Cambridge OL

Biology

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Chapter 09 and chapter 10

Human gas exchange and Respiration

Gas exchange in humans

All the processes carried out by the body, like movement, growth and reproduction, require energy. In animals, this energy can only be obtained from the food they eat. Before the energy can be used by the cells of the body, it must be set free from the chemicals of the food by a process called respiration

Features of respiratory surfaces

The exchange of oxygen and carbon dioxide across a respiratory surface, as in the lungs, depends on the diffusion of these two gases. Diffusion occurs more rapidly if

» There is a large surface area exposed to the gas
» The distance across which diffusion takes place is small
» There is a good blood supply
» There is a big difference in the concentrations of the gas at two points achieved by ventilation.

Large surface area

The presence of millions of alveoli in the lungs provides a very large surface for gaseous exchange.

Thin epithelium

There is only a two-cell layer, at the most, separating the air in the alveoli from the blood in the capillaries (Figure 9.4). One layer is the alveolus wall; the other is the capillary wall. So, the distance for diffusion is very short.

Good blood supply

The alveoli are surrounded by networks of blood capillaries. Carbon dioxide from the blood is delivered continuously into the alveoli. It is removed from the air passages by ventilation, maintaining a diffusion gradient in the same way. This encourages the diffusion of carbon dioxide from the alveolar lining into the **bronchioles**.

Ventilation

Ventilation of the lungs helps to maintain a steep diffusion gradient (see 'Diffusion' in Chapter 3) between the air at the end of the air passages and the alveolar air. The concentration of the oxygen in the air at the end of the air passages is high because the air is constantly replaced by the breathing actions.

Lung structure

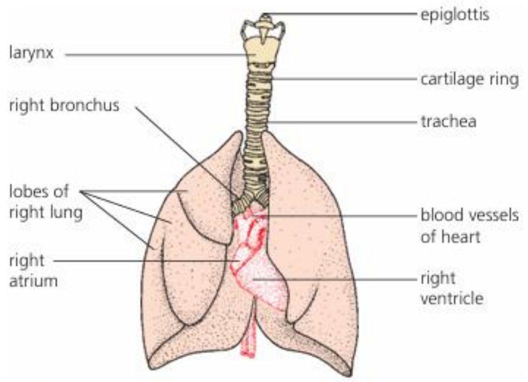
Figure 8.14). They have a spongy texture and can be expanded and compressed by movements of the thorax so that air is sucked in and blown out. The back of the mouth connects to the **larynx**, which joins onto the windpipe or **trachea** (Figure 9.1).

The trachea divides into two smaller tubes, called **bronchi** (singular = bronchus), which enter the lungs and divide into even smaller branches

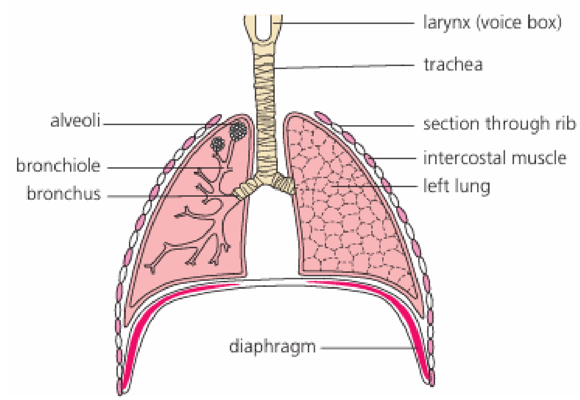
Figure 9.2 shows a section through the thorax. The ribs, shown in cross-section, form a cage, which has two main functions:

» To protect the lungs and heart.
» To move to ventilate the lungs.

