5.5 GAS EXCHANGE

5.5.1 List the features of alveoli that adapt them to gas exchange. © IBO 2001

Four features of **alveoli** that allow efficient gas exchange:

- large surface area.
- thin (short diffusion distance).
- moist (gases need to dissolve before passing through membranes).
- good blood supply (to maintain concentration gradient).

5.5.2 State the difference between ventilation, gas exchange and cell respiration.

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Breathing is ventilation of the lungs.

Gas exchange is the intake of oxygen and excretion of carbon dioxide.
Cell respiration is the process of releasing energy from food (large organic molecules), often using oxygen as the ultimate electron acceptor.

Ventilation involves muscular movement and as such requires energy (released by cell respiration). Ventilation is required to maintain a concentration gradient so that gaseous exchange can occur. Oxygen will diffuse from the air in the lungs into the blood only if the concentration of oxygen in the air in the lungs is higher than that in the blood. As the oxygen diffuses into the blood, the concentration of oxygen in the air of the lungs becomes less. By refreshing the air in the lungs, the concentration gradient is maintained.

Gas exchange is the movement of oxygen from the air in the lungs into the blood and carbon dioxide in the opposite direction. First the oxygen dissolves in the film of water around the cells that make the walls of the alveoli. The dissolved oxygen then diffuses through the alveoli cells and through the walls of the capillaries into the erythrocytes in the blood. The circulation of the blood will take the oxygen away from the area of gas exchange, also maintaining the concentration gradient.

The movement of carbon dioxide, produced in the tissues, takes place in the opposite direction. The blood carries carbon dioxide to the lungs. Here, it diffuses from the blood, across the walls of the capillaries and the walls of the alveoli into the air in the lungs. The circulatory system will continue to bring blood carrying carbon dioxide to the lungs and ventilation of the lungs will refresh the air so that the concentration gradient is maintained.

Cell respiration is the release of energy from large organic molecules. Every living cell requires energy for its metabolic processes, which means that cell respiration takes place in all living cells. Cell respiration can use oxygen as its ultimate electron acceptor. This is called aerobic respiration and this process releases more energy per molecule glucose than anaerobic respiration.

Ventilation, gas exchange and cell respiration are all dependent on each other. Ventilation requires energy provided by cell respiration. Gas exchange depends on a concentration gradient of respiratory gases, which is maintained by ventilation. Cell respiration is more efficient when using oxygen as its electron acceptor. The oxygen needed and the carbon dioxide produced are exchanged with the environment via gas exchange in the lungs.

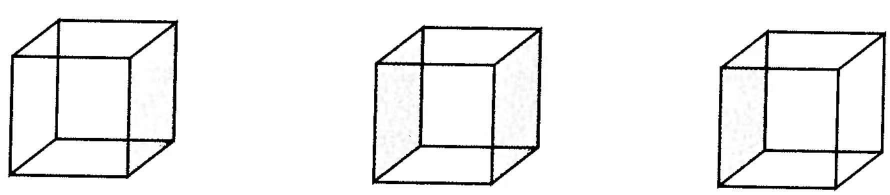
5.5.3 Explain the necessity for a ventilation system.

One of the characteristics of life is respiration. Respiration in this case has the biological meaning of the release of energy. This means that cellular respiration goes on in every living cell. Since anaerobic respiration releases about 5 - 7% of the energy that aerobic respiration releases (see section 9.1 or C.5), most cells require a constant supply of oxygen to function properly. (A few species of bacteria, living in the mud at the bottom of ponds and lakes, cannot tolerate oxygen; they employ alternative pathways to release energy.)

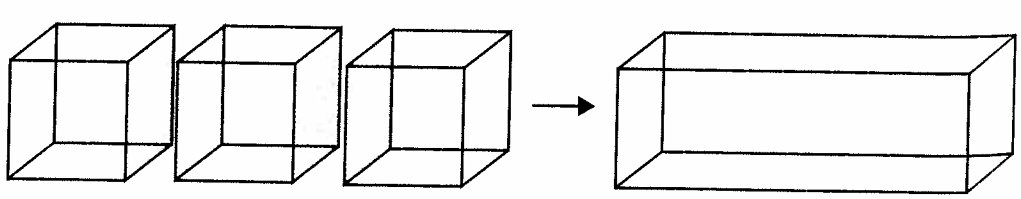
Unicellular organisms and small multicellular organism have few problems in gaseous exchange. The required gases will diffuse into and out of their system. For larger organisms this is not possible due to their smaller surface area over volume ratio. The decrease of the surface area over volume ratio is quite rapid as the size of an organism increases.

Two examples to convince you:

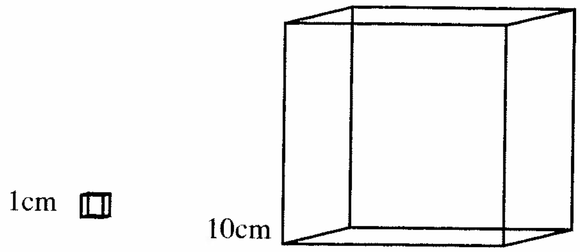
Example 1: If you study the cubes below, you can see the 4 shaded sides.



This is the amount of surface area which is 'lost' if you change these 3 small cubes into 1 larger structure, whilst no volume is lost.



Example 2: Again study the cubes below.



