Chapter 7
Supplying oxygen; removing carbon dioxide

Unit

1B

Unit content

Body systems

Organs within systems are organised for efficient functioning and interaction.

Systems:

- principal organs within the main body systems
- structural layout of at least two systems related to efficient functioning
- structure and function at cellular level related to tissue and organ levels *e.g. cilia in the lungs*
- interaction between systems *e.g. the circulatory system with both the digestive and respiratory systems*
- efficient functioning related to different structures in systems .

Cells, metabolism and regulation

The body detects and responds to changes in its internal environment that are outside its tolerance limits. Dysfunctions are caused when tolerance limits are exceeded.

Tolerance limits:

- conditions resulting from exceeding tolerance limits e.g. hypoxia, oxygen toxicity syndrome
- individual differences related to tolerance limits *e.g. oxygen*.

The relevance of human biology to everyday life

Interest in the human body has often resulted from … trying to improve human performance.

Improve performance:

- changes in training practices *e.g. individuals at Australian Institute of Sport.*

Figure 7.1 Scuba divers must take a supply of oxygen with them when diving but too much oxygen can be dangerous

When you exercise, your muscles are working actively, you breathe more deeply and your heart beats faster. Respiration in the muscle cells provides the energy for the working muscles. For respiration the muscle cells need oxygen and glucose and they produce carbon dioxide.

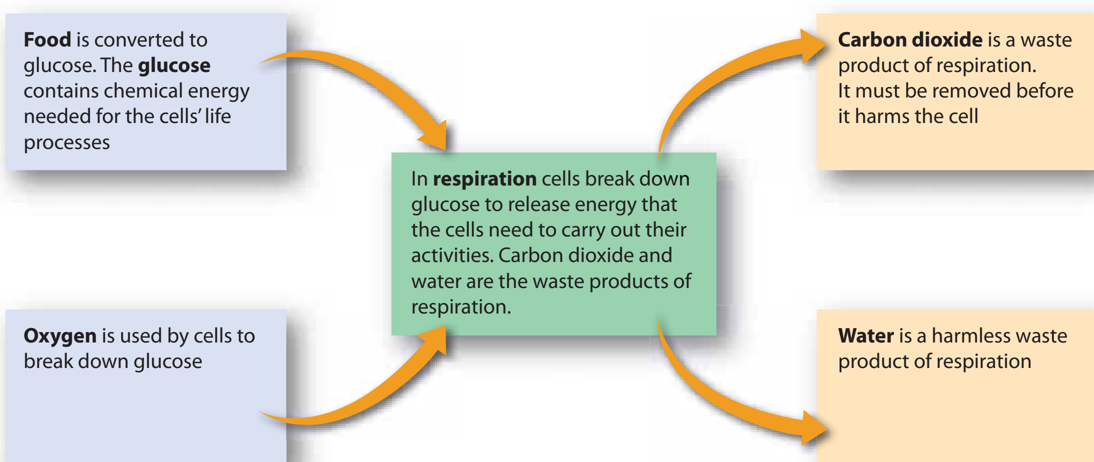
A summary of **respiration** is:

glucose + oxygen ⟶ carbon dioxide + water + energy

You breathe more deeply when you exercise because the lungs need to take in more oxygen for your active muscles and they need to get rid of the carbon dioxide produced. Your heart beats faster because it has to pump the blood that carries the extra oxygen to the muscles and takes carbon dioxide away from the muscles.

Breathing and respiration are *not* the same. **Breathing** is the movement of air in and out of the lungs. **Respiration** is a chemical reaction that occurs inside cells.

Figure 7.2 Respiration releases energy



It is not just the muscle cells that respire. All cells in the body need oxygen for respiration and all cells need to get rid of the carbon dioxide that they produce. In the lungs oxygen is taken from air into the blood and the blood transports the oxygen to the cells in all tissues of the body. In the tissues the blood picks up carbon dioxide and takes it to the lungs where it is passed into the air. The *circulatory* and *respiratory systems* work together to make sure that all cells have a constant supply of oxygen and that carbon dioxide is constantly removed from the cells. In this way the amounts of oxygen and carbon dioxide in the tissues are kept relatively constant.

