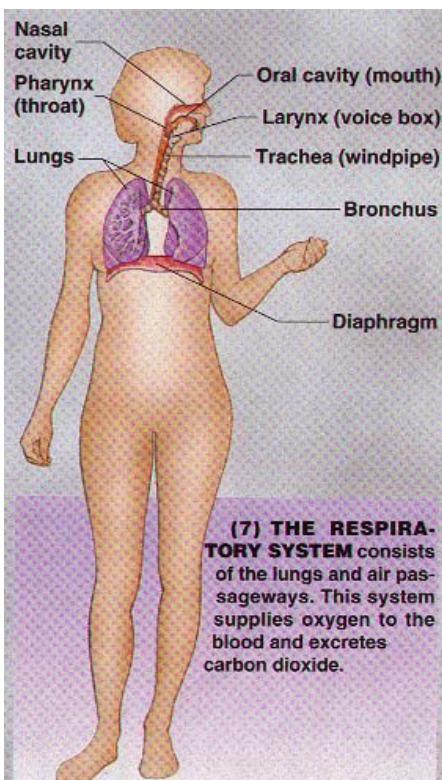


# AS Biology - Module 1



## CHAPTER 5 - BREATHING "THE RESPIRATORY SYSTEM"

You have read how the blood transports oxygen from the lungs to cells and carries carbon dioxide from the cells to the lungs. It is the function of the respiratory system to transport gases to and from the circulatory system. **External respiration** is the exchange of gases between the atmosphere and the blood. **Cellular respiration** is the way that cells obtain their energy – usually using oxygen to break down glucose in the cell (**aerobic respiration**). This Module examines the structures and mechanisms that carry oxygen to the cells for use in aerobic respiration and that eliminate the carbon dioxide that is produced as a by-product.



1. The function of the breathing system is to get oxygen into the body and waste gases out. These are involved in **respiration** - a vital function of all living organisms.

2. Respiration occurs at two different levels:

A. **The level of the cell.** In the mitochondria of Eukaryotic cells, aerobic respiration needs  $O_2$  to break down glucose. Thus releasing  $CO_2$ , water and producing large amounts of ATP in a process known as **cellular respiration**.

B. **The level of the organism.** An organism must get  $O_2$  into its cells and  $CO_2$  out. This is known as **external respiration** because the exchange of gases takes place with the external environment. In vertebrates, this involves the gases entering and leaving the animal's blood.

3. The breathing, or respiratory, system is a group of organs working together to bring about the exchange of  $O_2$  and  $CO_2$  with the external environment.

4. A single-celled organism living in water gets its oxygen directly from its surroundings by diffusion. The gases can easily cross the cell membrane by **simple diffusion**, obeying

**Fick's Law:**

$$\text{Rate of diffusion} \propto \frac{\text{Surface Area} \times \text{Concentration Difference}}{\text{Distance (membrane thickness)}}$$

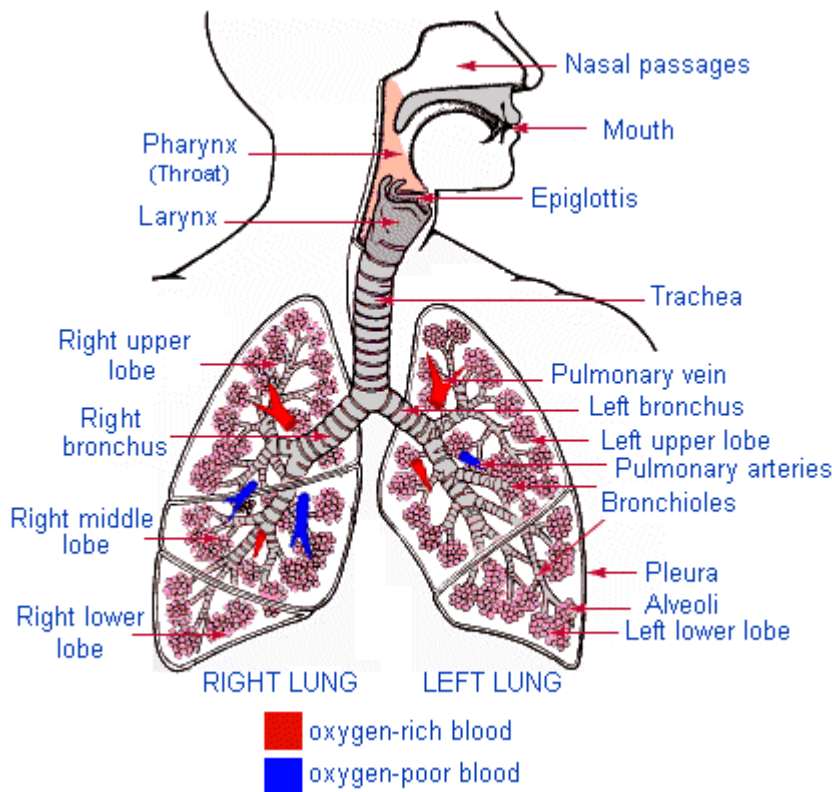
5. Because unicellular and other very small organisms have a **large Surface Area/Volume ratio**, they do not need a respiratory system.

