2 Ventilation: Mechanism

### 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

INHALATION

BREATHING IN

- EXTERNAL INTERCOSTAL MUSCLES CONTRACT
- RIBCAGE MOVES UP AND OUT
- DIAPHRAGM CONTRACTS AND FLATTENS
- VOLUME OF THORAX INCREASES
- PRESSURE INSIDE THORAX DECREASES
- AIR IS DRAWN IN

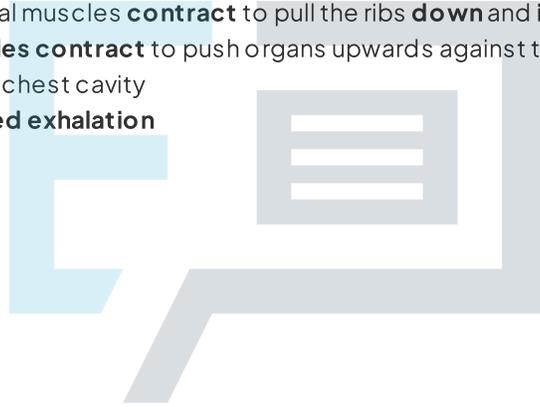
*The process of inspiration*

**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**
  - 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**



**EXHALATION**

**BREATHING OUT**

- EXTERNAL INTERCOSTAL MUSCLES RELAX
- RIBCAGE MOVES DOWN AND IN
- DIAPHRAGM RELAXES AND BECOMES DOME-SHAPED
- VOLUME OF THORAX DECREASES
- PRESSURE INSIDE THORAX INCREASES
- AIR IS FORCED OUT

*The process of passive expiration*

## Antagonistic Muscle Action

- 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 is 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

### Exam 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 time. Remember, if you learn one of either inspiration or expiration, the other is almost exactly the opposite.

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## 6.4.3 Lung Diseases

### 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

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

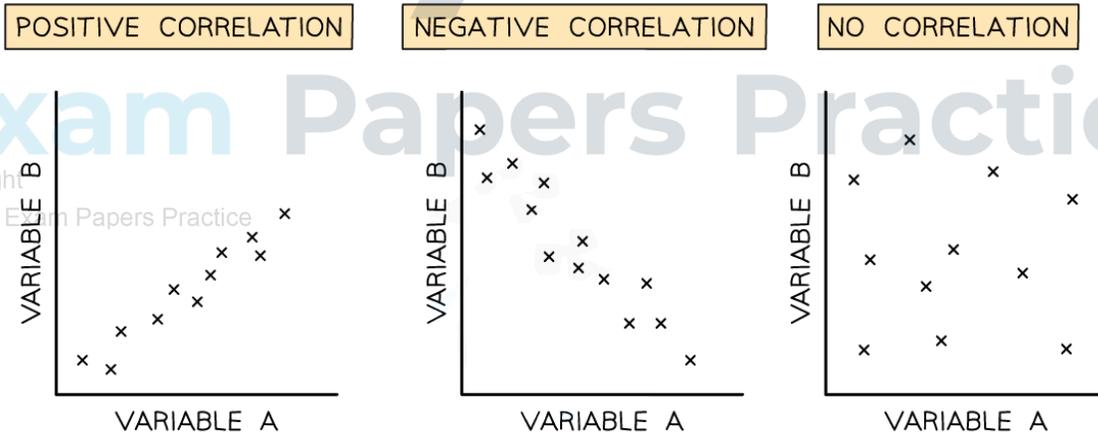
- There are many symptoms associated with a lung cancer diagnosis, including:
  - Breathing difficulties
  - Coughing, sometimes coughing up blood
  - Chest pains
  - Loss of appetite and weight loss
- Persistent fatigue
- Tumours can form in the lungs
- In severe cases, the **primary tumours metastasise**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