Exchange of oxygen and carbon dioxide

The lungs are made up of tiny air sacs called alveoli (see Chapter 5 and Figs 5.14 and 5.15 on page 57). In the alveoli, **exchange of gases** occurs. This is when oxygen is taken into the blood and carbon dioxide leaves the blood. The gases enter and leave the blood by diffusion. There is a higher concentration of oxygen in the air in the lungs than in the blood, so oxygen diffuses from the air into the blood. There is a higher concentration of carbon dioxide in the blood than in the air in the lungs, so carbon dioxide diffuses out of the blood into the air.

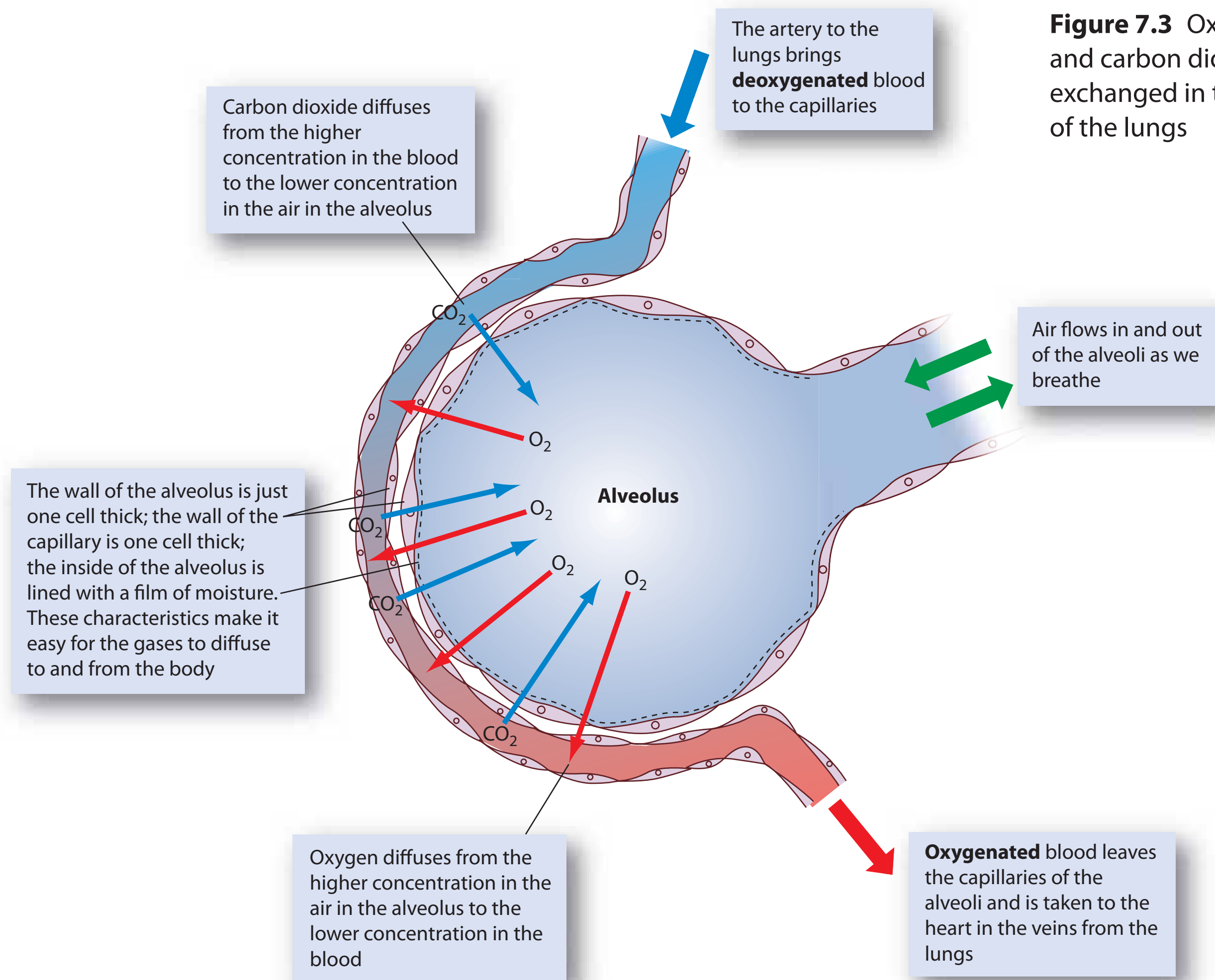


Figure 7.3 Oxygen and carbon dioxide are exchanged in the alveoli of the lungs

The lungs are very effective for gas exchange because:

