Biology

Student Textbook
Grade 10

Federal Democratic Republic of Ethiopia
Ministry of Education

ISBN 978-99944-2-010-0

Price: ETB 36.00

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Biotechnology

Unit 1

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1.1 What is biotechnology?

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

- Define biotechnology.
- Discuss the significance of biotechnology.
- Explain some of the traditional uses of biotechnology, for example, in preparing bread, yoghurt, cheese and beer.

Biology, as you discovered last year, is the study of living organisms. Now, at the beginning of your grade 10 biology course, you are going to be studying **biotechnology**.

Biotechnology is the use of micro-organisms to make things that people want, often involving industrial production.

Biotechnology has always been extremely important. It involves ways of making and preserving foods and making alcoholic drinks. Traditional applications of biotechnology involve brewing beers, making wines, making bread, and making cheese and yoghurt. Modern applications of biotechnology include using genetic engineering to change crops and animals; producing new medicines; and helping to provide new energy sources. It has enormous significance in helping people to improve and control their lives.

Biotechnology is based on **microbiology**. As you know, microbiology is the study of micro-organisms – tiny living organisms including **bacteria**, **viruses**, **fungi** and **protoctista**,

KEY WORDS

biotechnology *use of micro-organisms to make things that people want, often involving industrial production*

microbiology *study of micro-organisms and their effect on humans*

bacteria *unicellular micro-organisms*

viruses *sub-microscopic infectious agents that are unable to grow or reproduce outside a host cell*

fungi *simple organisms, often microscopic, that cannot photosynthesise and feed as parasites or saprophytes*

protoctista *unicellular organisms*

which are usually too small to be seen with the naked eye. Some micro-organisms cause disease; others are enormously useful to people – for example, they play a vital role in decay and the recycling of nutrients in the environment. With the arrival of new technologies such as genetic engineering, micro-organisms are becoming more useful all the time.

Not all types of micro-organism are used in biotechnology. The main groups are bacteria and fungi, although viruses are being used more and more for genetic engineering. Just to remind you – bacteria are single-celled organisms that are much smaller than the smallest plant and animal cells. In ideal conditions, they can reproduce very quickly. Viruses are even smaller than bacteria. They do not carry out any of the normal functions of living things. Moulds and yeasts are both fungi – living organisms which obtain their food from other dead or living organisms. Yeasts are single-celled organisms, while moulds are made up of thin, thread-like structures called hyphae.

KEY WORDS

anaerobically *without oxygen*

fermentation *anaerobic respiration in yeast that produces ethanol*

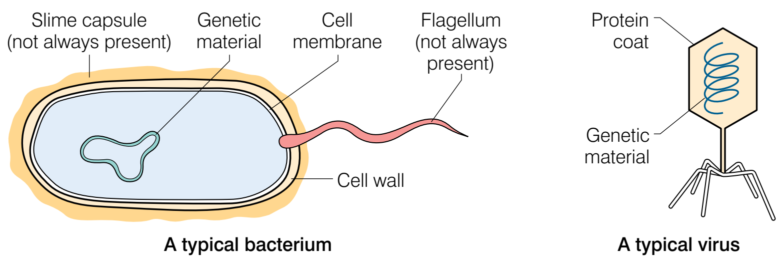


Figure 1.1 *Bacteria (left) and viruses (right) are both used in biotechnology.*

Developing new applications of biotechnology is one of the fastest-growing industries around the world, and is beginning to grow in Ethiopia too. It is easy to think that biotechnology is very new, but much of it has been in use for thousands of years. People have used micro-organisms to make food and drink almost as far back as our records go. Bacteria are used in the manufacture of *irgo* (yoghurt) and *Ayib* (cheese). Yeast is used to make many traditional Ethiopian fermented foods, including injera, and also to produce alcoholic drinks, such as tej and tella.

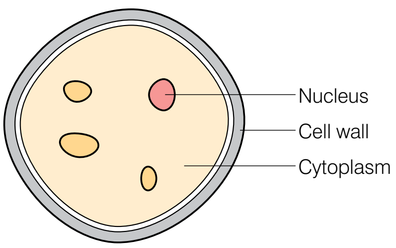


Figure 1.2 *Yeast cells – these microscopic organisms have been useful to us for centuries.*

Traditional technology using yeast

One of the most useful micro-organisms is yeast. The yeasts are single-celled organisms. Each yeast cell has a nucleus, cytoplasm and a membrane surrounded by a cell wall. The main way in which yeasts reproduce is by asexual budding – splitting into two, to form new yeast cells. Just one gram of yeast contains about 25 billion cells!

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. But yeasts are useful because they 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.

Aerobic respiration provides more energy than anaerobic respiration, allowing yeast cells to grow and reproduce. However, once they exist in large numbers, yeast cells can survive for a long time in low-oxygen conditions, and will break down all the available sugar to produce ethanol. The anaerobic respiration of yeast is sometimes referred to as **fermentation**.

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. Here in Ethiopia yeast (known locally as ershoo) has been used to make injera (bread) possibly since even earlier times.

Injera needs yeast

When you make injera, grind your teff or barley and then add water. Mix it well and leave the dough at room temperature for about two days. Natural yeasts start to grow and respire in the dough. At first the yeast respires aerobically, although this may change to anaerobic respiration. The yeast produces carbon dioxide, making the mix rise a little and giving it a tangy flavour. When you cook the mixture, the bubbles of gas expand in the high temperature, giving injera its typical texture, which is so good for soaking up the food. The yeasts are killed during the cooking process.

Figure 1.3 *When you make injera, the mix needs to be left for at least two or three days so the yeast can make the carbon dioxide gas needed to produce the holes in the bread.*

Activity 1.1: Making injera

You are going to investigate the factors that affect the growth of yeast in injera mix. Yeasts are living organisms – by changing their conditions, you can change the speed at which they respire and produce carbon dioxide in your dough.

1. Mix up some teff or barley flour with water, then divide your mix into three containers.
2. Leave one container at room temperature in the normal way for making injera.
3. Put the second container in the coolest place you have available. If there is a fridge, put your mixture in it.
4. Take your third mixture and heat it in a water bath to at least 50 °C. Make sure the mixture itself reaches 50 °C for 5 minutes. Then allow the mixture to cool down to room temperature and leave it with the other sample at room temperature.
5. After two to three days, observe the three mixtures very carefully. Describe their appearance and smell.
6. Then cook each of the three samples. Observe their appearance very carefully as they cook – the number of air bubbles that appear, and the texture of the bread that results.
7. Write up your experiment carefully, and explain your observations.

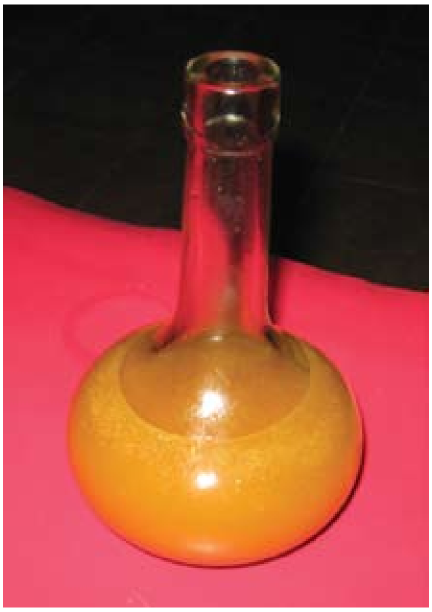


Figure 1.4 *Here in Ethiopia people have been drinking tej for thousands of years – the fermentation process by which it is made is an example of biotechnology.*

Making alcoholic drinks

When fruits fall to the ground and begin to decay, wild yeasts on their skin break down the fruit sugar to form ethanol and carbon dioxide. These fermented fruits can cause animals to become drunk when they eat them – and this is probably how our ancestors discovered alcohol! We now use this same reaction in a controlled way to make drinks such as beer, tej and wine. In both cases the yeast has to be supplied with carbohydrates to act as an energy source for respiration.

Tej is one of the oldest drinks known to the human race – it has been known since at least 400 BC. When you make tej, you need honey, water and gesho leaf or gesho stick. Gesho gives a bitter edge to the brew, and wild yeasts found on the plant start the fermentation going. The yeasts use the honey as a source of food. As the yeast colonies grow they start to respire anaerobically, and this produces ethanol and carbon dioxide. The alcohol content of tej varies from about 6 to 11%. Tej and tella are the most commonly consumed alcoholic drinks in Ethiopia.

In contrast, winemaking uses natural sugar, found in fruit such as grapes, as the energy source for the yeast. You press the fruit and mix the juice with yeast and water. You then let the yeast respire anaerobically until most of the sugar has been used up. At this stage, you filter the wine to remove the yeast and put it in bottles, where it will remain for some time to mature before it is sold. Most commercially sold wine is made from grapes, but wine can be made from almost any fruit or vegetable – the yeast doesn't care where the sugar it uses comes from!

Interestingly, alcohol in large amounts is poisonous to yeast as well as to people. This is why the alcohol content of wine is rarely more than 14% – once it gets much higher, it kills all the yeast and stops the fermentation.

Remember: yeast *can* respire aerobically in bread making, but *must* respire anaerobically to make alcoholic drinks.

Activity 1.2: Visiting a brewery/tej production

One way to become more familiar with the role of yeast in brewing is to visit a place where beer is brewed, or where tej or other alcoholic drinks are made in your neighbourhood. You can discuss with the craftsmen what might affect the growth of the yeast, and how much ethanol they produce during anaerobic respiration. Discuss what you discover in class with your teacher and other students.

Food production using bacteria

People began to domesticate animals quite early in human history. They soon realised that the milk female animals made for their babies could be used as food for us too. People have used milk from many different types of animal, including cows, sheep, goats, camels and horses. However, there is one big drawback in using milk as part of the diet – it very rapidly goes off, smelling and tasting disgusting! It didn't take people long to discover ways of changing milk, turning it into milk-based foods with a much longer life than the original milk. These changes depend on the action of micro-organisms.

Yoghurt has long been a staple part of the diet in the Middle East and Africa including Ethiopia. Cheese has also been around for a very long time almost all over the world.

Figure 1.5 *Many different animals, including cows, camels, horses, sheep and goats, are used for milking.*

Making yoghurt (irgo)

Traditionally, yoghurt is fermented whole milk. Yoghurt is formed by the action of bacteria on the lactose (milk sugar) in the milk.

To make yoghurt, you add a starter culture of the right kind of bacteria to warm milk. Often this starter culture is just a small amount of yoghurt you have already made. The mixture needs to be warm so the bacteria begin to grow, reproduce and ferment. As the bacteria break down the lactose in the milk, they produce **lactic acid**, which gives the yoghurt its sharp, tangy taste. This is known as lactic fermentation. The lactic acid produced by the bacteria causes the milk to clot and solidify into yoghurt. The action of the bacteria also gives the yoghurt a smooth, thick texture. Once the yoghurt-forming bacteria have worked on the milk, they also help prevent the growth of other bacteria that normally send the milk bad. Yoghurt, if it is kept cool, will last almost three weeks before it goes bad. Ordinary milk lasts only a few days – and then only if it's kept really cold. Once you have made your basic yoghurt, you can mix in flavourings, spices and fruit.

KEY WORD

lactic acid *product of anaerobic respiration in animal cells*

In Ethiopia, we often make yoghurt (irgo) in gourds or hollowed-out wooden vessels that have had sticks burned in them. These sticks are obtained from different plants such as the olive tree, and so on. As well as giving the yoghurt a pleasant flavour, this disinfects the vessel so that only good bacteria grow in the milk.

Activity 1.3: Making yoghurt

Discuss different factors that might affect the making of yoghurt. Mix up a class starter culture of milk and a small amount of live yoghurt. Discuss with your teacher what factors might affect how the bacteria work, and why. Plan your experiment carefully.

1. Working in groups, try different temperature conditions and see how they affect the formation of yoghurt. You might also change the pH of the mixture by adding substances such as lemon juice, and see how this affects the process.
2. After two or three days, make careful observations of your yoghurt culture.
3. Each group should share their results with the class and write them up on the board.
4. Write up your experiments carefully, and explain your observations.

***Figure 1.6** Curds are formed by the action of bacteria on the milk – this is the basis of ayib, although we often add seasoning and flavours before we eat it.*

DID YOU KNOW?

No one really knows when yoghurt making first started. It seems to have come from Turkey. Legend has it that travellers took some milk on a journey in a bag made of a sheep's stomach. The heat of the sun and the bacteria in the stomach worked on the milk, and in the cool of the desert night they discovered the bag was full of yoghurt! Carrying milk in the stomach of a camel has a similar effect.

Cheese making

Like yoghurt making, cheese making depends on the reactions of bacteria with milk changing the texture and taste, and also preserving the milk. Cheese making is very successful in preserving milk, and some cheeses can survive for years without decay. Around 900 different types of cheese are made around the world, but the basis of the production method is the same for them all.

Just as in yoghurt making, you add a starter culture of bacteria to warm milk. The difference is in the type of bacteria added. The bacteria in cheese making also convert lactose to lactic acid, but they make much more lactic acid. As a result, the solid part (curds) is much more solid than in yoghurt. Enzymes are also added to increase the separation of the milk. These often come from the stomachs of calves or other young animals. When it has completely curdled, you can separate the curds from the liquid whey (known as aguat here in Ethiopia). Then you can use the curds for cheese making. The whey is often used in other dishes.

The curds can be used fresh, and can be seasoned or flavoured. This is the basis of ayib. Alternatively, you can cut and mix the curds with salt along with other bacteria or even moulds, before you press them and leave them to dry out. The bacteria and moulds added at this stage of the process are very important. They affect the development of the final flavour and texture of the cheese as it ripens – a process that may take months or years, depending on the type of cheese being made. This is how the majority of cheeses are made in countries such as the UK and the USA.

Here in Ethiopia cheese is traditionally made by first making yoghurt from fresh milk, extracting the butter by continuous agitation, and finally boiling the remaining part to make the cheese.

Review questions

1. Which of the following statements about biotechnology is not true?
   - A Biotechnology is the use of micro-organisms to make things that people want.
   - B Biotechnology is a new, modern concept.
   - C Biotechnology is based on microbiology.
   - D Biotechnology is one of the fastest-growing industries in the world.
2. How many cells does one gram of yeast contain?
   - A about 10 million
   - B 25 million
   - C 4000
   - D about 25 billion

3. Which **two** of the following are the waste products of anaerobic respiration in yeast?

   A sugar

   B carbon dioxide

   C water

   D ethanol

4. Which of the following statements about lactic fermentation is not true?

   A It gives yoghurt its sharp, tangy taste.

   B It gives yoghurt a smooth, thick texture.

   C It means the yoghurt will only last a few days.

   D It causes the milk to clot and solidify into yoghurt.

1.2 New applications of biotechnology

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

- Identify new applications of biotechnology in agriculture, food production, medicine and energy production.

Around the world traditional biotechnologies – brewing, winemaking, bread making and the production of yoghurt and cheese – are extremely important. In many countries they are not only carried out in the home on a small scale, they also take place in massive industrial production processes.

Some new applications of biotechnology also take place in an industrial setting. Many advances in agriculture are the result of one of the most important new areas of biotechnology – **genetic engineering** (also known as **genetic modification**). Genetic engineering is used to change an organism and give it new characteristics which people want to see.

KEY WORDS

genetic engineering/ genetic modification *process of inserting new genetic information into existing cells in order to modify a specific organism for the purpose of changing its characteristics*

What is genetic engineering?

Genetic engineering involves changing the genetic material of an organism. Genetic material carries the instructions for a new organism, found in the nucleus of every cell. You take a small piece of information – a gene – from one organism and transfer it to the genetic material of a completely different organism. So, for example, a gene from one of your human cells can be 'cut out' using enzymes, and transferred to the cell of a bacterium. Your gene carries on making a human protein, even though it is now in a bacterium.

There is a limit to the types of protein that bacteria are capable of making. Scientists have found that genes from one organism can be transferred to the cells of another type of animal or plant at an early stage of their development. As the animal or plant grows,

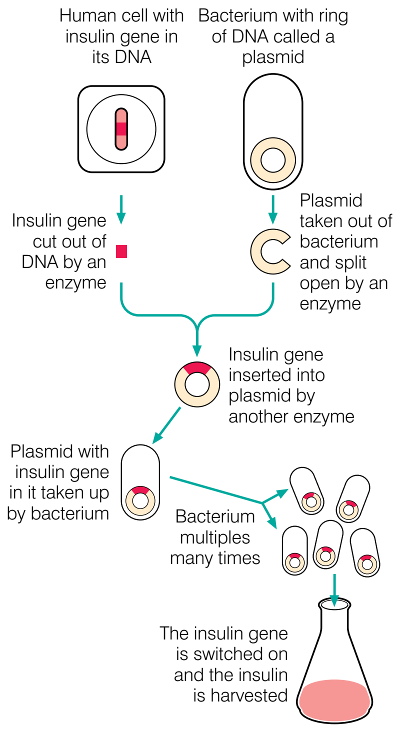


***Figure 1.7** The basic process of genetic engineering*

it develops with the new, desired characteristics from the other organism.

The technology

A lot of new biotechnology relies on growing large numbers of micro-organisms on an industrial scale in large vessels, known as fermenters. If a lot of micro-organisms are grown together, they can easily use up all the oxygen available and even poison each other with waste products. Industrial fermenters usually have a range of features to overcome the problems that stop a culture growing satisfactorily. They react to changes, keeping the conditions as stable as possible. This, in turn, means we can obtain the maximum yield. Industrial fermenters usually have:

- an oxygen supply – to provide oxygen for respiration by the micro-organisms
- a stirrer – to keep the micro-organisms in suspension, maintain an even temperature, and make sure oxygen and food are distributed evenly through the culture
- a water-cooled jacket – to remove the excess heat produced by the respiring micro-organisms – any rise in temperature is used to heat the water, which is constantly removed and replaced with more cold water
- measuring instruments – for continuous monitoring of factors such as pH and temperature so that adjustments can be made if necessary

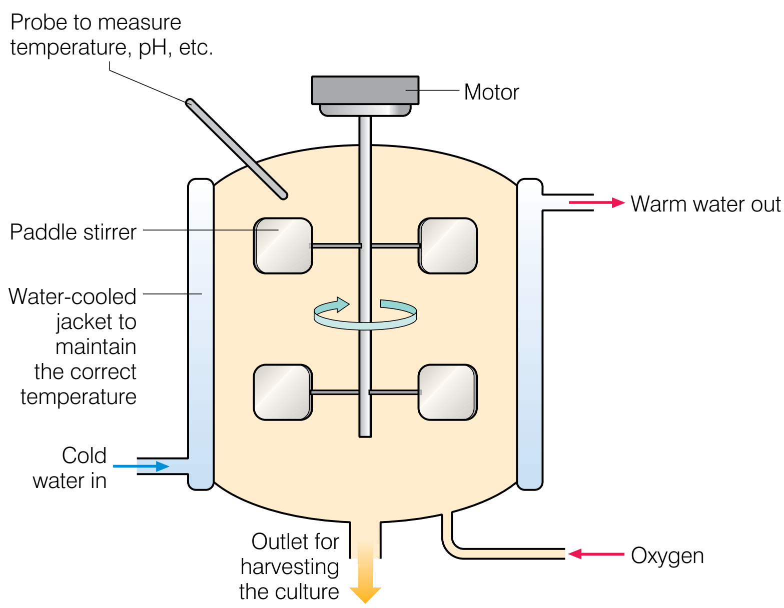


***Figure 1.8** The design of fermenters is improving all the time as new ways of keeping conditions inside the fermenter as stable as possible are developed all the time.*

There are many different areas where new biotechnology – and in particular genetic engineering – is very important. Some of them are summarised on the following pages.

Applications of biology in agriculture

For many years, we have used selective breeding to change our livestock and crops. We select animals or plants with characteristics we want, such as big grains, resistance to disease or plenty of milk, and breed from them. Gradually, the characteristics change to what we want. But selective breeding takes time, and there are limitations to it. You will be looking at this in more detail in the next unit.

By using genetic engineering, we can introduce new characteristics very rapidly. Engineered genes can be used to improve the growth rates of plants and animals. They can be used to improve the food value of crops. Genetic engineering has been used to make crop plants that are resistant to drought and to disease, and to produce plants that make their own pesticide chemicals. Glowing genes from jellyfish have even been used to produce crop plants that give off a blue light when they are attacked by insects so the farmer knows they need spraying! This means the farmer has to use less insecticide (chemicals that kill insects), which saves money and protects the environment.

Much of the research into genetically engineered crops and animals has been carried out in countries like the UK and the USA. However, here in Ethiopia our scientists are increasingly working with these new technologies. At the Ethiopian Institute of Agricultural Research and Addis Ababa University, scientists are analysing the genes of many of our most important crop plants, including teff. The Ethiopian Agricultural Research Institute is using modern biotechnology to improve teff, coffee, fruit plants and some of our forest trees for commercial cultivation.

KEY WORD

mycoprotein *fungal protein*

However, there are some possible problems with the new biotechnologies, so we must be careful. Insects may become pesticide-resistant if they eat a constant diet of pesticide-forming plants. Genes from genetically modified plants and animals might spread into the wildlife of the countryside, which could make difficulties. Genetically modified crops are often not fertile, which means farmers have to buy new seed each year. But if these problems can be overcome, biotechnology offers us the hope of better crops and more food, both for our own people and to sell internationally.

Figure 1.9 *Plant technologists at EIAR have improved different crops like this teff to ensure food security.*

Applications of biology in food

The new biotechnology is often used in food processing. One of the biggest changes is that enzymes are produced by genetically engineered bacteria, and the enzymes are then used in the production of processed foods and drinks. Enzymes are used to clarify beer. They are used to break down starch and convert the sugars into glucose syrup. They are used to make meat more tender, and to break down the food used to make commercial baby food.

Biotechnology plays a big part in food production. It has even been used to create a completely new food based on fungi, which has been developed in the UK. It is known as **mycoprotein**, which means 'protein from fungus'. It is produced using the fungus *Fusarium*, which grows and reproduces rapidly on a relatively cheap sugar syrup in large, specialised fermenters. It needs aerobic conditions to grow successfully, and can then double its mass every five hours or so. The fungal biomass is harvested and purified. Then it is dried and processed to make mycoprotein, a pale yellow solid with a faint taste of mushrooms. On its own, it has very little flavour, but mycoprotein can be given a range of tastes and flavours to make it similar to a whole range of familiar foods. It is a high-protein, low-fat meat substitute used by vegetarians, people who want to reduce the fat in their diet, and people who just want to eat cheap protein.

When mycoprotein was first developed, people thought a world food shortage was on its way. They were looking for new ways to make protein cheaply and efficiently. The food shortage never happened, but the fungus-based food continued. It is versatile, high in protein and fibre, and low in fat and calories, and so has found a secure and healthy place on the meal tables of the developed world.

Scientists in Ethiopia and elsewhere are trying to develop a local equivalent of mycoprotein, looking at different plants and fungi that have a relatively high protein content.

Applications of biology in medicine

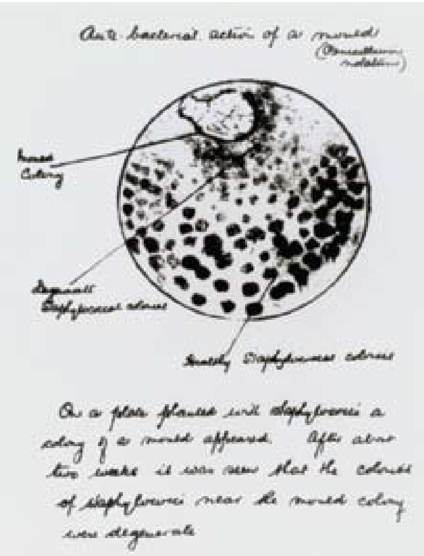


Figure 1.10 *The keen eyes of Alexander Fleming noticed the clear areas on his plates, and he realised he had made a discovery of enormous potential.*

Biotechnology is extremely important in modern medicine. It is used to develop vaccines and to create new medicines. The first medicine that really relied on microbiology was penicillin. This antibiotic is one of the best-known medicines in the world, and has revolutionised medicine in the time since it was first manufactured. We are going to look more closely at this story because it shows clearly how changes in biotechnology make life easier.

In 1928 Alexander Fleming, a young researcher at St Mary's Hospital in the UK, left some plates on which he was culturing bacteria uncovered near an open window. When he remembered to look at them, he found bacteria were growing on the surface of his dishes, as he expected. But Fleming also noticed spots of mould growing, and around these were clear areas of agar. The bacteria were no longer growing there. Whatever had blown in through the window and started growing on his plates was producing a chemical that killed the bacteria.

Fleming found that the micro-organism which had invaded his Petri dishes was a common mould called *Penicillium notatum*. He managed to extract a tiny amount of the chemical that killed the bacteria, and used it to treat an infected wound. He called his extract penicillin. But it was very hard to extract, and very unstable once extracted, so Fleming decided he wouldn't be able to obtain useful amounts of penicillin from his mould.

Howard Florey and Ernst Chain were working at Oxford University in the UK in a desperate search to find a drug to kill the bacteria that infected wounds suffered by soldiers in the Second World War. They used Fleming's mould and finally managed to extract enough penicillin to show what it could do. They wanted to manufacture it in large amounts, but the yield of drug was very poor.

Fleming's original mould, *Penicillium notatum*, was extremely difficult to grow in large cultures, yielding only one part penicillin for every million parts of fermentation broth. Then a mould growing on a melon in a market was found to yield 200 times more penicillin than the original. What is more, it grew relatively easily in deep tanks, making large-scale production possible. By 1945, enough penicillin was made each year to treat seven million people.

Modern strains of *Penicillium* mould give even higher yields. We grow the mould in a sterilised medium, containing sugar, amino acids, mineral salts and other nutrients, which is made from soaking corn in water. It is grown in huge 10 000 dm^3 fermenters, and still saves many thousands of lives every year.

When genetically engineered bacteria are cultured on a large scale, they can make huge quantities of protein. We now use them to make a number of drugs and hormones used as medicines. These genetically engineered bacteria make exactly the protein needed, in exactly the amounts needed, and in a very pure form. For example, people with diabetes need supplies of the hormone insulin. It used to be extracted from the pancreas of pigs and cattle, but it wasn't quite the same as human insulin, and the supply was quite variable. Both problems have now been solved by the introduction of genetically engineered bacteria that can make human insulin.

Biotechnology also makes it possible to develop vaccines more easily.

A number of sheep and other mammals have been engineered to produce life-saving human proteins in their milk. These are much more complex proteins than those produced by bacteria, and have the potential to save many lives. For example, genetically modified sheep can make special blood-clotting proteins in their milk. These can be used for people with haemophilia, so they are no longer at risk from receiving contaminated blood.

Figure 1.11 *Diabetes is a dangerous condition if it is not controlled with insulin. Biotechnology is making pure human insulin much more easily available.*

Applications of biology in energy production

Everyone needs fuel of some sort to provide them with energy. It might be direct energy such as heat to cook on, or it might be indirect energy – heat being used to make electricity, for example. However, there is only a limited amount of fossil fuels such as coal, oil and gas for us to use. Even wood and peat are becoming scarce. Around the world, we all need other, renewable forms of fuel. The generation of biogas from human and animal waste is becoming increasingly important in both the developing and the developed world. This depends on biotechnology.

Figure 1.12 Biogas generators like this have made an enormous difference to many families by producing cheap and readily available fuel.

What is biogas?

Biogas is a flammable mixture of gases, formed when bacteria break down plant material, or the waste products of animals, in anaerobic conditions. It is mainly methane, but the composition of the mixture varies depending on what is put into the generator and which bacteria are present.

Table 1.1 *The components of biogas*

Components	Percentage in the mixture by volume
Methane	50–80
Carbon dioxide	15–45
Water	5
Hydrogen sulphide	0–3
Other gases including hydrogen	0–1

Around the world, millions of tonnes of faeces and urine are produced by animals like cows, pigs, sheep and chickens. We produce our fair share of waste materials too! Also, in many parts of the world, plant material grows very rapidly. Both the plant material and the animal waste make up a potentially enormous energy resource – but how can we use it?

To produce biogas, you collect dung or plant material, which contains a high level of carbohydrates, and put it into a **biogas generator** or **digester**. Then you add a mixed population of many different types of bacteria which are needed to digest the carbohydrate. The bacteria you use are similar to those in the stomachs of ruminants such as cows or sheep. Some of the bacteria break down the cellulose in plant cell walls. Others break down the sugars formed, to produce methane and other gases. The biogas produced is passed along a pipe into your home, where you burn it to produce heat, light or refrigeration.

KEY WORDS

biogas generator/ digester *takes in waste material or plants, and biogas and useful fertilisers come out the other end*

exothermic *reaction that produces heat energy*

The bacteria involved in biogas production work best at a temperature of around 30 °C, so biogas generators tend to work best in hot countries. However, the process generates heat (the reactions are **exothermic**). This means that if you put some heat energy in at the beginning to start things off, and have your generator well insulated to prevent heat loss, biogas generators will work anywhere. Some generators are so simple, they are little more than a big plastic bag and some pipes. Yet they can make a big difference to our lives.

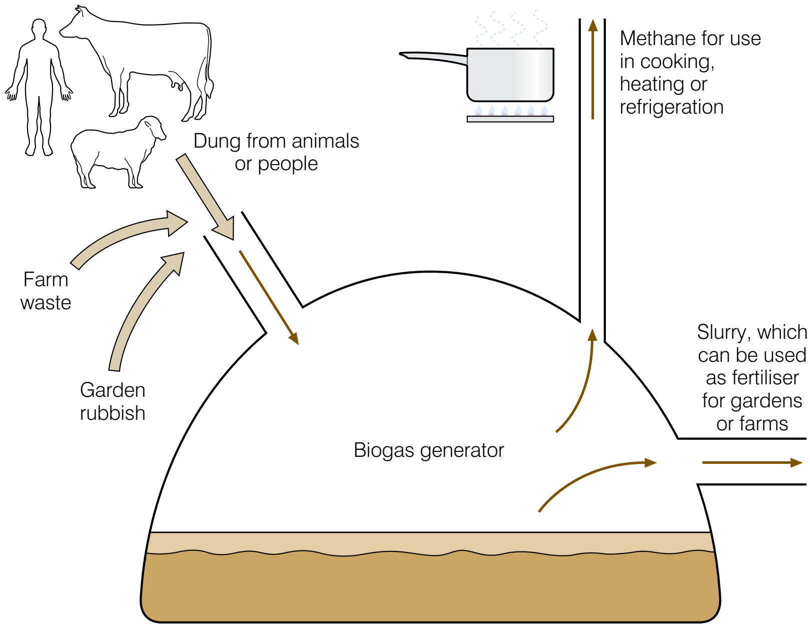


Figure 1.13 *Biogas generators take in waste material or plants, and biogas and useful fertilisers come out the other end. This simple generator, involving a big plastic bag, is being tried in Addis Ababa and the surrounding area.*

Scaling up the process

At the moment, most biogas generators around the world operate on a relatively small scale, supplying the energy needs of one family, a farm, or at most a village. What you put into your small generator has a big effect on what comes out.

Biogas units are widely used in China, where there are well over 7 million biogas units, producing as much energy as 22 million tonnes of coal. Waste vegetables, animal dung and human waste are the main raw materials. These Chinese digesters produce excellent fertiliser, but relatively low-quality biogas.

In India, there are religious and social taboos against using human waste in biodigesters. As a result, only cattle and buffalo dung is put into the biogas generators. This produces very high-quality gas, but much less fertiliser.

There are also different sizes and designs of biogas generator. The type chosen will depend on local conditions. For example, many fermenters are sunk into the ground, which provides very good insulation. Others are built above ground, which may be easier and cheaper, but offers less insulation. If night-time temperatures fall too low, it could cause problems.

Many countries are now looking at biogas generators, and experimenting with using them on a larger scale. The waste material we produce from sugar factories, sewage farms and rubbish tips all has the potential to act as a starting point for the production of biogas. We have some problems to overcome with scaling the process up, but the early progress looks promising. Biogas could

DID YOU KNOW?

Under ideal conditions, 10 kg of dry dung can produce 3 m^3 of biogas. That will give you three hours' cooking, three hours' lighting or 24 hours of running a refrigerator. Not only that, but you can use the waste from your generator as a fertiliser.

Figure 1.14 *Conditions in Ethiopia allow plants like this sugar cane to photosynthesise and grow very rapidly – the next step is to turn them into usable fuel.*

well be an important fuel for the future for all of us. It would help us to get rid of much of the waste we produce, as well as providing a clean and renewable energy supply.

More biofuels

In countries such as Ethiopia, plants grow quickly. Sugar cane grows about 4–5 metres in a year, and has a juice which is very high in carbohydrates, particularly sucrose. Maize and sweet potatoes also grow fast. We can break down the starch in maize kernels or potato tubers into glucose, using the enzyme **carbohydrase**. We can convert the carbohydrates we grow into clean and efficient fuels.

Ethanol-based fuels

If sugar-rich products from cane and maize are fermented anaerobically with yeast, the sugars are broken down incompletely to give ethanol and water. You can extract the ethanol from the products of fermentation by **distillation**, and you can then use it in cars and other vehicles as a fuel.

Car engines need special modification to be able to use pure ethanol as a fuel, but it is not a major job. Many cars can run on a mixture of petrol and ethanol without any problems at all.

Advantages and disadvantages of ethanol as a fuel

In many ways, ethanol is an ideal fuel. It is efficient, and it does not produce toxic gases when you burn it. It is much less polluting than conventional fuels, which produce carbon monoxide, sulphur dioxide and nitrogen oxides. In addition, you can mix ethanol with conventional petrol to make a fuel known as gasohol. This is increasingly being done, and reduces pollution levels considerably, although there is still some pollution from the petrol part of the mix.

KEY WORDS

carbohydrase *enzyme which breaks down carbohydrates*

distillation *process of purifying a liquid by boiling it and condensing its vapours*

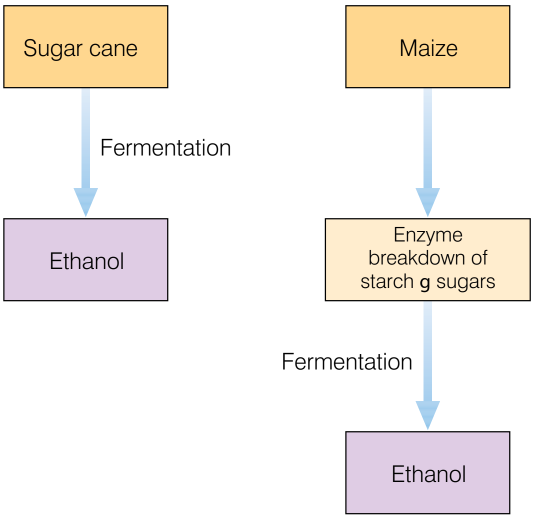


Figure 1.15 *The starch in maize needs to be broken down by enzymes before yeast can use it as fuel for anaerobic respiration. Although it takes more steps to produce ethanol from maize than from sugar cane, maize can be grown in many more countries around the world.*

Using ethanol as a fuel is a **carbon-neutral** activity. This means there is no overall increase in carbon dioxide in the atmosphere when you burn ethanol. The original plants removed carbon dioxide from the air during photosynthesis. When you burn the ethanol, you simply return it.

The biggest difficulty with using plant-based fuels for our cars is that it takes a lot of plant material to produce the ethanol. As a result, the use of ethanol as a fuel has largely been limited to countries with enough space, and a suitable climate, to grow a lot of plant material as quickly as possible. Here in Ethiopia, we have that capability.

The main problem for many countries is finding enough ethanol. If people in Europe added 5% ethanol to their fuel, it would reduce carbon dioxide emissions – but they would need 7.5 billion litres of ethanol a year, which they cannot produce themselves. The methods of ethanol production we use at the moment leave large quantities of unused cellulose from the plant material. To make ethanol production work financially in the long term, we need to find a way to use this cellulose. We might develop biogas generators, which can break down the excess cellulose into methane, another useful fuel. Genetically engineered bacteria or enzymes may be able to break down the cellulose in straw and hay and make it available for yeast to make more ethanol. We don't know exactly what the future will hold, but it seems likely that ethanol-based fuel mixes will be part of it. Here in Ethiopia the Ministry of Mines and Energy has already started mixing ethanol with petrol to provide fuel for cars.

Along with the production of biodiesel from plants such as castor oil beans and jatropha, which grows in dry climatic conditions that do not suit crop production, Ethiopia is making great strides in the use of biofuels. As long as we maintain a balance between the use of land to provide food and the use of land to provide us with fuel, the use of biotechnology in this way has great potential for us in the future.

KEY WORDS

carbon-neutral *process whereby the amount of carbon emitted is matched by the amount absorbed*

Review questions

1. Which of the following statements about genetic engineering is not true?

   A It is used to change an organism and give it new characteristics that people want.

   B It involves changing the genetic material of an organism.

   C It can be used to produce crops that are resistant to disease.

   D It does not allow genes to be transferred from one type of organism to another.

2. Which of the following is not a component of biogas?

   A carbon dioxide

   B ethanol

   C methane

   D water

3. Put the following stages of the process of making and using biogas into the correct order:

   A Some of the bacteria break down the plant cell walls while others break down the sugars formed, producing methane and other gases.

   B Dung or plant material is collected and put into a biogas generator, or digester.

   C The biogas produced is piped into homes, where it is burned to produce light, heat or refrigeration.

   D A mixed population of different types of bacteria is added.

4. Which of the following are advantages of using ethanol as a fuel, and which are disadvantages? Can you explain why?

   A It is a carbon-neutral activity.

   B It takes a lot of plant material to produce the ethanol.

   C It does not produce toxic gases when burnt.

   D It can be mixed with conventional petrol to make gasohol.

Summary

In this unit you have learnt that:

- Biotechnology is the use of micro-organisms to make things that people want, often involving industrial production.
- Biotechnology has been used for thousands of years to make bread, alcoholic drinks and fermented food products such as yoghurt and cheese.
- Yeast is a single-celled organism that can respire aerobically, producing carbon dioxide and water; this reaction is used in bread making to make the dough rise.
- Yeast can also respire anaerobically, producing ethanol and carbon dioxide in a process known as fermentation – the fermentation reaction of yeast is used to produce ethanol in the production of beer and wine.
- Bacteria are used in making both yoghurt and cheese. In the production of both, a starter culture of bacteria acts on warm milk. Lactose is converted to lactic acid in a lactic fermentation reaction. This changes the texture and taste of the milk to make yoghurt.
- In cheese making, a different starter culture is added to warm milk, giving a lactic fermentation which results in solid curds and liquid whey. The curds are often mixed with other bacteria or moulds before they are left to ripen.
- Modern biotechnology often involves genetic engineering and large-scale fermenters.

- In genetic engineering, desirable genes from one organism can be 'cut out' using enzymes and transferred to the cells of bacteria, animals and plants.
- Micro-organisms can be grown on a large scale in vessels known as fermenters, to make useful products such as antibiotics. Industrial fermenters have a range of features to make sure fermentation takes place in the best possible conditions.
- Modern biotechnology has many applications.
- In agriculture biotechnology is used to develop better crops and livestock, and to develop plants that contain their own pesticide.
- In food it is used in many ways: including to break down starch to form useful sugar syrups; to improve the production of beers and other fermented products; and to develop new foodstuffs.
- In medicine biotechnology is used to make drugs and medicines.
- Biotechnology is important in producing new forms of fuel to provide us with energy.
- Biogas – mainly methane – can be produced by anaerobic fermentation of a wide range of plant products and waste materials that contain carbohydrates.
- Ethanol-based fuels can be produced by the anaerobic fermentation of sugar cane juices and from glucose derived from maize starch by the action of the enzyme carbohydrase.

End of unit questions

1. What is biotechnology and why is it so important?
2. Name three different foodstuffs or drinks that are used by your family, and explain how biotechnology is involved in producing them.
3. a) You can leave injera mix in a fridge for hours without any gas bubbles being formed. Put it somewhere warm, and after a time bubbles start to appear again. Injera is usually ready to cook after two days. In a cool place it may take longer. Explain how these differences come about.

   b) Temperature is vital for successful beer and wine making. Why is it so important?
4. a) Write a brief report on 'Bacteria and fermented milk products'.

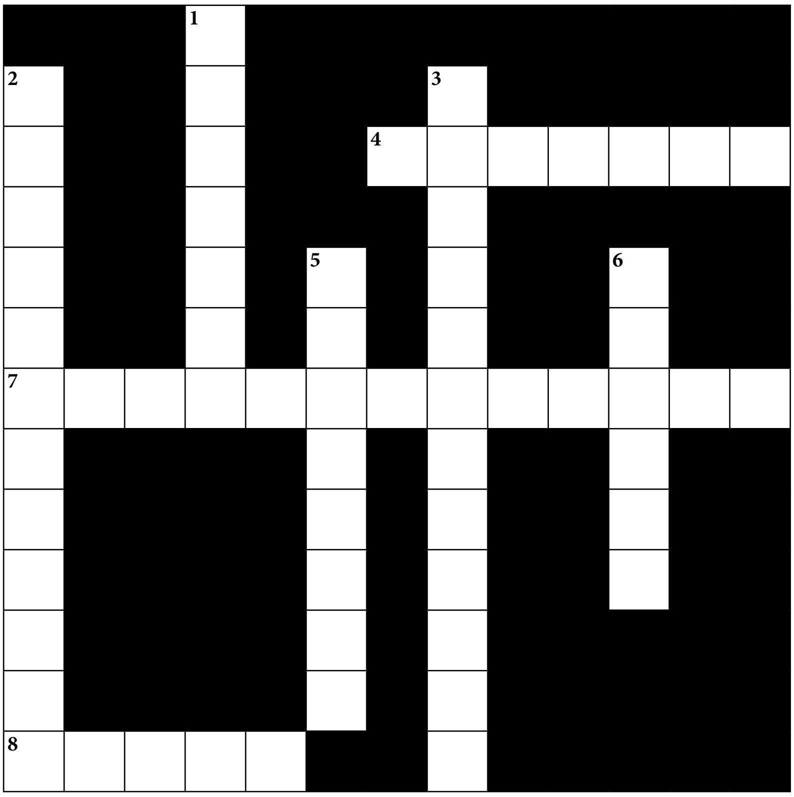
   b) Find out how fermented bean pastes are made and write about the biotechnology of this useful food.

5. Why are micro-organisms so important in the production of medicines? Describe two different medicines that rely on biotechnology in their production.
6. a) Using the data in the table on page 12, produce bar charts to compare high-quality biogas (high methane, low carbon dioxide) with poor-quality biogas (low methane, high carbon dioxide).

   b) What effect do you think differences in composition like this will have on the use of this gas as a fuel?

   c) Suggest ways in which people might improve the quality of the gas produced in their fermenter.
7. Write a letter to your head teacher or school administration explaining why you think they should look into the idea of providing energy for the school from biogas, and how they might do it.

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

4 Flammable gas made in biogas generator (7)

7 The study of living things used to perform industrial processes (13)

8 Microscopic fungi used to make alcoholic drinks and injera (5)

DOWN

1 Fermented whole milk (7)

2 The study of micro-organisms and their effect on humans (12)

3 Anaerobic respiration in yeast that produces ethanol (12)

5 Single-celled microscopic organisms which can reproduce very quickly (8)

6 Flammable mixture of gases formed when bacteria break down plant and animal material in anaerobic conditions (6)

Heredity

Unit 2

Contents

Section	Learning competencies
2.1 Mitosis and meiosis (page 19)	• Define heredity and compare mitosis and meiosis. • Define chromosome, DNA and genes. • Describe the structure of chromosomes and list the components of DNA.
2.2 Mendelian inheritance (page 30)	• Describe the work of Gregor Mendel on garden peas and relate his experiments to the principle of inheritance. • Demonstrate the principle of inheritance using beads. • Describe the methods, importance and examples of breeding farm animals and crops.
2.3 Heredity and breeding (page 45)	• Describe methods of breeding farm animals and crops. • Explain the importance of selective breeding for society. • Explain the difference between selective breeding and cross-breeding. • Give examples of selective breeding from your own experience.

2.1 Mitosis and meiosis

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

- Define a chromosome.
- Define DNA as the genetic material.
- Define genes.
- Describe the structure of the chromosomes.
- Describe the components of DNA.
- Define mitosis and describe its stages.
- Define meiosis and describe its stages.
- Relate the events of meiosis to the formation of the sex cells.
- Compare mitosis and meiosis.

Almost all the cells of your body – with the exception of your mature **red blood cells** – contain a nucleus, the 'control room' of the cell. The nucleus contains all the plans for making a new cell, and for making a whole new you.

Think of the plans for building a car. They would cover many different sheets of paper. Yet in every living organism, the nucleus

KEY WORDS

red blood cell *type of blood cell that carries oxygen around the body*

Figure 2.1 *Karyotypes, like these of a healthy man and woman, have helped scientists find out more about the mysteries of inheritance.*

Activity 2.1: Making a karyotype

You are going to make a human karyotype. You will be provided with a photograph or worksheet showing a photograph of unordered human chromosomes, exactly as a real scientist would take. Your task is to cut out each of the chromosomes and arrange them in pairs as you have seen in figure 2.1. Try and identify each pair and stick them onto a sheet of paper, labelling them carefully. Is your person male or female?

of the cells contains the information needed to build a whole new animal, plant, bacterium or fungus. A human being is far more complicated than a car – so where does all the information fit in?

Inside the nucleus of every cell there are thread-like structures called **chromosomes**. This is where the genetic information passed on from parent to child is stored.

The chromosomes are made up of **DNA** (**deoxyribonucleic acid**). This amazing chemical carries the instructions needed to make all the proteins in your cells. Many of these proteins are actually enzymes. These control the production of all the other chemicals that make up your body, and affect what you look like and who you are.

- A chromosome is a structure in the nucleus of a cell consisting of genes.
- Chromosomes are made up of the genetic material DNA in a DNA–protein complex.
- DNA is the genetic material contained in the nucleus.

Each different type of organism has a different number of chromosomes in the cells – humans have 46 chromosomes and tomatoes have 24, while elephants have 56. You inherit half your chromosomes from your mother and half from your father. Chromosomes come in pairs known as **homologous** pairs. So people have 23 pairs, tomatoes have 12 pairs and elephants have 28 pairs of chromosomes.

Scientists can photograph the chromosomes in human cells when they are dividing and arrange them in pairs to make a special picture known as a **karyotype**.

Human karyotypes show 23 pairs of chromosomes. In 22 of the pairs, both chromosomes are the same size and shape, regardless of whether you are a boy or a girl. These 22 pairs of chromosomes are known as the **autosomes**. They control almost everything about the way you look and the way your body works. The remaining pair of chromosomes is different for boys and girls. A girl has a pair of two similar X chromosomes, but a boy has one X chromosome and another, much smaller, Y chromosome. These are known as the sex chromosomes because they determine whether you are male or female. Everyone inherits an X chromosome from their mother. If this joins with a sperm carrying another X chromosome, you will be a girl. If it is fertilised by a sperm carrying a Y chromosome, you will be a boy. X chromosomes carry information about being female, but they also carry information about many other things – like the way your blood clots, and the formation of your teeth, body hair and sweat glands. Y chromosomes mainly carry information about maleness.

Chromosomes, genes and DNA

The chromosomes you inherit from your parents carry all the information needed to make a new you. The information is kept in the form of genes. Each gene is a small section of DNA. Life as we know it depends on the properties of this complicated chemical, so it seems amazing to think we have only understood it for about 50 years!

- A gene is a unit of hereditary material located on the chromosomes.

DNA is a long molecule, made up of two strands twisted together to make a spiral known as a **double helix** – imagine a ladder that has been twisted round. The big DNA molecule is actually made up of lots of smaller molecules (nucleotides) joined together. A nucleotide consists of a phosphate group, a sugar and a base. In DNA there are four different bases that appear time after time in different orders, but always paired up in the same way. The **bases** link the two strands of the DNA molecule together. Genes are made up of repeating patterns of bases in the DNA. (See page 22.)

By the 1940s, most scientists had decided that DNA was probably the molecule that carried inherited information from one generation to the next. But how did it work?

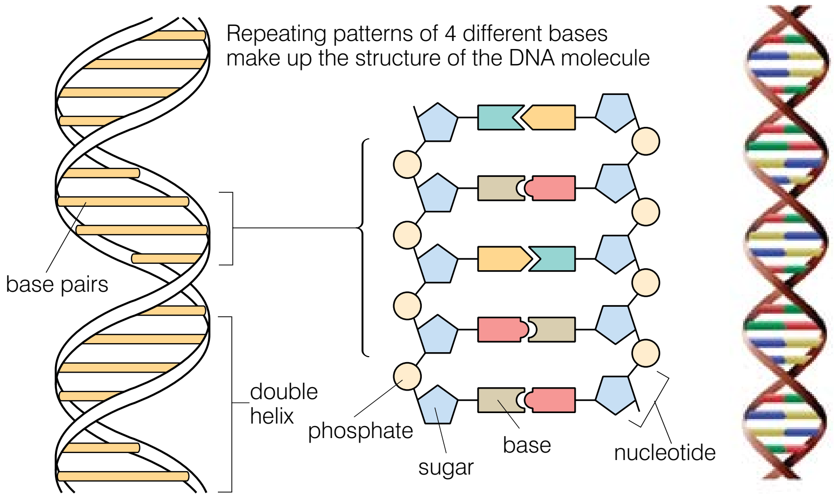


***Figure 2.3** The double helix structure of the DNA molecule takes you deep into the chemistry of life. A small change in the arrangement of bases in your DNA would have meant a very different you.*

By the 1950s, two teams in the UK were getting close to understanding the structure of this amazing molecule. Maurice Wilkins and Rosalind Franklin in London were taking special X-ray photographs of DNA and looking at the patterns in the X-rays in the hope that they would show them the structure of the molecule. At the same time, James Watson (a young American) and Francis Crick (from the UK) were working on the DNA problem at Cambridge. They took all the information they could find on DNA – including the X-ray crystallography from London – and kept trying to build a model of the molecule that would explain

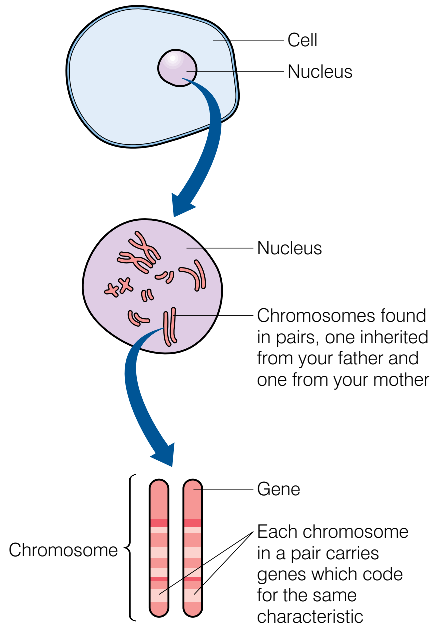


***Figure 2.2** The nuclei of our cells contain the chromosomes that carry the genes that control the characteristics of our whole body.*

KEY WORDS

chromosome *strand of DNA carrying genetic information*

DNA *nucleic acid containing the genetic instructions used in the development and functioning of all known living organisms and some viruses*

homologous chromosomes *a pair of chromosomes having the same gene sequences, each derived from one parent*

karyotype *map of the chromosomes in the nucleus of a single cell*

autosomes *chromosomes that are not sex chromosomes*

double helix *pair of parallel helices intertwined about a common axis* everything they knew. When they finally realised that the bases always paired up in the same way, they had cracked the code. The now famous double helix was seen for the first time. Watson, Crick and Wilkins all received the Nobel Prize for their work. Rosalind Franklin died of cancer before the prizes were awarded.

Since the structure of DNA was revealed, there has been an enormous explosion in the amount of research done on genetics. We now know that the bases that make up DNA are called **adenine**, **thymine**, **guanine** and **cytosine**. The two DNA strands are linked by these bases, where adenine pairs with thymine and cytosine pairs with guanine. The upright strands are made of deoxyribose sugar and phosphate. Each base, sugar and phosphate together form a **nucleotide**. DNA is therefore a **polynucleotide** chain.

The genes found on the chromosomes control everything that goes on in your cells by organising all the proteins that are made. As you learned in grade 9, a protein is a long chain of amino acids. Different combinations of amino acids can be joined together to make different proteins. So the order of the bases in the DNA acts as a code to instruct the cell about the order in which to join up the amino acids to make a particular protein. This is how the genes control what goes on in the cells and in the whole organism.

The Human Genome Project has been a massive international effort by scientists from many countries who set out to read the DNA of the entire human genome. This work is showing us exactly what genes we all have in common, and which characteristics they code for.

Mitosis

New cells are needed for an organism, or part of an organism, to grow. They are also needed to replace cells that become worn out and repair damaged tissue. However, the new cells that are produced must contain the same genetic information as the originals, so that they can do the same job.

In animals and plants that have asexual reproduction it is necessary for one cell to split into two genetically identical cells for the organism to reproduce.

KEY WORDS

adenine *one of the four bases that comprise DNA which pairs with thymine*

thymine *one of the four bases that comprise DNA which pairs with adenine*

guanine *one of the four bases that comprise DNA which pairs with cytosine*

cytosine *one of the four bases that comprise DNA which pairs with guanine*

nucleotide *a building block of DNA or RNA which consists of a sugar, a phosphate, and one of the four bases*

polynucleotide *long chains of linked nucleotides*

DID YOU KNOW?

The Human Genome Project has cost around 3 billion US dollars so far. Scientists have worked out the 3 billion base pairs that make up human DNA – and have shown that everyone shares around 99.99% of their DNA. It looks as if human beings have only between 20 000 and 25 000 genes, far fewer than scientists originally predicted.

Figure 2.4 *As we grow, it is important that we can make new cells which are just the same as the old ones, so we can grow and repair any damage that occurs during our life.*

KEY WORDS

somatic cells *any of the cells of a plant or animal except the reproductive cells*

mitosis *cell division in which the nucleus divides into nuclei containing the same number of identical chromosomes*

chromatids *the two strands of a chromosome that separate during mitosis*

daughter cells *the two identical cells that are formed when a cell reproduces itself by splitting into two*

Body cells (also known as **somatic cells**) divide to make new cells. The cell division that takes place in the normal body cells and produces identical cells is known as **mitosis**. As a result of mitosis, every body cell has the same genetic information. In asexual reproduction, the cells of the offspring are produced by mitosis from the cells of their parent. This is why they contain exactly the same genes with no variety.

- Mitosis is division of the somatic cells to make identical daughter cells.

How does mitosis work? Before a cell divides, it produces new copies of the homologous pairs of chromosomes in the nucleus. Each chromosome forms two identical **chromatids**. Then the chromatids divide into two identical packages, and the rest of the cytoplasm divides as well to form two genetically identical **daughter cells**. Once the new cells have formed, the chromatids are again referred to as chromosomes. The daughter cells each have exactly the same number of chromosomes as the original cell. To make it easier to understand what is going on, we divide this process into stages – interphase, prophase, metaphase, anaphase and telophase (figure 2.5) – but in fact mitosis is one continuous process.

In some areas of the body of an animal or plant, cell division like this carries on rapidly all the time. Your skin is a good example – thousands of cells are constantly being lost from the surface, and new cells are constantly being formed by cell division to replace them. As food passes along your gut (grade 9 biology), cells are scraped off the gut lining. Fortunately, there is a layer of cells underneath that is constantly dividing by mitosis to replace those that are lost.

DID YOU KNOW?

Your red blood cells have a finite life because they lose their nuclei as they mature. Worn-out red blood cells are destroyed, at a rate of around 100 billion per day, by your spleen and liver. Fortunately, mitosis takes place in your bone marrow just as quickly to make the new red blood cells you need.

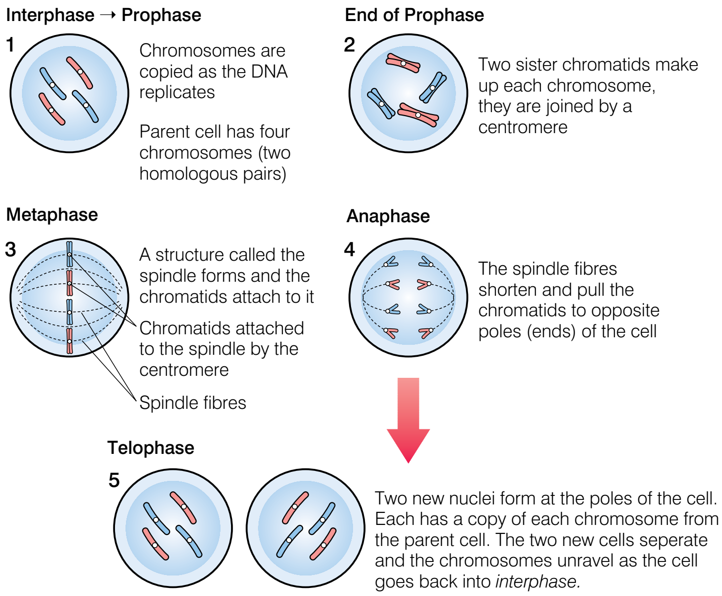


Figure 2.5 *The formation of identical daughter cells by simple division takes place during mitosis. It supplies all the new cells needed in your body for growth, replacement and repair. (Your cells really have 23 pairs of chromosomes – but for simplicity this cell is shown with only two pairs.)*

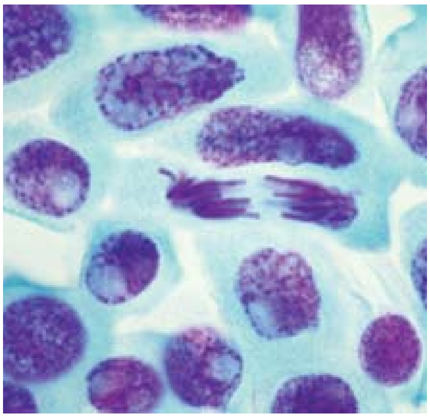


Figure 2.6 *These cells are in the growing root tip of an onion, so they are dividing rapidly and the chromosomes have taken up a red stain. You can see mitosis taking place, with the chromatids in different positions as the cells divide.*

Most of the time, you can't see the chromosomes in the nucleus of a cell, even under the microscope. However, when a cell is splitting in two, the chromosomes become much shorter and denser, and will take up special colours called **stains**. At this stage you can see them under the microscope. The name 'chromosome' means 'coloured body', referring to what the chromosomes look like when they have taken up the stain.

Activity 2.2: Seeing chromosomes

This experiment was done for the first time by Walther Fleming, a German scientist, and is now carried out regularly in school labs across the world. It allows you to see mitosis in action in the actively dividing cell in an onion root tip.

You will need:

- a light microscope

and either

- actively growing root from an onion
- watch glass
- acidified ethanoic orcein stain
- hot plate
- tweezers
- mounted needle
- microscope slide and coverslip
- blotting paper

or

- a prepared longitudinal section of an actively growing onion root tip stained with acidified ethanoic orcein stain

Method

If you are preparing your own slide:

1. Cut off the end of a growing root tip about 5 mm from the end of the root.
2. Pour a little acidified ethanoic orcein stain into the watch glass and add the root tip.
3. Place the watch glass, stain and root on a warm hot plate for five minutes.
4. Remove the watch glass from the hot plate and, using the tweezers, place the root tip on the slide with a drop of ethanoic orcein stain.

5. Break up the root tip with the needles to spread out the cells as much as possible.
6. Place a coverslip over the crushed root tip, place the blotting paper over it and press down gently – this will crush the root tip further. The slide is now ready to use.

Whether you have prepared your own root tip slide or have a ready made one, you are now going to make observations and drawings:

7. Look at your slide under the microscope, first using the low-power lens and then moving to higher magnifications.
8. Make careful observations of the chromosomes and the ways they are arranged in the cells. Make drawings of your observations. On your slide, try to find cells that are: resting, about to divide, in the middle of dividing, or just completing a division.

The cells of early animal and plant embryos (known as **stem cells**) are unspecialised. Each one of them can become any type of cell that is needed. In many animals, the cells become specialised very early in life. By the time a human baby is born, most of its cells have become specialised for a particular job, such as liver cells, skin cells and muscle cells. They have **differentiated**. Some of their genes have been switched on and others have been switched off. This means that when a muscle cell divides by mitosis, it can only form more muscle cells. Liver cells can only produce more liver cells. So in adult animals, cell division is restricted because differentiation has occurred. Some specialised cells can divide by mitosis, but this can be used only to repair damaged tissue and replace worn-out cells. Each cell can only produce identical copies of itself.