6. In larger, multicellular organisms, each cell consumes oxygen and produces  $CO_2$ . Such organisms must have a respiratory system to ensure the effective and efficient exchange of gasses with their external environment if they are to survive.

7. The Earth's atmosphere is approximately 78% N<sub>2</sub> and 21% O<sub>2</sub>. The remaining 1% is made up of CO<sub>2</sub>, and other trace gases. (*Water vapour is also present, but in variable quantities, so is excluded from these figures*)

8. Humans have evolved a breathing system that is adapted to these concentrations of gases in the atmosphere. If the level of oxygen falls much below 15 % (at sea-level), our breathing system is unable to provide enough oxygen to support cellular respiration.

## THE PASSAGE OF AIR AND THE RESPIRATORY STRUCTURES



1. The human respiratory system comprises the: nose, nasal cavity, pharynx, larynx, trachea, bronchi, bronchioles, and alveoli (together forming the lungs).

2. This may be divided into the upper and lower respiratory tracts.

3. The upper respiratory tract comprises all structures before the lungs; the lower respiratory tract consists of the lungs themselves and the structures within them.

4. Air enters the body through the nose or mouth.

5. Air entering the nose passes into the **nasal cavity**, which is richly supplied with arteries, veins, and capillaries. *It is these blood vessels which swell up when you have a cold, thus blocking the air*

*passages.*

6. Air passes through the nasal cavity, into the **pharynx**. The pharynx is the back of the mouth and serves as a passageway for both air and food. When food is swallowed, a flap of cartilage, called the **epiglottis**, presses down and covers the opening to the air passage (*ever have food go "Down the wrong way"?*).

7. From the pharynx, the air moves through the **larynx** and into the **trachea**, which leads directly into the lungs.

8. These passageways provide a direct connection between the outside air and some of the most delicate tissues in the body, and so these passageways must filter out dust, dirt, smoke, bacteria, and a variety of other contaminants found in air.

9. Preliminary cleaning takes place in the nose, where air is:

- A. Cleaned of large particles (*dust, insects*)
- B. Warmed
- C. Moistened

before it passes on into the rest of the respiratory system.

10. The **trachea**, **bronchi** and **bronchioles** are lined with **cilia** and kept moist by **mucus** secretions. The combination of cilia and mucus filters out solid particles from the air and warms and moistens the air, preventing damage to the delicate tissues that form the lungs.

11. The surface of the alveoli must be moist for them to function and so it is important that the air reaching them is moist to prevent their delicate membranes from drying out.

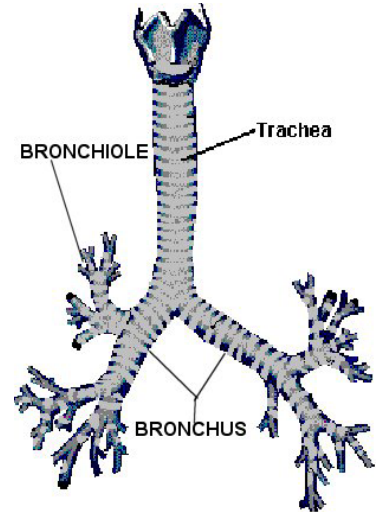
12. Similarly, their membranes would be ineffective if allowed to become too cold, so it is important that the air is warmed before it enters the lungs.