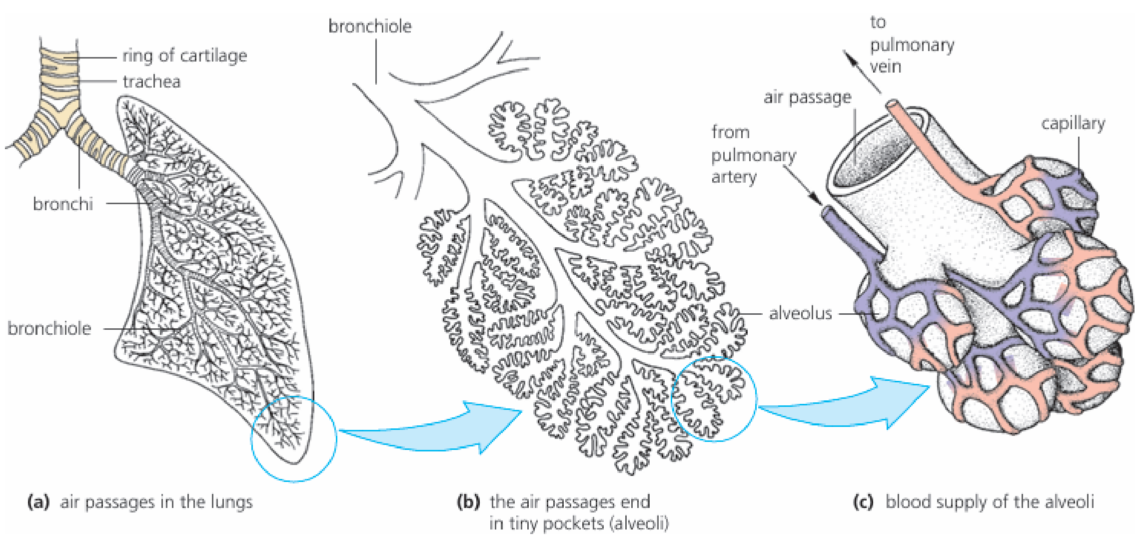
The alveoli have thin elastic walls made of a single cell layer or **epithelium**. Over the epithelium is a dense network of capillaries (Figure 9.3(c)) supplied with **deoxygenated** blood (see 'Blood' in Chapter 11). This deoxygenated blood is pumped from the right **ventricle** through the **pulmonary artery** (see Figure 11.17).



▲ **Figure 9.1** Diagram of lungs, showing position of heart



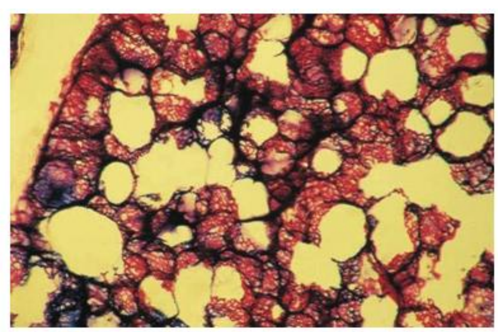
▲ **Figure 9.2** Section through the thorax



▲ **Figure 9.3** Lung structure

Gaseous exchange

Ventilation means the movement of air into and out of the lungs. Gaseous exchange is the exchange of oxygen and carbon dioxide, which takes place between the air and the blood vessels in the lungs (Figure 9.5).



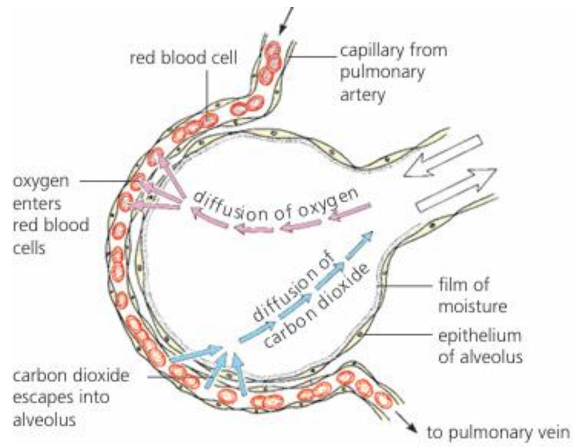
▲ **Figure 9.4** Small piece of lung tissue (×40). The capillaries have been injected with red and blue dye. The networks surrounding the alveoli can be seen

The capillaries carrying **oxygenated** blood from the alveoli join up to form the **pulmonary vein** (see Figure 11.17). This vein returns blood to the left **atrium** of the heart.

Table 9.1 shows changes in the composition of air as it is breathed in and out.

▼ **Table 9.1** Changes in the composition of breathed air

	Inhaled/%	Exhaled/%
oxygen	21.00	16.00
carbon dioxide	0.04	4.00
water vapour	variable	saturated



▲ **Figure 9.5** Gaseous exchange in the alveolus

Differences in composition of inspired and expired air

Air in the atmosphere contains 21% oxygen, which is absorbed into the bloodstream when entering alveoli. This reduces oxygen in exhaled air to 16% due to gas exchange processes. The remaining 79% is nitrogen and does not change much during breathing. Inspired air contains 0.04% carbon dioxide, which is carried to the lungs for excretion. The percentage breathed out is 4%, 100 times greater than breathed in. The air breathed out contains more water vapor than the air breathed in. In cold and mild climates, breathing helps lose heat to the atmosphere.