KEY WORDS

stem cells *cells that have the ability to grow into other kinds of cells*

differentiated *made different*

ovary *the female sex organ that produces ova*

testes *the male sex organ that produces sperm*

ova *egg cells (reproductive cells) produced by the ovary*

The cell cycle

The cells in your body divide on a regular basis to bring about growth. They divide in a set sequence, known as the cell cycle, which involves several different stages.

- A period of active cell division – this is when mitosis takes place and the number of cells increases.
- A long period of non-division – when the cells get bigger, increase their mass, carry out normal cell activities and replicate their DNA ready for the next division.

The length of the cell cycle varies considerably. It can take less than 24 hours, or it can take several years, depending on which cells are involved and at which stage of life. There are many cycles during the years of growth and development, but it slows down once puberty is over in the adult.

Mitosis is taking place all the time in tissues all over your body. But mitosis is not the only type of cell division. There is another type that takes place only in your reproductive organs.

DID YOU KNOW?

Your body cells are lost at an amazing rate – 300 million cells die every minute. Fortunately, mitosis takes place all the time to replace them.

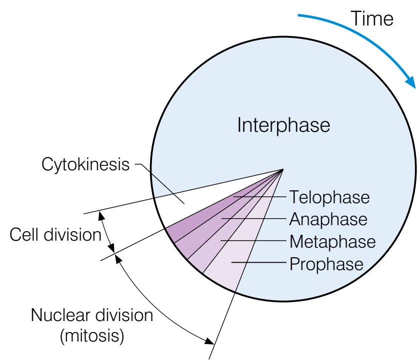


***Figure 2.7** The cell cycle. In rapidly dividing tissue and in cancer cells, interphase may only be a few hours. In other tissues, or in an adult animal, interphase may last for years.*

Meiosis

The reproductive organs in humans, as in most animals, are the **ovaries** and the **testes**. This is where the sex cells (the gametes) are made. The female gametes, or **ova**, are made in the ovaries; the male

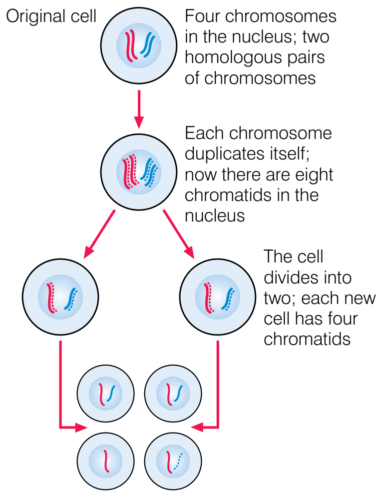


***Figure 2.8** This simple diagram sums up the main stages of meiosis – see figure 2.9 for the details.*

KEY WORDS

sperm *male reproductive cells produced by the testes*

meiosis *the type of cell division that creates egg and sperm cells*

DID YOU KNOW?

One testis can produce over 200 million sperm each day by meiosis. As most boys and men have two working testes, that gives a total of 400 million sperm produced every 24 hours! Only one sperm is needed to fertilise an egg. However, as each tiny sperm needs to travel 100 000 times its own length to reach the ovum, fewer than one in a million ever complete the journey – so it's a good thing that plenty are made.

gametes, or **sperm**, are made in the testes. In plants, the sex cells are the pollen and the ovules. The cells in the reproductive organs (also known as germ cells) divide to make sex cells. The cell division that takes place in the reproductive organ cells and produces gametes is known as **meiosis**.

Meiosis is a special form of cell division where the chromosome number is reduced by half. When a cell divides to form gametes, the chromosomes are copied so there are four sets of chromatids. The cell then divides to form two identical daughter cells. These cells then divide again immediately, without the chromatids doubling again, in the second meiotic division. This forms four gametes, each with a single set of chromosomes. The details of this process are shown in figures 2.8 and 2.9. As in mitosis, the process is shown as being broken up into different stages, but in real life it is a single, flowing process that has been described, rather poetically, as the 'dance of the chromosomes'.

- Meiosis is the division of the sex cells resulting in daughter cells with half the original number of chromosomes.

Why is meiosis so important? Your normal body cells have 46 chromosomes in two matching sets, 23 from your mother and 23 from your father. If two body cells joined together in sexual reproduction, the new cell would have 92 chromosomes, which simply wouldn't work. As a result of meiosis, your sex cells contain only one set of chromosomes, exactly half the full chromosome number. So when the gametes join together at fertilisation, the new cell that is formed contains the normal number of 46 chromosomes.

Gametogenesis

Meiosis occurs as part of a process known as gametogenesis, or gamete formation. In females this is called oogenesis. In a baby girl, the first stage of meiosis is completed before she is even born. The tiny ovaries of a baby girl contain all the ova she will ever have. The second meiotic division begins as the eggs mature in the ovaries during the monthly cycle.

In males, meiosis doesn't start until puberty, when the testes start to produce sperm. The production of sperm is called spermatogenesis, and carries on throughout a man's life.

Each gamete you produce is slightly different from all the others. The combination of chromosomes will be different. What's more, there is some exchange of genes between the chromosomes during the process of meiosis, which means that no two eggs or sperm are the same. This introduces a lot of variety into the genetic mix of the offspring.

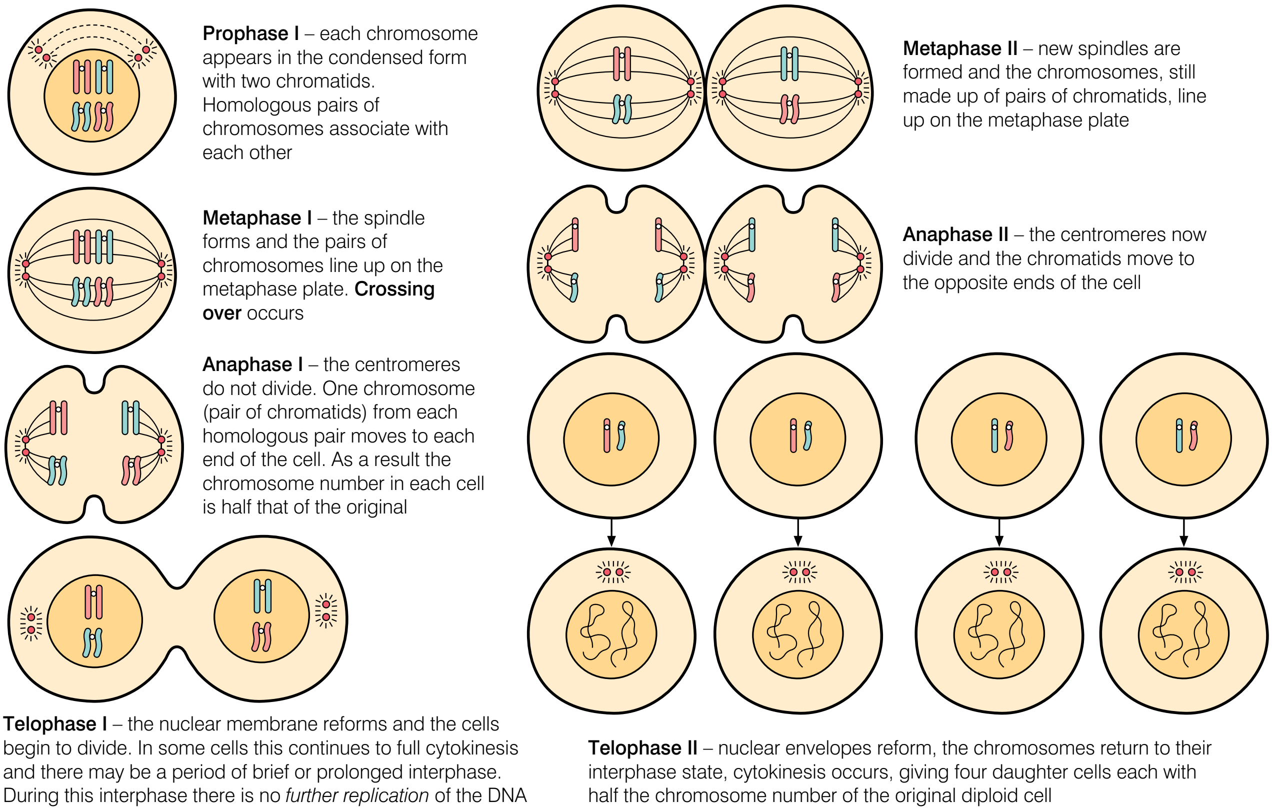


***Figure 2.9** The formation of sex cells in the ovaries and testes involves a special kind of cell division – meiosis – to halve the chromosome number. (The cell is shown with only two pairs of chromosomes, to make it easier to follow what is happening.)*

Activity 2.3: Making models of meiosis

It makes it much easier to understand and follow a process like meiosis if you can see the movement of the chromosomes. This is almost impossible in a school unless you have a video of the process, but it is possible to make models of the process to help you see what is going on. These models can range from something very simple using coloured string or modelling clay, through to computer animations or drama, depending on the time and materials available to you.

Plan two different models of meiosis, one as simple as possible and the other more complex. Show your plans to your teacher and then – with their approval – make one of your models and demonstrate it to your classmates.

Comparison of mitosis and meiosis

In some ways, mitosis and meiosis are very similar – both involve replication of DNA and the formation of daughter cells. But they are also very different because they play very different roles in your body. The table below compares the two processes.

Feature	Mitosis	Meiosis
Where does it take place?	Somatic cells (normal body cells)	Germ cells found in reproductive (sex) organs
Chromosomes in daughter cells?	Same number of chromosomes as original cell	Half the chromosome number of original cell
Number of daughter cells?	2	4
Variety?	Daughter cells identical to parent cells	Daughter cells different from parent cells – always variety
DNA replication?	Always occurs	Always occurs at first meiotic division, never at second meiotic division
How often?	Varies from every few hours to every few years, depending on cell type and age	In girls – first division before birth; second division monthly, completed on fertilisation Stops at menopause In boys – doesn't start until puberty, then continues steadily throughout life

Table 2.1 *Comparing mitosis and meiosis*

Summary

In this section you have learnt that:

- A chromosome is a structure, in the nucleus of a cell, consisting of genes. Chromosomes are made up of the genetic material DNA in a DNA–protein complex.
- Chromosomes contain genes that carry genetic information about an individual, which is passed on from one generation to another.
- DNA is the genetic material contained in the nucleus. It is a long molecule made up of two strands twisted together to make a double helix. The DNA molecule is made up of many smaller units called nucleotides that are joined together. Each nucleotide is composed of a sugar, phosphate and one of the four bases (adenine, thymine, guanine and cytosine).
- A gene is a unit of hereditary material located on the chromosomes.
- In the body's cells, chromosomes are found in homologous pairs.
- Humans have 46 chromosomes arranged in 23 pairs.
- 22 pairs of chromosomes carry information about the body generally. The final pair are the sex chromosomes, which determine whether you are female (XX) or male (XY).

- Mitosis is division of the somatic cells to make identical daughter cells.
- The stages of mitosis are interphase, prophase, metaphase, anaphase and telophase.
- Body cells divide by mitosis to produce more identical cells for growth, repair, replacement and, in some cases, asexual reproduction.
- Cells divide in a regular pattern known as the cell cycle.
- Body cells have two sets of chromosomes; gametes have only one set.
- Meiosis is the division of the sex cells resulting in daughter cells with half the original number of chromosomes.
- The process of meiosis introduces variety because no two gametes are ever the same.
- Meiosis is divided into two divisions. The first meiotic division is very similar to mitosis. The second is again similar, but there is no more replication of chromosomes, so the number of chromosomes in the final cells is halved.
- Meiosis takes place in the ovaries of girls and women. It is called oogenesis, and forms the ova. The first stage takes place before birth. The second stage occurs as the eggs ripen during the menstrual cycle and is completed after fertilisation of the egg.
- Meiosis takes place in the testes after puberty. Spermatogenesis produces sperm.
- Mitosis and meiosis show both similarities and differences.

Review questions

1. Chromosomes are made up of:

   A RNA
   B protein
   C DNA
   D acetic orcein

2. How many chromosomes would you expect to find in a normal human body cell?

   A 23
   B 50
   C 84
   D 46

3. Which combination of chromosomes would result in a human male?
   A XXX
   B XY
   C XX
   D YY
4. Which of the following statements is *not true* of mitosis?
   A In the initial stages of cell division, the chromosomes divide to form daughter chromatids.
   B Mitosis is used to replace old, worn-out cells.
   C Two identical daughter cells, known as clones, are formed.
   D Genetic variety is introduced during the process.
5. Which of the following statements is true of meiosis?
   A Genetic variety is introduced during the process.
   B Meiosis is used to replace old, worn-out cells.
   C Two identical daughter cells, known as clones, are formed.
   D Meiosis is involved in asexual reproduction.

2.2 Mendelian inheritance

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

- Explain the work of Mendel on garden peas.
- Relate Mendel's work to the principle of inheritance.
- Illustrate Mendelian inheritance.
- Explain the difference between a gene and an allele.
- Relate the difference between dominant and recessive alleles.
- Describe homozygous and heterozygous individuals for a particular gene.
- Explain the inheritance of a single pair of characteristics (monohybrid inheritance).
- Carry out simple genetic crosses.
- Explain the patterns of Mendelian genetics in organisms including plants, cattle and people.
- Demonstrate the principle of inheritance using beads.
- Relate that in some situations no allele is dominant and describe codominant alleles in terms of the inheritance of roan coat colour in cows and ABO blood groups.

In the previous section you looked at the processes of mitosis and meiosis. In this section you are going to look in more detail at genetics and inheritance – the science of how information is passed from parents to their children.

In the 21st century we know a lot about genetics, chromosomes and genes. Yet for hundreds of years people had no idea about how information passed from one generation to the next.

Mendel's discoveries

For centuries people thought that the characteristics of the parents blended together so that the distinct characteristics of each parent were lost. In other words, a cross between a black dog and a white dog would give grey puppies. The birth of Gregor Mendel in 1822 was the beginning of the end for those theories. Mendel was born into a very poor family but he was very clever. The only way in those days for a poor person to get an education was to join the church. Mendel became a monk at a monastery in Brunn in Austria, and he became fascinated by the breeding patterns of the peas in the monastery gardens. He carefully bred different pure strains of peas – round peas, wrinkled peas, green peas, yellow peas – and then carried out breeding experiments with them.

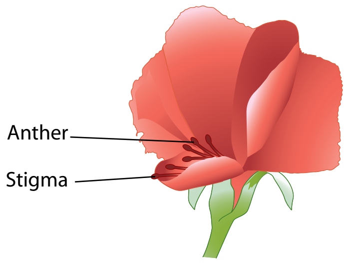
KEY WORDS

dominant *an allele where the characteristic is expressed in the phenotype even if only one copy of the allele is present*

recessive *an allele where the characteristic is only expressed in the phenotype if two copies of the allele are present*

How did Mendel breed his peas?

Both the male and the female parts of a pea flower are held inside a hood-like petal, so the flower often pollinates itself. Mendel opened the bud of his pea flowers before the pollen matured. He fertilised the stigma by brushing it with ripe pollen from another chosen flower. In this way he could control the cross. Mendel used seven clearly different, pure-breeding traits of the pea plant for his experiments. They are shown here in both their **dominant** and **recessive** forms. You will learn what these terms mean later in this chapter.



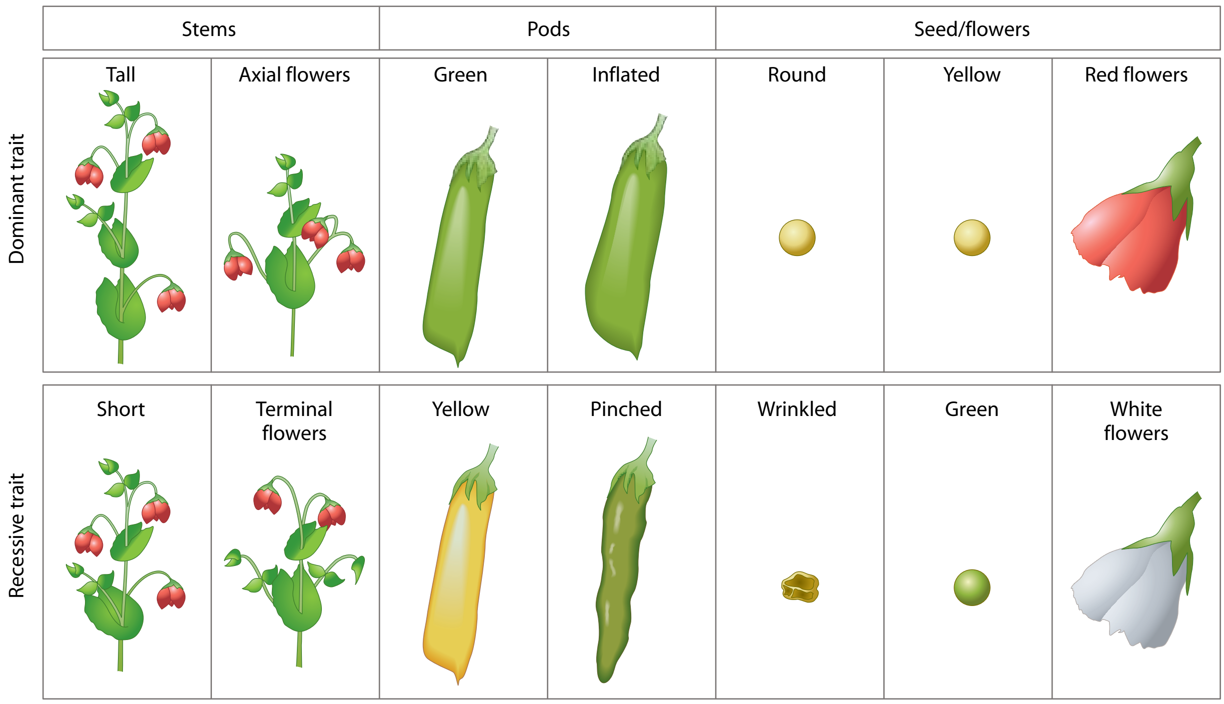


Figure 2.10 *Some of the features of the pea plant studied by Gregor Mendel*

Mendel developed a theory to explain his observations, based on independent particles of hereditary material, some of which were dominant over others but never mixed together. The abbot of the monastery supported his work and built him a large greenhouse in which to carry it out.

Mendel observed, for example, that the round shape of peas seemed to dominate the wrinkled shape, but that the information for a wrinkled shape continued to be carried and could emerge again in later generations – in other words there were unique units of inheritance that were not blended together.

Mendel kept precise records of everything he did, and made a statistical analysis of his results – something almost unheard of in those times. Finally in 1866, when he was 44 years old, Mendel published his findings; they explained some of the basic laws of genetics in a way we still refer to today.

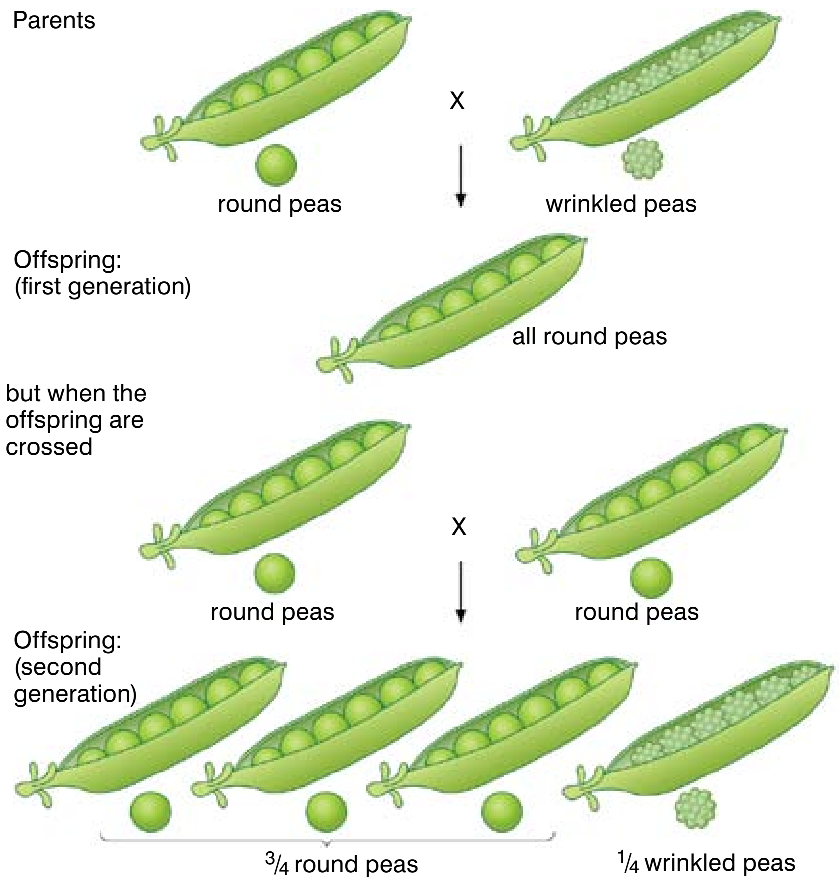


Figure 2.11 *It was experiments like this with peas that led Gregor Mendel to his ground-breaking conclusions.*

Sadly no one listened to Mendel. He was ahead of his time. Nobody yet knew of the existence of chromosomes, let alone genes, so there was no model to help people understand Mendel's new ideas. He died nearly 20 years later with his ideas still ignored – but still sure that he was right.

Sixteen years after his death, Gregor Mendel's work was finally recognised. By 1900 people had seen chromosomes through a microscope. Three scientists, Hugo de Vries, Eric von Seysenegg and Karl Correns, discovered Mendel's papers and duplicated his experiments. When they published their results, they gave Mendel the credit for what they observed. From then on ideas about genetics developed fast – it was suggested that Mendel's units of inheritance might be carried on the chromosomes seen beneath the microscope, and the science of genetics as we know it today was born.

Figure 2.12 *Gregor Mendel tending his pea plants. When he died in 1884 Mendel was still convinced that before long the whole world would acknowledge his discovery. In the 21st century we know just how right he was!*

How inheritance works

If we take a closer look at Mendel's findings and other observations, it becomes clear how inheritance works.

The chromosomes we inherit carry our genetic information in the form of genes. Many of these genes have different forms, known as **alleles**. A gene can be pictured as a position on a chromosome. An allele is the particular form of information in that position on an individual chromosome for example, the gene for dimples may have the dimple or the no-dimple allele in place. Most of your characteristics, like your eye colour and nose shape, are controlled by a number of genes. However, some characteristics like dimples and having attached earlobes are controlled by a single gene. Often there are only two possible alleles for a particular feature, but sometimes you can inherit one from a number of different possibilities. When we are trying to understand genetics, we tend to stick to traits that are controlled by a single pair of genes, because they are much simpler. Characteristics that are inherited through different forms of a single gene are examples of **monohybrid** inheritance. Almost every example you consider in this book will be a case of monohybrid inheritance.

There are genes that decide whether:

- your earlobes are attached closely to the side of your head or hang freely
- your thumb is straight or curved
- you have dimples when you smile
- you have hair on the second segment of your ring finger

We can use these genes to help us understand how inheritance works.

KEY WORDS

alleles *different forms of the same gene*

monohybrid *hybrid between two parents that have a difference of only one gene*

Dominant and recessive alleles (genes)

Some alleles control the development of a characteristic even when they are only present on one of your chromosomes. These alleles are dominant for example, dimples and dangly earlobes. Some alleles control the development of a characteristic only if they are present on both chromosomes – in other words, no dominant allele is present. These alleles are recessive.

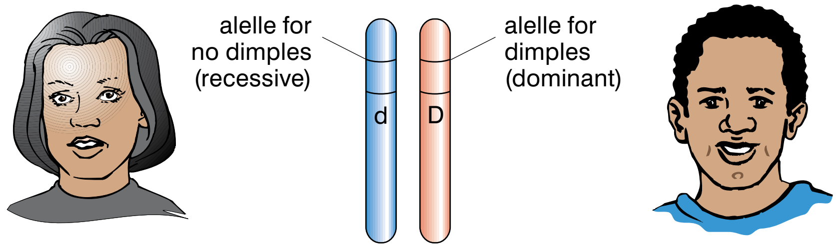


Figure 2.13 *The different forms of genes, known as alleles, can result in the development of quite different characteristics. Here the mother has passed on an allele for no dimples, and the father an allele for dimples. You can see the difference the alleles make to their appearance. The child represented by the pair of chromosomes will have dimples.*

The gene that controls dimples has two possible forms – an allele for dimples, and an allele for no dimples. The gene for dangly earlobes also has two possible alleles – one for dangly earlobes and one for earlobes that are attached. You will get a random mixture of alleles from your parents – which is why you don't look exactly like either of them. If you inherit two identical alleles – whether they are dominant or recessive – you are **homozygous** for that trait. If you inherit one of each type of allele, you are **heterozygous** for the trait.

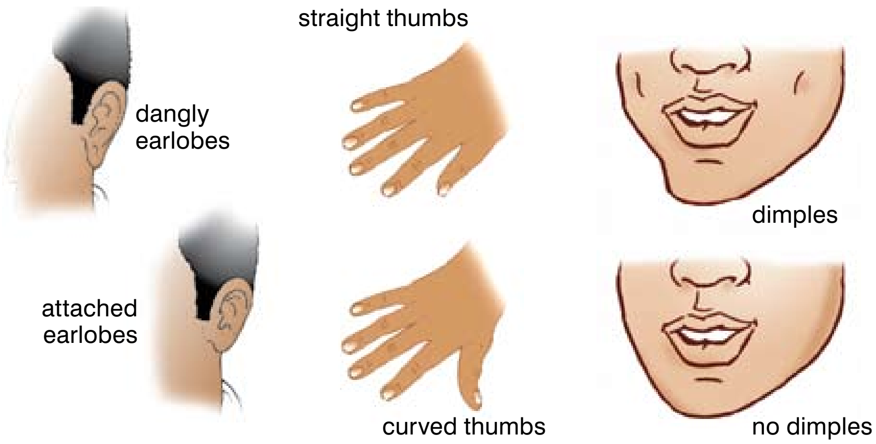


Figure 2.14 *These are all human characteristics that are controlled by a single pair of genes, so they can be very useful in helping us to understand how sexual reproduction introduces variety and how inheritance works.*

How does it work?

We can use a simple model to help us understand how sexual reproduction produces variety:

Imagine you have two bags, each containing the same number of beads. Each bag contains a random mixture of red and blue beads.

One bag represents the possible genes from the father and the other bag represents possible genes from the mother.

If you put your hand in and – without looking – picked out one bead from the father bag and one bead from the mother bag, what pairs might you get? If the bags contained only red beads or only blue beads, the pairs would all be the same. But if each bag held a mixture of red and blue beads you could end up with three possible pairs – two blue beads, two red beads or one of each.

This represents the random way in which you may inherit different genes from your parents, depending on the different alleles they have. For example, if both of your parents have two alleles for dimples (like the red beads) you will definitely inherit two dimple alleles – and you will have dimples!

KEY WORDS

homozygous *having two identical alleles for a particular feature*

heterozygous *having two different alleles for a particular feature*

If both of your parents have two alleles for no dimples, you will inherit alleles for no dimples and you will be dimple-free. But if your parents both have one allele for dimples and one for no dimples, you could end up with two dimple alleles, two no dimple alleles – or one of each!

If you happen to inherit one of each type of dimple allele, how does your body know whether to produce dimples or not? The allele for dimples is dominant so it will always be seen over the allele for no dimples. If you get one of each type of allele, you will have dimples.

What's more, if you have brothers and sisters, they could inherit a different combination to you, and so have different characteristics. This is why family members look similar – but different!

Figure 2.15 *Although these children have some family likenesses, the variety that results from the mixing of their parents' genetic information can clearly be seen!*

Monohybrid inheritance

You are going to start looking at how to work out genetic problems using the same organisms as Mendel did. You are going to be looking at inheritance of different forms of one gene at a time. This is called monohybrid inheritance.

Mendel started all his crosses using homozygotes because they are true breeding. This means that if you cross two individuals who are homozygous for the same characteristic, all of the offspring of all the generations that follow will have the same characteristic – unless a change in the DNA takes place. Heterozygotes are not true breeding. If you cross two heterozygotes, then the offspring may include a mixture of genotypes and phenotypes as you will see.

Look back to figure 2.11. We are going to look at a cross between a pea plant which is homozygous for the dominant round pea shape, and a pea plant which is homozygous for the recessive wrinkled pea. The first generation of any cross is called the F1 (first filial generation) and you can see in figure 2.11 that they all have the same heterozygous genotype for the characteristic. They also all have the same phenotype – the round pea shape – because the round allele is dominant. There is no sign of the wrinkled pea allele.

If we then cross members of the F1 generation we call the next generation the F2 (second filial generation). You can see in figure 2.11 that Mendel's theory predicts that the genotypes will be one homozygous round pea, two heterozygous round peas and one homozygous wrinkled pea. The recessive trait for the wrinkled pea has become visible again, after being 'hidden' in the F1 generation.

Genetic crosses can be shown with the use of simple genetic diagrams called Punnett squares like those shown below. A genetic diagram shows you the alleles for a characteristic carried by the parents, the possible gametes that can be formed from these and how they could combine to form the characteristic in their offspring.

R = round
r = wrinkled

Parental phenotype	round-seeded	×	wrinkle-seeded
Parental genotype	RR		rr
Gametes	R R		r r

	r	r
R	Rr	Rr
R	Rr	Rr

Offspring genotype (F_1 generation) Rr
Offspring phenotype round-seeded

If two F_1 offspring are crossed, we get the following results

F_1 phenotype	round-seeded	×	round-seeded
F_1 genotype	Rr		Rr
Gametes	R r		R r

	R	r
R	RR	Rr
r	Rr	rr

Offspring genotypes (F_2 generation) RR : 2Rr : rr
Offspring phenotypes 3 round-seeded : 1 wrinkle-seeded

Figure 2.16 *A cross between a pea plant homozygous for the round pea allele, and a plant homozygous for the wrinkled pea allele, through the F1 and F2 generations.*

Test crosses

As can be seen from figures 2.11 and 2.16, individuals which are homozygous dominant or heterozygous will look exactly the same. They have identical phenotypes. This can give you all sorts of difficulties if you want to breed plants or animals. A breeder needs to know that the stock will breed true – in other words, that it is homozygous for the desired feature. If the feature is inherited through recessive genes then what you see is what you get. However, if the required feature is inherited through a dominant gene the physical appearance does not show whether the organism is homo- or heterozygous. To find out the genotype of an individual showing the effect of a dominant allele it must be crossed with a homozygous recessive individual. Because the recessive genes have no effect on the phenotype of the offspring unless they are in the homozygous state, this type of cross can reveal the required parental genotype (see figure 2.17). It is known as a test cross.

For example, the colour of the pea seed is inherited as a dominant allele Y for yellow seeds or a recessive allele y for green seeds. Thus a

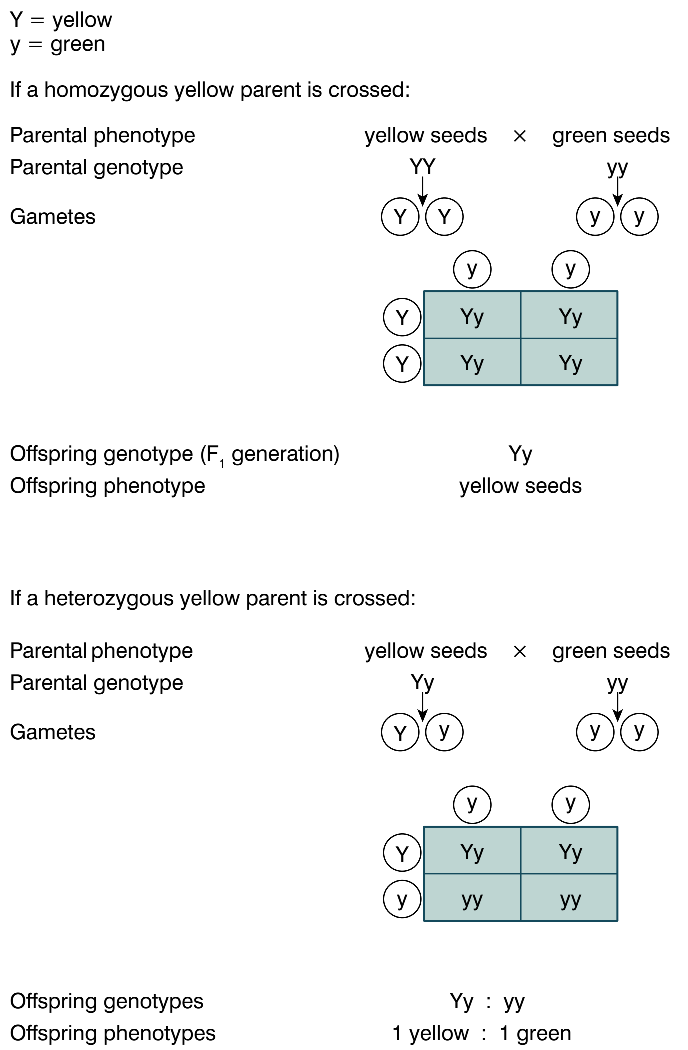


Figure 2.17 *Test crosses to show the genotype for seed colour of a parent pea plant: discovering the unknown genotype of a parent.*

plant producing yellow seeds could have the genotype YY or Yy. The phenotypic ratios of the progeny of the test cross reveal whether the yellow parent was homo- or heterozygous.

Mendelian genetics in people

The patterns of inheritance and the ratios of genotypes and phenotypes that Mendel saw in his peas apply to most organisms, including people. We will look at the way we inherit the shape of our ear lobes. There are two possible alleles controlling this characteristic – the allele to have dangly ear lobes (represented by a capital D because it is a dominant allele) or the allele to have attached earlobes (represented by a small d because it is the recessive allele).

If we inherit a dangly allele from both our parents (DD) or only from one (Dd), we will have dangly ear lobes. If we inherit an attached allele from both our parents (dd), we will have attached ear lobes. We will be looking at how we can use information like this to predict what offspring a couple might have. Using simple crosses such as Gregor Mendel used in his breeding experiments with peas, or situations in humans where a characteristic is inherited by a single pair of genes, we can begin to build up a way of predicting what offspring might result from a particular cross.

KEY WORDS

genotypes *a description of the alleles of an individual for a given genetic trait*

phenotype *a description of the physical appearance of an individual relating to a given genetic trait*

To work out the possible gametes, you need to look at the genotypes of each of the parents. So, to use our dangly ear lobes again, if you have the genotype DD, both of the possible alleles you could pass on in your gametes are D. If you have attached earlobes, you have genotype dd and both of the possible gametes you might produce would carry the recessive allele d. But if you are heterozygous, Dd, your gametes may contain either the dominant allele D or the recessive allele d – and it is completely a matter of chance which one will meet up with another gamete.

In a genetic diagram you will end up with all the possible **genotypes** of the offspring – that is, the alleles they might inherit. From this you can work out their possible **phenotypes** – the physical characteristics that they will have as a result of their

Figure 2.18 *Genetic diagrams like this show us the parents, the possible gametes that can be formed and the possible offspring that could result. They enable us to work out the likelihood of particular combinations of alleles being passed on. These genetic diagrams, known as Punnett squares, are very compact and easy to follow.*

Dangly earlobes

Attached earlobes

a) D = dangly earlobes
d = attached earlobes

Phenotype of parents	Dangly		Attached
Genotype of parents	DD	x	dd
Gametes	D D		d d

Possible genotypes of offspring

	D	D
d	Dd	Dd
d	Dd	Dd

All Dd

Phenotype: all dangly earlobes

b)

Phenotype of parents	Dangly		Attached
Genotype of parents	Dd	x	dd
Gametes	D d		d d

Possible genotypes of offspring

	D	d
d	Dd	dd
d	Dd	dd

Phenotype: 1 : 1
dangly : attached

c)

Phenotype of parents	Dangly		Dangly
Genotype of parents	Dd	x	Dd
Gametes	D d		D d

Possible genotypes of offspring

	D	d
D	DD	Dd
d	Dd	dd

Phenotype: 3 : 1
dangly : attached

genotype. For example, someone with a genotype DD or Dd will have dangly ear lobes as their phenotype. Only someone with the genotype dd will have attached ear lobes as their phenotype.

You can use simple diagrams to work out genetic crosses. Figure 2.18 provides you with some clear examples to follow. You need to choose suitable symbols to represent the dominant and recessive alleles. This is usually the capital and lower case version of a single letter. You also need to give a key to explain which symbol is which. You need to indicate clearly the genotypes of the parents, the possible gametes, the possible genotypes of the offspring and also the ratio of the different possible phenotypes of the offspring.

If one of your parents has a characteristic caused by a dominant allele (for example, dangly earlobes) you have a 50% chance of inheriting it. If both parents have a single recessive allele for a characteristic (for example, attached earlobes) you have a 25% chance of inheriting that characteristic. This doesn't matter when you are looking at a harmless characteristic such as earlobes, but it becomes more important when serious genetic diseases such as sickle cell disease are involved.

In most of the examples of monohybrid inheritance that you will be looking at, there is simple dominance of one allele over another. But it is important to realise that this isn't always the case. Not all genes show dominance so aspects of both characteristics show through. This is common in the colour of the coat of certain cattle. If a homozygous red cow is crossed with a homozygous white cow, the calves that result will all have roan coats, a mixture of red and white hairs.

Example: R = red r = white

Phenotype of parents	Red bull	x	White cow
Genotype of parents	RR	x	rr
Gametes	R R		r r

Possible genotypes of offspring

	R	R
r	Rr	Rr
r	Rr	Rr

F1 genotype: Rr

F1 phenotype: roan

Figure 2.19 *An example of a roan cow*

The same thing happens in the inheritance of the human ABO blood groups. There are three possible alleles that you might inherit – A, B and O. The O allele is recessive to A and B, but neither A nor B show dominance over the other one. This means that if you have blood group O, your genotype is OO. However, if you have blood group A you could have the genotype AA or AO, while blood group B could be BB or BO. However, if you inherit an A allele from one parent and a B allele from the other parent you have blood group AB. You will learn more about this if you study biology further.

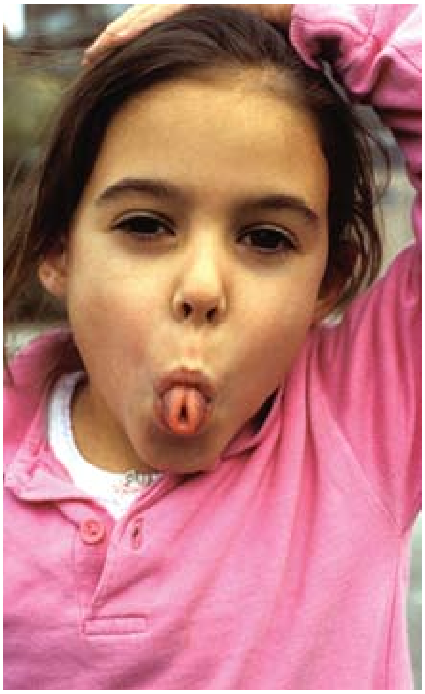


Figure 2.21 *We have many characteristics which – like tongue rolling – are genetic but are inherited through more than one gene, or are affected by environmental factors as well.*

Phenotype of parents	Blood group A		Blood group B
Genotype of parents	I^AI^O	x	I^BI^O
Gametes	I^A and I^O		I^B and I^O

female gametes

male gametes	I^A	I^O
I^B	I^AI^B	I^BI^O
I^O	I^AI^O	I^OI^O

Genotypes of children

Phenotypes of children are 1 group AB: 1 group A: 1 group B: 1 group O

Figure 2.20 *If a couple are heterozygous for blood groups A and B, their children could have any one of the four possible ABO blood groups!*

Tongue rolling – a new discovery

For many years people thought tongue rolling was a single gene character. This idea changed when it was observed that in some pairs of identical twins, one can roll their tongue and the other can't! Now geneticists are left trying to work out exactly what happens in this case, and tongue rolling is no longer seen as a simple example. Scientists now think tongue rolling may be inherited by two genes which are closely linked together, so they often appear as one. You will learn more about these kinds of inheritances in Grade 12.

Activity 2.4: Investigating genetics

You are going to investigate some of the simple, single-gene genetic traits you possess. You are then going to collect as much information about your fellow students as possible and draw bar charts to show the frequency of different traits in your class. It would be good to collect data from all the students in grade 10 in your school.

Method

1. Choose a number of single-gene or clear discontinuous traits, e.g. dimples or not, attached or unattached earlobes, straight or curved thumbs, the presence of hair on the second segment of the ring finger, tongue rolling (not clear cut genetically but fun to look at!).
2. Draw up a table showing each of the characteristics you have chosen. You can make up a table similar to the example below for each feature you investigate.
3. Make a tally of all the people in the class who possess each feature and record it in your table.
4. Display your data as bar charts, pie charts. etc.
5. Write up your investigation and results. Can you draw any conclusions? For example, are characteristics related to dominant alleles more common than characteristics related to recessive alleles or does it vary?

Section	Total number	Straight thumb		Curved thumb	
		Number	%	Number	%
1					
2					
3					
4					

More human inheritance

Your genetic inheritance from your parents often contains nothing worse than a big nose or a tendency to gain weight easily. However, sometimes the genetic combination you receive has more noticeable and dramatic effects. There are a number of genetic conditions which cause serious health problems and even death. Many other combinations have a relatively simple but very noticeable effect. One of these is albinism.

The high levels of melanin (black pigment) in Ethiopian skin gives a natural protection against UV radiation from the sun but even so it is still sometimes useful to have additional protection from sunscreens. People with paler skins are much more likely to suffer severe sun damage.

Figure 2.22 *Albinism is particularly noticeable in areas where most people have a high level of melanin in the skin, such as Africa. The appearance of an albino in a family can appear quite random, but it is the result of hidden recessive alleles.*

a) How two carriers can produce an albino child

Parental genotype: Aa x Aa

Possible gametes: A a | A a

Possible F1 genotypes:

	A	a
A	AA	Aa
a	Aa	aa

1AA : 2Aa : 1aa

Possible F1 phenotypes: 3 normal : 1 albino

b) How an albino and someone with a normal phenotype but heterozygous might produce an albino child or a normal child

Parental genotype: Aa x aa

Possible gametes: A a | a a

Possible F1 genotypes:

	A	a
a	Aa	aa
a	Aa	aa

1Aa : 1aa

Possible F1 phenotypes: 1 normal : 1 albino

c) how an albino and a homozygous normal individual would never have an albino child

Parental genotype: AA x aa

Possible gametes: A A | a a

Possible F1 genotypes:

	A	A
a	Aa	Aa
a	Aa	Aa

All Aa

Possible F1 phenotypes: All normal

KEY WORDS

albinism *a genetic condition in which no melanin pigment is formed in the cells*

For example, in the inherited condition known as **albinism** the melanin pigment in the skin, hair and eyes does not develop. The normal allele for pigment to develop is A and it is dominant. The allele for albinism, a, is recessive. Albinism is found throughout the animal kingdom and people are no exception. Albino individuals are very vulnerable to sun damage to their skin, so they have a greatly increased risk of developing skin cancer. They have to take great care to protect their vulnerable skin from sunlight. Their eyes are also very sensitive to light and they often have problems with their vision – but apart from this they lead completely normal lives.

If people do not understand genetics, the arrival of an albino baby can cause great distress and, in the past, albinos often suffered discrimination as a result of their unusual appearance. However, for albinism and indeed any other genetic traits, looking at the family history can show exactly how a characteristic has been passed on.

One way of investigating this is to build up a pedigree or family tree for a particular characteristic. On a family tree, men are usually shown as squares and women as circles. Individuals affected by a particular trait are shaded. Once a pedigree is built up, it is possible to see when a mutation may have taken place, and to work out the possible genotypes of many of the individuals.

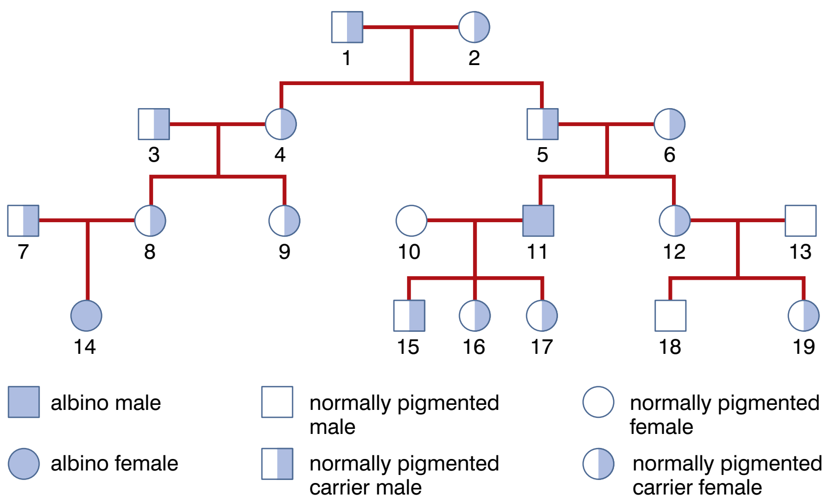


Figure 2.23 *In this family tree, you can see that albinism is relatively rare, because it depends on both partners carrying the recessive albino allele. The chances of two carriers marrying and having children are relatively small.*

Activity 2.5: Investigating genetics

It can be hard to imagine how a genetic cross works. Design and make a model that could be used to help teach genetics. It can be very simple – models which have been tried before include using beads, cutting out paper people and genes, modelling clay people in different colours, etc. Using what you have available, plan and make your model and use it to demonstrate how a genetic cross works to your peers. Let your teacher decide which model would be most useful in the classroom next year!

Activity 2.6: Genetics in other animals

You have looked at genetics in plants, people and roan cattle. The same principles work in all other animals. In some breeds of cattle the allele P for being *polled* (not having horns) is dominant to the allele p for horns.

Draw genetic diagrams to show the following:

1 A farmer with polled cattle gets a new bull who also does not have horns. Some of his cows give birth to horned calves.

2 A farmer has horned cattle. He decides polled cattle would be easier to handle. He gets a polled bull to breed with his horned cattle. Most of the calves born are polled, but several of his cows give birth to horned cows.

Summary

In this section you have learnt that:

- Gregor Mendel was the first person to suggest separately inherited factors, which we now call genes.
- Gregor Mendel carried out his experiments on seven different characteristics of garden peas.
- Genes can have different forms called alleles.
- Genes come in pairs. A pair of genes controls a particular characteristic or set of characteristsics.
- Each member of a pair of genes may have a different allele.
- The term genotype describes the genetic makeup of an individual, while their phenotype describes their physical characteristics.
- A characteristic controlled by a dominant allele will be present even if only one of these alleles is inherited (present on only one chromosome).
- A characteristic controlled by a recessive allele is only present if the allele is inherited from both parents (present on both chromosomes).
- In some cases alleles are codominant. This means that in a heterozygote features of both characteristics appear. Examples include human ABO blood groups and sickle cell anaemia.
- If an individual is homozygous for a genetic trait, they have two identical alleles for that characteristic.
- If an individual is heterozygous for a genetic trait, they have two different alleles for that characteristic.
- In human body cells the sex chromosomes determine whether you are female (XX) or male (XY).
- You can illustrate Mendelian inheritance (genetic crosses) – the parents, the gametes and the possible offspring – using simple genetic diagrams known as Punnett squares.
- Some features or characteristics are controlled by a single gene and you can use these to look at monohybrid inheritance. Examples include dangly or attached earlobes, dimples and straight or curved thumbs.
- Albinism is an inherited condition where melanin pigment is not produced in the body.

Review questions

1. The basic unit of inheritance is:

   A DNA

   B a chromosome

   C the nucleus

   D a gene

2. Bekele has dangly earlobes. He has inherited one allele for dangly lobes from his mother, and one for attached lobes from his father. Which of the following terms best describes Bekele's genotype for his earlobes?

   A homozygous

   B heterozygous

   C homologous

   D autosomal

3. Which of the following statements is a definition of a recessive allele?

   A An allele that controls the development of a characteristic even when it is only present on one of your chromosomes.

   B An allele that controls the development of characteristics alongside another different allele that is also expressed in the phenotype.

   C An allele that only controls the development of a characteristic if it is present on both chromosomes.

   D An allele that only occurs on the sex chromosomes.

4. Which of the following conditions is imherited?

   A TB

   B albinism

   C anaemia

   D HIV/AIDS

2.3 Heredity and breeding

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

- Describe methods of breeding farm animals and crops.
- Explain the importance of selective breeding for society.
- Explain the difference between selective breeding and cross-breeding.
- Give examples of selective breeding from your own experience.

One area where understanding genetics is very important indeed is in the breeding of farm animals and crop plants. People manipulated the genetics of domestic animals and plants long before anyone understood how genetics works!

For example, in Ethiopia we have 25 types of cattle, 13 types of sheep, 15 types of goats, four types of camels, five types of chickens, four types of donkeys, two of horses and two types of mules! All of these have come about as a result of careful breeding, which has given us animals with the features we need. It might be giving plenty of milk, or laying many eggs; it might be making lots of muscle to provide meat, or the ability to survive on very poor food plants. We have an amazing pool of genetic resources in our farm animals. What are the main ways in which we get the characteristics we want in our animals? To understand this you need to apply all the material on genetics you have learnt so far.

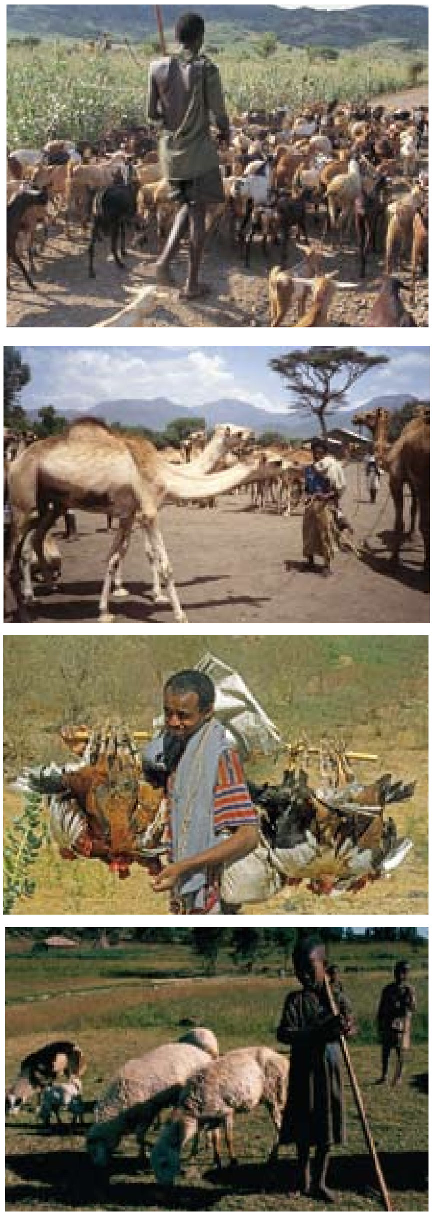


Figure 2.24 The animals you can see here – goats, camels, chickens and sheep are all the result of selective breeding which have given us animals well suited to particular areas of the country.

Selective breeding

One way to improve the performance of a crop plant or domestic animal is to select the best possible individuals of that type and use them to build up your stock.

Selective breeding is used to breed for particular traits. You need to select true-breeding plants or animals, so it is important that the history of the organism is known. If the characteristic you want to select for is recessive, it is easy to be sure that the parents are true breeding. If they show the characteristic, they will be homozygotes. If the trait you want is dominant, you may need to carry out a test cross using a known homozygous recessive on the parents to make sure they are homozygous.

For selective breeding to work, it is important to use only the best animals which have the characteristics you want in the breeding programme. This means that the male and female animals which have the characteristics you want should be allowed to mate, but animals which do not have the characteristic should be castrated or prevented from mating.

Sometimes it can be difficult to do this – everyone in the area needs to control their animals to make selective breeding work. Sometimes it is hard to select the animals or plants you want. For example, animals which grow fast and gain lots of muscle are very desirable both for meat and for their strength as work animals. However, farmers will often kill these young, fast-growing males to take to market – leaving the weaker, slower-growing males to reach sexual maturity and mate with the females. This can result in negative selection, so that the breed becomes slower growing and weaker. You also need to avoid the animals becoming too inbred – close relatives being used for breeding can eventually lead to genetic weakness. However, if care is taken, selective breeding is an excellent way of improving the performance of animals and plants, and giving you the characteristics you need.

Activity 2.7: Ethiopian breeds

Find out as much as you can about the breeds of animals and plants which are farmed in your area of the country. For each type of animal you study, list the characteristics of that breed which make it well suited to your area.

If possible, also find out about the breeds in another very different area of Ethiopia. Compare the characteristics that have been selected for in those animals and plants with your local breeds.

Selective breeding for particular traits usually takes place within a type or breed of animal or plant. An alternative approach is shown below.

Combination of traits – cross-breeding

An alternative way of improving a breed of animals or plants is to combine good traits from two different breeds. Take an example. One family has a herd of goats which give good milk yields, but do not cope well without shade. Another family has goats which give less milk but are very hardy and resistant to the heat of the sun. If both families selected their best male and female goats, and cross-bred them, some of the offspring would inherit both the genes for good milk production and the genes for heat resistance. By selecting the offspring carefully and breeding again and again, eventually a new, true breeding type of goat would emerge.

However, this is a long process – look back to section 2.2 and you will see that F1 generations do not breed true. It takes a lot of work to develop a new true breeding strain. Farmers often simply continue to cross-breed to get the benefits of each F1 generation. So perhaps they will have a good bull from one breed and let him service their cows from another breed, so that the calves all have the combination of characteristics that is desired.

Around the world, a combination of selective breeding and cross-breeding has produced cattle which come in an enormous range of shapes and sizes, as you can see in figure 2.25.

We must be careful with our breeding programmes, however. The Belgian Blue cattle which you can see in figure 2.25 have 'double muscles', which means they produce a very large amount of low-fat meat. However, the calves are often so big that the cows cannot deliver them and they have to be born surgically, by Caesarean section. Some European countries want to ban this breed completely.

Figure 2.25 *All cattle had similar ancestors in the distant past, but selective breeding has given us some very different breeds – here you can see a zebu, a Belgian Blue (bred purely for meat) and a Holstein Friesian, bred purely for milk.*

The Borene story

One example of the effect of selective breeding is the Borena breed of cattle. Borenes were originally developed by the Borena people in the south of Ethiopia, probably from the zebu breed. As the Borena people moved northwards, they settled with their cattle around Lake Tana and these populations bred cattle adapted to this new area – the Tanaland Borene. The Borene has spread throughout east Africa and in each different country or area selective breeding has led to changes which suited the needs of the people using them. Now in Ethiopia some farmers are crossing their Borenes with Holstein Friesians and Simmentals imported from Europe. The crosses have more calves and better milk yields, but maintain many of the positive characteristics of the Borenes. At the same time, Borenes have been exported and breeders in many countries around the world including Brazil, the USA and Australia are both breeding pure-bred Borenes and also using them to cross with indigenous breeds in order to improve them.

Figure 2.26 *Borene cattle have proved to be very hardy and suited to African climates; they also breed well with other types of cattle to give specialised and adaptable stock.*

Activity 2.8: Selective breeding

a) If possible, visit a local farmer and discuss the breeds of animals that he raises. Talk to him about selective breeding and cross-breeding and see if he carries out these practices.

b) Select an example of breeding from your own experience. It might be of sheep, goats, cattle, camels, cats or dogs, chickens, horses, crop plants or any other organism. Make a presentation about the process and the characteristics that are important in this animal. You may be asked to tell the rest of the class about your choice.

Importance of breeding for society

Ethiopia is a very big country. Many people rely on their crops and livestock for food, for milk, for hides and for their personal wealth. We have an enormous amount of genetic diversity in our farm animals and plants, which is important not just to Ethiopia but to the whole world as a source of new genetic material to help overcome changes in the world climate. If we can maintain our specialised breeds, we help ourselves and our international partners.

Within our country, selective breeding to maintain the best possible performance in our local breeds means those breeds will be maintained, and people will gain the biggest possible benefit from them. They will get the best possible yield from their crops, and the most milk from their cows, sheep, goats or camels, their animals will make the most of the food available to them as well as other such useful traits.

By cross-breeding and combining useful traits such as a good temperament with a fast growth rate, or a better milk yield with an ability to thrive on poor forage, we can create new breeds even better suited to the different areas of our country. The more food we can produce, the stronger and healthier both we and our children will be. This is good for each individual and for society as a whole.

Summary

In this section you have learnt that:

- Farm animals and plants are the result of selective breeding.
- In selective breeding, only the animals or plants with the characteristic you want are allowed to breed. In time, every member of the breed shows that characteristic.
- Another way of getting desirable characteristics is to cross -breed between two different breeds. This gives you a combination of traits from the two different breeds – the best of both can be used to develop a new breed.
- The many different breeds of Ethiopian cattle are the result of selective breeding and cross-breeding over many years. They, and all our breeds of other animals and plants, represent an important genetic heritage for our country.
- Breeding animals and plants to develop the best possible characteristics is very important for society, to enable us to make the best possible use of our resources, to feed our population, to maintain our genetic diversity and to provide new and useful genes for the international community.

Review questions

1. Which of the following is not an Ethiopian breed of cattle?
   A Borena
   B Zebu
   C Holstein Friesian
   D Raya
2. Cross-breeding is also known as:
   A selective breeding
   B genetic engineering
   C horticulture
   D combination of traits
3. Selective breeding involves:
   A choosing a weak characteristic and selecting for it
   B choosing a strong characteristic and selecting for it
   C mating your animals with a different breed
   D none of the above
4. Which of the following is NOT true of cross-breeding?
   A The offspring immediately form a new breed of animal or plant.
   B The offspring are the F1 generation.
   C The offspring do not breed true.
   D The offspring may combine the best traits of both breeds.

End of unit questions

1. Copy this statement and fill in the gaps with the appropriate terms:

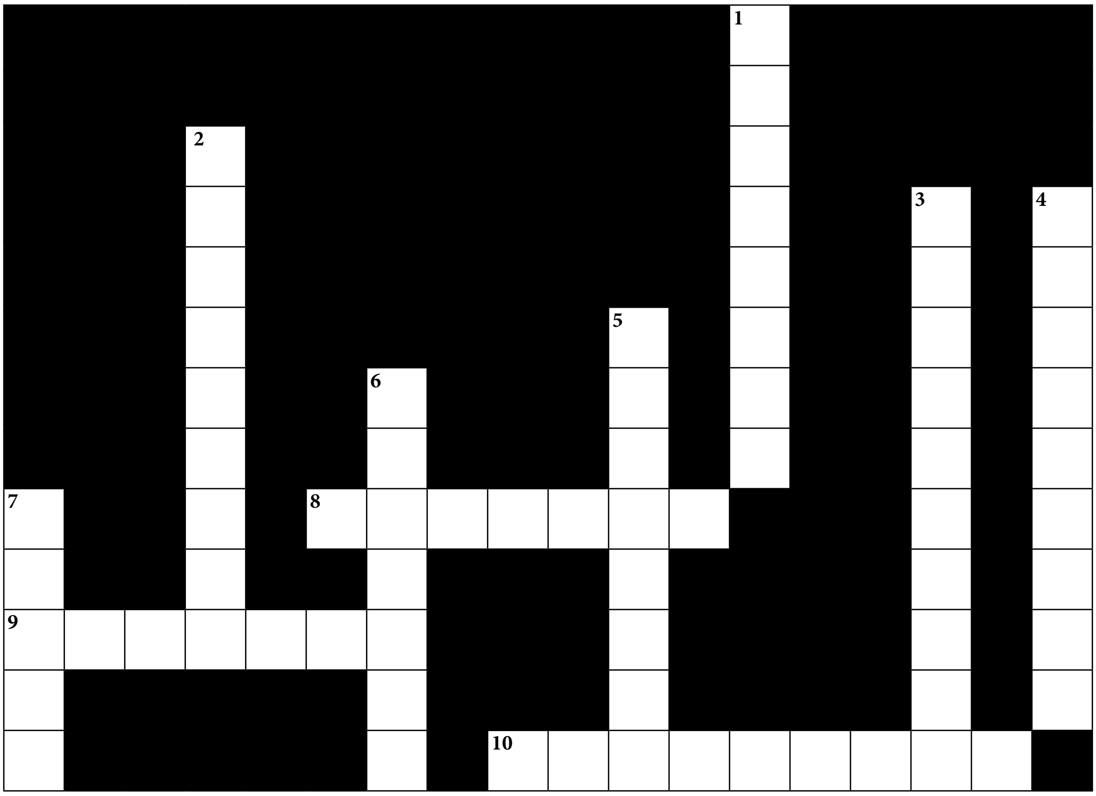
   New cells are needed for ________ and to ________ worn-out cells. The new cells must have the same ________ in them as the originals. Each cell has a ________ containing the________ grouped together on ________. The type of cell division that produces identical cells is known as ________ .
2. Division of the body's cells is taking place all the time in living organisms.
   a) Why is mitosis so important?
   b) Explain why the chromosome number must stay the same when the cells divide to make other normal body cells.
   c) Describe the process of mitosis, and explain the experimental procedure that enables us to see this process taking place.
3. What is meant by the term differentiation, and why is it so important?
4. a) How many pairs of chromosomes are there in a normal human body cell?
   b) How many chromosomes are there in a human ovum?
   c) How many chromosomes are there in a fertilised human ovum?
   d) What happens to the chromosomes when an ovum and a sperm meet at fertilisation?
   e) Explain how sex is determined in a human at the moment of fertilisation.
5. a) What is the name of the special type of cell division that produces gametes from ordinary body cells?
   b) Where in your body would this type of cell division take place?
   c) Why is this type of cell division so important in sexual reproduction?
   d) Describe the process of cell division by which gametes are formed – draw diagrams if necessary.