13. When air enters the body through the mouth, the air reaches the lungs in a less satisfactory state, so it is better to breathe through your nose than your mouth.

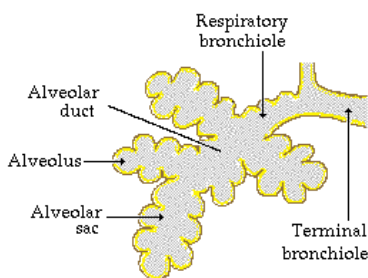
14. At the top of the trachea is the **larynx** (or *Adam's Apple*). Stretched across the larynx are two highly elastic folds of tissue (*ligaments*) called the **vocal cords**. Air rushing through the voice box causes the vocal cords to vibrate producing sound waves. *The larynx of a baby is higher in the throat, allowing them to breathe and feed (suckle) at the same time.*

15. From the larynx, the warmed, filtered and moistened air passes downward into the thoracic cavity through the **trachea**.

16. The walls of the trachea are made up of C-shaped rings of tough flexible cartilage. These rings of cartilage protect the trachea, make it flexible, and keep it from collapsing or over-expanding. They also allow the **oesophagus** (which is attached to the back of the trachea) to expand when a **bolus** of food is swallowed.



17. The epidermal cells lining the trachea produce mucus which helps to capture things still in the air (fine dust and microbes). This is swept out of the air passageway by tiny ciliary cells, into the throat, where it is swallowed.



18. Within the thorax, the trachea divides into two branches, the right and left **bronchi** - one **bronchus** entering each lung. Inflammation of these passageways (e.g. by cigarette tar), causes **bronchitis**.

19. The lungs are the site of gas exchange between the atmosphere and the blood. The right lung has three lobes, and is slightly larger than the two-lobed left lung (*the extra space is taken up by the heart*).

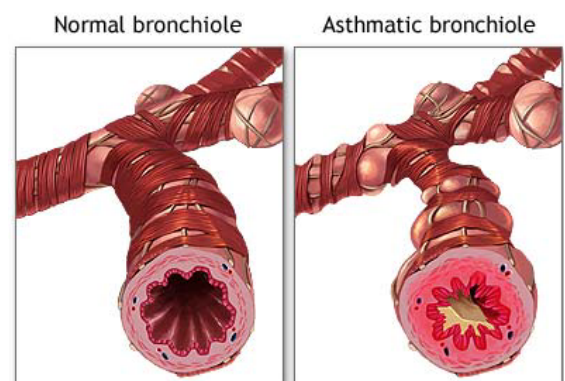
20. The lungs are inside the **thoracic cavity**, surrounded by the rib-cage and diaphragm. Lining the entire cavity and encasing the lungs are the **two pleural membranes**. These secrete **pleural fluid** that:

- a) **reduces friction** from the movement of the lungs during breathing and
- b) **attaches the lungs to the inside of the ribs** (by surface tension), so allowing them to move with the ribs.

21. The further branching of the bronchi is often called the **bronchial tree**. Imagine the trachea as the trunk of an upside-down tree with extensive branches that become smaller and smaller; the bronchioles.

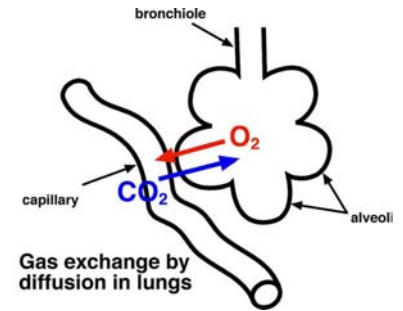
22. Both bronchi and bronchioles contain smooth muscle in their walls. This muscle tissue controls the size of the air passage.

23. Asthma occurs when these smooth muscles constrict, narrowing the air passage – ‘Ventolin’ and other inhalers contain a smooth muscle relaxant to relax these muscles and allow air to flow freely again.