Lung capacity and breathing rate

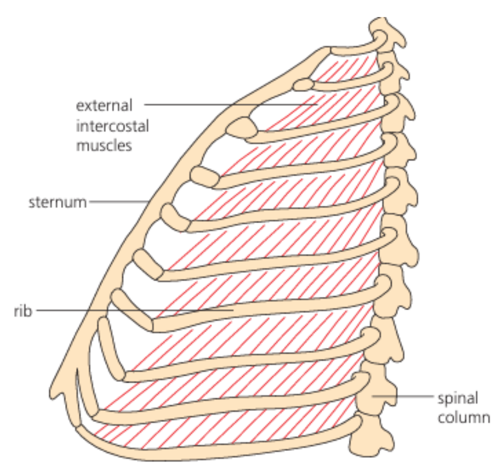
The total volume of the lungs when fully inflated is about 5 litres in an adult. However, in quiet breathing, when asleep or at rest, you normally exchange only about 500 cm3. During exercise you can take in and breathe out an extra 3 litres. There is a residual volume of 1.5 litres, which cannot be expelled no matter how hard you breathe out.

Breathing rate and exercise

The extra carbon dioxide that the muscles put into the blood is detected by the brain. It instructs the **intercostal muscles** and diaphragm muscles to contract and relax more rapidly, increasing the breathing rate. Carbon dioxide will be removed by the faster, deeper breathing.

Ventilation of the lungs

The ribs are moved by the intercostal muscles. The **external intercostals** (Figure 9.11) contract to pull the ribs upwards and outwards. The **internal intercostals** contract to pull them downwards and inwards. Figure 9.12 shows the contraction of the external intercostales making the ribs move upwards.



▲ **Figure 9.11** Ribcage seen from left side, showing external intercostal muscles

Inspiration

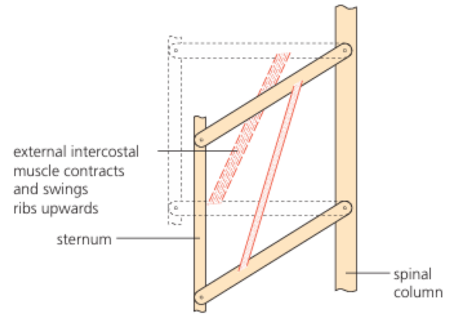
1. The diaphragm muscles contract and pull the diaphragm down (Figure 9.14(a)).

2. The internal intercostal muscles relax while the external intercostal muscles contract and pull the ribcage upwards and outwards (Figure 9.15(a)

Expiration

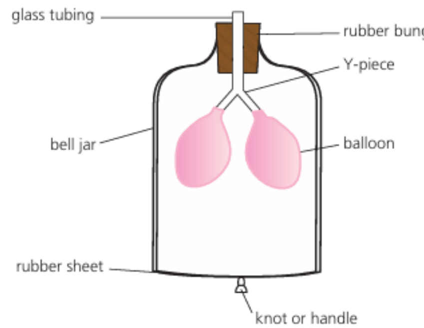
1. The diaphragm muscles relax, allowing the diaphragm to return to its domed shape (Figure 9.14(b)).

2. The external intercostal muscles relax while the internal intercostal muscles contract, pulling the ribs downwards to cause a forced expiration (Figure 9.15(b)).



▲ **Figure 9.12** Model to show action of intercostal muscles

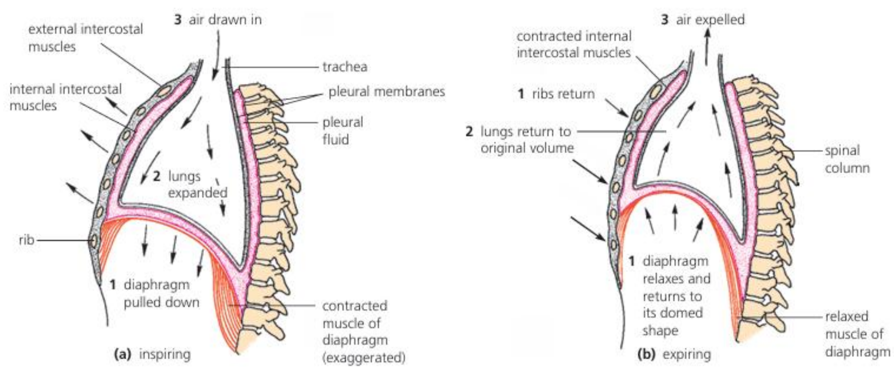
The lungs are elastic and shrink back to their relaxed volume, increasing the air pressure inside them. This results in air being forced out again. A piece of apparatus called the bell-jar model (Figure 9.13) can be used to show the way in which movement of the diaphragm results in inspiration and expiration



The balloons start off deflated. When the handle attached to the rubber sheet is pulled down, the balloons inflate. If the handle is released, the balloons deflate again.

