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3.4 Cellular respiration (page 99)	<ul style="list-style-type: none"> <li>• Explain cellular respiration and describe the formation of ATP and its importance to the body.</li> <li>• Define and compare aerobic and anaerobic respiration, and explain their importance in cells.</li> </ul>

3.5 The circulatory system (page 104)

- Explain how oxygen and nutrients are transported in the blood.
- Indicate the structures of the heart on a diagram/model.
- Explain the functions of the structures of the heart.
- Examine a mammalian heart using fresh or preserved specimens.
- Take your own pulse, counting the heartbeats using your fingers.
- List the three types of blood vessels.
- Explain the functions of the blood vessels.
- Name the components of the blood.
- Tell the functions of the components of the blood.
- List the four blood groups.
- Indicate the compatibility of the four blood groups.
- Explain the causes and prevention of anaemia and hypertension.

### 3.1 Food and nutrition

By the end of this section you should be able to:

- List the major nutrients needed by the human body and their sources.
- List the main sources of some of the vitamins and minerals needed by the human body.
- Carry out laboratory tests to identify different nutrient groups in a food sample.
- Explain the concept of a balanced diet and what it involves.
- Define nutrition and malnutrition and describe the effects of malnutrition on the human body.
- Understand the concept of height/weight tables and how they can be used to help maintain a healthy body mass.
- Analyse a local diet and if necessary suggest ways in which it might be improved to become more balanced.

#### KEY WORD

**heterotrophs** organisms that feed on other organisms

People, like all living organisms, need a source of energy to survive. In our case this is our food. We are **heterotrophs** – we cannot make our own energy supply by photosynthesis so we have to eat other living things. Throughout human history almost anything that can be eaten has been eaten, and around the world the variety of food taken in by people is still quite amazing. However, it doesn't matter what the food is – from tibs to injera be wot, from kitfo to kocho – as long as it contains the right balance of chemicals to provide your body with everything it needs to live, grow and reproduce.



*Figure 3.1 Food comes in all shapes and sizes – but whatever it looks like, the chemicals it contains are surprisingly similar.*

**KEY WORDS**

**macronutrients** food you need in large amounts

**carbohydrates** major food group made up of carbon, hydrogen and oxygen

**proteins** molecules made up of amino acids that are needed for the body to function properly

**minerals** inorganic compounds required by the body for good health

**vitamins** organic substances required by the body in order for it to function properly

**sucrose** a complex carbohydrate found in many plants and used as a sweetening agent

**glucose** sugar made by plants during photosynthesis

**photosynthesis** the process a plant uses to combine sunlight, water, and carbon dioxide to produce oxygen and sugar (energy)

**starch** a nutrient carbohydrate required by the body for healthy functioning

**The human diet**

What is food? Food is the source of nutrients and energy for the body. It usually comes from animals or plants and is taken into the body where it is broken down to provide the nutrients needed by the body.

Each one of us has to take in all of the chemicals we need from the food that we eat. We use our food in three main ways:

- To provide energy for our cells to carry out all the functions of life.
- To provide the raw materials for the new biological material needed in our bodies to grow and also to repair and replace damaged and worn out cells.
- To provide the resources needed to fight disease and maintain a healthy body.

Some types of food are needed in large amounts – these are known as the **macronutrients**. There are six main classes of food needed by the body. The main macronutrients are **carbohydrates**, **proteins** and fats. Other substances are equally important in your diet, but only in tiny amounts. They are known as the micronutrients and they include **minerals** and **vitamins**. You also need water. In this section you are going to look at all of the most important components of a healthy human diet.

**Carbohydrates**

Carbohydrates provide us with energy. Much of the carbohydrate you take into your body is broken down to form glucose, which is used in cellular respiration to produce energy in a form that can be used in all your cells (see section 3.4). Your body stores very little carbohydrate apart from glycogen, which is found in your liver, muscles and brain. Any excess carbohydrate that you eat is converted to fat, which is stored all too easily in your body.

The most commonly known carbohydrates are the sugars and starches. You will already be familiar with a few types of sugar: the sugar that is such an important product of many African countries, including Ethiopia, is known as **sucrose**; **glucose** is the sugar made by plants in **photosynthesis** and it is vital in cells for energy. It is also the energy supplier in sports and health drinks.

Another more complex carbohydrate known as **starch** is a storage carbohydrate in plants and it is commonly found in teff and potatoes. Carbohydrate-rich foods include anything containing sugar or flour, such as injera, fatira and honey. Potatoes, rice and dabo are also carbohydrate-rich foods.

The basic structure of all carbohydrates is the same. They are made up of carbon, hydrogen and oxygen. They fall into three main types, depending on the complexity of the molecules: simple sugars, double sugars and complex sugars.

## The simple sugars

In these simple sugars there is one oxygen atom and two hydrogen atoms for each carbon atom present in the molecule. This can be written as a general formula:



The best-known simple sugar is glucose, which has the chemical formula  $\text{C}_6\text{H}_{12}\text{O}_6$ . There are lots of other simple sugars, including fructose, the sugar found in fruit.

## KEY WORD

**fructose** a sugar found in sweet fruits and honey  
**condensation reaction** when two simple sugars combine to form a double sugar, removing a molecule of water

## The double sugars

Double sugars are made up of two simple sugars joined together, and sucrose (the substance you know as sugar) is one of the most common. It is formed by a molecule of glucose joining with a molecule of fructose. When two simple sugars join together to form a double sugar, a molecule of water ( $\text{H}_2\text{O}$ ) is removed. This type of reaction where water is produced is known as a **condensation reaction** (see figure 3.3).

When different simple sugars join together, not surprisingly different double sugars result. Here are some of the more common ones:

Table 3.1 Sources of disaccharides

Disaccharide	Source
Sucrose	Stored in plants such as sugar beet and sugar cane
Lactose	Milk sugar – this is the main carbohydrate found in milk
Maltose	Malt sugar – found in germinating seed such as barley

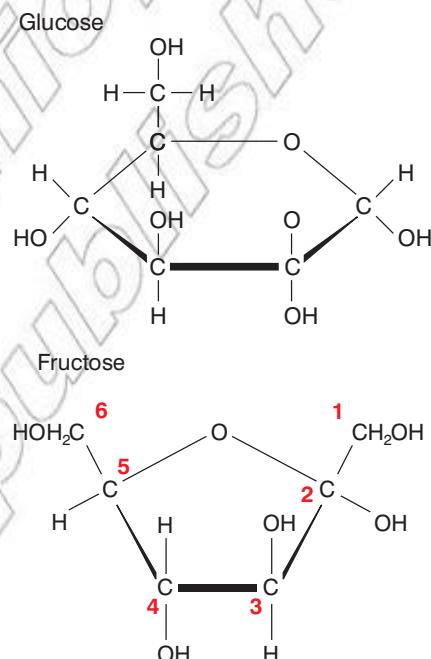
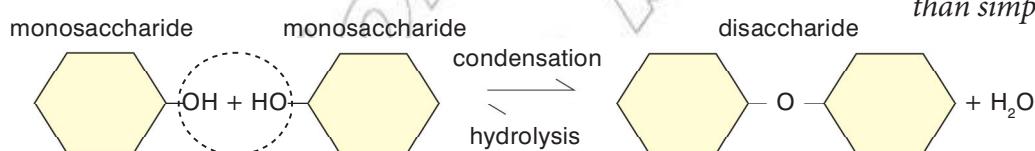


Figure 3.2 Glucose and the other simple sugars are fairly complicated molecules – they are often arranged in rings rather than simple chains.



Most simple and double sugars have two important properties in common. They dissolve in water and they taste sweet.

## The complex sugars

The most complex carbohydrates are formed when many single sugar units are joined to form a long chain. The sweet taste that is common to simple and double sugars is lost – and so is the ability to dissolve in water. But linking lots of sugar monomers (single units, in this case simple sugars) produces some complex polymers (long-chain molecules made up of lots of smaller repeating units). These

Figure 3.3 The formation of sucrose. The condensation reaction between the two simple sugars results in a double sugar and a molecule of water.

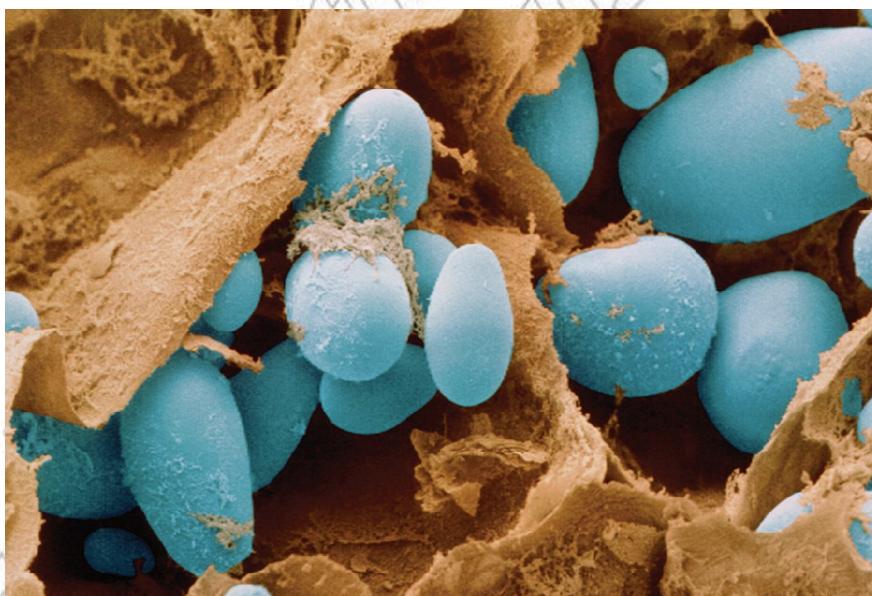
**KEY WORDS**

- complex sugars** when many single sugar units join to form a long chain
- glycogen** carbohydrate energy store found in animals
- cellulose** the main constituent in plant cell walls

polymers or **complex sugars** have some very important biological properties. They often form very compact molecules that are ideal for storing energy. The sugar units can then be released when they are needed to supply energy. And as complex sugars are physically and chemically very inactive, storing them does not interfere with the other functions of the cell.

Starch is one of the best-known complex sugars. It is particularly important as an energy store in plants. The sugars produced by photosynthesis are rapidly converted to starch. Particularly rich sources are plant storage organs such as potatoes.

**Glycogen** is sometimes referred to as ‘animal starch’. It is the only carbohydrate energy store found in animals. It is found mainly in muscle and liver tissue, which is very active and needs a readily available energy supply at all times.



**Figure 3.4** Starch grains found in potato cells are larger than those found in most plants.

**Cellulose** is an important structural material in plants. It is the main constituent in plant cell walls. Just like starch and glycogen it consists of long chains of glucose – but in this case the glucose molecules are held together in a slightly different way. This is very important, because human beings, and indeed most other animals, cannot break down these linkages and so they cannot digest cellulose.

So carbohydrates, from the simple sounding combination of carbon, hydrogen and oxygen, form a very varied group of molecules whose functions are vital to most living processes.

There are a number of chemical tests that you can carry out to test for the presence of carbohydrates of different types. Here you are given several tests which you can try first on known samples of carbohydrates. Later you can use these same tests to discover the chemical make-up of different foods that you eat.

### Activity 3.1: Starch test

You will need:

- a 1% starch solution made by boiling a mixture of starch powder and cold water
- two clean test tubes
- iodine solution

#### Method

1. Pour about  $1\text{ cm}^3$  of starch solution into a clean test tube and the same volume of water into the other test tube.
2. Add two drops of iodine solution to each tube.
3. Record your observations and conclusion in tabular form.



The colour of iodine solution is brown. Starch reacts with iodine to form a characteristic blue-black. In this test it is important to note that there is no heating involved. Only a few drops of iodine solution are necessary.

*Figure 3.5 The reaction of iodine with starch solution*

### Activity 3.2: Benedict's test for simple (reducing) sugars

Some sugars react readily with Benedict's solution. They reduce copper(II) ions to copper(I) ions and for this reason they are known as **reducing sugars**. So there is a straightforward chemical test for the reducing sugars. The reducing sugars include all of the single sugars and some double sugars.

You will need:

- a Bunsen burner
- tripod, gauze and heat-proof mat
- a large beaker half filled with water
- some glucose powder or food to be tested
- boiling tubes
- Benedict's solution
- different food samples to analyse (e.g. bread, fruit)

#### Method

1. Bring the water in the beaker to the boil, using the Bunsen burner.
2. In one boiling tube add water to a depth of about 2 cm – this will act as your control.
3. In another tube add a sample of glucose powder and water to a depth of about 2 cm.
4. Place any food samples to be tested in other boiling tubes in the same way.
5. Add a few drops of Benedict's solution to each boiling tube. Add enough to colour the mixture blue.
6. Place the tubes in the boiling water and leave for several minutes. TAKE CARE with the boiling water.
7. If a reducing sugar is present the clear blue solution will change as an orangey-red precipitate appears.
8. Write up your method and results, including the different foods you have analysed.



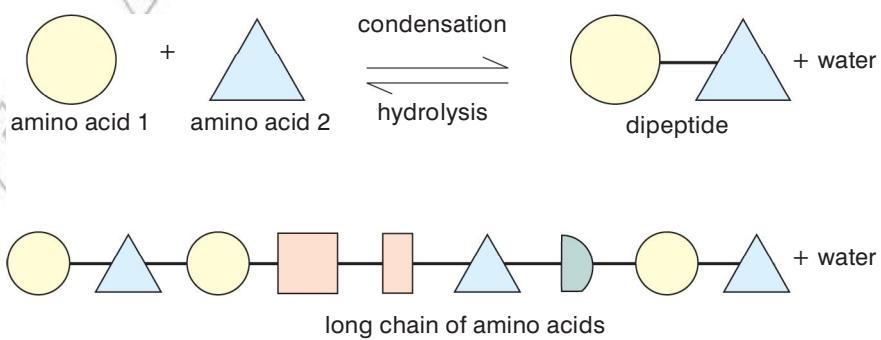
*Figure 3.6 Results of the Benedict's test for simple sugars before and after heating*

## Proteins

Proteins are used for body-building. They are broken down in digestion into amino acids that are then rebuilt to form the proteins you need. Protein-rich food includes all meat and fish, dairy products such as cheese and milk as well as pulses, such as white pea beans, chick peas and red kidney beans.

About 17–18% of your body is made up of protein – a high percentage second only to water. Your hair, skin, nails, the enzymes that control all the reactions in your cells and digest your food, many of the hormones that control your organs and their functions, your muscles and much, much more depends on these complex molecules. By understanding the way in which protein molecules are made up and the things that affect their shape and functions, you can begin to develop an insight into the biology not only of your cells but also all living things.

Just like carbohydrates and fats, proteins are made up of the elements carbon, hydrogen and oxygen, but in addition they all contain **nitrogen**. Some proteins also contain sulphur and various other elements. Proteins are polymers, made up of many small units joined together. These small units are called **amino acids**. In the same way that monosaccharide units join together to form polysaccharides, so amino acids combine in long chains to produce proteins. There are about 20 different naturally occurring amino acids and they can be joined together in any combination. Amino acids are joined together in a condensation reaction and a molecule of water is lost. The bond formed is known as a **peptide link**. The long chains of amino acids then coil, twist, spiral and fold in on themselves to make the complex structures we know as proteins. The structure of the proteins is held together by cross-links between the different parts of the molecule, and they can end up with very complex 3-D structures, which are often very important to the way they work in your body (see page 70 on enzymes).



**Figure 3.7** Amino acids are the building blocks of proteins and they can be joined in a seemingly endless variety of ways to produce an almost infinite variety of proteins.

Amino acids dissolve in water, but the properties of the proteins that are produced vary greatly. Some proteins are insoluble in water and are very tough, which makes them ideally suited to structural functions within living things. These proteins are found

### KEY WORDS

- nitrogen** a colourless, tasteless, odourless, gaseous chemical element
- amino acid** building block of protein
- peptide link** when amino acids are joined together in a condensation reaction and a molecule of water is lost

in connective tissue, in tendons and the matrix of bones (collagen), in the structure of muscles, in the silk of spiders' webs and silkworm cocoons and as the keratin that makes up hair, nails, horns and feathers.

Others are soluble in water. These form antibodies, enzymes and some hormones, and are also important for maintaining the structure of the cytoplasm in your cells.

The complicated way in which the structures of proteins are built up means that they can be relatively easily damaged and denatured. The relatively weak forces that hold the different parts of the amino acid chains together can be disrupted very easily. As the functions of most proteins rely very heavily on their structure, this means that the entire biochemistry of cells and whole organisms is very sensitive to changes that might disrupt their proteins. A rise in temperature of a few degrees or a change in pH is enough to destroy the 3-D structure of cellular proteins – and so destroy life itself. This is why your body has so many complex systems that keep the internal conditions as stable as possible and why very high fevers are so dangerous and can lead to death.

### DID YOU KNOW?

There are some amino acids that you must eat as part of your diet because your body cannot make them. They are known as essential amino acids and if they are lacking in your diet for too long you will die.

### KEY WORD

**pH** measure of the acidity or alkalinity of a solution

### Activity 3.3: Biuret test for proteins

When we test for proteins sometimes we add two separate chemicals (5% potassium or sodium hydroxide solution and 1% copper sulphate solution) to our test food.

You will need:

- test tubes
- 5% potassium or sodium hydroxide solution and 1% copper sulphate solution OR
- Biuret reagent
- different food samples

#### Method

1. In one test tube add water to a depth of about 2 cm – this will act as your control.
2. In another tube add a sample of protein powder, e.g. albumin, and water to a depth of about 2 cm. Shake to mix.
3. Place any other food samples to be tested in other test tubes in the same way.
4. Add an equal volume of dilute potassium or sodium hydroxide solution in all the test tubes and mix.
5. Add a few drops of dilute copper sulphate solution. (If you are using Biuret reagent steps 4 and 5 are combined in one.)
6. A purple (mauve) colour will develop if protein is present.
7. Write up your method and the results for the different foods you have tested.



Figure 3.8 Results of the Biuret test for proteins



**Figure 3.9** Children suffering from kwashiorkor can have big distended bellies, but the plumpness is swelling due to lack of protein, not health.

#### KEY WORDS

**lipids** general name for fats and oils

**cholesterol** compound produced by the body; raised blood levels indicate a high risk of heart disease

**oils** viscous liquid at room temperature

**glycerol** a syrupy, sweet liquid obtained from fats and oils

**saturated** fat with no double bonds in the structure

**unsaturated** fat with one or more double bonds in its structure

**single covalent bond** created when two atoms share a single electron

**double bonds** created when atoms share two electrons

Lack of protein in the diet may well be linked to an overall lack of energy intake, and results in a number of diseases known as protein-energy malnutrition. The best known of these are marasmus and kwashiorkor. In marasmus, both protein and overall energy intake is far below what is needed by the body. An increase of both protein and calories can save a child or adult. But if the body has not got enough protein to make the enzymes it needs it can cause death.

In contrast, kwashiorkor is thought to be caused by a lack of protein in the diet even if the overall energy intake is reasonable. It is particularly common around the time a child is weaned, when a diet high in starchy foods and very low in protein is often substituted for mother's milk. It is important to introduce protein in limited amounts as the liver is damaged and can't deal with any excess.

#### Fats and oils

Another group of organic chemicals that make up your body cells are the fats and oils, also known as the **lipids**. Lipids include some of the highest profile chemicals in public health issues at the moment – **cholesterol** and fat. Lipid-rich foods include anything containing large amounts of fats and oils. So, butter, beef fat, sesame oil, niger seed oil (nug) and olive oil are all lipids. Plant seeds like groundnuts and coconuts are also lipid-rich, providing an energy-rich store for the embryo plant. Meat, oily fish and eggs are high in lipids too. Any food that is cooked in fat or oil is also rich in lipids and the energy that they supply.

Fats and oils are an extremely important group of chemicals with major roles to play in your body. They are an important source of energy in your diet and they are the most effective energy store in your body – they contain more energy per gram than carbohydrates or proteins. This is why your body converts spare food into fat for use at a later date. Combined with other molecules, lipids also play vital roles as hormones, in your cell membranes and in the nervous system.

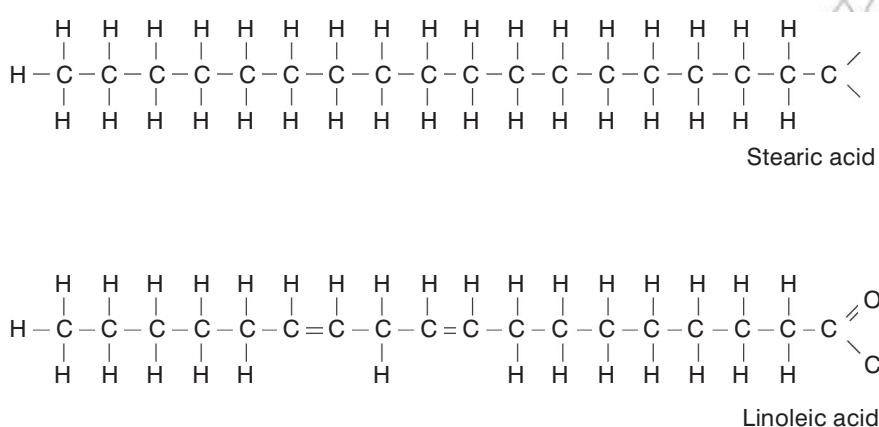
All lipids are insoluble in water, but dissolve in organic solvents. This is important because when they are present in your cells they do not interfere with the many reactions that go on in the cytoplasm, because the reacting chemicals are all dissolved in water.

The best-known lipids are the fats and **oils**. They are chemically extremely similar, but fats, e.g. butter, are solids at room temperature and oils, e.g. niger seed oil (nug), are liquids at room temperature. The lipids found in animals are much more likely to be solid at room temperature than plant lipids.

Just like the carbohydrates, the chemical elements that go into all lipids are carbon, hydrogen and oxygen. There is, however, a considerably lower proportion of oxygen in lipid molecules. Fats and oils are made up of combinations of two types of organic chemicals, fatty acids and **glycerol**.

Glycerol is always the same, with the chemical formula C<sub>3</sub>H<sub>8</sub>O<sub>3</sub>. On the other hand, there is a wide range of fatty acids. Over seventy different ones have been extracted from living tissues and the nature of the lipid depends a lot on which fatty acids are in it. All fatty acids have a long hydrocarbon chain – a pleated backbone of carbon atoms with hydrogen atoms attached. There are two main ways in which fatty acids vary; the length of the carbon chain can differ, and the fatty acid may be **saturated** or **unsaturated**.

In a saturated fatty acid each carbon atom is joined to the one next to it by a **single covalent bond**. In an unsaturated fatty acid the carbon chains have one or more **double bonds** in them. Unsaturated fatty acids are more common in plant lipids. An example of each type of fatty acid is shown in figure 3.10.

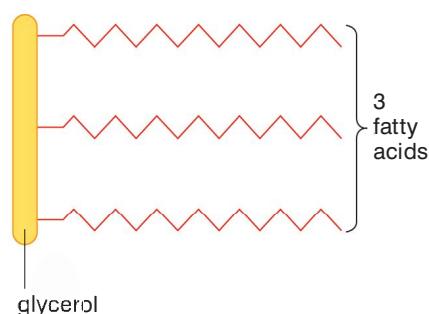


**Figure 3.10** One of these fatty acids is saturated and one is unsaturated – which one is which?

When a molecule of glycerol combines with three fatty acids, a lipid is formed. The molecules combine in a condensation reaction and a molecule of water is produced for each fatty acid that reacts with the glycerol.

Recent medical research seems to indicate that high levels of fat, and particularly saturated fat, in our diet are not good for our long-term health. Fatty foods are very high in energy, and so a diet high in fats when food is in plentiful supply is likely to result in obesity. Worse than this, however, is the implication that saturated fats – found particularly in animal products such as dairy produce and meat – can cause problems in your metabolism. They seem to cause raised levels of a lipid called cholesterol in your blood.