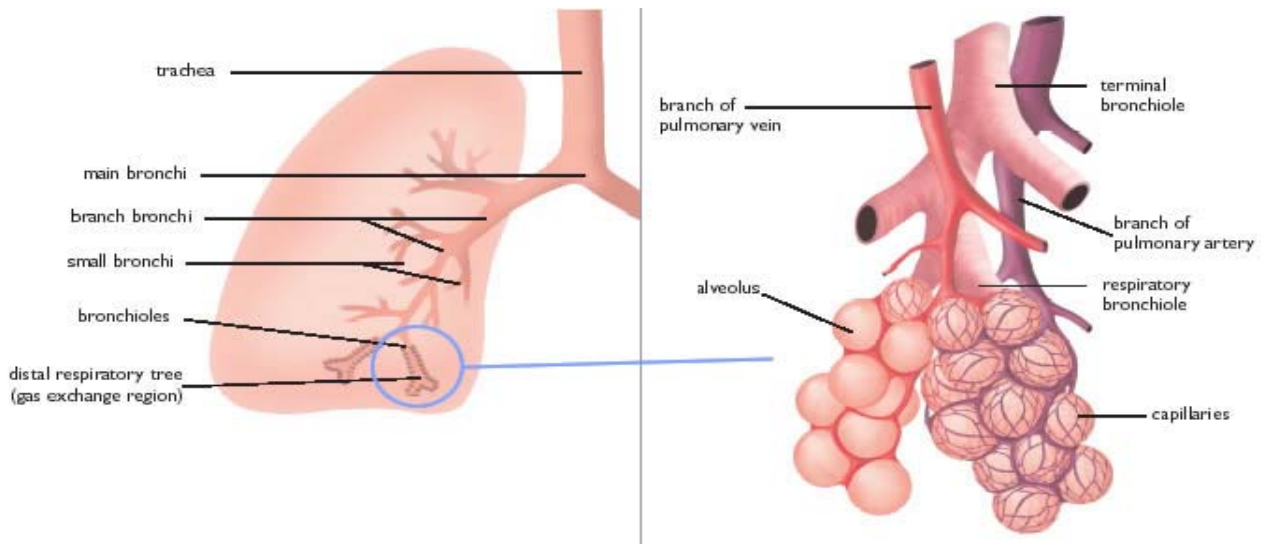


24. The bronchioles continue to subdivide until they finally end in clusters of tiny hollow air sacs or **alveoli**. Groups of alveoli look like bunches of grapes and this is the **ONLY site of gas exchange**.

25. The alveoli consist of thin, flexible membranes (**epithelium**) that contain an extensive network of capillaries, thus providing a **large surface area**, a **short diffusion distance** and, by having a good supply of fresh blood, **maximises the concentration difference**.



26. Each lung contains nearly 300 million alveoli and has a total surface area about 40 times the surface area of your skin.

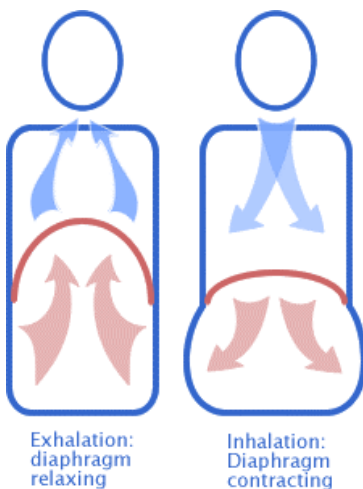


## THE MECHANISM OF BREATHING

1. Breathing is the movement of air into and out of the lungs – we normally breathe 10-15 times per minute. Each breathing cycle involves **two** stages:

A. **Inhalation** - or **inspiration** - is when the lungs expand and air is pulled into them.

B. **Exhalation** - or **expiration** – is when the lungs **reduce in volume** and air leaves the lungs.



The diaphragm flattens as it contracts, pushing the abdominal walls outwards

2. The lungs are not directly attached to any muscle, **so they cannot expand or contract on their own**.

3. Inhalation and exhalation are produced by movements of **two sets** of muscles: the **diaphragm** and the muscles between the ribs, known as the **intercostal muscles**.

4. There are **two sets** of intercostal muscles – the **internal intercostals** (inhalation) and the **external intercostals** (exhalation).

5. The diaphragm lies along the bottom of the ribcage and separates the thorax from the abdomen.

6. Before inhalation the diaphragm is **curved upwards** into the chest. During inhalation, the diaphragm contracts and **moves down**, causing the volume of the thorax to **increase**.