When the rubber sheet is pulled down, the volume inside the bell jar increases. This reduces the air pressure inside, making it lower than outside. The air rushes in, through the glass tubing, to equalise the air pressure.

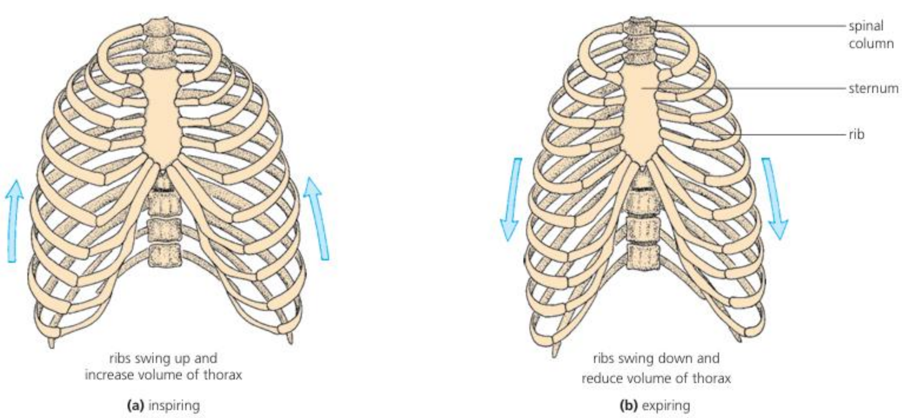
When the rubber sheet is released, the volume inside the bell jar decreases. This increases the air pressure inside, making it higher than outside. The air rushes out, through the glass tubing, to equalise the air pressure. This causes the balloons to deflate.



▲ **Figure 9.14** Diagrams of thorax to show mechanism of breathing

Protection of the gas exchange system from pathogens and particles

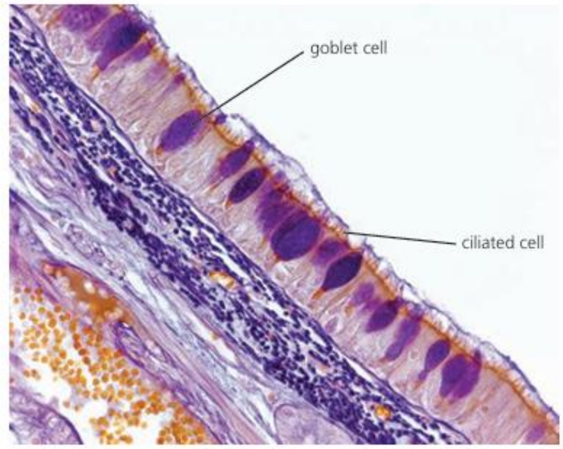
Pathogens are disease-causing organisms (see Chapter 12). Pathogens (e.g. bacteria) and dust particles are present in the air we breathe in and are potentially dangerous if not actively removed. There are two types of cells that are specialised to help do this.



▲ **Figure 9.15** Movement of ribcage during breathing

Goblet cells are found in the epithelial lining of the trachea, bronchi and some bronchioles of the respiratory tract (Figure 9.16). Their role is to secrete mucus. The mucus forms a thin film over the internal lining.

Ciliated cells are also present in the epithelial lining of the respiratory tract (Figure 9.16). They continually move in a flicking motion to move the mucus, secreted by the **goblet cells**, upwards and away from the lungs



▲ **Figure 9.16** Goblet cells and ciliated cells in the trachea

Chapter 10 – Respiration

Respiration

Most of the processes taking place in cells need energy to make them happen.

> **Key definitions**
> **Respiration** is described as the chemical reactions in all living cells that release energy from glucose.

This energy comes from the food that cells take in. The food mainly used for energy in cells is glucose. The process by which energy is released from food is called **respiration**.

Respiration is a chemical process in cells involving enzymes, not to be confused with breathing. Low temperatures slow down respiration due to fewer collisions, while higher temperatures increase it. Enzyme molecules denature at optimum temperatures, reducing respiration rate gradually. When yeast is mixed in boiling water, it kills cells, as respiratory enzymes in cells are denatured. Therefore, yeast should not be mixed in boiling water for bread-making processes.

Aerobic respiration

The word aerobic means that oxygen is needed for this chemical reaction. The food molecules are combined with oxygen. All food molecules contain carbon, hydrogen and oxygen atoms. The process of oxidation converts the carbon to carbon dioxide (CO_2) and the hydrogen to water (H_2O) and, at the same time, releases energy, which the cell can use to drive other reactions.