Cholesterol is a substance which you make in your liver. It gets carried around your body in your blood. You need it to make the membranes of your body cells, your sex hormones and the hormones which help your body deal with stress. Without cholesterol, you wouldn't survive. However, high levels of cholesterol in your blood seem to increase your risk of getting heart disease or diseased blood vessels. The cholesterol builds up in your blood vessels, forming fatty deposits which can even block the vessels completely. Heart disease is one of the main causes of death in countries such as the UK and USA where people often eat far too much fatty food.



**Figure 3.11** It is the combination of fatty acids in a triglyceride that decides what it will be like. Saturated fatty acids give solid fats like butter, whereas unsaturated fatty acids produce a liquid like corn oil.

### Activity 3.4: Test for lipids

#### a) Filter paper test

The filter paper test is also known as the **grease spot** or **translucent mark** test.

You will need:

- cooking oil or cooking fat
- a clean filter paper or sheet of paper
- a dropper

#### Method

1. Put a drop of cooking fat (or smear a little cooking fat) on a clean white sheet of paper.
2. Leave the paper for a few minutes.
3. Examine the spot where the cooking oil was dropped while holding the paper against light (not a flame!). Use light coming in through the window or from the electric bulb or tube.

A permanent translucent mark is formed by lipids on paper. A translucent mark is one that does not allow all the light to pass through. If you squeeze a food sample between two bits of filter paper any water that has been squeezed out will evaporate from the paper. Any lipids will leave a translucent mark that does not dry out and disappear. However, this test, although effective, is not very scientific because it does not depend on a chemical reaction.

#### b) Emulsion test

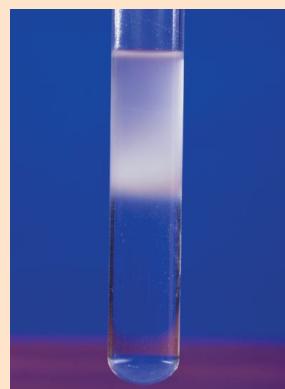
You will need:

- clean, dry test tubes – they MUST be dry
- ethanol
- cooking oil or cooking fat

#### Method

1. Place a sample of ethanol in a dry test tube to a depth of about 2 cm.
2. Place a small sample of oil/cooking fat or a food sample in a dry test tube and add a similar amount of ethanol.
3. Shake the tube to dissolve any lipid in the ethanol.
4. Take two more test tubes and about half fill each with water.
5. Carefully pour the contents of the tube containing the oil, fat or food sample into one of the tubes containing water.
6. Pour about  $2\text{ cm}^3$  pure ethanol into the other tube containing water and compare the two.
7. If lipid is present, a white, cloudy layer forms on top of the layer of water.
8. Use this test to investigate a number of common foods and find out if they contain lipids.
9. Write up your method and the results of any foods you have tested.

*Figure 3.12 Results of the ethanol test for fats*



## Minerals

It isn't just carbohydrates, proteins and fats that are important in your food. Mineral salts are needed in minute amounts, but lack of them in your diet can lead to a variety of unpleasant conditions. For example, you need **calcium (Ca)** in your diet to make your bones and teeth hard and strong. Without it, children develop rickets where the bones stay soft and cannot support the weight of the body so the legs become bowed. Milk and other dairy products such as ergoo and ayeeb are a very good source of this calcium. However, calcium alone is not enough to protect you from rickets. You also need vitamin D (see Vitamins).

**Iron (Fe)** is vital to make the **haemoglobin** found in your red blood cells that carry oxygen around your body (see section 3.5). If your diet lacks iron you will suffer from anaemia. Iron is found in food such as red meat, liver, red teff and eggs. Without iron you don't have enough haemoglobin in your red blood cells – in fact you can lack red blood cells – and so you don't get enough oxygen in the tissues of your body. This makes you look pale (lack of red blood cells) and feel tired and lethargic (lack of oxygen).

Your mineral needs change throughout your life – growing children need plenty of calcium for their bones to grow, whereas girls and women who have menstrual periods need more iron than others to replace the blood lost each month in their periods.

The **sodium** ions found in your food and in the salt we often add to food are needed to survive. Without it, your nervous system would

## KEY WORDS

**calcium (Ca)** *important constituent of bones and teeth, needed for many metabolic processes*

**iron (Fe)** *vital for making haemoglobin in red blood cells*

**haemoglobin** *red pigment in the blood cells that carries oxygen around the body*

**sodium** *vital element needed by the body for survival, by maintaining fluid levels*

**deficiency disease** *any disease caused by a lack of an essential nutrient*

**Table 3.2** Several of the main minerals needed in the diet and the deficiency diseases associated with them

Mineral	Approximate mass in an adult body (g)	Location or role in body	Examples of foods rich in mineral	Effects of deficiency
Calcium	1000	Making bones and teeth	Dairy products, fish, bread, vegetables	Rickets
Phosphorus	650	Making teeth and bones; part of many chemicals, e.g. DNA	Most foods	Improper formation of teeth and bones; failure of metabolism
Sodium	100	In body fluids, e.g. blood	Common salt, most foods	Muscular cramps
Chlorine	100	In body fluids, e.g. blood	Common salt, most foods	Muscular cramps
Magnesium	30	Making bones; found inside cells	Green vegetables	Skeletal problems; cell chemistry affected, defects in metabolism
Iron	3	Part of haemoglobin in red blood cells; helps carry oxygen	Red meat, liver, eggs, green leafy vegetables, e.g. spinach	Anaemia

**KEY WORDS**

**night blindness** *inability to see clearly in dim light due to vitamin A deficiency*  
**beri-beri** *deficiency disease from lack of vitamin B*

**DID YOU KNOW?**

If you ate a polar bear's liver you would die of vitamin A poisoning. Mammals store vitamin A in their livers. The liver of a polar bear is so rich in the vitamin that eating only 500 g (half a pound) would give you a lethal dose of vitamin A.



**Figure 3.13** The liver of a polar bear could kill you!

not work and the chemistry of all your cells would be in chaos. But for about a third of the population, too much salt in your diet can lead to high blood pressure. This can damage your heart and kidneys and increase your risk of a stroke. In some countries people can eat too much salt each day without knowing it. That's because many processed, ready-made foods contain large amounts of salt. But you can control your salt intake by doing your own cooking – or by reading the labels very carefully when you buy ready-made food. In fact there is enough salt in the cells of the animals and plants we eat to supply our needs without adding any extra for flavour. Table 3.2 shows you several of the main minerals needed in the diet and the deficiency diseases associated with them.

**Vitamins**

Just like minerals, vitamins are needed in very small amounts. They are usually complex organic substances that are nevertheless capable of being absorbed directly into your bloodstream from the gut. If any particular vitamin is lacking from your diet in the long term it will result in a deficiency disease. Different foods are rich in different vitamins and it is important to take in a range of all the important vitamin-rich foods in your diet. For example, vitamin A is needed to make the light-sensitive chemicals in the retina of your eye (you will learn more about the eye in Grade 10). If your diet lacks vitamin A – found in fish liver oils, butter and carrots – your eyesight is affected and you find it almost impossible to see in low light levels. This is known as **night blindness**.

Vitamin B<sub>1</sub>, found in yeast extract and cereals, is needed for the reactions of cellular respiration to take place. If you don't eat enough of it you get a condition called **beri-beri**, when your muscles waste away and you become paralysed. It can be fatal.

Lack of vitamin C causes **scurvy**, which used to kill many thousands of sailors as they travelled the world in sailing ships. Vitamin C is needed for the formation of the connective tissue which holds your body together! You find vitamin C in fruits, particularly citrus fruits and green vegetables, and once people started to take limes and lemons on sea voyages, scurvy became a thing of the past.

**Table 3.3** Several of the main vitamins needed in the diet and the deficiency diseases associated with them

Vitamin	Recommended daily amount in diet	Use in the body	Some good sources of the vitamin	Effect of deficiency
A	0.8 mg	Making a chemical in the retina; also protects the surface of the eye	Fish liver oils, liver, butter, margarine, carrots	Night blindness; damaged cornea of eye
B1	1.4 mg	Helps with cell respiration	Yeast extract, cereals	Beri-beri
C	60 mg	Sticks together cells lining surfaces such as the mouth	Fresh fruits and vegetables	Scurvy
D	5 g	Helps bones absorb calcium and phosphorus	Fish liver oils; also made in skin in sunlight	Rickets; poor teeth

Vitamin D is needed for your bones to take up the calcium they need to grow strong. Vitamin D is found in fish liver oils and it is also made in your skin in the sunlight. If children don't have enough vitamin D in their diet, or don't get enough sunlight, they will get rickets even if they have plenty of calcium.

Table 3.3 summarises four of the most common vitamins, the best food sources for them and the problems that can arise if they are deficient in your diet. These deficiency diseases can be avoided or remedied using vitamin supplements if it isn't possible to get them all from the food you eat. The vitamins were given letters to distinguish them in the days before scientists had discovered exactly what each vitamin was. Although we now know all their chemical names, they are still usually referred to as vitamin A (**retinol**), vitamin D (**calciferol**), etc. Some vitamins are soluble in water and these include vitamin B1 (**thiamine**) and vitamin C. Others are fat soluble, including vitamins A and D.

### KEY WORDS

**scurvy** a disease caused by lack of vitamin C in the diet  
**retinol** vitamin A  
**calciferol** vitamin D  
**thiamine** vitamin B1

#### Activity 3.5: Testing for vitamin C

You will need:

- freshly squeezed orange or lemon juice
- DCPIP (dichlorophenol indophenol) reagent
- three clean test tubes
- test tube rack
- pipette or dropper
- water

#### Method

1. Pour about 3 cm<sup>3</sup> of DCPIP into a clean test tube.
2. Using a dropper, add orange or lemon juice drop by drop to DCPIP in the test tube.
3. What happens to the colour of DCPIP?
4. Record your observations in a table.

#### Discussion

Vitamin C is present in citrus fruits like oranges and lemons. Other fruits like tomatoes and apples also contain vitamin C. A gradual fading of the blue colour of DCPIP in the above experiment shows that vitamin C is present in orange juice. This is because vitamin C has a reducing action on the DCPIP reagent which makes it lose its colour.

#### Investigation

Design and carry out a suitable experiment to find out which fruits contain the greatest concentration of vitamin C.

#### Activity 3.5a: Copy and complete

Table 3.3 provides details of four important vitamins. There are, however, a number of other vitamins that our bodies need. Copy the following table into your exercise book and complete it with as many more vitamins as you can find: conduct your research using reference books, the Internet, your teacher, and any other sources you can think of.

Vitamin	Recommended daily amount in diet	Use in the body	Some good sources of the vitamin	Effect of deficiency

**KEY WORDS**

**urea** *the main component of urine*

**hydrolysis reaction**  
*chemical reaction of a compound with water*

**nutrition** *the obtaining of food in order to survive*

**The role of water**

Another vital constituent of a balanced diet is water. An average person can survive with little or no food for days if not weeks, but a complete lack of water will bring about death in 2–4 days, depending on other conditions such as temperature. Your body is actually between 60 and 70% water, depending on your age, how much you have drunk recently, etc. So it is not surprising that water is crucial in your body for a number of reasons, including:

- All of the chemical reactions which take place in your body take place in solution in water – it is a vital solvent.
- Water is involved in the transport of substances around the body – food, hormones, waste products such as **urea** and many other substances are all carried around your body in solution in water as part of your blood.
- Water is involved in temperature regulation as you lose heat from your body through sweating (you will learn more about this in Grade 10).
- Water is involved in the removal of waste materials from your body in the urine and in your sweat (see section 3.2).
- Water is a reactant in many important reactions in the body – for example, as you will discover later in this section, many food molecules are broken down in **hydrolysis reactions** where water is added.
- Water is needed for the osmotic stability of the body (see page 39, on osmosis in animals). The concentration of the chemicals in your cells and in the body fluids surrounding them must be kept constant. If there is not enough water in the blood and tissue fluid, the body cells lose water by osmosis and can no longer function, causing death.

**Fibre in the diet**

A final important part of a healthy diet is something that you can't even digest or absorb. Roughage or fibre cannot be broken down in the human gut, yet it is an essential part of your diet because it provides bulk for the intestinal muscles to work on. It also absorbs lots of water. In a diet low in roughage the movements of the gut which transport the food through it (peristalsis) are sluggish and the food moves through the gut relatively slowly. This can result in constipation.

**Why is a balanced diet important?**

**Nutrition** is obtaining food in order to carry out life processes. Nutrition in plants involves manufacturing their own food in the process of photosynthesis (you will learn more about this in Grade 10). In animals, including ourselves, nutrition involves taking in food based on other living organisms.

Wherever you live and whatever the basis of your diet, it is not enough simply to get food. The right balance of food is of enormous importance to your overall health and well-being. A **balanced diet** includes enough of all the major food groups (carbohydrates, proteins, lipids, minerals, vitamins and water) to supply the energy and nutrients needed to maintain the cells, tissues and organs of your body in a healthy state. A balanced diet supports healthy growth and development of your body when it is needed. If too little food is eaten (**undernutrition**) or too much food is taken in (**overnutrition**), or any one element of the diet is lacking then you will suffer from **malnutrition**. Malnutrition affects the health of millions of people all over the world.

One of the most important factors in a balanced diet is that enough food is eaten to supply your energy needs. But how much energy is that? The amount of energy you need to live depends on lots of different things. Some of these things you can change and some you can't. If you are male, you will need to take in more energy than a female of the same age – unless she is pregnant. During pregnancy the energy needs of a woman increase steadily as she has to provide the raw materials for a developing baby and supply the energy it needs to live. If you are a teenager, you will need more energy than if you are in your 70s.

The amount of exercise you do affects the amount of energy you use up. If you do very little exercise, then you don't need so much food. The more you exercise the more food you need to take in to supply energy to your muscles as they work.

**Table 3.4 Daily energy needs**

Age/sex/occupation of person	Energy needed per day (kj)
Newborn baby	2000
Child aged 2	5000
Child aged 6	7500
Girl aged 12–14	9000
Boy aged 12–14	11 000
Girl aged 15–17	9000
Boy aged 15–17	12 000
Female office worker	9500
Male office worker	10 500
Heavy manual worker	15 000
Pregnant woman	10 000
Breastfeeding woman	11 300
Woman aged 75+	7610
Man aged 75+	8770

## KEY WORDS

**balanced diet** taking food from all major food groups in order to maintain a healthy body

**undernutrition** too little food is eaten

**overnutrition** too much food is eaten

**malnutrition** diet is lacking in important elements needed for a healthy body

**Figure 3.14** A balanced diet contains a wide variety of foods that give you everything you need.



**Figure 3.15** Athletes who spend a lot of time training and taking part in sport will have a great deal of muscle tissue on their bodies – up to 40% of their body mass. So they have to eat a lot of food to supply the energy they need.

### DID YOU KNOW?

Between 60 and 75% of your daily energy needs are used up in the basic reactions needed to keep you alive. 10% is needed to digest your food – and only the final 15–30% is affected by your physical activity!

### DID YOU KNOW?

Most of us look about the right size but there will always be extremes. Some people are very overweight and others appear unnaturally thin. Scientists and doctors don't just measure what you weigh. They look at your **body/mass index** or **BMI**. This compares your weight to your height in a simple formula:

$$\text{BMI} = \frac{\text{weight}}{(\text{height})^2}$$

Most people have a BMI in the range 20–30. But, if you have a BMI of below 18.5, or above 35, then you may have some real health problems.

People who exercise regularly are usually much fitter than people who take little exercise. They make bigger muscles – and muscle tissue burns up much more energy than fat. But exercise doesn't always mean time spent training or 'working out' in the gym. Walking to school, running around the house and garden, looking after small children or having a physically active job all count as exercise too.

Malnutrition due to too little food is a major problem in many parts of the world. Yet it is also important that too much food is not consumed. As you have seen the energy requirements of each individual vary depending on their age, sex and levels of activity. If you take in more energy than you need, the excess is stored as fat and obesity may result. In the developed world, overeating and the health issues linked to it are becoming more and more of a problem. Up to a third of the population of America is thought to be seriously overweight, mainly due to eating a diet rich in high-energy fat.

You need some body fat to cushion your internal organs and to act as an energy store for when you don't feel like eating. But when this is taken to extremes, and you consistently eat more food than you need, you may end up **obese**, with a BMI of over 30.

Our Ethiopian diet contains a wide range of foods, and by eating a good combination we can easily achieve a balanced diet. For example, a daily menu such as:

Breakfast: bread and groundnuts or chick peas with tea or milk

Lunch: kei wot with injera and orange or banana

Dinner: shiro wot with injera and fresh green pepper

These meals would give you a good balanced diet. If food is short in times of drought or other difficulty, then the diet becomes unbalanced and lacking in calories and various nutrients. On the other hand, if we are tempted by too much processed or fried food then we can become obese and put ourselves at risk. Use activity 3.6 to help you think about balanced diet and good nutrition.

### Activity 3.6: A diet diary

In this activity you should record everything you eat and drink every day for a week. Decide how you want to display your record – a table is a useful tool – and note down everything you eat at meal times. Also note down anything you eat between meals.

Analyse your food each day and decide if you have eaten something from all of the main food groups. At the end of the week, think carefully about your diet. Is it balanced? If not, how could you improve it? If it is balanced, could you make it better still?

## Summary

In this section you have learnt that:

- A balanced diet contains carbohydrates, proteins, lipids, minerals, vitamins and water in the right proportions to keep your body functioning effectively. Fibre is also important.
- Carbohydrates are the main energy supply for the body. Carbohydrates are found as simple sugars, double sugars and complex sugars.
- Iodine is used to test for the presence of starch and Benedict's solution for the presence of simple reducing sugars.
- Proteins are used as the building blocks of the body. They are made up of small units called amino acids.
- The Biuret test using 5% sodium hydroxide solution and 1% copper sulphate solution is used to show the presence of protein in the food.
- Lipids are fats and oils. They provide energy for the body. They are made up of fatty acids and glycerol.
- The translucent smear test and the ethanol test identifies lipids in foods.
- Iron is needed in the body for the production of haemoglobin to carry oxygen in the red blood cells. Lack of iron in your diet causes anaemia.
- Calcium is needed for healthy bones and teeth. Lack of calcium in your diet can cause rickets.
- Vitamins are needed in small amounts for your cells to work properly. Vitamins A, B<sub>1</sub>, C and D are all vital for health.
- Malnutrition is when your diet is unbalanced. This can result from too little food, when you are at risk of deficiency diseases, and also too much food, which can give rise to obesity.

## DID YOU KNOW?

The heaviest man ever recorded was Jon Brower Minnoch (USA, 1941–83). He was 185 cm (6'1") tall and was overweight all his life. At his heaviest he weighed 635 kg. The heaviest recorded woman was another American, Rosie Bradford, who weighed 544 kg in 1987.



**Figure 3.16** Manuel Uribe who holds the record for being the fattest man in the world at the moment. At his peak he weighed 559 kg.

## Review questions

Select the correct answer from A to D.

1. Which of the following is NOT part of a balanced diet?
  - A carbohydrates
  - B proteins
  - C cellulose
  - D lipids
2. Which of the following molecules are the building blocks of proteins?
  - A monosaccharides
  - B glycerol
  - C fatty acids
  - D amino acids

3. Which of the following groups are classed as macronutrients?
  - A proteins, minerals, vitamins
  - B carbohydrates, proteins, fats
  - C fats, fibre, folic acid
  - D carbohydrates, proteins, milk
4. Vitamin A is also known as:
  - A tocopherol
  - B retinol
  - C ascorbic acid
  - D calciferol
5. In what type of reaction do fatty acids and glycerol join together to form lipids?
  - A hydrolysis
  - B condensation
  - C reduction
  - D oxidation
6. A student carried out a Benedict's test on an unknown food sample and the blue liquid turned orange when it was heated. What food substance was present?
  - A protein
  - B starch
  - C simple sugar
  - D lipid
7. Which of the following will NOT cause obesity, even if you eat very large amounts of it in your diet?
  - A fat
  - B fibre
  - C carbohydrate
  - D protein

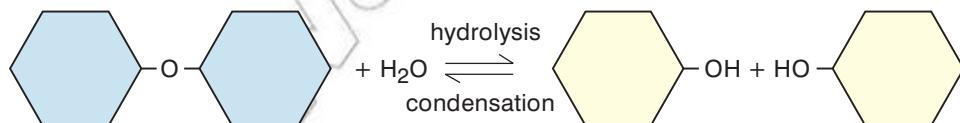
### 3.2 The digestive system

By the end of this section you should be able to:

- Label a diagram of the human digestive system.
- Describe the functions of the structures of the human digestive system.
- Define enzymes and describe their role in the process of digestion.
- Describe the structure of the teeth and explain their importance.
- Describe the processes of digestion in the mouth, stomach and small intestine.
- Demonstrate that starch digestion begins in the mouth using saliva and bread.
- Explain how the products of digestion are absorbed and assimilated by the body.
- Discuss constipation, care with canned, bottled and packed foods and food hygiene as issues of digestive health.

Carbohydrates provide the body with an energy source for respiration. Proteins are needed for building new cells and repairing old ones. Lipids are also an energy source and they provide a way of storing spare energy. However, in the form that they are usually eaten neither carbohydrates, proteins nor fats are useful to the body. The link between what comes in and what the body needs is the digestive system.

The human body needs small, soluble molecules to use in all the reactions of metabolism such as releasing energy and making new larger molecules. The food we eat usually arrives in the system as large chunks bitten off by the teeth, chunks that contain large insoluble molecules such as starch, proteins and fats. These large molecules cannot be absorbed into the bloodstream and used by your body so they need to be broken down into smaller, simpler, soluble molecules. This is the main job of the digestive system – food substances are broken down into small soluble molecules as they pass through the gut. As you have seen earlier in this chapter, the large molecules that make up the carbohydrates, proteins and fats are built up from small molecules that are joined together by condensation reactions, with a molecule of water being lost each time. When these large molecules are broken down during digestion it involves the opposite process – hydrolysis (splitting with water) reactions. As water molecules are added to the large food molecules, the monomer units, whether they are simple sugars, amino acids or fatty acids, are released.



**Figure 3.17** The large food molecules are broken down by hydrolysis reactions – the opposite of the condensation reactions by which they are built up in the first place.



**Figure 3.18** A piece of meat is broken down by hydrochloric acid in a few days – but we can't wait that long to get energy and useful chemicals from our food. In the human stomach a similar piece of meat is broken down in a few hours, thanks to the action of the enzyme pepsin.

### DID YOU KNOW?

Your gut is actually a hollow tube that runs from your mouth to your anus. Some things (such as a bead or a penny) can be taken in at the mouth and reappear completely unchanged at the other end. Do NOT try this – objects can get stuck and block the tube, making you very ill.

The working of your digestive system is based on two things:

- **The physical (or mechanical) breakdown of the food:** The food you eat is physically broken down into smaller pieces in two main ways. Your teeth bite and chew the food up in your mouth. Then your gut, which is a muscular tube, squeezes the food and physically breaks it up, while mixing it with various digestive juices to make it easier to move. By breaking the food up in this way, there is a much larger surface area for the digestive enzymes to work on.
- **The chemical breakdown of the food:** The large insoluble food molecules must be broken down by hydrolysis reactions into small, soluble molecules so they can be absorbed into your body. This chemical breakdown is controlled by enzymes. Enzymes are proteins that speed up (catalyse) other reactions. They do not actually take part in the reaction or change it in any way except to make it happen faster. Enzymes are biological catalysts that usually work best under very specific conditions of temperature and pH.

### More about enzymes

Enzymes play a vital role in digestion – but that is not all they do. For life to carry on successfully it is important that the hundreds of reactions that occur in your body, making new materials and breaking things down, take place in a rapid and controlled way. This control is brought about by biological catalysts known as enzymes. Enzymes are made of protein, and like any catalyst are not affected by the reaction they speed up, so they can be used many times.