7. The pressure in the thorax therefore **decreases**, sucking air **in**.

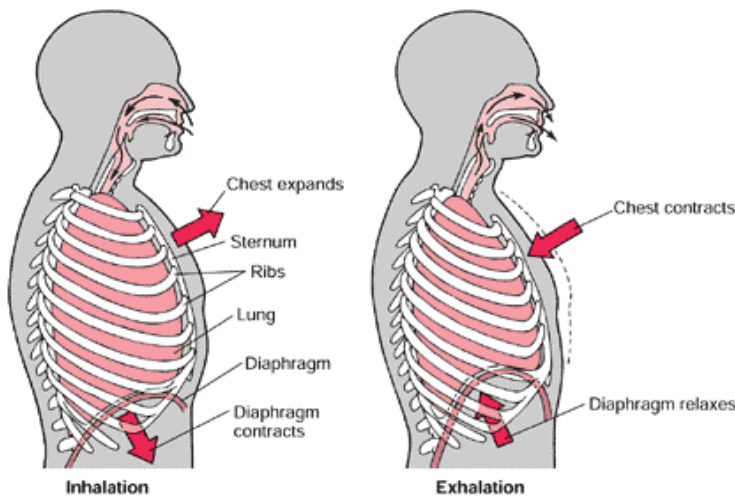
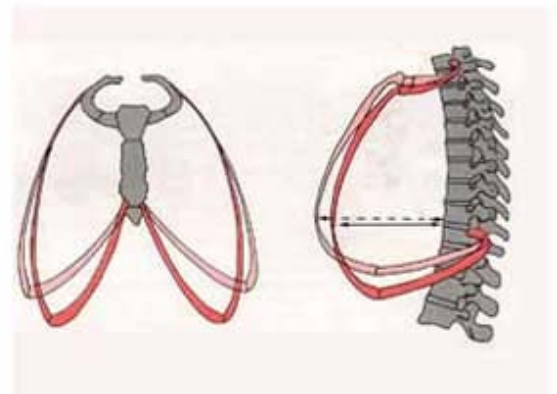
8. When the diaphragm relaxes, it returns to its curved position, aided by contraction of the muscles of the abdominal wall.

9. This causes the volume of the thorax to decrease, and the pressure to rise, thus forcing air back out of the lungs.

10. The intercostal muscles work in the same way – the **external intercostals contract**, swinging the ribs **upwards** and **outwards**, increasing the volume of the thorax, and causing us to inhale.

11. **Breathing out is easier**, since both gravity pulling the ribs down and the natural elasticity of the lungs help to collapse the lungs and squeeze air out.

12. **We generally breathe with the diaphragm and external intercostal muscles only**; it is only when exercising that we use the other muscles – our internal intercostals and the muscles of the abdominal wall to really force air out.



13. Since our breathing is based on atmospheric pressure, **the lungs can only work if the space around them is sealed** – if there is a hole in the thoracic cavity, the lung collapses and breathing ceases. This can happen with a broken rib, or when stabbed. Each lung is separately sealed, to reduce the risk of death from a (relatively) minor injury.

## HAEMOGLOBIN AND GAS EXCHANGE

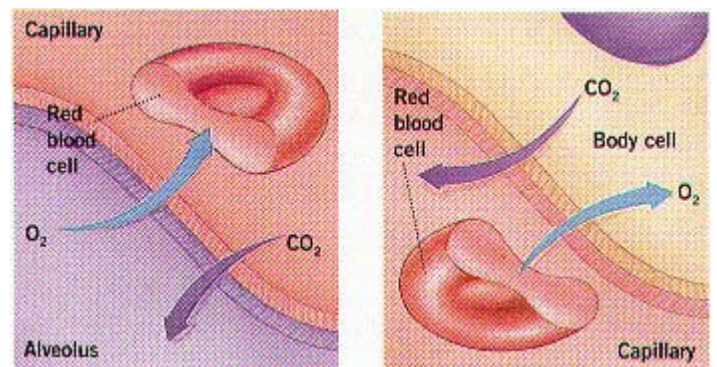
1. Percentage composition of the gases which are inhaled and exhaled:

GAS INHALED (%)		-v-	EXHALED (%)	
N <sub>2</sub> (etc)	79.25			75.4
O <sub>2</sub>	20.71			14.6
CO <sub>2</sub>	0.04			4.0
H <sub>2</sub> O	0.0			6.0

2. Three things happen to the air in our bodies – **only when in the alveoli**:

- A. Oxygen is removed
- B. Carbon dioxide is added
- C. Water vapour is added

3. Blood flowing from the heart (**pulmonary artery**) enters capillaries surrounding each alveolus and spreads around it. This blood is **high in CO<sub>2</sub>** and **low in O<sub>2</sub>**. It is known as **deoxygenated blood**, even though it is still about 70% saturated with O<sub>2</sub>!