Aerobic respiration can be summed up by the equation

$$\text{glucose} + \text{oxygen} \xrightarrow{\text{enzymes}} \text{carbon dioxide} + \text{water} + \textbf{ENERGY released}$$

The balanced chemical equation for aerobic respiration is:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \rightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{energy released}}{2830\ \text{kJ}}$$

Anaerobic respiration

A common example is the action of yeast on sugar solution to produce alcohol. The sugar is not completely oxidised to carbon dioxide and water. Instead, it is converted to carbon dioxide and alcohol. This process is called fermentation and is shown by the following equation:

$$\text{glucose} \xrightarrow{\text{enzymes}} \text{alcohol} + \text{carbon dioxide} + \textbf{ENERGY released}$$

Key definitions

Anaerobic respiration is the release of a relatively small amount of energy by the breakdown of glucose without using oxygen.

Anaerobic respiration also happens in muscles during vigorous exercise, because oxygen cannot be delivered fast enough for the muscle cells to respire aerobically. The products are different to those produced by anaerobic respiration in yeast. The process is shown by the following equation:

$$\text{glucose} \rightarrow \text{lactic acid}$$

During vigorous exercise, **lactic acid** may build up in a muscle. In this case it is removed in the bloodstream. The blood needs to move more quickly during and after exercise to maintain this lactic acid removal process, so the heart rate is rapid.

As a result, the person who is exercising breathes faster and more deeply (an athlete pants for breath rapidly). The build-up of lactic acid that is oxidised later is called an **oxygen debt.**

EPOC is the amount of oxygen needed to return the body to its normal, resting level of metabolic function (an example of **homeostasis**,) It is important because build-up of lactic acid in the muscles results in muscular fatigue, leading to cramp.

Revision questions

1. Fig. 4.1 shows part of the human gas exchange system.

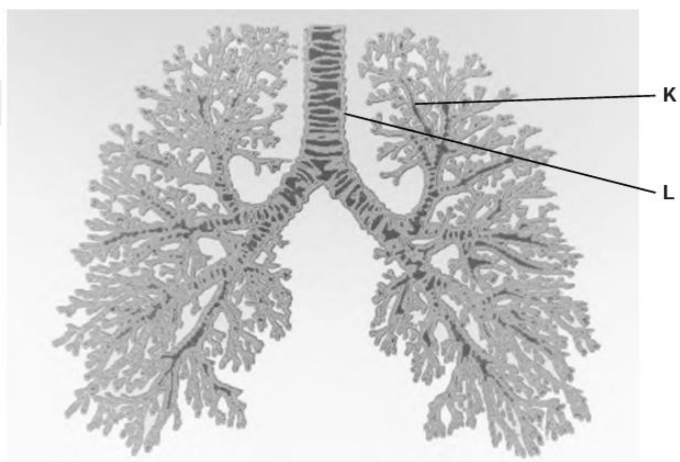


Fig. 4.1

a) (i) Name structure K

(ii) Ciliated cells and goblet cells line structure L.

Explain the function of these cells in structure L.

(b) Gas exchange occurs at the alveoli.

(i) Describe how oxygen molecules move from the alveoli into the blood.

(ii) During inspiration, air moves from the atmosphere into the lungs. Describe the mechanism of inspiration.

(iii) Name one gas that is found in a higher concentration in expired air than in inspired air.

(c) Tobacco smoke affects the gas exchange system. Name two components of tobacco smoke and describe their effect on the gas exchange system

2. The pressure in the lungs of a student before and during the start of a volleyball match was recorded. The results are shown in Fig. 2.1.

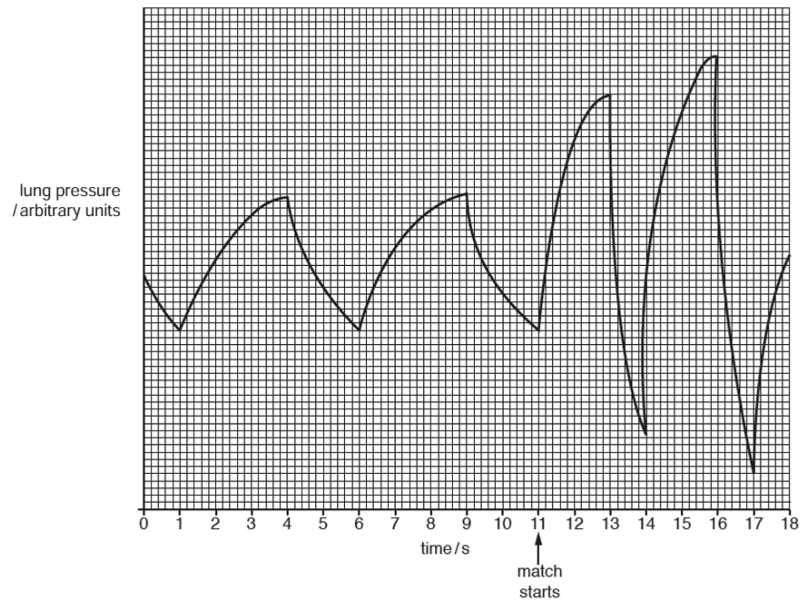


Fig. 2.1

(a) (i) Use the results in Fig. 2.1 to calculate the breathing rate before the start of the match. Express your answer to the nearest whole number. Show your working.