6. a) How did Mendel's experiments with peas convince him that there were distinct 'units of inheritance' that were not blended together in the offspring?
   b) Why didn't people accept his ideas?
   c) The development of the microscope played an important part in helping to convince people that Mendel was right. How?
   d) Gregor Mendel did his work on peas. What would be the genotypes and phenotypes of the possible F1 offspring of a cross between:
      i) pure breeding round peas (RR) with pure breeding wrinkled peas (rr)
      ii) a round pea carrying a wrinkled gene (Rr) and a wrinkled pea (rr)

   Show all your workings.
7. Define the following words:
   a) gene
   b) allele
   c) dominant allele
   d) recessive allele
   e) homozygous
   f) heterozygous
8. The allele that gives you dimples is dominant over the allele for no dimples. One partner in a couple has dimples and the other has no dimples. Would you expect their children to have dimples? Explain as fully as you can, using genetic diagrams to explain your answer.
9. Whether you are albino or not is decided by a single gene with two alleles. The normal allele A is dominant to the albino allele a. Use this information to help you answer the following questions. Show any working out you may do.

   Demissie is albino but Seble is not. They are expecting a baby.
   a) We know exactly what Demissie's alleles are. What are they and how do you know?
   b) If the baby has normal colouring, what does this tell us about Seble's possible genotype?
   c) If the baby is albino, what does this tell us about Seble's possible genotype?
10. How does the inheritance of dominant traits differ from the inheritance of recessive traits?
11. Look at your thumbs. Are they straight or curved? This is a characteristic inherited on a single gene. The allele for straight thumbs is dominant to the allele for curved thumbs. Chose suitable symbols and draw a genetic cross between:
    a) two heterozygotes
    b) a heterozygote and a homozygous recessive individual
12. List the main ways in which careful breeding of animals and plants benefits society.
13. Explain carefully the difference between selective breeding and cross-breeding as a way of improving the characteristics of your animals or plants.

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

8 Cell division which results in two identical daughter cells (7)

9 Different forms of the same gene (7)

10 The chromosomes which control everything about the body and the cells (not the sex chromosomes) (9)

DOWN

1 DNA base that pairs with guanine (8)

2 Physical appearance of an individual relating to a particular genetic trait (9)

3 Strand of DNA carrying the genetic material (10)

4 Map of the chromosomes in the nucleus of a single cell (9)

5 Allele which is expressed in the appearance even if only one copy is present (8)

6 Cell division which produces four non-identical sex cells with half the original number of chromosomes (7)

7 Female sex organ that produces ova (5)

Human biology and health

Unit 3

Contents

Section	Learning competencies
3.5 Homeostasis (page 121)	• Define homeostasis as maintenance of a constant internal environment and explain its significance. • Define poikilotherms as organisms whose temperature is governed by the external temperature. • Define homoiotherms (homeotherms) as organisms with constant body temperatures. • Explain the physiological methods of temperature regulation in homoiotherms. • Explain the behavioural methods of temperature regulation in homoiotherms and poikilotherms. • Label the structures of the kidney. • State the functions of the structures of the kidney. • Explain how the kidney regulates water and ionic balance. • Explain how the skin helps in water and salt balance. • Explain the role of the liver in regulation of the body.

3.1 The nervous system

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

- Name the parts of the nervous system.
- Explain the structures and functions of the human nervous system.
- List the three types of neurons, indicate their structures and explain their functions.
- Describe an action potential and the passage of a nerve impulse along a neuron with examples.
- Describe a synapse and how an action potential crosses it.
- Describe neurotransmitters with examples.
- Explain how the brain is protected and compare the functions of the fore, mid and hind brain.
- Describe the reflex arc, mention the structures involved and compare simple and conditioned reflexes.
- Demonstrate at least two examples of reflex actions such as knee jerks and blinking.
- Define substance abuse, explain its effects, its status in Ethiopia and possible preventative measures.
- Give examples of drugs abused in the locality.
- Express willingness to conform to a drug-free lifestyle.

Figure 3.1 *Human beings not only control our own bodies, we expect our co-ordination systems to control fast and complicated machines as well.*

The human sense organs

All living organisms need some level of awareness of their surroundings so they can avoid danger, find food and, in some cases, find a mate. Whatever the level of awareness, it requires co-ordination and control within an organism to respond to changes in the surroundings. In large and complex organisms like ourselves it is also very important that the different systems within our body are co-ordinated and work together.

Awareness of changes in our surroundings is only useful if the reactions of our body can be co-ordinated and controlled to take advantage of the information. It is no good if an antelope smells or sees a lion stalking if it cannot run away! We need to pick up all sorts of changes in the environment, and respond to them. Your body has two very different ways of bringing about this co-ordination and control.

The nervous system is involved in all the most rapid responses. It involves the passage of electrical impulses around the body. The endocrine (hormonal) system involves the movement of chemical messages around the body. It is rather slower than the nervous system but is responsible for the co-ordination of much of the functioning of the body.

KEY WORDS

spinal cord *column of neurons within the backbone*

neurons *nerve cells*

sensory receptors *nerve endings that can sense stimuli, e.g. pressure, pain, temperature, and start a nerve impulse that sends this information back to the brain*

affector (afferent) *neuron that sends impulses from organs to the spinal cord and brain*

effector (efferent) *neuron that sends impulses from the brain and spinal cord to organs*

Nervous co-ordination

Single-celled organisms do not have nervous systems or any type of nervous co-ordination and control and neither, as far as we know at the moment, do plants. But most other living multicellular organisms have some sort of nervous system, even if it is very simple.

In human beings our nervous system is a highly complex system that provides us with rapid, co-ordinated responses to the situations we meet in our lives. It allows us to react to our surroundings and co-ordinate our behaviour. The nervous system has two main parts. The central nervous system (CNS) is made up of your brain and **spinal cord**. The peripheral (body) system is made up of the **neurons** (nerve cells) and the **sensory receptors**.

How nervous co-ordination works

Once a stimulus is picked up by a sensory receptor, the information is passed along special nerve cells, **affector** or **afferent** neurons, to the central nervous system (CNS), made up of your brain and spinal cord. Once the information has been processed in the CNS, instructions are sent out to the body along more neurons called **effector** or **efferent** neurons. These stimulate the effector organ, usually muscles or a gland.

sense organ → afferent neuron → central nervous system → efferent neurons → muscles

These neurons are the basic unit of your nervous system, with millions of them working together in your body. Neurons are extremely specialised for the transmission of electrical impulses. They have a cell body that contains the cell nucleus, mitochondria, and other organelles. They also have slender finger-like processes called **dendrites** that connect to neighbouring nerve cells. The most distinctive feature of all nerve cells is the **axon** or nerve fibre, which is extremely long and thin. The nerve impulse travels along the axon from one place to another (see figure 3.2). Neurons are also irritable – which means they react to the world around them – and they can conduct electricity. This is the result of the structure of the axon. The axon membrane changes its permeability to sodium ions to create an electrical impulse (see the action potential below), while the **myelin sheath** provides a layer of insulating material so the nerve impulse travels as fast as possible.

So, to recap, afferent neurons carry information from your receptors to your central nervous system (CNS). In the brain the information is added to the vast amounts of other information arriving from all over the body. The brain co-ordinates all this information and then sends messages out along efferent neurons. These effector neurons carry messages from the CNS to different parts of the body to make muscles contract and/or organs respond to the changes in the surroundings. The huge network of nerves running all over your body carrying information to and from the CNS is called your peripheral nervous system. The muscles or organs of the body that bring about the response to the original stimulus are known as effectors.

KEY WORDS

dendrites *tree-like branches from nerve cell bodies that receive signals from other nerve cells at synapses*

axon *long process from nerve cell that carries the nerve impulse*

myelin sheath *fatty insulating sheath that grows around many nerves*

DID YOU KNOW?

The average axon is only 10 µm in diameter but in a large animal like an elephant or a giraffe they can be up to 4 m in length.

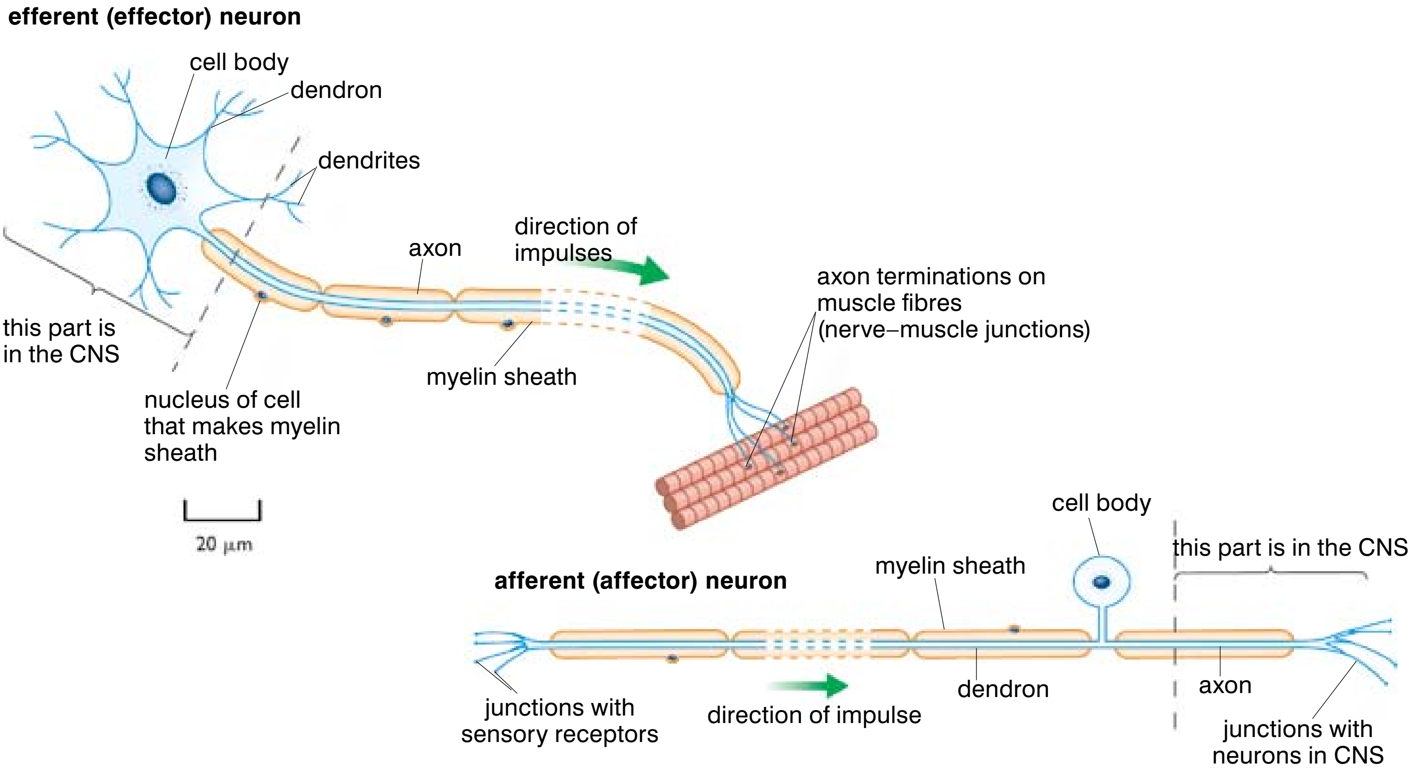


Figure 3.2 *The afferent (affector) neurons and efferent (effector) neurons carry messages to and from your central nervous system and are vital for the co-ordination of your body.*

KEY WORDS

action potential *a short-term change in the electrical potential on the surface of a cell when it is stimulated*

synapse *the junction between two neurons (axon-to-dendrite) or between a neuron and a muscle*

neurotransmitters *chemicals that transmit nerve impulses across synapses*

neuromuscular junctions *the junction between an axon terminal of a motor neuron and a muscle fibre*

cranium *the part of the skull that encloses the brain*

Nerves are bundles of neurons. Some carry only effector neurons and are known as effector nerves, some carry only affector neurons and are known as affector nerves, whilst others carry a mixture of effector and affector neurons and are called mixed nerves.

Your nervous system relies on nerve impulses travelling along the neurons. Each nerve impulse is a minute electrical event that is the result of charge differences across the membrane of the axon. The wave of positive charge inside the axon when the neuron is stimulated is known as the action potential.

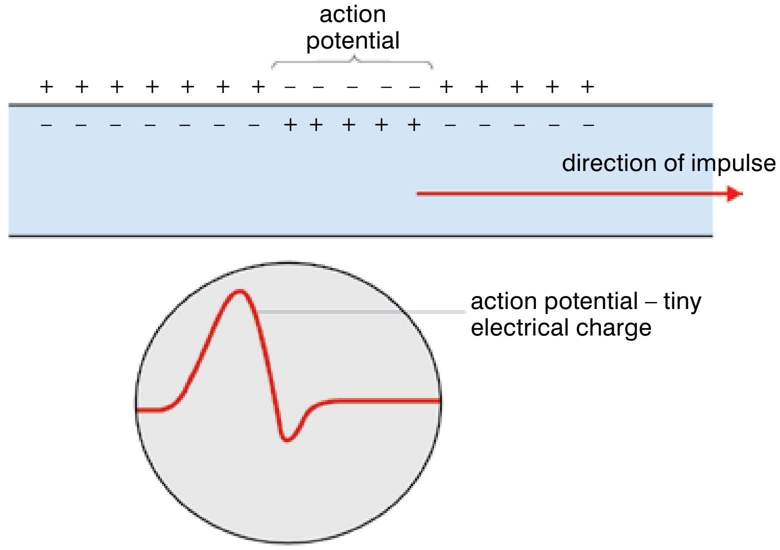
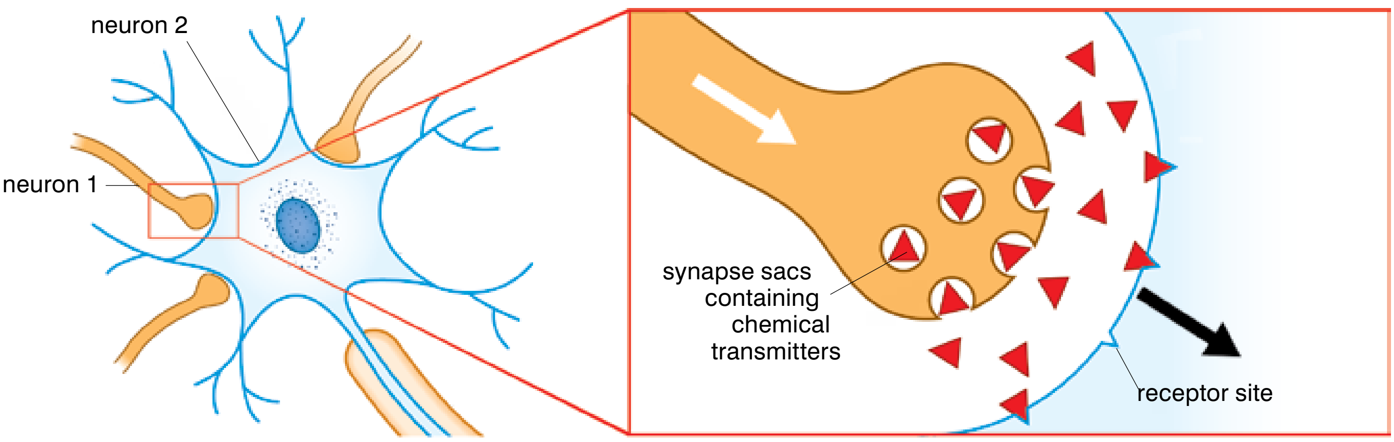


Figure 3.3 *The action potential is the basis of all the electrical signals in the nervous system of your body.*

Neurons are not continuous 'wires' running about your body. Whenever one neuron ends and another begins there is a gap known as a **synapse**. The electrical impulses that travel along your neurons have to cross these synapses, but an electrical impulse cannot leap the gap. So when an impulse arrives at the end of a neuron, chemicals are released. These chemical transmitters (**neurotransmitters**) cross the synapse and are picked up by special receptor cells in the end of the next neuron. In turn this starts up an electrical impulse, which then travels along your next neuron. This is how impulses pass from one neuron to another all over your body.

Figure 3.4 *A synapse – the junction between one neuron and another. The electrical impulse cannot cross the gap – it relies on chemical transmission across the synapse.*



Every neuron – and particularly the neurons in your brain – will have thousands of synapses, each one connecting it to other neurons. So synapses are very important for the co-ordination of information in your central nervous system, information that is coming in from many different areas of your body. There are special synapses between effector neurons and the muscles they stimulate. These are known as **neuromuscular junctions** and they work in the same way as a normal synapse, except the chemical crossing the gap causes the muscles to contract.

The chemical transmitters produced by different cells are not always the same. Sometimes one neurotransmitter will cancel out another. Some medicines – and some poisons – work by blocking chemical transmission across a synapse or by speeding it up.

Review questions

1. What are the differences between a neuron and a nerve?
2. What makes up the central nervous system?
3. What is an effector organ?
4. How do synapses work?

The central nervous system

You have seen how the neurons carry messages around the body in the form of electrical impulses, and have considered the sense organs that respond to changes in both your internal and external environments. But the affector inputs and the impulses are no use without some sort of co-ordination – and this is where the central nervous system comes into its own.

The central nervous system consists of two main regions – the brain and the spinal cord.

Your brain is a delicate mass of nervous tissue with the consistency of thick yoghurt. It is enclosed in membranes and protected by the bones of your skull in a space known as the **cranium**. The spinal cord runs out from your brain down your body. It is encased and protected by the vertebrae making up your spine.

As you have seen, the nerves that run to and from the CNS make up your peripheral nervous system. The nerves that come out of the brain are known as the **cranial nerves**. They go mainly to structures in your head and neck, like your eyes, tongue and jaws. The majority of the nerves come out of the spinal cord and these are known as the **spinal nerves**. They go to the arms, the legs and the trunk (the rest of your body).

KEY WORDS

cranial nerves *12 pairs of nerves that emerge directly from the brain stem*

spinal nerves *mixed nerves containing both sensory and motor neurons*

DID YOU KNOW?

One of the most common chemical transmitters found in synapses is a chemical called acetylcholine. A number of well-known poisons work by affecting synapses with this neurotransmitter:

- **Botulinus toxin** affects the first membrane and stops the release of acetylcholine. No transmission of impulses across synapses prevents the nervous system from working and causes death.
- **Strychnine** and **organophosphorus compounds** (sometimes used as weedkillers and insecticides) deactivate the enzymes on the second membrane and so prevent the breakdown of acetylcholine. The nerves fire continuously and the muscles contract all the time causing rigid paralysis.
- **Curare** (used on arrow tips by South American Indians) stops the second membrane from responding to the chemical transmitter. This causes paralysis as the muscles can no longer be stimulated by the nerves.

DID YOU KNOW?

An average human brain weighs 1300–1400 g (about 3 lb) yet the cerebral cortex, which controls most of our conscious thought and action, is only about 3 mm thick.

KEY WORDS

grey matter *areas in the brain and spinal cord that consist of unmyelinated nerve cells*

fore brain *the large frontal area of the human brain*

Your brain is a very complex structure that carries out an amazing variety of functions. The different areas of the brain carry out very different functions, from the basic reflexes that keep us breathing to the complex ideas needed to create a story or write and play music. Our understanding of how the brain works is based partly on observations of people who have suffered injuries to different areas of the brain through accidents or disease. The impact of damage in a certain area on abilities to speak and think can give us clear clues as to the working of the brain. More recently, new technology has enabled us to see inside the living brain – but we still have a lot to learn about how this most complex organ works.

The bulk of your brain is made up of **grey matter** – the cell bodies of neurons and the synapses that connect them. Inside the brain is the white matter – the axons that lead into and out of the brain.

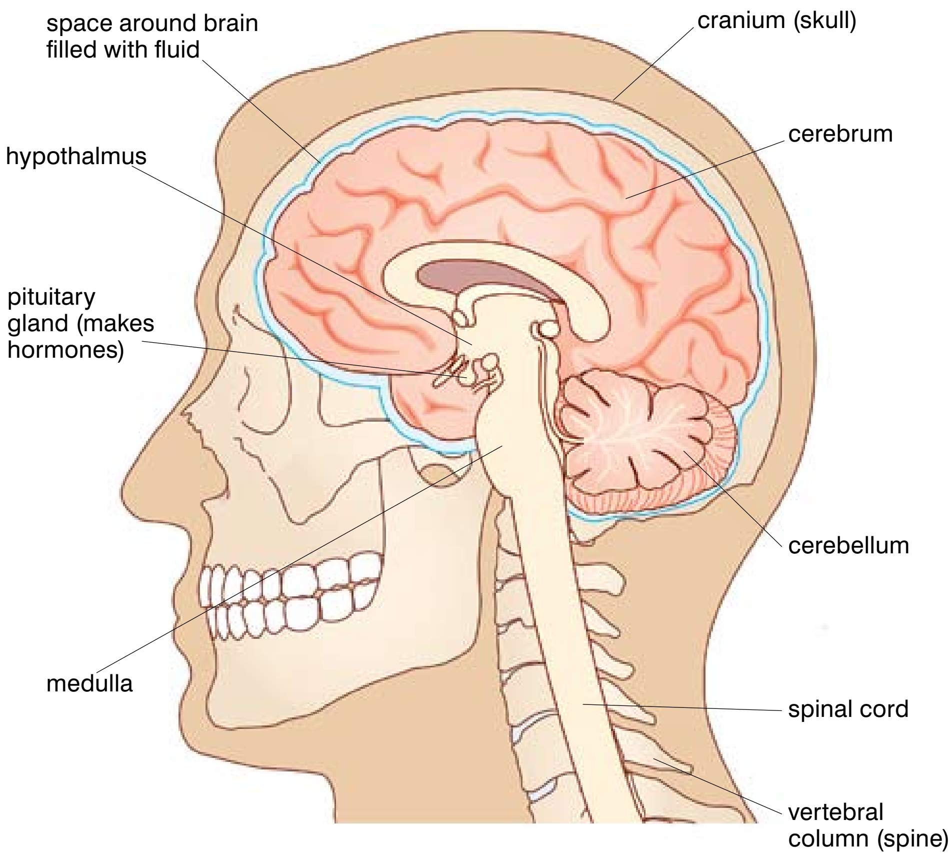
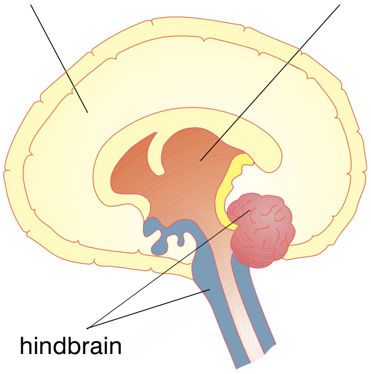


Figure 3.5 *The fore, mid and hind brain are the three main areas as the brain develops.*

As an embryo develops in the womb, the brain starts off as a tube in the head with three main areas. The **fore brain** develops into the olfactory lobes, which deal with smell, and the cerebral hemispheres that are involved in all the higher levels of thought. Some areas of the cerebrum (cerebral hemispheres) are involved in the co-ordination and interpretation of affector input from your sense organs. Other areas are involved in sending out effector impulses to control the actions of your body in response to the affector information.

The mid brain develops into the areas of your brain that deal with vision (the optic lobes) while the hind brain forms the areas of the brain that deal with balance and orientation (the cerebellum) and the most fundamental reflexes of life (the medulla). Even if all of your higher brain is damaged and destroyed, you may continue to breathe if your medulla is intact.



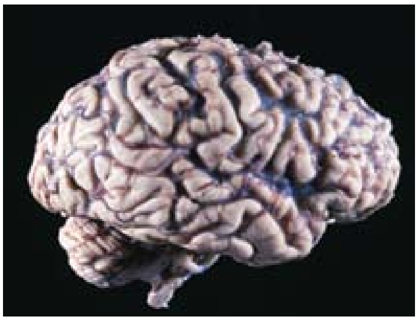


Figure 3.6 *The human brain – its appearance may not be spectacular but it is capable of the most amazing things.*

The spinal cord has a much simpler structure than your brain. The grey matter (cell bodies and short **relay neurons**) are in the middle and the white matter (axons) are on the outside. At regular intervals along the spinal cord there are entrance points for affector nerves bringing information into the CNS and exit points for effector nerves carrying instructions from the CNS.

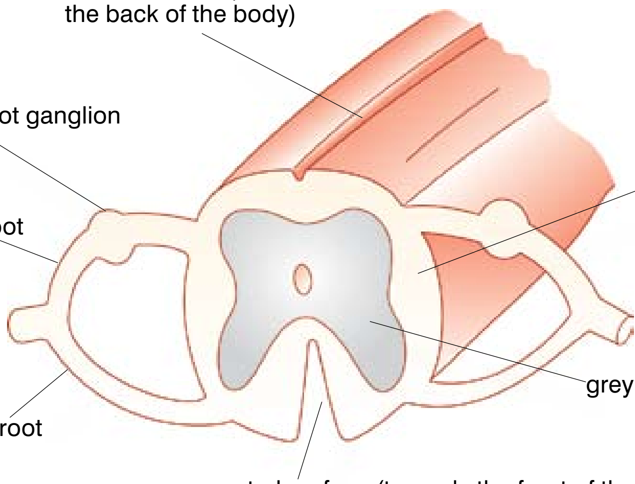


Figure 3.7 *The structure of your spinal cord. If your spinal cord is damaged you may lose all sensation below the damaged area, or lose effector control – or both.*

The way in which the human brain works to make each of us who we are is still not understood very well. So it is perhaps not surprising that we don't fully understand what happens when things go wrong. Sometimes the processes in the brain don't work as they should. **Mental illness** is a very general term that is difficult to define. It is the term we use to describe a wide variety of disorders and diseases, which are diagnosed as mental illnesses because they involve thought processes, emotional disturbances and/or behaviour that are considered abnormal. Mental illness may range from mild depression, when someone feels low and sad for no apparent

KEY WORDS

relay neurons *neurons which are activated by other neurons*

mental illness *general term referring to psychological, emotional, or behavioural disorders*

DID YOU KNOW?

Each side of your body is controlled by the opposite side of your brain – so what you see with your right eye goes to the left-hand side of your brain. The left-hand side of your brain is good at processing information and largely controls your speech, while the right-hand side is better at spacial awareness and recognising faces. If the right-hand side of your brain is damaged you may be unable to recognise even your closest family. It is often only when parts of the brain are damaged that we appreciate just what an amazing organ it is.

reason and cannot lift their mood, to conditions such as psychosis, when your ability to distinguish between what is real and what is imaginary becomes seriously affected in a way that can completely take over your life.

Mental illness can be the result of an imbalance of the chemical transmitters in your brain, and so for some conditions there are effective treatments. However, scientists and doctors have a great deal of research to do before all of these conditions are fully understood and can be treated. One growing concern is that the use of illegal drugs, which affect the chemistry of the brain, is leading to an increase in mental illness in young people. You will look at the effect of drugs in more detail on pages 64–74.

Voluntary and reflex control

Sense organs such as the eye, which you will look at in detail later in this unit, respond to changes in the world around you, and to changes in your internal environment. However, a change in a sense organ alone is simply not enough. The information needs to reach your central nervous system and you need to process the information and then respond. Many of the activities you carry out are voluntary – you choose to do them. So how do they come about? For example, if you see a mango or a banana that looks ripe on a market stall, you may well pick it up, feel it and smell it before deciding if it is as good as it looks and buying it.

- When you see the mango the information from your eyes travels along affector neurons to your spinal cord.
- From the spinal synapses the electrical signal continues up affector neurons in the spinal cord until it reaches the brain.
- The information is assimilated along with other information that places you in a market and links into memories of buying unripe or over-ripe mangos in the past as well, and the pleasure of a ripe mango.
- Electrical messages are sent back along from the brain along the effector nerves down your spinal cord.
- At more spinal synapses the message is transferred to effector nerves running to the muscles of your arm and hand that enable you to make a voluntary movement, reaching out to take hold of the mango, feel it and bring it to your nose to smell it.
- Another flood of information from stretch receptors in your muscles, olfactory (smell) receptors in your nose, pressure receptors in your skin and many more goes back to your brain, all in a very short space of time, to be processed again before you make your next voluntary movement.

Think of a different situation – crossing a road, greeting a friend, eating a meal – and work out what is happening in your nervous system.

Figure 3.8 *Buying fresh food from a local stall – just one of the millions of voluntary actions we carry out each day.*

To summarise the situation, the nervous system is involved in rapid responses by the human body to changes in the world around it and within the body as well. Receptor cells collect information about a particular stimulus and electrical impulses transmit the information from the receptor cells along affector neurons to the central nervous system (CNS). Here the information is processed and another electrical impulse is sent out along the effector nerves to a muscle or gland (effector) that will then cause the appropriate body response. Muscles contract whilst glands release chemical substances.

Activity 3.1: Investigating reaction times

The length of time it takes you to recognise a stimulus and react to it is your reaction time. These are very important in many situations – for example, when you are driving, or at the start of a race. Some people react more quickly than others – and you can train yourself to speed up. In this investigation you will be looking at reaction times by measuring how quickly your partner catches a metre ruler when you let it fall. If you collect all the data for the class, you can produce a graph to show the range of reaction times for your science group, and also do some statistical analysis to find the average, median and mean reaction times for your class.

You will need:

- A metre ruler (or a stick and a ruler)

Method

1. Work in pairs, with one partner holding the ruler and recording the distance and the other catching.
2. Hold the ruler so that your partner's hand is level with the 10 cm mark. They should be able to see the ruler and your hand.
3. Warn them that you will soon be dropping the ruler and, after a few seconds, let go.
4. Repeat this three times and calculate the average distance the ruler travelled before your partner caught it.
5. Reverse roles.
6. Draw up a table and collect the results for the whole class.
7. Write up your investigation, including a graph to show the distribution of reaction rate across the class.
8. How could you develop or refine this investigation?

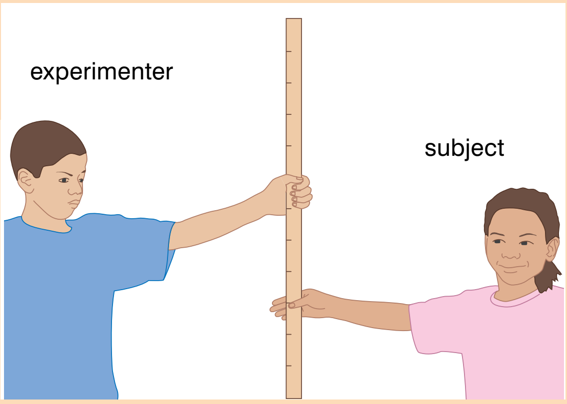


Figure 3.9 *Testing reaction times using a metre ruler*

In a normal conscious action we are in control – we see a book, reach out and pick it up or hear an approaching car and stop moving. But some of the actions of our body are so rapid that there is no time for conscious thought. Others take place without any awareness on our part – when was the last time you realised your pancreas was producing insulin or that your gastric pits were filling up with digestive enzymes? So what is happening in these involuntary or **reflex** actions?

KEY WORDS

reflexes *automatic, instinctive, unlearned reactions to stimuli*

KEY WORDS

reflex arc *neural path of a reflex*

reflex action *automatic, instinctive, unlearned reaction to a stimulus*

A reflex action

Some of our responses to stimuli are purely automatic. When we touch something very hot we withdraw our hand before we are consciously aware of the sensation of pain. If an object approaches our face we blink. We breathe and the muscles of our gut churn our food. Reactions such as these are known as reflexes.

Reflexes occur very fast. They are usually involved in helping us to avoid danger or damage. We also have lots of reflexes taking care of basic bodily functions, leaving the brain free for thinking about other things. Breathing is a good example. You don't consciously instruct your diaphragm to flatten and your intercostal muscles to contract yet your breathing movements continue, because breathing is a reflex action. Not only does gaseous exchange take place constantly, but you don't have to waste precious thinking time making sure it keeps going. The pupil reflex, where the pupil of your eye dilates or constricts depending on the light levels, is another example of a protective reflex action that you don't have to think about. It protects your retina from damage from too much light, and enables you to see as well as possible in low light levels. The blink reflex, where you blink your eyes if something comes towards your face, protects your eyes from physical damage. The key point about a reflex action is that the messages do not reach a conscious area of your brain before instructions are sent out to take action. Many reflexes involve the spinal cord while others involve the brain. They involve three types of neuron – affector neurons, relay neurons and effector neurons. Relay neurons connect the affector and effector neurons directly in the CNS, without input from other areas. The receptors, neurons and effectors involved are referred to as a **reflex arc**. The brain and spinal cord together act as co-ordinators that process the information coming from sensory receptors and neurons and instruct effector neurons and effectors to react.

A **reflex action** is a sudden, automatic and uncontrolled response of parts of the body or the whole body to external stimuli.

The reflex jerk of your knee is used by doctors to check that your reflexes are working properly – but it normally works if you stumble and the tendon is stretched. The reflex helps to straighten your leg and stop you falling.

Activity 3.2: The knee jerk reflex

You can demonstrate a simple spinal reflex used by doctors.

1. Work in pairs.
2. One person sits down with one leg loosely crossed over the other.
3. The other hits the crossed leg just below the knee cap (patella) gently but firmly. Use the edge of the hand, a special hammer or the edge of a ruler to do this. It should not hurt!
4. This hits a ligament which stretches a muscle. This is picked up by stretch receptors setting up a reflex arc. The impulse travels to the spinal cord and back to the quadriceps muscles in the thigh. These contract, causing the lower leg to jerk upwards and outwards as the leg straightens. It drops straight back into its normal position.
5. Change places and repeat.

How reflexes work in detail

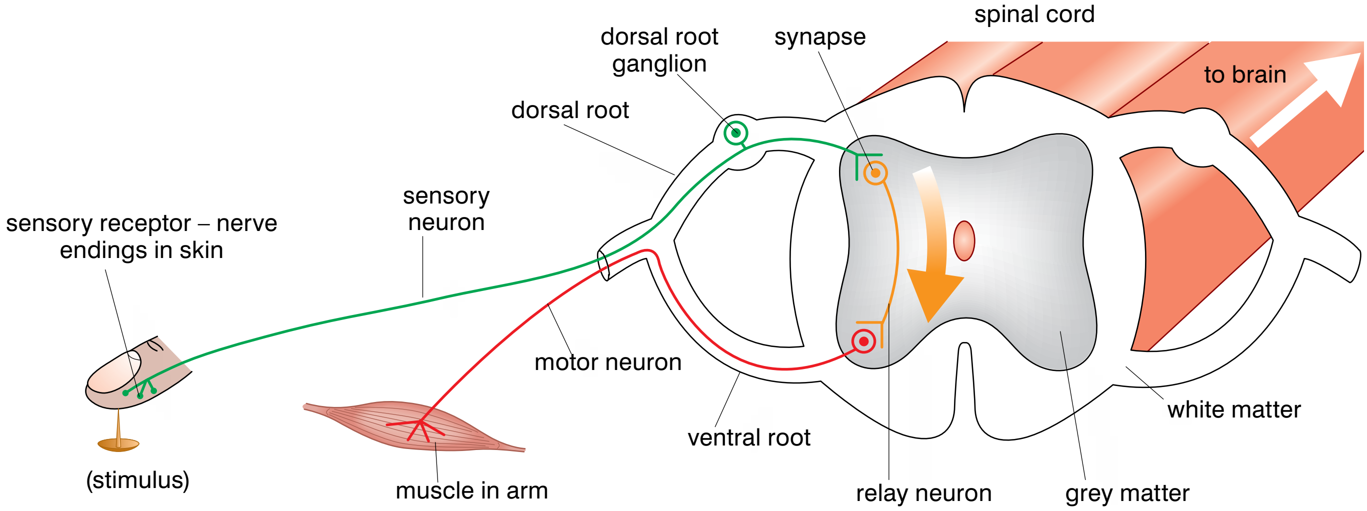


Figure 3.10 *This reflex action moves your hand away from the pin before you hurt yourself too much.*

In the example shown in Figure 3.10, when you put your finger on a sharp pin:

- Impulses from a sensory receptor in the skin pass along an affector neuron to the central nervous system – in this case the spinal cord.
- The neuron enters the spinal cord through the **dorsal root**.
- When an impulse from the affector neuron arrives in the synapse with a short relay neuron a transmitter is released (see earlier in the section), which causes an impulse to be sent along the relay neuron.
- When the impulse reaches the synapse between the relay neuron and an effector neuron returning to the arm again another transmitter chemical is released.
- This starts impulses travelling along the effector neuron to the organ (effector), which brings about change. The effector neuron leaves the spinal cord by the **ventral root**. In this example the impulses arrive in the muscles of the upper arm, causing them to contract and move your hand upwards sharply.

Most reflex actions can be analysed as follows:

stimulus → receptor → afferent neuron → co-ordinator → efferent neuron → effector → response

This is very similar to a normal conscious action, except that in a reflex the co-ordinator is a relay neuron either in the spinal cord or in the unconscious areas of the brain.

If you put your hand down on something hot this analysis would show:

hand on hot plate → temperature and pain receptors in skin → afferent neuron → relay neuron in spinal cord → efferent neuron → muscles of arm → moving hand away from hot object

By missing out the process of conscious thought the whole action is speeded up. However, even as the impulse is moving through the

KEY WORDS

dorsal root *root at the back of the spinal cord*

ventral root *root at the front of the spinal cord* reflex arc, other neurons have also been stimulated at the synapses in the CNS and these carry information up to the conscious brain so that you know what has happened after the event.

Conditioned reflexes

However, not all reflexes are simple. Some of them can be learnt. In 1902, a Russian scientist called Ivan Pavlov investigated conditioned reflex action using a dog. He noticed that a dog produces a lot of saliva at the sight of food. The production of saliva is a reflex action in response to the sight of food. In this experiment, a bell was rung every time food was supplied to a dog. After the experiment was repeated several times he noticed that when the bell was rung the dogs salivated, even if there was no food present.

Usually the sound of a bell does not cause a dog to salivate. In the experiment, however, the dog had learnt to associate the sound of the bell with the presence of food. Thus, the sound of the bell started the secretion of saliva in the same way as the sight of food. Salivation at the sound of the bell thus became a reflex action. Since this reflex action was not innate (there at birth), it is a result of experience or learning. This learned reflex action is called a conditioned reflex action.

It is possible to change an animal's behaviour in this way. This helps an animal to learn new ways of behaving. Conditioned reflexes also produce responses which are favourable. For example, a child is usually attracted to anything that moves, especially animals. This is an automatic behaviour. If, however, a safari ant happens to bite the child it is almost certain that in future, instead of being attracted to it, the child will fear to move towards a safari ant. Thus the child's behaviour has been changed or conditioned. So reflexes are important both for keeping us safe, and for helping us to learn.

DID YOU KNOW?

Action potentials can travel along axons at speeds of 0.1–100 m/s. This means that nerve impulses can get from one part of a body to another in a few milliseconds. This is why reflexes can happen so quickly. It is the processing of information and decision making in your brain that tends to take the time.

Activity 3.3: Reflex action

Notice how much saliva you make. You probably make more when you smell food cooking or expect a meal.

List as many conditioned reflexes as you can think of.

Review questions

1. What is a reflex action?
2. What is a voluntary action and how does it differ from a reflex action?
3. If you touch something hot, you withdraw your hand very quickly in a reflex action. Draw a diagram to show this reflex arc and label it carefully.

Drug abuse

Almost every person reading this book will have taken a drug – and not just medicine from the doctor or healer. Most of you will have had a cup of coffee at some point in your lives – and so you have taken caffeine, a legal stimulant drug! What do we mean by a drug? A drug is a substance which alters the way in which your mind, or body, or both, works. In every society there are certain drugs which are used for medicine and others which are used for pleasure. Usually some of these substances are socially acceptable and others are illegal. In Ethiopia caffeine, nicotine, khat and alcohol are the legal recreational drugs. The status of a drug may be related to its effect on people, or it may be simply down to the history of its use.

Most of the drugs which we use for medicine affect our bodies. The drugs we use for pleasure tend to have a distinct effect on our minds.

Drug (or substance) use is when you choose to take a substance that affects your brain and/or body function and mental activity. It is done for a variety of reasons. Legal drugs are used for the mild pleasure they bring, to be sociable and because using them becomes a habit. People start to use illegal drugs for much the same reasons – because everyone else does and because you like the effect – but as many of these drugs are highly addictive, they can soon lead to many problems.

Drug (or substance) abuse is when you use a substance to the point of excess and/or dependence. When you take an excess of a drug you risk serious side effects and even death. Drug dependence is when you use a drug again and again and become **addicted**. Drugs change the chemical processes in your body and this is why you can become addicted to them (dependent on them). If you are addicted to a drug you cannot manage or function properly without it. This may be psychological – the need to keep using it becomes a craving or compulsion. On the other hand it may be a physical dependence where your body no longer works properly without added chemical extras. Once addicted to a drug, you cannot manage without it and you generally need more and more of it to keep you feeling normal. When an addict tries to stop using their drug they will feel very unwell, often experiencing combinations of aches and pains, shaking, sweating, headaches, cravings for the drug and even fevers as the body reacts – these are known as **withdrawal symptoms**.

Drug abuse, of both legal and illegal substances, is becoming more of a public health problem in Ethiopia because the numbers of people involved is growing. School surveys have shown that alcohol, khat, tobacco, cannabis (marijuana) and solvents are the substances most widely used in Ethiopia. Alcohol, khat and tobacco are legal drugs in Ethiopia – you can buy them easily in shops and bars, but cannabis is illegal. Solvents like gasoline are legal but are not meant for humans to inhale. Drugs such as LSD, ecstasy, cocaine and heroin are illegal but rarely used in Ethiopia.

Khat, alcohol and tobacco are linked to a wide range of health problems. The health issues linked to these legal drugs are mainly the result of their effect on the systems of your body. However, illegal drugs also affect the health, in two quite different ways. Firstly, like any other drug, they cause changes in your body and can damage vital systems. But also, because these drugs are both illegal and addictive, people need to find considerable sums of money to feed their addiction. They may spend all of their cash on drugs, not feed themselves properly because they are buying drugs with the money, turn to crime or prostitution to raise the money

Figure 3.11 *We use legal drugs such as alcohol as part of our normal social life. No one at this party will be thinking of themselves as drug users – but that is what they are doing!*

DID YOU KNOW?

Alcohol is highly intoxicating and extremely poisonous. If it was a newly discovered substance it would almost certainly be illegal and regarded as highly dangerous. But because in many countries alcohol has been used for centuries, the drug is widely accepted as part of normal social life.

KEY WORDS

addicted *compulsively or physiologically dependent on something habit-forming*

withdrawal symptoms *a set of unpleasant effects upon the body caused by a sudden stopping of using a drug* they need and take part in risky activities such as sharing needles, which increases the risk of becoming infected with HIV/AIDS or hepatitis. So the lifestyle associated with illegal drug use also has a major impact on health. However, these behaviours are relatively rare in Ethiopia, as you will see.

In the next part of this chapter you are going to look at some of the most commonly used recreational drugs in Ethiopia. They all have the following features in common:

- They are addictive.
- They affect brain function and alter behaviour.
- They damage health, resulting in lower productivity and absence from school/work.
- They adversely affect the individual, families, community and country.

You will explore all of these in this section.

Smoking

Figure 3.12 *Smoking is expensive, very addictive and causes many health problems.*

Smoking is not as common in Ethiopia as it is in many parts of the world. However, the evidence suggests that more and more young people are taking up smoking across the whole of Africa. The addictive drug in cigarette smoke is nicotine, which affects the brain and produces a sensation of calm well-being and being able to cope. However, it is very physically addictive. Unfortunately cigarette smoke also contains many very harmful chemicals, and these are linked to a number of very serious health conditions. Smoking increases your risk of the following diseases:

- **Coronary Heart Disease** – the chemicals in the tobacco smoke affect the walls of your arteries. They make the blood vessels supplying oxygen to the heart narrow. This reduces the blood supply to the heart and other areas of the body. They also tend to damage the smooth lining of the arteries, which makes it much more likely that atherosclerosis will occur.
- **Strokes** – the blood vessels taking blood to the brain suffer the same damage as the vessels going to the heart described above. If the blood vessels going to the brain become blocked you suffer a stroke. An area of your brain is damaged which may lead to paralysis, memory loss and even death.
- **Lung Disease** – tar and other chemicals in tobacco smoke damage the tissues of the lungs and lead to a greatly increased risk of developing chronic obstructive pulmonary disease (COPD) and lung cancer.
- **Cancers (lip, mouth, throat, pancreas, bladder and kidney)** – many of the chemicals in cigarette smoke are carcinogenic (cancer causing) and smoking has been shown to increase the risk of all these listed cancers. The mouth, lips and throat are obvious, but no one is quite sure exactly why the pancreas, bladder and kidney are particularly affected by cigarette smoke.

In recent years scientists have realised that smoking does not just affect the person who smokes. Passive smoking (inhaling smoke from those around you) can be equally dangerous to your health, and smoking while pregnant has been shown to affect the unborn child.

Review question

1. When a pregnant woman smokes, how does it affect her baby?

Because nicotine is so addictive it can be very difficult to give up smoking once you have started. You have to break the addiction. There are a number of ways which people use – some more successful than others! Will power and determination are needed whichever method you chose. Some people rely on this alone. Others give up smoking but use nicotine patches or gum to help wean themselves gradually off the drug. At least then they are not taking in all the chemicals from the cigarette smoke and get used to being without a cigarette in their hands or mouth. Other people cut down on their cigarettes gradually, cutting out one or two at a time until they can give up entirely. Each individual has to find their own way to give up! It is easier not to start smoking at all!

Activity

Look at the representation of smoking in the media: newspapers, magazines, films, advertisements, and anything else you can think of. Collate examples and discuss with the rest of the class.

Alcohol

Alcohol is one of the drugs most commonly used by people of all ages in Ethiopia, but we still drink far less than many other countries. For many people alcohol is part of their social life. They like to share a drink with friends and don't think of themselves as drug users. In small amounts, alcohol makes people feel relaxed and cheerful. It makes you less inhibited. So shy people can feel more confident when they've had an alcoholic drink.

But alcohol has a powerful effect on your body. It is very addictive and it is also very poisonous. Although some religions ban the use of alcohol, it is accepted all over the world. Perhaps this is because alcohol has been around for thousands of years. We also see that many important and famous people like a drink!

Review question

1. Why is alcohol described as a drug?

How does alcohol affect your body?

Alcohol is poisonous. However, your liver can usually break it down. It gets rid of the alcohol before it causes permanent damage and death. Alcohol acts quickly because it is readily absorbed into the bloodstream from the stomach. When you have an alcoholic drink, the alcohol passes through the wall of your gut and goes into your bloodstream. From your blood, the alcohol passes easily into nearly every tissue of your body.

It dilates blood capillaries near the skin surface producing a feeling of warmth and well-being. It increases the heart rate as well as

DID YOU KNOW?

It takes your liver at least one hour to break down the alcohol in an average drink of tella.

increases hunger. It gets into your nervous system and brain. This slows down your reactions. It can make you lose your self-control. It contributes to poor muscular co-ordination, resulting in slurred speech and a lack of balance. Alcohol is a diuretic, which means that it makes you lose water through increased urination.

As the effects of the alcohol wear off, it can cause headaches, due to dehydration, and nausea. When you have had too much to drink, you lack judgement.

Research has shown that young people who drink alcohol are more likely to have unprotected sex. This means they are more likely to become pregnant, and also much more likely to become infected with HIV/AIDS. Young people who drink every day are three times more likely to have unprotected sex than those who do not drink. Alcohol can cause you to make stupid or dangerous decisions, decisions you might regret for the rest of your life. And if you drink large amounts of alcohol, like a whole bottle of spirits, your liver simply cannot cope. You suffer from alcohol poisoning. This can quickly lead to unconsciousness, coma and death.

KEY WORDS

alcoholics *people who are addicted to alcohol*

cirrhosis of the liver *endstage liver disease*

Review question

1. Give an example of a poor decision that someone under the influence of alcohol might make.

Some people drink heavily for many years, becoming **alcoholics**. They are addicted to the drug. Their liver and brain suffer long-term damage and eventually the drink may kill them.

They may develop **cirrhosis of the liver**. This disease destroys your liver tissue. They can also get liver cancer, which spreads quickly and can be fatal. In some heavy drinkers their brain is so damaged (it becomes soft and pulpy) that it can't work any longer. This causes death.

Short bouts of very heavy drinking can cause the same symptoms to develop quite quickly.

The effects of drinking on society

Alcohol can also put you at risk because of the way you behave under the influence of the drug. Because alcohol slows down your reactions, you are much more likely to have an accident. This is very dangerous if you drive after drinking. As car ownership increases in Ethiopia, so do the number of deaths and injuries in car accidents.

Figure 3.13 *Your liver deals with all the poisons you put into your body. But if you drink too much alcohol, even your liver can't cope. The difference between the healthy liver on the left and the liver with cirrhosis shows just why people are warned against heavy drinking!*

We need to make sure that people are aware of the dangers of drinking and driving. For example, alcohol is a factor in a high percentage of all fatal road accidents in the Caribbean. In fact, a survey in Trinidad a number of years ago showed that almost 50% of the men admitted to hospital had alcohol-related conditions. Let us make sure that here in Ethiopia we avoid these problems from the start!

Alcohol abuse affects personal lives as well. Domestic violence is often linked to patterns of heavy drinking. Many crimes take place when people are under the influence of alcohol, often mixed with other drugs.

Binge drinking is a recent problem. This often involves young people. They go out and get very drunk several nights a week. They can become violent and abusive, damage property and put their own health at risk both in cars and from HIV/AIDS through unprotected sex.

KEY WORDS

binge drinking *consuming excessive amounts of alcohol in a short period of time*

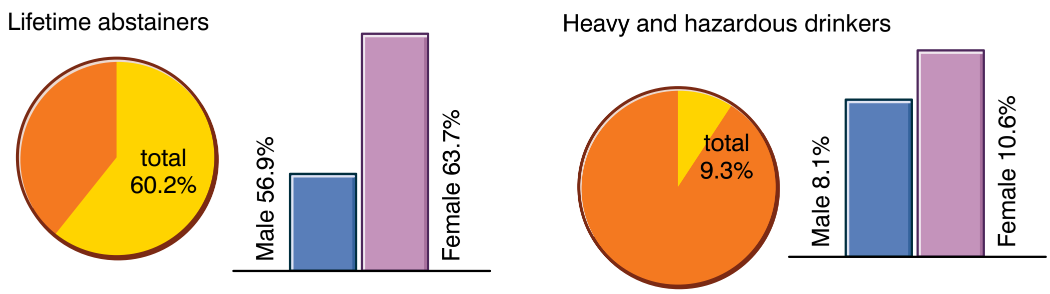


Figure 3.14 *This data is based on information collected by the World Health Organisation. It shows that while many people in Ethiopia do not drink alcohol at all, over 9% of our population drink very heavily indeed.*

Khat

Khat is the leaves of the khat shrub. People chew fresh khat leaves which contain a drug which affects the brain. It can also be made into a tea. It is a mild stimulant, makes people feel happy and also reduces your appetite. It is often used in social situations. In Ethiopia, khat use is growing fast among young people. It is a legal drug in our country. A survey showed that over 30% of our population use khat regularly.

The drug cathinone from the khat leaves is absorbed into the bloodstream through the membranes lining the mouth and the stomach as the leaves are chewed. It acts quickly, within 30 minutes of starting to chew, before it is broken down and removed by the liver. People can become addicted to khat, and when they cannot get the drug feel depressed, tired and unable to concentrate.

Surveys have shown that young people who are in school are much less likely to use khat than young people who are not in education. Khat use is linked to unprotected sex, putting young people at risk of pregnancy and HIV/AIDS infection. Young men who use khat have been shown to be more likely to use a sex worker, and more likely to have many different sexual partners. All of these

Figure 3.15 *Khat – a local drug that causes harm in our society, but has been used for centuries.*

behaviours increase their risk of becoming infected with HIV/AIDS and of passing that infection on to someone else. Using khat also makes people more likely to be injured in accidents, more likely to be involved in crime, less likely to have a job and more likely to have problems in their family lives.

Khat has been a part of our Ethiopian culture for centuries, but now there are growing concerns about its use. It is an important part of our economy – in 1999–2000 sales of khat brought around $60 million into the economy. Khat is relatively easy to grow and it creates jobs in the harvesting, packing and transporting of it as well as in selling it. What is more, it stops you feeling hungry. If people have little food to eat, it helps them to cope if they can chew leaves which make them feel good and stop them feeling hungry.

But the negative effects of the drug may be damaging the economy even more. People spend hours chewing and dreaming when they could be working. If people spent less time chewing khat and more time cultivating the fields there might be more food to eat. Khat affects the health of the population directly and indirectly by the behaviour it causes. For many young people, khat is destroying their chances in life. Many people in Ethiopia need to work together to find the best way to deal with the problem of khat. It might seem impossible, but in the UK 50 years ago smoking was widespread. Hundreds of thousands died from smoking-related diseases. Some people still smoke in the UK, but numbers have fallen dramatically and it is now against the law to smoke in public buildings. The numbers of people dying from smoking-related diseases has fallen steadily. This shows that it is possible to reduce the use of familiar local drugs.

The final commonly used drug in Ethiopia is **cannabis**, also known by many other names including **marijuana**, **ganja** and **weed**.

KEY WORDS

cannabis/marijuana *drug made from the cannabis plant*

ganja/weed *drug made from the cannabis plant*

hallucinogens *psychotoxic drugs that affect the mind in a way that produces distorted sensations abnormal in content*

Cannabis (marijuana)

Cannabis is a plant that contains 400 known chemicals, 60 of which, called the cannabinoids, are unique to the plant. The most potent is delta-9-tetrahydrocannabinoid (THC). THC is known to affect the brain cells responsible for memory, emotion and motivation. Cannabis is usually smoked but it can also be eaten, when it has a much stronger effect because your liver converts it into a much more powerful drug. It can make you feel a great sense of well-being and relaxation, happy and euphoric – and this is why people use it. It is a mild hallucinogenic drug. **Hallucinogens** are drugs that produce vivid waking dreams, where the user sees or hears things that are not really there, or has a distorted view of the world. However, some people find the effect of the drug a very unpleasant and disturbing experience.

The effect of cannabis is very variable. It affects different people in different ways, and even the same person can react very differently depending on how it is used.

Review question

1. Why do you think people use cannabis?

Many people mix cannabis with tobacco, so they have all the health problems linked to tobacco smoke as well as the problems cannabis can bring. Finally, because cannabis is illegal, people have to buy their supplies from illegal drug dealers. This means it can have a 'gateway' effect, putting people in touch with dealers who will later try to sell them harder and more expensive drugs.

Cannabis is illegal in Ethiopia, but in spite of this there is a long tradition of using it. It is currently used in a number of social contexts. As well as personal enjoyment with friends, it is used in folk medicine – and it seems to be very effective in pain relief for diseases such as multiple sclerosis.

It is difficult to see a way forward to reduce the use of the drug. It is already illegal but this has not stopped people. Better education so that people understand the health risks of using the drug can only help.

Most drugs carry risks. A survey showed that 43% of the people in mental hospitals in Ethiopia had abused alcohol, khat or cannabis. All of these drugs increase the risk of becoming infected with HIV/AIDS and other sexually transmitted diseases through unprotected sex. They make people less able to work.

There are many other illegal drugs but they are not widely used in Ethiopia, although in some places they are becoming more common. They include:

- **LSD (lysergic acid diethylamide)**. This is a very strong hallucinogenic drug made in the laboratory. It has such a powerful effect on the brain that many people who have used the drug for some time – and even first time users – develop severe mental illness as a result. Its effects can be so powerful that people believe they can fly, and there have been many cases of young people high on LSD (an LSD trip) leaping from buildings and falling to their deaths.
- **Cocaine**. When you take cocaine you get a rush of energy and a high where you feel very powerful. The downside is that you can end up feeling paranoid and depressed afterwards. It is an extremely addictive drug – your body quickly craves more and more of it. As a result people get addicted very quickly. It is also quite expensive, so people end up spending all their money to get enough fixes to satisfy their craving. Cocaine raises your blood pressure, causes your heartbeat to become fast and irregular and increases your body temperature. It can kill you the first time you use it, as some people have complete heart failure as a reaction to the drug. Every time you use the drug you are putting your mental and physical health at risk.

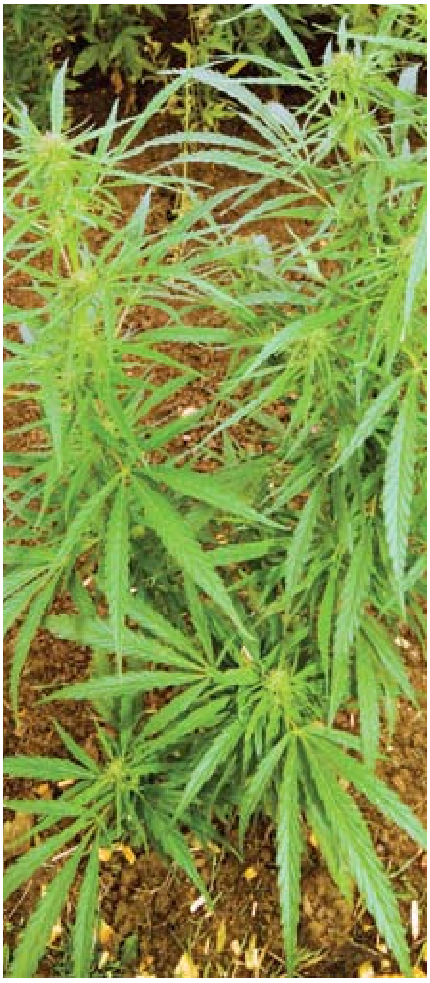


Figure 3.16 *Different types of cannabis plants produce different amounts of the hallucinogenic drug. Even the same type of plant, grown in different conditions, will produce more or less of the drug.*

Activity: Role Play

Divide into pairs and plan and act out a role play between a person who is abusing drugs and a friend or neighbour concerned about his or her behaviour and the effects on other people.

- **Heroin**. Heroin is one of a family of drugs known as the opioids formed from the opium poppy. People have used opiates, both medically as very good painkillers and as recreational drugs, for centuries. Heroin is usually found as a white or brownish powder, which is dissolved in water and injected either under the skin or directly into a muscle or vein. It can also be 'snorted' into the nose, smoked, eaten or inserted as a suppository into the rectum. The heroin molecules interact with receptors in the brain to create strong sensations of pleasure and to block pain. Most heroin users do not feel hunger, pain or sexual feelings when they are under the influence of the drug. A high dose of heroin kills very easily. Many heroin addicts get ill through sharing needles. They run a high risk of getting HIV/AIDS. They also risk abscesses, liver diseases such as hepatitis and even heart and brain damage.

The social effects of drug abuse on individuals, families and communities

The excessive and wrong use of drugs is considered drug abuse. Often this excessive use arises because what was initially a liking becomes an addition. As you have seen, most drugs tend to be habit-forming, if not physically addictive. The sensation that accompanies the use of drugs is often very appealing and satisfying and as a result this 'high' is sought after. This great high, however, is usually followed by depression and an extreme craving for another 'hit' just to feel better again. Many people spend a lifetime chasing that high and it becomes very difficult to break the cycle. The effects of drug abuse are many and varied. The excessive use of drugs significantly affects the individual user, the family and the wider community.