- The insides of the alveoli have a huge surface area, so that large amounts of gases can be exchanged quickly.
- The alveoli are covered with blood capillaries, so that as much blood as possible is close to the air.
- The membrane that forms the walls of the alveoli is very thin, so that gas molecules do not have far to travel when diffusing into or out of the blood.
- The lungs are inside the body to prevent evaporation of the fluid that covers the inside of the alveoli—gases diffuse in and out of the blood only when they are dissolved in fluid.
- Air moving in and out of the lungs and blood flowing through the capillaries keep a concentration difference between the air and the blood.

You can see a video of gas exchange at http://library.thinkquest.org/28807/data/resp2.htm

Transport of oxygen and carbon dioxide

The transport of oxygen and carbon dioxide is one of the major functions of the blood. Although both gases are carried by the blood, they are transported in different ways.

Oxygen

Oxygen does not dissolve easily in water, so only about 3% of the oxygen that the blood carries is dissolved in the blood plasma. The other 97% is carried in the red blood cells combined with haemoglobin molecules. Haemoglobin is able to combine with oxygen to form a compound called **oxyhaemoglobin**. Oxyhaemoglobin can easily break down to release the oxygen.

$$\underset{\text{haemoglobin}}{Hb} + \underset{\text{oxygen}}{O_2} \rightleftharpoons \underset{\text{oxyhaemoglobin}}{HbO_2}$$

Oxygen combines with haemoglobin in places where plenty of oxygen is available. This would occur in the capillaries in the lungs, where oxygen diffuses into the blood from the air in the alveolus (see Fig. 7.3). Oxyhaemoglobin breaks down to haemoglobin and oxygen in places where the amount of oxygen is low. Because the cells of the body are continually using up oxygen, the tissue fluid around the cells has a relatively low oxygen concentration. While flowing through the capillaries between the body cells, the red cells give up their oxygen, which diffuses into the tissue fluid and then into the cells.

Blood that is carrying lots of oxygen is called **oxygenated blood**. Oxygenated blood has a high proportion of oxyhaemoglobin. Oxyhaemoglobin is bright red in colour, so the blood in the arteries (except for the arteries to the lungs) is bright red. Blood with little oxygen is called **deoxygenated**. It contains haemoglobin, which is dark red or purplish in colour. The deoxygenated blood in the veins (except the veins from the lungs) is therefore dark red.

Carbon dioxide

The carbon dioxide in the blood is carried in a number of different ways. Some is dissolved in the plasma. Some combines with haemoglobin but most is carried in the plasma as bicarbonate (see Table 7.1).

Table 7.1 Proportion of oxygen and carbon dioxide transported in the blood in different ways

Oxygen	Carbon dioxide
3% dissolved in plasma	8% dissolved in plasma
97% as oxyhaemoglobin	22% combined with haemoglobin 70% as bicarbonate (HCO_3^-)

Regulation of breathing

The amount of oxygen that the body needs varies according to activity. When sleeping you need less oxygen than when awake. When running you need more oxygen than when walking. Cells need a constant supply of oxygen, so the intake of oxygen must change to suit the demands of the cells. In the same way, carbon dioxide production varies and the removal of CO_2 from the body must keep pace with production.

Breathing is the way in which oxygen enters the body and carbon dioxide leaves the body. Therefore, by regulating breathing, oxygen intake and carbon dioxide output can be regulated.

Control of breathing is normally a reflex activity (see Chapter 8 for discussion of reflexes). We do not have to think about it. It is controlled by a group of nerve cells in the brain called the **respiratory centre**. These cells regulate the rate and depth of breathing automatically. However, we can voluntarily control breathing if we need to. This happens when you speak or sing, when you blow up a balloon or when you hold your breath to swim under water.

Regulation of heartbeat

Increased breathing rate or depth allows extra oxygen to be taken into the body when required. However it is not enough just to take in extra oxygen; it must be transported to the tissues that need it. To get extra oxygen to the tissues the heart must increase its output of blood.