4. Since the concentration of the gases in the blood and the alveoli are not equal, there is a concentration gradient which causes the diffusion of CO<sub>2</sub> from the blood to the alveolar air and of O<sub>2</sub> from the alveolar air into the blood. This process obeys Fick's law and is known as gas exchange.

5. The blood leaving the alveoli (in the **pulmonary vein**) has almost tripled the oxygen it carried when it arrived in the lungs (in the **pulmonary artery**).

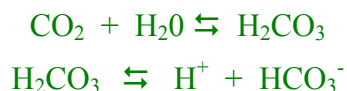
6. Two molecules help the process of gas exchange become more efficient:

A. **Surfactants** – these soap-like molecules, consisting of phospholipid and protein, coat the inner surface of the alveoli and reduce surface tension. Without them, the alveolar walls would stick together, making breathing very difficult. *[This is one effect that cystic fibrosis suffers have; they produce **too much, very thick mucus.**]*

B. **Haemoglobin** – the red oxygen-carrying molecule that fills RBC's. Each haemoglobin molecule has **four** oxygen-binding sites. Most of the oxygen in blood - 97 percent – is combined with haemoglobin. *[see Module 6 notes]*

## REGULATION OF BREATHING (NB mainly Module 6)

1. Breathing is so important that your body will not let you have complete control of it.
2. Breathing is controlled by the **medulla oblongata** in the lower part of the brain, though, obviously, you can temporarily suppress this reflex. The **diving reflex** (not breathing when your face is submerged – particularly in cold water) is found even in babies, and allows them to be bathed and swim (under supervision) with complete security.
3. Although you can hold your breath for a while, you cannot die this way. You can only hold your breath until you lose consciousness - then the brain takes control and normal breathing resumes.
4. The concentration of oxygen in the blood has little effect on breathing rate and you can suffocate in a low oxygen environment (e.g. on a mountain or in a plane when the pressurisation fails.)
5. Breathing is controlled by the levels of CO<sub>2</sub> and H<sup>+</sup> ions in the blood. These are measured in **two places** in the neck (**carotid arteries**) and just outside the heart (**aorta**). These regions have swollen areas known as **sinuses** which also measure blood pressure. Nerves lead from these regions to the hypothalamus (hind-brain), which controls most aspects of homeostasis.
6. These two factors are interlinked: when CO<sub>2</sub> dissolves in the blood, it forms **carbonic acid**. Inside the RBC's, the world's fastest enzyme, **carbonic anhydrase**, the carbonic acid immediately dissociates into H<sup>+</sup> ions and hydrogen carbonate ions (HCO<sub>3</sub><sup>-</sup>):



7. **Most (85%) of the CO<sub>2</sub> travels in the blood as HCO<sub>3</sub><sup>-</sup> ions.** When the blood reaches the lungs, the series of reactions is reversed, and the CO<sub>2</sub> diffuses out of the capillaries, into the alveoli and is exhaled into the atmosphere.
8. The H<sup>+</sup> ions change the pH of the blood, and it is **this change in pH** that is detected in the body.
9. The lungs of an average person have a **total lung capacity** of about 6.0l. Only about 0.6l is exchanged during normal breathing – the **tidal volume**.
10. During exercise, deep breathing forces out much more of the total lung capacity – up to 4.5l of air can be inhaled or exhaled (**vital capacity**).
11. The vital capacity is always 1.0 - 1.5l **less** than the total capacity because of air trapped in the trachea and bronchi. This air is known as the '**residual volume**' (or 'dead space').

12. The extra capacity allows us to exercise for long periods of time. Rather than breathing 12 times a minute, as most of us do at rest, a runner may breathe as often as 50 times a minute. This increases the volume of air passing through the lungs by over x30, or 3000%!