Effects on individuals

Because most drugs affect the nervous system, someone who abuses drugs usually displays an unusual sense of relaxation on one hand and a superhuman energy and strength on the other. Drug use is sometimes accompanied by aggressive and abusive behaviour, especially when someone wants some of the drug and can't get it.

Figure 3.17 *People who use drugs often become isolated from their families and the community.*

Using drugs reduces your ability to concentrate, to pay attention and to think logically and clearly; your judgement is impaired, which results in poor decision making. People often suffer from insomnia, anxiety, depression and acute panic reactions. These reactions inevitably affect other people as well. People who are experiencing paranoia and hallucinations are not easy to live with! Drug users often become suspicious of others, which can lead them into arguments and fights. Some drugs lead to an increase in appetite and weight gain, others to lack of appetite and weight loss. All these changes have a big impact on work as well as social and family life.

Many drug users turn to crime to fund their drug habit. Often this involves prostitution, so drug users are particularly prone to sexually transmitted diseases including HIV/AIDS. The lifestyle linked to drugs often leads users to neglect their personal hygiene and fail to feed themselves properly. They often suffer ill health as a result. Drug users who inject themselves often share needles, which leads to a greatly increased risk of catching blood-borne diseases such as hepatitis and HIV/AIDS. Finally, some drugs can have a direct effect on your health. They may trigger mental illness, and they can kill you or leave you brain damaged.

Effects on family and friends

Very often relationships at home are affected and regular friendships are seriously damaged. The drug user may lose his/her job due to poor-quality work, regular absences or the inability to function. Loss of employment means a loss of income, creating serious financial problems. Drugs often impair sexual function, which will affect the relationship between the drug user and their partner. Many drug users crave attention and affection, often leading to an increasingly promiscuous lifestyle. Divorce is often the outcome of continued drug use.

Some people use drugs to help them cope with problems in their family. But often, it is drug use that causes a family to break up under the strain. People who become long-term, regular drug users often become isolated from their families and community. This isolation can make it harder for friends and family to keep in touch with the drug user to encourage them to break the habit.

The family of the drug abuser can often feel defeated, helpless and hopeless; they can experience a range of emotions such as anger, depression, fear, aggression, loneliness, hostility and embarrassment. This in turn affects the other relationships in the family. The family is often divided on how to address the problem and how to relate to the drug user, which creates its own conflict within the family.

In many cases in order to maintain their habit, drug users will steal and sell items from home, creating further distress to the family. Even where the drug abuser is not in the family home there is the emotional and psychological pain from being uncertain of his or her whereabouts and state. Children in these families become lonely in their confusion, depressed, aggressive and disruptive and often become a drugs user themselves to manage their pain – so the cycle continues.

Effects on the community

The wider community is severely challenged by the presence of those who have become abusers of drugs. One of the main social issues surrounding drug use is theft to finance the addiction – this could be through burglary, car theft or mugging. Violence, theft, sexual abuse and assault, murder, damage to property and violent crimes plague many communities where drug usage is high. Because drug use affects vision, sense of timing and co-ordination, many accidents can be attributed to drug use. Consequently,

Activity

Work in groups to research the prevalence of drug abuse in your own area, and write a report to present to the class. Identify the most commonly used drug, and assess why this is, and look at the effects on the individuals and wider community'.

communities where there is a high number of drug users are often gripped by fear, anxiety and grief as a result of accidents. People cannot work effectively, families break up – the impact of drug use on a community can be huge in both economic and personal terms.

What is more, the community has to pay for the health care of addicts, for the education programmes, for hostels and to help support the families left in despair. The cost of drug abuse is a very high one indeed.

To overcome the problems of drug abuse you need to be strong and prepared to avoid the use of drugs within your own life, and help others to avoid them too. Ethiopia will grow stronger and be a better place in the future if we all use alcohol sensibly and try to prevent the use of khat, cannabis and other illegal substances in our communities.

Summary

In this section you have learnt that:

- Living organisms need systems of co-ordination and control.
- Many multicellular organisms including human beings have both nervous and hormonal co-ordination and control systems.
- The nervous system is the most rapid. Nervous control involves:

  stimulus → receptor → co-ordinator → effector → response
- A nerve cell or neuron consists of a cell body, dendrites and an axon.
- Sensory neurons carry information from the sense organs to the central nervous system (CNS).
- Motor neurons carry instructions from the CNS to the effector organs (muscles and glands).
- The central nervous system is the brain and spinal cord. Information is assimilated and co-ordinated in the CNS.
- Neurons carry electrical impulses known as the action potential.
- In any pathway the junctions between neurons are called synapses. When an impulse arrives in one neuron chemicals are released in the synapse to trigger an impulse in the next neuron.
- A nerve contains many neurons. There are sensory nerves, motor nerves and mixed nerves.
- The spinal cord carries information from all over the body to and from the brain.
- Mental illnesses describe a wide variety of disorders and diseases that involve thought processes, emotional disturbances and/or behaviour that are considered abnormal.
- Cranial nerves come from the brain, while spinal nerves are from the spinal cord.
- Reflex actions avoid danger and run mundane bodily functions – they avoid conscious thought.
- Reflex actions involve:

  stimulus → receptor → co-ordinator → effector → response

  but the co-ordinator is the relay neuron in the spinal cord and there is no conscious thought involved.
- The knee jerk reflex is a common example of a reflex. It is used by doctors to test reflexes and in ordinary life to prevent stumbling.
- **Drug abuse** is when you use a substance to the point of excess and/or dependence. When you take an excess of a drug you risk serious side effects and even death.

- **Drug dependence** is when you use a drug again and again and become **addicted.**
- Drugs change the chemical processes in your body so you can become **addicted** to them (dependent on them). This means you cannot manage or function properly without the drug. This may be psychological – the need to keep using it becomes a craving or compulsion – or a physical dependence where your body no longer works properly without the drug.
- Alcohol, tobacco, khat and cannabis are the most widely used substances in Ethiopia.
- Other drugs which can be misused include prescription sedatives, cocaine, LSD, ecstasy and heroin.
- Drug abuse and dependence can hurt the individual user, their family and the entire community.

Review questions

1. Which of these statements correctly explains the relationship between neurons and nerves?
   A A neuron is a bundle of nerves.
   B They are the same thing.
   C Neurons carry messages to the brain and nerves carry messages away from the brain.
   D A nerve is a bundle of neurons.
2. Which of the following is NOT part of a nerve cell?
   A cilia
   B dendrites
   C cell body
   D axon
3. A nerve impulse crosses a synapse by means of:
   A electricity
   B vibration
   C chemical transmitters
   D light rays
4. One of these actions is NOT a reflex. Which one?
   A blinking
   B moving your foot away when you tread on a pin
   C driving
   D a new-born baby gripping your finger
5. Which of the following drugs is not legal in Ethiopia?
   A nicotine
   B alcohol
   C khat
   D cannabis
6. a) What is the main difference between a voluntary action and a reflex action?
   b) What is the value of reflex actions to the body?
   c) Analyse the following reflex actions using the sequence:
   stimulus → receptor → co-ordinator → effector → response
   i) A doctor hits you just below the knee cap with a rubber hammer.
   ii) You put your bare foot down on a drawing pin.
   iii) Someone claps their hands near your face.
7. a) Define the terms 'drug use', 'drug abuse' and 'drug dependence'.
   b) List the three most commonly abused substances by young people in Ethiopia.
   c) Explain the impact of substance abuse on the family and community.

3.2 Sense organs

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

- Indicate the structures of the human eye, ear, skin, tongue and nose using diagrams or models, and describe their functions and methods of caring for them.
- Show the structures of the eye using a sheep's or cow's eye.
- Describe image formation and accommodation.
- Demonstrate the blind spot.
- List common eye defects in humans and explain their causes and the available corrective measures.
- Explain how balance is maintained by the inner ear.
- Identify the taste areas of the tongue.
- Conduct an experiment to prove that the actual taste of food is a mixture of taste and smell.
- Draw and label the smelling organ.
- Draw and label the structure of the skin.

Figure 3.18 *Different parts of the body contain different numbers of sensory receptors – this is what we would look like if our body parts reflected how sensitive they are.*

For any nervous system to work there must be sensory receptors that respond to stimuli. Stimuli are the changes in the environment that you need to know about to decide whether they are useful, dangerous or neutral – and what you need to do about them. In the human body there are many different types of sensory receptors that respond to different stimuli. In every case sensory receptors change the energy of the stimulus into electrical energy in a nerve impulse. Some of the most important include:

Table 3.1: *Table to show the main sense organs of the body and the type of stimulus they respond to*

Receptor	Energy
Eye (retina, provides vision)	Light
Ear (cochlea, organ of hearing)	Sound
Ear (semi-circular canals, organ of balance)	Movement (kinetic)
Tongue (taste buds, enable us to taste)	Chemical
Nose (olfactory organ or organ of smell)	Chemical
Skin (touch, pressure and pain)	Movement (kinetic)
Skin (temperature receptors)	Heat
Muscles (stretch receptors)	Movement (kinetic)
Arteries and brain (chemoreceptors responding to pH and carbon dioxide levels)	Chemical

The human eye

You are going to look in detail at one of our most important sense organs – the eye. Although the detailed anatomy of your other sense organs is very different, the same basic principles for transferring energy apply.

Sight is an important sense for human beings. The reason we can see so well is largely due to the very complicated sense organs that we use to pick up light stimulation – our eyes.

A **sensory organ** is an organ that contains a large number of sensory receptor cells and the human eye is a good example. Our eyes enable us to see in clear focus, in three dimensions and in colour. Not many other animals can manage all three. Let's take a look at the structure of the human eye and find out exactly how it works.

KEY WORDS

sensory organ *an organ that receives and relays information about the body's senses to the brain*

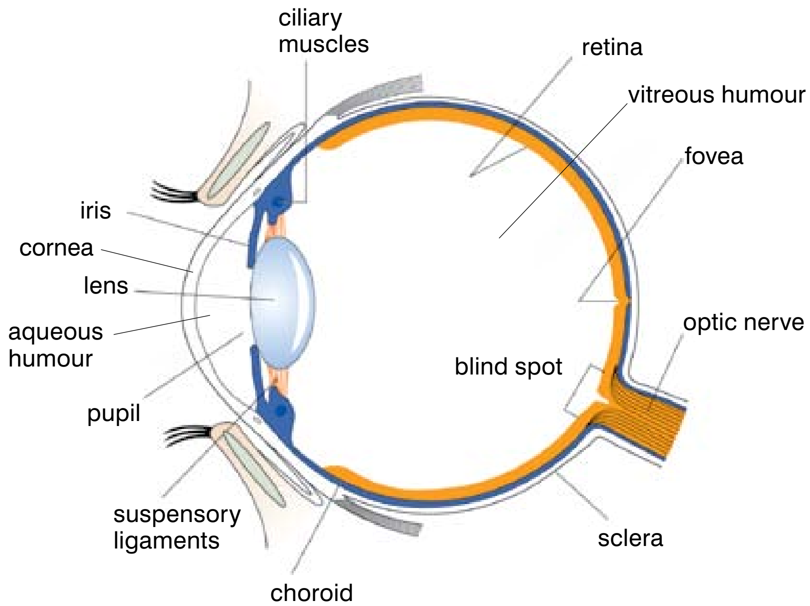


Figure 3.19 *This vertical section shows the main structures of the human eye – a very effective sense organ.*

Activity 3.4: Investigating the structure of the human eye

In this investigation you are going to look at eyes – your own and one from another animal.

You will need:

- a mirror
- a white tile
- sharp dissecting scissors
- eye of a sheep, cow or other mammal

Method

1. Look at your eyes in a mirror. How many of the features shown in figure 3.19 can you see? Draw and label your eyes.
2. Move your eyes from side to side or up and down to see the whites of your eyes – which part of the eye is this?
3. Look at the animal's eye provided by your teacher. Draw the external appearance of this eye and label it clearly. Can you see any of the muscles that are used to move the eyeball in the socket?
4. Using your scissors CAREFULLY cut a hole in the side of the eyeball. What comes out? How does this affect the eyeball?
5. Open the eyeball up more fully. Find the lens, the retina and as many other features from figure 3.19 as you can – NB you won't be able to see them all. Draw and label what you can see once you have opened the eyeball up fully.

KEY WORDS

sclera *the tough, opaque tissue that serves as the eye's protective outer layer*

cornea *transparent structure over the front of the eye that allows light to enter. A cornea resembles a contact lens in size and appearance*

choroid *the middle layer filled with blood vessels that nourish the retina*

pupil *a hole in the centre of the iris that changes size in response to changes in lighting*

iris *a membrane in the eye, responsible for controlling the amount of light reaching the retina*

dilated *becomes wider*

constricted *becomes smaller*

Your eyes are set in eye sockets in your skull that protect them. You also have eyelids that close over your eyes to protect them from the entry of material like dust, sand and insects, which might injure or irritate them. The eyelids also sweep tear solution regularly over the surface of your eye, which contains enzymes that destroy bacteria that might infect your eye.

The white outer layer of the eye, the **sclera**, is very tough and strong so the eyeball is not easy to damage. It has a transparent area at the front known as the **cornea**, which lets light into the eye. The curved surface of the cornea is also very important for bending the light coming into the eye to make sure it enters the eye and is focused on the retina. The rest of the sclera has many blood vessels, which supply your retina with food and oxygen, and a dark layer underneath – the **choroid**. This layer is dark because it contains pigmented cells that absorb light and stop it being reflected around the inside of the eye. Your eyeball is filled with a jelly-like fluid that helps to hold its shape.

Once the light has travelled through the cornea it has to pass through the **pupil** in the centre of the **iris**. The iris is the coloured part of the eye, but it is not there simply to look pretty. It is made up of muscles that contract or relax to control the size of the pupil and so to control the amount of light reaching the retina. The circular muscles run around the iris, while the radial muscles run across it like the spokes of a bicycle wheel. When the light is relatively dim, the radial muscles contract and the circular muscles relax and the pupil is pulled open wide (it **dilates**). When the pupil is dilated, lots of light can get into the eye and so you can see even in relatively low light levels. In bright light, however, the circular muscles of the iris contract and the radial muscles relax, which makes the pupil very small (it **constricts**). This reduces the amount of light that goes into the eye, so that the delicate light-sensitive cells are not damaged by too much bright light. The change in the size of the pupil in response to light is a reflex action – you don't have to think about it. You have already learnt about reflex actions earlier in this chapter.

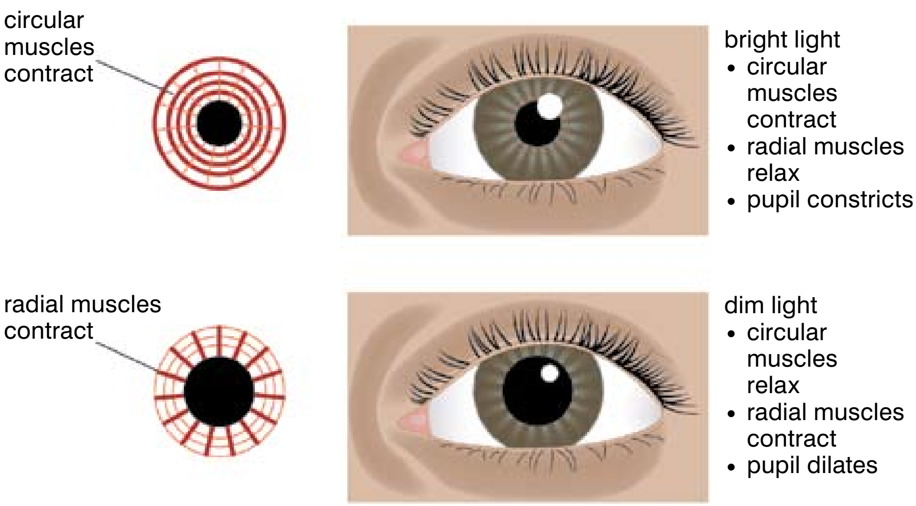


Figure 3.20 *The eyes have been described as the windows of the soul. They are certainly the windows of the body, letting the right amount of light in to fall on the sensitive cells of the retina.*

Activity 3.5: Investigating the effect of light on the size of the pupil

You can observe the way the size of the pupil changes in response to light in two simple ways – either work with a partner or use a mirror and observe your own eyes.

1. Observe the size of your partner's/your own pupils in the normal working light of your classroom.
2. Cover your eyes with your hands, or with a piece of cloth, for a minute or so – but keep your eyes open normally (you can blink).
3. Remove the cover from the eyes and observe the pupils closely. Note down what you see both immediately after removing the cover and as the eye adjusts to normal light levels (diagrams may help).
4. Now increase the light intensity – move outside into the sunlight or just move nearer to the windows. Again watch and record what happens to the pupils in the brighter light – and when you return to normal classroom levels of light.

KEY WORDS

lens *a flexible disc that helps focus light on the retina*

suspensory ligaments *elastic-like structures that suspend the lens and pull it into shape for focusing distant objects onto the retina*

ciliary muscles *eye muscles that automatically contract or relax the shape of the lens of the eye to help focus light on the retina*

Once light has entered your inner eye through the pupil it passes through the **lens**, a clear disc made up largely of proteins. The lens is held in place by **suspensory ligaments** and the **ciliary muscles**. It is the lens of the eye that 'fine-tunes' the focusing of the light, bending it to make sure that it produces an image on the retina (see How the retina works – Focusing the light).

All of the light-sensitive cells are arranged together in a special light-sensitive layer at the back of the eye known as the **retina**. When an image is produced on the retina, the light-sensitive cells are stimulated. They send impulses to the brain along affector (sensory) neurons in the optic nerve. When the brain receives these messages it interprets the information and we understand the impulses as an awareness of a visual image – in other words, we see something.

At the point where your optic nerve leaves your eye there is no retina. You have a blind spot. But take a look around your classroom – there are no missing bits in your field of vision. Your brain does a very good job of filling in the missing bits from your blind spots with information from the other eye. The only way you can prove that it is there is to use a bit of trickery yourself.

Activity 3.6: Demonstrating the blind spot

1. Look at the picture below. Hold the book so it is 30 cm from your eyes, with the pictures below level with your eyes.
2. Close your left eye completely and focus on the person with your right eye.
3. SLOWLY bring the book towards your face, keeping your right eye focused on the person all the time.
4. What happens to the lion as you move the picture towards you? How do you explain what happens?
5. What happens if you repeat the investigation with both eyes open? Explain any differences you observe.

KEY WORDS

retina *a light-sensitive tissue lining the inner surface of the eye*

rods *cells in the retina that perceive light and movement and work well in dim light*

cones *cells in the retina that perceive light and movement and only work in bright light*

DID YOU KNOW?

The pigment in the rods that responds to light is based on vitamin A. This is why a lack of vitamin A in your diet causes **night blindness**. You can't make the visual pigment you need to see in low light levels if you are short of vitamin A.

Review questions

1. What are sense organs?
2. What is the role of the iris, the ciliary muscles and the retina in your eye?

How the retina works

The light energy that falls on your retina is changed into electrical energy by the light-sensitive cells known as the **rods** and **cones** that make up your retina. Rods and cones contain chemicals that change when light falls on them. This change triggers an impulse in the affector neurons that make up the optic nerve. The impulses travel along the optic nerve to the visual areas of the brain (see page 59). The rods and cones then use energy to restore the chemicals to their original form.

Rods respond to relatively low light levels, but they do not give a very clear image and they do not respond to different colours. This explains why, when light levels fall in the evening, the colour drains away and everything looks black and grey. Rods are spread across your retina except over the fovea (the small area of your retina which contains ONLY cones).

Cones only work properly in bright light – but they respond to colours and give very clear, defined images. There are fewer cones than rods, and there are very few of them around the edges of the retina. This is why the edges of your visual field are blurred – but very sensitive to movement. The closer you get to the fovea the more cones there are, and the fovea itself has only cone cells. When light falls on your fovea you see clearly and in colour. Each cone responds to red, green or blue light. The colours you see depend on which combination of cones is stimulated – if all three are stimulated equally, you see white.

Some people cannot see all the colours because they are missing one or more type of cone. This is known as colour blindness. It is not a major problem although there are a few jobs you can't do easily if you are colour-blind.

Focusing the light

If you are going to see clearly, light from an object must be focused on your retina. For this to happen the light must be bent or refracted. Light rays are refracted when they pass from one medium to another – for example, from air into water.

a light-sensitive pigments
b mitochondria to supply energy
c nucleus
d dentrites synapse with optic nerve

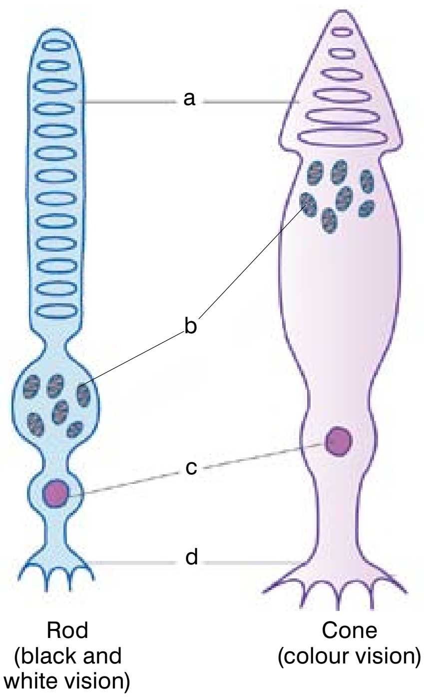


***Figure 3.21** The rods and the cones in the retina of your eye are efficient energy transducers that enable you to see in black-and-white and colour.*

Activity 3.7: Investigating refraction

This is a very simple exercise to remind you of the way light can be refracted as it changes medium.

You will need:

- a beaker or glass of water
- a glass rod, ruler or your finger

Method

Look carefully at your rod, ruler or finger. Then dip it into the water in the beaker or glass and observe what appears to happen. Any changes you see are due to the rays of light bending as they pass from water to air.

In your eye, the light coming in is bent (refracted) twice – once as it passes from the air through the cornea and then again as it passes through the lens. As a result of this refraction the image is focused onto your retina – and it is also upside down. The optical areas of the brain interpret this inverted image so that you are aware of the world the right way up.

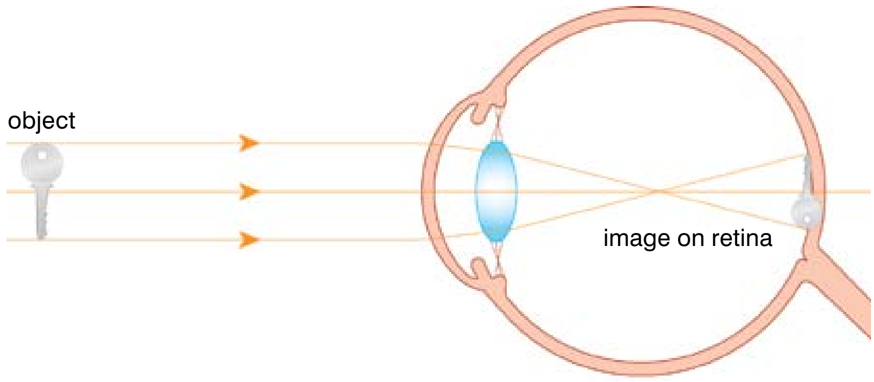


Figure 3.22 *When an inverted image falls on the light-sensitive cells of the retina and a message is sent through the optic nerve to the brain, you can see.*

Sometimes we look at objects close to us – for example, when we are reading or studying. At other times we are gazing into the distance, looking at objects a long way away. The light arriving at our eyes in these circumstances is travelling differently. The light from a distant object reaching our eyes will be travelling in almost parallel rays, whilst the light from close objects will be spreading out or **diverging** very strongly.

The cornea bends all of the light entering the eyes towards the retina, but it is the lens that makes sure that we can see both close and distant objects equally well. It does this by changing shape. Light from **distant** objects needs little further bending once it has passed through the cornea, so the lens is stretched long, thin and relatively flat and has little effect. However, light from close objects still needs some considerable bending to bring it into focus on the

DID YOU KNOW?

There are around 100 million light-sensitive cells in each of your retinas.

KEY WORDS

diverging *spreading apart*

distant *far away*

convex *curving or bulging outwards*

converging *two or more things coming together*

concave *curving or bulging inwards*

DID YOU KNOW?

In an investigation a group of people were given special goggles that inverted the image going into their eyes. As a result, the image on their retina was the right way up – so they perceived the world as upside-down! In time their brains adapted, and eventually they 'saw' the world as completely normal, even though they were still wearing the goggles. The only problem was, when they removed the goggles, everything looked upside down again… until their brains readjusted yet again.

retina. The lens of the eye needs to be much thicker to focus light from near objects. It becomes shorter, fatter and much more convex (rounded) so that it bends the light much more. These changes in the shape of the lens are brought about by the contraction and relaxation of the ciliary muscles that surround them, which in turn pull – or don't pull – on the suspensory ligaments that hold the lens in place. Ability of the human eye to focus on objects at different distances is known as accommodation.

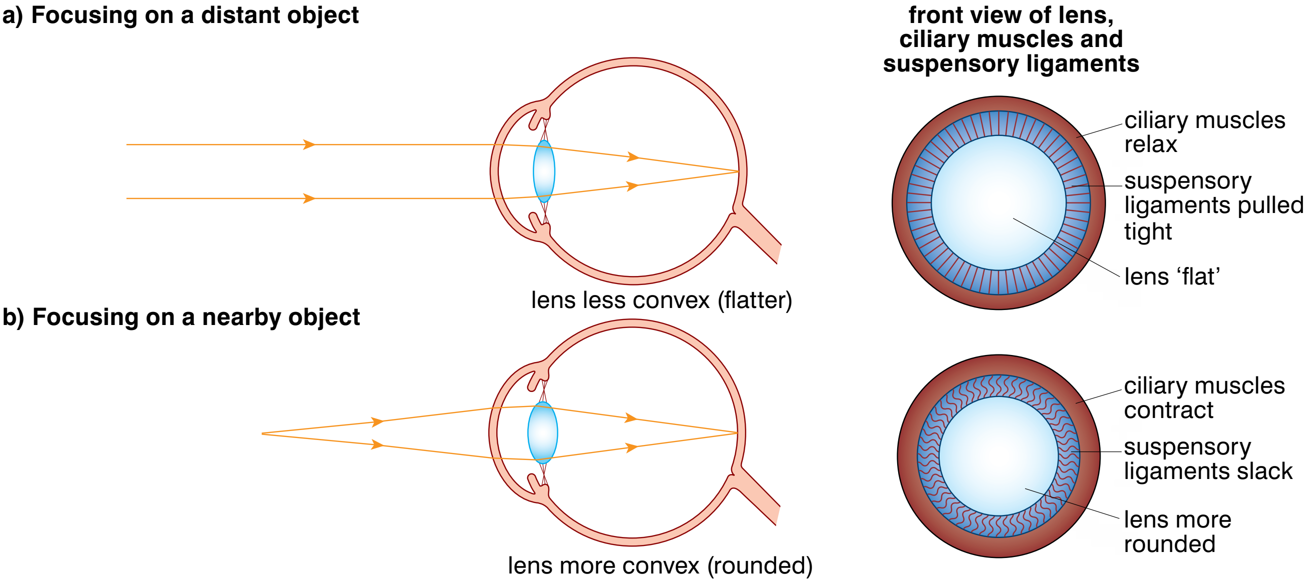


Figure 3.23 *Accommodation in the eye. It is the relaxation and contraction of the ciliary muscles that change the shape of the lens and allow distant and close objects to be focused equally clearly on the retina.*

Activity 3.8: Bending light rays

For this investigation you will need to raid the stores of the physics department.

You will need:

- light boxes or small, bright light sources
- lenses

Method

Switch on the light box and observe the light emerging. Try putting the different lenses in the light and make drawings to show how they affect the light rays.

Common eye defects

As people get older the lens of the eye may begin to harden, so accommodation becomes more difficult and they cannot focus so easily on close objects. This can make reading a problem, for example.

However, it isn't only older people who can have problems with their vision. There are a number of common eye defects that can and do affect many people of all ages. There are a number of ways in which these problems can be treated – but they all involve the use of extra lenses to bend the light. A lens is a piece of transparent material (usually glass or plastic) that has one or more curved surfaces. An outward curve makes a **convex** lens and this will bend the light rays towards each other (a **converging** lens). An inward curve makes a **concave** lens and this will spread the light rays out (a diverging lens).

In some people the normal method of accommodation in the eye that enables them to see close-up and distant objects with equal clarity just doesn't work properly:

Short sight: A short-sighted person can focus clearly on things that are close to them but has much more difficulty with objects in the distance, which appear blurred. This may be as a result of a lens that is effectively 'too strong' – it is too curved even when the ciliary muscles are fully relaxed and so the light from distant objects is focused in front of the retina, making the image that actually lands on the retina spread out again and blurry. Another cause of short sightedness is when the lens is normal but the eyeball is particularly long – and again this means light is focused in front of the retina.

This problem can be corrected using concave (diverging) lenses that spread the light out more before it gets into your eye. This means that the thicker lens can bring the rays of light into perfect focus on the retina – or there is room in the long eyeball for the light rays to be focused on the correct point.

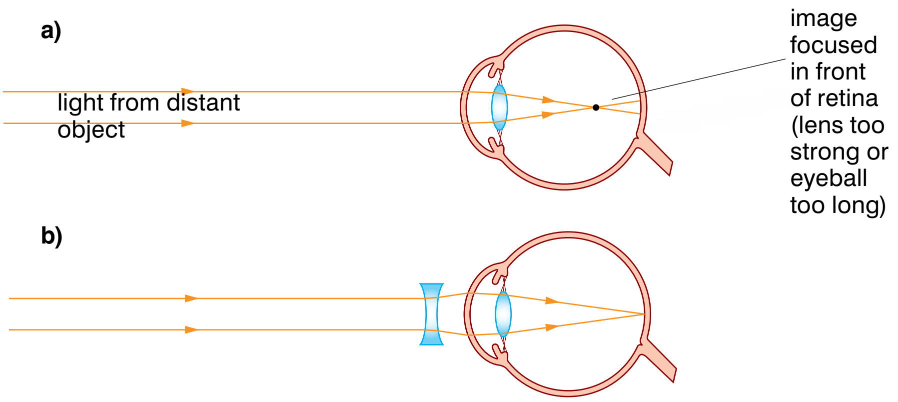


***Figure 3.24** The eyes of short-sighted people focus light from distant objects in front of the retina, which makes it difficult to see clearly. A simple concave lens makes all the difference.*

Long sight: A long-sighted person can focus clearly on things that are at a distance but has much more difficulty with objects close to them, which appear blurred. This may be as a result of a lens that is effectively 'too weak' – it is too flat even when the ciliary muscles are fully contracted and so the light from close objects is focused behind the retina, so the image that actually lands on the retina is spread out and blurred. Another cause of long sightedness is when the lens is normal but the eyeball is particularly short – and again this means light is focused behind the retina.

This problem can be corrected using convex (converging) lenses that bring the light rays together more before they reach your eye. Now the thinner lens can bring the rays of light into perfect focus on the retina – or the short eyeball becomes the right length for the light rays to be focused on the correct point.

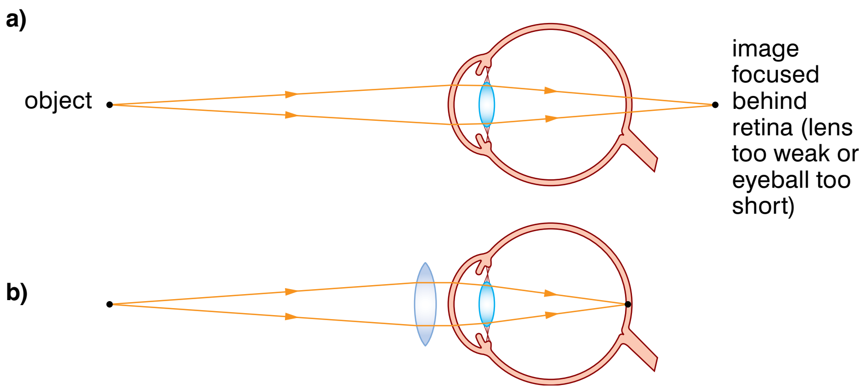
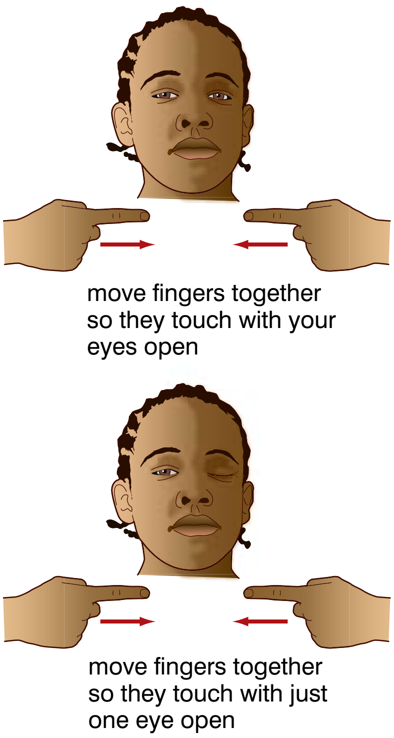


***Figure 3.25** The eyes of long-sighted people focus light from close objects behind the retina, which makes it difficult to see clearly and makes tasks such as reading very difficult. In this case a simple convex lens makes all the difference.*

Astigmatism: Astigmatism is another fairly common eye defect. The shape of the eye is irregular – more egg-shaped than round – so the cornea is curved asymmetrically and this affects the way light is focused on your retina. In some people it is the lens rather than the eyeball itself that is an unusual shape, but the end result is the same. Astigmatism can also be corrected by the use of lenses, but the situation is more complex than for long and short sight.



3-D vision

We not only see in colour and in clear focus – we also see in three dimensions. Our view of the world gives us enough information to build up a 3-D picture of the world around us. This 3-D vision is vital for giving us the judgement of distances that we need to do so many things, from threading a needle to driving a car. This amazing spatial awareness comes from the overlapping of the visual field from our two eyes. If you look at the world through one eye it appears flat. You may not notice particularly – but try this. Hold out both hands, with one finger pointing on each. Bring your fingers together with the tips meeting in one smooth movement. Now close one eye and repeat the manoeuvre – it isn't so easy!

Seeing in depth depends on you using both eyes. Each eye sees a slightly different view of the same object. Your brain combines the two images and uses all the information to give you a 3-D view of the object.

Review questions

1. How are lenses used to correct sight defects?
2. Why is 3-D vision so useful to us?

The ear as a sense organ

Your ears are specialised organs which enable you to hear sound. They are also concerned with the balance and position of the body.

The ear is divided into three regions: the **outer ear**, **middle ear** and **inner ear**. Look at figure 3.27 to see the structure of the ear as you read about how it works.

The outer ear consists of a flap called a pinna. Leading from the pinna is a tube, the ear canal. In humans this is about 2 cm long. The pinna helps to trap and funnel sound into the ear. This is particularly important in animals with longer ears than humans, which can move the pinna to pick up sounds.

At the end of the ear canal is a sheet of very thin membrane called the **eardrum** or tympanum that closes the tube.

The pinna, ear canal and the eardrum form the outer ear. At the entrance of the ear canal are a number of small hairs. These filter out dust particles from the air entering the ear canal. The cells lining the ear canal produce waxy material which traps dust and germs, and lubricates the eardrum.

KEY WORDS

astigmatism *an optical defect in which vision is blurred due to the inability of the optics of the eye to focus a point object into a sharp focused image on the retina*

outer ear *the part of the ear visible externally*

middle ear *the main cavity of the ear, between the eardrum and the inner ear*

inner ear *a complex system of interconnecting cavities, concerned with hearing and equilibrium*

eardrum *the membrane in the ear that vibrates to sound*

Behind the eardrum is a cavity filled with air. This cavity contains three tiny bones and forms the middle ear. The three tiny bones – called the **malleus** (**hammer**), the **incus** (**anvil**) and the **stapes** (**stirrup**) because of their shape – are the smallest bones in your body. They form joints with one another, with the malleus attached to the eardrum and the stapes to the oval window. The cavity of the middle ear is connected to your throat by a tube called the Eustachian tube. This is usually closed but when the pressure in the middle ear increases – when you are flying, for example – the tube opens until the air pressure in the middle ear is equal to that in the throat and therefore to the atmosphere.

At one end of the middle ear, opposite to the eardrum, there are two openings: one of them is oval in shape and hence it is called the oval window. The other is round and is called the round window. The openings are covered by very thin membranes.

The inner ear consists of a cavity filled with a fluid, two sac-like structures called the sacculus and utriculus, three semicircular canals and a coiled tube called the cochlea.

The sacculus, utriculus, semicircular canals and the cochlea are filled with a liquid. A cross section of the cochlea reveals that it is made up of three tubes in one (figure 3.28). The floor of the middle tube is lined with sensory cells linked to affector neurons. These nerve fibres join to form the auditory nerve which leads to the brain.

Figure 3.26 *The pinna plays an important role for these antelopes, allowing them both to pick up sounds very easily and also to find out which direction the sound is coming from.*

Activity 3.9: Examination of the human ear

You will need:

- a model of a mammalian ear

Method

1. Examine the external part of the ear of your neighbour. Note its shape and texture.
2. Examine a model of a mammalian ear. Note the shape of the various parts.
3. Make a drawing of the model.
4. Compare your diagram with that in figure 3.27.

Review question

1. How can you use your ears to help you find where a sound is coming from?

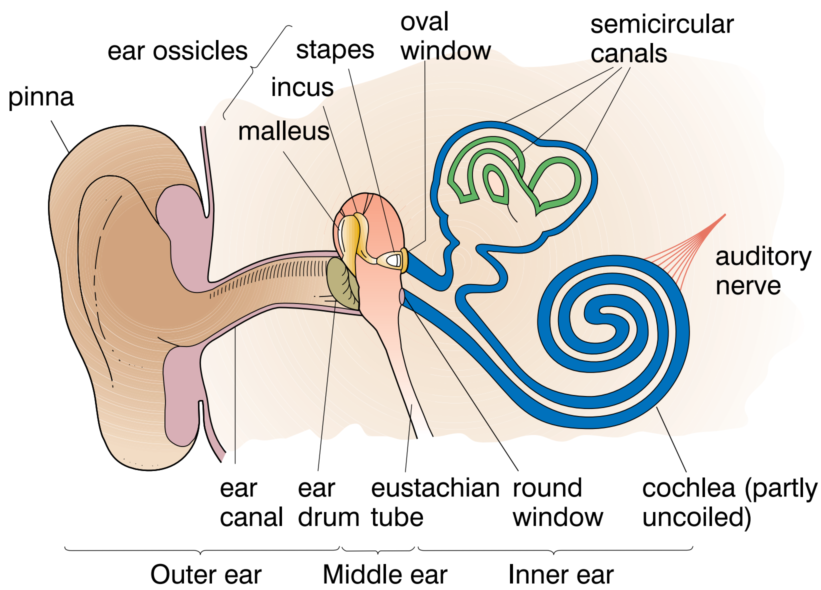
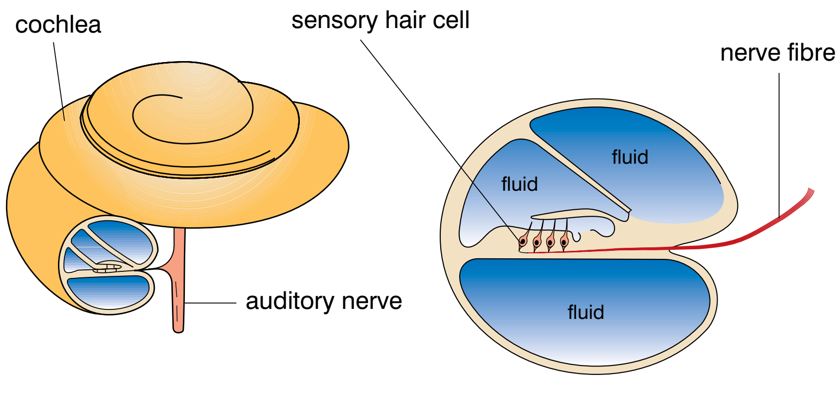


Figure 3.27 *The structure of the human ear.*

The mechanism of hearing

You have had a look at the structure of the ear. Now you need to look at how the ear works. The pinna collects sound waves and directs them to the eardrum through the ear canal. When sound waves hit the eardrum, it vibrates. This magnifies the vibrations,



which are then transmitted through the ear ossicles (the small bones) to the oval window. The ear ossicles also amplify the vibrations (make them bigger).

The vibrations of the stapes make the membrane at the oval window vibrate. The vibrations of the oval window are transmitted to the fluid and then spread to the cochlea. Vibrations of the fluid cause the hair-like sensory cells to move. These movements in turn cause production of nerve impulses in the affector nerve fibres. These impulses are transmitted to the brain for interpretation.

__Figure 3.28__ This cross section through a cochlea shows how the movement of the fluid in the inner ear affects the sensory hair cells – and the impulses they send to your brain are interpreted as sounds.

The human ear is sensitive to vibrations ranging from those of a very low note of about 20 vibrations per second, to a very high note of about 30 000 vibrations per second. High notes are detected in the first part of the cochlea and low notes are recorded in the last part of the cochlea.

The senses of balance and movement

The semicircular canals in your inner ear are concerned with the detection of motion. The swellings on each of the semicircular canals (the **ampullae**) contain sensory cells attached to sensory nerve endings. The sensory cells have hairs which are enclosed in a core of jelly substance called a cupula (figure 3.29). Whenever the body or the head moves, the semicircular canals move with the head. The fluid in the semicircular canals also starts to move but it lags behind in its motion and so it apparently moves in the opposite direction. The moving fluid causes the cupula to tilt, thus pressing the hairs of the sensory cells. The pressing of the sensory hairs creates nerve impulses in the sensory nerve endings. The nerve impulses are transmitted to the brain. The brain then interprets the direction and speed of motion of the body or head.

The semicircular canals are all at right angles to each other, so each one is sensitive to movement in a different plane. One canal responds when you nod your head, one when you shake it and one when you tilt your head to the side. If you spin round and round fast and then stop, you will feel dizzy. This is because the fluid in your semicircular canals keeps on moving after you have stopped. Your ears are telling your brain that you are moving round, but your eyes and other senses are saying you are standing still – and these mixed messages result in the dizzy sensation.

The utriculus and sacculus are concerned with your sense of balance and posture. The inner surfaces of these structures contain sensory cells with protruding hairs embedded in a jelly-like substance containing tiny particles of chalk called **otoliths**. When your head is tilted on one side, the otoliths move in the opposite

KEY WORDS

malleus (hammer) *the ossicle attached to the eardrum*

incus (anvil) *the ossicle between the malleus and the stapes*

stapes (stirrup) *the stirrup-shaped ossicle that transmits sound from the incus to the cochlea*

ampullae *the swelling at the base of each semicircular canal, containing sensory cells which detect movement of the fluid within the canals* direction, pulling or pressing the sensory hairs. This initiates nerve impulses which are transmitted to the brain. The brain then detects the angle of tilt and sets of reflexes are initiated, which tend to return the body to its normal posture.

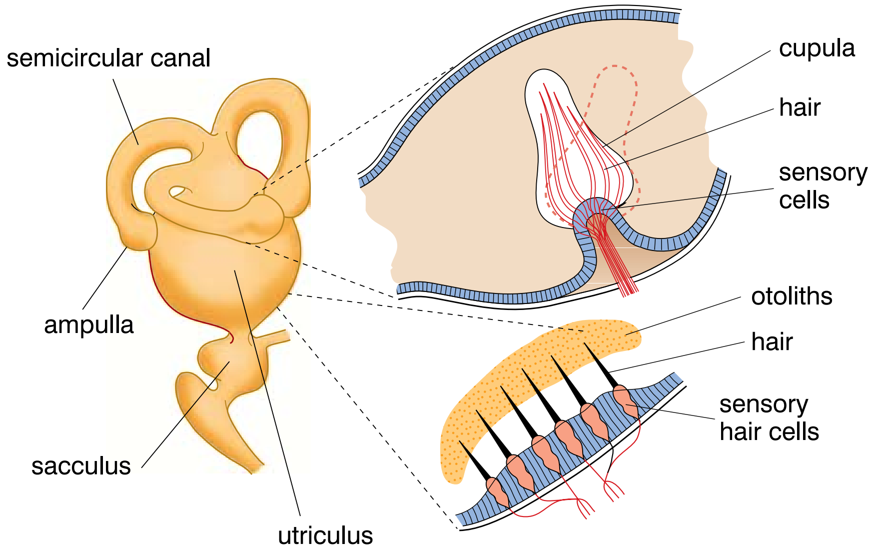


Figure 3.29 *The balance organs of the ear.*

Your ear is not the only part of your body involved in giving you a sense of balance. The sense of balance is also affected by your vision and by stretch receptors in the muscles, which constantly help you to be aware of your position. Someone trying to stand on their toes with their eyes closed will invariably begin to fall forward. This is much less likely to happen if the same exercise is performed with the eyes open!

Common disorders of the ear

Deafness, or the inability to hear, is one of the most common disorders of the ear. Deafness may be temporary or permanent. It can be caused in many ways. If the eardrum is damaged, by a blow or by a very loud noise, deafness will result. This may be temporary or, if the eardrum fails to heal, it can be permanent. If the tiny bones of the middle ear become damaged or fused by infection, or crumble away with age or disease, you will be permanently deaf. Damage to the auditory nerve is another cause of deafness, and once the nerve is damaged it cannot be restored.

Hearing loss can also be the result of infection, when the middle ear becomes full of thick infected mucus. This type of hearing loss can be reversed if the infection is cleared with antibiotics. However, if the infection lasts too long, permanent hearing loss may result.

Taste and smell

The sensory receptors of your tongue and those found in the nostrils are sensitive to solutions of certain chemical substances. The sensory receptors of taste are located on the upper surface of the tongue, and to a lesser extent on the surface of the throat. The receptors for smell are located in the upper parts of the nasal passages.

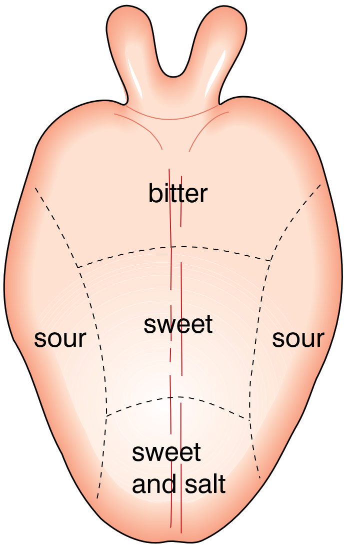


Figure 3.30 *This 'map' of the main taste areas of the tongue has been taught for many years. Scientists have discovered that in fact there are five different types of taste buds spread evenly across the tongue – and the idea for the map comes from a German text which was translated wrongly many years ago!*

There are five basic taste sensations. The first four are sweet, sour, bitter and salt. We have known about these for many years. Very recently scientists have discovered a fifth taste called umami (a very savoury flavour found in foods such as meat, cheese, broth and mushroom). For many years it was thought that the receptors for the four known senses had their areas of greatest concentration on different parts of the tongue. It has now been clearly shown that in fact all of the five different taste organs are spread out all over the tongue, although some of them may seem to be in a greater concentration in certain places.

Activity 3.10: Investigating the sense of taste

You will need:

- sugar solution
- salt solution
- vinegar
- rhamnus
- cotton buds or clean pieces of cotton wool or cloth

Method

1. Draw a blank map of your tongue.
2. Work in pairs.
3. One person dips a cotton bud in the sugar solution and touches it in several places on the tongue of their partner.
4. Each time the tongue is touched, the subject says what they can taste (if anything). Mark the taste on the map.
5. Throw away that cotton bud. Dip another in salt solution and repeat.
6. Do this for all four solutions.
7. Then exchange roles and repeat the experiment.
8. What sort of map did you get – and is everyone's tongue map the same?
9. The tongue can only taste chemicals that are in solution. Design an experiment to demonstrate this.

Figure 3.31 *The taste of your food is partly the result of information from the taste buds on your tongue and partly from the sense of smell in your nose.*

A few substances stimulate only one of the five types of receptors, but most stimulate two, three, four or five types to varying degrees. The taste sensations you experience are produced by a blending of the five basic sensations in different relative intensities along with the input of smell from your nose.

The sensation experienced by different people in response to the same stimulus may not be the same. The same substance can give rise to a sensation of sweet in one person if it stimulates primarily the sweet receptors. It can give rise to a sensation of bitter in a second person if it stimulates primarily the bitter receptors. There can be no sensation at all to a third person if it fails to stimulate any of the receptors. This is why the same food can taste delicious to one person and disgusting to another!

It is possible for someone to have particularly sensitive sweet receptors and particularly insensitive sour receptors. Such a person might not like sugary food, because it would stimulate the sweet receptors excessively and arouse a sickening sweet sensation. But they might be very fond of lemons so sour that most people would reject them. This is because the sour receptors in this person, being unusually insensitive, would be hardly stimulated by the lemon juice.

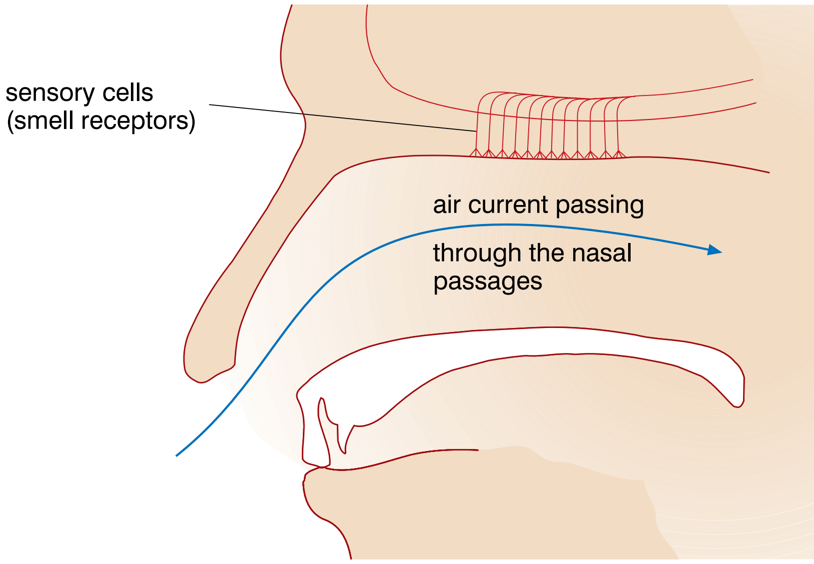


Figure 3.32 *You are aware of the sense of smell as air is drawn through your nasal passages over the smell receptors in your nose.*

The receptors of taste and smell are essentially similar in function. In fact much of what is called taste is in fact a function of the sense of smell. When a person speaks of taste sensation they are referring to a compound sensation produced by stimulation of both taste and smell receptors. One reason why hot foods often have more 'taste' than cold foods is because they vaporise more. The vapour passes from the mouth up into the nasal passages, where it stimulates smell receptors (figure 3.32). The reason why you cannot 'taste' foods well when suffering from a cold is that, with your nasal passages inflamed and coated with mucus, your smell receptors cannot work. In other words, much of what is called taste is really smell.

For you to be able to taste and smell, chemicals must go into solution in the film of liquid coating the membranes of receptor cells before they can be detected. The major functional difference between the two kinds of receptors is that smell receptors are more specialised for detecting vapours coming to the organism from distant sources. Taste receptors are specialised for detection of chemicals present in the mouth itself. Furthermore, smell receptors are much more sensitive than taste receptors.

Activity 3.11: Conduct an experiment to prove that the actual taste of food is a combination of taste and smell

How can you prove that the taste of everyday food is a combination of information from the sense of taste on your tongue and the sense of smell from your nose?

Plan a simple investigation to prove that people cannot tell what they are eating when their eyes are closed unless they can both taste and smell the food.

Show your plan to your teacher and then carry out your investigation.

Write up your experiment carefully so that other students could repeat the experiment and check your results.

The skin as a sense organ

The skin is a remarkably complex organ which carries out a number of important functions in your body. Some of these you will be looking at in section 3.5 on homeostasis, but the skin also contains very many sense organs, which give you your senses of touch, temperature and pain:

- It contains a huge variety of sense organs (touch, temperature, pressure, pain).
- It forms a waterproof layer around your body tissues, which protects you against the loss of water by evaporation and prevents you gaining water by osmosis every time you swim in the river or wash.

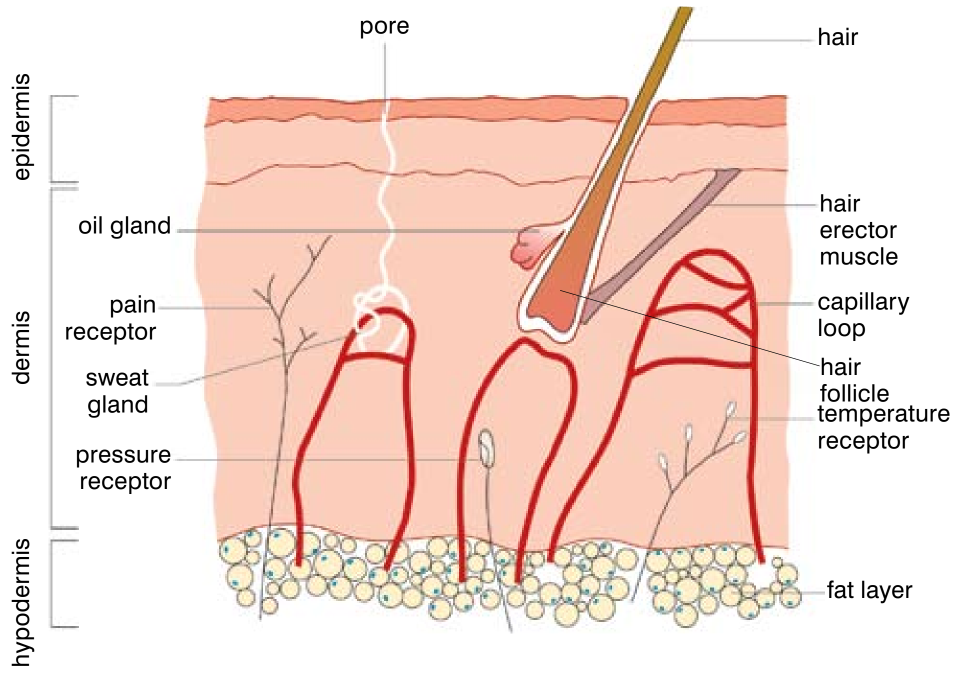


***Figure 3.33** This cross section through the human skin helps you to understand how the structure of the skin is related to its functions.*

KEY WORDS

hypodermis *the lower fatty layer of skin which helps to insulate the body against heat loss*

dermis *the middle layer of skin, which is made up of blood vessels, lymph vessels, hair follicles, and sweat glands*

epidermis *the outermost layer of skin, comprising dead cells which protects against water loss and entry of pathogens*

- It protects you from the entry of bacteria and other pathogens.
- It protects you from damage by UV light from the sun.
- It is an excretory organ (nitrogenous wastes are lost in your sweat).
- It is vital in controlling your body temperature.

Your skin has three main layers. The lower layer, the **hypodermis**, contains fatty tissue which is both an energy store and acts as an insulation layer, protecting you against heat loss. The middle layer or **dermis** contains the blood vessels, the sweat glands, the sensory receptors and the hair follicles. This layer is closely involved in temperature control in homeostasis and in your sense of touch. The upper layer or **epidermis** is made up of dead cells. These stop water loss and also protect against the entry of pathogens. It is the dermis which is particularly involved in the homeostatic mechanisms of the skin.

Activity 3.12: Identifying the parts of the skin

You will need:

- a light microscope
- a prepared slide of skin

Method

1. Using the techniques for using a light microscope which you have met in grade 9, examine your slide of the skin and identify as many features as possible.
2. Draw and label your section through the skin.
3. Identify and draw higher magnification details of particular tissues such as the sweat gland, any sense organs, etc.

Activity 3.13: Investigating the senses of touch and temperature

1. Touch:

You are going to investigate the sense of touch in different areas of skin.

You will need:

- a fine ballpoint or felt pen
- a bristle mounted on wooden holder or blunt seeker or fine piece of wire or very sharp pencil

Method

1. Work in pairs. Take it in turns to carry out the investigation.
2. With the pen, draw a grid of 25 squares on the back of your partner's hand. Each square should be 2 mm x 2 mm.
3. Draw an identical grid on paper and label it with the name of the subject and the area of the body.
4. The subject should close their eyes or look away – they must rely on the sense of touch alone. Ask them to say YES when they feel a touch.
5. Press the tip of the bristle against the skin in one of the squares until it just bends, or touch the skin with the blunt seeker as gently as possible. Touch each of the squares in turn, marking on your paper each one that gives a positive response.
6. Now try other areas of the skin that you might expect to be more or less sensitive, e.g. the palm of the hand, the arm, the leg, the foot, etc.
7. Once you have tested three different areas, swap roles.
8. Are some parts of the skin more sensitive than others? Write up your experiment along with the results and explain your observations as well as you can.

2. Temperature:

Is your sense of temperature absolute – or comparative? In other words, are your temperature receptors working like mini-thermometers or do they measure temperature relative to your body?

You will need:

- three bowls of water – one containing ice-cold water, the second hot water (but not too hot – you have to put your hand in it) and the third water at approximately room temperature.
- a watch, stopwatch or clock

Method

1. Place your left hand in the hot water and your right hand in the cold water for one minute.
2. Once the minute is up, place both hands in the water at room temperature.

   What does each hand feel like?
   What does this tell you about your sense of temperature?
3. Write up your method, observations and explanations.

Summary

In this section you have learnt that:

- Sense organs detect changes in the internal or external environment.
- The human eye includes: sclera, cornea, iris, pupil, lens, ciliary muscle, suspensory ligament, retina and optic nerve.
- The light-sensitive cells – the rods and the cones - are found in the retina.
- The iris controls the amount of light entering the eye.
- The cornea bends the light into the eye.
- The lens controls the fine focus of the image onto the retina.
- Short sight, long sight and astigmatism are three common defects of the eye.

- The ear is an organ of hearing and of balance.
- Hearing involves the outer, middle and inner ear. Balance involves the semicircular canals.
- Identify the taste areas of the tongue.
- Conduct an experiment to prove that the actual taste of food is a mixture of taste and smell.
- Draw and label the smelling organ.
- Draw and label the structure of the skin.

Review questions

1. Which of the following is not part of the eye?

   A lens

   B retina

   C pinna

   D eyelid

2. Imagine you have been out on the beach looking at some friends in the sea. You walk into the shade of a palm tree and begin to read a book. What changes would take place in your eyes?

   A Your pupils would constrict and your lens would become flatter and less convex.

   B Your pupils would constrict and your lens would become rounder and more convex.

   C Your pupils would dilate and your lens would become flatter and less convex.

   D Your pupils would dilate and your lens would become rounder and more convex.

3. Which is the correct order of the bones in the middle ear, from the eardrum inwards?

   A hammer, anvil, stirrup

   B anvil, hammer, stirrup

   C stirrup, anvil, hammer

   D none of these

4. Which is the most recently discovered sense of taste?

   A sweet

   B bitter

   C sour

   D umami

3.3 The endocrine glands

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

- Define glands as structures that produce hormones or other secretions and distinguish between exocrine and endocrine glands.
- Locate the position of the main endocrine glands and describe their functions.
- State the cause and treatment of goitre.
- State the cause and treatment of diabetes mellitus.
- Describe the menstrual cycle and the associated changes.

It is very important that our bodies are co-ordinated not just from minute to minute, but from day to day and from year to year throughout our lives. Many processes in the body are co-ordinated by chemical substances known as **hormones**. Hormones act as chemical messages, produced in one part of the body but having an effect somewhere entirely different. Glands are structures which produce hormones and other useful substances. Hormones are produced (secreted) by special endocrine glands found around the body. Many glands in your body are exocrine glands. This means they have a special tube or duct that carries the secretion from the gland where it is made to the place where it is needed. Sweat glands, salivary glands and mammary glands are all examples of exocrine glands. The endocrine glands that produce your hormones have no ducts, so they are sometimes known as ductless glands. They secrete hormones directly into your blood, and the chemicals are carried from the glands all around your body in the bloodstream. Most hormones only affect certain tissues or organs – their target organ – and the hormone is picked up from the blood by receptors in the cell membranes. They can act very rapidly, but often their effects are slower and longer lasting than the results of nervous control. This will be discussed in the next section.

The pituitary gland, found in the brain and about the size of a pea, is sometimes described as the controller of the endocrine orchestra. The hormones made in this tiny gland control the secretion of many other hormones. Because of its position in the brain, it is also involved in co-ordination between the nervous and hormonal systems of control.