Enzymes are very specific – each type of reaction that takes place in your body is controlled by a specific enzyme that does not catalyse any other type of reaction. Some enzymes work inside your cells (intracellular enzymes) and some of them are secreted into organs of your body such as the gut where they catalyse specific reactions (extracellular enzymes). The digestive enzymes are extracellular – they work outside your cells in the lumen of your gut.

Enzyme names usually (but not always) end in -ase, e.g. **amylase** breaks down starch, **lipase** breaks down fats, **catalase** breaks down hydrogen peroxide – but **pepsin** breaks down proteins!

### Activity 3.7: Investigating the activity of amylase

Amylase is an enzyme that is made in the salivary glands in your mouth and in your pancreas; it catalyses the breakdown of starch to the sugar maltose. You can use the reaction of starch with iodine solution to indicate how quickly the enzyme does its job – and use this to investigate the effect of temperature on the way the enzyme works.

You will need:

- amylase solution
- starch suspension
- iodine solution
- a stopwatch or clock with clear second hand
- two spotting tiles or white tiles
- beaker of water heated to 30 °C
- boiling tubes
- two 5 cm<sup>3</sup> syringes or pipettes
- thermometer
- marker pen

#### Method

1. Place drops of iodine solution in the depressions on both of the spotting tiles.
2. Place 5 cm<sup>3</sup> of starch suspension in each of two boiling tubes, one labelled starch and the other labelled starch/amylase.
3. Place 5 cm<sup>3</sup> of amylase solution in another boiling tube, labelled amylase.
4. Place the three tubes in the water bath at 30 °C. Leave for five minutes for the temperatures to equilibrate.
5. Measure out 5 cm<sup>3</sup> of amylase solution and add it to the labelled boiling tube of starch.
6. Start the stopwatch and immediately take a small sample of the starch/amylase mixture and add it to the first drop of iodine on the spotting tile.
7. Take regular samples of the mixture – every 30 seconds – for about ten minutes and record the colour of the iodine each time.
8. At the end of the ten minutes, test a sample of the simple starch suspension in one well of the spotting tile and compare it with the sample which has been mixed with amylase. This will confirm that any change is due to the enzyme rather than the temperature of the solutions.
9. This investigation can be repeated with the starch suspension and the starch/amylase mixture kept at a range of different temperatures and the results recorded in a table like the one shown below:

	Colour of iodine/starch/amylase mixture at different temperatures				
Time (min)	20 °C	30 °C	40 °C	50 °C	60 °C
0.5					
1.0					
1.5					
2.0 etc.					
10.0					

10. You can make a graph of your results, looking at the time taken to break down all the starch at different temperatures or looking at the rate at which the enzyme broke down 1 cm<sup>3</sup> of starch at each temperature.
11. Write up your investigation, explain your results and suggest ways in which your investigation could be made more reliable.

**KEY WORDS**

**ingestion** taking in food  
**mastication** chewing  
**enamel** the top surface of teeth

**The working of the gut**

The process by which the food you eat is taken into your body, broken down and used by your cells, with the indigestible material removed, is very complex and it involves the various areas of your digestive system or gut.

As we eat our food, it sets off on a journey of digestion. The first stage is **ingestion**, or taking foodstuff into your body through the mouth. We bite off a chunk of food using our teeth, and then physically chop the food up into smaller pieces by chewing it. Your teeth play a very important role at the beginning of the process of digestion, physically breaking down your food and providing a greater surface area for your digestive enzymes to work on. This process is known as **mastication**.

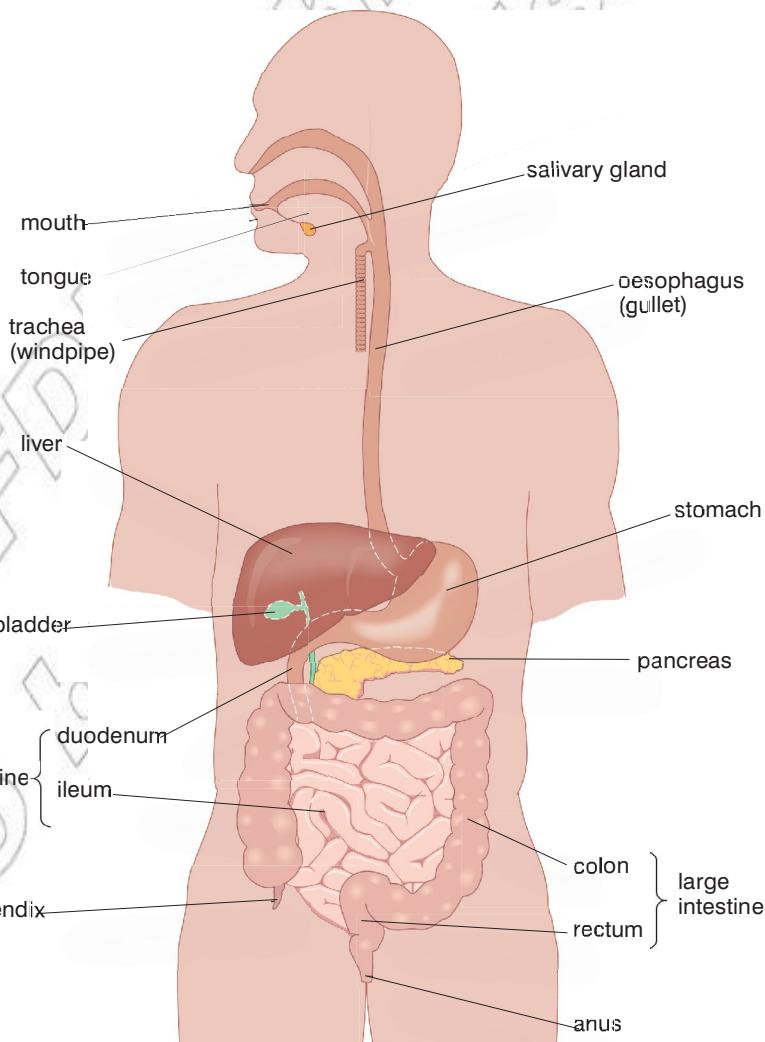


Figure 3.19 The human digestive system

Teeth have evolved to be very strong – in fact the **enamel** that covers them is the strongest substance made by the human body. Teeth are needed for a variety of different jobs – gripping food, tearing food and chewing food, for example. The shape of different teeth means they are ideally suited to their different functions.

Because humans have a very varied diet (we are omnivores so we eat animals and plants) we also have a variety of different types of teeth. The incisors and canines are used for biting while the premolars and molars are used for chewing and crushing food.

All of your teeth have a similar make-up. The top surface is covered by a layer of non-living enamel, and under this is the living **dentine**. This is not as hard as enamel, but it is still very hard, being similar to bone. In the centre of the tooth is the **pulp cavity**, which contains nerves and blood vessels. The dentine contains many fine channels filled with cytoplasm. These are supplied with oxygen and nutrients by the blood vessels in the pulp cavity. Your teeth are set into your jaw bone, and they are held in place by a layer of fibrous **cement**. This cement keeps your teeth firmly in place but at the same time allows a certain amount of flexibility as you are chewing.

Your adult teeth should last you all through your life. This doesn't always happen, because your teeth can be affected by the bacteria that cause dental caries. There are many different bacteria that are found naturally in your mouth. These bacteria, combined with food and saliva, form a thin film known as plaque on your teeth. If these bacteria are given a sugar-rich diet (in other words, if you eat a lot of sweet, sugary food) they produce a lot of acid waste. This acid attacks and dissolves the tough enamel coating of your teeth. Once through the enamel, the acid also dissolves away some of the dentine and then the bacteria can get into the inside of your tooth. The bacteria will then reproduce and feed, eating away at your tooth until they reach the nerves of the pulp cavity causing toothache. The bacteria and the acid they produce can eat away at your teeth to the extent that they break up completely if you don't get effective dental treatment.

What's more, the bacteria don't only attack your teeth. The same bacteria can affect your gums, causing **periodontal disease**. The symptoms include tender gums, bleeding when you clean your teeth and eventually the possible loss of all your teeth, not from tooth decay but from gum disease.

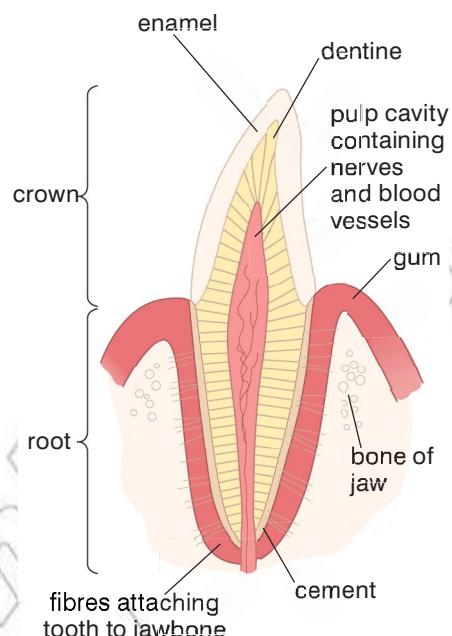
Taking in lots of acidic food and drink, such as fruits and cola, can also weaken the enamel on your teeth. This is particularly the case if you clean your teeth straight after an acidic drink such as fruit juice or cola, when the softening effect on the enamel is strongest and brushing your teeth can actually wear the enamel away.

Tooth and gum disease are extremely common all over the world. They cause pain, bad breath, loss of teeth and difficulty eating. The good news is that they can both be avoided, especially if you have good dental care available. Ways to avoid tooth decay include:

- Regular brushing of your teeth and gums twice a day. This removes the plaque from the teeth, preventing the build-up of a sticky, acidic film over the enamel.
- Avoiding sweet, sugary foods – if the bacteria in your teeth are deprived of sugar, they cannot make acidic waste and your teeth are safe.

If they are available:

- Have regular dental check-ups. A dentist can clean your teeth more thoroughly than you can, and any early signs of decay can be treated. Your teeth won't heal themselves, but any tooth decay can be removed and replaced by a filling.



**Figure 3.20** The structure of teeth makes them very well adapted to their various functions.

### KEY WORDS

**dentine** living layer underneath tooth enamel

**pulp cavity** centre of the tooth which contains nerves and blood vessels

**cement** fibrous layer that holds the teeth into the jaw bone

**periodontal disease** bacterial infection of the gums



**Figure 3.21** Tooth decay not only causes pain and bad breath – it doesn't look very nice either!

### DID YOU KNOW?

Around 40 million people in America have lost all their own teeth and have to wear dentures (false teeth)! They use tiny amounts of fluoride in their toothpaste and water to help them prevent tooth decay. Here in Ethiopia, some of our water-courses contain so much fluoride that it damages our teeth. We use defluorination plants to take fluoride out of our water to protect our teeth and keep them healthy!

### Moving the food on

The breaking down of your food into smaller pieces by the chewing of your teeth isn't the only part of digestion that takes place in your mouth. Your food is also coated in saliva from the salivary glands. Saliva contains a **carbohydrase** enzyme called amylase. Carbohydrases break down carbohydrates. The amylase in your saliva begins the digestion of the starch in complex carbohydrates such as bread or potatoes, turning it into simpler sugars. The saliva-coated chunk of food (known as a **bolus**) moves to the back of your throat to be swallowed. Swallowing is a **reflex** action that takes place when food reaches the back of your throat. As you swallow, your epiglottis closes over the trachea, preventing food going down into your lungs; you can't swallow and breathe in at the same time. If you try to, you will choke and your body will produce violent coughing and heaving movements to make sure the food doesn't get down into your lungs, where it can cause serious problems.

When your food is swallowed it travels down the **oesophagus** or gullet, squeezed along by muscular contractions known as **peristalsis**. As a result you can eat at any angle you like – even standing on your head – because food does not rely on gravity to arrive in your stomach. Peristalsis is not confined to your oesophagus – it is important all the way through your gut to move the food through as it is digested, to mix the food with the digestive enzymes produced in the various parts of the gut and to continue the physical break-up of the food. The walls of your gut have a layer of circular muscles forming rings around it and a layer of longitudinal muscles that run the length of the gut. Waves of alternate contraction and relaxation of the different muscles (see figure 3.23) move food through from one end of the gut to the other.

### KEY WORDS

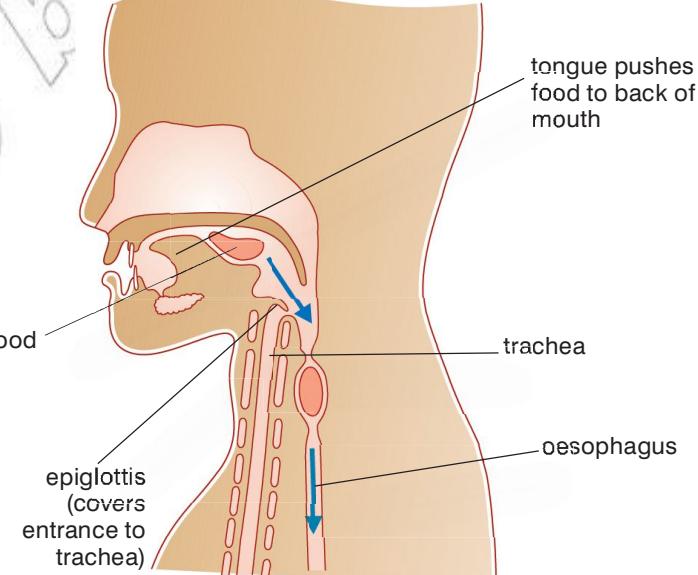
**carbohydrase** an enzyme in saliva

**bolus** a saliva-coated chunk of chewed food

**reflex** an automatic reaction in the body that cannot be controlled

**oesophagus** passage that food travels down from mouth to stomach

**peristalsis** wavelike muscle contractions to move food along



**Figure 3.22** The swallowing reflex means you don't get food down into your lungs – and you can't breathe in while you are swallowing food.

## Stomach churning activity

At the lower end of the oesophagus your food passes through a ring of muscle called a **sphincter** into your **stomach**. This sphincter is usually closed except when you are swallowing food, or being sick. The stomach is a muscular bag that produces protease enzymes to digest protein. The main protease made in the stomach is **pepsin**. The stomach also produces a relatively concentrated solution of **hydrochloric acid**. This acid kills most of the bacteria that are taken in with our food. The acid also helps indirectly in the breakdown of the protein in your food, because pepsin works best in acid conditions. Your stomach also makes a thick layer of mucus, which protects the muscle walls from being digested by the protease enzymes and attacked by the acid. The muscles of your stomach squeeze the contents into a thick creamy paste containing partly digested protein along with all the rest of your food.

After a time – usually between one and four hours – a paste of partly digested food is squeezed out of the stomach through another sphincter into the first part of the small intestine known as the duodenum. As soon as it arrives the food is mixed with two more liquids: bile and enzymes.

## Bile

**Bile** is a greenish-yellow alkaline liquid that is produced in the liver (a large reddish-brown organ that carries out lots of important jobs in the body). It is made by the liver cells and then stored in the **gall bladder** until it is needed. As food comes into the duodenum from the stomach, bile is squirted onto the stomach contents. The bile does two important jobs:

- It neutralises the acid from the stomach and makes the semi-digested food alkaline. This is ideal for the enzymes in the small intestine, which work most effectively in an alkaline environment.
- Bile also **emulsifies** the fats in your food – it breaks down large drops of fat into smaller droplets. This provides a much bigger surface area of fats for the **lipase** enzymes to work on to break down the fats completely into fatty acids and glycerol.

## Enzymes

The first part of the small intestine (the duodenum) cannot make its own enzymes, but this doesn't matter because they are supplied by the pancreas. Part of the pancreas makes the hormone insulin, which helps to control your blood sugar levels (you will learn more about this in Grade 10). The rest of the pancreas makes and stores enzymes that digest carbohydrates, proteins and fats. As food enters the small intestine from the stomach these enzymes are released to be mixed with the food paste by muscle action.

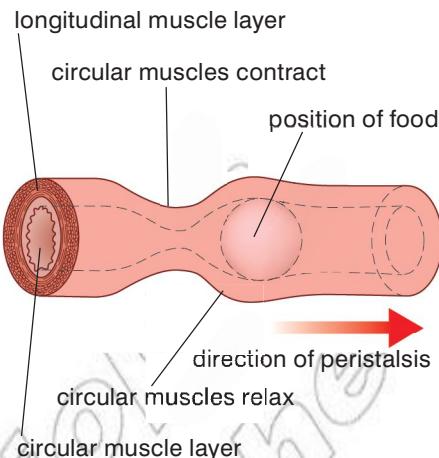


Figure 3.23 Muscular action in your gut pushes the food along.

## KEY WORDS

**sphincter** ring of muscle  
**stomach** muscular bag that produces protease enzymes to digest protein

**pepsin** enzyme that breaks down proteins

**hydrochloric acid** produced in the stomach to kill bacteria

**gall bladder** muscular sac connected to the liver that stores bile

**bile** produced by the liver to aid in breakdown of food in the duodenum

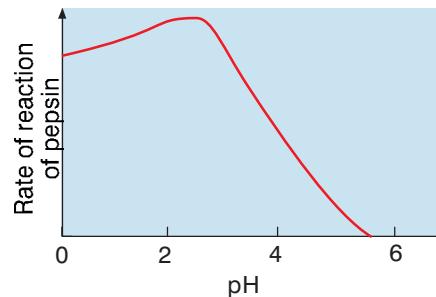


Figure 3.24 The protein-digesting enzymes of the stomach only work at their best in low pH, so the acid made by the stomach wall is very important.

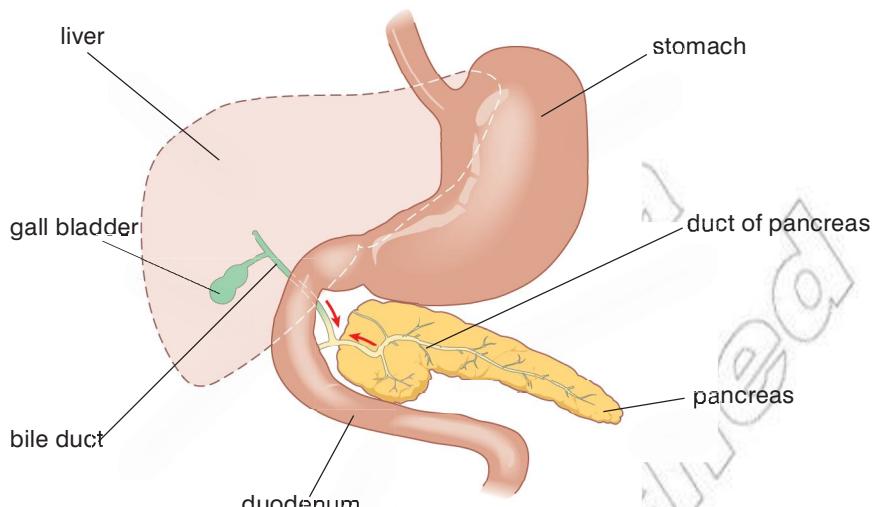
**KEY WORDS**

**emulsify** breaking of large drops of fat into small droplets

**lipase** enzyme that breaks down fats

**absorption** the process whereby the body absorbs food molecules

**villi** finger-like projections of the lining of the small intestine



**Figure 3.25** The liver and pancreas are important to the successful digestion of food in the small intestine in a number of ways.

The rest of the small intestine is a long (6–8 m) coiled tube that produces carbohydrase, protease and lipase enzymes of its own. The tube is coiled up to fit inside the body cavity. Your food, which is rapidly becoming completely digested in the alkaline environment, is moved along by peristalsis.

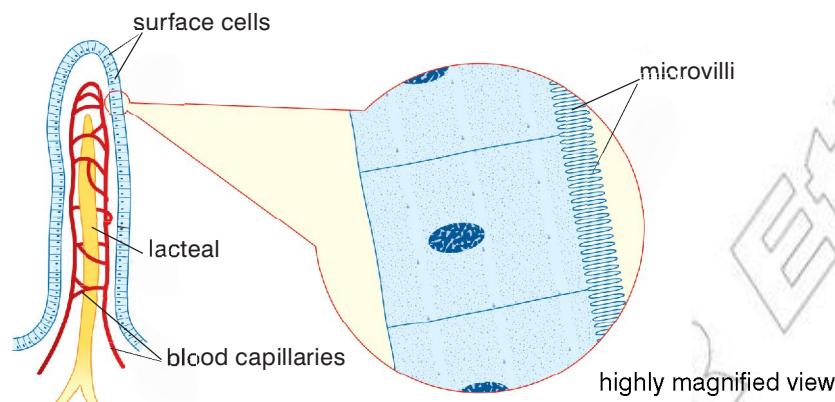
Throughout the small intestine enzymes speed up the breakdown of large molecules into smaller molecules. The main types of enzymes found in the human digestive system are summarised in the table below:

**Table 3.5 Enzymes of the human digestive system**

Type of enzyme	Where it is found in the gut	What does it act on?	What are the breakdown products?
Carbohydrase, e.g. amylase, maltase	Salivary glands, pancreas, small intestine	Starch, maltose	Glucose
Protease, e.g. pepsin, trypsin	Stomach, pancreas and small intestine	Protein	Amino acids
Lipase	Pancreas and small intestine	Lipids (fats and oils)	Fatty acids and glycerol

Once the food molecules have been digested, giving glucose, amino acids, fatty acids and glycerol, they are absorbed by your body (**absorption**). They leave the small intestine by diffusion and go into the blood supply to be carried around the body to the cells that need them. The lining of the small intestine is specially adapted to allow as much diffusion as possible and as rapidly as possible. It has many finger-like projections of the lining (called **villi**) to increase the surface area for diffusion, and each individual villus in turn is covered in even smaller projections called microvilli. The villi also have a rich blood supply that carries away the digested food molecules and maintains a steep diffusion gradient. The diffusion distances are very small, and the whole process takes place in a water-based solution. All of these factors make the absorption of

the digested food molecules from the small intestine into the blood supply very efficient. The glucose molecules and amino acids go directly into the blood. The fatty acids and glycerol move initially into the lacteals, which are part of the lymph system. The lymphatic fluid with its load of fatty acids and glycerol then eventually drains into the blood as well. Once the digested food molecules have all been taken into the blood they are taken in the **hepatic portal vein** to the liver, which processes some of the food (see section 3.5). The remaining products of digestion are carried around the body to the cells where they are needed. They are built up into the molecules required by the cells. This is known as **assimilation**.



## KEY WORDS

**hepatic portal vein** blood vessel that takes digested food molecules to the liver

**assimilation** taking in and use of digested food by the body

**egestion** removal of undigested food from the body (faeces)

**Figure 3.26** Millions of villi make it possible for all the digested food molecules to be transferred from the small intestine into the blood by diffusion.

## The end of the story

After the digested food molecules have been absorbed into the blood, a watery mixture of enzymes, undigested food (mainly cellulose), bile pigments, dead cells and mucus is left in the small intestine and is moved along by muscle contractions into the large intestine. In this wide, thin-walled tube water is absorbed back into bloodstream by diffusion. By the end of the large intestine the thick paste that remains is known as the faeces. The journey ends as the faeces leave the body through the rectum and the anus as a result of a final set of muscle contractions.

This removal of the faeces from your body is called **egestion**. It is not excretion because excretion involves the removal of the waste products from the cells, and the final contents of your gut have never been inside your cells. The number of times people pass faeces varies from person to person and with the diet that is eaten. Once a day is probably average, but some people go several times a day, while others may go only once or twice a week.

So at the beginning of the process of digestion you eat a meal, taking food into your body. After several hours the digestive process, including ingestion, physical and chemical digestion, absorption, assimilation and egestion, will be complete. The time it takes to digest a meal completely will depend on a variety of things – in particular, the size of meal you eat and the type of food it contains. If the nutritional balance of the food you eat is right, the chances of your body remaining fit and healthy throughout your life are greatly increased.