The heart has its own in-built rhythm of contractions. A heart removed from a freshly killed animal will continue to beat provided it is supplied with oxygen and nutrients. The in-built contractions of the heart are brought about by the heart's pacemaker. The **pacemaker** is a small clump of nervous tissue that is located in the wall of the right atrium.

Figure 7.4 shows how nerve impulses spread out from the pacemaker over the muscle of the atria, causing the atria to contract. The impulses then spread through the ventricles and the ventricles contract.

The pacemaker is connected by nerves to a group of cells in the brain. This is the **cardiac centre**. Although the pacemaker can work on its own to make the heart contract, the cardiac centre can send messages to speed up or slow down the normal rhythm of the pacemaker. In this way the rate of the heartbeat can be varied to suit the activities of the body and the requirements of the cells.

Effects of behaviour

The things that we do, our **behaviour**, affect breathing and heartbeat. The need to supply extra oxygen to the muscles and to remove extra carbon dioxide during physical activity has already been mentioned.

Other aspects of behaviour also affect heartbeat and breathing. You have probably noticed how your heart beats faster during the tense parts of a movie. The heart and breathing rate also speed up when you are scared or angry. Before the start of a running or swimming race the heart and breathing speed up in anticipation of the extra activity that is to come. Breathing and heartbeat are closely related to behaviour and emotions.