**Exam 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

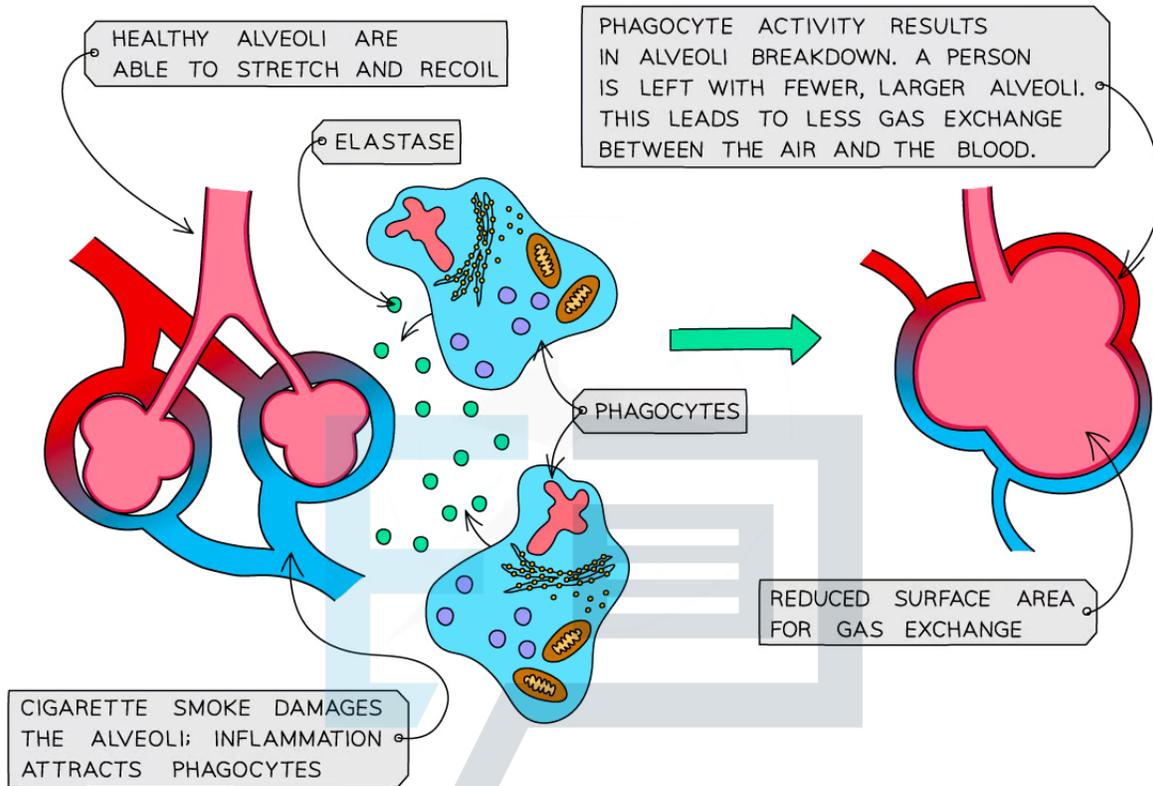
## Emphysema

### 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



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

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## 6.4.4 Skills: Monitoring Ventilation

### 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

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#### Apparatus

- Stopwatch
- Inflatable chest belt and pressure sensor OR spirometer

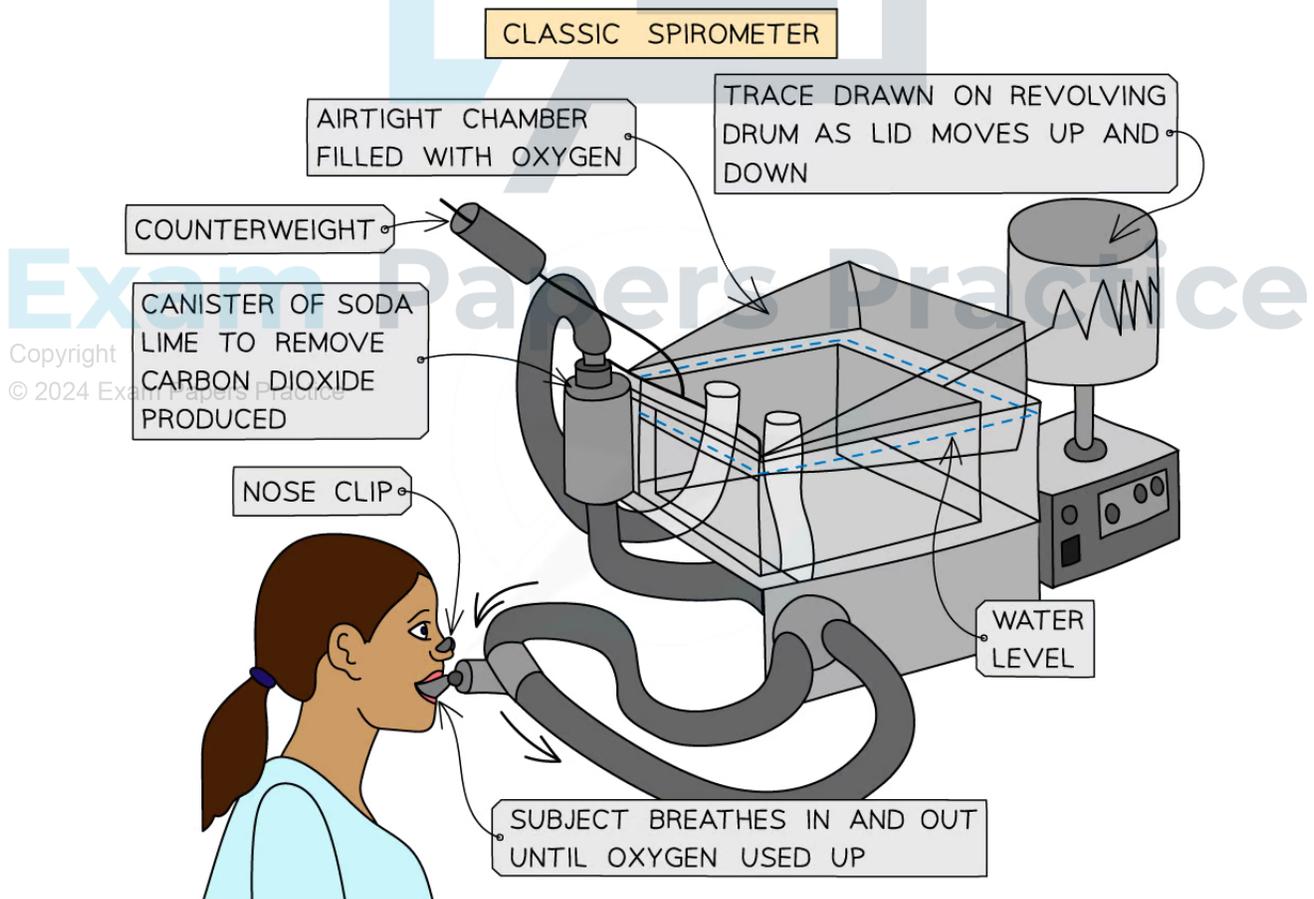
#### Method: Using an inflatable chest belt