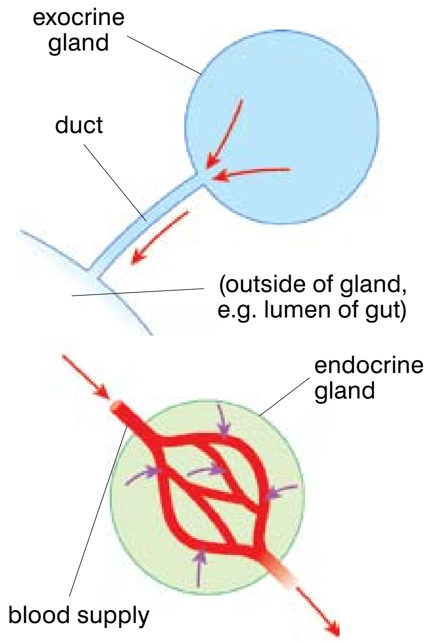


***Figure 3.34** The secretions of an exocrine gland can only go as far as the duct reaches – but the hormones produced by your endocrine glands travel all around your body in your blood.*

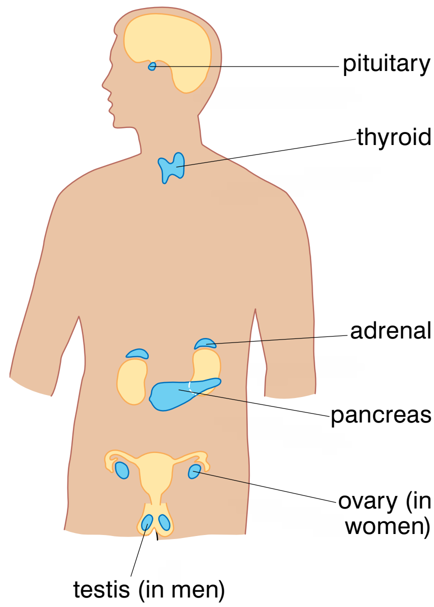


***Figure 3.35** These endocrine glands control many things about us, including the way we grow, our sexual development, reproduction and the sugar levels in our blood.*

Iodine deficiency and goitre

The thyroid gland in your neck uses iodine from your diet to produce the hormone **thyroxine**. Thyroxine is one of the hormones involved in the long-term chemical control of your body. It controls the metabolic rate of your body – how quickly substances are built up and broken down, how much oxygen your tissues use and how the brain of a growing child develops. If someone has an overactive

KEY WORDS

hormones *chemicals produced in one part of an organism which produce specific effects on a different part of the organism*

thyroxine *hormone produced by the thyroid glands to regulate metabolism by controlling the rate of oxidation in cells*

Figure 3.36 *The thyroid gland is very important for the normal control of your metabolic rate and growth. When things go wrong, as in this picture of a woman with goitre, it is important to treat the situation as soon as possible to prevent permanent damage.*

thyroid that makes too much thyroxine, their metabolism starts to go very fast – the symptoms include losing a lot of weight, sweating a lot and becoming irritable. If the thyroid doesn't make enough thyroxine, people feel tired and lack energy. They may gain weight. Low levels of thyroxine can cause problems in getting pregnant, miscarriages and still births. If small children do not make enough thyroxine, their growth is stunted and they do not develop normally, and this damage can be permanent. They have difficulties in learning. This is called cretinism.

The most common reason for not making enough thyroxine is a lack of iodine in the diet. Without iodine, the thyroid gland works very hard to try and make enough thyroxine but it cannot do it. The gland will grow and enlarge in an attempt to make the right amount of thyroxine. This is known as goitre. The enlarged gland can be felt in the neck. Eventually the goitre gets so big it can be seen as a swelling in the neck. Many people do not like the appearance of a goitre in their neck.

Iodine deficiency disorders such as goitres are very common in Ethiopia. Several scientific studies have shown that between 30 and 40% of our population are affected by iodine deficiency to some extent. Women and children tend to be more affected than men. This may be because women have big demands on their bodies with pregnancy and breastfeeding, while children are growing. The problem is worse in rural areas, particularly in the mountainous regions where any iodine tends to be washed away out of the soil. In some areas up to 90% of school children show some level of iodine deficiency. Iodine deficiency affects the health of millions of people in Ethiopia.

There is a simple solution for most of the problems of iodine deficiency and goitre. We need to include more iodine in our diet. There is a simple way to do this. Iodine can be added easily to the salt we use to season our food. Just that tiny amount of extra iodine is all we need to overcome all the problems that goitre and IDD (iodine deficiency disease) can bring! In areas where the iodine levels are very low, special iodised capsules can be used to help people overcome the deficiency. In the year 2000 about 28% of all households in Ethiopia used iodised salt. The Government and the Department of Health are working with other agencies to try and make sure that everyone in Ethiopia can get iodised salt by 2015. This would mean all of the disorders linked to iodine deficiency would go. Our goitres would disappear. Our women would suffer far fewer losses during pregnancy and birth. Our children would not fail to develop and become cretins. Every child would benefit and be able to learn more effectively. People would have more energy and be able to work more effectively. Adding more iodine to our diet in this simple way can have major effects on the well-being of millions of people in our country. It has worked elsewhere in the world – now it is our chance to overcome this simple but devastating disease.

Table 3.2 *Goitre rate of women by regional states (1997)*

The different areas	Percentage of women with goitres
Amhara	28.8%
Oromia	31.3%
Tigray	35.6%
SNNPR	59.9%
Addis Ababa	22.3%
Afar	15.6%
Benshangul Gumuz	37.3%
Dire Dawa	12.4%
Harari	6.7%
Gambella*	1.4%
Total goitre rate (weighted)	35.8%

*Under-represented because of insufficient data.

Figure 3.37 *Iodised salt made and sold in Ethiopia can help us prevent all the problems caused by iodine deficiency diseases including goitre.*

Insulin, controlling the blood sugar levels and diabetes mellitus

It is very important that your cells have a constant supply of the glucose they need for cellular respiration. Glucose is transported around your body to all the cells by your blood. However, you don't spend all of your time eating to keep your blood sugar levels high and provide a constant source of glucose for your cells. Instead the level of sugar in your blood is controlled by hormones produced in your pancreas.

When you digest a meal large amounts of glucose pass into your blood. Without a control mechanism your blood glucose levels would vary wildly. After a meal they would soar to a point where glucose would be removed from the body in the urine. A few hours later the levels would plummet and cells would not have enough glucose to respire.

This internal chaos is prevented by your **pancreas**. The pancreas is a small pink organ found below your stomach. It constantly monitors your blood glucose concentration and controls it using two hormones known as **insulin** and **glucagon**. When your blood glucose concentration rises above the ideal range after you have eaten a meal, insulin is released. Insulin stimulates your liver to remove any glucose which is not needed at the time from the blood.

KEY WORDS

pancreas *a gland that produces digestive enzymes and manufactures hormones, including insulin and glucagon*

insulin *a hormone that lowers the blood glucose level*

glucagon *a hormone that raises the blood glucose level*

glycogen *a form of carbohydrate stored primarily in the liver and broken down into glucose when needed by the body*

The soluble glucose is converted to an insoluble carbohydrate called **glycogen** and stored in your liver.

When your blood glucose concentration falls below the ideal range, the pancreas monitors it and secretes glucagon. Glucagon stimulates your liver to break down glycogen, converting it back into glucose and so releasing stored sugar back into the blood. By using these two hormones and the glycogen store in your liver, your pancreas keeps your blood glucose concentration fairly constant at about 90 mg glucose per 100 ml of blood (4–6 millimoles per litre).

Review questions

1. Why are the levels of glucose in your blood so important?
2. Which two hormones are involved in the control of your blood sugar levels?

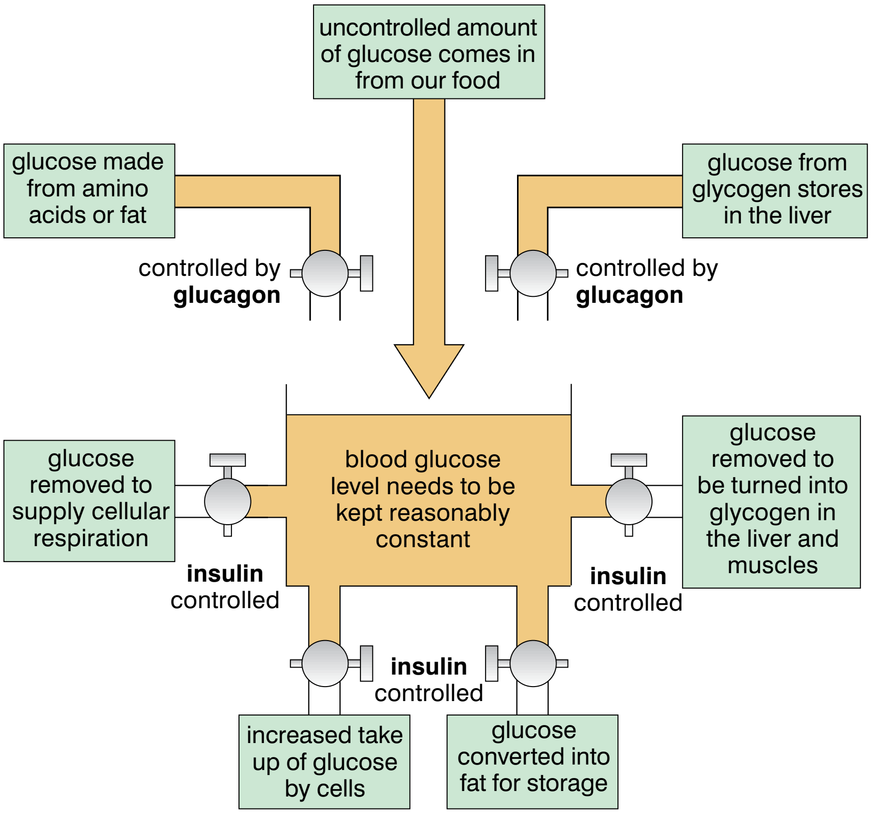


Figure 3.38 This model of your blood glucose control system shows the blood glucose as a tank. It has both controlled and uncontrolled inlets and outlets. In every case the control is given by the hormones insulin and glucagon.

The causes and treatment of diabetes

Most of us never think about our blood sugar levels because they are perfectly controlled by our pancreas. But for some people life isn't quite this simple, because their pancreas does not make enough – or any – insulin. Without insulin your blood sugar levels get higher and higher after you eat food. Eventually your kidneys produce glucose in your urine. You produce lots of urine and feel thirsty all the time. Without insulin glucose cannot get into the cells of your body, so you lack energy and feel tired. You break down fat and protein to use as fuel instead, so you lose weight. Type 1 diabetes appears in children and young people. It is inherited and you cannot avoid it. Type 2 diabetes appears later in life and it can be linked to being obese or possibly very underweight as well. Before there was any treatment for diabetes, people would waste away, fall into a coma and die. Fortunately there are now some very effective ways of treating diabetes. However, not everyone in Ethiopia knows about the treatment, and it can be difficult to get the treatment you need.

If you have a mild form of diabetes, managing your diet is enough to keep you healthy. Avoiding carbohydrate-rich foods keeps the blood sugar levels relatively low so your reduced amount of insulin can cope with them. Getting regular exercise also helps your body cope with diabetes.

However, many people with diabetes need replacement insulin before meals. Insulin is a protein which would be digested in your stomach, so it is usually given as an injection to get it into your blood. This injected insulin allows glucose to be taken into your body cells and converted into glycogen in the liver. This stops the concentration of glucose in your blood from getting too high. Then as the blood glucose levels fall, natural glucagon makes sure glycogen is converted back to glucose. As a result your blood glucose levels are kept as stable as possible. Insulin injections treat diabetes successfully but they do not cure it. Until a cure is developed, someone with diabetes has to inject insulin several times every day throughout their life.

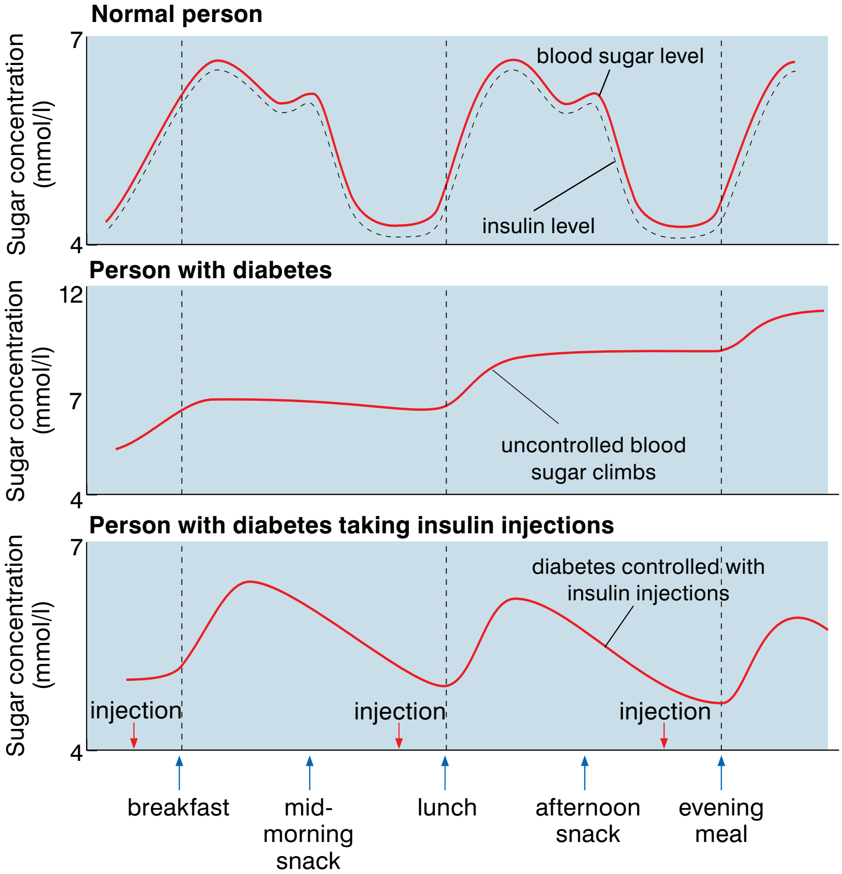


Figure 3.39 *Insulin injections keep the blood sugar level within safe limits. They cannot mimic the total control given by the natural production of the pancreas – but they work well enough to let people lead a full and active life.*

DID YOU KNOW?

In 2005 doctors in Japan performed a successful living transplant of pancreas tissue. Cells from a mother were given to her daughter who had severe diabetes. Within three weeks the daughter no longer needed insulin injections – her new cells were controlling her blood sugar.

Figure 3.40 *The treatment of diabetes involves regular blood sugar tests and insulin injections. These could become a thing of the past if some of the new treatments being developed work as well as scientists hope!*

DID YOU KNOW?

In 2005 research scientists produced insulin-secreting cells from human stem cells which cured diabetes in mice. More research is needed but the scientists hope that before long diabetes will be a disease which can be cured instead of treated.

KEY WORDS

adrenaline *a hormone produced by the adrenal glands that elevates heart and respiration rates; also called 'epinephrine'*

The treatment of diabetes has changed a great deal over the years. For centuries nothing could be done. Then in the early 1920s Frederick Banting and Charles Best realised that extracts of animal pancreas could be used to keep people with diabetes alive. For many years insulin from pigs and cows was used to treat affected people. This saved millions of lives.

In recent years bacteria have been developed using genetic engineering which produce pure human insulin. This is now used by the majority of people affected by diabetes. It means that a regular, reliable supply of exactly the right chemical is always available. Now scientists are trying to find easier ways – like nasal sprays – to get insulin into the body. If the regular injections could be replaced it would certainly improve the quality of life for diabetics. But it is still a miracle of medicine that this potentially devastating condition can be managed and controlled effectively, and homeostasis restored.

In Ethiopia there are relatively low rates of reported diabetes but it often causes many problems. It is thought that many people suffering from diabetes are not diagnosed and so may suffer symptoms and die without ever having treatment. Even when people are diagnosed with diabetes it can be difficult to keep under control. This is because in Ethiopia many people do not have a hospital or doctor close to their home. People may have to travel many kilometres to collect their insulin and the testing kits they need. Also these medications can be expensive. Hopefully more doctors and nurses will be found working in the countryside in the future, providing the insulin that is needed to keep people with diabetes healthy and well.

Adrenaline is a well-known hormone – we talk of things 'getting the adrenalin running'. It is produced by your adrenal glands, which sit on top of your kidneys and it is the hormone of 'fight or flight'. If you are stressed, angry, excited or frightened your adrenal glands will secrete lots of adrenalin. Carried rapidly round in your blood, adrenalin affects many different organs from the pupils of your eyes (it dilates them) to the beating of your heart (it speeds it up). Adrenalin basically prepares your body for action, so that you can run fast to escape or fight successfully if you need to. The main changes produced by adrenalin are:

- Increased heart rate, sending more blood carrying food and oxygen to the muscles.
- Increased breathing rate to increase the amount of oxygen coming into the blood and to get rid of excess carbon dioxide produced.
- Stored carbohydrate in the liver is converted into glucose in the blood, and the muscle cells absorb more glucose for cellular respiration to provide extra energy.
- Your pupils dilate, allowing more light into your eyes and making you oversensitive to movement.

- Your body hair stands on end – not much use to us, but it makes other animals like cats look much bigger.
- Increased mental awareness and speed of reaction times.
- Blood diverted away from your gut and into your big limb muscles – you don't need to digest food but you do need a good blood supply to the muscles.

There are some concerns that when people are stressed in their lives they will produce adrenalin. Their heart and the rest of their body will be affected, but they don't get involved in physical activity. Eventually this may have a damaging effect on their health.

Other hormones

Growth hormones produced by the pituitary gland have a long, slow effect on you throughout childhood, and then when you reach puberty, the sex hormones are produced, which lead to long-term physical development and growth. You will be looking at these hormones in more depth next.

The gonads

The gonads are the endocrine glands which produce some of the sex hormones. These are the testes in boys and the ovaries in girls. They become active at the time of puberty when the big physical changes which make boys and girls look very different take place and the body takes on its adult form. The changes come about in response to hormones released by the brain and by the gonads themselves.

The role of the testes

Puberty in boys usually begins somewhere between the ages of 9 and 15 years old. It may happen very rapidly, over the space of a year or so, or it may take place much more slowly over a number of years. A general sequence of events is described here, but the order and speed in which changes occur is very much an individual thing – no two people experience puberty in exactly the same way.

The chemical changes which trigger puberty are unseen, another important example of hormonal co-ordination and control. The pituitary gland in your brain starts to produce increasing amounts of FSH. This in turn stimulates the male gonads or testes to begin developing and producing the male sex hormone **testosterone**. The rising levels of testosterone trigger the many changes which affect the body during puberty, causing the development of the **secondary sexual characteristics**. The main ones are listed below:

- The whole body undergoes the adolescent growth spurt, so you get taller.
- Pubic hair, body hair and facial hair begin to grow. Some men are naturally smooth and develop little body hair. Others are much hairier. The full development of facial and body hair can take many years.

KEY WORDS

testosterone *the primary male hormone responsible for the development of masculine traits*

secondary sexual characteristics *distinguish between the two sexes; includes facial hair of the human male and enlarged hips and breasts of the female*

- The larynx enlarges so the voice deepens. This is known as the voice 'breaking' and it can happen very slowly over a period of months or very suddenly, almost overnight!
- The shoulders and chest broaden as you develop more muscle.
- The testes grow larger, become active and start producing sperm and the other chemicals necessary to produce semen, the nutritious sperm-containing fluid which is ejaculated into the female reproductive system.
- The penis enlarges and the skin of the penis and the scrotum may darken.
- The brain changes too as you make the transition from boy to man. Adolescents become more independent, more questioning and start to look out beyond their families. They can also feel young and insecure, confused or angry for no real reason. It is all part of growing up and changing hormone levels are at least partly to blame.

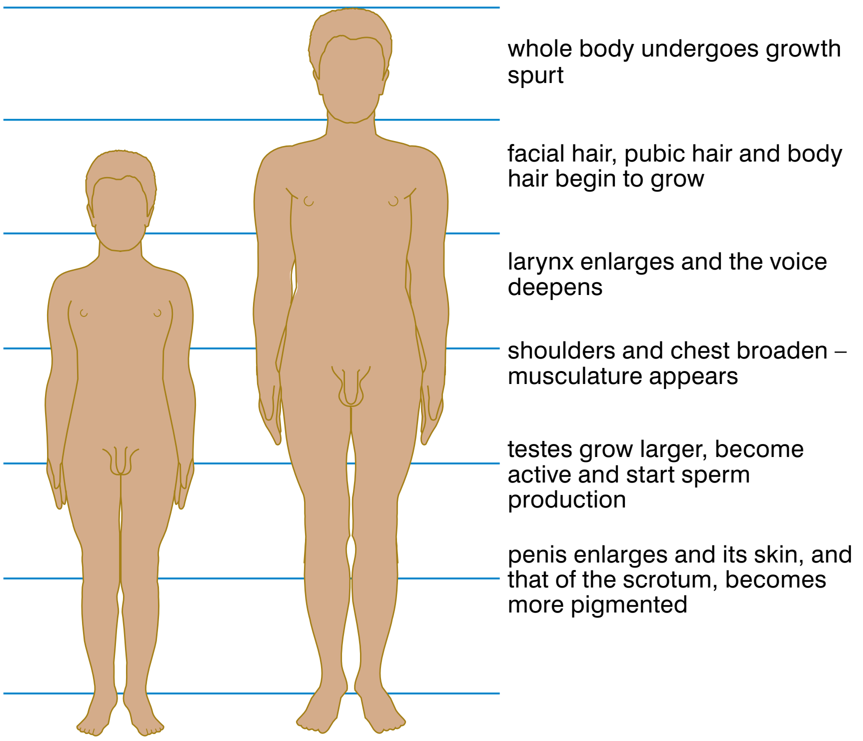
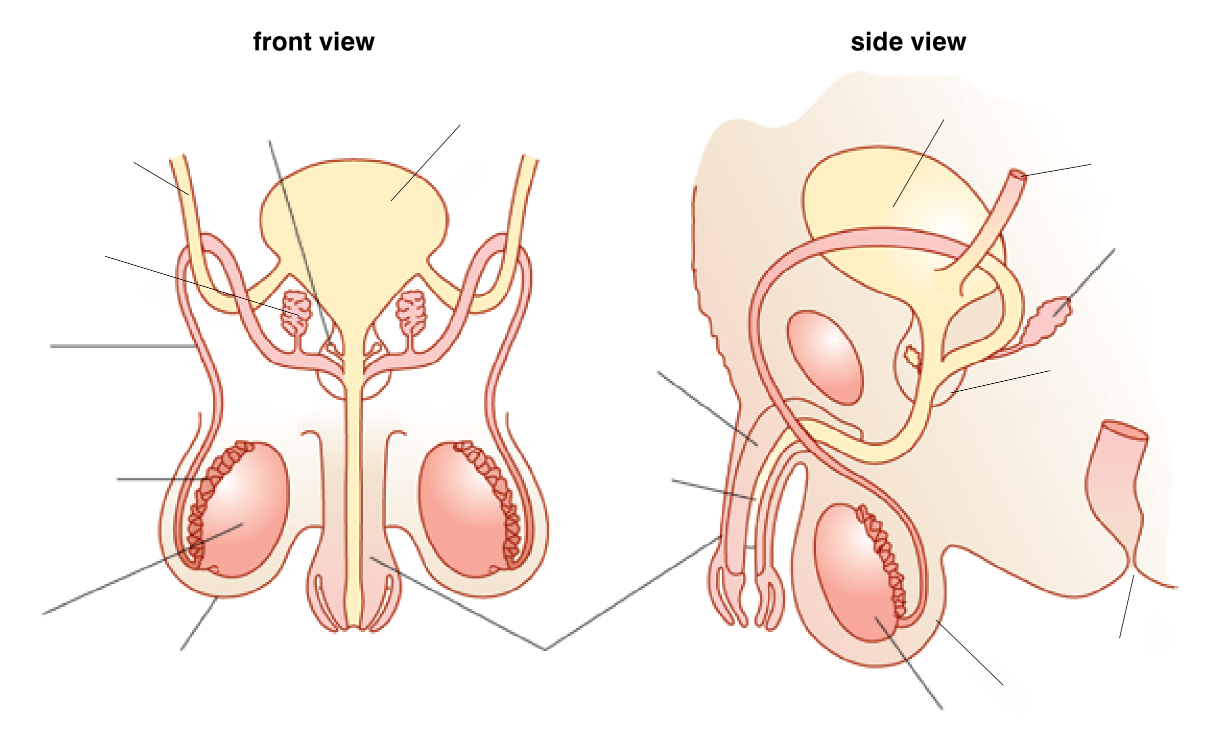


Figure 3.41 *The changes which take place during puberty result in a fully mature and functioning male reproductive system.*

ACTIVITY 3.14: Remembering the male reproductive system

You learnt about the male reproductive system when you were in grade 8. These are the organs that are particularly affected by the hormones produced by the gonads. See how much of the system you can remember – copy and label this diagram.



The role of the ovaries

The role of a woman in human reproduction is to produce a relatively small number of large gametes or ova, to provide the developing embryo with food and oxygen, remove its waste products and, after delivering a baby into the world, to provide it with a continued supply of food for a period of time.

The female gonads are the ovaries, two walnut-sized organs found low in the abdomen. They are closely associated with the uterus and the Fallopian tubes, but are not actually attached to them.

Girls often go into puberty slightly earlier than boys, and so between the ages of 8–14 most girls begin the changes which will take their bodies into sexual maturity. As with boys, the time and speed of puberty varies greatly from one person to another. Although it is different for everyone – and everyone ends up a slightly different shape and size – the basic changes which take place are the same.

Just as in boys, puberty is controlled by hormones from the pituitary gland in the brain and from the gonads themselves – in this case the ovaries. FSH from the brain stimulates the ovaries to become active and start producing the female sex hormone oestrogen. As the levels of oestrogen rise and the body responds, all kinds of changes are triggered and the female secondary sexual characteristics develop.

> **DID YOU KNOW?**
>
> By the time a baby girl is born, her ovaries contain all the eggs she will ever have – several hundred thousand of them in each ovary! But only about 450 of those eggs will ever be released, and a tiny fraction of those will become babies.

- The whole body undergoes the adolescent growth spurt, so you get taller.
- Pubic hair and body hair (underarms) begin to grow.
- The breasts develop.
- The external genitalia become larger and the colour of the skin darkens.
- The female pattern of fat deposits on the hips, buttocks and thighs develops.
- The ovaries begin the production of mature ova and menstruation begins.
- The uterus grows and begins to produce a thickened lining each month in response to hormones from the ovary.
- The brain changes too as you make the transition from girl to woman. Just like boys, as girls become adolescents they become more independent, more questioning and start to look out beyond their families. They can also feel young and insecure, confused or angry for no real reason. It is all part of growing up and changing hormone levels are at least partly to blame.

The female reproductive system is adapted so that a mature ovum is released each month. It provides for an embryo to develop and grow into a baby which is then delivered. As you look at the menstrual cycle you will see how closely it is controlled by hormones.

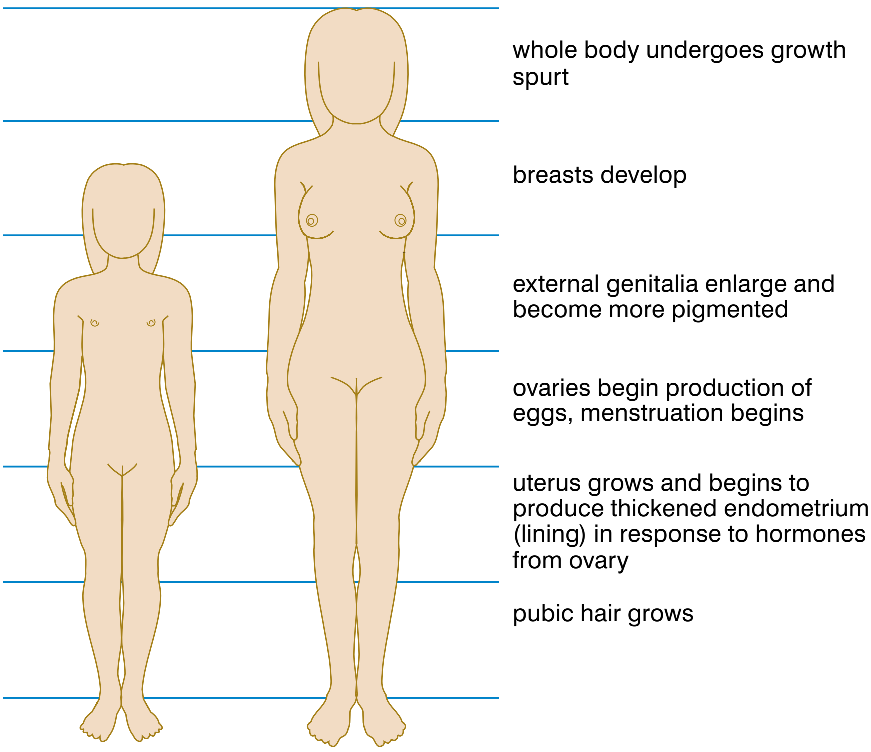
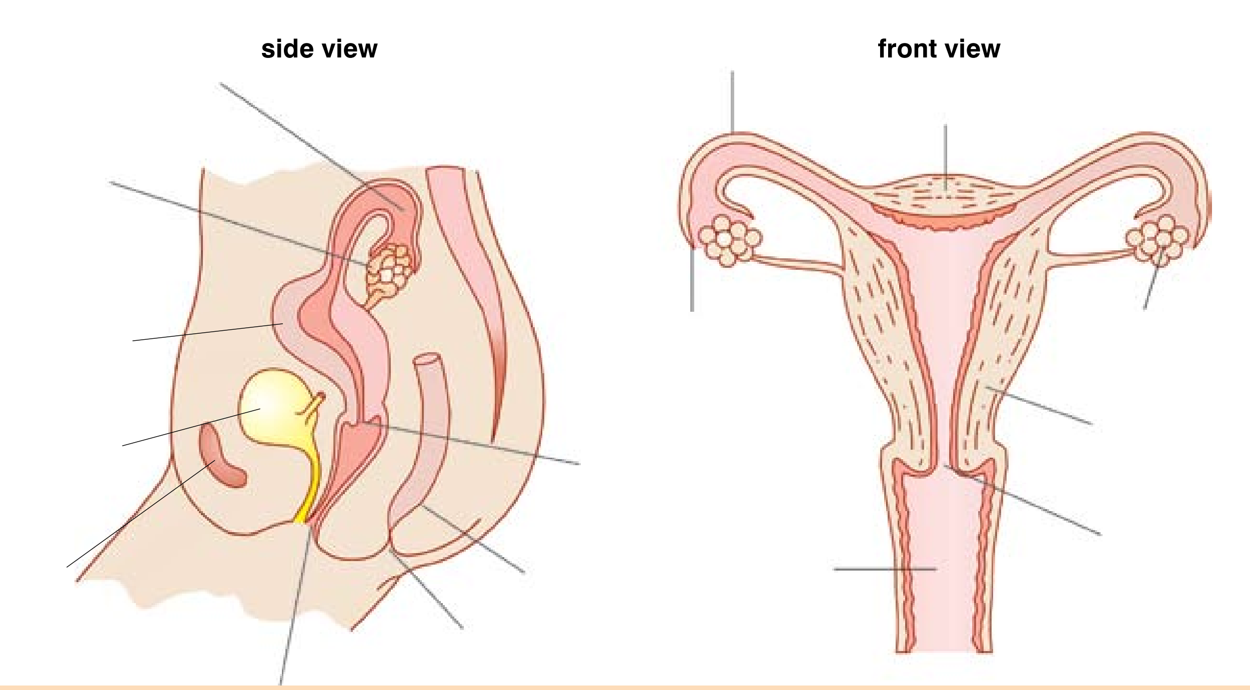


Figure 3.42 *The changes which take place during puberty result in a fully mature and functioning female reproductive system.*

ACTIVITY 3.15: Remembering the female reproductive system

You learnt about the female reproductive system when you were in grade 8. These are the organs that are particularly affected by the hormones produced by the gonads. See how much of the system you can remember – copy and label this diagram.



Review question

1. What are the similarities and differences between the changes which take place at puberty in boys and girls? Make a table to help you with your summary.

The menstrual cycle

Chemical control by hormones is vital in the female reproductive system. Hormones control the whole process of menstruation and pregnancy. The menstrual cycle is a sequence of events which takes place approximately every four weeks throughout the fertile life of a woman, from the age of puberty to around 50 years of age.

A baby girl has ovaries full of immature ova, but they do nothing until after puberty. Then, once a month, a surge of the hormone FSH from the pituitary gland in the brain starts a few of the ova developing.

FSH also affects the ovary itself which starts making the female hormone oestrogen. This in turn stimulates the uterus to build up a thick, spongy lining with lots of blood vessels ready to support a pregnancy. About 14 days after the ova start ripening, one of them bursts out of its follicle. This is called ovulation and when it happens the hormone levels from the pituitary begin to drop dramatically.

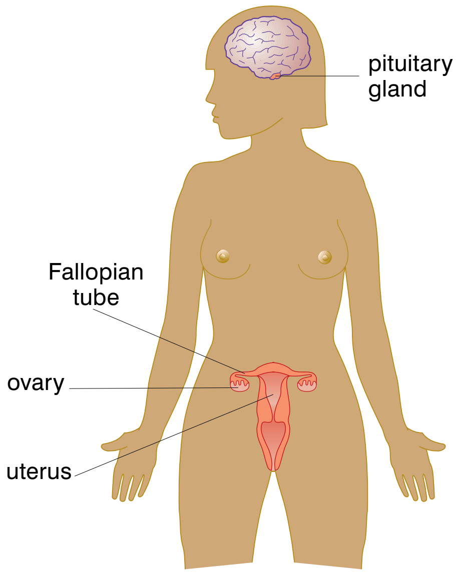


Figure 3.43 *The action of hormones from the pituitary gland and the ovary makes it possible for women to produce fertile eggs and become pregnant.*

KEY WORDS

corpus luteum *the cell mass that remains after the release of an egg. It secretes both progesterone and oestrogen*

progesterone *a hormone that prepares the uterus for the implantation of a fertilised ovum and to maintain pregnancy*

implant *fix or set securely*

After ovulation the remains of the follicle forms the **corpus luteum** (which means yellow body because it is filled with a yellowish fat) and this secretes a different hormone (**progesterone**). Progesterone makes sure that for some days the uterus lining stays thick and spongy and stimulates the growth of more blood vessels, ready to receive a fertilised ovum. If a pregnancy occurs the embryo will immediately get a rich supply of food and oxygen. But most months the ovum is not fertilised and the woman does not become pregnant.

About ten days after ovulation (when no pregnancy has occurred) the ovary reduces the levels of both oestrogen and progesterone. As the chemical messages change again the blood vessels which are supplying the thick spongy lining of the uterus close down. The lining detaches from the wall of the uterus and is lost through the vagina as the monthly period or bleeding.

However, if the ovum has been fertilised it will reach the uterus and sink into the thick, spongy lining, attach itself (**implant**) and start to develop.

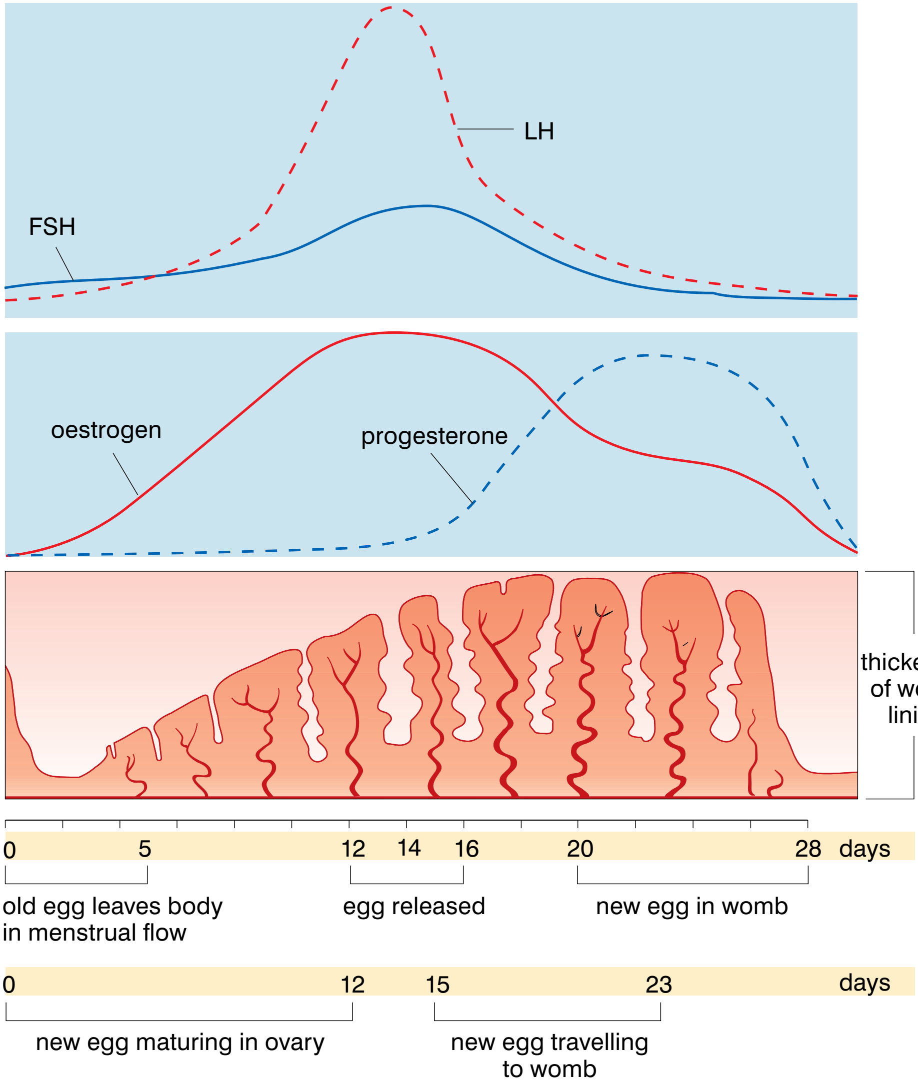


***Figure 3.44** How changes in hormone level influence the events of the menstrual cycle*

The hormones of the menstrual cycle

Remember, there are four main hormones which have an effect on the female reproductive system and between them control the menstrual cycle and female fertility.

Produced by the pituitary gland in the brain:

FSH (**follicle stimulating hormone**) stimulates the development of a follicle in the ovary, and within the follicle the egg matures and ripens. FSH also stimulates the ovaries to produce hormones, particularly oestrogen.

LH (**luteinising hormone**). stimulates the release of the egg from the ovary in the middle of the menstrual cycle and also affects the ovary so that it produces another hormone (progesterone) to keep the uterus lining in place.

Produced by the ovaries:

Oestrogen stimulates the lining of the uterus to build up in preparation for pregnancy. It also affects the pituitary gland. As the oestrogen levels rise, the production of FSH by the pituitary gradually falls – which in turn means the oestrogen levels fall. The rise in oestrogen levels has the opposite effect on the levels of the other pituitary hormone, LH. As oestrogen rises, the production of LH goes up. When LH reaches its peak in the middle of the menstrual cycle it stimulates the release of a ripe egg from the ovary.

Progesterone maintains the thickened lining of the uterus and stimulates the growth of blood vessels in the lining to prepare for a pregnancy – and if a fertilised ovum arrives in the uterus, progesterone helps to maintain the pregnancy.

By the end of the cycle, when the menstrual bleeding is about to start, all of the hormones are at a low ebb.

Because the ovaries only contain a limited number of ova, women do not have periods throughout their lives. Eventually the ova in the ovaries run out. The hormone levels drop, the ovaries and uterus shrink and the woman stops having periods. She is no longer fertile. This change, which takes place around the age of fifty, is known as the menopause.

KEY WORDS

FSH (follicle stimulating hormone) *a hormone produced by the pituitary gland that stimulates the growth of eggs in the ovaries*

LH (luteinising hormone) *a hormone that triggers the onset of ovulation. Works in concert with FSH*

oestrogen *the primary female hormone responsible for the development of feminine traits*

DID YOU KNOW?

An average girl loses around 50 cm^3 of blood in each menstrual period, and will have approximately 450 periods during her fertile lifetime, although this will depend on how many times she is pregnant. This means she will lose around 22.5 litres (39 and a half pints) of blood before she goes through the menopause!

Nervous and hormonal systems in co-ordination

So as you have seen, some hormones do bring about rapid responses – adrenaline, insulin and glucagon are examples of these. But many others such as thyroxine, growth hormone and the sex hormones have a much longer, slower impact on the body – but they are no less important for co-ordination and control.

Both the nervous system and the hormone system are important for co-ordination and control. They both have features in common, but in many ways they are very different.

Nervous system:

- Electrical messages travel along neurons.
- Chemical messages travel across synapses.

- Messages travel fast.
- Messages usually have rapid effect.
- Usually a short-lived response.
- Nerve impulse affects individual cells, e.g. muscle cells, so have a very localised effect.

Hormonal control:

- Messages transported slightly more slowly in the blood – minutes rather than milliseconds.
- Only chemical messages involved.
- Often take longer to have an effect.
- Effect often widespread in the body – affect any organ or tissue with the correct receptors.
- Effects often long lasting.

The combination of nervous and hormonal control enables your body to work as a co-ordinated whole – and plays a vital role in the homeostasis you will be looking at in section 3.5.

Review questions

1. Which of the following endocrine glands secretes a hormone that directly affects the metabolic rate of the body?

   A pituitary gland

   B ovary

   C thyroid

   D pancreas

2. Which of the following reproductive hormones is produced by the pituitary gland?

   A oestrogen

   B testosterone

   C follicle stimulating hormone

   D progesterone

3. Which of the following changes takes place at puberty ONLY in boys?

   A growth spurt

   B larynx enlarging and voice deepening

   C body shape changes

   D mature gametes produced

***Table 3.3** Table to show the main hormones produced in the body, the endocrine organ that produces them and the function in the body*

Gland	Hormone	Functions of the hormones
Pituitary	Growth hormone Thyroid stimulating hormone (TSH) Anti-diuretic hormone (ADH) Follicle stimulating hormone (FSH) Luteinising hormone (LH)	Controls the growth rate of children Stimulates the thyroid gland to secrete thyroxine Controls the water content of the blood by its effect on kidneys (see homeostasis) Stimulates egg development and oestrogen production in women and sperm production in men Stimulates egg release in women and testosterone production in men
Thyroid	Thyroxine	Controls the metabolic rate of the body
Pancreas	Insulin Glucagon	Lowers blood sugar levels Raises blood sugar levels
Adrenal glands	Adrenaline	Prepares the body for stressful situations – 'fight or flight'
Ovaries	Oestrogen Progesterone	Controls development of female secondary sexual characteristics Involved in menstrual cycle Involved in menstrual cycle
Testes	Testosterone	Controls development of male secondary sexual characteristics Involved in sperm production

Summary

In this section you have learnt that:

- Chemical co-ordination and control of the body is brought about by hormones secreted by special endocrine glands.
- The hormones are secreted directly into the blood and are carried around the body in the blood.
- They may affect a single target organ or a range of organs and tissues. They have their effect through special receptor molecules on the cell membranes of the target organs and tissues.
- Hormonal control may be rapid but is often relatively slow and long term.
- Important endocrine organs include the pituitary gland, the thyroid gland, the adrenal glands, the pancreas, the ovaries and the testes.
- Insulin produced by the pancreas controls the blood sugar levels. If the insulin metabolism goes wrong you have diabetes.
- Hormones from the pituitary and the ovary control the menstrual cycle.

3.4 Reproductive health

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

- List the different birth control methods and explain how each one works.
- Describe the symptoms and incubation period of HIV/AIDS.
- Explain how AIDS is currently treated.
- Describe female genital mutilation as a harmful traditional practice.
- Demonstrate life skills that will help you prevent the spread of HIV/AIDS.

You are going to be looking at the different ways in which we can control our fertility and limit our family size to the number of children we can feed and care for. To understand how these birth control methods work, you need to understand how pregnancy comes about. For human reproduction to be successful the sperm made in the man's testes must meet up and join with an ovum released from the woman's ovary. The sperm gets inside the body of the woman during **sexual intercourse**. The erectile tissue in the penis fills with blood so that it becomes erect and can be placed inside the vagina. The sperm move from the testes through the urethra, and semen containing millions of sperm is released inside the vagina in a process known as **ejaculation**. The sperm move through the cervix into the uterus. They then make their way through the uterus and into the Fallopian tubes. It is here that the sperm will meet a ripe ovum, if the woman is at the right stage of her menstrual cycle. Out of the millions of sperm which set off, only a few hundred to a few thousand actually reach the ovum – and only one of those will actually fertilise it. Yet in spite of all the difficulties they face, sperm manage to reach the Fallopian tubes only around half an hour after they are released.

The ovum which bursts from the follicle at the moment of ovulation has no way of moving itself. The end of the Fallopian tube moves across the surface of the ovary to pick up the ovum. It is then moved along the tube by the beating of the cilia, which carry the ovum towards the uterus.

When a single sperm joins with the ovum this is the moment of **fertilisation**, which in humans is also known as **conception**. The nucleus from the sperm, containing the chromosomes from the father, fuses with the nucleus from the ovum, containing chromosomes from the mother, and a potential new life begins. The new cell (known as the **zygote**) has a unique set of chromosomes. If all goes well, it will develop into a baby.

Sadly here in Ethiopia we have a very high rate of maternal deaths in childbirth – 871 women for every 100 000 births. This is partly because in our large and rural country, many women do not have

KEY WORDS

sexual intercourse *the erect penis of the male entering the vagina of the female*

ejaculation *the release of semen from the penis*

DID YOU KNOW?

Sperm can live for up to three days inside a woman's body, waiting for an ovum. But once an ovum is released from the ovary, it is fertile for only a few hours – 24 at most.

DID YOU KNOW?

Sometimes two ripe ova will be released during the same monthly cycle. If they are both fertilised by sperm, two babies may develop in the uterus and the mother will deliver **non-identical twins**. The babies may be the same or different sexes, and are really normal siblings born at the same time.

More rarely, the fertilised ovum splits completely in two as the early embryo forms. Again two babies develop – but these are **identical twins**. Because they come from the same fertilised egg they are genetically identical – they are human clones!

health professionals with them to help when they are giving birth. But some of the problems we can do something about ourselves. Girls' bodies do not stop growing and maturing until they are at least 18. If a girl becomes pregnant before she is 18–19 years old, she is much more likely to be damaged as she gives birth, and there is a higher chance that she and her baby might die. Sensible use of contraception (see below) means that women need not become mothers while they are still children themselves. If a wife is young, the couple can be careful and use contraception until the girl is older and can bear a baby safely. Women are also more likely to die in childbirth if they have many children close together. Again we can do something about this. If couples use contraception to help them space their children further apart, this gives the mother's body time to heal and get strong again. She is less likely to die giving birth, and her children will be stronger and healthier too. Healthy women have healthy babies, so the more we can do to prevent diseases such as goitre and HIV/AIDS in our country, the healthier our families will be.

Controlling fertility – contraception

Many people do not wish to risk pregnancy whenever they have sex. People have tried for thousands of years to control their fertility and to have babies exactly when they wanted them. Methods of avoiding pregnancy have included vinegar-soaked sponges and mixtures of camel dung and various herbs placed in the vagina before intercourse, and reusable condoms made from animal intestines. Many of these traditional methods of contraception were harmful and did not work, they were not scientific at all.

In the 21st century we have a wide range of **contraceptive** choices. Contraception means 'against pregnancy' and it describes ways in which pregnancy can be avoided. There are several different types of contraception. The effectiveness of contraceptive methods is measured per '100 woman years' – in other words, if a hundred women use a method of contraception for a year, how many of them would end up pregnant? By choosing to use contraception, men can protect their wives from having too many children too quickly, or from having a baby too young. By using condoms, men cannot only avoid unwanted pregnancies but protect themselves and their partners from HIV/AIDS and other sexually transmitted diseases. Women can protect themselves by insisting men use condoms, or by using female methods of contraception such as the pill. When couples work together, the reproductive health of both of them can be protected.

Natural methods of contraception are based on understanding the menstrual cycle and accurately predicting the moment of ovulation. Ovulation can be detected by the increase in temperature associated with it, by changes in the vaginal mucus or by using a monitor which detects changes in the chemicals in the urine around ovulation. If sexual intercourse is avoided around the fertile time, pregnancy can be avoided.

KEY WORDS

fertilisation *a single sperm combining with an ovum*

conception *a single sperm combining with an ovum*

zygote *a fertilised ovum*

contraceptive *the prevention of conception*

DID YOU KNOW?

60–70% of fertilised ova never make it to be a baby – in fact about 50% of all fertilised eggs are lost before a woman even realises she is pregnant. This is usually because there is something wrong with the embryo and it cannot develop normally.

Figure 3.45 *The arrival of a healthy full-term baby is the hoped-for outcome of every planned pregnancy.*

Advantages: there are no side effects and this method is permitted by most religions. Carried out with care and scientific precision about recording techniques it can be very effective.

Disadvantages: it depends on full co-operation of both partners and it is not always easy to pinpoint ovulation so pregnancy can result.

Effectiveness: 10 pregnancies per 100 woman years.

Natural methods are considered to be birth control because they use the natural cycles of the body to space out the number of children born and simply avoid sexual intercourse to ensure that the ovum and the sperm do not meet. Breastfeeding a baby also helps to space a family as a woman often does not ovulate while she is fully breastfeeding a baby. However, most methods of contraception set out to prevent conception or the implantation of the embryo whilst sexual activity continues whenever the couple desire it. Community-based reproductive health programmes can give help, advice and contraception.

Physical or barrier methods of contraception involve physical barriers which prevent the meeting of the ovum and the spermatozoa.

- **Condoms** – a thin latex sheath is placed over the penis during intercourse to collect the semen and so prevent ovum and sperm meeting. Gives better protection against pregnancy when combined with spermicide.

Advantages: no side effects, don't need medical advice, used every time you have sex offers protection against sexually transmitted diseases such as syphilis and HIV/AIDS.

Disadvantages: can interrupt intercourse. Sheath may tear or get damaged during intercourse, allowing semen to get through.

Effectiveness: 2.5 pregnancies per 100 woman years.

- **The female condom** – a thin sheath worn by a woman during sex. It lines the vagina so that sperm cannot enter the cervix.

Advantages: no side effects, don't need medical advice, used every time you have sex it protects from infection with HIV/AIDS or other sexually transmitted diseases.

Disadvantages: can only be used once, can be expensive, gives better protection against pregnancy when used with spermicide, takes practice to insert it properly.

- **The diaphragm or cap** – a thin rubber diaphragm is inserted into the vagina before intercourse to cover the cervix and prevent the entry of sperm.

Advantages: no side effects, offers some protection against cervical cancer.

Disadvantages: must be initially fitted by a doctor. May be incorrectly positioned or damaged and allow sperm past. Gives better protection against pregnancy when combined with spermicide.

Effectiveness: 2.5 pregnancies per 100 woman years.

a

b

c

Figure 3.46
(a) Male condoms; (b) Female condom; (c) Diaphragm: all physical barriers to conception.

Hormonal methods use variations on your natural hormones to prevent conception.

- **The mixed pill** – one of the most reliable methods of contraception. The pill contains the female hormone oestrogen. This raises the level of oestrogen in the blood which is detected by your pituitary gland, which in turn slows the production of FSH. Without rising FSH levels no follicles develop in the ovary and no eggs mature to be released. Without mature ova there can be no pregnancy. The pill also contains progesterone, so the mucus in the vagina and cervix change as if a pregnancy has occurred to stop more sperm getting in. The pill must be taken regularly – if the artificial hormone levels drop the body's own hormones can take over and an egg can be released unexpectedly. The **progesterone only pill** (**mini-pill**) doesn't contain oestrogen so it does not inhibit ovulation and needs to be taken at very precise time intervals to be effective.

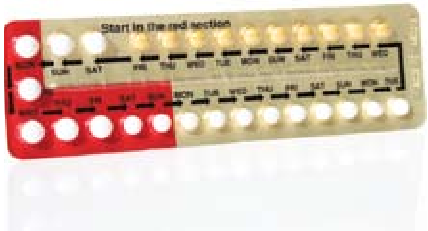


Figure 3.47 *A tiny pill containing a mixture of female hormones can trick the body and prevent the release of any further eggs.*

Advantages: the combined pill particularly is very effective at preventing pregnancy. The pill is taken at regular daily intervals and so does not interfere with intercourse. It may offer some protection against certain tumours.

Disadvantages: the pill may increase the risk of certain tumours. It can cause raised blood pressure and an increased tendency for the blood to clot.

Effectiveness (combined pill): 0.5 pregnancies per 100 woman years (due to human error in taking the pill).

- **Hormone injections** – in this method of contraception a woman is given an injection of hormones which prevents pregnancy for up to three months. The injections stop ovulation, cause changes in the mucus of the cervix to prevent sperm getting through and reduce the lining of the uterus so a fertilised ovum would not be able to implant.

Advantages: very effective at preventing pregnancy. Only need an injection every three months.

Disadvantages: you can't change your mind once you have had the injection – you can't get pregnant for about 3 months. There are some side effects – it can affect your periods and may give you headaches.

Effectiveness: 1 pregnancy per 100 woman years (because sometimes women don't get their injections regularly enough).

- **Hormone implants** – this method involves implanting small silicone capsules containing female hormones very like those in the contraceptive pill under the skin. They release small doses of hormone and prevent pregnancy for up to five years. If a woman wants to become pregnant the implant can be removed.

Hormone implants being implanted under the skin.

Advantages: the implant is very effective at preventing pregnancy and can last for up to five years.

Disadvantages: there can be side effects including changes to your periods, headaches and depression.

Effectiveness: 0.5–1 pregnancy per 100 woman years.

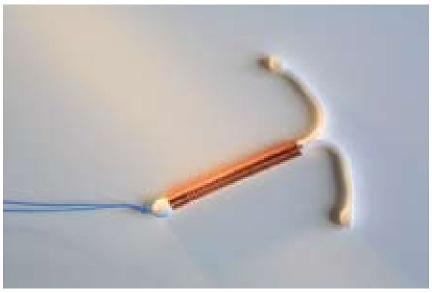
Sterilisation or surgical contraception is the ultimate form of contraception. By cutting or tying the tubes along which eggs or sperm travel conception is rendered almost impossible. This has the additional benefit of removing the human element of contraception, which is the major cause of failure in the other methods.

- **Vasectomy** – in men the sperm ducts (vas deferens) are cut, preventing sperm from getting into the semen.
- **Female sterilisation** – in women the Fallopian tubes are cut or tied to prevent the ovum reaching the uterus or the sperm reaching the ovum.

Advantages: almost 100% guaranteed to prevent pregnancy. Permanent control of fertility. Removes the problem of human error in contraception.

Disadvantages: for women in particular it involves a general anaesthetic. Not easily reversible.

Effectiveness: 0.05 pregnancies per 100 woman years.



An IUD

The IUD or **intrauterine device** does not prevent conception – the ovum and the sperm may meet – but it interferes with and prevents the implantation of the early embryo. An IUD is a device made of plastic and a metal, frequently copper, which is inserted into the uterus by a doctor and remains there all the time.

Advantages: once inserted, no further steps need to be taken. Relatively effective at preventing implantation and pregnancy.

Disadvantages: can cause pain and heavy periods. Can cause uterine infections which may lead to infertility. If pregnancy does occur it has a high chance of being in the Fallopian tubes (ectopic pregnancy).

Effectiveness: 2.5 pregnancies per 100 woman years.

Effective family planning using a reliable method of contraception can have a big impact on individuals and on society. If every child is a wanted child, born when the parents feel ready both financially and emotionally to support a baby, then everyone benefits. Couples who have children when they want them can enjoy those children. Having the number of children you choose, and spacing the births to give the mother time to recover from one pregnancy before she is pregnant again, makes for healthier women, healthier children, less poverty and generally happier families. This in turn means society functions better. Less money needs to be spent supporting children who are unwanted or uncared for by their families or on dealing with the health problems which result from too many pregnancies too close together. This frees up money for other things. Regular use of condoms can also reduce all the problems which come from HIV/AIDS.

Human Immunodeficiency Virus and Acquired Immune Deficiency Syndrome (HIV/AIDS)

Acquired Immune Deficiency Syndrome (AIDS) is the medical term for a combination of illnesses that result when the immune system is weakened or destroyed. It is the advanced form of an infection caused by Human Immunodeficiency Virus (HIV), a virus that attacks the immune system, making the sufferer susceptible to other diseases.

Introduction

HIV/AIDS is a big problem in Ethiopia. Between 60 000–70 000 people die of AIDS every year, at the moment, and well over a million people are infected with the virus.

HIV attacks the your immune system so you cannot fight off infections such as TB or even a cold.

HIV, the virus that leads to AIDS, can be spread through four bodily fluids – blood, semen, vaginal secretions and breast milk. The virus can only be spread from an infected person if his or her bodily fluids enter the bloodstream of an uninfected person. It is most commonly spread through unprotected sex with an infected partner (without using a condom). In Ethiopia more people are infected through heterosexual sex than any other way.

Figure 3.48 *Practising life skills such as assertiveness, decision making and problem solving, will help young people avoid infection with HIV/AIDS.*

An HIV-infected mother can infect her baby during pregnancy, at birth or through breastfeeding. HIV can also be passed on by an infected blood transfusion or by sharing non-sterilised needles, syringes or razors. It is a particular problem with drug addicts who share needles.

An individual can become infected from only one exposure. You only need to take a risk once – but once you are infected with HIV you can infect others. How would you know if you have HIV/AIDS – what are the symptoms?

Symptoms of HIV/AIDS

The symptoms of HIV/AIDS are different at different stages of the disease. After about three months some people start to feel unwell – early symptoms include fevers, headaches, tiredness, and swollen glands, but not everyone infected with HIV feels ill. These symptoms are very mild and easily mistaken for an ordinary infection. But after about three months, HIV antibodies appear in your blood – you become HIV-positive

As the immune system weakens, an infected person may develop more symptoms (relatively mild at first), including swollen lymph glands, night sweats, fever, cough, diarrhoea, and/or weight loss. As the disease progresses the symptoms become more noticeable and more severe.

Figure 3.49 *Because there is no cure yet, everyone who becomes HIV-positive will eventually die of AIDS. However, with a healthy lifestyle and with modern retroviral medicines, some people are living for longer before the disease reaches its final stages.*

The symptoms of the final stages of AIDS include:

- extreme fatigue
- rapid weight loss
- appearance of swollen or tender glands in the neck, armpits or groin
- unexplained shortness of breath, frequently accompanied by a dry cough
- infections such as TB and pneumonia
- persistent diarrhoea
- intermittent high fever
- appearance of one or more purple spots on the surface of the skin, inside the mouth, anus or nasal passages caused by a rare cancer, Karposi's sarcoma
- whitish coating on the tongue, throat or vagina as fungal infections take hold
- forgetfulness, confusion and other signs of mental confusion

The incubation period

The first symptoms appear 3–12 weeks after you have become infected. This is the initial incubation period of the virus. Before this you can't even detect the infection with a test because your body has not produced enough antibodies. People who think they may have been infected and receive a negative test result should do a second test three months later to be absolutely sure of their HIV status. During the waiting period they should either not have sex or use a condom properly at all times. **People who look healthy can infect you with HIV/AIDS**.

After the first mild symptoms the disease incubates again. In Ethiopia many people will progress from HIV infection to full-blown AIDS in 2–3 years, because they are already suffering from other diseases or just from a shortage of food. During this time the virus reproduces rapidly, infecting the cells of the immune system and destroying them. However, in very healthy, well-fed people with the best medicines available the incubation period is much longer. It can take 20 years or more before all the symptoms of the disease appear.

Treatment

There is no cure for HIV/AIDS, and there is as yet no effective vaccine either. Antiretroviral medications are used to control the reproduction of the virus and slow the progression of HIV-related disease. Some of the early symptoms of HIV can be treated – the secondary infections can be treated with antibiotics, the fungal infections with antifungal drugs and any anaemia with iron and transfusions.

Some of the factors that affect how quickly HIV infection can develop into AIDS can be controlled by the infected person. A healthy lifestyle, with a good balanced diet, regular exercise, no smoking or illegal drug use, and drinking alcohol in moderation if at all can help you to stay well for longer. By carefully managing your lifestyle and so keeping your immune system healthy you can help your body cope with the effects of the virus for as long as possible.