(ii) Use the results in Fig. 2.1 to describe how the pattern of breathing during the match is different from the pattern of breathing before the match starts.

(b) Describe the process of inhalation.

(c) Carbon dioxide is excreted from the body through the lungs.

(i) Explain why this process is termed excretion.

(ii) Name the part of the blood in which most carbon dioxide is transported.

iii) Describe the effect of increased carbon dioxide concentration on blood pH

(d) Carbon dioxide moves from the blood capillaries into the alveoli by diffusion. Explain why the rate of diffusion of carbon dioxide increases during exercise

3. Fig. 6.1 shows the movement of the ribs and the diaphragm during breathing in.

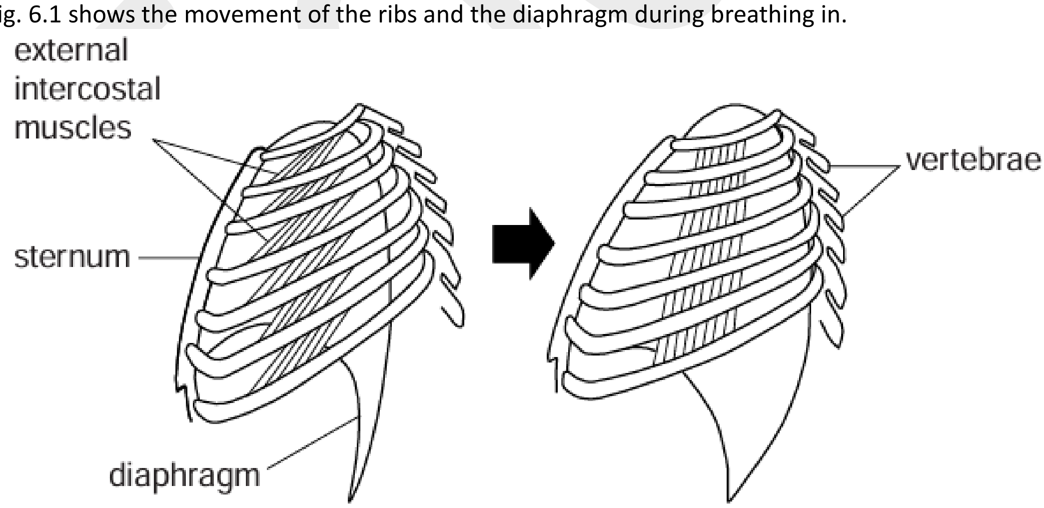


Fig. 6.1

(a) State what happens to the following structures during breathing in

b) Explain the effect of strenuous physical activity on the pH of the blood

4. Fig. 3.1 shows structures in the human thorax.

(a) Complete the table by identifying parts A, B and C and describing their roles in breathing in.

part	name	role in breathing in
A	....	....
B	....	....
C	....	....

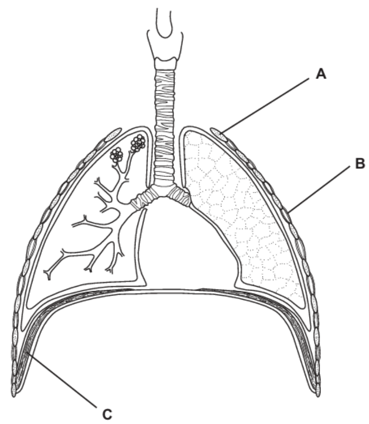


Fig. 3.1

Fig. 3.2 shows some cells from the lining of the bronchus.

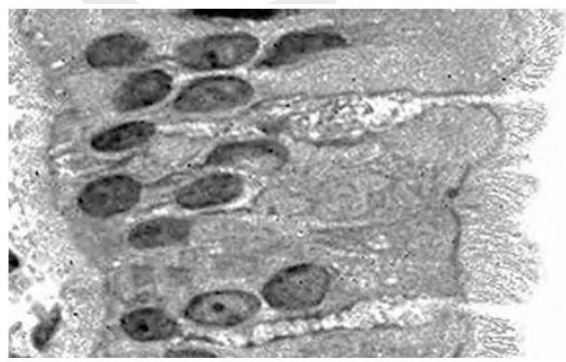


Fig. 3.2

(b) (i) Explain how these cells help to keep the bronchus free from dust and bacteria.