## DID YOU KNOW?

The villi are tiny – each individual villus is only 1–2 mm long. However as there are millions of villi, and each of them in turn is covered in microvilli, it has been calculated that the surface area of your small intestines is actually around  $300\text{ m}^2$  – that's about half the area of a tennis court.

## DID YOU KNOW?

The colour of your faeces comes from the breakdown products of your bile. If you have problems with your gall bladder or bile duct, your faeces may turn silvery-white as they are missing the pigments from your bile.

### Activity 3.8: Timing food through your system

The time it takes for food to travel through your digestive tract is known as the throughput time. It varies from individual to individual and with diet. It is possible to investigate your own throughput time using a marker food. For example, corn is very high in fibre, so some of it appears undigested in your faeces. To measure the activity of your own gut, eat a couple of corn cobs and measure how long it takes for them to put in a reappearance!

### KEY WORDS

**constipation** faeces that remain too long in the large intestine have too much water removed and become compacted and difficult to evacuate from the body

**diarrhoea** loose, watery faeces

**salmonella** bacteria that causes food poisoning

## Issues of digestive health

### Constipation

If the faeces remain in your large intestine for too long, too much water is removed from them. They become compacted, hard and difficult to evacuate from your body. This is **constipation** and the most common causes are a lack of fibre in the diet and not drinking enough water. Straining to pass faeces can cause haemorrhoids (piles) or a tear in the anus. Constipation can usually be treated relatively easily. This may involve eating more fibre (which gives the muscles of the gut more material to work on), drinking plenty (so the faeces remain soft) and sometimes taking laxatives (chemicals which stimulate the gut to contract and force out the faecal material). If the faeces become completely compacted (which happens very rarely) they can block the gut. This is a very serious situation which may have to be relieved by surgery.

### Diarrhoea

On the other hand, if an infection causes the gut to contract more strongly or more rapidly than usual, the faeces that are produced may be very loose and watery. This is known as **diarrhoea**. Often this condition clears up within 24 hours, but in the very young and the very old – and anyone if it persists – diarrhoea can be fatal as it causes dehydration of the tissues. It can be treated very simply by giving the sufferer frequent drinks of water with rehydration salts (mainly salt and sugar). These replace the fluids that are being lost and keep the body tissues hydrated until the immune system overcomes the infection. Millions of people around the world, particularly children and old people, die from untreated diarrhoea every year.

### Food hygiene

It is not only the balance of food in your diet that can affect your health. There are a number of food-borne diseases. Bacteria growing on food that you eat can make you very ill and even kill you. For example, raw meat and raw eggs can contain bacteria such as **salmonella** that cause diarrhoea and sickness (vomiting). In most people food-borne diseases are not too serious, but young children, the elderly and anyone who has other health problems can be very seriously affected.

You need to maintain very strict food hygiene when you are preparing food to avoid these diseases. Store raw meat and eggs separately from salad vegetables and fruit. Wash the knives used to cut meat and the work surfaces on which it is prepared before preparing salads or cutting cheese. Disinfect work surfaces regularly. And most important of all, anyone preparing food must wash their hands between handling different types of food and when they have been to the toilet. Gut bacteria from the faeces can

be transferred from the hands to the food very easily and cause stomach upsets to spread around a family or a community.

Some of the food we eat is preserved so that it will last longer. There are a number of ways of preserving food and they all work by preventing bacteria from growing on the food. When food is canned it is heated to high temperatures and sealed so that the air cannot get in – this kills the bacteria which might cause food poisoning and deprives them of the oxygen they need to grow. Bottling is a similar process which uses glass bottles – people can bottle their own excess crops as well as buying commercially produced bottled food. Often a sugar syrup or brine is used. Again this method kills the bacteria with heat, deprives them of oxygen and also causes osmotic damage using the sugar or salt solution. When food is packed in a vacuum pack the air is sucked out of the packaging which is then sealed. This means there is no oxygen available so bacteria cannot grow in the food. Finally food can be dried – there is no water so bacteria cannot grow and the food stays good.

All of these methods of preserving food should mean that the food lasts a very long time and remains safe and good to eat. However, you need to be careful and employ good food hygiene even when using canned or packaged foods. Here are some of the precautions you should use:

- Check that the ‘best before’ date stamped on the can or package is OK. In many cases, particularly with tinned food, the ‘best before’ date means that the food will not taste at its best rather than that it will be going bad and a health risk. However, it is always best to avoid eating food that is past its ‘best before’ date to avoid the risk of infections.
- Make sure that the can, bottle or packet has not been damaged in any way which would allow air into the container. If air gets into a food container it carries microbes with it which can grow on the food using oxygen from the air to respire. Some of these micro-organisms can cause disease if you then eat the food. Others produce toxins (poisons) as they grow which can cause severe illness and death if they are eaten.
- Once a food container has been opened, eat the contents quickly. If anything is left over, store it in a refrigerator to keep the temperature low if possible to stop bacteria growing. If not, keep the food as cool as possible and cover it to prevent flies from landing on it and transferring microbes from their feet and mouthparts to the food.
- Check for any bulging in the shape of a can which might show you that bacteria have got into the tin and grown, producing gases which build up and make the tin bulge.



**Figure 3.27** Canned foods are usually very safe – the food is heated to kill bacteria and sealed in airtight tins. But very occasionally, if there is a tiny hole in the can, the bacterium *Clostridium botulinum* gets in. These bacteria produce the deadly *botulinus* toxin and anyone eating the food can become paralysed or even die.

## Summary

In this section you have learnt that:

- The breakdown of large food molecules into smaller soluble molecules through hydrolysis reactions is catalysed by enzymes.
- Enzymes are proteins that catalyse specific reactions.
- Each enzyme has an active site that fits the reactants of the reaction it catalyses.
- Enzymes are affected by temperature. Up to their optimum temperature, raising the temperature increases the rate of reaction. Once the temperature goes above the optimum, the protein structure of the enzyme is denatured, the shape of the active site is destroyed and the rate of the reaction decreases rapidly.
- Enzymes work best at specific pH levels – pH affects the structure of the active site.
- Different areas of the gut have different pHs to suit the enzymes involved.
- The process of eating your food involves ingestion, digestion, absorption, assimilation and egestion.
- The human digestive system is a muscular tube running through the body with specialised areas adapted to carry out different parts of the digestive process.
- Peristalsis is a wave of muscular contraction pushing food along the gut.
- The liver makes bile, which emulsifies fats, increasing the surface area for enzyme action.
- The ileum has a very large surface area due to the presence of villi and microvilli. This enables the digested food products to be absorbed into the blood and lymph systems. Water is removed from the remaining undigested food in the large intestine and the remaining material is egested from the body as the faeces.
- Food must be handled and stored carefully to avoid the transmission of diseases.



## Review questions

Select the correct answer from A to D.

1. Enzymes are made of:
  - A carbohydrates
  - B vitamins
  - C proteins
  - D fats
2. Which of the following does NOT affect the activity of an enzyme?
  - A pH
  - B temperature
  - C the surface area of the reactants
  - D light levels
3. Extracellular enzymes work:
  - A outside of your cells
  - B inside your cells
  - C inside your mitochondria
  - D only in your mouth
4. Which part of a tooth contains the living nerves?
  - A enamel
  - B dentine
  - C cement
  - D pulp cavity
5. The finger-like projections in the small intestine are known as:
  - A bilirubin
  - B microvilli
  - C sphincters
  - D villi

### 3.3 The respiratory system

By the end of this section you should be able to:

- Explain the importance of breathing in humans.
- Describe the structure and functions of the human respiratory system.
- Examine the structure of a lung from an animal such as a cow or sheep.
- Explain the mechanism of breathing using a lung model.
- Explain the process of gas exchange.
- Demonstrate the presence of  $\text{CO}_2$ , water vapour and heat in exhaled air.
- Compare the composition of inhaled and exhaled air.
- List the factors which affect breathing and explain how they affect it.
- Explain the effects of cigarette smoking and inhaling gaya, suret and shisha on health and on the economy of the family.
- List the methods of maintaining the hygiene of breathing.
- Describe the steps followed during artificial respiration and be able to demonstrate these steps.

The first breath a baby takes when it is born signals the start of a new independent life. Why is breathing so important, and how does it work? In single-celled organisms and other small living things, oxygen diffuses into the cells from the air or water, and **carbon dioxide** diffuses out. But human beings are much too large, and have far too many cells, for simple diffusion from the air to be enough. Breathing brings oxygen into your body and removes the waste carbon dioxide produced by your cells as they work. In this section you will learn how your respiratory system works.



#### The human respiratory system

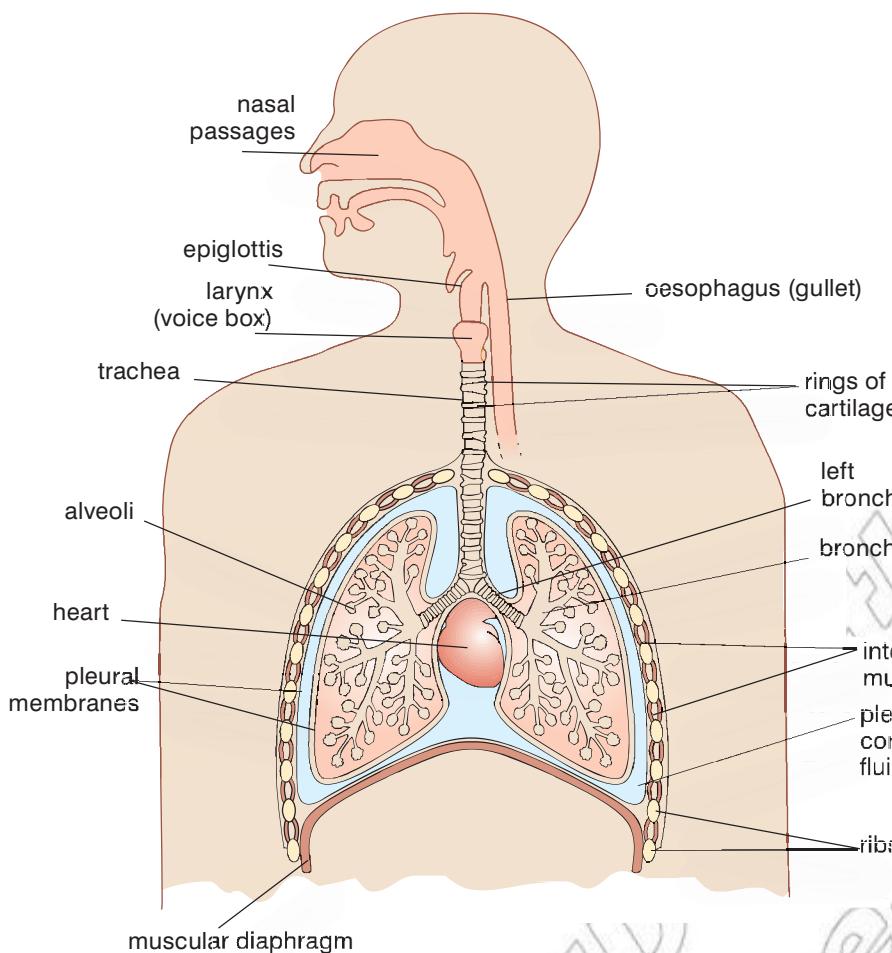
Your respiratory system is beautifully adapted for the job it has to do. Your nose contains the nasal passages, which have a large surface area, a good blood supply, lots of hairs and a lining that secretes mucus. The hairs and mucus filter out much of the dust and small particles such as bacteria and pollen that we breathe in, whilst moist surfaces increase the humidity of the air we breathe into our bodies and the rich blood supply warms it. All this means that the air we take in is already warm, clean and moist before it gets into the delicate tissue of our lungs.

As air moves down into the **trachea** it passes the oesophagus – the entrance to your gut. Whereas air can – and does – make its way down into your gut, this doesn't matter as you can simply bring it back up in the form of a burp. However, it is very important that food does not get into your lungs. It can block the airways or cause a fatal infection and so the epiglottis closes off your trachea every time you swallow in a reflex action (you will learn more about this in Grade 10). You cannot swallow and breathe at the same time.

**Figure 3.28** Once a baby starts breathing on its own, it is well and truly born. We carry on breathing – on average about 14 times a minute – until the day we die.

#### KEY WORDS

**carbon dioxide** colourless, odourless gas formed during respiration and a widely produced greenhouse gas  
**trachea** major airway connecting the larynx with the lungs



### KEY WORDS

**abdomen** contains the digestive system and many body organs

**diaphragm** muscle separating the chest cavity from the abdomen

**larynx** voice box

**cartilage** smooth rubbery material that reduces friction and cushions joints

**cilia** tiny moving hairs attached to cells

### Activity 3.9: The breathing structures of a mammal

The breathing structures of most mammals are very similar to human ones. If you look at the trachea and lungs of an animal such as a cow or a sheep you will be able to see the different tissues. Your teacher will show you the rings of cartilage and the division of the tube into the bronchi which feed into the lungs.

You may see air breathed into the lungs through a tube (possibly using a bicycle pump) and if so you will see how the lung tissue inflates and deflates.

Cutting small sections of the lungs will allow you to see inside the tissue and so understand the spongy structure that they have.

**Figure 3.29** The respiratory system supplies your body with vital oxygen and removes poisonous carbon dioxide. The lungs are in the upper part of the body – the thorax. The **abdomen** contains the digestive system and many other body organs. The **diaphragm** is a sheet of muscle separating the thorax and the abdomen, keeping the contents of each part of the body quite separate and making breathing movements.

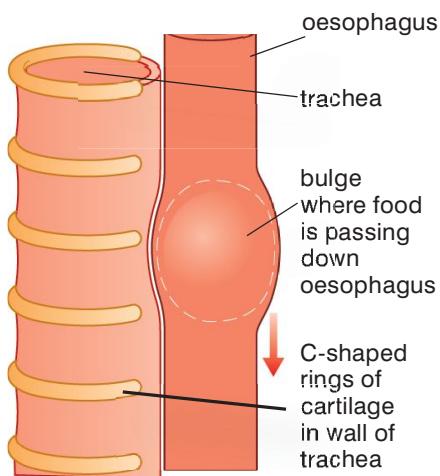
At the top of your trachea sits your **larynx** or voice box. By directing air leaving the lungs over the vocal cords (flaps of muscle) in the larynx, you produce the sounds that you use in speech. The trachea itself has a series of incomplete rings of **cartilage** (shaped like the letter C) that support it and hold it open. They are incomplete so that you can swallow your food. Your oesophagus and trachea run next to each other so as a lump (bolus) of food moves down your oesophagus it presses against your trachea. If the trachea had solid cartilage rings this would be very uncomfortable. But the open part of the ring faces the oesophagus so the food passes by with no problems (see figure 3.30).

The lining of your trachea secretes mucus, which like the surface of the nose collects bacteria and dust particles. The cells that line the trachea are also covered in hair-like **cilia** that beat to move the mucus with any trapped micro-organisms and dirt away from your lungs and towards your mouth. This mucus is then either swallowed and digested or coughed up.

**DID YOU KNOW?**

Using traditional cooking fires means many people breathe in a lot of smoke particles. This means the mucus produced from your nose will often be grey or black, as your body filters out the particles and gets rid of them.

The trachea splits into two tubes; the left and right **bronchi** (singular **bronchus**), one leading to each lung. The bronchi are also supported by rings of cartilage. Inside your lungs, the bronchi divide into smaller tubes known as the **bronchioles**. The bronchioles are much smaller than the bronchi, dividing into ever smaller tubes until they reach the main structures of the lungs – the **alveoli** (singular **alveolus**). There are millions of these tiny air sacs, giving a massive surface area for the main exchange of gases in the lungs to take place.



**Figure 3.30** The incomplete cartilage rings that support your trachea are a useful adaptation when it comes to swallowing your food successfully.

**KEY WORDS**

**bronchus** one of two main tubes branching off the windpipe

**bronchioles** small air tubes in the lung

**alveoli** tiny air sacs in a lung

**Activity 3.10: Looking at the tissues of the respiratory system**

By looking at some prepared microscope slides you can see the difference in the structure of different areas of the respiratory system.

You will need:

- a microscope
- a lamp
- prepared microscope slides of trachea and lung tissue to show bronchioles and alveoli

**Method**

*Remember, microscopes are expensive and delicate pieces of equipment so always take care of them and handle them safely.* Use the technique for using microscopes described in section 2.1.

1. Set up your microscope.
2. Clip the prepared slide into place on the stage and focus carefully.
3. Draw some of the structures you see and label them as well as you can. Look for the cilia on the epithelium of the trachea and the cartilage rings. In the lungs themselves look carefully at the structure of the alveoli and try to work out why they are so effective at gaseous exchange.

**How is air brought into your lungs?**

For your respiratory system to work you need to move air into your lungs and then move it out again. This is brought about by movements of the ribcage, which you can see and feel, and by movements of the diaphragm, which you can't.

The breathing movements are brought about by two different sets of muscles that change the pressure in the chest cavity. When we breathe in, our ribs move up and out, and the muscles of the diaphragm contract so that it flattens from its normal domed shape. The intercostal muscles between the ribs contract, pulling them upwards and outwards at the same time as the diaphragm muscles

contract to flatten the diaphragm. These two movements increase the volume of your chest (thorax). Because the same amount of gas is now inside a much bigger space, the pressure inside the chest drops. This in turn means the pressure inside the chest is lower than the pressure of the air outside. As a result air moves into the lungs.

Then, when the intercostal and diaphragm muscles relax, the ribs drop and the diaphragm domes up. The volume of the thorax is decreased, so the pressure inside your chest increases as the air is squeezed and forced out of your lungs. You breathe out.

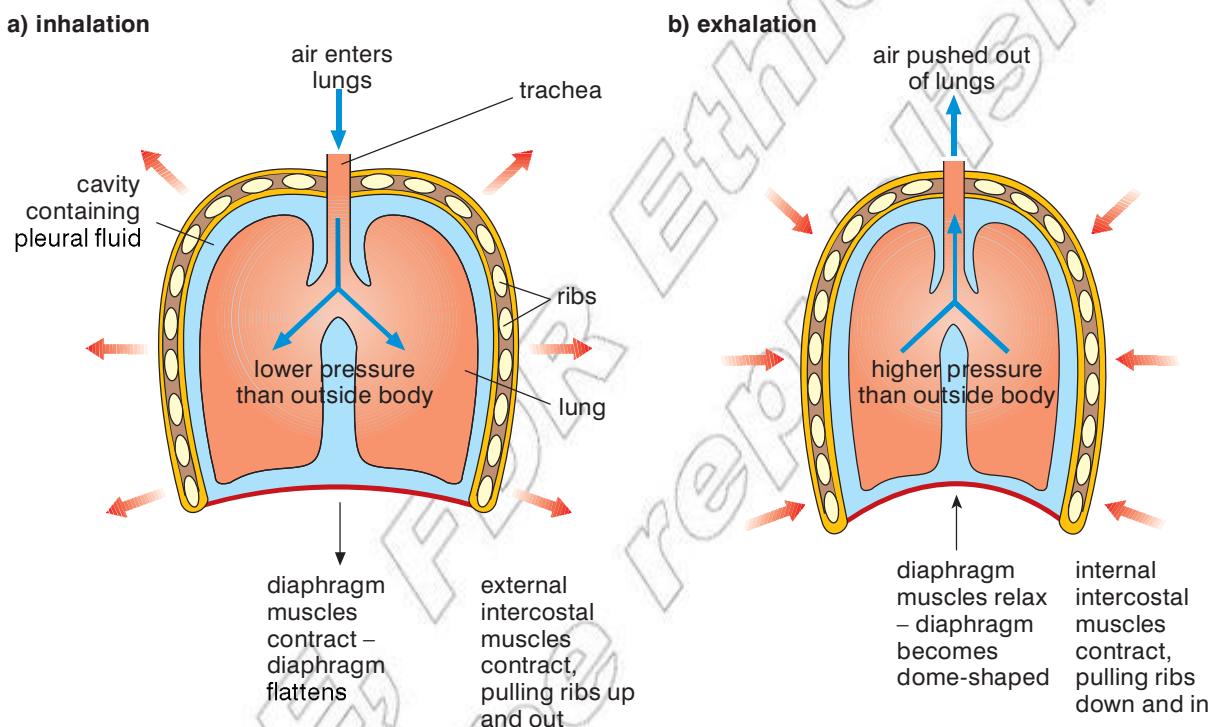
This movement of air in and out of the body is known as **ventilation** of the lungs.

### KEY WORDS

**ventilation** moving air into and out of the lungs

**intercostal muscles**

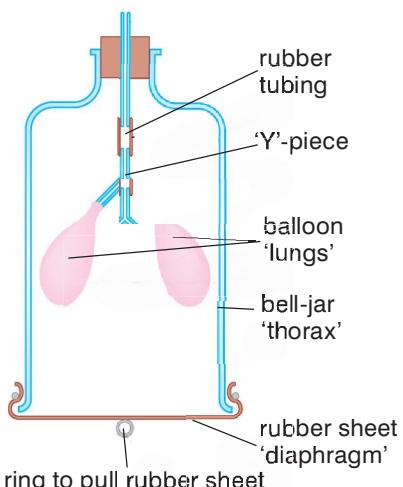
muscles used in breathing



**Figure 3.31** Breathing movements bring about changes in the air pressure in your chest that result in air moving into and out of your lungs. The movements of your diaphragm are hidden but the movements of the ribs can be seen and felt easily.

We have two sets of **intercostal muscles**. In normal, quiet breathing we use only our external intercostal muscles, which lift our ribs. When these muscles relax, our ribs fall back to their original position due to gravity. However, if we need to breathe out deliberately, forcing the air out of our lungs, or when we are exercising really hard, we also use our internal intercostal muscles, which pull the ribs down hard and squeeze more air out of your lungs. You can also use the muscles of your abdomen deliberately to increase the amount of air you move in or out of your lungs. Professional singers often make use of this when they perform.

### Activity 3.11: Investigating breathing movements



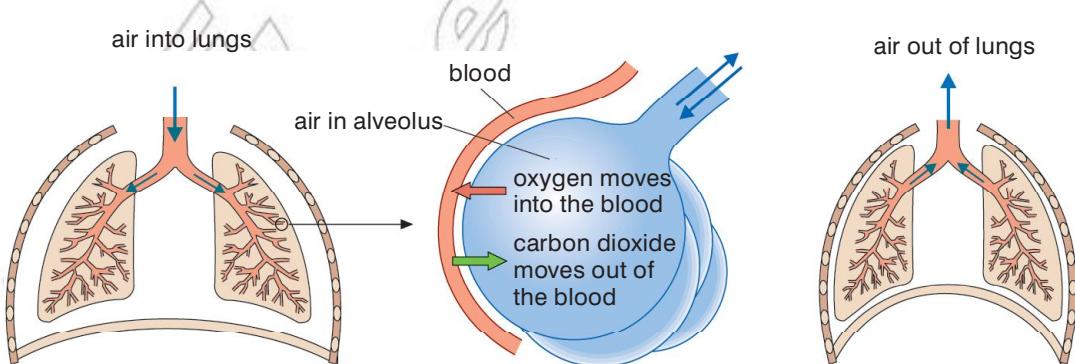
**Figure 3.32** Bell-jar model of the thorax

It is impossible to see exactly what is happening inside your chest as you breathe without using special imaging techniques. However, there are two simple investigations you can try to build up a useful model of what is going on inside you.

1. If you stand up and place your hands on either side of your body, on your ribs, you can feel your breathing movements. Experiment with breathing gently and then more deeply, and feel the changes in the size and shape of your ribcage.
2. You can also get an idea of the effect of your diaphragm moving down and up again on the pressure in your thorax and the air in your lungs using a model thorax like the one shown in figure 3.32. Pull the rubber 'diaphragm' down, then force it up again and observe the effect this has on the balloon 'lungs'. This gives you an insight into the role of your diaphragm in filling and emptying your lungs.