Anti-HIV medications do not cure HIV infection and individuals taking these medications can still transmit HIV to others. They can, however, lengthen the period of healthy, active life available to an infected individual. The earlier they are started, the more effective they are at lengthening the lifespan of an HIV-positive individual.

Figure 3.50 *Posters like this are used to help educate people about the risk of HIV/AIDS.*

Life skills for responsible sexual behaviour

The most effective ways of reducing or halting the spread of HIV/AIDS involve changing the way people – and young people in particular – behave.

It is vitally important to be aware of the risk of HIV/AIDS in any sexual relationship.

Using condoms is very effective at reducing the risk of the infection spreading – although it is not risk free as condoms can break. Ideally everyone would have an HIV test at the onset of establishing a new relationship.

Abstinence from extra-marital sex and being faithful within marriage or a relationship is by far the safest option. The more partners you have, and the more times you have unprotected sex, the more you put yourself at risk. If people avoid the use of substances, such as alcohol, which can affect their judgement and make you more likely to take part in risky behaviour, fewer mistakes will be made.

There are other ways in which you can protect yourself. You should never use drugs that are non-medicinal, especially those that require needles. Sharing needles between drug users is very dangerous, so setting up needle exchanges where intravenous drug users can get clean, sterile needles on a regular basis is another way of preventing the spread of HIV/AIDS.

It is important to practice precautions when handling blood and the body fluids as well as body refuse. This has important implications for hospitals and doctors. What's more, blood for transfusions needs to be thoroughly screened for HIV antibodies – a precaution already taken in Ethiopia.

Pregnant women need to be screened, and if found to be at risk, given drugs to reduce the risk of infecting their unborn child. Caesarean deliveries are advised, and HIV-positive mothers should bottle feed their babies if at all possible as the virus can pass through to the baby in the breast milk. Without this intervention, 25–30% of all babies born to HIV-positive mothers will be infected with the

Activity 3.16: Don't pass it on

Anyone who might be infected with HIV/AIDS must act carefully to prevent the virus from spreading. Make a list of behaviours which should be followed to prevent the spread of HIV/AIDS by people who may be incubating the virus. The title of your list is:

You may have HIV – Don't pass it on!

Activity 3.17: Family support

Discuss the problems for a family affected by HIV/AIDS, and how your school community can help affected families and change attitudes in the community.

Activity 3.18: Role play

Sometimes it can be difficult to behave sensibly, but young people must be careful when they have sexual relations. They need to be assertive and sensible. Plan and act out one of these role plays:

a) A young girl and her boyfriend
The boy wants them to have sex. The girl wants to abstain.

b) A nurse/village elder has a discussion with some young pregnant women on how they can reduce the risk of their baby contracting HIV/AIDS

virus. At the moment only about 1% of pregnant women who are HIV-positive in Ethiopia are given the antiretroviral drugs needed to protect their unborn child.

Most of all, people around the world need to be educated about the risks of HIV/AIDS, how it is passed on and how to avoid it.

It is very important that you, our young people, develop the personal skills which will help you reduce the risk that HIV/AIDS poses both to you as individuals and to our society. It is important to be assertive. Girls and young women must be able to insist that their sexual partners use a condom for sex. Boys and young men must learn to respect their partners and to take responsibility for their own sexual health and that of others by using condoms. Young people need to make decisions about their own behaviour and that of their local community about how to care for and support people who are already living with HIV/AIDS, and how to reduce the risk of this terrible disease for future generations.

Female genital mutilation and reproductive health

In Ethiopia, we are leading the way in recognising that some of our traditional practices, carried out with the best of intentions, can in fact cause great damage and are part of the reason for our high rates of HIV/AIDS infections. One of these harmful traditional practices is female genital mutilation (FGM) also known as female genital excision (FGE) or more locally as 'removing the dirt'.

Female genital mutilation is a process which is carried out across Ethiopia. There are various forms of FMG. All of them involve removing part of the external genitalia of young girls in surgery which is carried out without any anaesthetic, using blades or sharpened obsidian. In some forms of the process almost all of the external genitalia are removed, and the whole region is sewn together leaving a single small opening for the passage of urine and menstrual blood. Sometimes FGM is carried out on babies, but more often it is performed when girls are aged from six up until just before marriage. Traditionally people believed that FGM keeps girls pure and is necessary for them to be accepted by men in marriage.

Women were traditionally completely dependent on men, and so anything which helped them to marry successfully was done.

In some regions of our country almost every girl will undergo FGM. In other areas, numbers are lower. For example, about 54% of girls in SNNPR experience FGM, with 92% in Amhara and up to 100% in Somali.

In Ethiopia, with great wisdom and understanding, many people have begun to understand that this traditional practice causes harm rather than good. Bogaletch Gebre is a shining example of this. Not only was she the first Ethiopian woman to join the science faculty at the University of Addis Ababa, she has also established the Kembatta Women's Self-Help Centre, Kembatti Mentii Gezzima-Tope (KMG). This organisation aims to help women and men throughout Ethiopia understand the best way forward for a strong and healthy population in our country.

Figure 3.51 *Bogaletch Gebre is internationally recognised for the work she has inspired in Ethiopia in supporting the right of women to be freed from harmful traditional practices such as FGM.*

Our government has set up a national committee known as the Eradication of Harmful Traditional Practices (EHTP). This committee is working with leaders of Islam, Christianity and other religions and with many other organisations to help everyone in our country change their minds and make different choices. People often do not understand all of the problems which can result from cutting a young girl in this way.

Unfortunately FGM, rather than protecting our girls, puts them at great risk in many different ways.

- The process of FGM when a girl is cut can result in serious bleeding and infections which can kill. In Ethiopia today, with our high rates of HIV/AIDS, it can put our girls at risk of HIV infection too. The traditional practitioners who carry out the process may carry out 20 FGMs a day. If one of those girls was infected as a baby, her blood could infect all of the other girls cut that day.
- When the genital region is sewn closed, girls are at constant risk of infection. This can make them infertile (unable to have children). It can also affect their kidneys and kill them.
- Because the process of FGM leaves much scarring, this means that sexual intercourse is often very painful for women. This does not help them to feel close and loving towards their husbands. It also means that sexual intercourse often causes bleeding on the damaged scar tissue of the genitalia. This makes it very easy for them to become infected with HIV/AIDS if their partner carries the disease. FGM is one of the reasons why HIV/AIDS levels are so high in Ethiopia. It is also part of the reason why our women – and so, very often, our children – are so badly affected by this killer disease.
- The terrible scarring and narrow vaginal opening often left by FGM means that cut women often have big problems giving birth. The stitching and scarring can tear open, so the woman loses a great deal of blood. Sometimes the baby cannot be delivered alive, and in many cases the woman may die.

Figure 3.52 *A sign warning about the dangers of FGM.*

EHTP and others are helping people across the country to understand just how damaging FGM can be and that the alternatives are very positive for the country as a whole. When girls are not cut they remain healthier. They are less likely to become infected with HIV/AIDS which also means they are more likely to have healthy children. They are more able to have a full and happy relationship with their husbands. Because they are healthier, they can work harder and bring more prosperity to the family. And they are much less likely to die in childbirth or to lose their baby. Of course women want to be married, but as more and more girls become educated they can be equal partners with their husband and they do not need to be cut to be married.

To help people around the country understand the choices that can be made there are films of a young girl being cut. Many men realise for the first time what a terrible thing is done to their daughters and wives. They recognise how damaging FGM really is.

Organisations such as the EHTP show people how positive marriage can be when girls remain uncut, and how much healthier those girls remain.

The Government wants to make full use of the women of Ethiopia to help our country grow. To do that it needs them to be healthy and whole and so FGM is against the law. Our Government recognises that people need to feel good about their decisions and is working hard to help people see the advantages of leaving girls uncut. Education for both boys and girls is very important in this.

Religious leaders have made it clear that FGM is against the principles of both Islam and Christianity and is not part of the Koran or the Bible. They too are working to make their communities healthier for everyone and protect the girls under their care from this harmful practice.

The traditional practitioners who carry out the cutting are very influential in the community. The money they earn for cutting girls increases their income and it gives them high status. However, more and more traditional practitioners are giving up cutting girls. They are using their knowledge and status in the local communities to explain to parents why it is better to leave their daughters uncut. They are becoming very valuable advisers on the prevention and treatment of HIV/AIDS. They are paid for this work and become more important in the community than ever before. They will play a big part in maintaining the future health of Ethiopia.

Activity 3.19: Campaign against FGM

Work in groups and plan a campaign to help people in your area understand the dangers of the traditional practice of female genital mutilation and the benefits of keeping girls uncut.

Think about why people do this to their children, and make sure you make the benefits very clear.

Design a poster or a leaflet which could be used in your local community to help people understand the problem and the solution.

Around the world many people admire the way that the Government and people of Ethiopia have recognised that modern knowledge and the arrival of HIV/AIDS means that some long-held traditional practices are now very harmful. The way our country is changing its traditions to keep our women healthy and reduce the spread of HIV/AIDS is an example to many other countries in Africa and beyond.

Ethiopia is not alone in trying to tackle this harmful traditional practice. In December 2009, female genital mutilation was made illegal in Uganda, punishable by 15 years in jail.

Summary

In this section you have learnt that:

- There are a number of different birth control methods which can be used to control the size and the spacing of a family. They include natural methods, physical or barrier methods such as condoms, chemical methods such as the contraceptive pill or implants and surgical methods such as sterilisation.
- HIV is the virus that causes AIDS. It is spread through blood, semen, vaginal secretions and breast milk. The most common way in which it is transmitted is by unprotected sex. Patients often do not have any symptoms to begin with but deteriorate and eventually show many signs and symptoms of a weakened immune system.
- Treatment options include use of antiretroviral drugs, healthy lifestyle practices and strong support systems.
- Female genital mutilation is a traditional practice which people are now realising causes much harm. It increases the spread of HIV/AIDS and means many girls and women suffer and die in childbirth unnecessarily.

Review questions

1. In which part of the female reproductive system does fertilisation of the ovum take place?
   A uterus
   B cervix
   C fallopian tube
   D vagina
2. How long is the average human pregnancy?
   A 30 weeks
   B 35 weeks
   C 40 weeks
   D 45 weeks
3. Which of the following is NOT a way to help prevent the spread of HIV/AIDS?
   A washing your hands after using the toilet.
   B using a condom when you have sex.
   C having only one sexual partner.
   D not sharing needles for intravenous drug use.

3.5 Homeostasis

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

- Define homeostasis as maintenance of a constant internal environment and explain its significance.
- Define poikilotherms as organisms whose temperature is governed by the external temperature.
- Define homoiotherms (homeotherms) as organisms with constant body temperatures.
- Explain the physiological methods of temperature regulation in homoiotherms.
- Explain the behavioural methods of temperature regulation in homoiotherms and poikilotherms.
- Label the structures of the kidney.
- State the functions of the structures of the kidney.
- Explain how the kidney regulates water and ionic balance.
- Explain how the skin helps in water and salt balance.
- Explain the role of the liver in regulation of the body.

KEY WORDS

homeostasis *the body's ability to maintain normal function and stability*

homoios *like, or the same*

stasis *state*

Just stop and think for a moment about the different conditions in which people live around the world. From the warmth of Africa to the cold of the Arctic tundra, from the arid dryness of the Sahara desert to the risk of flooding in the Nile delta – there are few areas of the planet where people have not settled, survived and thrived. What is more, think about the different conditions your own body finds itself in during a single day. You may eat lots of food, or you may eat very little, you may spend time training for sport in the sun, or swim in the river, or sit in the shade. You may be ill and have a fever. You may even take a flight to a country with a very different climate from your own land. But, however much your external environment may change, things inside your body need to stay the same.

DID YOU KNOW?

The word **homeostasis** comes from the Greek words **homoios**, which means 'like' or 'the same', and **stasis**, which means 'state'. So the word tells you exactly what it means – keeping the conditions in the inside of your body (the internal environment) in the same state all the time.

Figure 3.53 *The beautiful countryside of Ethiopia and our thriving cities bring pleasure to local people and tourists alike – and everyone maintains a constant internal environment, regardless of the external conditions they are familiar with.*

Figure 3.54 *In warm sunny weather like this, or cold snowy weather, and whatever clothes we wear, homeostasis makes sure conditions inside our bodies stay the same.*

Here are some of the main threats to a stable state inside your body.

- You eat several times a day, so sometimes products of digestion are flooding into your blood and at other times little or no food is available from the gut, yet your cells need a constant supply of glucose for respiration.
- When you respire, you produce a poisonous waste product – carbon dioxide. If levels build up in your body they change the pH of your tissues. This in turn could denature your enzymes and so stop your cell chemistry completely.
- As you break down the products of digestion, poisonous wastes are produced, such as the urea which comes from the breakdown of amino acids in your liver. A build-up of urea could poison and kill you.
- Whenever you exercise you produce heat from your muscles. This can increase your core body temperature, as can spending too much time in the sun or having a fever. If your body temperature gets too high, your enzymes will denature and so all your cell chemistry will come to a halt and you may die.
- If you lose too much heat from your body because the external conditions are very cold, or you lose a lot of body heat, the cellular reactions slow down and you may die.
- The amounts of water and salt you take in vary greatly throughout the day and from day to day, and so does the amount of water and salt you lose through sweat and urine – yet the water balance inside your body needs to stay the same to keep the cells in osmotic balance.

As you can see, keeping your internal conditions in a stable state isn't easy – yet this is what your body manages to do 24 hours a day, every day of your life. The nervous and hormonal systems which you discovered in sections 3.1, 3.2 and 3.3 play an enormous role in maintaining this important balance. Feedback mechanisms involving both the nervous system and hormonal systems play a very important part in maintaining homeostasis. Most of these control systems in the body are examples of negative feedback. This means that when levels of a substance in your body rise, changes are made which *lower* the levels again. Similarly, when levels of a substance fall, changes are made so that it *rises* again to the original levels. Look out for these feedback mechanisms as you learn about homeostasis.

Controlling temperature

One of the most important factors which animals need to control is the internal or core body temperature.

Heat is a form of energy which is produced in a number of ways including by the sun and by artificial heating systems. It is also generated by the chemical reactions which take place in your own body. Temperature is a way of measuring hotness or coldness (the effect of heat energy) on a relative scale.

It is vitally important that wherever we go and whatever we do our body temperature is maintained at the temperature (around 37 °C) at which our enzymes work best. It is not the temperature at the surface of an organism which matters – the skin temperature can vary enormously without causing harm. It is the temperature deep inside the body, known as the internal or core body temperature, which must be kept stable. We can get a good measure of our human core body temperature by taking the temperature in the mouth, in the anus or on the surface of the eardrum.

Living organisms are continually gaining heat from cellular respiration and by conduction, convection and radiation from their surroundings. They are also constantly losing heat by the evaporation of water from the body surfaces and by conduction, convection and radiation to their surroundings. It is the balance of these gains and losses that gives the core temperature. Organisms use a number of different ways to shift the balance and allow themselves to gain or lose heat as they need to.

Not all animals need to control their core body temperatures. Protista and small animals living in big bodies of water like the sea have no means of temperature regulation because they do not need them.

Larger animals living in many different habitats must be able to regulate their body temperatures so they can avoid cell damage from overheating, but also gain enough heat to have an active way of life. There are two types of animals:

Poikilotherms – organisms whose body temperature is governed by the external temperature. They rely largely on the environment for their body heat. Their body temperature can vary over a wide range, for example, fish and reptiles.

Homoiotherms – organisms with a relatively constant internal body temperature which is usually higher than the external temperature, for example, birds and mammals.

Humans are a well-known example of homoiotherms.

Figure 3.55 *People can live in conditions of extreme heat and extreme cold and still maintain a constant internal body temperature.*

KEY WORDS

poikilotherms *animals whose internal temperature varies along with that of the ambient environmental temperature*

homoiotherms *animals whose internal temperature is relatively constant and independent of the environmental temperature*

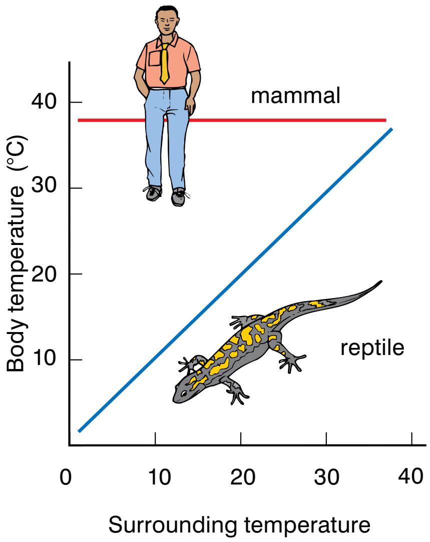


Figure 3.56 *The difference between homoiotherms like us and poikilotherms like this lizard can be seen very clearly when you look at the comparison between the internal and external temperatures of both organisms if they are not allowed to move or use behaviour to control their temperature.*

> DID YOU KNOW?
>
> A liquid evaporating to become a gas is a physical state change which needs energy to take place – **the latent heat of vaporisation**. So when your sweat evaporates, the energy required is supplied by the heat of your body. As your body loses heat, it cools down.

KEY WORDS

dilate *to become wider or larger; expand*

Temperature control in poikilotherms

Poikilothermic animals have to rely on changes to their behaviour and their body structures to use the heat in their environment to maintain a reasonably steady and useful body temperature.

When they are cold they may:

- bask in the sun
- press their bodies close to a warm surface
- erect special sails or areas of skin which will allow them to absorb more heat from the sun

When they are getting too hot they may:

- move into the shade
- move into water or mud

Temperature control in homoiotherms

Human beings are good examples of homoiotherms. Our body temperature is controlled by a number of physiological mechanisms which work together to allow us to gain or lose heat as we need to.

Physiological methods of temperature regulation in homoiotherms

- **Sweating** – when you are hot sweat oozes out of the sweat glands and spreads over the surface of the skin. Sweat is made up mainly of water and salt but also contains a small amount of nitrogenous waste. As the water evaporates it cools the skin, taking heat from the body. Because water and salt are lost in the sweat, when you sweat a lot this can affect your water and ion balance so you need to take more water and ions in through drink or food to replace the water and ions which are lost. It is important to remember that sweat itself is not cool, and it can only cool you down if it evaporates. In hot, humid conditions you may sweat a lot – but it won't cool you down because the water can't evaporate! In cold weather, little or no sweat is formed so that as little heat as possible is lost by evaporation.
- **Vasodilation** – if the body temperature starts to go up, the blood vessels supplying the capillaries in your skin **dilate**, so that more blood flows through the capillaries. Your skin flushes and more heat is lost through radiation from the surface. This is known as vasodilation and it is particularly obvious in pale-skinned people. Less blood flows through the slightly deeper vessels in your skin as a result.
- **Panting and licking** – many mammals have thick, furry coats and so cannot evaporate sweat easily from the skin surface even when they are getting hot. Some animals, such as dogs and cats, only have sweat glands in small areas of the skin such as the feet. So to increase the amount of heat lost through evaporation, these animals may lick themselves, coating parts of their bodies with

saliva which evaporates and cools them down. They also pant, which allows water to evaporate from the moist surfaces of the mouth and this also cools them down.

- **Vasoconstriction** – if your core temperature begins to fall the blood vessels which supply your skin capillaries **constrict** (close up) to reduce the flow of blood through the capillaries. This reduces the heat lost through the surface of the skin, and makes you look paler. This is known as **vasoconstriction** and it works to keep you as warm as possible. More blood flows through the deeper blood vessels of your skin as a result.
- **Piloerection** (**pulling the hairs upright**) – human beings, like other mammals, have a layer of hair over their bodies. Our hair is very light compared to a dog or a cat, for example, but our bodies still react as if we are furry. The hair erector muscles contract. In furry animals this pulls the hairs upright, trapping an insulating layer of air which is very effective at conserving heat. Our hairs are also pulled upright, but we have so little body hair that it has little or no effect on heat conservation. The most obvious effect is that we get goosebumps on our skin – each bump is the contracted muscle pulling on a hair. When the core temperature starts to climb, the hair erector muscles which move our body hair all relax and our hair lies very flat against our skin. Again in humans this has very little effect, but in hairy animals this reflex action is important because it reduces the layer of insulating air trapped in the fur and so makes it easier to lose heat by convection.
- **Shivering and metabolic responses** – if your core body temperature drops your metabolic rate speeds up, producing more heat energy so your body temperature starts to go up. Your liver in particular is involved in this because it is a very large organ which carries out many different metabolic reactions. As part of this response you may start to shiver. When you shiver your muscles contract rapidly, which involves lots of cellular respiration. This releases some energy as heat which is used to raise the body temperature. As you warm up, shivering stops. But if your core body temperature starts to rise, the metabolic rate drops so less heat is produced.
- **Fat layer under the skin** (**subcutaneous fat**) – it is important that homoiotherms only lose or gain heat when they really need to. So under the surface of the skin is an insulating layer of fat. This prevents unwanted heat loss. It is particularly noticeable in animals which live in very cold conditions, for example, seals and whales. The very thick layer of fat under their skin is known as blubber.

Homoiotherms do not only rely on physiological methods to control their internal body temperature. Like poikilotherms, they use **behavioural methods of temperature control**. Some of these methods are similar to those used by poikilotherms, some are only seen in homoiotherms and some are unique to human beings.

Figure 3.57 *Panting is another physiological way to lose heat by evaporation.*

KEY WORDS

constrict *squeeze, or press together*

vasoconstriction *constriction of a blood vessel*

Behavioural methods of temperature regulation

- **Clothing** – people choose suitable clothes for the weather as we do not have fur or feathers to keep us warm. We wear warm clothes when the weather is cold and fewer, cooler clothes when the external temperature is hot.
- **Seeking shade or shelter** – like many other animals, people look for shade to keep them cool when it is hot and sunny, and look for shelter from cold, wet or windy conditions to help prevent excess heat loss and keep themselves warm, for example, native male rats live underground in burrows all the time in arid deserts.
- **Taking high-calorie food** in cold conditions. We need to use more metabolic energy to keep warm so we eat high-calorie food in cold conditions. Birds and other mammals do the same.
- **Hibernation** – in countries which have very cold winters, some homoiothermic animals will hibernate. They cannot eat enough to keep their body temperature stable through the cold winter, so they sleep through the bad conditions. These animals eat a lot and gain a lot of fat before hiding away in a warm nest or burrow and going into a very deep sleep. Their metabolic rate falls and so does their body temperature. They do not wake up until the warmer weather of spring arrives with more food for them to eat, for example, dormice and hedgehogs in the UK.

Figure 3.58 *In countries such as the UK small animals like this hedgehog cannot cope with the cold winters so they hibernate through them.*

- **Aestivation** – in hot countries, some animals 'hibernate' through the hottest weather as they cannot keep their bodies cool enough. These animals usually hide themselves underground or under a layer of mud and go into a deep sleep until conditions cool down again, for example, East African land snails can aestivate for up to three years in times of extreme drought.
- **Wallowing or bathing** – some animals cannot lose enough heat through sweating alone to keep their bodies cool enough in hot weather. This is a particular problem for some larger animals. By wallowing in mud or bathing in water, the animals cover themselves in water and the water evaporates from the surface of their skin, cooling them down, for example, elephants and pigs.
- **Burning fires, central heating, air conditioning, etc**. – people can change the temperature of their environment. By burning a fire or turning on the heating we can warm things up and reduce the heat we lose, keeping us warmer. Air conditioning is used in some buildings and vehicles to cool the air down if it gets too hot, so the people inside can lose more heat and keep themselves cool.

Controlling the core body temperature

At only a few degrees above or below normal body temperature our enzymes cannot function properly. If this goes on for any length of time the reactions in our cells cannot continue and we die. As you have seen, all sorts of things can affect your internal body temperature, including heat generated in your muscles during exercise, fevers caused by disease and the external temperature rising or falling.

Human beings have an internal control mechanism, a system of homeostasis which enables us to lose excess heat if our core temperature starts to rise, yet generate and conserve heat when our core temperature starts to fall. How does this temperature control mechanism work? Control of the temperature relies on the thermoregulatory centre in the brain. This centre contains receptors which are sensitive to the temperature of the blood flowing through the brain itself. Extra information comes from the temperature receptors in the skin, which send impulses to the thermoregulatory centre giving information about the skin temperature. These receptors are so sensitive they can detect a difference of as little as 0.5 °C. When the **thermoregulatory centre** detects changes in temperature, our first responses are conscious – we put more clothes on, or take clothes off, move outside or light a fire. But if the core temperature starts to move in one direction or the other, automatic body responses take over. The control of the body temperature is an example of a negative feedback loop. The feedback control of the body temperature involves the thermoregulatory centre in the brain and the skin.

KEY WORDS

thermoregulatory *centre area of the brain responsible for controlling body temperature*

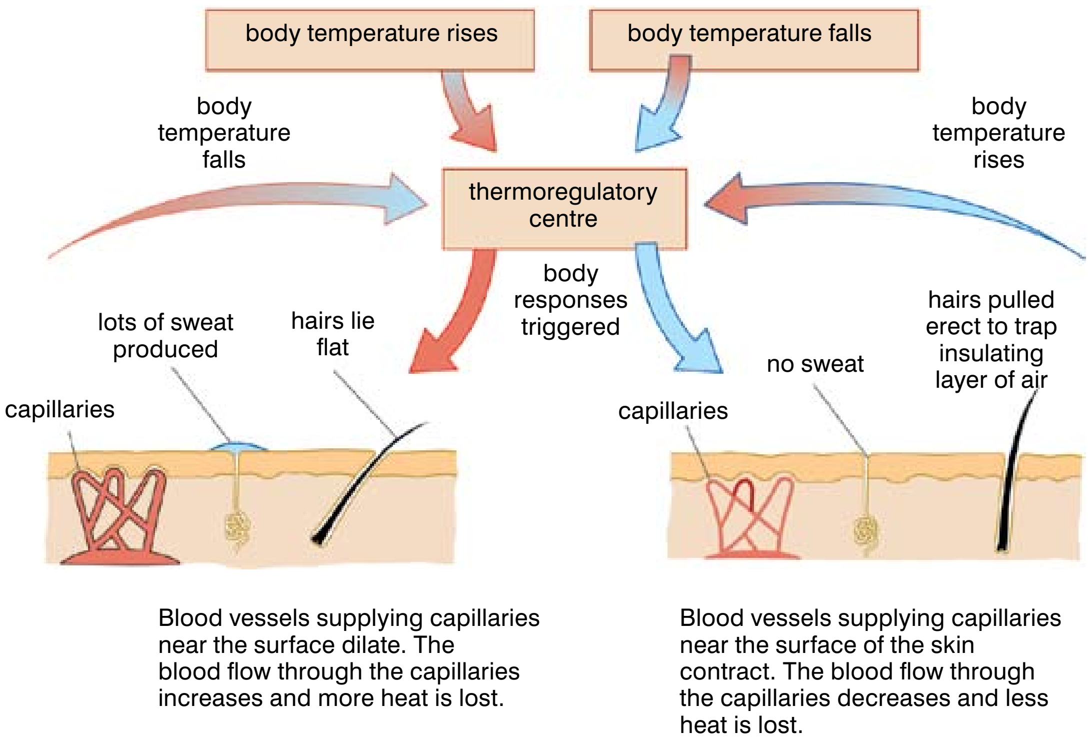


Figure 3.59 *The thermoregulatory centre in the hypothalamus of your brain acts as your body thermostat. As a result of all these sensitive control mechanisms, the core temperature of your body is usually kept the same with only about 1 °C variation.*

When things go wrong

The homeostatic mechanisms of temperature control in your body usually work very effectively. However, if conditions become too extreme and things go wrong with your temperature control mechanism, the need for this homeostasis quickly becomes very clear indeed.

For example, when the weather becomes extremely hot and humid, and when people undertake exceptionally challenging physical activity like running a marathon, the normal homeostatic mechanisms may not cope. For example, eventually there is not enough spare water in the body to produce sweat. The salt and water balance is destroyed and then the core temperature will rise to dangerous levels. Once this happens people may die.

On the other hand, if your core body temperature falls too low you suffer from hypothermia. In Ethiopia hypothermia can be seen sometimes in new-born infants if they are small and have little body fat, or if they are not dried and wrapped up warm to be cuddled by their mother as soon as possible after birth. In cooler climates such as the UK this silent killer claims around 30 000 lives every year.

People with hypothermia have greyish-blue, puffy faces and blue lips. Their skin feels very cold to the touch, and they will be drowsy with slurred speech. As it gets worse, they will stop shivering. If the body temperature falls too low the sufferer will become unconscious and may die.

Activity 3.20: Investigating factors which affect heat loss

Different factors affect how quickly a person loses heat – surface area to volume ratio, insulation, whether they are wet, etc. You can mimic these situations in a number of ways using beakers or conical flasks, and use this to investigate factors which affect heat loss. You can use all of the different suggestions in the equipment list in one large investigation, or different groups can investigate different factors and then the whole class share and compare results.

You will need:

- a 250 cm^3 beaker or conical flask (your control)
- a 100 cm^3 beaker or conical flask
- a 250 cm^3 beaker or conical flask wrapped in cotton wool or fabric
- a 250 cm^3 beaker or conical flask wrapped in wet cotton wool or fabric
- for each container you use, a cardboard lid with a thermometer poking though it. If you have cotton wool or wet cotton wool around your container, cover the lid with it as well
- hot water – 60–70 °C is hot enough – be very careful how you handle it
- a stopwatch or clock with minute hand

Method

1. Arrange your containers – work with a control and at least one other container each time.
2. Add the same volume of hot water – e.g. 75 cm^3 – to each container and gently place the lids on. Make sure the bulb of the thermometer is in the water.
3. Take and record the temperature in each container.
4. Repeat the temperature readings at 1-minute intervals for 20 minutes.
5. If you have time, repeat the experiment using the same control but a different combination of containers – or vary the conditions, placing all the containers in a draught or outside in the sun, for example.
6. Record your results on a graph, plotting temperature against time. Use the same axes for all your results – use different colours or clear labels to identify the different containers. This allows you to compare your results very easily.
7. Write up your experiment and explain the results you have obtained. Which container loses heat fastest? Which retains the most heat? How does this relate to temperature control in humans? Do you think these containers are good models? How could you improve or extend this investigation?

Your surface-area-to-volume ratio is an important factor here. Smaller people – such as children – have a much bigger surface area to volume ratio than larger people. You lose heat through the surface of your body – so small people lose heat relatively faster than larger people. As a result babies, children and small adults are more at risk of becoming too cold than larger people. Big people, on the other hand, have a greater risk of overheating as their relatively small surface area to volume ratio means they cannot lose large amounts of heat effectively.

Review questions

1. Explain the feedback system which is used to control your body temperature within narrow limits.
2. Why is it so important to control your body temperature?

Homeostasis and the kidney

Excretion – getting rid of the waste products which could build up in your body and damage your cells – is one of the most important aspects of homeostasis. There are two main metabolic waste products which would cause major problems in your body if the levels rise – carbon dioxide and urea. Your body deals with them both very differently. Metabolic wastes are materials which are produced by the metabolic processes of life. The organs which are involved in getting rid of these metabolic wastes are known as **excretory organs**. The main excretory organs in your body are your lungs, your kidneys and your skin.

The carbon dioxide produced during cellular respiration is almost all removed from the body via the lungs when you breathe out. So the lungs are not only the site of gas exchange for respiration, they are also an excretory organ removing carbon dioxide waste very effectively from your body. If the levels of carbon dioxide increase as you exercise, the level is picked up by sensory receptors in your arteries and brain, which send electrical impulses to stimulate the breathing centres in your brain. In turn, these send impulses to make you breathe faster and deeper. As a result, the carbon dioxide levels fall. This is picked up by the same receptors and so the stimulation of the breathing centres is reduced, and in turn the breathing rate falls. This is an example of a feedback mechanism – as the carbon dioxide levels go up, the breathing rate goes up which makes the carbon dioxide levels fall, so the breathing rate returns to normal as well.

Another metabolic waste which can cause serious problems is urea. Urea is produced in your liver when excess amino acids are broken down. These excess amino acids come from protein in the food you have eaten and from the breakdown of worn-out body tissue. If you eat too much carbohydrate or fat, you can store it (as glycogen or fat) until you need it. However, your body cannot store excess protein or amino acids, so any excess is always broken

KEY WORDS

excretion *the bodily process of discharging waste matter*

excretory organs *organs involved in excretion*

Activity 3.21: Surface area: volume ration

Sort this list of animals in order of their surface area: volume ratio. Put the ones with the biggest surface area: volume ratio first, and the ones with the smallest ratio last.

elephant	dik dik
mouse	rat
gelada baboon	camel
ethiopian wolf	giraffe

KEY WORDS

nitrogenous waste *nitrogen-rich chemical waste of several cellular processes, excreted via urine*

osmoregulation *control of the water and electrolyte balance in the body*

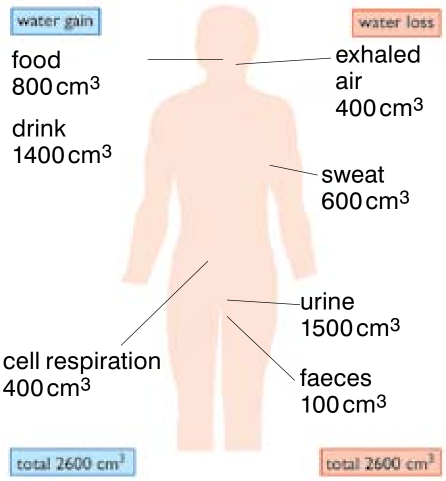


Figure 3.60 *The daily water balance of an adult*

DID YOU KNOW?

Your kidneys are vital – if they fail you will die unless you can use a special 'artificial kidney' known as a **dialysis machine**. Patients have to be connected to the machine several times a week, for several hours each time to clean and balance the blood. They have to be very careful what they eat as well. The only other alternative is a kidney transplant.

down. The amino acids are converted into carbohydrate (which can be stored or used) and ammonia. The ammonia is then combined with carbon dioxide (getting rid of another metabolic waste) to make urea. The urea which is produced is a form of **nitrogenous waste** and it leaves your liver via the blood. The urea is then filtered out of the blood by the kidneys and removed in the urine. Your kidneys are one of your main excretory organs, and also one of your main organs of homeostasis. They play a vital role in the removal of urea from the body, but their role in homeostasis is even more important, because they also play a major part in regulating the water and salt balance of your body.

Controlling the internal concentration

If the concentration of the body fluids changes, water will move into or out of the cells by osmosis and they could be damaged or destroyed. Yet some days you may drink several litres of liquid and other days much less. How is the balance maintained?

We gain water when we drink and eat. We lose water constantly from the lungs when we breathe out – water evaporates into the air in the lungs and is breathed out. This water loss is constant. Whenever we exercise or get hot we sweat and lose more water.

The water balance is maintained by the kidneys. They remove any excess water and it leaves the body as urine. If we are short of water we produce very little urine and most water is saved for use in the body. If we have too much water then our kidneys produce lots of urine to get rid of the excess.

The ion concentration of the body – particularly ordinary salt – is also important. We take in mineral ions with our food. Some are lost via our skin when we sweat. Again the kidney is most important in keeping an ion balance. Excess mineral ions are removed by the kidneys and lost in the urine. The balance of water and salts in your body is very important because of the osmotic impact on your cells if the balance is wrong so controlling this balance is known as **osmoregulation**. Your kidneys are vitally important in two aspects of homeostasis, both in excretion and in osmoregulation. Let's take a look at how they work.

Review questions

1. What is meant by the term 'internal environment'?
2. What is homeostasis?
3. What is excretion and why is it so important?

The kidneys

How do the kidneys remove urea and control the levels of water and ions in your body? Blood flows into the kidney along the renal artery. The blood is filtered, so fluid containing water, salt, urea, glucose and many other substances is forced out into the kidney tubules. Then everything the body needs is taken back (reabsorbed), including all of the sugar and the mineral ions needed by the body. The amount of water reabsorbed depends on the needs of the body. The waste product urea and excess ions and water not needed by the body are released as urine. Each kidney has a very rich blood supply and is made up of millions of tiny microscopic tubules (nephrons) which are where all the filtering and reabsorption takes place.

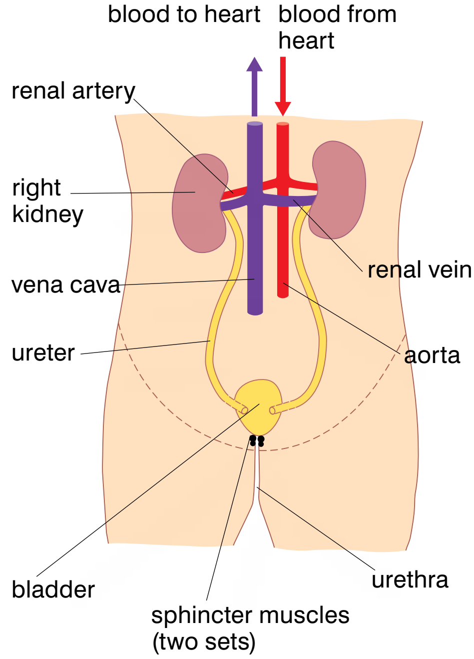


***Figure 3.61** Our kidneys are very important organs of homeostasis, involved in controlling the loss of water and mineral ions from the body as well as getting rid of urea.*

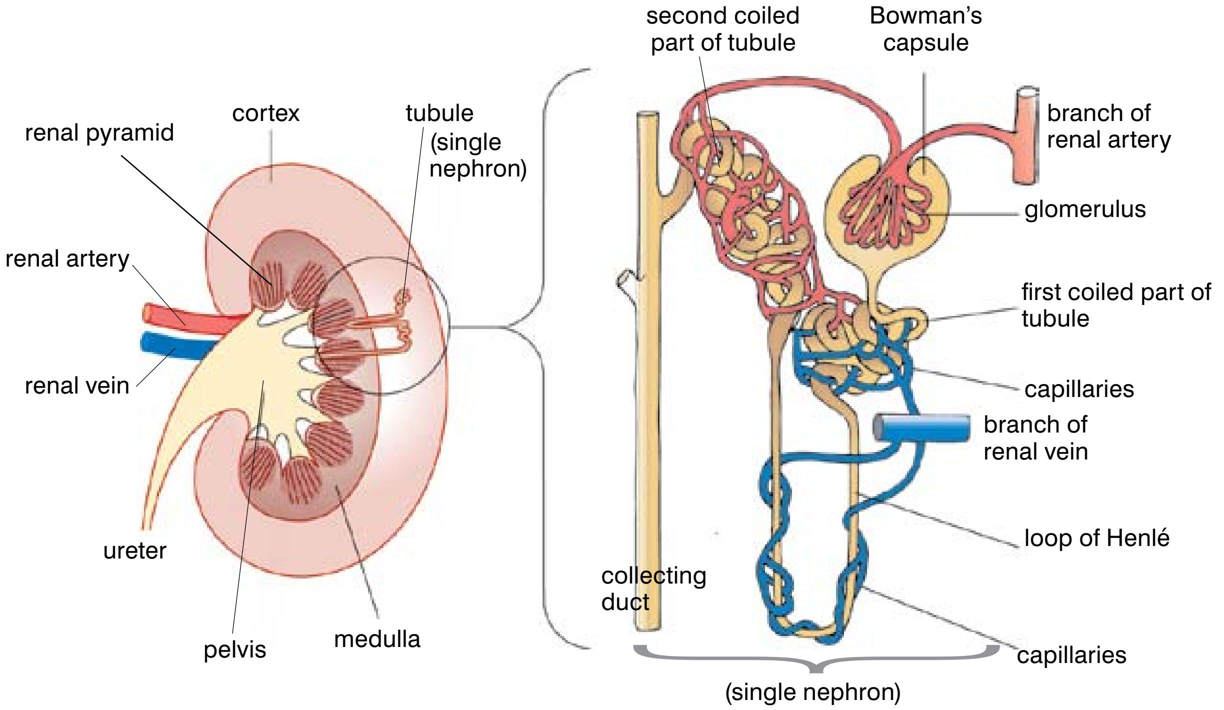


***Figure 3.62** The kidney filters the blood and removes materials which are not needed to form the urine. The kidney tubules or nephrons are the units which carry out the work.*

DID YOU KNOW?

Each nephron is 12–14 mm long, but only about 10 microns wide, and there are around 1.5 million of them in each kidney!

Activity 3.22: Investigating kidney structure

By dissecting a kidney you can see the way the different tissues are arranged. Remember to indicate the magnification of your drawing each time – if it is life size, it is × 1.

You will need:

- a kidney (lamb or pig) from the butcher, preferably with the fat surrounding the kidney in place
- dissecting instruments – a scalpel, forceps and a seeker
- dissecting board

Method

1. Observe the outer appearance of the kidney with the fat on, if possible. Draw and label what you see.
2. Carefully remove the fat, clearing the tubes leading into and away from the kidney carefully. Again draw and label what you see.
3. Slice the kidney in half longitudinally (along its length) and open it out to see the internal structure. Again draw and label the regions carefully – use figure 3.62 to help you identify them.
4. You may have the opportunity to look at prepared slides of kidney tissue under the microscope – if so, keep the drawings you make with these drawings from a fresh kidney to build up a record of the whole organ from your own observations.

KEY WORDS

Bowman's capsule *the expanded end of a kidney tubule or nephron that acts as a filter to produce urine*

ultrafiltration *the removal of excess water and other substances from the blood*

glomerular filtrate *the liquid resulting from filtration in the Bowman's capsule*

The roles of the different areas of a single kidney tubule in the production of urine are described below:

- **Bowman's capsule**: the site of the **ultrafiltration** of the blood. The blood vessel feeding into the capsule is wider than the vessel leaving the capsule, which means the blood in the capillaries is under a lot of pressure. Several layers of cells – the wall of the blood capillaries and the wall of the capsule – act as a filter and the blood cells and the large blood proteins cannot leave the blood vessels as they are too big to fit through the gaps. However, water, salt, glucose, urea and many other substances are forced out into the start of the tubule – in fact the concentration of substances in the liquid in the capsule is the same as that in the blood itself. This process is known as ultrafiltration – filtration on a very small scale.
- **Glomerulus**: the knot of blood vessels in the Bowman's capsule where the pressure builds up so that ultrafiltration occurs. The volume of blood leaving the glomerulus is about 15% less than the blood coming in – which is a measure of the liquid which has moved into the capsule as a result of ultrafiltration.
- **First coiled (convoluted) tubule**: the liquid which enters this first tubule is known as the **glomerular filtrate**. The first tubule is where much of the reabsorption takes place. All of the glucose is actively taken back into the blood along with around 67% of the sodium ions and around 80% of the water. It has many microvilli to increase the surface area for absorption.
- **Loop of Henlé**: where the urine is concentrated and more water is conserved.
- **Second coiled (convoluted) tubule**: where the main water balancing is done. If the body is short of water, more is

reabsorbed into the blood in this tubule under the influence of the **anti-diuretic hormone** or **ADH**. (Diuresis means passing urine, so anti-diuresis means preventing or reducing urine flow.) See below for more details of this mechanism. Also ammonium ions and some drugs (if they have been taken into the body) are secreted from the blood into this tubule to get rid of them. By the end of this second coiled tubule all of the salt which is needed by your body has been reabsorbed, leaving the excess in the filtrate along with most of the urea.

- **Collecting duct**: where the liquid (essentially urine) is collected. It contains about 1% of the original water, with no glucose at all. The level of salt in the urine will depend on the amount of salt in your diet and the water content of the urine. There is also a much higher concentration of urea in the urine than in the blood – about 60 times more, in fact. But if your body badly needs more water, more may be reabsorbed along the collecting duct – again under the influence of ADH – until the urine passes into the pyramid of the kidney and on into your bladder.

Urine is formed constantly in your kidneys, and it drips down to collect in your bladder. The bladder is a muscular sac which can hold between 600 and 800 cm^3 urine, although we usually empty it when it contains only 150–300 cm^3. We can control the opening of the bladder thanks to a strong ring of muscle known as a **sphincter** at the entrance to our **urethra**, the tube that leads from the bladder to the outside world. We can open and close this sphincter voluntarily, although it also opens as a reflex action if the bladder is too full – or if we are very frightened! When we are young, we have to learn to control our bladder sphincter voluntarily.

The amount of water lost from the kidney in the urine is controlled by a sensitive feedback mechanism involving the hormone ADH.

If the water content of the blood is too low (so the salt concentration of blood increases) special sense organs known as **osmoreceptors** in your brain detect this. They stimulate the pituitary gland in the brain to release ADH into the blood. This hormone affects the second coiled tubules of the kidneys, making them more permeable so more water is reabsorbed back into the blood. This means less water is left in the kidney tubules and so a more concentrated urine is formed. At the same time the amount of water in the blood increases and so the concentration of salts in the blood returns to normal.

If the water content of the blood is too high, the pituitary gland releases much less ADH into the blood. The kidney then reabsorbs less water back into the blood, producing a large volume of dilute urine. Water is effectively lost from the blood and concentration of salts returns to normal.

This system of osmoregulation is an example of negative feedback. As the water concentration of the blood falls, the level of ADH produced rises. Then as the water concentration of the blood rises again, the level of ADH released falls.

KEY WORDS

antidiuretic hormone (ADH) *hormone produced by the pituitary gland that reduces the production of urine in the kidneys and thereby prevents water loss*

sphincter *a ring of muscle that contracts to close an opening*

urethra *a duct through which urine is discharged*

osmoreceptors *specialised nerve cells responsible for monitoring the osmotic pressure of the blood and extracellular fluid*

DID YOU KNOW?

How do we know so much about how the kidney tubules work when they are so tiny? As well as using electron microscopes, which have revealed many details about the tubule cells, scientists have developed microscopic micropipettes which they have used to sample the liquid inside the different regions of an individual nephron.

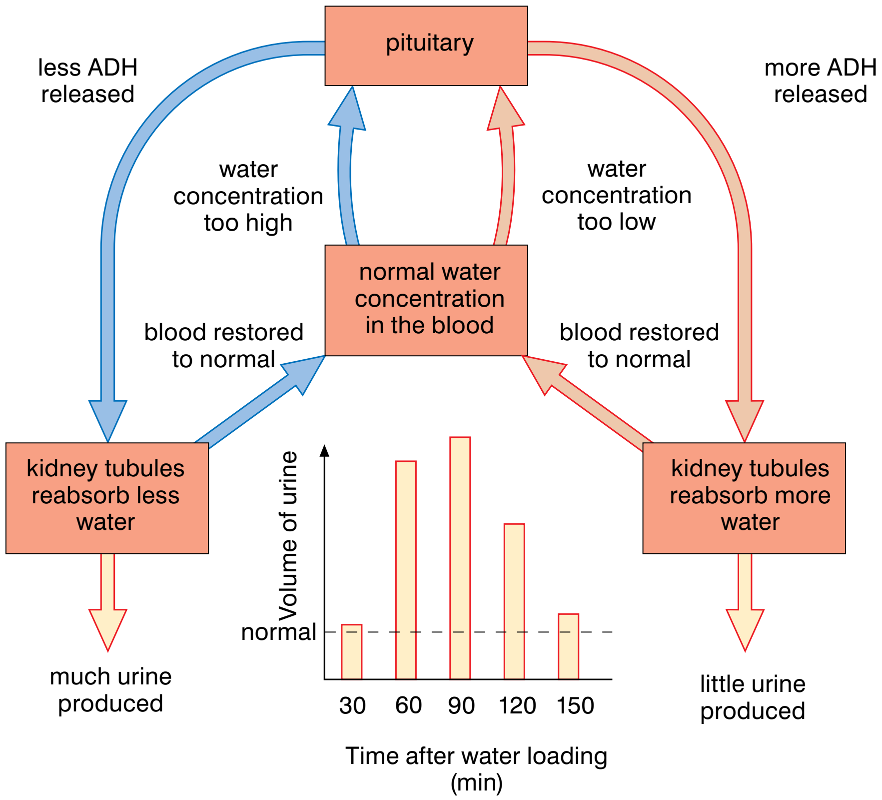


__Figure 3.63__ The negative feedback system which operates to control the amount of water which the kidney removes from the blood means that we can cope with temporary shortages or loading of water surprisingly well.

On an average day your kidneys will produce around 180 l (that's about 50 gallons) of liquid filtered out of your blood in the glomerulus (**glomerular filtrate**) – but only about 1.5 l (just over 2.5 pints) of urine. So more than 99% of the liquid filtered out of your blood is eventually returned to it. You can observe the way in which your kidney works to maintain water balance in your own body. If you drink a lot of water, you will quickly notice that you need to urinate more often, and that you produce large quantities of very pale coloured, dilute urine. If, on the other hand, you are in a situation where you cannot get enough to drink, you will urinate much less frequently and produce a small volume of dark coloured, concentrated urine. This is a very elegant example of homeostasis in action.

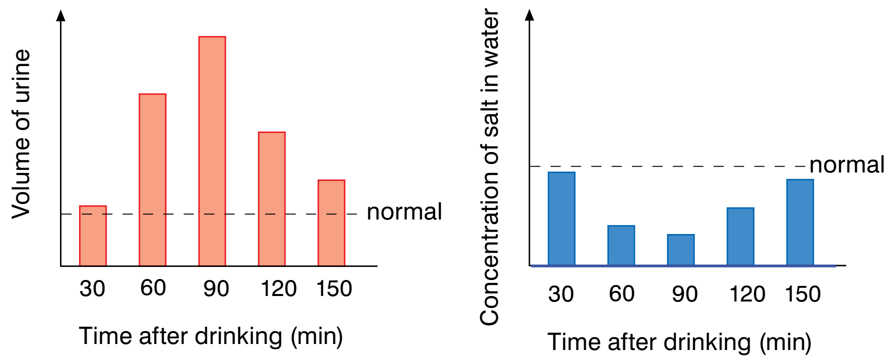


__Figure 3.64__ The graphs show the effect of drinking a given volume of water on both the volume and the salt concentration of the urine produced. Urine was collected at 30-minute intervals after the drink was given and it clearly shows how sensitive the response of the body is. The water load is removed, but without losing much-needed salt.

DID YOU KNOW?

Your blood passes through your kidneys at the rate of 1200 cm^3 per minute, which means all the blood in your body passes through your kidneys and is filtered and balanced approximately once every five minutes.

Your skin also plays a part in the salt and water balance of the body. It forms a waterproof layer around the body tissues which protects us from the uncontrolled loss of water from our body tissues by evaporation. It also prevents you from gaining water by osmosis every time you go swimming in the river! The skin also loses salt and water through the process of sweating. This can affect the ion and water balance of your body when you sweat a lot. But this is a relatively uncontrolled loss. You sweat to help the body cool down, not to control the ion and water balance of the body. The kidneys have to work to support the changes to the concentration of the body fluids that result from sweating excessively.

The liver and homeostasis

Your kidneys and skin are not the only organs of homeostasis. The liver also plays a large role in maintaining a constant internal environment. It is the largest individual organ in your body – in fact it makes up around 5% of your body mass. Your liver cells are very active – they carry out a wide range of functions, many of which help to maintain a constant internal environment. The liver has a very special blood supply. As well as the usual artery and vein (the hepatic artery and vein) there is another blood vessel which comes to the liver directly from the gut. This is the hepatic portal vein and it brings the products of digestion to the liver to be dealt with.

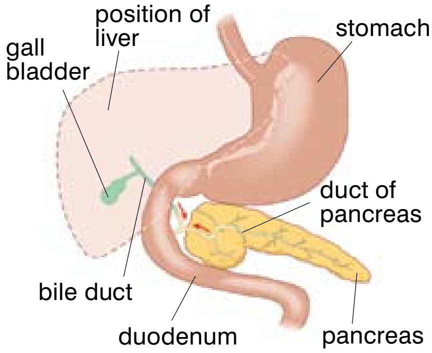


Figure 3.65 *The liver is one of the most active organs in your body – it carries out over 500 different functions!*

A large number of reactions take place in the liver. Many of them are involved in homeostasis in one way or another. It plays a part in all of the following functions:

- Control of the sugar levels in the body (through stored glycogen in the liver itself).
- Controlling and balancing the fats that you eat and the cholesterol levels in your blood.
- Protein metabolism – your liver breaks down excess amino acids and forms urea. If you eat more carbohydrate or fat than you need in your diet your body simply stores the excess energy as fat. If you eat too much protein, it isn't so easy. Your body cannot store the excess amino acids or simply convert protein to fat. Instead the amino acids which make up the protein are broken down in your liver. The amino (nitrogen containing) part of the amino acid molecule is removed and converted into ammonia and then urea in the liver. The rest of the amino acid can be used in cellular respiration or converted to fat for storage. The process of removing the amino group from excess amino acids is known as **deamination** and it is a very important function of the liver.
- The breakdown of worn-out red blood cells – in particular the red pigment haemoglobin.
- The formation of bile which is made in the liver and stored in the gall bladder before it is released into your gut to emulsify fats and help in their digestion.

KEY WORDS

deamination *the removal of an amine group from a molecule*

- Control of toxins – your liver breaks down most of the poisons you take into your body, including alcohol. This is why the liver is so often damaged when people drink heavily.
- Temperature control. Around 500 different reactions take place in the liver at any time. For many years it has been believed that as a result of all these reactions the liver generates a lot of heat which is then spread around the body by the bloodstream. Increasingly scientists think that the reactions which generate heat are cancelled out by reactions which use heat, so that in fact the liver produces very little excess heat. Any that is produced is used around the body.

The liver is a very important organ and we need to look after the health of our livers. The best way to do this is to avoid drinking too much alcohol, which can cause cirrhosis of the liver. The liver tissue is destroyed which can eventually kill you. Heavy drinkers also often develop liver cancer which spreads quickly and can be fatal.

As you have seen, homeostasis is a delicate balance throughout your body as all of the changes which come with everyday life are resisted by your body to maintain the constant internal environment that cells need to work properly.

Summary

In this section you have learnt that:

- Living organisms need systems of co-ordination and control.
- Many multicellular organisms including human beings have both nervous and hormonal co-ordination and control systems.
- The nervous system is the most rapid. Nervous control involves:

  stimulus → receptor → co-ordinator
  → effector → response
- A nerve cell or neuron consists of a cell body, dendrites and an axon.
- Sensory neurons carry information from the sense organs to the central nervous system (CNS).
- Motor neurons carry instructions from the CNS to the effector organs (muscles and glands).
- The central nervous system is the brain and spinal cord. Information is assimilated and co-ordinated in the CNS.
- Neurons carry electrical impulses known as the action potential.
- In any pathway the junctions between neurons are called synapses. When an impulse arrives in one neuron chemicals are released in the synapse to trigger an impulse in the next neuron.

- A nerve contains many neurons. There are sensory nerves, motor nerves and mixed nerves.
- The spinal cord carries information from all over the body to and from the brain.
- Mental illnesses describe a wide variety of disorders and diseases that involve thought processes, emotional disturbances and/or behaviour that are considered abnormal.
- Cranial nerves come from the brain, while spinal nerves are from the spinal cord.
- Reflex actions avoid danger and run mundane bodily functions – they avoid conscious thought.
- Reflex actions involve stimulus → receptor → co-ordinator → effector → response but the co-ordinator is the relay neuron in the spinal cord and there is no conscious thought involved.
- The knee jerk reflex is a common example of a reflex. It is used by doctors to test reflexes and in ordinary life to prevent stumbling.
- Drug abuse is when you use a substance to the point of excess and/or dependence. When you take an excess of a drug you risk serious side effects and even death.
- Drug dependence is when you use a drug again and again and become addicted.
- Drugs change the chemical processes in your body so you can become addicted to them (dependent on them). This means you cannot manage or function properly without the drug. This may be psychological – the need to keep using it becomes a craving or compulsion – or a physical dependence where your body no longer works properly without the drug.
- Alcohol, tobacco, khat and cannabis are the most widely used substances in Ethiopia.
- Other drugs which can be misused include prescription sedatives, cocaine, LSD, ecstasy and heroin.
- Drug abuse and dependence can hurt the individual user, their family and the entire community.

Review questions

1. Which of the following is not an example of homeostasis?

   A control of the blood sugar levels

   B control of the body temperature

   C control of the water content of the blood

   D control of the length of the limbs

2. Which of the following areas is NOT part of the nephron (kidney tubule)?

   A Bowman's capsule

   B urinary bladder

   C loop of Henlé

   D first coiled tubule

3. Which of the following statements is true about ADH?

   A ADH is a hormone produced in the brain which affects the second coiled tubules of the kidneys, making them more permeable so more water is reabsorbed back into the blood and little, concentrated urine is formed.

   B ADH is a hormone produced in the brain which affects the first coiled tubules of the kidneys, making them more permeable so more water is reabsorbed back into the blood.

   C ADH is a hormone produced in the kidney which affects the coiled tubules of the kidneys, making them more permeable so more water is reabsorbed back into the blood.

   D ADH is a hormone produced in the brain which affects the second coiled tubules of the kidneys, making them less permeable so less water is reabsorbed back into the blood and much dilute urine is formed.

4. Here is a jumbled list of the events by which your body temperature is controlled when it starts to go up. Which sequence of events is correct?

   I Tilahun exercises hard and his body temperature starts to rise.

   II Tilahun takes a long, cool drink to replace the liquid he has lost through sweating.

   III His temperature returns to normal.

   IV Tilahun's skin reddens and he sweats heavily so the amount of heat lost through his skin goes up.

   A I, II, III, IV

   B I, III, IV, II

   C I, IV, III, II

   D I, III, IV, II

End of unit questions

1. Explain what happens in the Bowman's capsule of a kidney tubule.
2. What happens to the filtrate as it passes through the kidney tubule?
3. How does urine differ from the original filtrate?
4. a) What is a hormone?

   b) Where are the main human hormones produced? (Make a table to show the main hormones produced in the body, where they are produced and what they do.)

   c) How is control by hormones different from control by the nervous system?
5. There are two main metabolic waste products which have to be removed from the human body: carbon dioxide and urea.

   a) What is meant by the term 'metabolic waste'?

   b) For each waste product named above describe:

      i) how it is formed

      ii) why it has to be removed

      iii) how it is removed from the body
6. a) What does the word contraception mean?

   b) Describe the main available forms of contraception.

   c) The biggest cause of failure of contraception is usually human error. What does this mean?
7. a) Hormones can be used to control fertility artificially. Explain how hormones can be used to prevent pregnancy in the contraceptive pill.

   b) What are the benefits of family planning to:

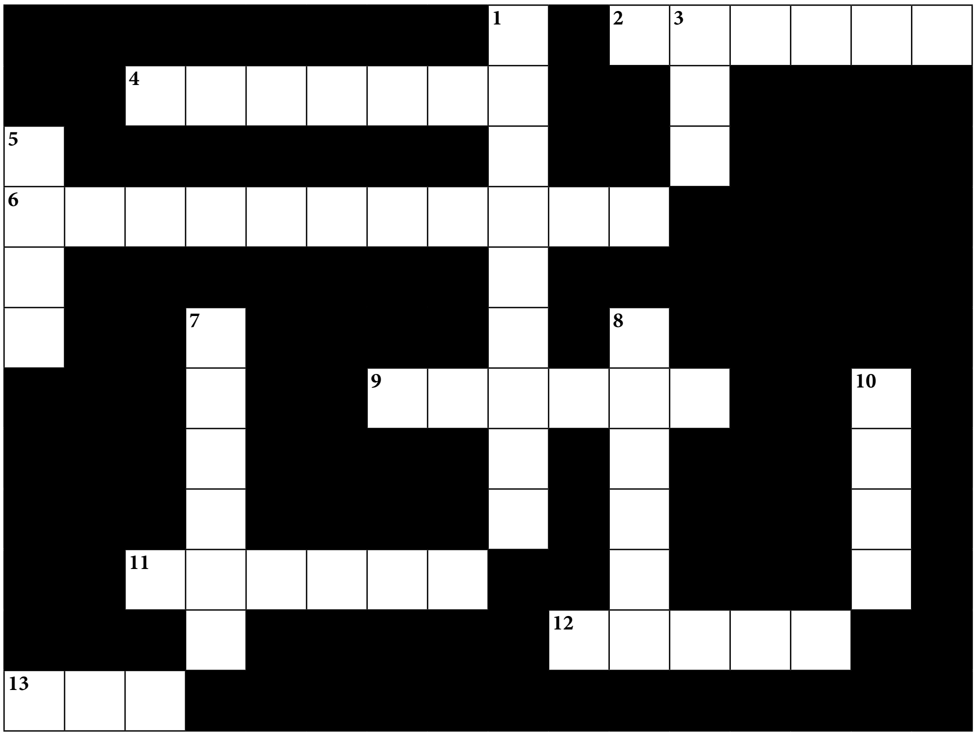
      i) the individual and

      ii) to society?
8. HIV/AIDS is a sexually transmitted disease which is a major problem in Ethiopia. Describe the disease and explain both why it is such a problem in Ethiopia and how the disease may be controlled.
9. a) What is female genital mutilation?

   b) What are the health risks caused by FGM?

   c) How are the people of Ethiopia changing opinions and removing this harmful traditional practice?