(ii) Describe how the actions one named compound of tobacco smoke.

5. (i) State the oxygen uptake at rest, before the athlete started running

(ii) Use Fig. 2.2 to describe the changes in oxygen uptake during and after running on the treadmill (from 2 to 25 minutes).

(iii) Explain the change in oxygen uptake during the run (between 2 and 13 minutes).

b. The lactic acid concentration in the blood of the athlete was measured at intervals. At the end of the slow run the lactic acid concentration had increased by 30%. After a rest, the athlete ran at a much faster speed on the treadmill. At the beginning of this exercise the lactic acid concentration in his blood was 100 mg dm^{-3}. After 11 minutes running at the faster speed, his lactic acid concentration was 270 mg dm^{-3}.

(i) Calculate the percentage increase in lactic acid concentration at the end of the faster run. Show your working.

(ii) Explain why the percentage increase in lactic acid is much greater when running at the faster speed.

6. Researchers designed an investigation to find the effect of increasing levels of exercise on two groups of people. The first group of people were trained cyclists, and the second group were untrained cyclists.

The researchers asked all the people to cycle at four levels of effort: 30%, 45%, 60% and 75% of their maximum cycle speed. They cycled for eight minutes at each level of effort.

(a) The researchers predicted that the pulse rate of all the cyclists would increase during exercise. Explain this prediction

Fig. 3.1 shows the average concentration of lactic acid in the blood of the trained cyclists and untrained cyclists in the investigation.

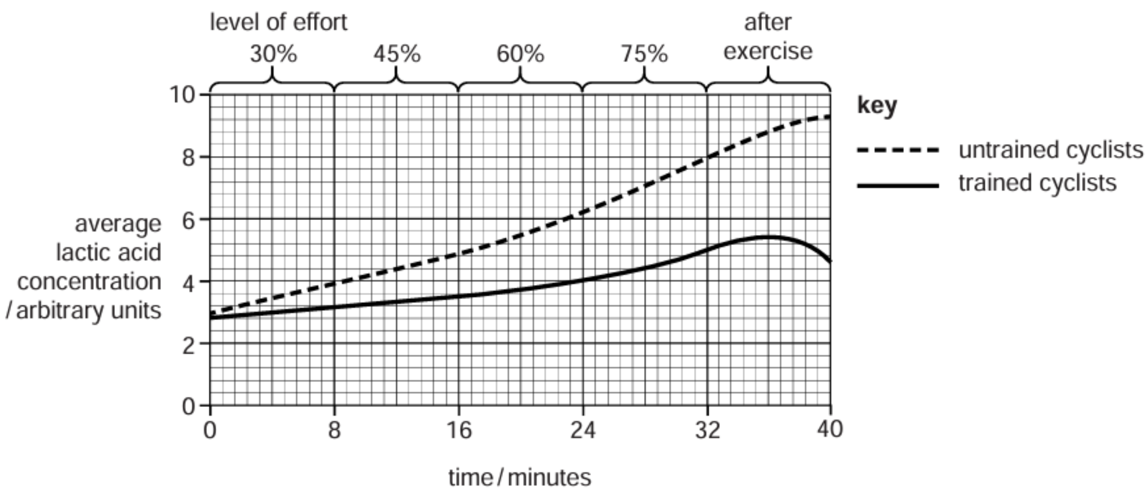


Fig. 3.1

(b) Describe the effect of the increasing levels of effort on the average lactic acid concentration in the blood of the untrained cyclists. You should use data from Fig. 3.1 in your answer.

(c) Lactic acid is produced in the muscles during anaerobic respiration. (i) Define the term anaerobic respiration.

(ii) Describe how the lactic acid produced in muscle cells enters the blood.

(iii) Name the component of the blood that transports lactic acid.

(d) Explain why the lactic acid concentration in the blood in trained cyclists is different from the untrained cyclists eight minutes after the exercise. You should use data from Fig. 3.1 in your answer

7. (a) Define the term respiration.

(b) A rowing machine is a piece of apparatus that is used in many fitness centres. Fig. 4.1 shows a man training on a rowing machine. The man in the photograph has his arms extended during the rowing stroke as shown in Fig. 4.2.