### The process of gaseous exchange

Breathing in supplies us with the oxygen we need for cellular respiration, while when we breathe out waste carbon dioxide is removed from the body. But how is this exchange brought about? When the air is breathed into the lungs, oxygen passes into the blood by diffusion along a concentration gradient. At the same time carbon dioxide passes out of the blood into the air of the lungs, also by diffusion along a concentration gradient. This exchange of gases takes place in the alveoli, the tiny air sacs with a large surface area that make up much of the structure of the lungs.



**Figure 3.33** An exchange of gases between the blood and the air takes place in the lungs.

The movement of oxygen into the blood and carbon dioxide out of the blood takes place at exactly the same time – there is a swap or exchange between the two and so this process is known as gaseous exchange.

The tiny air sacs of the alveoli provide an ideal site for the most effective possible diffusion of gases into and out of the blood. They have a very large surface area that is kept moist. This is important for the most effective diffusion of the gases, as they need to be in solution to diffuse into the blood.

The alveoli also have a rich blood supply, which is vital if substances are going to move into and out of the blood. The blood that the heart pumps to the lungs has come from the active body tissues and is low in oxygen and relatively high in carbon dioxide. Oxygen is constantly moved into the blood, but more deoxygenated blood immediately replaces it. Similarly, carbon dioxide is constantly delivered to the lungs, where it is diluted in the volume of air maintaining a concentration gradient between the blood and the air in the lungs. This is made even steeper each time new air moves into the lungs. As a result gas exchange in both directions can take place along the steepest concentration gradients possible, so that it occurs rapidly and effectively.

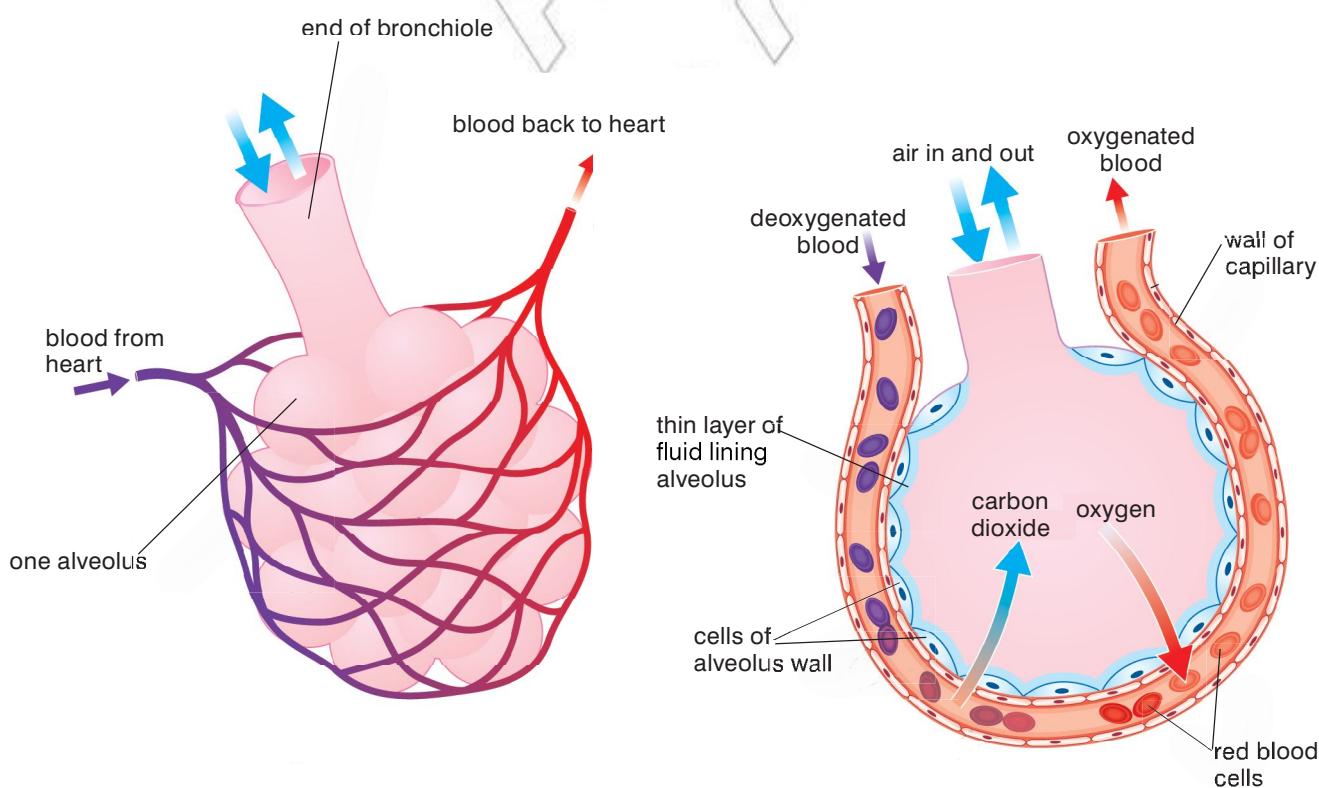
Within the alveoli, the gases in the air and the gases dissolved in the blood are only separated by two cell layers, a distance of only about a thousandth of a millimetre, so the diffusion distances are as short as possible. This means that diffusion takes place as quickly as possible.

The mechanism of gas exchange in the alveoli depends on a large surface area, moist surfaces, short diffusion distances, and a rich blood supply maintaining steep concentration gradients.

The breathing movements tell us that air is moved into and out of the lungs. If we analyse the gases in inhaled and exhaled air we can compare their composition and show the levels of oxygen and carbon dioxide change.

### DID YOU KNOW?

It has been calculated that your lungs contain about 500 million alveoli. If all of these alveoli were spread out flat, they would have a surface area about the size of a tennis court!



**Figure 3.34** The alveoli are the site of very efficient gas exchange in the lungs.

**Table 3.6** An analysis of the air taken into and breathed out of the lungs shows how the chemical make-up is changed by the diffusion that takes place in the lungs.

Atmospheric gas	Air breathed in	Air breathed out
Nitrogen	About 80%	About 80%
Oxygen	21%	16%
Carbon dioxide	0.04%	4%

### Activity 3.12: Demonstrating the presence of carbon dioxide ( $\text{CO}_2$ ) in exhaled air

A detailed analysis of inhaled and exhaled air is not easy in the school lab, but you can do a relatively simple experiment to demonstrate that the carbon dioxide content of the air you breathe out is different from the air breathed in. This experiment uses lime water ( $\text{Ca}(\text{OH})_2$ ) as an indicator of the presence of carbon dioxide. The clear liquid turns cloudy when carbon dioxide is bubbled through it, and the faster it turns cloudy, the greater the concentration of carbon dioxide present.

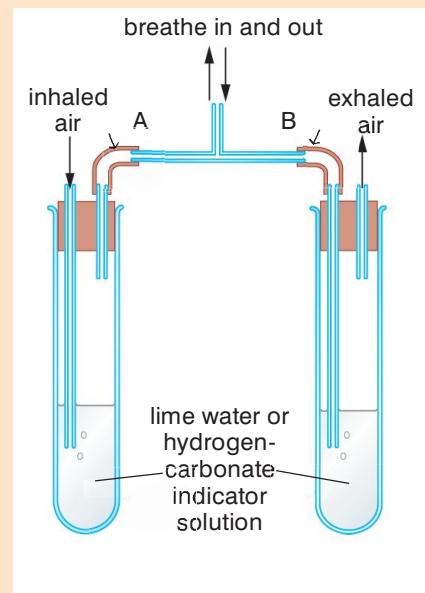
In the simplest form of this experiment you simply need a tube containing some lime water and a straw. Breathe in normally and gently but breathe out gently through the straw. Repeat this until the lime water turns cloudy, counting how many breaths it takes. This shows that there is carbon dioxide in the air you have breathed out.

If you run on the spot for three minutes and then repeat this experiment, would you expect the lime water to turn cloudy more slowly or more quickly? Try this out and then explain your results.

There is a slightly more complicated version of this simple experiment where you can compare the carbon dioxide content of the air you breathe in with the air you breathe out.

You will need:

- two boiling tubes
- bungs and delivery tubes linked as shown in figure 3.35
- lime water



**Figure 3.35** Using relatively simple apparatus it is possible to see differences between the air we breathe in and the air we breathe out.

#### Method

1. Set up the apparatus as shown in figure 3.35.
2. Observe the appearance of the lime water in both tubes before beginning your practical investigation.
3. Breathe in gently through the central glass tube.
4. Breathe out gently through the central glass tube.
5. Repeat this sequence for several minutes. You will draw air in so that it bubbles through one tube of limewater. The air you breathe out will bubble gently through the other tube of lime water. DO NOT blow too hard. DO NOT SUCK hard on the tube.
6. Observe any changes in the lime water in both tubes.
7. Write up your investigation and record your results. Explain your observations as fully as you can in terms of the air that is inhaled and exhaled from your lungs.

### Activity 3.13: Demonstrating the presence of heat in the air you breathe out

It isn't easy to demonstrate that the temperature of the air you breathe out is higher than the temperature of the air you breathe in, but there are ways of doing it. Can you think of investigations using ice cubes or thermometers that would let you do this?

### What affects your breathing rate?

The average resting breathing rate for an adult human being is around 12–14 breaths per minute. This supplies the oxygen needed for all of the normal activities of your cells, but it does not use up all of the capacity of your lungs. When you are breathing normally at rest, you take about  $500\text{ cm}^3$  of air in and out each time you breathe – this is only about 15% of your possible maximum. This is known as your **tidal volume** of air. The **vital capacity** of your lungs is the absolute maximum amount of air you can take into or breathe out of your lungs. If you need more oxygen for any reason, you have two ways of getting more air into your body. You may breathe faster and you may breathe more deeply, taking more air into your body with each breath. Usually you do a combination of the two. So what factors affect your breathing rate? Anything that increases the oxygen requirements of your body will tend to increase your breathing rate. The main factors known to have an effect are:

- Exercise
- Anxiety
- Drugs
- Environmental factors
- Altitude
- Weight
- Smoking

#### Exercise

Even when you are resting, your muscles use up a certain amount of oxygen and glucose. This is because some of your muscle fibres are constantly contracting to keep you in position against the pull of gravity. Muscles are also involved in your life processes such as breathing and circulation of the blood. But when you begin to exercise, your muscles start contracting harder and faster. As a result they need more glucose and oxygen to supply their energy needs. During exercise the muscles also produce increased amounts of carbon dioxide, which needs to be removed for them to keep working effectively.

So during exercise, when muscular activity increases, your breathing rate increases and you breathe more deeply. These

### Activity 3.14: Demonstrating the presence of water vapour in exhaled air

The air you breathe in is the air in the classroom around you. If you have a piece of cold glass, the air in your classroom will not make any changes appear.

However, if you breathe out several times on a piece of cold glass, tiny drops of a colourless liquid will appear. Test this liquid with blue cobalt chloride paper or white anhydrous copper(II) sulphate to show that the air you breathed out contains water vapour – and a lot more water vapour than the classroom air you breathed in.

(Blue cobalt chloride paper turns pink in the presence of water, whereas white anhydrous copper(II) sulphate turns blue.)

#### KEY WORDS

**tidal volume** *the amount of air breathed in*

**vital capacity** *the maximum amount of air that can be taken into the lungs*

### DID YOU KNOW?

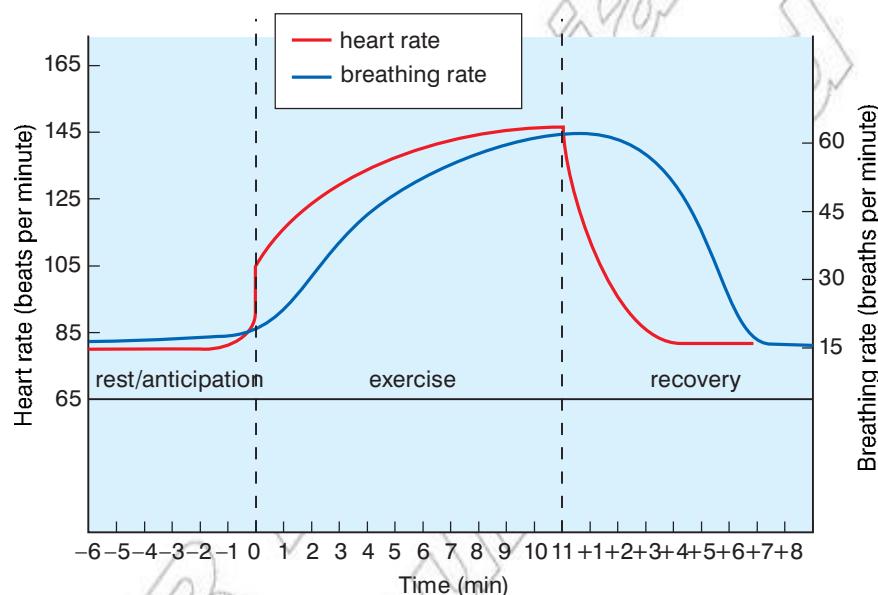
In a 100 m sprint race some athletes do not breathe at all. This means that the muscles use the oxygen taken in at the start of the race and then don't get any more oxygen until the race is over. Although the race only takes a few seconds, a tremendous amount of energy is used up so a big oxygen debt can develop.

**Figure 3.36** During exercise the breathing rate increases to supply the muscles with the oxygen needed and remove the extra carbon dioxide produced.



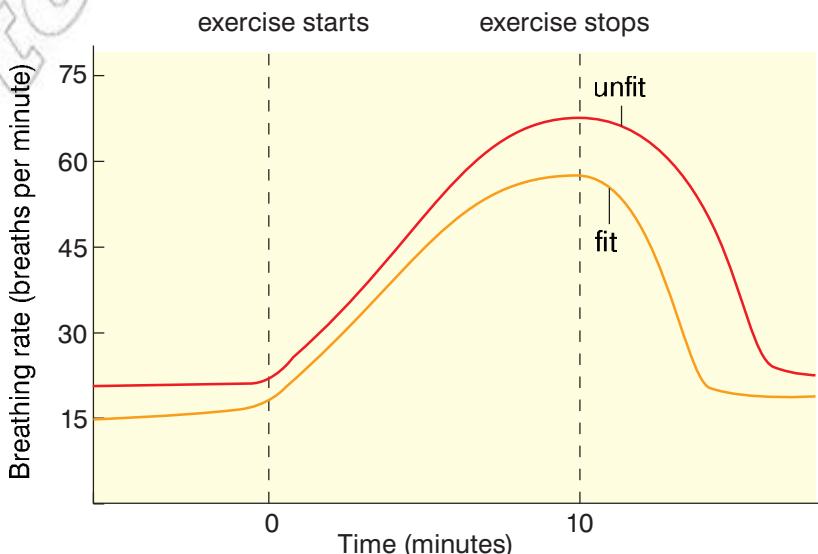
**Figure 3.37** Hard exercise means everyone has to pay off their oxygen debt – but if you are fit you can pay it off faster.

changes mean that not only do you breathe more often, but you also bring more air into your lungs each time you breathe. This increases the amount of oxygen brought into your body and carried to the exercising muscles. It also means more carbon dioxide can be removed from the blood in the lungs and breathed out.



Exercising and getting fitter means your lungs get bigger. They can supply more oxygen to your muscles so you build up much less oxygen debt. As a result fit people often have a slower breathing rate than unfit people, because they take more air in and out with each resting breath.

Regular exercise has been shown to have a number of benefits for health and fitness. It keeps your muscles toned, so that the fibres are constantly slightly tensed and ready to contract. This speeds up your reaction time and uses up energy, helping you to maintain a healthy body weight. When you use your muscles regularly they get stronger as more muscle fibres develop. Another benefit is that your muscles are much less likely to feel stiff and sore after exercise when



### Activity 3.15: Investigating the effect of exercise on breathing rate

A good way of telling how fit you are is to measure your resting breathing rate. The fitter you are, the fewer breaths you will take. Then see what happens when you exercise – the increase in your breathing rate and how fast it returns to normal is another way of finding out how fit you are – or aren't! Anyone who is affected by asthma or has any other illness should take care before taking part in this practical and take any medication they would normally use before a PE session. Anyone who does not normally take part in PE should act as time-keeper and recorder in this investigation and not take part in the physical exercise.

You will need:

- stopwatch or clock with clear second hand

#### Method

1. Find out your resting breathing rate. Sit quietly without speaking for two minutes at least. Then start the stopwatch and record how many times you breathe in and out a minute (breathing in and out again counts as one breath). Repeat this three times to get an average resting breathing rate.
2. Now exercise gently for two minutes by walking on the spot. As soon as you stop exercising start to record your breathing rate. Record it every minute until it returns to your resting rate.
3. Now change the way you exercise. Exercise harder for two minutes by gentle jogging on the spot. As soon as you stop exercising start to record your breathing rate. Record it every minute until it returns to your resting rate.
4. Finally exercise hard for two minutes – run on the spot as hard as you can. As soon as you stop exercising start to record your breathing rate. Record it every minute until it returns to your resting rate. If you prefer, you can simply extend your period of more gentle exercise, by walking or jogging gently for four minutes instead of two.
5. Write up your investigation, including your results. Make a graph of your own personal data and explain what you have observed. In some cases your breathing rate may drop below your normal resting rate as you recover. Can you explain what is happening?
6. Collect data from other members of the class and compare the breathing rates and recovery times of the group. Can you find any patterns in the data? Are there differences between boys and girls? Do the members of sports teams show different patterns to the rest of the class?

you use them regularly. The blood supply to your muscles increases, bringing glucose and oxygen to the tissues more efficiently, removing carbon dioxide and avoiding oxygen debt. Your joints also tend to work more smoothly if you take regular exercise. This is because the blood flow to your joints is increased so your body maintains and repairs them more effectively.

The benefits of regular exercise are not confined to your muscles and skeleton. Your heart and lungs benefit too. Both the heart and the lungs become larger, and they both develop a bigger and very efficient blood supply. This means they function as effectively as possible at all times, whether you are exercising or not.

## Anxiety

Anxiety affects your breathing rate because when you are anxious your body reacts as if you are in danger and need extra oxygen. As a result, your breathing rate will increase, ready to supply extra oxygen and get rid of carbon dioxide if you have to run away or fight (you will learn more about this response in Grade 10).

## Drugs

Drugs can affect your breathing rate in a number of ways. Some of the drugs we take into our bodies are medicines designed to make us better. Others are drugs that we take for pleasure, some of which are legal and some of which are not. But drugs, whether they are medicines, legal or illegal, may affect your breathing rate – sometimes fatally. Khat, amphetamines and cocaine, for example, can cause your breathing rate to increase dramatically, whereas depressants can cause the breathing rate to drop alarmingly and even stop. Any drug that lowers the rate at which you get air into your lungs risks depriving your body and brain tissues of oxygen, which can have devastating results.

## Environmental factors

Certain environmental factors can either change your oxygen needs or change the concentrations of the gases that control breathing. If conditions are particularly hot, your body has to work very hard to keep cool and you may find your breathing rate increases. If the levels of carbon dioxide in the air increase, so will your breathing rate – because a build-up of carbon dioxide in the body triggers the breathing response.

## Altitude

Height above sea level (altitude) can also affect your breathing rate. The higher you go above sea level, the lower both the atmospheric pressure and the oxygen levels in the air. Once you go above 3650 m above sea level, there is a noticeable lack of oxygen and your breathing rate will increase to try and keep your oxygen levels up. Many people feel ill at altitude although you may begin to acclimatise, getting more air into your lungs with every breath as well as producing more red blood cells to carry oxygen. People who are born and live at high altitudes – for example, in the Himalayas and the Andes – don't suffer in this way. They have an increased lung volume with many more alveoli, as well as more blood capillaries and red blood cells to pick up the oxygen from the air.

## Weight

Excess **weight** can also affect your breathing rate. It can be difficult to breathe deeply because of the fat around the abdominal organs, which makes it difficult for the diaphragm to lower properly. Yet your muscles have to work to move the excess weight around. So people who are very overweight or obese (see page 66) are often

### KEY WORD

**weight** *measure of the heaviness of a person/object*

breathless as they cannot get the oxygen they need very easily; they may do little exercise and as a result they are very unfit. However, if overweight people begin to take more exercise, they will lose weight, their breathing rate will fall and become more efficient and they will quite rapidly see the benefits of improving fitness.

## Smoking

Finally, one major factor that affects breathing rates is smoking. Smoking is a habit that directly affects your respiratory system as well as other areas of your body, so we will look at it in rather more detail.

### The effect of smoking on the lungs and the rest of the body

People in Ethiopia tend to smoke cigarettes less than those in many other countries. However, we do also smoke shisha, and also people use native tobaccos such as gaya, which may be smoked in a pipe, inhaled like snuff or chewed. In spite of this, scientific evidence suggests that many deaths in Ethiopia are smoking-related. In the year 2000, statistics showed that nine people in every 100 000 of the population died of smoking-related cancers such as lung cancer, and 18.9 in every 100 000 died of cancers linked not just to smoking and inhaling cigarettes but also to pipe smoking and chewing tobacco, such as cancers of the mouth and throat. Every cigarette smoked produces around 4000 chemicals that are inhaled into the lungs. Every time you inhale shisha, pipe smoke or cigarette smoke these chemicals are taken into your mouth, throat and lungs and some go into your blood.

**Nicotine** is the addictive drug found in tobacco smoke.

**Carbon monoxide** is a very poisonous gas found in cigarette smoke.

It takes up some of the oxygen carrying capacity of the blood – after smoking a cigarette up to 10% of a smoker's blood will be carrying carbon monoxide rather than oxygen.

This can lead to a shortage of oxygen for the smoker, and the effect is most marked in pregnant women. If the mother's blood does not contain enough oxygen as a result of smoking, the foetus is deprived of oxygen and does not grow as well as it should. This can lead to premature births, low birthweight babies and stillbirths where the baby is born dead.

## Smoking-related diseases

Tar is a sticky black chemical in tobacco smoke that is not absorbed into the bloodstream. It simply accumulates in the lungs, turning them from pink to grey. In a smoker, the cilia which move things away from the lungs are anaesthetised by each cigarette and stop working for a time, allowing dirt and bacteria down into the lungs.

### KEY WORDS

**nicotine** addictive drug found in tobacco smoke  
**carbon monoxide** poisonous gas found in smoke

**KEY WORDS**

**bronchitis** *inflammation and infection of the bronchi*  
**chronic obstructive pulmonary diseases (COPD)** *reduction of surface area of the lungs due to breakdown of the alveoli*  
**lung cancer** *disease linked to smoking*

Tar makes smokers more likely to develop **bronchitis** – inflammation and infection of the bronchi. The build-up of tar in the delicate lung tissue can also lead to a breakdown in the alveolar structure. In these **chronic obstructive pulmonary diseases (COPD)** the structure of the alveoli break down and much larger air spaces develop. This means the surface area of the lungs is reduced. As a result the person affected is always short of oxygen and feels breathless. COPD kills and disables millions of people around the world.

Tar is also a major carcinogen (a cancer causing substance). **Lung cancer** – the most well-known disease linked to smoking – is the result of this accumulation of tar. Up to 90% of lung cancers are directly the result of smoking. Tobacco smoking is also linked to cancers of the throat, mouth and larynx – the whole respiratory tract is affected.

The chemicals in tobacco smoke also affect the heart and blood vessels, making it more likely that blood vessels will become blocked, causing heart attacks, strokes and thrombosis. This link between heart disease and smoking will be considered in more detail in the next section.