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

2 The light sensitive layer of the eye (6)

4 The gap between two neurons (7)

6 The maintenance of a constant internal environment (11)

9 A nerve cell (6)

11 Rapid response that does not involve conscious thought (6)

12 The most recently discovered taste (5)

13 The human sense organ that responds to sound (3)

DOWN

1 --------- cycle – the fertile cycle in women (8)

3 Human sense organ that responds to light (3)

5 Legal drug that is commonly used in Ethiopia (4)

7 An important organ of homeostasis which balances water and salt and excretes urea (6)

8 A form of barrier contraceptive used by men which can also prevent the spread of HIV/AIDS (6)

10 Long extension from motor nerve that carries the nerve impulse (4)

Food making and growth in plants

Unit 4

Contents

Section	Learning competencies
4.1 The leaf (page 142)	• Label the internal structures of leaves. • Explain the functions of the internal structures of leaves. • Use the microscope to study the internal structures of leaves.
4.2 Photosynthesis (page 146)	• Explain the importance of light, chlorophyll and carbon dioxide (CO_2) for photosynthesis. • Demonstrate the importance of light, chlorophyll and carbon dioxide (CO_2) for photosynthesis with simple experiments. • Explain how plants convert carbon dioxide and water into carbohydrate by describing the light and dark reactions. • List the various food storage organs of plants with examples. • Explain the importance of photosynthesis in agriculture. • Explain that much photosynthesis takes place in water bodies and that people need to try and make use of this. • Explain how photosynthesis helps to balance the concentrations of oxygen (O_2) and carbon dioxide (CO_2) in the atmosphere. • Explain how deforestation may lead to a CO_2 build-up in the atmosphere and finally to global warming.
4.3 Transport (page 158)	• Explain water uptake by the roots. • Explain the mechanism of water movement in plants. • Describe transpiration, the factors affecting it and its implications for agriculture. • Demonstrate water transport in plants using simple experiments. • Explain the mechanism of uptake of mineral salts through roots. • Describe the movement of organic materials in the phloem.
4.4 Response in plants (page 170)	• Demonstrate the processes of germination in dicots and monocots. • List the plant hormones. • State the functions of the plant hormones. • Outline the mechanism of action of auxins. • Explain the effect of removing apical dominance on plant growth. • Demonstrate how sunlight influences plant growth. • Name the different types of tropisms in plants. • Explain the processes of tropism.

4.1 The leaf

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

- Label the internal structures of leaves.
- Explain the functions of the internal structures of leaves.
- Use the microscope to study the internal structures of leaves.

The flowering plant is a complete organism with organs carrying out particular functions. There are four main organs of a flowering plant. Understanding them will help you understand how a plant makes food and grows.

- The **flowers** which contain the reproductive organs.
- The **leaves** which use light energy, carbon dioxide and water to make food by photosynthesis.
- The **stem** which provides support and a transport system for water and minerals to the leaves and flowers. It also transports food from the leaves to the roots and flowers.
- The **roots** which anchor the plant to the ground and absorb water and minerals.

In the following activity, you will examine the organs of a flowering plant.

Activity 4.1: Examining the external features of a flowering plant

You will need:

- a typical dicotyledonous plant with roots, e.g. bean plant, black jack
- a hand lens

Method

1. Identify the following parts on your flowering plant: shoot system, root system, terminal bud, axillary bud, node, internode, leaves, stem, flowers, fruits, lateral roots, tap root.
2. Note the distinguishing features of the stem and root.
3. With the help of a hand lens, examine the root hairs.
4. Make a large, well-labelled drawing of your specimen showing all the parts that you have identified.

Review question

1. How does the plant you have observed in the above activity differ from a maize plant?

A photosynthesising machine

Plants take the inorganic molecules carbon dioxide and water and use them to produce the organic molecule glucose along with inorganic oxygen in the presence of energy from light. This amazing process is the basis of all life on Earth – it provides the food we eat and the oxygen we breathe. And it all takes place in the leaves of plants. Plant leaves are perfectly adapted to allow the maximum possible amount of photosynthesis to take place whenever there is light available.

Adaptations of a leaf for photosynthesis

- The **leaf** is flat and wide, giving a large surface area to collect light and short distances for gases to diffuse. The veins bring water from the soil to the cells.
- The **waxy cuticle** is a waterproof layer found on the surface of many leaves to help prevent water loss.
- The **palisade mesophyll** is the main photosynthetic tissue of the plant. There are many cells, closely packed together near the surface of the leaf to get as much light as possible. Each cell has many chloroplasts – hundreds of them – which are spread out through the cytoplasm of the cell when light levels are high but which cluster at the top of the cell when light levels are low.
- The **spongy mesophyll** has fewer cells with fewer chloroplasts. However, there are lots of air spaces and a big surface area for gas exchange. Some photosynthesis takes place here but more importantly it is where the carbon dioxide needed for photosynthesis moves into the cells, and the oxygen moves out. The water lost in transpiration evaporates from the cells here as well.
- The **lower epidermis** has openings known as **stomata** which allow carbon dioxide to diffuse into the leaf and oxygen and water vapour to diffuse out. The **guard cells** open and close to control the entry of carbon dioxide into the leaf and also to control the loss of water by transpiration.

KEY WORDS

waxy cuticle *waterproof upper surface layer found in many types of leaf*

palisade mesophyll *the main photosynthetic tissue of a leaf*

spongy mesophyll *the main gas exchange tissue of a leaf*

lower epidermis *surface layer of a leaf containing stomata*

stomata *pores mostly on the lower surface of leaves that can be opened or closed to control gas exchange and water loss*

guard cells *pairs of cells which surround and control the size of stomata by altering their shape*

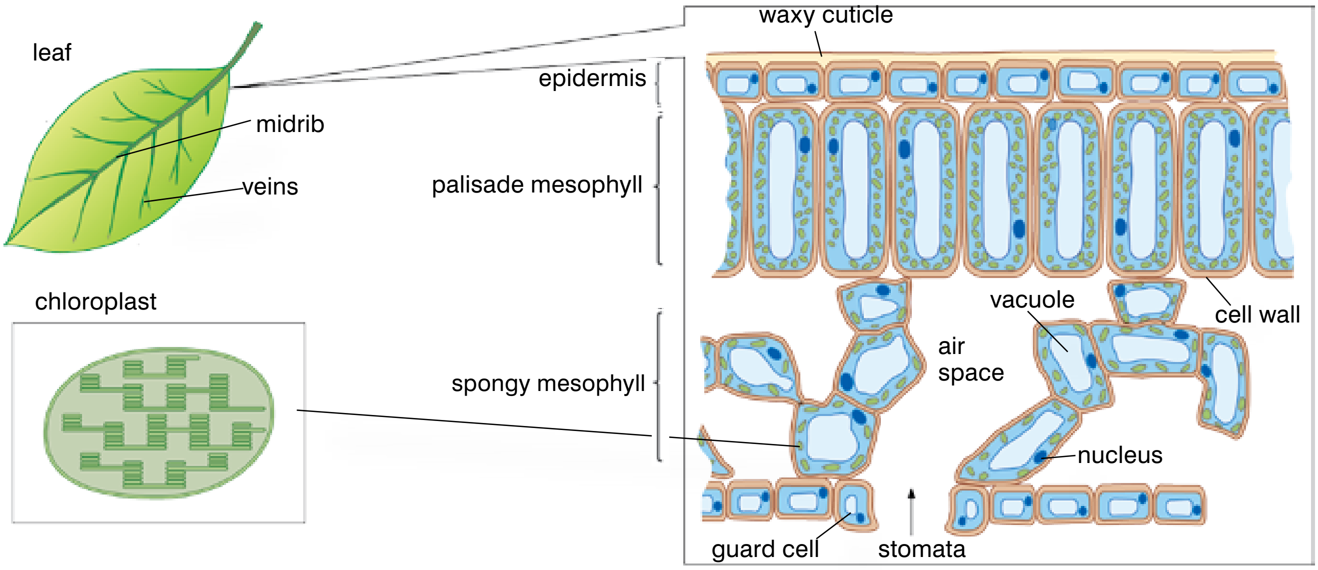


Figure 4.1 *This cross section of a leaf shows that leaves of plants are perfectly adapted to make the best possible use of the light that falls on them.*

- The **vascular bundles** contain the **xylem**, dead tissue which brings water from the soil to the cells of the leaves, and the **phloem**, living tissue which carries the products of photosynthesis away from the leaves to all of the cells of the plant.
- Each **chloroplast** contains stacks of membranes and chlorophyll to give an increased surface area for photosynthesis to take place.

Activity 4.2: Investigating leaf structure

The diagram in figure 4.1 of the tissues inside a leaf is – as always – of an ideal piece of tissue. Your work with microscopes so far will have shown you that cells aren't always as easy to see and identify down a microscope as they are in the diagram of a textbook! Your task is to look at a living leaf and then at a prepared slide of a section through a leaf and identify as many of the regions listed as possible.

You will need:

- a light microscope
- a lamp
- a fresh leaf
- a piece of graph paper
- a prepared microscope slide of a section through a leaf

Method

1. First look carefully at your fresh leaf. Identify the midrib (the main vein) and the smaller veins running through the leaf tissue. Draw and label your leaf.
2. Work out the surface area of your leaf exposed to the sunlight using the graph paper. Draw the outline of your leaf on the paper and count the small squares it covers to reach a rough approximation of the area of your leaf in mm^2 or cm^2 (depending on the size of the leaf you have chosen).
3. Now estimate how many leaves there are on the whole plant – and work out a very rough estimation of the surface area available to the plant to capture light for photosynthesis. You may be surprised! Add your calculations to your drawing of the leaf.
4. Now use your microscope to look at a cross section of the leaf in more detail. Remember – microscopes are expensive and delicate pieces of equipment so always take care of them and handle them safely.
5. Observe your prepared slide carefully and identify as many of the different tissues listed on pages 143–144 as possible.
6. Make a plan of your section, showing where each of the different areas are but without putting in any cell details. Label the different layers. Show the magnification.
7. Now make a more detailed drawing of the section, showing just a few of each type of cell. Show the magnification. Give full annotations to explain how each tissue is adapted to carry out its function in the leaf.

Summary

In this section you have learnt that:

- The internal structures of leaves are adapted for photosynthesis to take place.
- Leaves have a number of different tissues including the waxy cuticle, the epidermis, the palisade mesophyll, the spongy mesophyll, the vascular bundles, the stomata and guard cells.
- The different tissues of the plant leaf have different functions, e.g. waxy cuticle prevents water loss, palisade mesophyll allows maximum photosynthesis, stomata allow the diffusion of gases into and out of the leaf.
- You can use the light microscope to study the internal structures of leaves.

KEY WORDS

vascular bundles *part of the transport system in vascular plants, containing xylem and phloem*

xylem *the hollow cells of a plant that transport water and minerals to plant cells*

phloem *the food-conducting living tissue of a plant*

chloroplast *the organelle in the cytoplasm of plant cells where chlorophyll is stored, and photosynthesis takes place*

Review questions

1. Which of the following is not an external feature of a leaf?

   A petiole

   B midrib

   C chloroplast

   D cuticle

2. Which of the following is the tissue where most photosynthesis takes place?

   A spongy mesophyll

   B palisade mesophyll

   C epidermis

   D stomata

3. Gases move in and out of a plant through:

   A the cuticle

   B the stomata

   C the epidermis

   D the roots

KEY WORDS

photosynthesis *a plant chemical process of making food (sugars) and oxygen, from carbon dioxide and water, in the presence of light*

heterotrophs *organisms that obtain their energy through consuming other organisms*

autotrophs *organisms that make their own food from inorganic substances, via photosynthesis*

4.2 Photosynthesis

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

- Explain the importance of light, chlorophyll and carbon dioxide (CO_2) for photosynthesis.
- Demonstrate the importance of light, chlorophyll and carbon dioxide (CO_2) for photosynthesis with simple experiments.
- Explain how plants convert carbon dioxide and water into carbohydrate by describing the light and dark reactions.
- List the various food storage organs of plants with examples.
- Explain the importance of photosynthesis in agriculture.
- Explain that much photosynthesis takes place in water bodies and that people need to try and make use of this.
- Explain how photosynthesis helps to balance the concentrations of oxygen (O_2) and carbon dioxide (CO_2) in the atmosphere.
- Explain how deforestation may lead to a CO_2 build-up in the atmosphere and finally to global warming.

Like all living organisms plants need food to provide them with the energy for respiration, growth and reproduction. Many organisms, including all animals, eat food to get the energy they need to live. They are known as **heterotrophs** (feeding on others). In contrast, plants produce their own food in a process known as **photosynthesis**. They are known as **autotrophs** (feeding themselves). Photosynthesis takes place in the green parts of plants, especially the leaves, in the presence of light.

Figure 4.2 *Plants can make their own food by photosynthesis and they use it to grow in some spectacular ways. Oxygen is a by-product of photosynthesis and it is used for respiration by plants and animals alike.*

What is photosynthesis?

Photosynthesis can be summed up in the following equation:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{light energy}]{\text{chlorophyll}} \text{glucose} + \text{oxygen}$$

The chemical equation for the same process is:

$$6CO_2 + 6H_2O \xrightarrow[\text{light energy}]{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$$

During photosynthesis light energy from the sun is absorbed by a green substance called chlorophyll that is found in the chloroplasts of some plant cells. The energy that is captured is used to convert carbon dioxide from the air and water from the soil into a simple sugar, glucose, with oxygen as a by-product.

Some of the glucose produced during photosynthesis is used immediately by the cells of the plant for respiration to provide energy for cell functions, growth and reproduction.

The energy released in respiration is used to build up smaller molecules into bigger molecules:

- Sugars like glucose are built into starch for storage.
- Sugars like glucose are built into molecules like fructose (fruit sugar) and sucrose (a double sugar unit) to be transported around the plant.
- Sugars like glucose are built up into more complex carbohydrates like cellulose to make new plant cell walls.
- Sugars, along with nitrates and other nutrients that the plant takes up from the soil, are used to make amino acids. These amino acids are then built up into proteins to act as enzymes and make up much of the cytoplasm of the cells.
- Sugars may be built up into fats and oils (lipids) for storage in seeds and to make up part of the cell membranes.
- Sugars may be used to build up important large molecules such as chlorophyll, using minerals such as magnesium taken up from the soil.

Some of the glucose produced by photosynthesis is always converted into starch for storage, at least as a first step. This is because glucose is soluble and so could affect the water balance within the plant. If the concentrations of glucose vary in different parts of the plant then osmosis takes place to correct this and this could upset the whole organism. Starch is insoluble, which means that it does not dissolve, so it has no effect on the concentration of solutions. This means that it can be stored in different places without having any effect on the water balance of the plant. Starch is also a very compact molecule, so it takes up relatively little room, and it is easily broken down again into glucose molecules when it is needed by the cells of the plant. Because so much starch is produced, we often use it to show us that photosynthesis has taken place in a plant.

DID YOU KNOW?

Plants synthesise around 35×10^{15} kg of NEW biological material and produce about 36.8×10^{13} kg of the invaluable waste product of oxygen each year. This is why plants are vitally important to the survival of all species on Earth.

What is needed for photosynthesis?

As you can see from the equation at the beginning of this chapter, for photosynthesis to occur successfully the inorganic molecules carbon dioxide and water are needed, along with a supply of light energy and the means to capture that energy in the form of the green pigment chlorophyll. But to show that certain factors are needed for photosynthesis, or to have an effect on its rate, we need a way of demonstrating that photosynthesis has actually taken place.

The simplest way to do this is to look at the end products of the process. We can use the presence of starch in the leaf of a plant to show that it has been photosynthesising. Iodine solution is reddish brown. In the presence of starch, iodine turns blue-black.

Unfortunately you can't just add a few drops of iodine solution to the leaves of a plant to see if it has made starch – the waxy cuticle forms a waterproof layer so the iodine cannot penetrate and the green colour could mask a slight colour change. However, there is a simple procedure to test a leaf successfully for the presence of starch that you can use in many different experiments to investigate photosynthesis.

Activity 4.3: Testing a leaf for starch

A common way of demonstrating that a plant has or has not carried out photosynthesis is to test a leaf for the presence of starch (see figure 4.3).

To see the effect of starch on iodine solution place a few drops of iodine solution onto a piece of bread or a cut piece of potato or even a piece of paper and observe the colour change.

To be able to see clearly that a leaf has been photosynthesising and that starch has indeed been produced, you need to remove the outer waxy layer. To do this you need to follow these steps:

You will need:

- potted plants, e.g. geraniums (pelargoniums) that have been kept in the light for several hours before the investigation
- a large beaker
- a Bunsen burner, a tripod, gauze and a heatproof mat
- ethanol (NB. Keep ethanol away from the naked flame.)
- a boiling tube
- forceps
- a white tile

Method

1. Set up your Bunsen burner on a heatproof tile with the tripod and gauze. Half fill the beaker with water and bring it to the boil.
2. Remove a leaf from the plant and, holding it in the forceps, plunge it into boiling water and continue to boil briefly (about 30 seconds). TAKE GREAT CARE. This serves two main purposes. It stops all the biochemical processes by killing the leaf, and it breaks open the cells making them more accessible to the iodine solution.
3. Turn off the Bunsen burner. Place the leaf in a boiling tube half filled with ethanol, so the ethanol covers the leaf. Place the boiling tube in the beaker of water that has just stopped boiling. The ethanol will boil and the green colour will be removed from the leaf. This MUST be carried out in a water bath and great care taken as ethanol is very flammable. NEVER heat ethanol directly with a Bunsen burner. The removal of the green pigment from the leaf means that any colour changes in the iodine solution will be more clearly seen.
4. Ethanol makes the leaf brittle so remove the white leaf from the boiling tube with the forceps and wash it in the hot water again to soften it.
5. Then spread the leaf out on a white tile – or a Petri dish on a piece of white paper – to make colour changes more obvious, and add a few drops of iodine solution.
6. Observe any colour changes – the parts of the leaf that contain starch will turn blue-black and this indicates that photosynthesis has taken place.

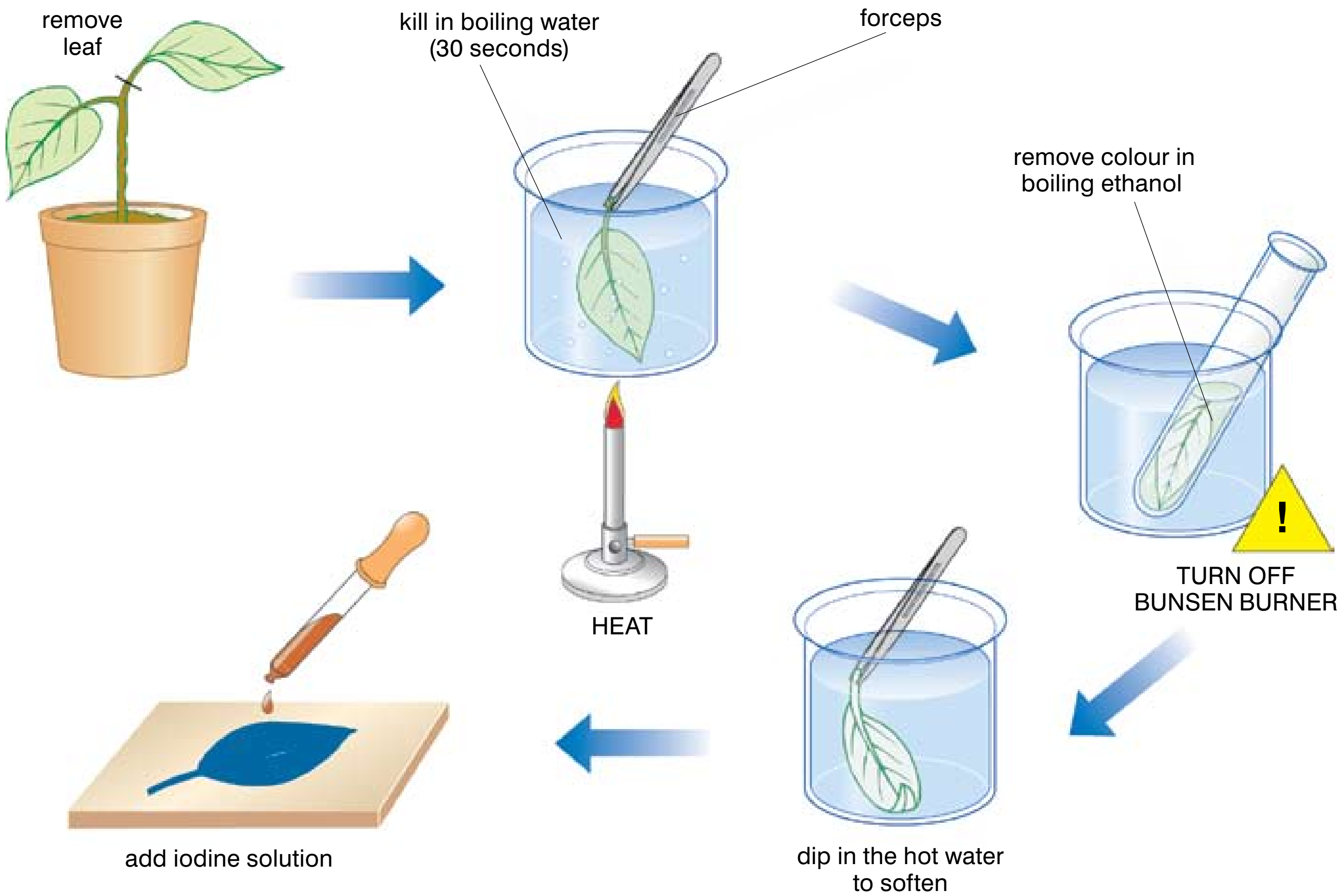


Figure 4.3 *We use the iodine test for the presence of starch to show us that photosynthesis has taken place. A blue-black colour indicates starch is present in the leaf and so photosynthesis has taken place.*

Review questions

1. Where does a plant get the carbon dioxide, water and light that it needs for photosynthesis?
2. Work out the path taken by a carbon molecule as it moves from being part of the carbon dioxide in the air to being part of a starch molecule in a plant.

The need for light

Everyone knows that plants need light for photosynthesis – but in fact that is not completely true. The simple equation we use for photosynthesis represents many different chemical reactions that go on in the chloroplasts of a plant to convert carbon dioxide and water into glucose and oxygen. And while light is absolutely necessary for some of those reactions, others can continue even if there is no light at all. The light-dependent reactions cannot take place without light energy. The light energy is absorbed by chlorophyll molecules through activation of their electrons and used to split water molecules into hydrogen and oxygen. Adenosine triphosphate (ATP) for energy is produced as well. The hydrogen is used in the rest of the process, and the oxygen is given off as a gas. It is a waste product of the light reactions of photosynthesis.

The hydrogen and ATP produced in the light reaction are then used in a series of reduction reactions that convert carbon dioxide into

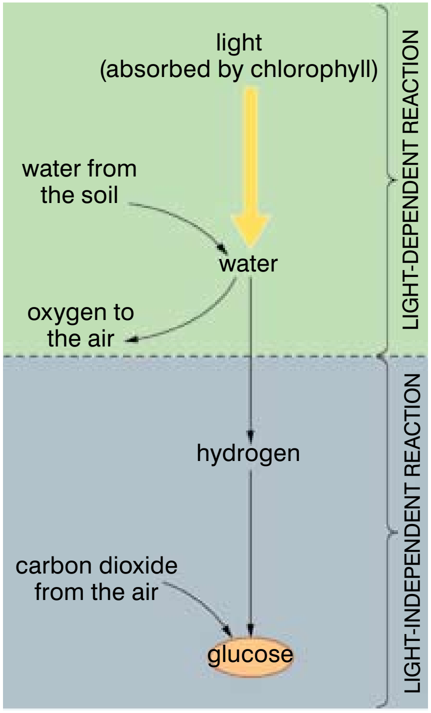


Figure 4.4 *The light-dependent and -independent reactions of photosynthesis can be summarised like this. They both take place in the chloroplasts.*

glucose. This stage of the process does not need light to take place and is known as the light-independent reaction.

However, for all practical purposes we can still say that plants need light for photosynthesis – because without the products of the light-dependent reaction the light-independent reactions can't take place at all! For most plants the source of light energy for photosynthesis is the sun, although in some cases people intervene and supply extra artificial light. If plants are deprived of light for any substantial amount of time they will die, because once the stores of starch have been used up they are not replaced and so there is no energy available for the metabolic reactions of the cells.

It is important to be able to show that plants need light for photosynthesis – how do you think it might be done? Make a list of your ideas and then read on.

The simplest way of demonstrating the need of a plant for light is to deprive it of light and see what happens. You can keep a whole plant in the dark for two to three days – this is called **destarching** the plant – and then compare the leaves with those from a plant kept in the light. Alternatively you can cover either a whole leaf or part of a leaf of a destarched plant with black paper or foil. This prevents light from reaching the covered area. If the plant is then left in the light for several hours and the covered leaf is tested for the presence of starch and compared to an uncovered leaf the difference is plainly visible (see figure 4.5).

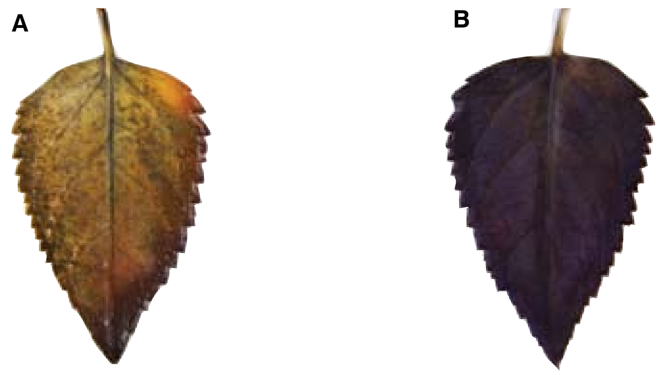


Figure 4.5 *The results of the iodine test for starch: leaf A is from a destarched plant which has been kept in the dark; leaf B is from a plant kept in the light.*

However, starch is not the only end product of photosynthesis. Oxygen gas is produced as well. While we cannot easily observe the oxygen gas produced during photosynthesis in land plants, it is a useful way of showing that photosynthesis is taking place in water plants. They give off bubbles of oxygen-rich gas from their leaves and from any cut or broken stems when they are photosynthesising. You can use this to show that light is needed for photosynthesis to take place, simply by collecting the gas collected from a water plant kept in the dark and one kept in the light. The gas given off by the plant in the light will relight a glowing splint – showing that it is rich in oxygen. The much smaller amount of gas collected from the plant in the dark does not do this – in fact it will extinguish the splint as it is rich in carbon dioxide from respiration. You can also use this method to measure the rate at which photosynthesis takes place when you look at the limiting factors in photosynthesis.

KEY WORDS

destarching *the process of eliminating starch reserves from a plant by depriving it of light*

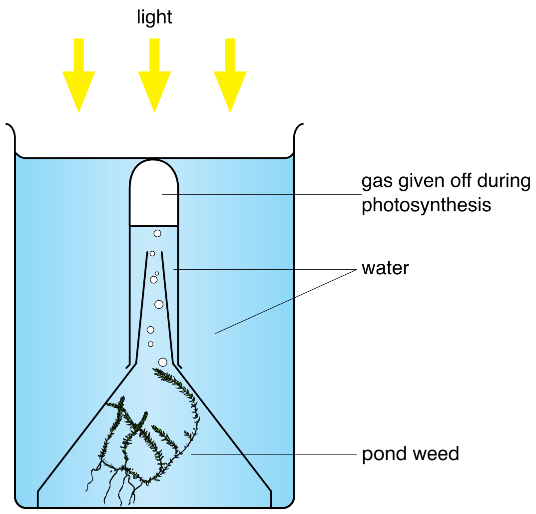


Figure 4.6 The oxygen-rich gas released by water plants as they photosynthesise gives us another way of showing that light is needed for the process to happen.

Activity 4.4: To show that oxygen is produced during photosynthesis

In the equation for photosynthesis, we saw that oxygen is given off as a waste product.

When the light intensity is high (bright sunshine), much oxygen is produced.

The oxygen can easily be collected from water since it is not very soluble in water.

This explains why we use an aquatic plant.

You will need:

- local pond weed
- a 250 cm^3 beaker
- a glass funnel
- a test tube
- small stones
- sodium hydrogen carbonate
- water or pond water

Method

1. Place the pond weed in a large beaker filled with about 150 cm^3 of pond water. You may add sodium hydrogen carbonate to the water to produce more carbon dioxide.
2. Carefully invert a funnel over the pond weed as shown in figure 4.6.
3. Fill a test tube with the same amount of water as in the beaker. Carefully and without allowing any water out of the test tube, invert the test tube over the stem of the funnel as shown in figure 4.6.
4. You will need to put some small stones at the bottom of the beaker to support the funnel so that it is raised above the bottom of the beaker. This arrangement allows free water circulation.
5. Place the apparatus in bright sunlight for 3–4 hours.
6. After this period, move the inverted test tube from the inverted funnel stem while still under water. Then cover the test tube with your thumb before removing it from the beaker.
7. Remove your thumb from the test tube mouth and quickly plunge a glowing splint into the test tube.

Activity questions

1. What did you observe during the four hours?
2. What happens to the glowing splint when plunged into the test tube?
3. What is the identity of the gas?
4. What conclusion can you make from this activity?

Activity 4.5: Showing that light is needed for photosynthesis

Follow these steps to plan your own experiment to show that light is needed for photosynthesis to take place.

1. Plan two experiments, one using land plants and one using water plants, which could be used to demonstrate that light is needed for photosynthesis.
2. Make sure that you describe carefully how to demonstrate that photosynthesis has taken place in each case, and think carefully about any safety issues.
3. Once you have planned your demonstrations, ask your teacher to check them through.
4. If you are given permission, set up ONE of your demonstrations and write up your observations and your conclusions on its effectiveness.
5. Make sure you evaluate your method and discuss any ways in which you might improve it.

The need for carbon dioxide

A source of carbon is needed for the plants to synthesise sugars. There are lots of carbon-containing chemicals in existence, but carbon dioxide from the air or in solution in water is the only form that plants can use in photosynthesis. Carbon dioxide is found more or less everywhere. It is even produced by the plants themselves as a result of cellular respiration, so getting hold of it isn't usually a problem. However, although there is always sufficient carbon dioxide available for some photosynthesis to take place, sometimes the levels are too low for plants to take full advantage of the light available.

Demonstrating that plants need carbon dioxide for photosynthesis is not easy. You can easily remove the carbon dioxide from the air surrounding a leaf or a plant using potassium hydroxide, which absorbs CO_2. However, the individual plant cells still produce

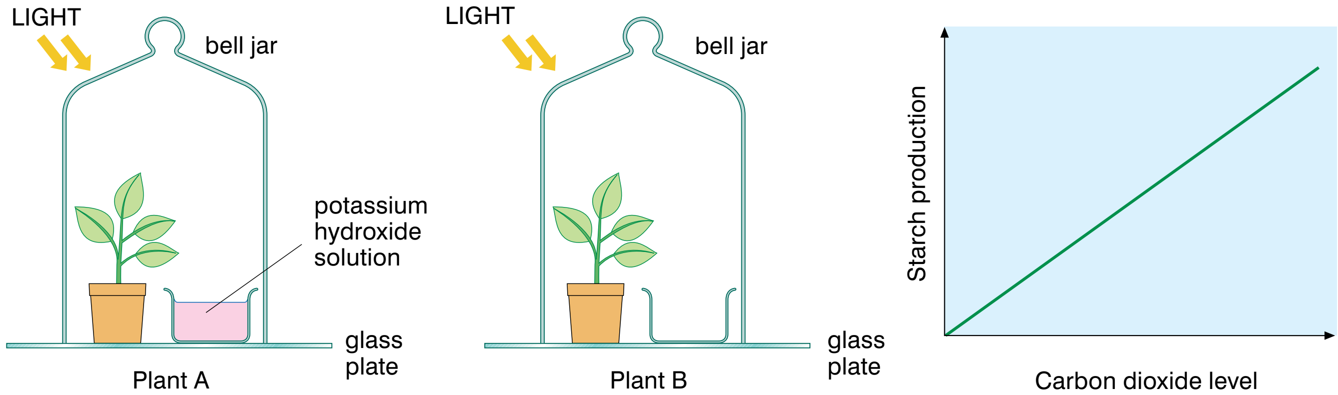


Figure 4.7 *Plant A and plant B are both destarched. Plant A has no carbon dioxide in the surrounding air, while plant B has normal levels of carbon dioxide. Both are given light for 12 hours and tested for the presence of starch. Less starch is produced by plant A than by plant B, but plant A makes a small amount of starch using carbon dioxide produced in the leaves by respiration.*

carbon dioxide as they respire and so it is almost impossible to entirely deprive a plant of the gas. A more valid approach is to change the levels of carbon dioxide in the air surrounding a plant in high-intensity light and measure the changes in the rate of photosynthesis. As the carbon dioxide level increases, the rate of photosynthesis goes up. With plenty of raw materials the plant is able to take full advantage of the light energy falling on it.

The need for water

Carbon dioxide alone is not sufficient to produce carbohydrates. Hydrogen is needed too, and water is the only source of hydrogen that plants can make use of. All the cells of a plant have a constant supply of water both as a waste product of respiration and from the transpiration stream (see section 4.3), so there is always plenty of water for photosynthesis.

Water is vital to all the functions of a plant. This means you cannot demonstrate that water is required for photosynthesis just by depriving the plant of it – the plant would die long before the effect of lack of water on photosynthesis would show. The only way to show that water is needed for the process of photosynthesis is to supply the plant with 'heavy' water containing the ^{18}O isotope of oxygen. These atoms are radioactive, and the radiation they produce can be detected as it is taken up and used by the plant. Substances like this are known as **radioactive tracers**. This experiment not only shows that water is needed for photosynthesis, it also makes clear what part the water plays. It shows that the oxygen gas produced during photosynthesis comes from the splitting of the water molecules using light energy. This is known as photolysis (splitting using light).

The need for chlorophyll

The final requirement for photosynthesis to take place is a way of capturing the energy from the sun and this is carried out by the green pigment chlorophyll.

The simplest way to demonstrate that chlorophyll is needed for photosynthesis to take place is to consider the leaves of a variegated plant. Variegated leaves have areas that contain chlorophyll and areas that do not. The chlorophyll-free regions are usually yellow or creamy-white in colour. If a destarched variegated plant is then exposed to light for several hours and you test one of the leaves for the presence of starch, the iodine solution changes colour only in those regions of the leaf that were green. This shows that without chlorophyll photosynthesis did not take place.

DID YOU KNOW?

There are some plants – known as the **resurrection plants** – which can survive without water. In dry conditions they can lose up to 95% of their water and end up as tiny shrivelled remains. But just add water and within 24 hours they have recovered and are photosynthesising again as good as new!

KEY WORDS

radioactive tracers *radioactive molecules that can be sent through a vascular system (animal or plant) with their progress followed by a radiation-sensitive machine*

resurrection plants *plants with the habit of reviving after seeming to be dead*

DID YOU KNOW?

Chlorophyll is the green pigment in plants that captures the energy from the sun for photosynthesis. But chlorophyll isn't really green – it is a mixture of five different pigments that range in colour from orange and yellow to blue-green and yellow-green and the result is the green colour we see!

Figure 4.8 *The leaves on the left and the right come from plants that have been in bright light for 48 hours. Both plants have had plenty of time to photosynthesise and make glucose to turn into starch. However, only the green areas of the variegated leaf on the right have been able to make starch, because the white areas do not contain chlorophyll. The middle leaf is from a plant that has been in the dark for 48 hours.*

Activity 4.6: Showing that chlorophyll is needed for photosynthesis

You can see how important chlorophyll is for photosynthesis by carrying out the following experiment on a variegated leaf. You are going to keep one plant with variegated leaves in the dark, and place another variegated plant in bright light for several hours, and then test a leaf from both plants for the presence of starch. What do you expect to see – and why?

You will need:

- two potted plants with variegated leaves, e.g. geraniums (pelargoniums) or ivy, that have been destarched. Keep one plant in the dark, and bring the other into the light for several hours before the investigation
- a large beaker
- a Bunsen burner, a tripod, gauze and a heatproof mat
- ethanol (NB. Keep ethanol away from the naked flame.)
- a boiling tube
- forceps
- a white tile

Method

1. Remove one leaf from the destarched plant with variegated leaves that has been kept in the dark and one leaf from the plant that has been exposed to a bright light for several hours.
2. Prepare both leaves to be tested for the presence of starch using the method described on page 148.
3. Spread both leaves on a white tile and add iodine solution.
4. Make careful observations and drawings of your results.
5. Write up your experiment and explain the results you get. Do they fit with your initial hypothesis?

The importance of photosynthesis

Photosynthesis is one of the most important reactions on Earth. It is through photosynthesis that the ultimate source of energy for the Earth – in other words, the sun – is tapped and converted into chemical energy which is available to life. Around 35×10^{15} kg of new biological material is produced every year as a result of photosynthesis. This new material can then be used as a food source by billions of living organisms, including people. On the land, it is plants that photosynthesise and make food. It is easy to forget that actually almost two-thirds of the surface of the Earth is covered in water, and much of the photosynthesis of the world goes on in large bodies of water. The organisms that carry out photosynthesis in water may be true plants, such as water weeds, but they also include many algae and most importantly of all, the photoplankton (also known as phytoplankton). These are tiny organisms, protists and bacteria, which carry out photosynthesis and produce over half of the biomass of the Earth. That is a lot of material – remember the total biomass made by photosynthesis each year is around 36.8×10^{13} kg!

At the moment people rely mainly on the photosynthesis which takes place on land to supply them with their food. Most of our food crops such as teff, sorghum, millet, corn, barley, beans and other pulses are all plants grown in the soil. Some cultures such as China use seaweeds and other algae which photosynthesise in water as an important source of food but most only use the biomass created by photosynthesis in the oceans indirectly, when they eat fish. So in many ways the photosynthesis which takes place in large bodies of water is a wasted resource.

Scientists are looking hard at ways in which algae might be used as a future source of both human food and fuels to replace fossil fuels. Algae grow at a tremendous rate and replace themselves very rapidly. They not only produce biomass very rapidly, they also produce large amounts of oxygen and use up carbon dioxide. At the moment there are a number of problems to overcome, including how to grow and harvest algae in a controlled way, how to make food from algae acceptable to eat in cultures which are not familiar with it and how to convert algae into fuel. However, as the human population grows and food becomes more of a problem, scientists will almost certainly overcome these difficulties and algae will become a regular part of the human diet around the world.

Photosynthesis is very important as the source of energy for almost all living organisms, because of the way in which photosynthesis provides us with new biological material. However, it is important to the health of the environment in other ways as well.

Almost all living organisms need oxygen for cellular respiration. That oxygen is produced as a waste product of photosynthesis. We need enormous numbers of plants to photosynthesise to maintain atmospheric and water oxygen levels. Living organisms produce carbon dioxide as a waste product when they respire. Carbon dioxide is a greenhouse gas – it helps to trap heat from the sun around the surface of the Earth. It is also poisonous at high levels. However, carbon dioxide is also vital for photosynthesis to take place. Plants and other photosynthesising organisms remove carbon dioxide from the atmosphere all the time. So photosynthesis is very important for maintaining the balance of oxygen and carbon dioxide in the atmosphere.

If something happens to affect this balance, it can affect the life of everyone on Earth. For example, if carbon dioxide levels build up, this may lead to global warming. Anything which reduces the amount of carbon dioxide removed from the atmosphere by photosynthesis can lead to a carbon dioxide build-up. In many countries around the world, people have been cutting down trees both to use for timber and also to provide more open land for growing food crops or grazing cattle. This deforestation results in the loss of massive areas not only of trees but of all the other plants which grow in a wooded area. In South America deforestation is a tremendous problem with vast areas of tropical rainforests being destroyed every year. Once they are lost it is hard to replace that richness and variety of plants.

Figure 4.9 *Billions of photo-synthesising plants have been lost in Ethiopia as we have cut down our forests – and huge amounts of carbon dioxide remain in the atmosphere which should have been taken up as the trees and other plants photosynthesised.*

We in Ethiopia have been involved in the process of deforestation – between 1990 and 2005 only we reduced our beautiful forests by 14% – that is about 2.1 million hectares of photosynthesising woodland. Loss of photosynthesising power like this can lead to a build-up of carbon dioxide in the atmosphere and ultimately an increase in global warming. However, here in Ethiopia we have recognised the problem and we are leading the way in replanting forests with native trees. You will learn more about global warming in unit 5, section 5.5.

Summary

In this section you have learnt that:

- Photosynthesis is the process by which:

  carbon dioxide + water [+ chlorophyll + light energy] → glucose + oxygen

  $6CO_2 + 6H_2O$ [+ chlorophyll + light energy] → $C_6H_{12}O_6 + 6O_2$
- The light energy needed for photosynthesis is captured by the green pigment chlorophyll.
- The light-dependent reactions of photosynthesis depend on the presence of light to occur, while the light-independent reactions do not need light directly (although they need the products of the light reactions).
- The glucose made in photosynthesis can be converted to insoluble starch for storage to avoid osmotic problems.

- The glucose made in photosynthesis can be used in respiration to provide energy.
- The energy released in the plant during respiration is used to build up smaller molecules into larger molecules, e.g. cellulose, lipids and oils and chlorophyll.
- Leaves are well adapted to allow the maximum photosynthesis to take place.
- The need for carbon dioxide, water, chlorophyll and light in photosynthesis can all be demonstrated experimentally.
- The glucose made in photosynthesis is converted into starch for storage in the cells. It may be stored in special storage organs such as stems or root tubers to help the plant survive adverse conditions.
- Explain how photosynthesis helps to balance the concentrations of oxygen (O_2) and carbon dioxide (CO_2) in the atmosphere.
- Photosynthesis is very important in agriculture as the source of all the new plant biomass.
- Much photosynthesis takes place in water bodies and that people need to try and make use of this.
- Deforestation may lead to a CO_2 build-up in the atmosphere and finally to global warming.

Review questions

1. Iodine is used to test for which substance to show that photosynthesis has taken place in the leaf of a plant?

   A glucose

   B cellulose

   C protein

   D starch

2. Which of the following is not needed for photosynthesis to take place?

   A carbon dioxide

   B oxygen

   C chlorophyll

   D light

3. Photosynthesis is a process that requires a pair of raw materials, a pair of conditions and produces a pair of products.

   Name the:

   i) pair of raw materials

   ii) pair of conditions

   iii) pair of products

4.3 Transport

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

- Explain water uptake by the roots.
- Explain the mechanism of water movement in plants.
- Describe transpiration, the factors affecting it and its implications for agriculture.
- Demonstrate water transport in plants using simple experiments.
- Explain the mechanism of uptake of mineral salts through roots.
- Describe the movement of organic materials in the phloem.

As you saw in grade 9, osmosis plays a very important role in plants. Now you are going to look at the main transport systems in plants. These transport systems rely heavily on osmosis, diffusion and active transport.

Trees are obviously supported by their woody trunks. But many plants do not have woody tissue, and so they have no structural support. They rely on having cells which are rigid and firm. These firm cells are maintained by the movement of water into the cells by osmosis to create turgor. This is one reason why osmosis is so important for plants.

KEY WORDS

root hairs *hair-like extensions that increase the surface area, thereby enhancing osmosis*

Osmosis is not only vital for keeping the plant cells turgid. It is also very important for moving water around within the plant itself. Plants take up water through their roots. The water in the soil has a very low concentration of dissolved minerals. In other words, there is a very high concentration of water. Water moves into the plant root cells across the cell membrane along a concentration gradient. The roots are covered with special cells, which have tiny hair-like extensions called the **root hairs**. These root hairs increase the surface area for osmosis to take place. Once water has moved into the root hair cells, the cytoplasm of the root hair cells is more

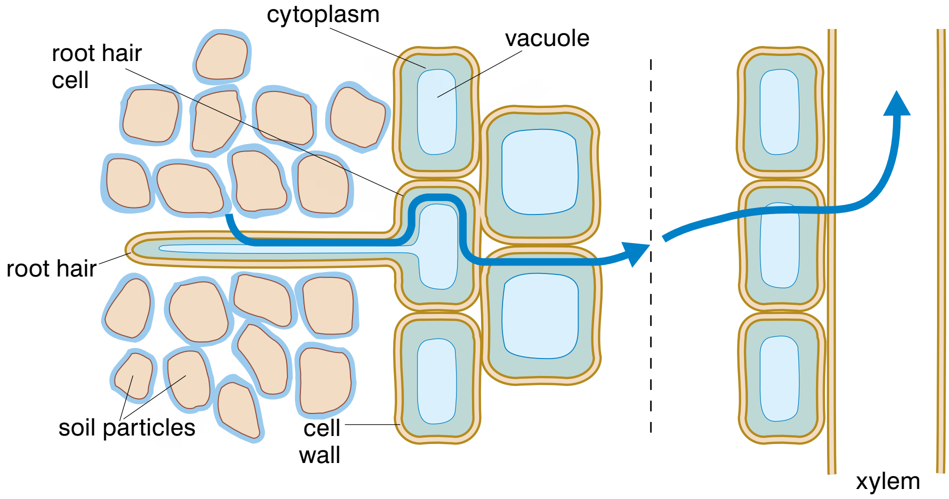


Figure 4.10 *Water moves across the tissues of a plant by osmosis. It moves along a water potential gradient.*

dilute than the cytoplasm of the surrounding cells. Water moves into the neighbouring cells by osmosis (see figure 4.10). These cells now have more dilute cytoplasm than the cells next to them, and the water moves on by osmosis until it reaches the xylem and the transpiration stream.

Active transport in plants

Plants don't just rely on osmosis and diffusion. Active transport is also widely used in plants. There are some situations where active transport is particularly important. For example, the mineral ions in the soil are usually found in very dilute solutions – more dilute than the solution within the plant cells. By using active transport plants can absorb these mineral ions, needed for making proteins, and other important chemicals from the soil, even though it is against a concentration gradient. Active transport like this involves the use of energy produced by respiration in the cells.

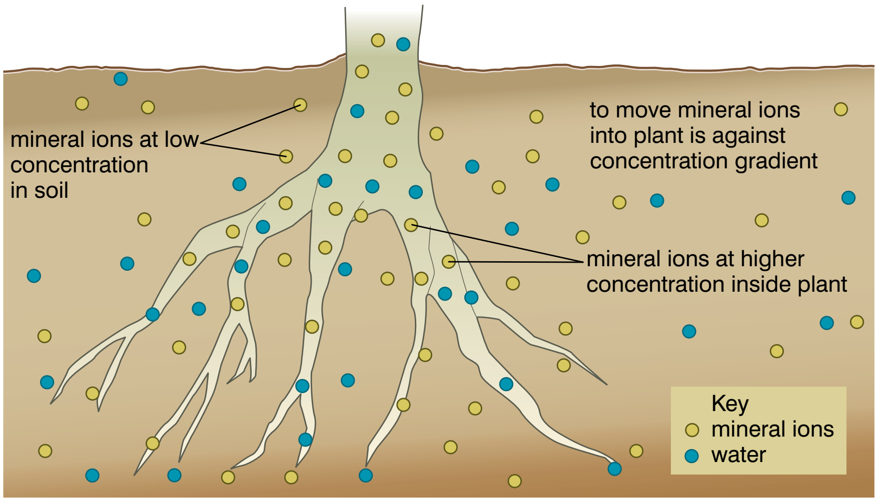


Figure 4.11 It takes the use of energy in active transport to move mineral ions against a concentration gradient like this.

So far we have looked at how substances – water and minerals – are transported into plants. Now you are going to study the ways in which substances are transported around the plants themselves.

Transport of materials around the plant

As you have seen in this unit, plants make food by photosynthesis in the leaves and other green parts but it is needed all over the plant. Similarly water and minerals move into the plant through the roots in the soil, but they are needed by every cell in the body of the plant. Plants need a transport system to move substances around their bodies.

A double transport system

There are two separate transport systems in plants. The **phloem** is made up of living tissue and it is involved in the transport of organic materials – the nutrients made by photosynthesis – from the leaves to the rest of the plant. Phloem cells are thin walled and are regularly replaced when they are worn out. They contain a liquid rich in sugar.

Figure 4.12 *Trees like this Keraro can be many metres tall – and then the roots go down almost as far underground. Plants need a very effective transport system to move substances distances like these.*

KEY WORDS

transpiration *the process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, principally from the leaves*

passive *requires no energy from the plant*

When insect pests such as aphids attack plants, they stick their feeding parts into the phloem to suck up the food-rich liquid. By depriving much of the plant of food, these pests can destroy crops and cause terrible hardship.

The plant has to use energy to move substances around the phloem, and food substances can move both up and down the plant. The nutrients are carried to all the areas of the plant including the growing regions where they are needed for making new plant material, and the storage organs where they are needed to provide a store of food for the winter.

The **xylem** is the other transport tissue. It carries water and mineral ions from the soil around the plant. The xylem tissue is dead and there is no active transport taking place. The movement of the water in the xylem is due to **transpiration** (see the next few pages) and it is **passive**. This means it uses no energy from the plant. Water only moves up from the roots to the leaves.

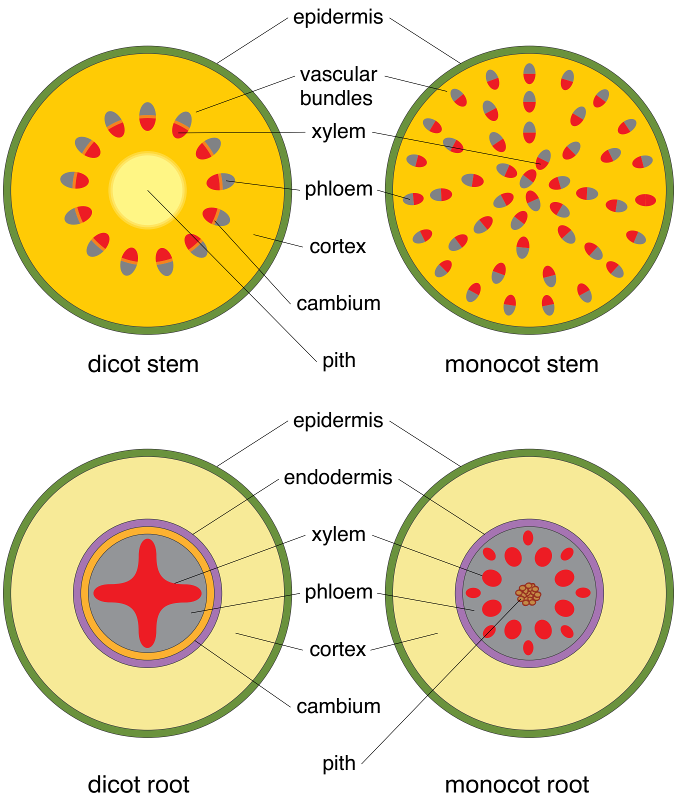


Figure 4.13 *The transport system in a non-woody plant is arranged in bundles around the outside of the stem, with the xylem and the phloem arranged together. In the root the transport tissue is all in the centre.*

In woody plants like trees the xylem tissue makes up the bulk of the wood, and the phloem is found in a ring just underneath the bark. This makes young trees in particular very vulnerable to damage by animals because, if a complete ring of bark is nibbled, transport in the phloem comes to a complete halt and the tree will die. Sometimes the animals have to be killed to protect the young trees.

The need for transport in plants

The importance of moving the food made by photosynthesis around the plant is obvious – all the cells need glucose for cellular respiration as well as materials for growth. The sugars that are produced in the leaves and carried all around the plant can also be

Activity 4.7: Finding out about the distribution of plant transport tissues

You will need:

- either a small plant with its leaves and roots intact or a bean seedling which has been grown in the dark so it is very pale or a plant with white flowers
- a beaker or jar containing water with a coloured dye
- a sharp knife or scalpel
- a sheet of white paper or a white tile

Method

1. Wash the soil off the roots of your plant if there is any attached.
2. Stand your plant in the jar containing coloured water for about 24 hours.
3. Remove the plant from the water. Observe its appearance, particularly if it is a pale plant or has white flowers. Make a note of what you see.
4. Cut the stem of the plant in half across the plant – where is the dye? Use a hand lens to look more closely and draw what you see.
5. Then cut the stem lengthways to see if you can find out more about where the dye is found within the stem. Draw and label your findings.
6. Repeat these steps with the roots.
7. Explain your observations.

stored. However, plants cannot store sugars, because they have an osmotic effect. If a cell had lots of sugar in it, lots of water would move into it by osmosis. So sugars are converted into starch, which is osmotically inert. This means that a cell can contain lots of starch and it has no effect on the movement of water by osmosis into or out of the cell. The starch stored in plant cells is broken down to sugars again to provide them with energy when the need arises – for example, when there isn't enough light to photosynthesise.

One of the main places where starch is stored is in the storage organs of plants. Root tubers, stems and leaves can all be filled with starch to form storage organs. These enable plants to survive difficult conditions and also to reproduce.

Starch is also deposited in large amounts in many fruits and seeds. In fruits the starch provides a reason for animals – including people – to eat the fruit and the seeds, helping to disperse the seeds. In the seeds, starch is one of the energy stores for the developing embryo to use as the seed starts to develop. We take advantage of these starch stores in plants and use them as food. Starch from plants is a very good energy source for people all around the world!

Figure 4.14 *These bananas and cassava are very rich in starch, which provides energy for the plant, and also for any people who eat them!*

The movement of water and minerals from the roots is just as important as the movement of food. The minerals are needed for the production of proteins and other molecules within the cells. The water is needed for two main reasons. One is that water is needed for photosynthesis and without water photosynthesis cannot take place. Less obviously, but just as important, water is needed to maintain the turgor pressure within the cells. As you saw earlier, water moves into plant cells by osmosis. This produces turgor so the cytoplasm presses against the cell walls. In fact for young plants and non-woody plants this is the main method of support. This pressure in the cells is very dependent on water moving up through the xylem from the soil. It is also very important in keeping the leaves firm and spread out to catch the sunlight. If the supply of water stops, the whole plant, or just the leaves, will wilt and all the chemical processes of photosynthesis and respiration will be affected.

Activity 4.8: Using food tests to investigate the content of plant storage organs

You will need:

- plant storage organs such as cassava roots, potatoes or onions
- iodine solution
- Benedict's solution
- a pestle and mortar
- a beaker
- test tubes
- a white tile
- a Bunsen burner
- a heatproof mat
- gauze
- goggles
- tongs

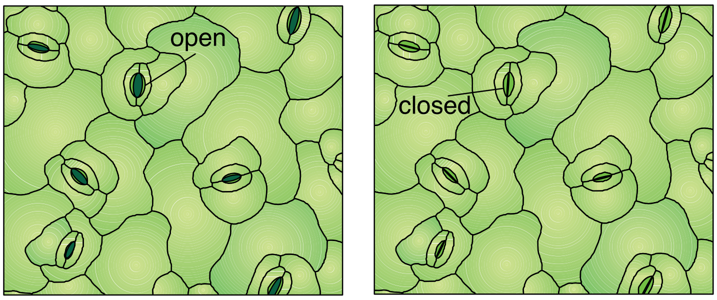
Method

1. Draw and label the storage organ you are investigating.
2. You are going to test the contents of a plant storage organ for the presence of starch and of reducing sugars.
3. Take a small sample of the storage organ and carry out the iodine test for starch. Record your results.
4. Take another sample of the same storage organ and grind it up with a little water in the pestle and mortar.
5. Now use Benedict's solution to test for reducing sugars in the plant tissue.
6. Write up your investigations, including your observations, and record your results. What does this tell you about the contents of the plant material you have investigated?

The transpiration stream

Water is taken into a plant through the roots and moves by osmosis to the xylem tissue. There is no active transport in the xylem. So how is water moved from the roots of a plant up to the uppermost leaf, a distance which can be many metres? The transport of water through a plant is the result of the transpiration stream.

Plants lose water vapour from the surface of their leaves. This loss of water vapour is known as transpiration. Most of the transpiration takes place through the tiny holes in the surface of the leaf known as stomata. The stomata are there to allow air containing carbon dioxide into the leaf for photosynthesis. They can be opened and closed by the guard cells which surround them (see activity 4.9). Losing water through the stomata is a side effect of opening them to let carbon dioxide in, but it is vital for transpiration. Most of the stomata are found on the underside of the leaf.



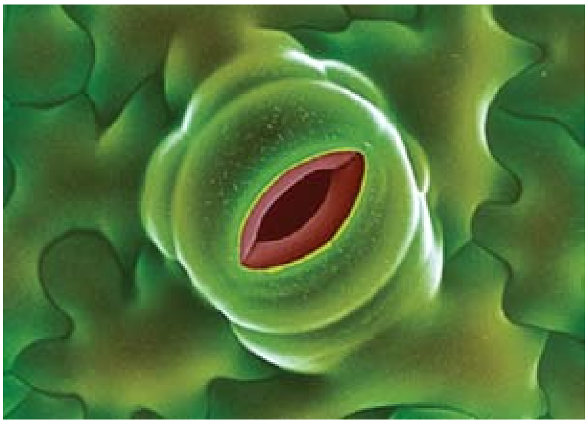


Figure 4.15 *Guard cells open and close the stomata to control both the carbon dioxide going into a cell and the water coming out of it.*

Activity 4.9: Looking at the stomata in a leaf

You will need:

- a *Tradescantia* sp. or a *Commelina* sp. plant
- a pot of clear varnish (for nails, or other varnish)
- a paintbrush
- forceps
- a microscope slide, coverslip, dropper and mounted needle (for making a temporary mount)
- a light microscope

Method

1. Take a leaf from the plant.
2. Apply a thin layer of clear varnish to a small area of the underside of the leaf. It is worth covering several patches in case you have problems with one of them.
3. Once the varnish is dry, peel it off carefully with forceps or your fingernails. The varnish will have made an exact copy of the surface of the leaf.
4. Put the varnish film on a slide with a drop of water and cover with a coverslip – remember to avoid air bubbles if possible.
5. Examine your slide under the low power of the microscope. Can you see the stomata? Approximately how many are visible in your field of view? Can you tell if they are open or closed? If so, what proportion are open?
6. Now move a single stoma to the centre of your field of view and look at it under the higher powers of magnification. Can you see the guard cells? Draw and label the stoma.
7. If you have time, repeat this process for the top surface of the leaf. How do the numbers of stomata compare?

What affects the opening and closing of the stomata? This seems to be linked to osmosis. Guard cells contain chloroplasts so they can photosynthesise, unlike the other cells in the epidermis layer. So when there is sunlight, the concentration of sugar in the guard cells goes up as a result of photosynthesis. Water then moves into the guard cells by osmosis from the epidermal cells around them. The sausage-shaped guard cells become very turgid, and as they swell up they bend, opening a gap – the stoma – between them (see figure 4.15). The pore closes by the reverse process – water moves out of the guard cells by osmosis into the surrounding cells and as the level of turgor in the guard cells falls, the stoma closes.

You can make a model of a stomatal pore using long balloons to represent the guard cells. Try it yourself – when the balloons are

KEY WORDS

adhesive forces *forces of attraction between different types of molecule*

cohesive forces *forces of attraction between similar types of molecule*

fully blown up, the pore is open. When the balloons are slightly deflated, the pore closes.

Moving water through the plant

As water evaporates from the surface of the leaves, water is pulled up through the xylem to take its place. This constant moving of water molecules through the xylem from the roots to the leaves is what is known as the transpiration stream. What factors move the water upwards?

There is pressure pushing the water up from the bottom – the root pressure – as water moves in by osmosis.

In the xylem, two physical forces help the water to move upwards. There are **adhesive forces** between the water and the walls of the xylem which support the whole column of water, no matter how tall it is. And as molecules evaporate away from the surface of the leaf, the following molecules are pulled upwards by **cohesive forces** between the water molecules. In other words, the water molecules tend to stick together and get pulled upwards like a string of beads.

However, the main pull which moves water up from the roots to the leaves is the almost constant evaporation of water from the leaves.