The smaller cube:
The surface area is $6 \times 1 \times 1$ cm^2 = 6 cm^2
The volume is $1 \times 1 \times 1$ cm^3 = 1 cm^3

The surface area over volume ratio is $\frac{6}{1} = 6$

The larger cube:
The surface area is $6 \times 10 \times 10$ cm^2 = 600 cm^2
The volume is $10 \times 10 \times 10$ cm^3 = 1 000 cm^3

The surface area over volume ratio is $\frac{600}{1000} = 0.6$

This means that the smaller cube has 6 cm^2 of surface for every cm^3 of volume, whereas the larger cube has 0. 6 cm^2 of surface for every cm^3 of volume. (The mathematical explanation is that when increasing size of factor y, the surface increases with y^2 but the volume increases with y^3).

So, when organisms become larger, there is simply not enough surface for gaseous exchange. An added problem is that the oxygen, once inside the organism, has to travel a long way to reach some cells. Since diffusion in liquids is a fairly slow process, this is unsatisfactory.

When the size of the organism is limited, the above problems can be solved by flattening the body (e.g. flatworms). This increases the surface area and decreases the diffusion distance. However, in larger organisms, even this measure is insufficient and a need for a respiratory surface exists.

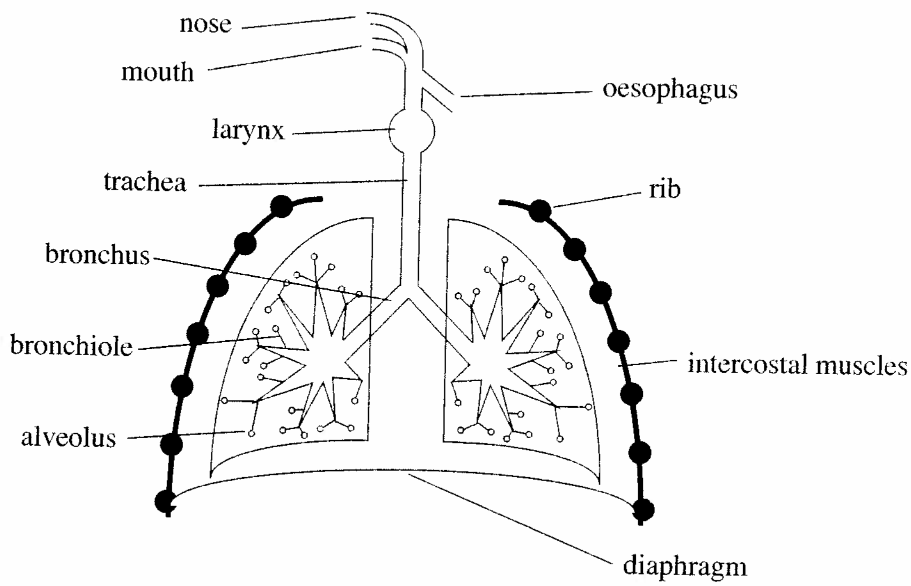
Insects have a system of tracheal tubes. These many tubes run from the exoskeleton throughout the insect's body. They are partially air filled, which ensures much faster diffusion.

Larval amphibians often have external gills. These are thin structures with a large surface area especially suited for gaseous exchange. Due to their position they are easily damaged.

Fish have internal gills. These are similar to external gills but safely inside the body. A fine capillary network transports the gases around the body. Many terrestrial animals have lungs. A ventilation movement refreshes the air in these sacs, which have a large surface area, are moist, and have an excellent blood supply.

5.5.4 Draw a diagram of the ventilation system including trachea, bronchi, bronchioles and lungs.

SCHEMATIC DIAGRAM OF THE HUMAN RESPIRATORY APPARATUS



The lungs are found in the chest cavity or thorax, together with the heart. Around each lung, a pleural membrane is found. Lining the inside of the thorax is another pleural membrane. These membranes surround the pleural fluid.

Structure of the lungs.
The air enters the body through the nose or mouth. From there it passes the trachea, into the bronchi which branch into many smaller bronchioles. Finally the air ends up in the airsacs: the **alveoli**. Alveoli are small thin walled sacs in which most of the gaseous exchange takes place. The oxygen diffuses across the wall of the alveolus, through the capillary cells, across the membrane of the erythrocytes to bind with haemoglobin. The blood then transports it to the tissues. Carbon dioxide from the tissues is carried back to the lungs (see section H.6), diffuses into the alveoli and is breathed out.

5.5.5 Explain the mechanism of ventilation in human lungs including the action of the internal and external intercostal muscles, the diaphragm and the abdominal muscles.

Ventilation of the lungs
The air in the lungs constantly needs to be refreshed. Since the lungs only have one connection with the atmosphere, the 'old' air needs to be exhaled before fresh air can be taken in.

Inspiration

The intercostal muscles contract and move the ribcage up and outward. The diaphragm contracts, flattening it downward. Both actions have the effect of increasing the volume of the chest cavity. If the volume increases, the pressure decreases and as a result the air will flow into the lungs.

Expiration

The relaxation of the intercostal muscles and the diaphragm will bring them back into their original position. The volume decreases as the increase in pressure will make the air leave the lungs. In forced expiration the abdominal muscles contract, which increases the pressure in the abdominal cavity. This pushes the diaphragm up further.

A normal breath will move approximately 500 cm^3 of air into and out of the lungs. This is called the tidal volume. After breathing in normally, you can breathe in an extra 3000 cm^3 of air: the **inspiratory reserve volume** or complemental air. If you then breathe out as much as you can, you expire approximately 4500 cm^3. This is your **vital capacity**. All you have left now is approximately 1200 cm^3 of residual air which you cannot force out or your lungs would collapse. The air which you can exhale after breathing out normally is approximately 1100 cm^3 of **expiratory reserve volume** or supplemental air.