### Activity 3.16: Demonstration of the tar in cigarette smoke

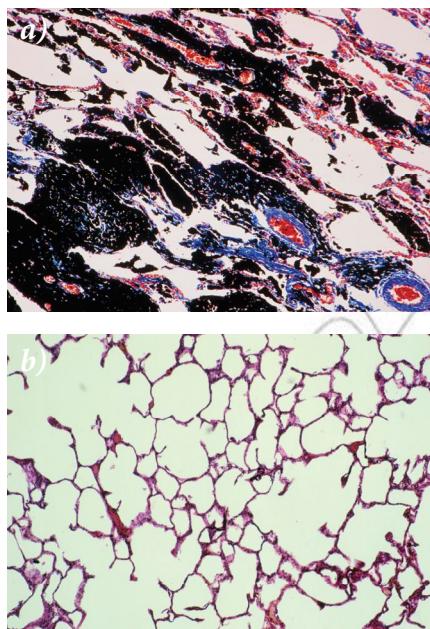
You can investigate the levels of tar in different types of tobacco products using the internet or some textbooks. However, you can set up a simple smoking machine to demonstrate the tar that is produced from a single cigarette – which would go down into your lungs if you inhaled the cigarette smoke.

You will need:

- a plastic bottle
- some cotton wool
- a length of tubing or even a straw
- sticky tape, blue tack, modelling clay or any material that will act as a seal
- a cigarette and matches

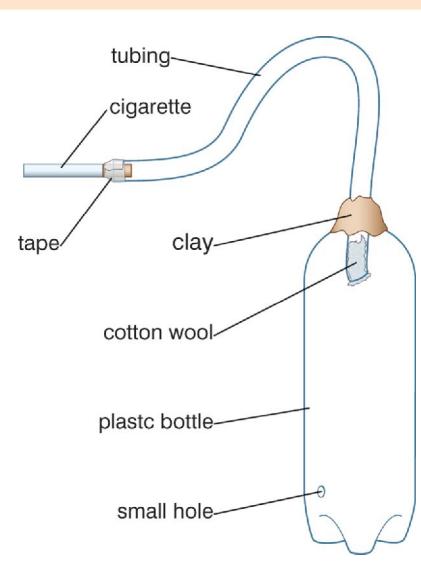
#### Method

1. Make a small hole in the bottom of the plastic bottle.
2. Put the cigarette into one end of the tube and seal the join with tape or other material – it must be airtight.
3. Push some clean cotton wool into the other end of the tube.
4. Place the cotton wool filled end of the tube into the top of the bottle and seal it with tape, modelling clay, etc. Make sure this seal is airtight.



**Figure 3.38** The difference in the appearance of the lungs of a smoker (a) compared to a non-smoker (b) is obvious even to the untrained eye.

5. Light the cigarette and gently squeeze the bottle and release, so that the smoke is sucked back through the cotton wool into the bottle.
6. Repeat until the cigarette has completely burned away.
7. Remove the cotton wool plug and compare it to the original clean cotton wool.
8. To see the effect even more clearly, burn more than one cigarette before looking at the cotton wool.



**Figure 3.39** Equipment needed to set up a plastic bottle smoking machine

### Smoking and the family

Smoking tobacco – or chewing or inhaling it – is not just a matter for each individual. Smoking has a big effect on the whole family. Smoking costs money – and if part of the family income is spent on smoking, that money cannot be used to buy food and clothes, or help with education or health care. What is more, if a father smokes and becomes ill with one of the diseases linked to smoking, the whole family will suffer from lack of income. They will also have the sadness of seeing a member of the family ill. The same is true if it is the mother who smokes or chews – the loss of a mother to the family is a very great blow. The illnesses of smokers affect the economy of the whole country as well as the family – smoking-related diseases mean people cannot work and they need health care. In Ethiopia at the moment we are very fortunate – our young people are very sensible and levels of smoking are very low compared to many other countries in Africa and around the world. A study published in 2007 by Emmanuel Rudatsikira, Abdurahman Abdo and Adamson S Muula showed that in Addis Ababa only 4.5% of teenage boys and 1% of teenage girls are smokers, and that the great majority of young people thought that smoking was harmful. We are doing well but we must work hard to make sure that young and old alike continue to understand the dangers of inhaling tobacco smoke and avoid it as much as possible.



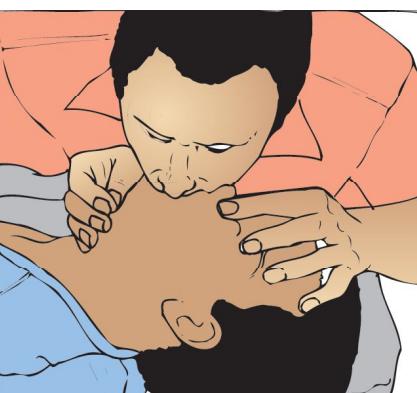
**Figure 3.40** The evidence for the link between smoking and cancer is so strong now that it is universally accepted. Many governments will not ban smoking but anti-smoking messages are given out. Unfortunately many people still ignore the warnings and put their health at risk.



Call for help



Raise the casualty's chin and press the forehead backwards to open the airway.



Pinch the casualty's nostrils firmly. Take a deep breath and put your mouth over the casualty's mouth. Breath four quick, deep breaths into the casualty's mouth and repeat this every 5 seconds until the casualty starts to breathe independently.

**Figure 3.41** Following these instructions can – literally – help you to save someone's life.

## Breathing hygiene

When you breathe you take air in and out of your body. This makes the respiratory system a very easy way for microbes that cause disease to get into your body. There are certain basic principles of breathing hygiene which will make you less likely to catch diseases or pass them on to others.

Firstly, sometimes people's breath smells bad. This is usually due to poor oral hygiene – often food trapped on the teeth or the tongue causes bad breath. You must clean your teeth and tongue – particularly the back of the tongue – regularly to avoid bad breath. However, sometimes bad breath is due to problems with the gut or the kidneys. So if bad breath does not clear up, visit the doctor.

If you have an infection such as a cold or tuberculosis, you will spray out the microbes that cause disease every time you speak or laugh, but most of all when you cough or sneeze. It is very important to cough or sneeze into your hand or the crook of your elbow and then wash it immediately. This avoids passing germs into the air for other people to breathe in.

If a dentist or doctor is going to examine a patient, they may wear a mask over their mouth and nose. This prevents them passing on infections to you, and also helps prevent them getting an infection from you – this is good breathing hygiene.

## When breathing fails

Sometimes breathing fails. This can be the result of a number of different things, including an accident, drowning or a heart attack. Once breathing stops, death will result in a matter of minutes as the brain in particular is starved of oxygen. However, it is possible to take over breathing for a casualty in this situation, and this may be enough to keep them alive until medical support arrives. The way this is done is by expired air resuscitation, which is also more commonly known as mouth-to-mouth resuscitation. The idea of this technique is that you keep forcing air into the lungs of the person who has stopped breathing, so that gaseous exchange can continue and their tissues continue to receive oxygen. It is very important that mouth-to-mouth resuscitation should ONLY be given when the casualty has stopped breathing, not just when they are unconscious. The procedure for this is as follows:

1. **Call for help loudly.** Use a phone to get help if you can.
2. **Check to see if the casualty is conscious** – use their name if you know it, ask their name and ask if they can hear you. NEVER use artificial respiration on a conscious patient. **Call for help.** If you are sure the patient is unconscious...
3. **Open the airway.** Remove any obstacles from the mouth which might block the airway, e.g. water weed, vomit. Tilt the head back and lift the chin. This opens the airways and may be enough to start breathing again. **Call for help again.**

4. **Check for breathing.** Put your head near the casualty's nose and mouth.

Look along the chest to check for breathing movement.

Listen for the sounds of breathing.

Feel for breath on your cheek.

Observe for at least 5 seconds before you decide the person is not breathing. **Call for help. NEVER use artificial respiration on a casualty who is breathing.**

5. **Make sure the airway is open and the head is tilted back. Pinch the casualty's nostrils closed with one hand. Keep the chin lifted with the other hand.**
6. **Use a clean piece of cloth over the mouth to avoid the transfer of HIV through contact and other infections. Take a deep breath and then seal your mouth around the person's mouth. Breathe out firmly into the person's mouth until you see the chest rise. This will show you that you are getting air into their lungs.**
7. **Remove your lips and let the chest fall naturally.**
8. **Repeat these steps at about 12 breaths per minute – a steady rate. The colour should return and the person may begin breathing for themselves. If not, continue until medical help arrives.**

## Summary

In this section you have learnt that:

- The breathing system takes air into and out of the body to supply oxygen and remove carbon dioxide.
- The respiratory system is made up of the mouth and nose, larynx, trachea, bronchi, bronchioles and alveoli. The lungs are surrounded by the pleural membranes and enclosed in the thorax.
- The movement of air is brought about by the intercostal muscles moving the ribs and the diaphragm.
- Breathing movements cause changes in the volume and pressure of the chest that bring about ventilation of the lungs.
- In the lungs oxygen from the air diffuses into the bloodstream at the same time as carbon dioxide from the blood diffuses out of the bloodstream into the air. This is known as gas exchange.

- The alveoli provide a very large, moist surface area, richly supplied with blood capillaries to allow the most efficient possible gas exchange.
- The rate of breathing is affected by a number of factors including exercise, anxiety, drugs, environmental factors, altitude, body weight and smoking.
- Nicotine is the addictive drug found in tobacco.
- Tobacco smoke also contains carbon monoxide, which reduces the oxygen carrying capacity of the blood.
- In pregnant women carbon monoxide deprives the foetus of oxygen and can lead to low birthweight babies and stillbirths.
- Tobacco smoke contains tar and other chemicals, which contribute to lung cancer, bronchitis, emphysema and disease of the heart and blood vessels.

### Review questions

Select the correct answer from A to D.

1. The organ of your body where gas exchange takes place is the:
  - A liver
  - B lungs
  - C trachea
  - D heart
2. The role of the cilia on the epithelium of the trachea is to:
  - A move dirt and mucus away from the lungs
  - B move dirt and mucus down the trachea into the lungs
  - C to produce mucus
  - D to prevent food getting into the lungs
3. Which of the following is not part of the respiratory response to exercise?
  - A breathing faster
  - B producing more oxygen
  - C breathing deeper
  - D producing more carbon dioxide
4. Which of the following is NOT a constituent of cigarette smoke?
  - A oxygen
  - B nicotine
  - C carbon monoxide
  - D tar

## 3.4 Cellular respiration

By the end of this section you should be able to:

- Explain cellular respiration and describe the formation of ATP and its importance to the body.
- Define and compare aerobic and anaerobic respiration, and explain their importance in cells.

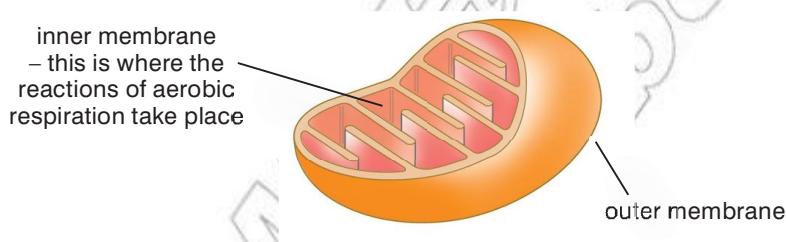
### Aerobic respiration

The digestive system, breathing and circulation systems all exist to provide the cells of the human body with what they need for respiration. (You will learn more about the circulatory system in the next section.) During the process of cellular respiration, glucose (a sugar produced as a result of digestion) reacts with oxygen to release energy that can be used by the cell. Carbon dioxide and water are produced as waste products.

The reaction can be summed up as follows:



This is called **aerobic** respiration because it uses oxygen from the air. Aerobic respiration takes place in the mitochondria in cells. These are tiny rod-shaped bodies (organelles) that are found in almost all cells. They have a folded inner membrane that provides a large surface area for the enzymes involved in aerobic respiration. Cells that use a lot of energy, such as muscle cells, liver cells and the rods and cones of your eye contain lots of mitochondria because they use a lot of energy.



All of your cells need energy to carry out the reactions of life, and respiration provides this energy.

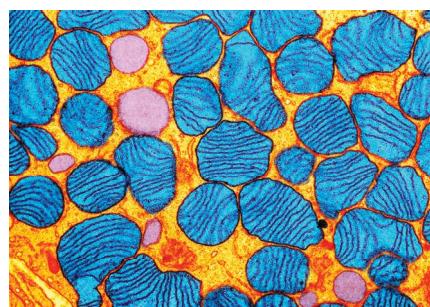
Respiration releases energy from the food we eat so that the cells of the body can use it. The energy that is used by the cells is stored in the form of a molecule known as ATP, which stands for **adenosine triphosphate**. This is an adenosine molecule with three phosphate groups attached to it. When energy is needed for any chemical reaction in the cell, the third phosphate bond is broken in a hydrolysis reaction. This results in a new compound, ADP or **adenosine diphosphate**, a free inorganic phosphate group – and the all-important energy needed in the cell. This is a reversible reaction, and so during cellular respiration the energy from the reactions

#### KEY WORDS

**aerobic respiration using oxygen**

**adenosine triphosphate (ATP)** main energy storing molecule in a cell

**adenosine diphosphate (ADP)** an inorganic phosphate compound



**Figure 3.42** Mitochondria are the powerhouses that provide energy for all the functions of a cell.

**KEY WORDS**

**anabolism** reactions in the body which build up small chemicals into larger ones

**catabolism** reactions in the body that break down large chemicals into smaller ones

**metabolism** the sum of anabolism and catabolism in the body

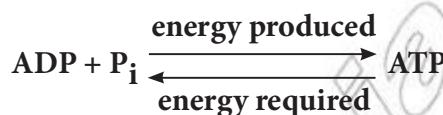
**DID YOU KNOW?**

Cyanide is a deadly poison beloved of crime writers. It smells faintly of almonds and once you have taken it, you quickly die. Cyanide kills because it stops the reactions of respiration in your mitochondria. If you give individual cells cyanide, all active transport stops as their energy supply dries up. But if you supply the cells with energy in the form of ATP, even though the mitochondria are still poisoned, active transport starts again.

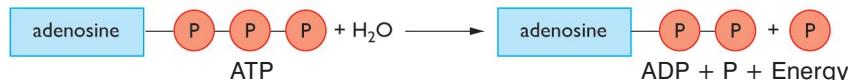


**Figure 3.44** Warm-blooded animals like us use up some of the energy produced by aerobic respiration just keeping a steady body temperature regardless of the weather.

of glucose with oxygen is used to produce large quantities of ATP ready for use in the cells. This is why cellular respiration is so very important – ATP is the single energy providing and energy storing molecule for all the processes in living cells.



(a) When energy is needed ATP is broken down into ADP and phosphate ( $\text{P}_i$ ):



(b) During respiration ATP is made from ADP and phosphate:



**Figure 3.43** ATP is the energy currency of the cell.

**The importance of ATP to the body**

- Your cells need energy from ATP to carry out the basic functions of life, known as metabolism. One of their main functions is to build up large molecules from smaller ones to make new cell material (**anabolism**). Much of the energy released in respiration is used for these ‘building’ activities. Cells also break large molecules down into smaller molecules. This is known as **catabolism** and it also requires energy.

$$\text{anabolism} + \text{catabolism} = \text{metabolism}$$

- Another important use of the ATP energy from respiration is in making muscles contract. Muscles are working all the time in our body, even when we are not aware of using them. Even when we are asleep our heart is beating, our rib muscles and diaphragm contract as we breathe, our gut is churning – and all of these muscular activities use energy.
- We are ‘warm-blooded’. This means that our bodies are the same temperature inside almost regardless of the temperature around us. On cold days we use energy to keep our body warm, whilst on hot days we use energy to sweat and keep our body cool.
- The ATP produced by aerobic respiration in cells also provides energy for the active transport of some materials across cell boundaries.

**Anaerobic respiration**

The energy released by aerobic respiration in muscle cells allows them to move. However, during vigorous exercise the muscle cells may become short of oxygen – the blood simply cannot supply it fast enough. When this happens the muscle cells can still obtain energy from the glucose but they have to do it by a type of respiration that does not use oxygen (**anaerobic respiration**).

Anaerobic respiration produces far less ATP than aerobic respiration. It also produces a different waste product called **lactic acid**. The body cannot get rid of lactic acid by breathing it out as it does carbon dioxide, so when the exercise is over, lactic acid has to be broken down. This needs oxygen, and the amount of oxygen needed to break down the lactic acid is known as the **oxygen debt**. Even though our leg muscles have stopped, our heart rate and breathing rate stay high to supply extra oxygen until we have paid off the oxygen debt. After exercise, the lactic acid is oxidised by oxygen to produce carbon dioxide and water.

#### Anaerobic respiration:



#### Oxygen debt repayment:



When muscle cells have been used for vigorous exercise for a very long time they become fatigued, which means they stop contracting efficiently. They switch to anaerobic respiration, and as the levels of lactic acid build up, your muscles really start to ache. This is known as muscle cramp. Also, anaerobic respiration is not as efficient as aerobic respiration. It does not break down the glucose molecules completely so far less ATP energy is released than during aerobic respiration. So your muscles tire more rapidly and cannot work as well when they are respiring anaerobically, as there is not enough energy for them.

#### KEY WORDS

**anaerobic respiration**  
*breaking down food to release energy without oxygen*

**lactic acid** *product of anaerobic respiration in animal cells*

**oxygen debt** *amount of oxygen needed to break down lactic acid*

### Activity 3.17: Investigating anaerobic respiration in muscles (muscle fatigue)

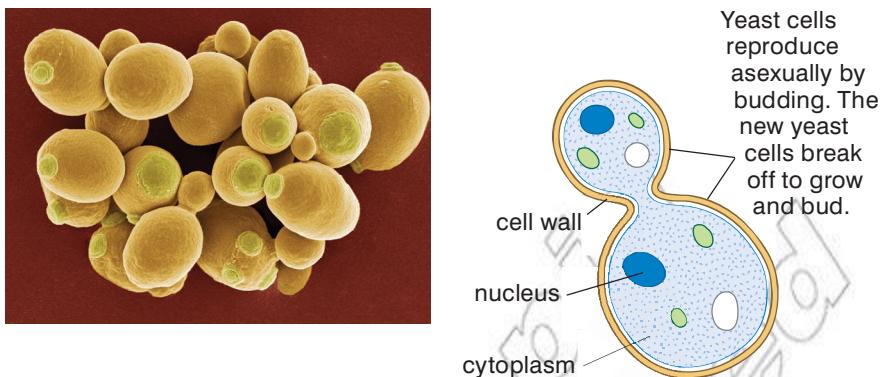
If you carry out a single repetitive action such as stepping up and down or lifting a weight or a book from the bench to your shoulder time after time, you will soon feel the effect of a build-up of lactic acid in your muscles.

You will need:

- book, or other weight that can be held easily in one hand
- stopwatch or clock with clear second hand

#### Method

1. Work in pairs.
2. One member of the pair takes the weight in one hand, with their lower arm flat on the surface of the bench or desk. During the investigation lift the weight regularly from the desk to your shoulder and back down again, taking about one second for each movement. Wait to be told when to start.
3. The other member of the pair starts the stopwatch and gives the instruction to start lifting at the same time.
4. Record how long it takes before the first aching in the muscles start – indicating the beginning of fatigue and the production of lactic acid in the muscles – and how long it takes before you can no longer continue lifting.
5. Swap roles and then repeat the investigation.
6. Collect data from the whole class on the time taken for the first awareness of fatigue to develop and the total time before lifting stops and produce graphs or bar charts to help you analyse the information. What is the range of times for the class? What are the average and the mean times before fatigue develops and before exercise stops? What factors might be affecting the time exercise continues?

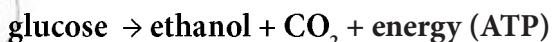


**Figure 3.45** Yeast cells – these microscopic organisms have been useful to us for centuries.

Anaerobic respiration isn't simply something that affects people. It takes place in all living organisms, and in a number of cases we have put anaerobic respiration to very good use, both in our industries and in our homes. For example, one of the micro-organisms that is most useful to people is yeast, a single-celled fungus.

When yeasts have plenty of oxygen they respire aerobically, breaking down sugar to provide energy for the cells and producing water and carbon dioxide as waste products. However, yeast can also respire anaerobically. When yeast cells break down sugar in the absence of oxygen they produce ethanol (commonly referred to as alcohol) and carbon dioxide. The anaerobic respiration of yeast is sometimes referred to as fermentation.

The yeast cells need aerobic respiration because it provides more energy than anaerobic, so it allows them to grow and reproduce. However, once there are large numbers of yeast cells, they can survive for a long time in low oxygen conditions and will break down all the available sugar to produce ethanol.



We have used yeast for making bread and alcoholic drinks almost as far back as human records go. We know yeast was used to make bread in Egypt in 4000 BC, and some ancient wine found in Iran dates back to 5400–5000 BC. You will be learning more about using yeast in your studies in Grade 10.

## Summary

In this section you have learnt that:

- Aerobic respiration is the breakdown of glucose with oxygen to provide energy for the cells. Carbon dioxide and water are the waste products.
- ATP is the molecule that supplies energy to all of the reactions in the cell.
- Anaerobic respiration is respiration without oxygen. In humans, glucose is broken down to form lactic acid and a small amount of energy.
- If muscles work hard for a long time they become fatigued and don't contract properly. If they don't get enough oxygen they will respire anaerobically.
- After exercise, oxygen is still needed to break down the lactic acid that has built up. This oxygen is known as an oxygen debt.

## Review questions

Select the correct answer from A to D.

1. glucose + oxygen → carbon dioxide + water + .....?

Which term is needed to complete the word equation for aerobic respiration?

- A ADP
  - B carbon monoxide
  - C ATP
  - D gas
2. Which of the following is not a commercial use for anaerobic respiration?
    - A production of biogas from human waste
    - B beer making
    - C yoghurt production
    - D bread making

**KEY WORDS****surface area to volume ratio** amount of surface area per unit of volume**blood circulation system** system of blood vessels

transporting blood around the body via the heart

**blood vessels** pipes throughout the body carrying blood**heart** the pump inside the body that moves blood through the vessels**blood** the medium which transports nutrients around the body**DID YOU KNOW?**

William Harvey, a 38-year-old doctor, gave lectures correctly explaining the circulation of the blood for the first time in Europe. In fact he is usually given the credit for having worked out the way the blood circulates in the human body, but in fact the Chinese had understood the process well before the birth of Christ. The Arab doctor Ibn al-Nafis also described the circulation through the lungs in the 13th century AD.

**Figure 3.46** The surface area to volume ratio of the small cube is three times bigger than that of the large cube – imagine the difference between an amoeba and you.

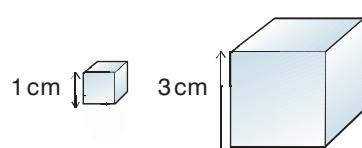
**3.5 The circulatory system**

By the end of this section you should be able to:

- Explain how oxygen and nutrients are transported in the blood.
- Indicate the structures of the heart on a diagram/model.
- Explain the functions of the structures of the heart.
- Examine a mammalian heart using fresh or preserved specimens.
- Take your own pulse, counting the heartbeats using your fingers.
- List the three types of blood vessels.
- Explain the functions of the blood vessels.
- Name the components of the blood.
- Tell the functions of the components of the blood.
- List the four blood groups.
- Indicate the compatibility of the four blood groups.
- Explain the causes and prevention of anaemia and hypertension.

All organisms need their cells to be supplied with oxygen and food in order to function. Small, single-celled organisms rely on simple diffusion to exchange materials between the outside world and the inside of their cells. The diffusion distances are short, so diffusion works really well. However, as animals get larger and are made up of more and more cells, simple diffusion alone is not enough to supply the body needs; there is simply not enough surface area available for the exchanges to take place. This is partly because as animals get bigger, the ratio between the surface area and the volume gets smaller. As diffusion takes place through the surface area but has to reach the innermost volume, the bigger the organism, the less effective simple diffusion becomes as a means of transport.

Human beings are made up of billions of cells, most of them a very long way from a direct source of food or oxygen, so a more complex transport system is required to supply the needs of the body cells and remove the waste material they produce.



amoeba



human

This is why large animals like humans need very complicated transport systems – our **surface area to volume ratio** is such that diffusion simply cannot cope. All of the cells need oxygen and glucose for cellular respiration, the waste products of metabolism must be removed and the many chemicals needed everywhere in the body must be transported to and from the different organ systems.