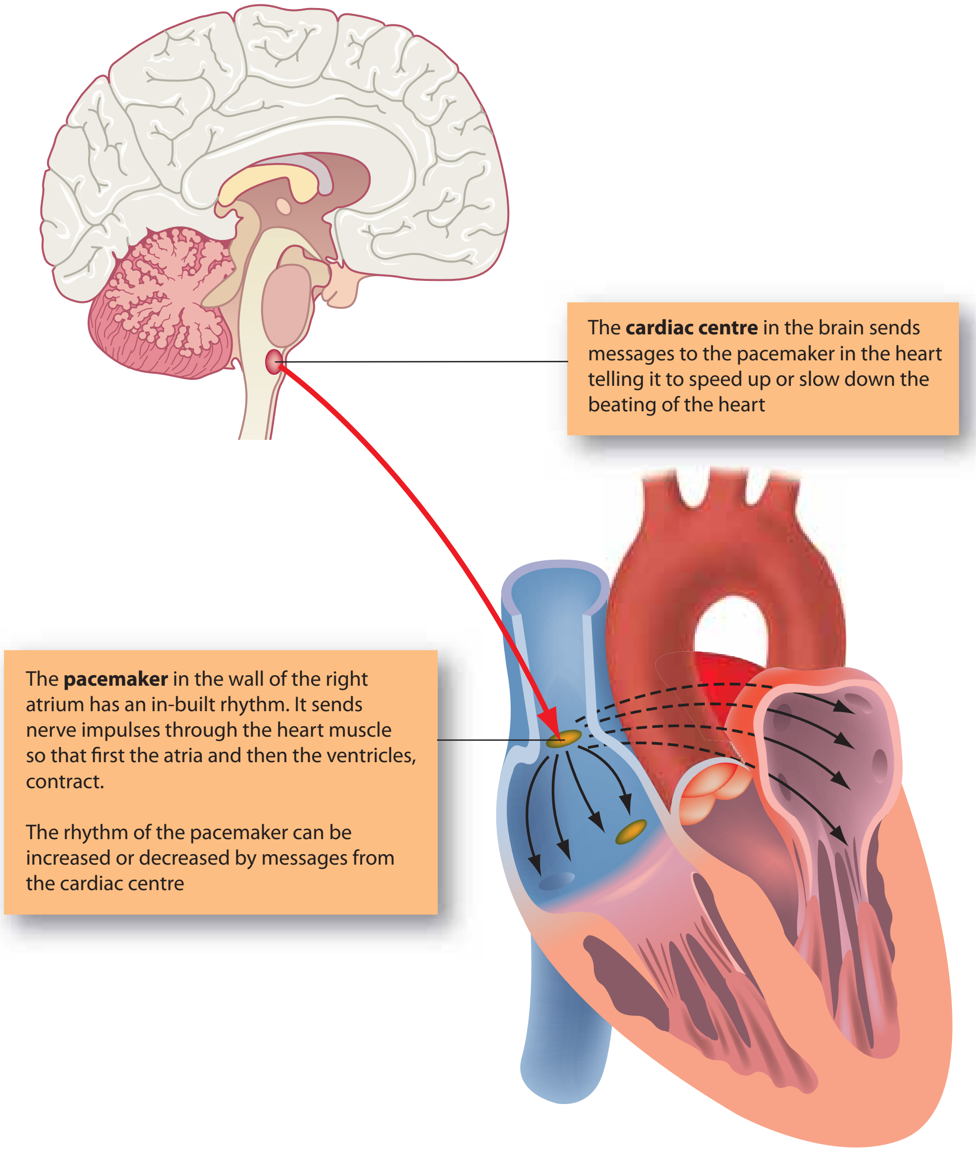


Figure 7.4 Control of heartbeat

Exceeding tolerance limits for oxygen

Many factors can vary in the human body. Factors such as oxygen concentration in the tissues, salt concentration, temperature and glucose concentration all rise and fall a little. If there is too big a rise or too big a fall then things start to go wrong with the way the body works.

Tolerance limits are the upper and lower limits to a range of factors. Within these limits the body functions normally. A rise above, or a fall below, the normal range means that the individual's tolerance limits have been exceeded and dysfunctions will occur.

Hypoxia

Hypoxia is a condition in which insufficient oxygen reaches body tissues—oxygen concentration has fallen below the tolerance limit.

Situations that can cause hypoxia include:
- cutting off or reducing air supply to the lungs by drowning, suffocation, choking, strangling or disease that causes paralysis of respiratory muscles
- reduction in blood supply to the tissues such as with a heart attack or carbon monoxide poisoning
- head injury
- high altitude due to the reduced amount of oxygen in the atmosphere
- drug overdose.

Brain cells are very sensitive to any lack of oxygen. The brain is therefore the first part of the body to be affected by hypoxia. In severe cases of hypoxia the person will become unconscious and brain cells will begin to die within five minutes of the oxygen supply being stopped.

At high altitudes the hypoxia develops gradually and results in nausea, fatigue, shortness of breath and headaches. This is known as altitude sickness.

Sleep apnoea is another cause of hypoxia. Narrowing of the throat during sleep causes snoring. If the throat is severely narrowed it will cause **obstructive sleep apnoea**. Breathing actually ceases momentarily until reflex mechanisms, caused by lack of oxygen and build-up of carbon dioxide, cause the throat to open and breathing to resume. The result is very restless sleep and the patient may suffer from constant fatigue, daytime sleepiness, mood changes and poor memory. Accidents and poor performance at work can also result from sleep apnoea.

The danger of hypoxia is illustrated by the crash of an aircraft in September, 2000. The plane took off from Perth Airport to fly to Leonora in the West Australian goldfields. Radio contact with the plane was lost soon after take-off but the plane continued to fly straight and level well beyond its destination. After more than five hours it eventually ran out of fuel and crashed in north Queensland killing the eight occupants. It is believed that the plane lost cabin pressure and the people on board became unconscious due to hypoxia.

See a video of a person affected by hypoxia at http://www.youtube.com/watch?v=qLQMupV3DLk

More information about hypoxia can be found at:
- http://www.oxymega.com/hypoxia_oxygen_deficiency.html
- http://medical-dictionary.thefreedictionary.com/hypoxia (includes descriptions of the different types)

Oxygen toxicity syndrome

Body cells cannot survive without oxygen but too much oxygen can also be dangerous. When oxygen concentrations in the tissues rise above the tolerance limit, it is known as **oxygen toxicity** or oxygen poisoning.

Under usual conditions oxygen toxicity will not occur. At normal pressure it is possible to breathe pure oxygen for several hours without harm. Oxygen toxicity can rapidly develop when pure oxygen is breathed at higher pressures. This can occur when Scuba diving, especially on deep dives or long dives. The symptoms of oxygen poisoning can include nausea, dizziness, loss of coordination, blurred vision and convulsions. The affected diver often loses consciousness and drowns.

Pure oxygen can be breathed at *lower* than normal pressure without problems. The astronauts of the Gemini and Apollo space programs breathed 100% oxygen at low pressure for up to two weeks without any harmful effects.