Fig. 4.1

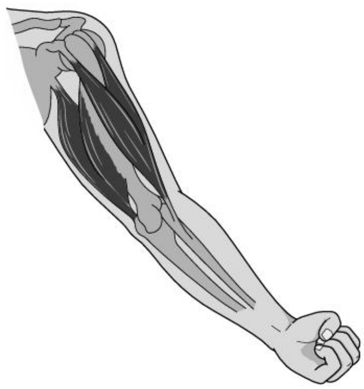


Fig. 4.2

Use Fig. 4.2 to describe how the hand is moved closer to the chest during the rowing stroke.

(c) The man has an intense workout on the rowing machine. Fig. 4.3 shows his oxygen uptake before and during the exercise.

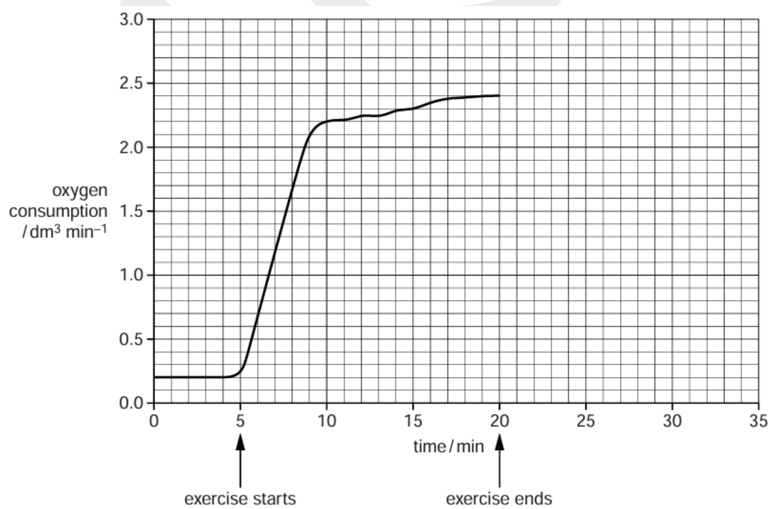


Fig. 4.3

(i) Explain why there is a steep increase in the man's oxygen consumption at the start of the exercise.

ii) It took 10 minutes after the man had stopped rowing for his oxygen consumption to decrease to its resting value.

On Fig. 4.3 draw a line between 20 minutes and 35 minutes to show the change in oxygen consumption after exercise has stopped.

(iii) Explain why the man's oxygen consumption did not return to the resting value immediately after exercise

8. Fig. 2.1 shows a person sitting in a room. A thermometer shows the temperature of the room

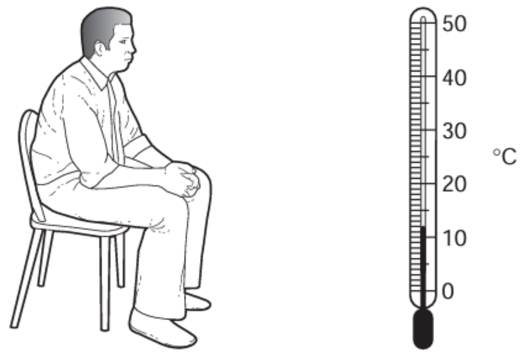


Fig. 2.1

(a) Give three uses of energy in the body of the person in Fig. 2.1.

(b) Name the process carried out by the person in Fig. 2.1 that releases energy.

(c) The person leaves the room and runs very fast for 200 m. When the person stops running, his breathing rate and his heart rate remain high. Explain why the person's breathing rate and heart rate remain high after the run

(d) There are changes in the skin at the beginning of the run and during the run. These changes involve the blood vessels and the sweat glands. Describe what happens to the blood vessels and sweat glands at the beginning of the run and during the run. Explain why these changes happen.

9. (a) Define the term aerobic respiration.
During exercise the movement of the ribcage enables air to enter the lungs.

b) Describe how the ribcage is moved during inspiration (breathing in) and explain how this causes air to enter the lungs.

(c) Explain how the ribcage returns to its resting position during expiration (breathing out)

Some students carried out an investigation on a 16-year old athlete. Table 3.1 shows the results of their investigation on the athlete's breathing at rest and immediately after 20 minutes of running. Ventilation rate is the volume of air taken into the lungs per minute.

Table 3.1

	at rest	immediately after 20 minutes of running
rate of breathing / breaths per minute	12	20
average volume of air taken in with each breath / dm^3	0.5	3.5
ventilation rate / dm^3 per minute	6.0	....

(d) d) Calculate the ventilation rate of the athlete immediately after 20 minutes of running. Write your answer in Table 3.1.

(ii) Explain why the athlete has a high ventilation rate after the exercise has finished