The human transport system is the **blood circulation system**. It has three elements – the pipes (**blood vessels**), the pump (**the heart**) and the medium (**the blood**). All mammals have a similar system.

## A double circulation

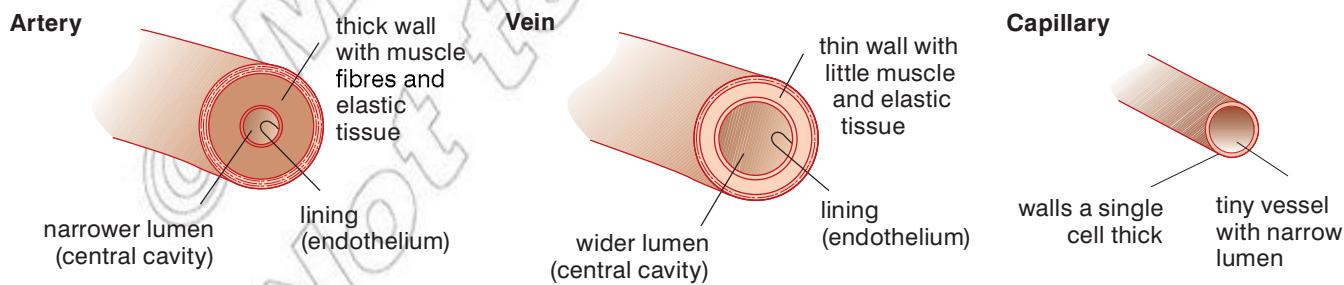
We have a **double circulation**, one carrying blood from the heart to the lungs and back again to exchange oxygen and carbon dioxide with the air, the other carrying blood all around the rest of the body and back again. This gives us a very effective way of getting oxygen into the blood and then supplying it to all the body cells.

In the **pulmonary circulation**, blood flows from the heart to the lungs and back again. In the **systemic circulation** blood is pumped from the heart all around the body and back again.

A double circulation like this is very important in warm-blooded, active animals like ourselves because it is very efficient. It lets our blood get fully oxygenated in the lungs before it is sent off to the different parts of the body. In animals like fish that have a single circulation, as soon as the blood has picked up oxygen it starts to lose it again to the tissues, so very few parts of the body receive fully oxygenated blood.

## The blood vessels

A very important element of any transport system is the pathways along which the transport takes place. In the human body we have three main types of blood vessels, arteries, veins and capillaries, which are adapted to carry out particular functions within the body, although they are all carrying the same blood.



The **arteries** carry blood away from the heart so they have to be able to withstand the pumping of the heart forcing the blood out into the circulation. This is usually oxygenated blood so it is bright red. Arteries have thick walls that contain muscle and elastic fibres, so that they can stretch as the blood is forced through them and go

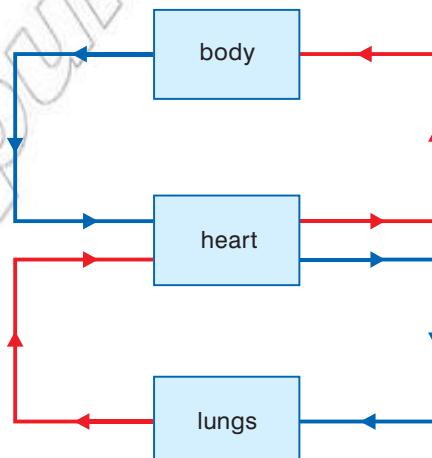
## KEY WORDS

**double circulation** two transport systems within the body carrying blood from the heart to the lungs and back again; and all around the body and back again

**pulmonary circulation** blood flows from the heart to the lungs and back again

**systemic circulation** blood is pumped from the heart, all around the body and back again

**arteries** carry blood away from the heart



**Figure 3.47** The two separate circulation systems supply the lungs and the rest of the body.

## Arteries, veins and capillaries

**Figure 3.48** Arteries, veins and capillaries – different blood vessels for different functions in the body.

**DID YOU KNOW?**

The blood from a severed artery can spurt about 2 metres away from your body!

**KEY WORDS**

**veins** carry blood towards the heart

**capillaries** link veins and arteries and take blood to all the organs and tissues of the body



**Figure 3.49** The valves in the veins stop your blood from flowing backwards and so move it on towards your heart.

back into shape afterwards. Arteries have a pulse in them that you can feel at certain places in the body (like the wrist) where they run close to the surface – the pulse is the surge of blood from the heart when it beats. Because the blood in the arteries is under pressure, it is very dangerous if an artery is cut because the blood spurts out rapidly every time the heart beats. This means blood is lost very rapidly and the bleeding is difficult to stop. The only arteries that carry deoxygenated blood are the pulmonary arteries, which carry the blood away from your heart to your lungs, and the umbilical artery, which carries blood away from a foetus into the placenta (you will learn more about this in Grade 10).

The **veins** carry blood towards your heart – it is usually low in oxygen and so is a deep purple-red colour. They have much thinner walls than arteries and the blood in them is under much lower pressure because it is a long way away from the thrust of the heart. They do not have a pulse, but they often have valves to prevent the back-flow of blood as it moves from the various parts of the body back to the heart. The only veins that carry bright red blood are the pulmonary veins, which carry oxygenated blood back from your lungs to the left-hand side of your heart, and the umbilical vein, which carries oxygenated blood from the placenta back to the developing foetus to supply it with the food and oxygen it needs to grow.

**Activity 3.18: Investigating the role of valves in veins**

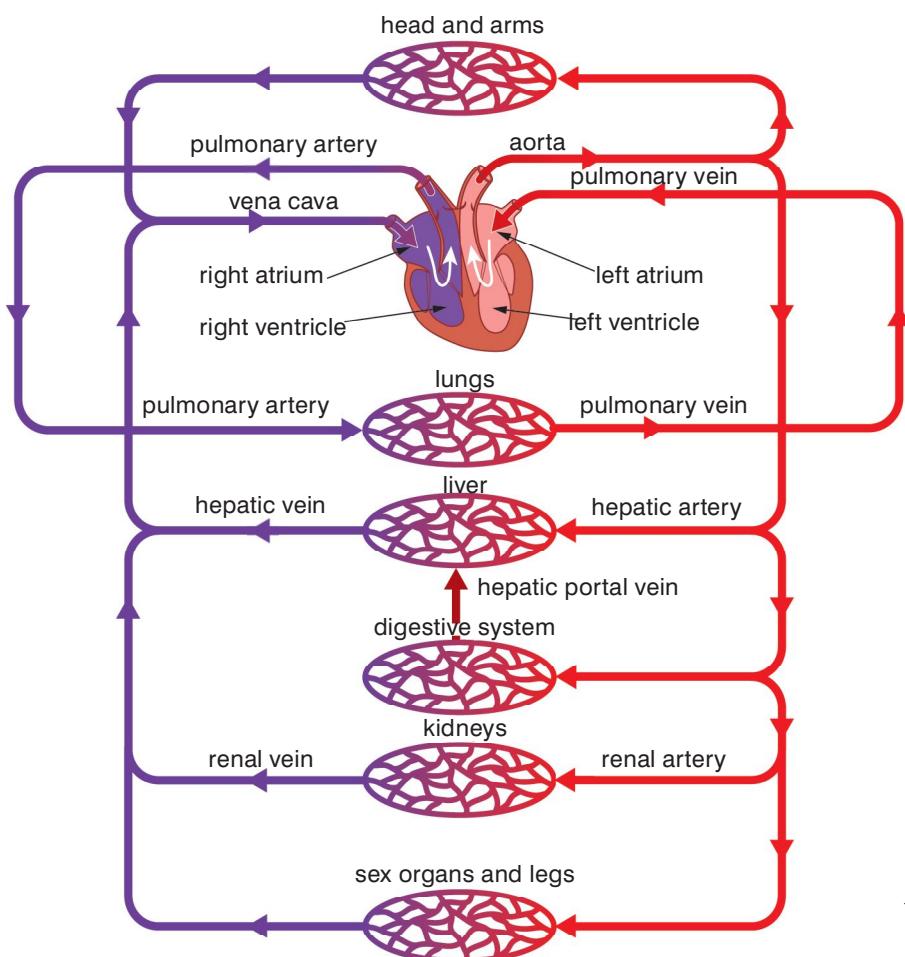
You can easily investigate the role of the valves in preventing the backflow of blood using your own hand.

Swing your arm around a few times to move blood down into your hand and then keep your hand hanging down. The veins in your hand and lower arm should have become more prominent and you should see bulges in places on the veins. These are the valves. Find two valves with some vein visible between them.

First press on the valve nearest to your heart and then gently squeeze the blood out of the vein towards the other valve. Release the second valve, and you should see blood flow back into that stretch of vein.

Now repeat the other way round. Press on the valve furthest from your heart, gently clear the blood to the next valve – and then release the second valve. There should be no flow of blood back into that stretch of vein, because the valve prevents the backflow from higher up the arm. Once you release the first valve, blood will flow back into the vessel from the hand.

Between the arteries, that bring blood from the heart, and the veins, that take it back to the heart, are very narrow, thin-walled blood vessels called capillaries. The **capillaries** link the other two types of blood vessels. These take the blood into all the organs and tissues of



**Figure 3.50** This diagram shows you the main components of the human circulatory system.

the body. The capillaries are the site of the exchange of substances within the body. Blood from the arteries passes into the capillaries, which have very thin walls and a massive surface area. Substances such as oxygen and glucose that are needed by the cells of your body can easily pass out of the blood by diffusion along a concentration gradient. In the same way substances produced by the cells such as carbon dioxide pass into the blood through the walls of the capillaries. The blood leaves the capillary network flowing back into veins to be returned to the heart and recirculated around the body.

## The human heart

The human heart is a bag of reddish-brown muscle that beats right from the early days of our development in the uterus until the end of our life, sending blood around the body. The heart is made up of two pumps that beat at the same time so that blood can be delivered to the body about 70 times each minute. The heart is made up of a unique type of muscle known as **cardiac muscle**, which can contract and relax more or less continuously without fatiguing.

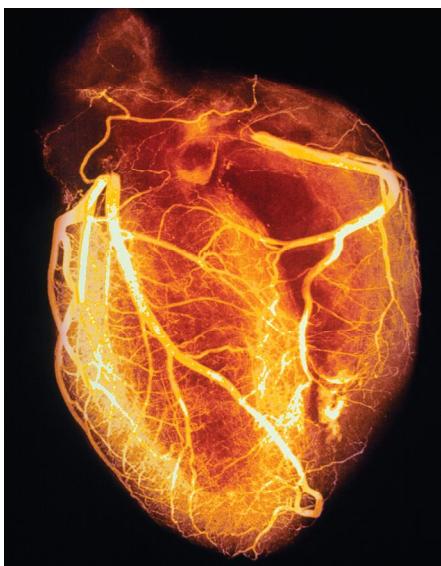
The walls of the heart are almost entirely muscle. These muscular walls are supplied with blood by the **coronary arteries**, so that they have a constant supply of glucose and oxygen and the carbon dioxide produced is not allowed to build up in the tissue. The deoxygenated blood is carried away in the coronary veins, which feed back into the right **atrium**.

### KEY WORDS

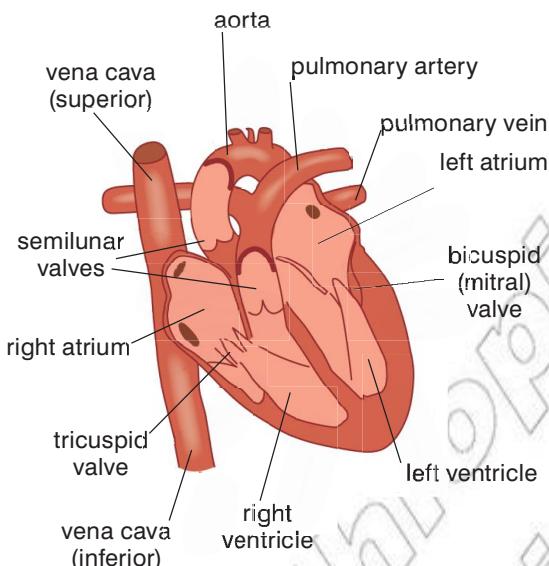
**cardiac muscle** contracting muscle of the heart

**coronary arteries** supply blood to the cardiac muscles

**atria** top chambers of the heart

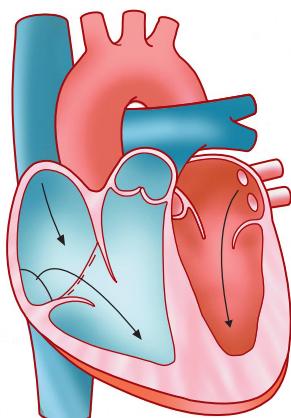


a) External view to show coronary arteries

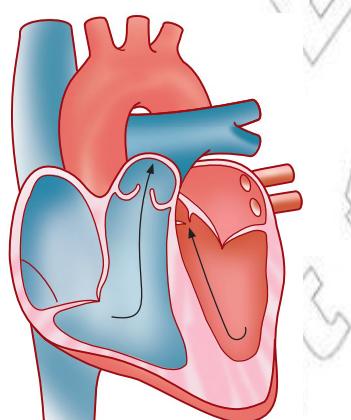


b) Vertical section through the heart

**Figure 3.51** The structure of the human heart is perfectly adapted to the job it has to do.



Diastole: heart muscle is relaxed and atria and ventricles fill with blood.



Systole: ventricles contract and force blood out through the arteries. Tricuspid and bicuspid valves close to prevent blood passing back into atria.

**Figure 3.52** As the heart fills and empties the two sides of the heart work in perfect harmony.

The walls of the atria are relatively thin, so they can stretch to contain a lot of blood. The walls of the **ventricles** are much thicker, as they have to pump the blood out through the major blood vessels. The muscle walls of the left-hand side of the heart are thicker than on the right (see figure 3.51). This is because the left-hand side of the heart has to pump blood around the whole body whilst the right-hand side pumps only to the lungs.

### The working of the heart

The two sides of the heart fill and empty at the same time to give a strong, co-ordinated beat, but to understand what happens it is easier to follow a single volume of blood around the heart.

- Deoxygenated blood, which has supplied oxygen to the cells of the body and is loaded with carbon dioxide, comes into the right atrium of the heart from the veins of the body.
- The atrium contracts and forces blood into the right ventricle.
- The right ventricle contracts and forces blood out of the heart and into the lungs where it is oxygenated – it picks up oxygen.
- Oxygenated blood returns to the left-hand side of the heart from the lungs and the left atrium fills up.
- The left atrium contracts forcing blood into the left ventricle.
- The left ventricle contracts forcing oxygenated blood out of the heart and around the body.

Inside the heart there are many different **valves**. Their names describe their appearance – bicuspid (two parts) tricuspid (three parts) and semilunar (half-moon). Each time the muscular walls of the heart contract and force blood out, some of these valves open to allow the blood to flow in the right direction, and other valves close to make sure that the blood does not flow backwards. The noise of the heartbeat we can hear through a stethoscope is actually the sound of these valves transporting the surging blood. First the

atria fill with blood and then the ventricles fill, followed by the contraction of both ventricles, emptying the heart.

**Diastole** is when the heart muscles relax and it fills with blood.

**Systole** is when the heart muscles contract and force the blood out of the heart.

The pressure at which the blood travels around your arteries varies as the heart beats. So when doctors measure your blood pressure they usually do it in a way that covers the two extremes of the cardiac cycle. At systole, when the heart is contracting and forcing blood out into your arteries, the blood pressure is at its highest – this is the systolic blood pressure and it is the higher of the two readings taken. At diastole, when the heart is relaxed and filling, the pressure is lower – this is the diastolic blood pressure and it is the lower reading. A normal blood pressure is 120 mmHg/80 mmHg – usually quoted as 120 over 80 or 120/80. Your blood pressure will vary through the day and depending on what you are doing. Blood pressure is used as a measure of the health of both the heart and the blood vessels.

## KEY WORDS

**ventricles** large, lower chambers of the heart that pump blood out to the lungs and body

**valve** mechanism in the veins that allows blood to flow in one direction only

**diastole** the relaxed heart when the blood pressure is lowest

**systole** the heart as it contracts, when the blood pressure is highest

### Activity 3.19: Examining a mammalian heart

If you have the opportunity to dissect the heart of an animal like a sheep or a pig, you can see the different features from the diagram and gain an insight into their adaptations and how the whole heart works. However, the blood vessels and the atria can be damaged by the butcher, so you may not be able to see everything you would like to.

You will need:

- board for dissection
- dissecting equipment including a scalpel and a mounted needle – take care, the blade is very sharp
- heart from domestic animal, e.g. sheep, cow – you need as many of the tubes intact as possible and any surrounding fat

#### Method

1. Examine the heart carefully while still intact. Find the blood vessels, the atria, the ventricles, the coronary arteries and any fat. Draw and label what you can see.
2. Make cuts through the wall of the heart as shown in figure 3.53.
3. Open the heart gently and try to identify as many structures as you can. Compare the thickness of the walls of the atria (if they are present), the right ventricle and the left ventricle and remind yourself of why they are so different. Look for the valves between the atria and the ventricles and the valves between the ventricles and the great vessels – the pulmonary vein and the aorta.
4. Draw and annotate your dissection.

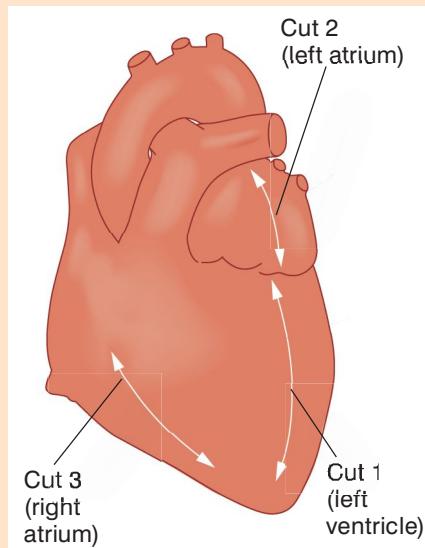


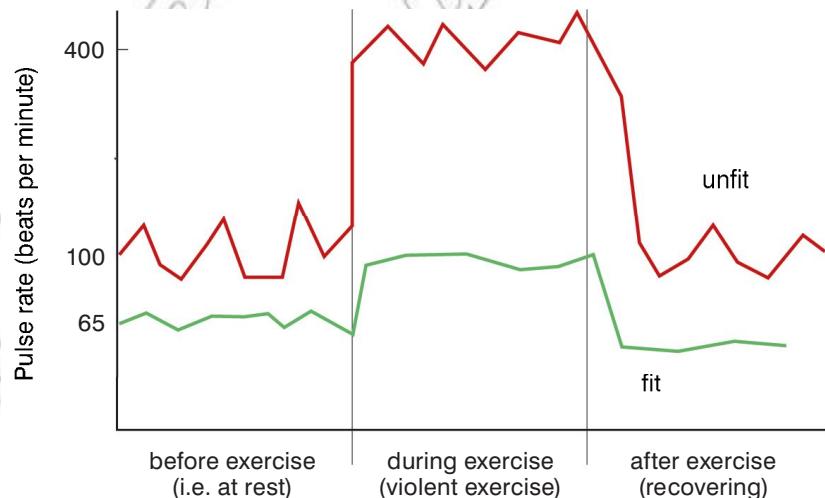
Figure 3.53 Guide to dissecting a mammalian heart

### The flexible heart

When we are resting our heart beats steadily at around 70 beats every minute, supplying all the needs of the cells. However, physical exercise means that muscles need more food and oxygen to work, and so the heart needs to supply more blood. It does this in two ways. The heart beats faster – the pulse rate can easily go up from rest to 120 or even 140 beats a minute, increasing the amount of blood flowing around the body. The heart can also increase the amount of blood pumped out at each heartbeat.

If people do lots of physical exercise and are fit, their heart responds by becoming bigger and stronger. Because their heart pumps more blood with each beat, fit people tend to have relatively slow resting heartbeats – some are as low as 50 beats a minute.

Your heart doesn't beat with a steady rhythm all the time – it responds to all the needs of your body. When you exercise your heart rate increases; if you are worried, stressed or angry your heart rate will go up as well – sitting an exam or having an argument can raise your heart rate as much as if you were running a race!



**Figure 3.54** A fit heart responds quickly to exercise and returns rapidly to its resting rate when exercise is finished. People with less fit hearts can feel them racing for several minutes after they stop exercising!

### Activity 3.20: Measuring your own heart rate and investigating the effect of activity on your heart rate

A good way of telling how fit you are is to measure your resting heart rate. The simplest way to investigate your heart rate is to take your pulse – your pulse simply reflects the surge of blood in the arterial system each time your heart contracts, so it is a good way of recording your heart rate. The fitter you are, the fewer beats per minute you will have. Then see what happens when you exercise – the increase in your heart rate and how fast it returns to normal is another way of finding out how fit you are – or aren't! Anyone who is affected by asthma or has any other illness should take care before taking part in this practical and take any medication they would normally use before a PE session. Anyone who does not normally take part in PE should act as timekeeper and recorder in this investigation and not take part in the physical exercise.

#### You will need:

- stopwatch or clock with clear second hand

#### Method

1. First practise actually finding and taking your pulse either in your wrist or in the side of your neck!
2. Find out your resting pulse rate. Sit quietly without speaking for two minutes at least. Then start the stopwatch and record the number of pulse beats in 15 seconds. Repeat this three times to get an average resting pulse.
3. Now exercise gently for two minutes by walking on the spot.
4. As soon as you stop exercising, find your pulse and record the number of beats in 15 seconds. Repeat this every 30 seconds until your pulse returns to your resting rate.
5. Now change the way you exercise. Exercise harder for two minutes by gentle jogging on the spot. As soon as you stop exercising, start to record your pulse beats. Record for 15 seconds every 30 seconds until it returns to your resting rate.
6. Finally exercise hard for two minutes – run on the spot as hard as you can. As soon as you stop exercising start to record your pulse. Record it as above until it returns to your resting rate. If you prefer, you can simply extend your period of more gentle exercise, by walking or jogging gently for four minutes instead of two.
7. Write up your investigation, including your results. If you multiply all of your results by four it will give you your pulse rate per minute.

	Beats in 15 seconds	Pulse rate (beats per minute)
Before exercise	1	
	2	
	3	
	mean	
Time after exercise(s)	0	
	30	
	60	
	90	
	120, etc.	

Make a graph of your own personal data and explain what you have observed. In some cases your pulse rate may drop below your normal resting rate as you recover. Can you explain what is happening?

8. Collect data from other members of the class and compare the pulse rates and recovery times of the group. Now look for patterns in your data. Are there differences between boys and girls? Do the members of sports teams show different patterns to the rest of the class?

**DID YOU KNOW?**

Each adult has approximately 5 litres (10.6 pints) of blood containing about 15 billion red blood cells that travel around their body in around 80 000 kilometres (50 000 miles) of blood vessels!

**KEY WORD**

**plasma** pale yellow liquid component of blood that transports the blood cells

**DID YOU KNOW?**

The more red blood cells an athlete has, the more oxygen they can carry and so the better they can perform. Some athletes train at altitude because one way in which your body responds to the low oxygen levels at altitude is to make more red blood cells. Training at altitude is legal, but some other ways of increasing your red blood cell count to avoid oxygen debt are not: sometimes athletes remove some of their own blood, store it and then, just before a competition, transfuse it back again (blood doping); others use hormones to stimulate the growth of more red blood cells. Both of these methods give an athlete extra red blood cells to carry more oxygen to the working muscles so they can run faster or compete better.