Another situation in which too much oxygen may cause problems is in patients who are supplied with oxygen while in intensive care. If the lungs are exposed to more than 60% oxygen for longer than twenty-four to thirty hours, severe and irreversible changes can occur in the lungs. In premature infants blindness can be caused if high levels of oxygen are given. Infants in intensive care are usually given only 40% oxygen.

Individual differences in tolerance limits for oxygen

The tolerance that individuals have for high and/or low levels of oxygen vary. This variation may be due to the particular genes that they have inherited or it may be due to the environment in which they live.

Effects of altitude

As you go up through the earth's atmosphere the air becomes less dense. This means that at an altitude of 5000 m the quantity of oxygen available is only half that of sea level (the height of Mt Everest is 8848 m).

Humans who live at an altitude of around 4000 m, like the people of Tibet and the Andeans of South America, have special characteristics that enable them to survive in an atmosphere where there is less oxygen available. At such altitudes people used to living at sea level would suffer hypoxia. The Andeans, through natural selection, have adapted to the thin air by developing red blood cells that can carry more oxygen than usual. Oxygen is delivered to their cells more effectively so they can tolerate the lower availability of oxygen.

Tibetans have also adapted to life at high altitude but in a different way. They compensate for the low oxygen availability by taking more breaths per minute than people who live at sea level. Tibetans also have a way of increasing the diameter of their blood vessels, which means they can offset the low oxygen in their blood by increased blood flow to the tissues.

In 1968 the Olympic Games were held in Mexico City, which is at an altitude of 2300 m. Many endurance athletes performed poorly at the games because the atmosphere at that altitude had 30% less oxygen than at sea level. On the other hand many records were set in sprints, jumping and throwing events where oxygen availability is not so important and the athletes benefited from the reduced air resistance.

Altitude sickness

People who normally live around sea level will suffer from hypoxia if they ascend to high altitude. In some people this causes illness known as **altitude sickness** (also called acute mountain sickness). Altitude sickness normally occurs above 2400 m. The symptoms include headache, fatigue, nausea, dizziness and disturbed sleep. It is not known why some people suffer from altitude sickness more than others.

Acclimatising to high altitude

For people used to living at low altitudes, the body undergoes many changes when they ascend to high altitude. In the first few hours at high altitude the rate and depth of breathing increase so that more oxygen can be taken into the blood. Heart rate increases to get the blood to the tissues more quickly and there is increased blood flow to the brain so that the brain is kept well supplied with oxygen.

Within four or five days there is an increase in production of red blood cells by the bone marrow. The extra red blood cells increase the ability of the blood to carry oxygen. More blood capillaries gradually develop as a response to altitude. This brings the blood closer to the cells that have to be supplied with oxygen.

After six weeks at high altitude a person would be about 95% acclimatised. On descending to low altitude again the changes would be lost just as quickly as they were gained.

High altitude training

Some endurance athletes have trained at high altitudes so that their bodies will develop more red blood cells. When they return to sea level to compete, the muscles will be more effectively supplied with oxygen and performances will be improved. The disadvantage of living at high altitude is that training sessions are less effective because of the lower oxygen availability.

In many countries training camps for athletes now include a 'high altitude house'. The Australian Institute of Sport in Canberra has such a house. Rooms in the house are sealed off and nitrogen gas is pumped in reducing the concentration of oxygen. This makes it similar to conditions at altitudes of 2600 to 3000 m. Before competing in a major event, endurance athletes may spend eight to twelve hours per day over a two to three week period in the altitude house. Increased production of red blood cells and other changes help to enhance the athletes' performances.

Working scientifically

Activity 7.1 Breathing rate

In this activity you will consider the stimuli that could be involved in regulating breathing rate.

You will need

Stopwatch or clock with second hand; large paper bag

What to do

Warning: *Do not act as a subject for this activity if you suffer from any respiratory or heart problems.*

Work with a partner. Read through these instructions and draw up a suitable table in which to record your results.

1. Each member of the pair should count his or her own breathing rate (in breaths per min) while sitting quietly at rest. Record the resting breathing rate.
2. After a normal quiet expiration hold your breath for as long as you can. Count and record your breathing rate immediately after holding your breath.
3. Flatten a brown paper bag so that it has little air in it. Place the opening of the bag over your nose and mouth and breathe into and out of it for one minute (so that you are re-breathing the same air). Count and record your breathing rate immediately after breathing into the bag.