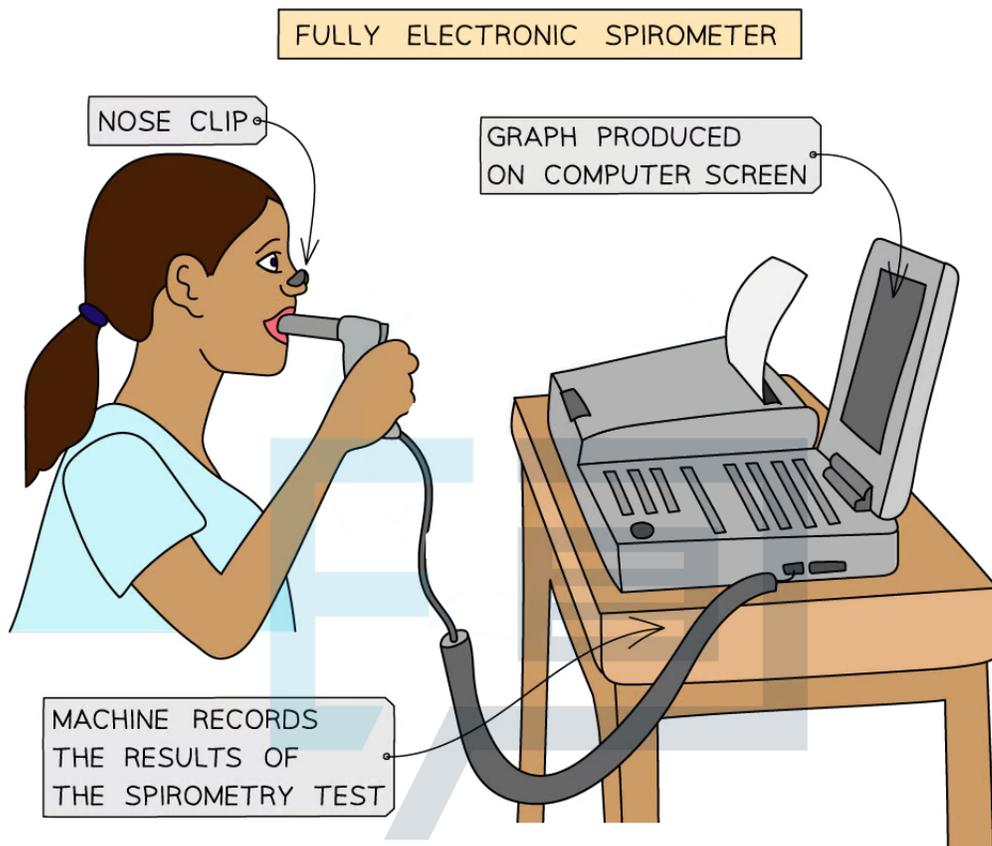
1. Taking breathing measurements using an inflatable chest belt and pressure sensor
2. The person (subject) being examined breathes in and out with a **chest belt** placed around the thorax, that has had air pumped into it
3. As the subject breathes the pressure sensor logs the changes in pressure due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

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**





*Using a spirometer to monitor ventilation*

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## Analysis

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