**The blood**

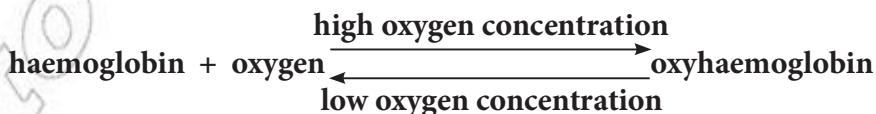
The heart and the blood vessels are there to carry the transport medium around your body – and the transport medium is your blood. Your blood is a complex mixture of cells and liquid that carries a huge range of substances around the body. It consists of a liquid called the plasma, which carries red blood cells, white blood cells and platelets.

The **plasma** is a pale yellow liquid that transports all the blood cells but also a number of other things. Carbon dioxide produced in the organs of the body is carried in the plasma back to the lungs. Similarly urea, a waste product from the breakdown of excess proteins formed in the liver, is carried in the plasma to the kidneys where it is removed from the blood to form urine.

All the small, soluble products of digestion pass into the blood from the gut. They are carried in the plasma around the body to the organs and individual cells that need them.

One of the main components of your blood is the **red blood cells**. There are more red blood cells than any other type of blood cell. They are superbly adapted to their role in carrying oxygen around your body and supplying it to the cells where it is needed.

The red blood cells can do this because they are packed with a special red substance called **haemoglobin**, which picks up oxygen. Haemoglobin is a very special red pigment, a large protein molecule folded around four iron atoms. In a high concentration of oxygen, such as in the lungs, the haemoglobin reacts with oxygen to form oxyhaemoglobin. This is bright scarlet, which is why most arterial blood is bright red. In areas where the concentration of oxygen is lower, such as the cells and organs of the body, the reaction reverses. The **oxyhaemoglobin** splits to give purple-red haemoglobin (the colour of venous blood) and oxygen. The oxygen then passes into the cells where it is needed by diffusion. This reversible reaction makes active life as we know it possible by carrying oxygen to all the places where it is really needed.



The red blood cells are made in your bone marrow and once they are mature they lose their nucleus. This means that there is more room to carry extra haemoglobin – another adaptation to their all-important function. Because they have no nucleus, the red cells only live 100–120 days in your body, so they are constantly being replaced. Because the haemoglobin in your red blood cells is based on iron, it is important to eat enough iron in your diet. Without it, the body cannot make enough red blood cells and you suffer from **anaemia**. People who are anaemic are pale and lack energy, because they cannot carry enough oxygen around the body for their needs.

The red blood cells have a unique shape – they form biconcave discs. This is another adaptation to their function. The shape gives

them a large surface area to volume ratio for the diffusion of oxygen into and out of the cell. It also means they are relatively thin, giving short diffusion distances, which again makes the exchange of gases more efficient.

Red blood cells also have a thin surface membrane for ease of diffusion. This allows them to squeeze easily through the very narrow capillaries.

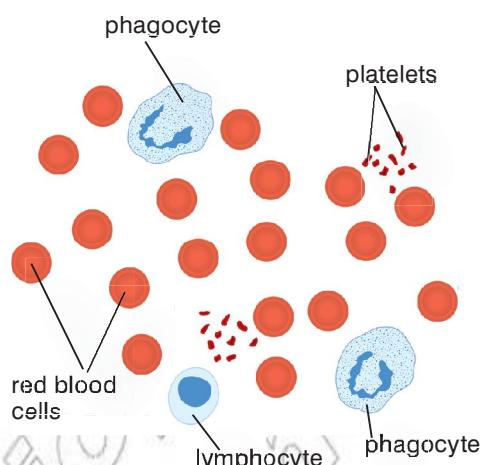
Another important component of your blood is the **white blood cells**. They are much bigger than the red cells and there are fewer of them. They have a nucleus and form part of the body's defence system against microbes. Some white blood cells – the lymphocytes – form antibodies against microbes whilst others – the **phagocytes** – engulf invading bacteria. You will find out more about the role of the white blood cells in your body when you study the immune system later in this book.

**Platelets** are another component of your blood. They are small fragments of cells and they are very important in helping your blood to clot at the site of a wound. When platelets arrive at a wound site they are involved in the formation of a network of protein threads. Then as more platelets and red blood cells pour out of the wound they become entangled in the mesh of threads forming a jelly-like clot. This soon dries and hardens to form a scab. The clotting of the blood is a very important process. It prevents you from bleeding to death from a simple cut. It also protects your body from the entry of bacteria and other pathogens (disease-causing micro-organisms) through an open wound, and protects the new skin from damage as it grows.

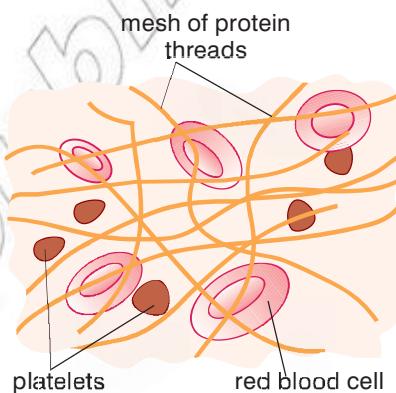
## Human blood groups

A number of special proteins called **antigens** are found on the surface of all cells. They allow cells to recognise each other and also to recognise cells from different organisms. If the cells of your immune system recognise a foreign antigen on a cell in your body, they will produce **antibodies**. These antibodies will join on to the antigen and destroy the foreign cells. This is how your immune system recognises and fights the organisms which cause disease.

A number of different antigens are found specifically on the surface of the red blood cells. This gives us the different human blood groups. There are several different blood grouping systems, but the best known is the ABO system. In this system there are two possible antigens on the red blood cells – antigen A and antigen B. There are also two possible antibodies in the plasma, known as antibody a and antibody b. Unlike most other antibodies, these antibodies are present in your body all the time. They are not made in response to a particular antigen. Table 3.7 shows you the four combinations of antibodies and antigens which give rise to the four ABO blood groups.



**Figure 3.55** Mixed together with plasma these different types of cells make up our blood.



**Figure 3.56** Without platelets, clotting would not occur and we could bleed to death from a simple cut.

## KEY WORDS

- red blood cells** carry oxygen around the body
- haemoglobin** red pigment inside red blood cells
- oxyhaemoglobin** bright red product that forms in the blood when oxygen from the lungs combines with haemoglobin
- anaemia** deficiency disease from lack of iron
- white blood cells** form part of the body's defence against microbes

**KEY WORDS**

**phagocytes** white blood cells that engulf invading bacteria

**platelets** small components of blood that help it to clot at the site of a wound

**antigens** proteins found on the outer surface of all cells

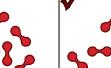
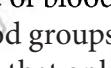
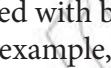
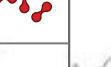
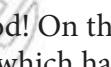
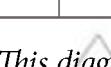
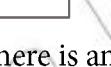
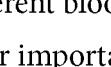
**antibodies** proteins made by white blood cells that inactivate pathogens

**Table 3.7 Antigens and antibodies of different blood groups**

Blood group	Antigen on red blood cells	Antibody in the plasma
A	A	b
B	B	a
AB	AB	none
O	none	ab

If the blood from different blood groups is mixed together, there may be a reaction between the antigen and the complementary antibody which makes the red blood cells stick together (agglutinate). This means they cannot work properly. They block the capillaries and even larger blood vessels. Most of the time this is not important since everyone keeps their own blood in their own circulatory system. But if someone loses a lot of blood in an accident, an injury, when giving birth or during an operation then they may need a blood transfusion. This is when blood taken from

one person is given to another to save their life. Before a transfusion it is vital to know the blood groups of both the person giving the blood (the donor) and the person receiving the blood (the recipient). This means the right type of blood can be given to prevent agglutination. The blood groups must be compatible. It is not usually the case that only one type of blood can be given, simply that blood containing a particular antigen must not be mixed with blood containing the matching antibody. For example, blood group O has no antigens so it can be given to anyone, but someone who has blood group O has both antibodies so they can only receive group O blood! On the other hand someone with blood group AB which has no antibodies can receive any type of blood! Figure 3.57 summarises the compatibilities of the different blood groups.

Recipient \ Donor	O (antibodies a and b)	A (antigen A, antibody b)	B (antigen B, antibody a)	AB (antigens A and B)
O (antibodies a and b)	✓ 	✓ 	✓ 	✓ 
A (antigen A, antibody b)	X 	✓ 	X 	✓ 
B (antigen B, antibody a)	X 	X 	✓ 	✓ 
AB (antigens A and B)	X 	X 	X 	✓ 

**Figure 3.57** This diagram shows you the compatibility of the different blood groups.

There is another important factor which affects the safety of blood donations. HIV/AIDS is a very serious disease which affects the blood and the immune system. If someone receives a blood donation from a person infected with HIV/AIDS they too will become infected. For this reason all blood which is used for blood donations needs to be screened carefully. Only people who are free from HIV infection should donate blood, and blood should be treated to remove any risk of cross-infection. You will be learning a lot more about HIV/AIDS in section 4.3 of this book.

### Two common problems of the circulatory system

One common problem of the circulatory system is a condition called anaemia. If you are anaemic you have too few red blood cells in the body, or the levels of the oxygen-carrying red pigment haemoglobin in your blood are too low. There are a number of causes of anaemia. The most common is a lack of iron in the diet.

As you saw in section 3.1, iron-rich food includes meat and liver as well as apricots, eggs and some green leafy vegetables. If your diet is lacking in these foodstuffs, you may suffer anaemia. The main symptoms are tiredness and lack of energy, because your body cells are constantly deprived of oxygen. This means you cannot study or work as effectively. Girls are more likely to be anaemic than boys because they lose iron each month in their menstrual bleeding. Women are more likely to be anaemic than men because of the demands of pregnancy when they need to take in enough iron for both themselves and their developing baby, and because of the blood loss during and after childbirth. However, both men and women who are malnourished can be affected by anaemia. Anyone who suffers an injury and bleeds a lot, or who has internal bleeding for any cause, is also likely to become anaemic if they do not have a blood transfusion and a diet rich in iron.

**Hypertension** is another common complaint of the circulatory system. Hypertension is the medical name for high blood pressure. Blood pressure is considered high if the systolic pressure is greater than 140 mmHg or the diastolic pressure is greater than 90 mmHg.

For 90% of the cases of hypertension, the cause is unknown. For the other 10%, hypertension is a symptom of another disease, such as chronic kidney diseases or diseases in the arteries supplying the kidneys, chronic alcohol abuse, hormonal disturbances or tumours.

There are a number of factors that can increase the risk of you developing hypertension. Many of these factors mean that your blood vessels are likely to be getting narrower, or becoming more rigid, both of which increase your blood pressure.

These factors include: increasing age, being overweight, excessive salt intake, excessive consumption of alcohol, sedentary (inactive) lifestyle, smoking, kidney diseases, diabetes and certain medicines, such as steroids.

There is also evidence to suggest that hypertension may be genetic (i.e. run in the family).

### Hypertension in Ethiopia

There are record high levels of high blood pressure in Ethiopia. Although people living and working in the countryside have very low levels, recent scientific studies show us that as many as 30% of the adults living in cities such as Addis Ababa have hypertension or are on medication to control high blood pressure. There are similarly high levels of obesity and people who take very little exercise. This growth of hypertension in Ethiopian cities may lead to many problems in the future, because high blood pressure causes damage to many systems in the body. It can cause heart attacks and strokes.

### Treatment of hypertension

For many people hypertension can be managed through lifestyle adjustments. Losing weight, lowering the salt levels in the diet and

### KEY WORD

**hypertension** *high blood pressure*



**Figure 3.58** It takes very little time to take your blood pressure. Yet regular checks to monitor your blood pressure can pick up any problems early before your heart and blood vessels are damaged.

### Activity 3.21: Modelling the effects of narrowing blood vessels on blood pressure

You can model the way in which narrow blood vessels increase your blood pressure using water from the tap.

Attach a piece of rubber tubing to a tap and let it run.

Observe the force of the water coming out (the water pressure).

Now squeeze the rubber tubing gently to narrow it.

What happens to the water pressure now – and how is this relevant to what happens in your body if your blood vessels narrow with age or disease?



**Figure 3.59** Careful monitoring at clinics, changes in lifestyle and the use of medication will bring high blood pressure under control for most people.

becoming more active will lower the blood pressure back within normal level for some people. However, for some people these changes have little effect on their blood pressure.

Fortunately, if your blood pressure is raised and does not respond to changes in your lifestyle, there are also medications that can be taken. Some common ones include **diuretics**, which increase the frequency of urination. These remove water from the body, which reduces the blood volume and so lowers the blood pressure. There are other drugs that block the nerves which narrow the arteries. These are known as **beta blockers**, while there are other drugs which act directly on the brain. Once people start using medication for hypertension, they will usually need it for many years or life. Because of the long timescale for treating hypertension, cost is an important consideration in the choice of drugs.

## Summary

In this section you have learnt that:

- The body transport system consists of the blood vessels (the pipes), the heart (the pump) and the blood (the medium).
- Human beings have a double circulation – the pulmonary circulation to the lungs and the systemic circulation to the body.
- The three main types of blood vessels are the arteries, veins and capillaries and they are each adapted for a different function.
- The heart is mainly made of muscle.
- It pumps blood around the body in response to the needs of the tissues.
- Blood enters the atria of the heart, which contract to force blood into the ventricles. When the ventricles contract blood leaves the heart to go to the lungs (from the right) and around the body (from the left).
- Valves control the flow of blood in the heart.
- The blood has four main components:
  - 1 – Plasma, which transports dissolved food molecules, carbon dioxide and urea.
  - 2 – Red blood cells, which transport oxygen.

3 – White blood cells, which defend against attack by microbes.

4 – Platelets, which help clot the blood.

- Oxygen is carried by haemoglobin, which becomes oxyhaemoglobin in a reversible reaction.
- Tissue fluid is forced out of the blood in the capillaries and bathes the cells of the body. Exchange of substances by diffusion between the blood and the cells takes place through the tissue fluid.
- When the tissue fluid passes into the lymph system it becomes lymph. Lymph eventually returns to the blood enriched with antibodies.
- There are four main blood groups: A, B, AB and O. They are not all compatible and they must be matched carefully before a blood transfusion.
- Anaemia and hypertension are two diseases of the circulatory system which are particularly common in Ethiopia.

## Review questions

Select the correct answer from A to D.

1. What are the main parts of the human transport system?
  - A the heart, the blood vessels and the blood
  - B the heart, the blood and the lymph
  - C the heart, the arteries and the veins
  - D the arteries, the veins and the capillaries
2. The main job of the arteries is:
  - A to carry deoxygenated blood away from the heart
  - B to carry oxygenated blood away from the heart
  - C to carry deoxygenated blood to the heart
  - D to carry oxygenated blood to the heart
3. Which type of vessels have a pulse?
  - A capillaries
  - B lymph vessels
  - C veins
  - D arteries
4. Which chamber of the heart has the thickest walls?
  - A right atrium
  - B left atrium
  - C right ventricle
  - D left ventricle
5. The main role of the platelets in your blood is in:
  - A the clotting mechanism
  - B the carriage of oxygen
  - C the carriage of carbon dioxide
  - D the production of antibodies against invading organisms

## KEY WORDS

**diuretics** chemicals which increase the output of urine

**beta blockers** drugs that are used to lower blood pressure

### End of unit questions

1. What are the main similarities and differences between the three main food groups, carbohydrates, proteins and fats?
2. What is a condensation reaction and why is it so important in the food we eat?
3. How would you test a food sample to see if it contained i) starch and ii) fat?
4. Plan a menu of meals for a day and show how eating this food would give a person a balanced diet.
5. The three main types of food molecules are carbohydrates, proteins and fats.
  - a) For each of these substances, give three examples of foods and where you would find them.
  - b) State what each substance is used for in the body.
6. a) What are enzymes?
  - b) How do enzymes work?
  - c) List the types of enzymes made in the salivary glands, the stomach, the pancreas and the small intestine. In each case say which food substance the enzymes break down.
7. a) Explain how the gut is adapted to allow digested food to be absorbed readily into the blood.
  - b) Explain what happens if too much water is reabsorbed into the blood from the material in the large intestine and the problems this can cause.
  - c) Explain what happens if too little water is reabsorbed into the blood from the material in the large intestine and the problems this can cause.
8. a) Define the terms ingestion, digestion, absorption, assimilation and egestion.
  - b) There can be a number of problems with egestion. Explain how these problems can affect the health of the individual concerned.
9. a) Explain how canning preserves food.
  - b) Give two examples of common canned food.
  - c) Cans should always be handled and stored carefully. Explain why this is.

10. For gas exchange in the lungs to work effectively we need to move air in and out of the lungs regularly. We do this by breathing. Our breathing movements involve the muscles between the ribs and the diaphragm. Explain carefully, using diagrams if you feel they will help, the events that take place:
- when you breathe in
  - when you breathe out
11. The air you breathe in contains about 20% oxygen and only 0.04% carbon dioxide. The air you breathe out contains around 16% oxygen and 4% carbon dioxide. What happens in your lungs to bring about this change? (Include details of the alveoli of the lungs in your answer.)
12. Make a table summarising the main components of tobacco smoke and their effects on the human body.
13. a) Smokers are more likely to get infections of their breathing system than non-smokers. Why do you think this might be?  
 b) In bronchitis, the tubes leading down to the lungs produce a lot of mucus. Compare the way the body of a non-smoker would deal with this mucus with the effect it would have on a smoker.
14. a) Define the following terms:  
 aerobic respiration; anaerobic respiration; oxygen debt  
 b) Write a word equation for aerobic respiration.  
 c) How does aerobic respiration differ from anaerobic respiration?
15. a) Aerobic respiration provides energy for the cells of the body. Explain why cells need this energy and what they use it for.  
 b) If you exercise very hard or for a long time, your muscles begin to ache and do not work so effectively. Explain why.  
 c) If you exercise very hard, you often puff and pant for some time after you stop. Explain what is happening.
16. Copy and complete this table to show the main components of the blood, their appearance and what they do in your body.

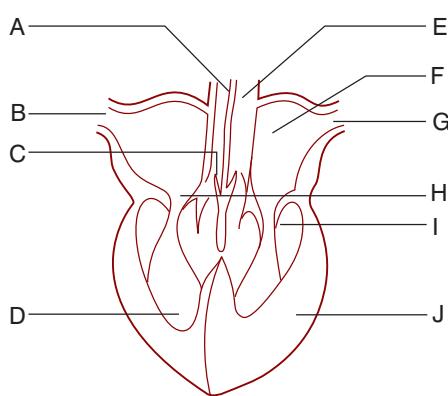
Part of the blood	Description

17. The plasma is very important for transporting substances round the body. Three of the main substances transported are carbon dioxide, urea and digested food.

- For each substance say where in the body it enters the plasma.
- For each substance say where it is transported to, and what happens to it when it gets there.

18. The red blood cells carry oxygen around the body.

- Draw and label a typical red blood cell.
- Explain how red blood cells carry oxygen around your body and release it in the tissues where it is needed.
- How are red blood cells adapted for their role in your body?



19. a) The diagram opposite shows a vertical section of a human heart. Match the structures listed below to the labels on the heart. Write the letter from the diagram with the correct label.

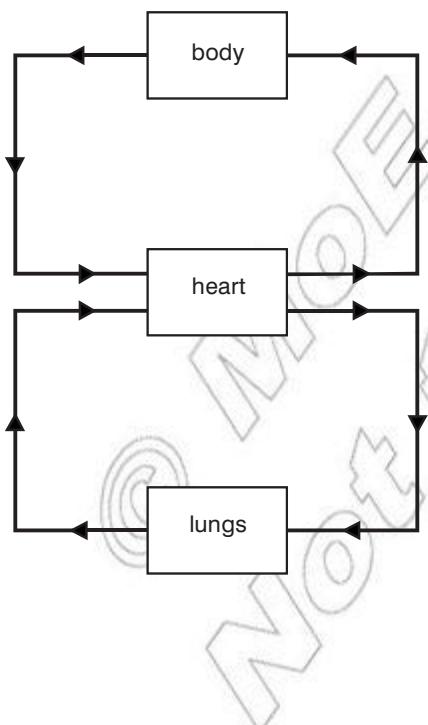
- |                  |                 |
|------------------|-----------------|
| aorta            | left atrium     |
| pulmonary artery | right ventricle |
| pulmonary vein   | bicuspid valve  |
| vena cava        | tricuspid valve |
| left ventricle   | semilunar valve |

- Describe the flow of blood through the heart, from the time it enters the heart through the vena cava to leaving the heart through the aorta.

20. This diagram shows the double circulation of the human heart. Use it to help you answer the following questions:

- Copy the diagram and shade it blue in the areas where the blood is deoxygenated and red in the areas where you would expect oxygenated blood.
- What happens to the blood in the body?
- What happens to the blood in the lungs?
- Why is it called a double circulation?

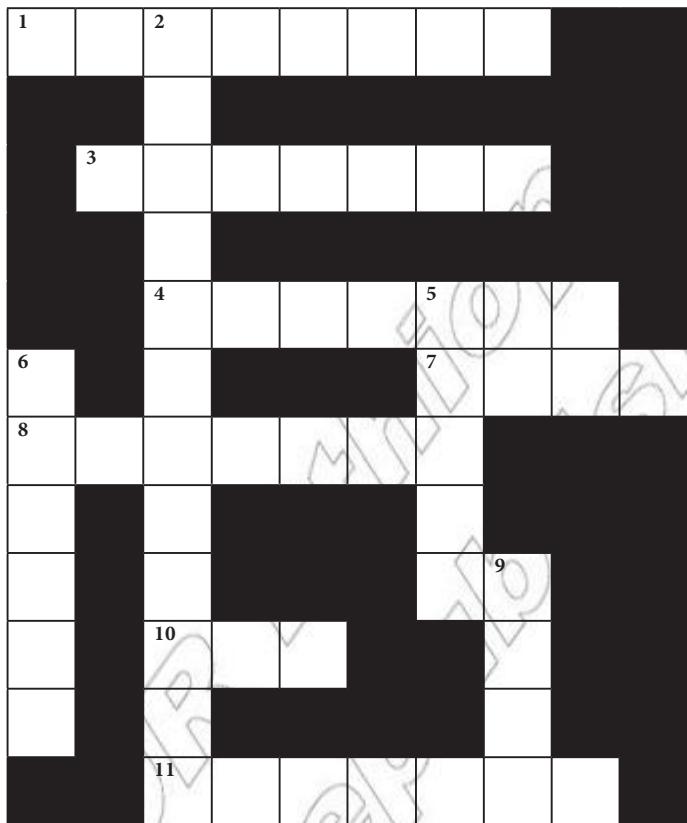
- Name the three main types of blood vessel.
- Describe the job of each type of blood vessel in the body.
- Draw an annotated diagram of each type of blood vessel, using the annotations to describe how the blood vessel is adapted to its function.



22. Plan an investigation into the heart fitness levels of the teachers in your school. Describe carefully how you would set up the investigation, what precautions you would need to take and how you would display your results.
23. a) Define the term hypertension.  
b) Explain the term blood pressure and how it is maintained.  
c) Give five major risk factors for hypertension.  
d) Levels of hypertension are increasing rapidly in Ethiopian cities, but much less so in rural communities. How would you explain this difference?

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Copy the crossword puzzle below into your exercise book (or your teacher may give you a photocopy) and solve the numbered clues to complete it.



#### Across

- 1 The addictive drug in cigarettes (8)
- 3 The food group needed for body building and growth (7)
- 4 Too much food can cause excess fat called \*\*\*\*\* (7)
- 7 The organ in which gas exchange takes place (4)
- 8 The gas carried around the body in the red blood cells (6)
- 10 The form in which energy is needed in the cell (3)
- 11 Food in the digestive system is broken down by \*\*\*\*\* (7)

#### Down

- 2 The main food group used to supply energy to the body (12)
- 5 The region of the small intestine where digested food is absorbed into the blood (5)
- 6 The chemical used to test for starch (6)
- 9 Greenish liquid formed in the liver and stored in the gall bladder (4)