Studying your results

1. How did your breathing rate change after holding your breath and after breathing into the paper bag?
2. Suggest reasons for the changes in breathing rate.
3. What could be the stimulus that regulates a person's rate of breathing? Suggest as many possibilities as you can.

Activity 7.2 Breathing rate and exercise

This activity gives you an opportunity to make up a hypothesis and to design an experiment to test it.

1. Propose a hypothesis that states what you think is the relationship between the two variables: breathing rate and exercise.
2. Design an experiment to test your hypothesis. (See Chapter 1, page 5.) In your description of the experiment make sure that you state:
   (a) the independent variable (the variable that you are going to change)
   (b) the dependent variable (the variable that you are going to observe or measure)
   (c) the controlled variables (the variables that you will keep the same) and how you will control them
   (d) the equipment you will need
   (e) how you will measure the dependent variable
   (f) how you will tabulate your results
   (g) how you will make sure that your results are reliable.

Your teacher may want you to carry out your experiment and write a formal scientific report (see page 10 for report format).

REVIEW QUESTIONS

1. Write a summary equation for respiration.
2. Where do cells get their oxygen from, and how is it delivered to the cells?
3. Why is it that, in the lungs, oxygen diffuses into and carbon dioxide out of the blood, whereas in other body tissues oxygen diffuses out of and carbon dioxide into the blood?
4. List the characteristics of the lungs that make them well suited to the function they perform.
5. **(a)** Describe how oxygen is carried in the blood.
   (b) Describe how carbon dioxide is carried in the blood.
6. What is the function of the respiratory centre in the brain?
7. Explain how the cardiac centre regulates heart rate.
8. Give some examples of how behaviour can affect breathing rate and heart rate.
9. Explain the difference between hypoxia and oxygen toxicity.
10. Describe three situations that could lead to hypoxia.
11. Oxygen toxicity is closely related to the pressure at which the oxygen is breathed. What is the relationship between oxygen toxicity and pressure?
12. Describe the changes that would occur if a person who normally lived at sea level moved to a high altitude.

APPLY YOUR KNOWLEDGE

1. Explain how the circulatory and respiratory systems work together to make sure that the amounts of oxygen and carbon dioxide in the tissues are kept relatively constant.
2. If air enters the chest cavity through a puncture wound to the chest wall, the lung may collapse. As the collapsed lung is no longer attached to the chest wall, air cannot be made to move into and out of the lung. However, a person with a collapsed lung can function fairly normally.
   (a) Explain how it would be possible for such a person to function in a fairly normal way.
   (b) Would there be any activities that such a person would not be able to perform?
3. **(a)** Why is the colour of blood in the arteries that take blood to the lungs different from that of blood in the other arteries?
   (b) Why is the colour of blood in the veins leaving the lungs different from that of blood in the other veins?
4. People living at sea level have about 5 million red blood cells in every mm^3 of blood. It has been found that people who live at an altitude of 5500 m have about 7.4 million red cells per mm^3 of blood. Suggest a reason for this difference.
5. Students measured the breathing rate and depth of breathing of a girl before and after exercise. Their results are shown in Table 7.2.

Table 7.2 Breathing rate and depth before and after exercise

	Volume of air per breath (cm^3)	Breaths per minute
At rest	460	19
After running	1075	38

   (a) Calculate the total volume of air that the girl breathed in one minute before and after exercise.
   (b) What is the reason for the increase in rate and depth of breathing after exercise?
   (c) Describe the changes that would occur in the body to bring breathing back to the normal resting level after exercise.
6. The ability to voluntarily control breathing is important when speaking, but it is also important when eating or drinking. Explain why this is so.
7. Explain how the respiratory system and the circulatory system interact with each other to supply the cells with oxygen and to remove the carbon dioxide produced by the cells.
8. Divers who dive to great depths usually breathe a special mixture of gases rather than normal air. Low concentrations of oxygen are used in the special gas mixture. Why would a low concentration of oxygen be necessary for deep dives?
9. The city of La Paz in Bolivia is at an altitude of 3600 m. If you went to live in La Paz, what changes would occur in your body?
10. Passenger aircraft cruise at an altitude of around 10 000 m. Why don't the passengers suffer from hypoxia?