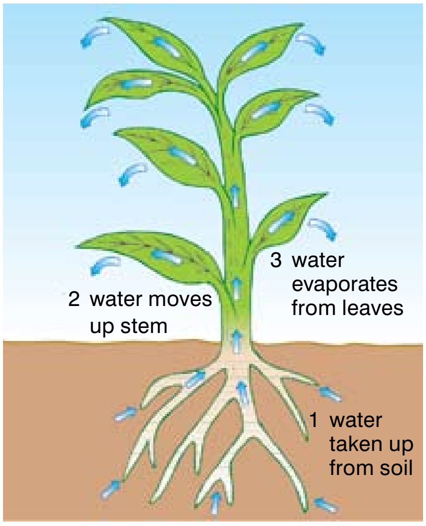


Figure 4.16 *The transpiration stream – capable of pulling a column of water in the xylem up to 30 m above the surface of the Earth.*

When water reaches the xylem in the leaves, there is a reversal of the situation in the roots. Now the solution in the xylem has a much higher concentration of water than the solution in the mesophyll cells in the leaf. Water moves out from the xylem into the mesophyll cells and so across the leaf by osmosis. When it reaches a mesophyll cell which is surrounded by air, water evaporates from the surface into the air and diffuses out through the stomata along a concentration gradient.

Factors affecting the role of transpiration

Because the transpiration stream is driven mainly by the evaporation of water from the leaves, anything which affects the rate of evaporation will affect transpiration.

Conditions which increase the rate of evaporation also increase the rate of transpiration. The higher the temperature, the more evaporation takes place. Water evaporates more rapidly into dry air than into humid air. If the air is moving – it is windy – then water-vapour-rich air is always being removed from around the leaf. This maintains a good concentration gradient for diffusion and increases evaporation. So transpiration is more rapid in hot, dry and windy conditions than it is in still or humid conditions.

Plenty of light also speeds up transpiration. In good light conditions, lots of photosynthesis takes place and so the stomata are opened to allow plenty of carbon dioxide in. When the stomata are open, lots more water can evaporate from the surface of the leaves.

Activity 4.10: Investigating factors which affect transpiration – 1

In this activity you are going to investigate transpiration using a piece of apparatus which measures the amount of water lost from the leaves of a plant. You can use shoots from a plant or whole plants for this experiment.

You will need:

- apparatus as shown in figure 4.17
- an accurate balance
- Vaseline

Method

You can carry out this investigation by measuring the amount of water taken up by the plant, by measuring any change in mass, or both. Make sure you record whatever observations you make very carefully.

1. Set up several sets of the apparatus as shown in the diagram.
2. Take your initial readings of the water level in the cylinders and of the mass (if used).
3. Place one set of apparatus by the window.
4. Place another set of apparatus with a light shining on it all the time, day and night.
5. Cover the underside of the leaves of another plant with Vaseline.
6. If you have a fan, place one of the plants in a constant gentle air flow.
7. Leave all the plants for 24 hours.
8. Repeat all your measurements and record them.
9. Write up your investigation and discuss your findings.

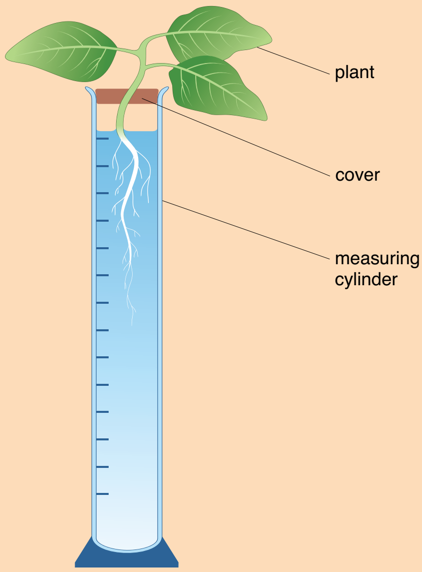


Figure 4.17 *Apparatus for measuring water loss in plants*

Activity 4.11: Investigating factors which affect transpiration – 2

In this investigation you are going to investigate transpiration using a piece of apparatus called a potometer, which measures the amount of water taken up by a plant. You need shoots from a plant for this experiment. Although this is not a perfect measure of transpiration, it can give us a good picture of what affects the rate. If you get your apparatus set up well and quickly, you will be able to investigate several different conditions in a single lesson.

You will need:

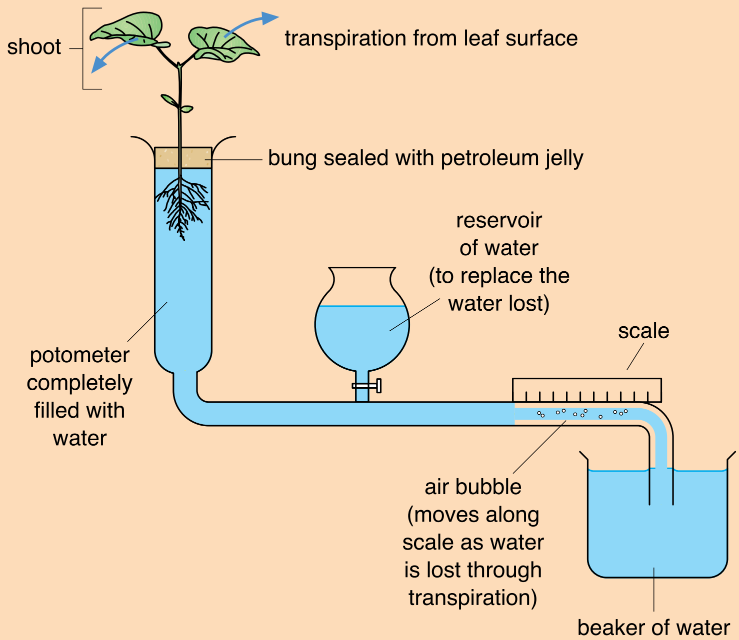


Figure 4.18 *A potometer*

Method

1. Set up your equipment as shown in Figure 4.18. You need to take care with your leafy shoot – cut it under water and transfer the cut end straight into the water-filled tubing. It is important NOT to get air into the stem of the plant.
2. Position your apparatus in good light and, using the reservoir, position the air bubble near the end of the scale.
3. Start timing. You may measure how far the bubble travels in five minutes (set time, measure distance) or you may choose to measure how long it takes your air bubble to travel from one end of the scale to the other (set distance, measure time). Record your measurements. Once you have tried the procedure, decide which way of measuring you want to use.
4. Repeat your investigation twice more to get three readings.
5. Now change the conditions – shine an extra light on your plant to increase the light intensity, fan the plant to increase air movement, etc.
6. Reset the air bubble and again record the movement of the air bubble – distance travelled in a set time or time taken to travel a set distance.
7. Again, repeat this to take three readings.
8. If you have time, change the conditions again – you could use light and breeze or a stronger breeze, etc.
9. Again, repeat the procedure to take three separate readings.
10. Write up your investigations, including all your results. Find the average reading for each set of conditions and plot a graph of your findings. What conclusions can you draw from your investigation? What further investigations would you like to do? How could you make your procedure more reliable and accurate?

Activity 4.12: Investigating factors which affect transpiration – 3

This investigation involves using cobalt chloride (or cobalt thiocyanate) paper. This is blue when it is dry, but turns pink when it is moist. You can use this investigation to look at how different conditions affect the rate of transpiration. If you work in groups, different people can investigate different conditions and then you can share your results.

You will need:

- cobalt chloride paper or cobalt thiocyanate paper
- a plant in a pot or a leafy shoot in water
- clear sticky tape

Method

1. Stick one piece of cobalt chloride (or cobalt thiocyanate) paper to the top surface of a leaf. Make sure the leaf is completely dry and cover the paper completely with the sticky tape.
2. Stick another piece of paper to the lower side of a different leaf in the same way.
3. If working in groups, some people keep the plant in normal lab conditions, some shine a bright light on the plant, some have the plant in a breeze, etc.
4. Note the time and observe the two pieces of indicator paper at intervals. How long does it take for the first trace of pink to appear on each piece of paper? How long does it take for each piece of paper to go completely pink?
5. Write up your experiment and collect results from other groups using the same or different conditions from your own.
6. Work out the average results for each set of conditions and use your findings to help you answer the following questions:

   Which side of the leaf loses water faster – the upper or the lower?

   Why do you think one side loses water faster than the other?

   How do different conditions affect the speed at which the plant loses water by transpiration?

Reducing water loss

If a plant begins to lose water faster than it is replaced by the roots, it runs the risk of wilting. The stomata in the leaves will close to stop this if possible. To make sure that water is not lost from the surface of the leaf generally, most leaves have a waxy, waterproof layer (known as the **cuticle**) to prevent uncontrolled water loss. In very hot environments the cuticle may be very thick and shiny. The fact that the stomata are on the underside of the leaf also helps because this means that they are not as exposed to the heat of the sun as they would be on the top of the leaf.

KEY WORDS

cuticle *waterproof upper surface layer found in many types of leaf*

Activity 4.13: To investigate water loss from the leaves of a plant

You are going to plan and carry out an investigation into the loss of water by a plant through its leaves. If you cover the surface of a leaf with Vaseline, you will block all the stomata and so prevent water loss. You are provided with the following:

- up to four small plants of the same species in pots
- Vaseline
- an accurate balance
- string

You may choose to experiment on whole plants or on individual leaves.

Plan an investigation following clear scientific principles to find out through which surface of the leaves a plant loses most water.

When your teacher has agreed to your plan, you may be allowed to carry out the investigation.

Adaptations of plants to reduce water loss in difficult environments

Plants manage to grow and survive in many different environments. In many places survival is a real struggle. Plants need to balance opening the stomata to allow photosynthesis to take place with the loss of water which takes place when the stomata are open. Plants which live in very hot areas like Somali, or in areas where there is relatively little water, often have adaptations which help them to balance up their different needs. They may have very thick, waxy cuticles to reduce any water loss through the overall leaf surface to an absolute minimum. Others have developed very hairy leaves, which trap a micro-atmosphere around the stomata and reduce water loss. Yet other plants have reduced their leaves to very narrow spikes to reduce the surface area over which water may be lost. On some plants the stomata are sunk into pits. Another way of preventing water loss, which you often see in grasses, is for the

Figure 4.19 *Aloe vera – this plant stores water in its fleshy leaves.*

Activity 4.14: Investigating ways of reducing water loss in Ethiopian plants

Explore the area around your home and your school. Collect leaves from a number of plants which you think may be adapted to prevent water loss.

Take them into your class and examine them carefully using a hand lens and possibly a microscope. You may want to make a varnish film from the leaves.

Draw and label the leaves you have investigated and make notes about your findings.

leaves to be rolled, trapping a micro-environment of moist air inside. The purpose of all these adaptations is to reduce the loss of water from the leaves by transpiration, so the plant can photosynthesise and avoid wilting whatever the conditions around it.

Transpiration and agriculture

Transpiration has many implications for the way we grow our crops – and the crops we choose to grow. If our crop plants do not get enough water, then they will not be able to transpire and they will wilt. This means the cells will not work properly and the crops will not grow as well as they should. So, whenever possible we need to irrigate our fields and water the plants so that they can transpire fully, which allows them to photosynthesise and grow as much as possible.

It is not only the level of sunlight and the temperature which affects transpiration rates in our plants. Wind also increases the rate of transpiration. If we can grow our crops in relatively sheltered places, the rate of water loss will be slower and so our crops are more likely to grow well.

The final way in which transpiration affects agriculture is in our choice of crop plants. Some plants are more resistant to water loss by transpiration than others. By choosing crops which are suited to the conditions where we are growing them, we can improve our yields and make sure that transpiration works for us and does not cause our plants to wilt and fail.

Summary

In this section you have learnt that:

- Water is transported from the roots to the rest of the plant in the xylem in a passive process which does not use energy.
- Water is taken up by the roots of the plants through osmosis.
- Water moves through the cells of the root to the xylem by osmosis. Once in the xylem, adhesive forces between the water and the walls of the xylem support the whole column of water, and as molecules evaporate away from the surface of the leaf, the following molecules are pulled upwards by cohesive forces between the water molecules. The main pull which moves water up from the roots to the leaves is the almost constant evaporation of water from the leaves. In the leaves water moves out of the xylem into the cells and across the leaf. When it reaches a mesophyll cell which is surrounded by air, water evaporates from the surface into the air and diffuses out through the stomata along a concentration gradient.
- The movement of water through the plant is known as transpiration. It is affected by a number of factors including light levels, temperature and wind.

- Plants are constantly losing water through transpiration, farmers need to irrigate their crops. Methods to reduce water loss through transpiration such as sheltered fields reduce the need for irrigation.
- Water transport in plants can be demonstrated using simple experiments.
- Mineral salts are taken in through the roots using active transport.
- Organic materials such as sugars from photosynthesis are moved around the plant in the phloem in an active process.

Review questions

1. Which of the following conditions will not increase the rate of transpiration in a plant?
   A high humidity in the air
   B windy conditions
   C high temperatures
   D high light levels
2. Water moves out of plant leaves through the:
   A epidermis
   B mesophyll
   C stomata
   D chlorophyll
3. Cobalt thiocyanate changes colour in the presence of water. Does it go from:
   A pink to blue
   B blue to pink
   C blue to yellow
   D pink to white
4. Explain why a constant supply of:
   a) food
   b) water
   is so important to the cells of the plant.
5. a) What are stomata?
   b) What is their role in the plant?
   c) Describe exactly how water moves up the plant in the transpiration stream.

4.4 Response in plants

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

- Demonstrate the processes of germination in dicots and monocots.
- List the plant hormones.
- State the functions of the plant hormones.
- Outline the mechanism of action of auxins.
- Explain the effect of removing apical dominance on plant growth.
- Demonstrate how sunlight influences plant growth.
- Name the different types of tropisms in plants.
- Explain the processes of tropism.

KEY WORDS

hormones *chemicals produced in one part of an organism which produce specific effects on a different part of the organism*

endosperm *the nutritive tissue of a seed, consisting of carbohydrates, proteins and lipids*

plumule *the bud, or growing point, of the embryo, above the cotyledons*

radicle *the first part of a seedling (a growing plant embryo) to emerge from the seed during the process of germination*

cotyledons *the first leaves sent out by the germinating seed – the seed leaves*

testa *the hard external coating of a seed*

All living organisms need to be able to respond to their surroundings. This may be to find food, move towards the light or avoid danger. To take in information about the surroundings and then react in the right way is known as co-ordination. It is easy to see why animals need to respond, and you will be looking at co-ordination in animals later in this section. But plants need to be co-ordinated too. They need to respond to factors such as light, water and gravity to make sure that they grow the right way up, and that they make as much food by photosynthesis as possible.

Plants achieve their co-ordination and responsiveness through a system of **hormones**. Hormones are chemical messengers which are produced in one part of an organism and have an effect elsewhere. Plant hormones (phytohormones) have several effects on plants. For example, they co-ordinate flowering, cell division and cell elongation. These are essentially growth processes and plant responses of this type are called growth responses. Since growth is a slow process, most plant responses are slow.

Figure 4.20 *Plants respond to a number of things and their responses show clear co-ordination.*

The germination of seeds

In most flowering plants, growth starts when the seed begins to germinate.

Seeds come in many different sizes and shapes, but the basic structure of seeds always contains certain things:

- Food storage tissue known as the **endosperm**.
- An embryo plant made up of three main parts – the **plumule** (embryonic shoot), the **radicle** (embryonic root) and the **cotyledons** (embryonic leaves).
- The **testa** – the seed coat, which may be thin and papery like the covering on a groundnut or very strong and hard like the shell of a nut.

It is the number of these embryonic leaves that are present which gives us the main division of the angiosperms into monocotyledons (one seed leaf) and dicotyledons (two seed leaves).

In monocots the main food store is the endosperm and the embryo remains a very small part of the seed. In dicots the endosperm moves food into the cotyledons which become the main food store. By the time the seed is mature the endosperm has all but disappeared. The embryo with its food-swollen leaves takes up most of the seed (see figure 4.21). Once the food store has been laid down and the embryo has developed the seed dries out (dehydrates). It loses much of its wet mass and becomes dormant.

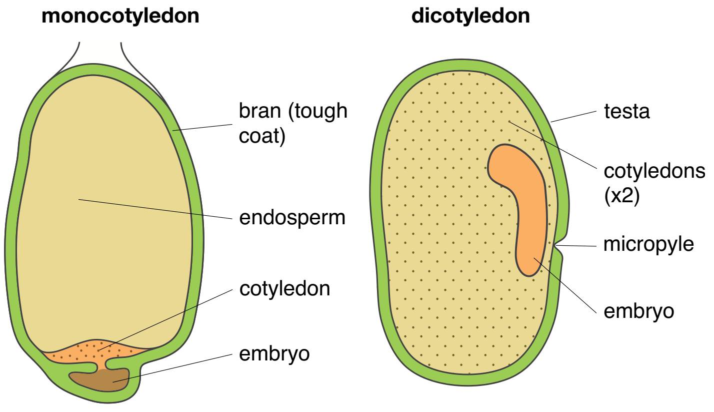


Figure 4.21 *The internal arrangements of monocot and dicot seeds may look very different, but their basic parts are the same – an embryo ready to develop, a food store to supply the energy needed and a protective seed coat.*

Activity 4.15: Investigating dicot and monocot seeds

You will need:

- a fresh or soaked dicot seed such as a bean or a pea
- a fresh or soaked monocot seed such as maize
- a knife or scissors
- a hand lens if available

Method

1. Observe and draw the external appearance of the two different seeds. You should be able to make out the shape of the radical through the testa and you may be able to see the micropyle, the tiny hole through which water enters the seed.
2. Remove the testa of the dicot seed and carefully separate the two cotyledons. Observe the embryo plant carefully (use a hand lens if you have one available) – and draw what you can see. Use figure 4.21 to help you.
3. Cut the monocot seed in half vertically and again observe, draw and label what you see.
4. Make a table comparing the two types of seed.

Once a seed is mature and conditions are right – it needs water, warmth and oxygen – the seed begins to germinate. To begin with chemical changes take place inside the seed. As the seed absorbs water, the large insoluble food molecules stored in it undergo changes. They are broken down (hydrolysed) into soluble food. The main food storage material in seeds is starch, and it is stored either in the cotyledons or in the endosperm. This starch store is converted to sugars by the action of the enzyme diastase. In some seeds fats and oils are stored. In these seeds the enzyme lipase catalyses the hydrolysis of fats to fatty acids and glycerol. Proteolytic enzymes present in the seeds catalyse the hydrolysis of proteins to amino acids.

A lot of energy is needed during germination. The seed cannot make its own food by photosynthesis while it is underground, so the energy needed comes from the stored food materials. It follows

KEY WORDS

hypocotyl *the first leaf-like structure that appears on a germinating seed. Grows upward in response to light*

epigeal *germination cotyledons are carried above the ground*

hypogeal *germination cotyledons remain below the ground*

therefore that as a seed germinates its weight decreases as the stored food is used up. The decrease in weight continues until the seedling is capable of photosynthesising.

The following is a summary of changes which occur during the germination of a bean seed – a dicot seed.

1. The seed absorbs water through the micropyle (small hole) and swells.
2. The testa (seed coat) bursts and the radicle emerges. The radicle continues to elongate and gives rise to many side roots.
3. As the radicle elongates it pushes the seed out of the ground. The curved part of the radicle which protrudes is called the epicotyl. The seed coat is discarded and the two cotyledons (seed leaves) open out and begin to photosynthesise.
4. The plumule emerges from in between the cotyledons and produces the first true leaves. At this stage, the young plant is called a seedling.

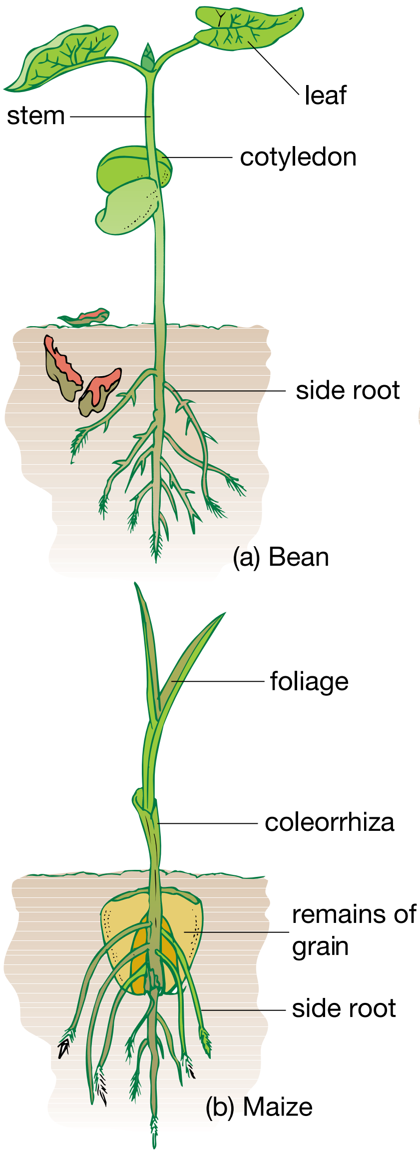


***Figure 4.22** a) Dicot (epigeal) germination, b) monocot (hypogeal) germination*

Epigeal (dicot) and hypogeal (monocot) germination

Seeds germinate in different ways. When the bean seedling emerges from the soil it is curved. The curved portion, the **hypocotyl**, pushes through the soil. As germination continues, the hypocotyl straightens and carries the cotyledons and the plumule above the soil surface. This type of germination, where the cotyledons are carried above the soil, is called **epigeal germination**. Most dicotyledonous plants have seeds which exhibit epigeal germination. Such seeds include castor oil seeds, groundnuts, cotton and bambara nuts. Epigeal germination also occurs in a few monocotyledonous seeds such as onions and lilies.

Germination of a maize grain follows a different pattern from that of a bean seed. The plumule pushes its way out of the soil while the cotyledon remains underground. The plumule does not form a hook as in bean seeds. This type of germination in which the cotyledons remain underground is called **hypogeal germination**. Other examples of grains exhibiting hypogeal germination are wheat, sorghum and millet. A few dicotyledonous seeds such as kidney beans and broad beans exhibit hypogeal germination.

Activity 4.16: Observation of dicot (epigeal) and monocot (hypogeal) germination in bean seeds and maize grains

You will need:

- bean seeds
- maize grains
- two beakers with blotting or absorbent paper around the sides and water in the bottom (see figure 4.23)

Method

1. Germinate some bean seeds and maize grains in two separate beakers.
2. Observe the seedlings as they emerge from the seeds.
3. Draw diagrams of the bean and the maize seedlings.
4. Compare your diagrams with those in figure 4.22.
5. Label your diagrams.

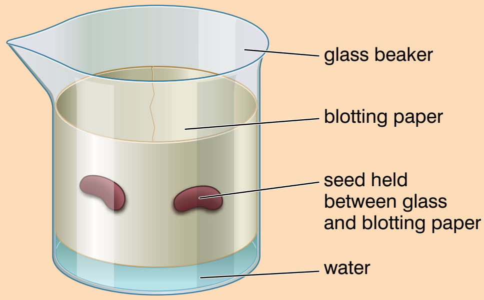


Figure 4.23 *Growing seeds in a beaker*

Germination of any type can occur only in a seed which is viable. A viable seed is one in which the embryo is alive. The length of time a seed can remain viable varies in different species. Many seeds can remain viable for up to 50 years if properly stored.

When seeds germinate it is vital that the parts of the seedling grow in the right directions. The new roots must grow down into the soil to get the water and minerals the new plant needs. The shoot must grow upwards towards the light so that the new shoots can photosynthesise and make as much food as possible so the seedling can grow. How is the direction of growth of plants controlled?

Plant hormones and growth

Growth in plants is influenced by chemical messengers called plant hormones. Examples of plant hormones are **auxins** (including indole-acetic acid, IAA), **gibberellic acid**, **cytokinin**, **ethylene** and **abscisic acid**. Some of these hormones promote growth, others inhibit it. Some of them will promote growth in one type of plant tissue and inhibit it in others!

Auxin (IAA) is the best-known plant hormone and it is involved in general plant growth. It stimulates the elongation of the new plant cells, so they get longer and bigger. It is also involved in **apical dominance**. IAA is made at the tip of the main shoot and as it moves down the stem it slows down the growth of side shoots. So the main shoot dominates the whole plant. If you cut off the growing tip of a plant it will bush out. The side shoots grow quickly once you remove the apical dominance from the auxins produced by the main shoot.

Auxin also stimulates the growth of roots. If auxin is applied to a cut stem it will stimulate new roots to grow – this is widely used by gardeners and farmers in some parts of the world to help them take successful cuttings.

The best-known function of auxins is in the responses of plants to the world around them. The responses of plants towards things such as light and gravity are called **tropisms** and you will be looking at these in more detail later in this section.

Another group of plant hormones are the **gibberellins**. These hormones stimulate the growth of plant stems. If you take a dwarf plant and give it IAA, nothing much will happen. If you give it

KEY WORDS

auxins *plant growth hormones*

gibberellic acid *a growth-stimulating and dormancy-breaking plant hormone*

cytokinin *plant hormones that promote cell division*

ethylene *a gaseous plant hormone that stimulates fruit ripening and the dropping of leaves*

abscisic acid (ABA) *a growth-inhibiting hormone*

apical dominance *growth concentrated in the terminal bud, allowing it to grow taller, thereby increasing its exposure to sunlight*

tropisms *the reactions of plants to stimuli*

gibberellins *group of hormones that regulate plant growth* gibberellins the stems will grow until the plant is a normal size. Gibberellins also help seeds to break their dormant period and start to grow. Scientists think they do this by stimulating the production of the enzymes needed to break down the food stores in the seeds.

Cytokinins are hormones that stimulate cell division in plants so they are very important in plant growth. The balance between auxins and cytokinins in a tissue culture of plant cells decides whether roots or shoots will grow.

Ethylene, a plant hormone, is a gas at room temperature and it causes fruit to ripen. It also causes fruit and leaves to fall from the plant in some species.

Abscisic acid (**ABA**) is another important plant hormone. It inhibits growth and plays a major role in leaf fall. It is also involved in seed dormancy. There is some evidence that it may be involved in geotropisms, but it plays a small part compared to IAA.

KEY WORDS

phototropism *the tendency of plants to move or grow towards light*

Tropic responses

Plants need light for photosynthesis, and they grow towards the light. When a seed germinates the roots grow downwards and the shoots grow upwards. These responses to gravity are vital if the new plant is to be anchored firmly in the soil, and the shoots and leaves held above the ground in the sun. Responses to stimuli that come from one direction are known as tropisms. The following investigations will allow you to observe some tropisms for yourself.

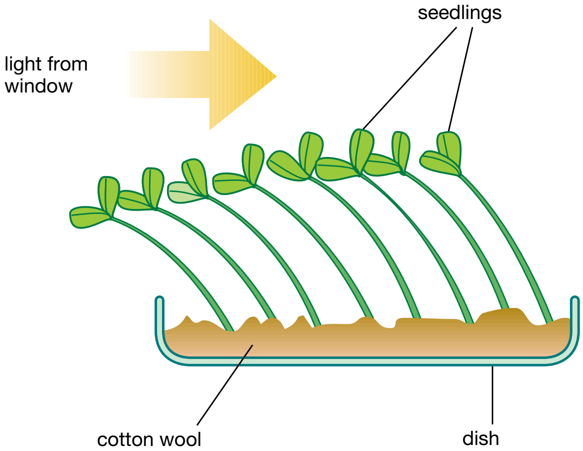
Activity 4.17: Determination of the effect of light on shoot growth

You will need:

- bean seeds
- pots
- soil
- a lightproof box with a hole on one side

Method

1. Germinate some bean seeds in two different pots.
2. When the shoots are about 6 cm long, place one pot in a lightproof box with a hole on one side, and the other pot in full sunlight.
3. Leave both pots in a well-lit place.
4. After 2–3 days observe what has happened to the seedlings in the two pots.



The shoots of seedlings which were uncovered will grow upwards normally. Those which were in a lightproof box grow towards the hole. Since the hole was the only source of light into the box, you can see that the growth curvature of the shoots was a response to light reaching the plants from one side only. This type of response in which shoots grow towards the light is termed positive **phototropism**.

Figure 4.24 *Seedlings respond vigorously to light – and if it only comes from one side, they will grow towards it.*

Light isn't the only thing that plants respond to – they are also affected by gravity.

Activity 4.18: Determination of the effect of gravity on shoot and root growth

You will need:

- bean seeds
- blotting paper
- a Petri dish

Method

1. Germinate some bean seeds on damp blotting paper in a Petri dish.
2. When the radicles and plumules have emerged, arrange the seedlings in two different positions. Place some seedlings in a horizontal position and others vertically with their radicles facing downwards.
3. Leave the setup for 2–3 days in the dark to eliminate the effect of light.
4. Observe what happens to the direction of growth of the radicles and plumules. Make careful annotated drawings of your results.

In activity 4.18 you will have observed that when seedlings are placed horizontally, their roots grow downwards and their shoots upwards. Roots of seedlings which were vertically placed continued to grow downwards and their shoots continued to grow upwards. Whichever way up you put the seeds the roots grow downwards and the shoots upwards. This suggests that the normal direction of growth of roots downwards and shoots upwards is affected by the force of gravity. Movement in response to the stimulus of gravity is called geotropism. Roots are positively geotropic (they grow towards gravity) while shoots are negatively geotropic (they grow away from gravity). The response of seedlings to gravity can also be investigated using a piece of apparatus known as a klinostat. This rotates, so by fixing some seedlings to the klinostat in a horizontal position (see figure 4.25) you can make sure that gravity acts equally all over the plant. You need other seedlings fixed horizontally but not rotated as a control. After two days you can see clearly the effect of the rotation. The root keeps bending towards gravity, and the shoot away from gravity, but because the stimulus is not unilateral, due to the klinostat the movements all cancel out and the plants stay straight!

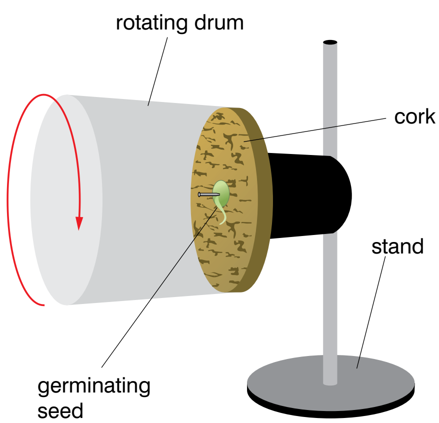


Figure 4.25 *A klinostat can effectively stop gravity from being a unilateral force on your plant.*

Light and gravity both have an important effect on the growth of plants. Water is also very important, and so it is not surprising that plants respond to water as well.

Activity 4.19: Investigating the effect of water on root growth

You will need:

- wire gauze
- bean seedlings
- cotton wool
- retort stand clamps

Method

1. Secure a wire gauze horizontally using two retort stand clamps.
2. Place some bean seedlings on the wire gauze in such a way that the radicles pass through the pores of wire gauze.
3. Surround the seedlings with wet cotton wool above the gauze.
4. Leave the setup for two to three days.
5. Make sure that the cotton wool is kept wet.
6. Observe what happens to the roots.

KEY WORDS

hydrotropism *the tendency of plants to move or grow towards water*

indole-3-acetic acid (IAA) *a plant growth hormone*

In activity 4.19 you should have observed that the radicles grew upwards towards the wet cotton wool. Since the cotton wool was the only wet area, it can be concluded that the growth curvature of the radicles was due to the water present in the cotton wool. The type of response by which roots grow towards water is termed **hydrotropism**. The growth of roots upwards towards water against the force of gravity suggests that water as a stimulus has a greater influence on root growth than gravity.

In each of the activities, the stimulus has been from one direction (unilateral) and the growth responses have been either towards or away from the source of the stimulus. These responses are therefore described as directional responses, tropic responses or tropisms.

How are tropic responses brought about?

As you can see from your earlier experiments, plants respond to unilateral stimuli. Further experiments have allowed scientists to find out more about these responses. Maize grains germinate to produce a straight shoot called a coleoptile. Coleoptiles are widely used in experiments to investigate the role of hormones in shoot growth.

It is known that the growth region of a shoot is some distance below the tip. This fact suggests that removal of the tip would not affect the growth of the shoot. However, when the tips of the coleoptiles are removed (they are decapitated), they don't grow. Since we know that the growth of a shoot is promoted by auxins, failure of decapitated seedlings to grow suggests that the auxins are probably produced in the tip. It has been found out that the growth hormone, auxin, produced in the tip is **indole-3-acetic acid** (**IAA**). IAA diffuses from the tip to the growth region to initiate growth. In the decapitated seedlings, although the source of IAA production was removed, the seedling grew for a while and then stopped. This is because some IAA had already diffused away from the tip before decapitation. This amount of IAA was responsible for the slight growth.

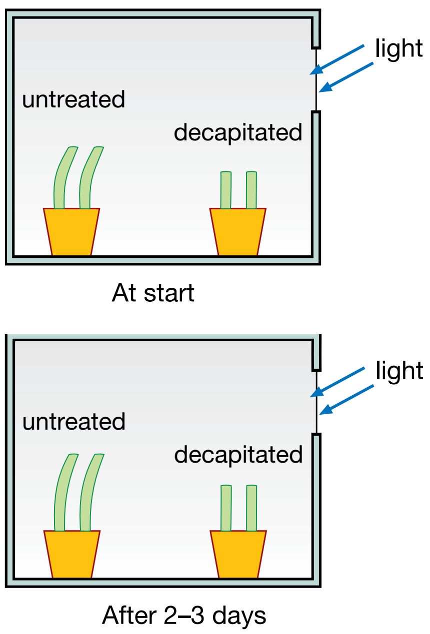


Figure 4.26 *A simple experiment like this suggests that growth is stimulated by something made in the tip of the shoot.*

The fact that IAA promotes growth in shoots suggests that it is also involved in the responses of the shoots to light and gravity. A simple experiment such as that in figure 4.25 shows you clearly that the tropic response of a plant to gravity is brought about by growth. Shoots lit from one side only also respond by growth – the shaded side grows faster than the illuminated side so the shoot bends over towards the light. IAA promotes growth so it seems likely that the shaded side of shoots affected by one-sided light had more IAA than the illuminated side. Since the growth curvature was influenced by light, it suggests that light is somehow involved in the distribution of IAA in the shoot. Experiments have shown that IAA diffuses away from light. When a shoot is illuminated on one side, IAA in that side diffuses towards the dark side of the shoot. This causes a build-up of the hormone in the dark side of the shoot. Since growth is directly proportional to the amount of IAA, the dark side will grow faster than the illuminated side. This explains the observed growth curvature of shoots shown in the experimental set up in figure 4.26.

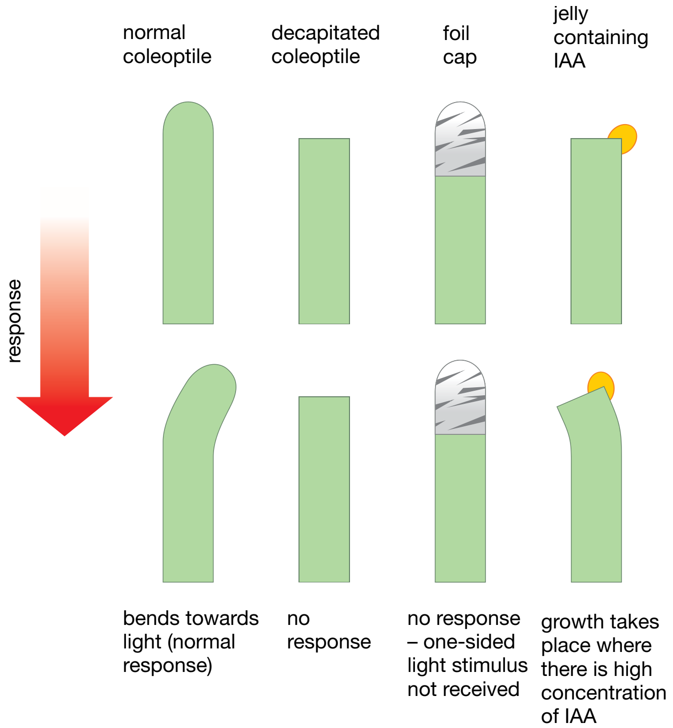


Figure 4.27 *Experiments such as these help us to understand how tropic responses in plants work.*

The upward growth of the shoot and the downward growth of the root, when the bean seedlings were placed horizontally, involve plant hormones. In the shoot, the force of gravity causes an accumulation of IAA on the underside of the plumule. The build-up of IAA on the underside promoted more growth in that region than the upper portion. This differential growth resulted in the stem growing upwards.

The downward growth of the root is also influenced by IAA, but in the root tip the hormone inhibits growth, rather than stimulating it. The force of gravity causes an accumulation of IAA on the underside of the root, resulting in reduced growth in that region. The corresponding upper side of the root, which had very little or no IAA, grows faster than the underside. This differential growth results in the downward curvature of the roots. The different effects of this hormone on root and shoot growth are illustrated in figure 4.28.

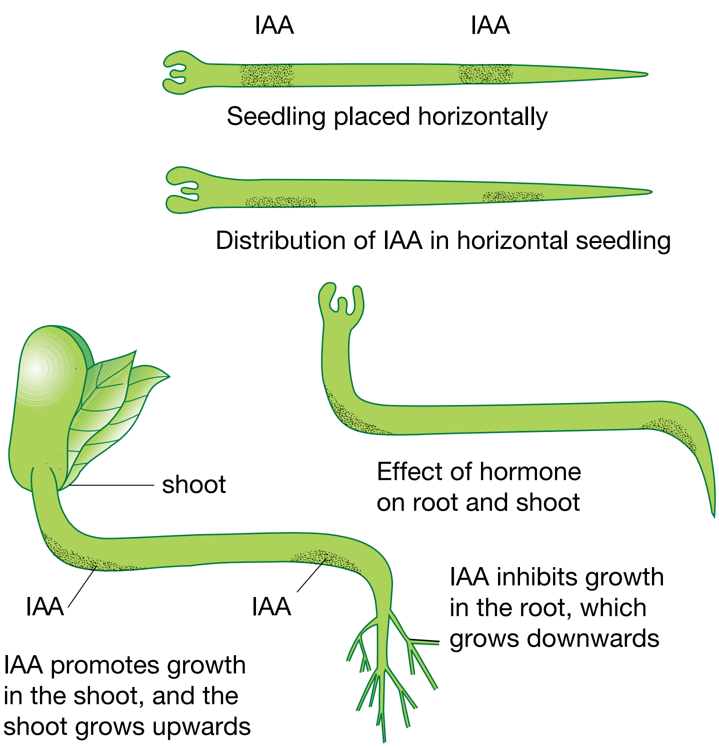


Figure 4.28 *The different effects of auxin on the growth of roots and shoots.*

Activity 4.20: Investigation of the role of the shoot tip in the growth of a plant

You will need:

- about ten maize grains
- two beakers
- cotton wool
- a lightproof box with hole at one side

Method

1. Germinate about five maize grains on damp cotton wool in each of two beakers. Germination should be done in darkness.
2. When the coleoptiles are about 4 cm long and are not yet open, cut off the tips of five coleoptiles in one beaker.
3. Leave the five seedlings in the other beaker intact.
4. Measure and record the height of each set of seedlings.
5. Place the beakers in a lightproof box which has a hole on one of its sides.
6. Leave the setup for 2–3 days.
7. Observe what has happened to each set of seedlings.
8. Measure and record the height of each set of seedlings.

Importance of tropic and nastic responses

In tropisms, some stimuli to which plants respond positively are the basic requirements for the plant's life. Water, for example, is one of the important requirements for photosynthesis. This means that when positive hydrotropism occurs, roots come into close contact with water. This makes it possible for them to absorb as much water and mineral salts as possible for the plant. In addition to water, plants require light for photosynthesis. When a plant responds positively to light its leaves become well exposed to it. This maximises the amount of light available for photosynthesis.

Summary

In this section you have learnt that:

- Monocot and dicot seeds both undergo germination when the new plant starts to grow, but the process differs in different types of seeds.
- Plants have hormones which include auxins, gibberellins and ethylene.
- Plant hormones have a number of different functions in the plant including the control of growth, the response to stimuli such as light and gravity, flowering and leaf fall.
- Auxins work by affecting the rate of growth and elongation of the cells. For example, if there is more auxin on one side of a shoot than the other, that side will grow more and the shoot will bend.
- If you remove the leading shoot from a plant you remove the apical dominance – this is the effect of the auxin made in the lead shoot which inhibits the growth of side shoots.
- Sunlight influences plant growth – it slows upward growth and causes responses to unilateral light. These effects can be demonstrated experimentally.
- There are several different types of tropisms in plants including phototropisms, and geotropisms.
- In a tropism, a plant responds to a stimulus by producing different levels of auxins which in turn affects growth. As a result, part of a plant grows towards or away from a stimulus.

Review questions

1. Which of the following is NOT a tropic response in plants?
   A phototropism
   B geotropism
   C nitrotropism
   D hydrotropism
2. The young shoots which are often used in experiments on tropisms are known as:
   A coleoptiles
   B adventitious roots
   C cotyledons
   D cornucopia
3. Which of the following is NOT a plant hormone?
   A IAA
   B gibberellin
   C abscisic acid
   D adrenalin

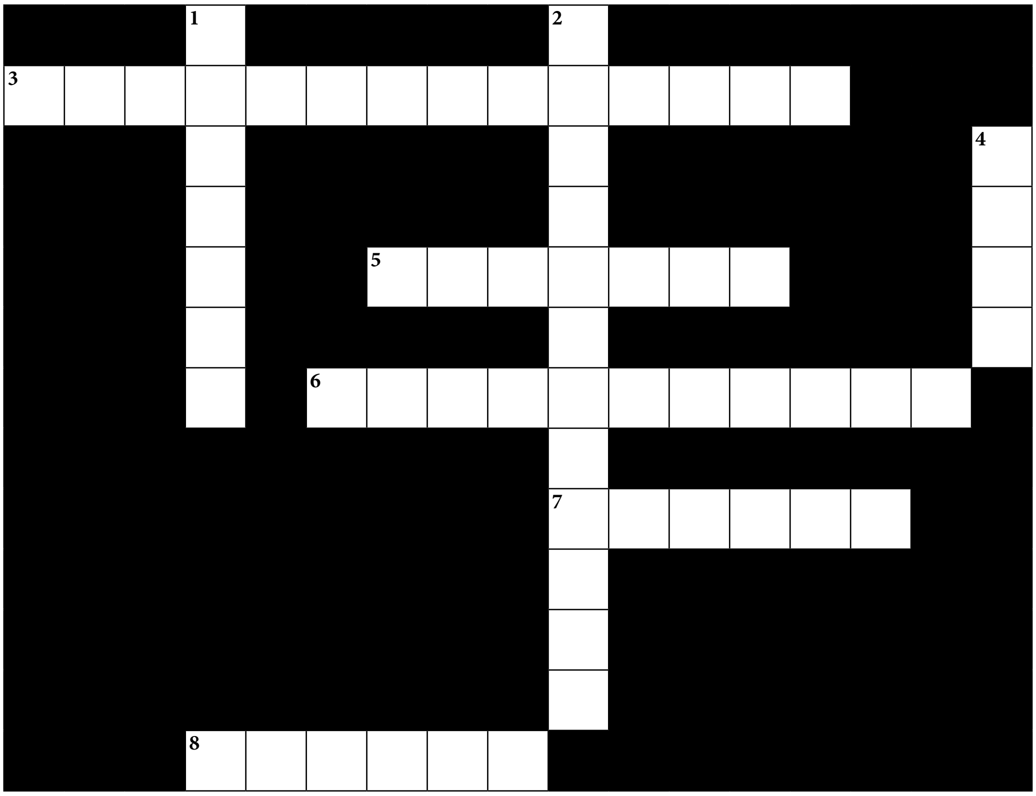
End of unit questions

1. The vascular bundles contain:
   A xylem and epidermis
   B epidermis and phloem
   C xylem and phloem
   D stomata and phloem
2. Which tissue contains the most chloroplasts?
   A epidermis
   B palisade mesophyll
   C spongy mesophyll
   D phloem
3. The stomata open and close to allow:
   A carbon dioxide to diffuse into the leaf and oxygen and water vapour to diffuse out of it
   B oxygen to diffuse into the leaf and carbon dioxide and water vapour to diffuse out of it
   C water vapour to diffuse into the leaf and carbon dioxide and oxygen to diffuse out of it
   D carbon dioxide, oxygen and water vapour to diffuse into the leaf

4. A leaf has large surface areas both outside and inside. Describe three ways in which these adaptations help it to photosynthesise effectively.
5. Which of the following is the correct equation for photosynthesis:
   A carbon dioxide + oxygen [+ chlorophyll + light energy] → glucose + water
   B oxygen + water [+ chlorophyll + light energy] → glucose + carbon dioxide
   C carbon dioxide [+ chlorophyll + light energy] → glucose + oxygen + water
   D carbon dioxide + water [+ chlorophyll + light energy] → glucose + oxygen
6. The glucose made during photosynthesis is converted into which compound to be stored?
   A fat
   B starch
   C cellulose
   D protein
7. Water is split to provide hydrogen to make glucose and oxygen as a waste product during:
   A the light-dependent reaction of photosynthesis
   B the light-independent reaction of photosynthesis
   C the trapping of light by chlorophyll
   D none of the above
8. Explain any two ways in which photosynthesis is important to animal life.
9. a) Define the term photosynthesis.
   b) State the environmental factors that are necessary for photosynthesis.
   c) How would you show the necessity of one of the factors you have given in b) above in photosynthesis?
10. Water is taken up through the roots of plants by a process known as:
   A diffusion
   B osmosis
   C active transport
   D evaporation

11. Farmers need to irrigate their fields to replace water because plants constantly lose water through:
    A osmosis
    B photosynthesis
    C transpiration
    D diffusion
12. Which of the following is not an adaptation used by some plants to reduce water loss?
    A thick waxy cuticle
    B stomata on the underside of the leaf sunk into pits
    C leaves reduced to thin spines
    D stomata on the upper surface of the leaf
13. Make a table to compare and contrast the structure and function of the xylem and the phloem in a plant.
14. Which of the following statements are correct?
    I shoots are positively phototropic but negatively geotropic
    II roots are positively hydrotropic but negatively geotropic
    III roots are positively hydrotropic and geotropic
    IV shoots are negatively hydrotropic but roots are negatively phototropic
    A I, II and III
    B I, III and IV
    C I, II and IV
    D II, III and IV
15. Which of these plant responses are not controlled directly by simple plant hormones?
    A shoots bending towards the light
    B fruit falling when ripe
    C roots bending towards gravity
    D the time of year a plant flowers
16. a) What is meant by phototropism?
    b) Describe an experiment which would demonstrate phototropism in shoots.
    c) Explain how you could demonstrate directly that IAA is involved in plant phototropisms.
17. Describe how a klinostat can be used to demonstrate the role of gravity in geotropisms.

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

3 The reaction by which plants make their own food from carbon dioxide, water and light energy (14)

5 A plant with only one cotyledon in the seed (7)

6 Green pigment which traps light energy for photosynthesis (11)

7 Food carrying, living transport tissue in plants (6)

8 Yellow-brown chemical which turns blue-black in the presence of starch (6)

DOWN

1 Pores in the lower surface of a leaf that control the entry and exit of gases (7)

2 The tendency of plants to move or grow towards or away from light (12)

4 Plant organ where most photosynthesis takes place (4)

Conservation of natural resources

Unit 5

Contents

5.1 Definition of resources

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

- Define natural resources.
- Define renewable and non-renewable resources.
- Classify natural resources as renewable and non-renewable.
- Define conservation as the protection and preservation of our natural environment.

KEY WORDS

natural resources *resources (actual and potential) supplied by nature*

renewable *capable of being produced indefinitely, not used up*

non-renewable *once used, cannot be easily made or replaced*

extinct *no longer in existence*

conservation *the act of preserving, guarding or protecting*

Ethiopia has many **natural resources**. Natural resources include anything that is found naturally in the country which is useful to human beings. In our country we have gold, platinum, potash, limestone, natural gas, coal and hydropower. We may have some deposits of oil as well. We have timber and many different crop plants, particularly our coffee plantations. We have many different species of animals and plants which make up rich ecosystems. We have many different breeds of domestic animals. Ethiopia is a country rich in natural resources, but many of them will not last forever.

Natural resources can be classified as either **renewable** or **non-renewable**. Renewable resources are mainly living things and their products. Managed carefully, they can be used, reused and replaced. Examples of renewable resources are crop plants, trees, cattle and chickens. Non-renewable resources are not living, and when they are used they cannot be replaced. Examples of non-renewable resources include metals like gold and iron and fossil fuels like gas, coal and oil.

Even renewable resources can be lost if we do not manage them carefully. Trees can produce new trees and forests can last thousands of years – but if all the trees are cut down and used for timber in a very short time the forest will not be able to renew itself and all the species within it will be lost. Similarly if an animal is hunted until there are no more of that species left (extinction) or its habitat is destroyed so it can no longer feed and breed, then another natural resource will be lost forever when the species becomes **extinct**. It may be lost in a particular area, or it may be lost everywhere in the world, when it is totally extinct.

To protect our natural resources, both here in Ethiopia and around the world, people are becoming more aware of the need for **conservation**. Conservation is the protection and preservation of our natural environment, so that non-renewable resources are used sparingly and renewable resources are managed so that they can last for the foreseeable future.

Figure 5.1 *Coffee is an important renewable resource in Ethiopia.*

Activity 5.1: Natural resources of Ethiopia

Have a brainstorming session and think of as many natural resources of Ethiopia as you can.

Now divide them up into renewable resources and non-renewable resources.

Make a poster or collage to show these natural resources. Divide the poster into renewable and non-renewable resources. You can draw the living or non-living things, cut pictures from magazines and stick them on, collect fur or feathers from animals – use your imagination to make your poster as interesting as possible to show people the great variety of natural resources that we have.

Summary

In this section you have learnt that:

- A natural resource is anything natural that is useful
- Some natural resources are renewable – they are mainly living things and their products, and with management they can be used, reused and replaced.
- Some natural resources are non-renewable – they are not living, and when they are used up they cannot be replaced. Classify natural resources as renewable and non-renewable.

Review questions

1. Which of the following is a non-renewable resource?

   A timber

   B gold

   C coffee

   D khat

2. Which of the following is a renewable resource?

   A oil

   B coal

   C gas

   D wood

3. Write about the natural resources of Ethiopia and why we need to take care of them.

5.2 Conservation and biodiversity

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

- Define biodiversity as the wealth of species in a given place.
- Explain the importance of conserving biodiversity.
- Summarise the general methods of conserving biodiversity.

One of the most important things that concerns scientists around the world at the moment is the loss of **biodiversity** that is taking place very quickly. This means that renewable resources are disappearing from our countries.

Biodiversity is a measure of the wealth of species in a given place. It includes everything from the smallest microbe to the largest animal.

KEY WORDS

monocultures *the cultivation of single crops*

Sometimes biodiversity is measured just as the number of species in a given area at a particular time. Sometimes it is measured as the number of species breeding in an area at a particular time. This second measure is more accurate. An animal might be just passing through on the day you observe what is there so it is more accurate to measure the species which live and breed in an area! But just counting the number of different species of organisms in an area gives us a good idea of biodiversity and is easier to do.

Why is biodiversity so important?

You have learnt in your work on food chains and food webs how all the organisms in an ecosystem are dependent on one another. You have also learnt that the variety of organisms can affect the physical conditions around them. Ecosystems are linked on a large scale across the Earth. If biodiversity is reduced in one area, the natural balance may be destroyed elsewhere. Healthy biodiversity is important for the health of the planet. The air and water of the Earth are purified by a wide range of organisms. Waste is decomposed and removed by many different organisms. Photosynthesis by plants plays an important part in stabilising the atmosphere and the world climate. Plants absorb water from the soil which evaporates into the atmosphere through transpiration. This helps determine where rain will fall. Plant roots hold the soil together. This reduces the risk of flooding and makes sure that the soil is not blown away and remains fertile. Plant pollination, seed dispersal, soil fertility and the nitrogen cycle are all needed for natural ecosystems and for farming. They rely on good biodiversity to work properly.

Figure 5.2 *An aerial shot of a major migration, demonstrating how hard it is to accurately measure species and diversity.*

Biodiversity also gives us the genetic diversity we need to develop crops to grow in different conditions. A wide range of biodiversity means we can breed the cattle, sheep, goats and other livestock that are best suited to our climate. We can also bring in new genes as climate conditions change. Biodiversity also means that there are many different types of plants and animals which can act as a source of medicines, clothing, food and other useful things for people.

Biodiversity matters for the appearance of our country. Areas that are rich in a wide variety of plants and animals are good to look at. People come from all over the world to admire and enjoy our wonderful biodiversity as we have such a rich heritage of animals and plants. Huge fields with a single crop (called **monocultures**) are not attractive to look at and they do not support a wide range of other animals and plants. However, it is not just a matter of looks. If biodiversity is low, the organisms are much more likely to be attacked by disease as it will spread from one to another very quickly. In a more diverse ecosystem some of the organisms will not be affected by a disease and the spread will be stopped.

However, biodiversity is being lost around the world for many different reasons. In many countries huge areas of land are used to grow single crops such as oil palms, maize and wheat. These monocultures greatly reduce biodiversity. Deforestation is a big

Figure 5.3 *Deforestation such as this seen outside Gonder greatly reduces the biodiversity of the area.*

problem too – here in Ethiopia we have cut down most of our original forests with huge loss of biodiversity. Climate change, pollution and human activities have reduced biodiversity around the world.

Now we understand how important biodiversity is, we need to look at ways in which it can be conserved. **Conservation** means keeping and protecting a living environment. There are a number of ways in which we can conserve biodiversity.

Individual species may be protected, so that it is illegal to capture, kill or harm them.

People can reduce pollution and around the world nations are looking at ways in which they can reduce the levels of carbon dioxide in the atmosphere and reduce climate change if possible.

The loss of habitats can be reduced – for example, if deforestation is stopped and more forests are replanted biodiversity may be increased again.

One of the most effective ways of conserving biodiversity is to protect large areas of habitat so that natural biodiversity is conserved in a very large area. Ethiopia is leading the way in this. We have designated at least 12 regions of the country as National Parks, areas where the wildlife and plants are protected and biodiversity can thrive. You will be looking at some of our National Parks in more detail in this section.

Summary

In this section you have learnt that:

- Conservation is the protection and preservation of our natural environment.
- An important aspect of conservation is to preserve biodiversity.
- Biodiversity can be defined in several ways – the most useful is as the wealth of species in a given place.
- Biodiversity is important because it maintains the balance in an ecosystem, produces genetic variety, makes places look good with a mixture of different species rather than a monoculture and helps reduce the spread of disease.

Review questions

1. A monoculture is:
   A a field containing a single crop
   B a clone
   C a country with only one type of person in it
   D an environment with a rich diversity of species
2. How is biodiversity being lost in Ethiopia and why is it important to conserve it?

5.3 Vegetation

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

- State some uses of vegetation.
- Discuss the impact of human activity on natural vegetation.
- Discuss how Ethiopian vegetation was affected in history.
- List some of the endemic vegetation species in Ethiopia.
- Discuss methods of conservation of vegetation.
- Narrate how Ethiopian vegetation was affected in history.

Here in Ethiopia we have a rich and varied vegetation. We have ecosystems which vary from desert to tropical rainforests, and the vegetation across the country changes dramatically with the conditions. We have some of the lowest-lying areas of Africa, and some of the highest peaks.

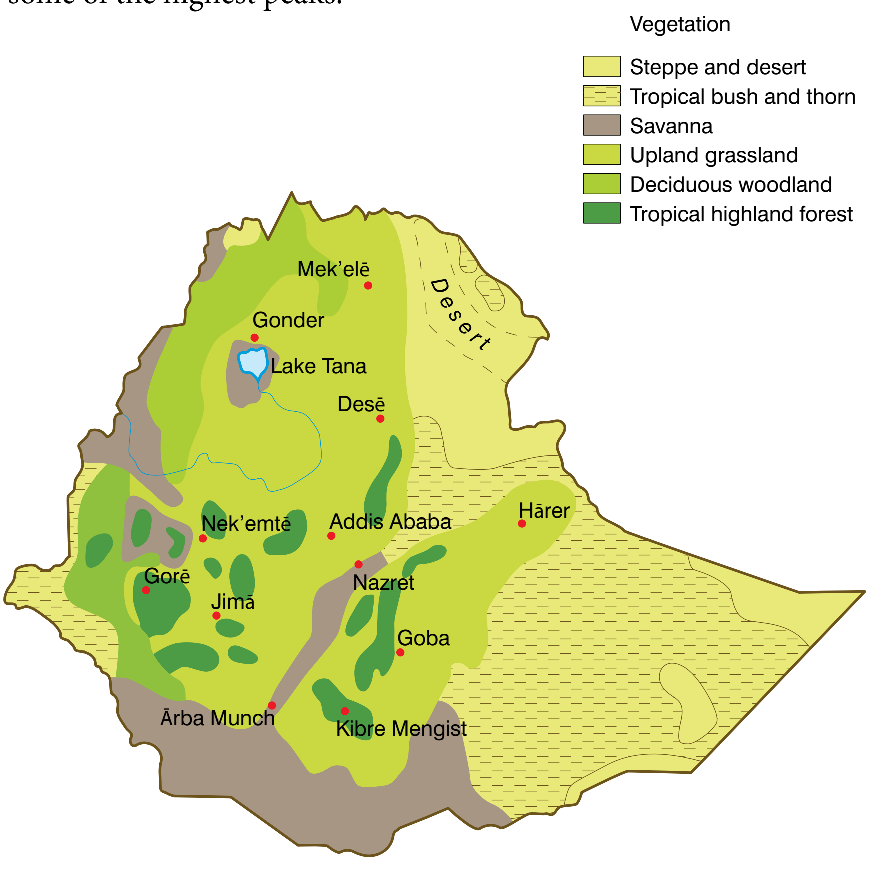


Figure 5.4 Different areas of vegetation across Ethiopia

Using plants

Plants are of great importance to human beings all around the world. We use them in many different ways. We use them for food, for example, teff, sorghum, anchote and beans. We use them to make drinks such as tella, and coffee (bunna). The coffee plant is not only used in our homes for drinks, it is very important in our economy as coffee is one of our main exports too. Plants are used for building materials – wood is used to build our homes and plants are used to thatch the roofs. We also export timber such as blue gum (bahir zaf) logs as construction material. We use vegetation to make clothing – cotton and hemp are just two examples of plants that are used to make fabrics for clothing. Plants are also a source of medicines; both herbal medicines and many western medicines are originally based on chemicals from plants. For example, the root bark of the tree known locally as 'waginos' (in Ge'ez) or 'yedega abalo' has been used for centuries to treat dysentery and koso is a medicinal plant that gets rid of worms. Trees provide the building material for many boats. Plants provide us with fuel when we burn wood or use biofuels. And our relatively lush vegetation in Ethiopia means we have the highest bee population in Africa, making us the tenth biggest honey producers in the world. Vegetation is vital for human life and for biodiversity in Ethiopia and across the world.

Figure 5.5 *Here in Ethiopia we rely on our vegetation in many different ways.*

Activity 5.2: The uses of vegetation

Work in small groups and brainstorm as many examples of ways in which people use plants, and of the plants that we use, as you can.

Share your ideas with the whole class.

Then each group can take a different use of vegetation and produce a poster or collage to go on the classroom walls explaining how plants are used in that way and giving as many examples as possible. Try and use examples from your local area and from other places. Make your poster as lively and interesting as you can.

Human effect on vegetation

People can have a major effect on the vegetation of an area. People may cut down and clear large areas of forest. This may be to sell the timber or to make the land available to grow crops or farm cattle. It greatly reduces the biodiversity of the vegetation and often destroys the structure of the soil. People also change the vegetation of an area when they farm the land – they may grow local plants as food or commercial crops (for example teff), or they may grow introduced species for local use or to sell (for example coffee). By fertilising the soil, removing weeds and planting specific crops, people have an effect on the local vegetation. Grazing our domestic animals also affects the vegetation around us. Animals such as goats, sheep and

Figure 5.6 *This* Guizotia abyssinica*, used as a vegetable oil, is just one example of our many endemic species of plants.*

Activity 5.3: Finding out about endemic species

Ethiopia is renowned for its rich diversity of plants and for its endemic species.

Find out as much about our endemic plant species as you can. Make a presentation about some of the endemic species of Ethiopia, particularly any that grow in your own area.

KEY WORDS

endemic *unique to a particular geographic location*

sustainable resource *capable of being maintained and/or replaced*

cattle eat much of the ground vegetation and will stop the growth of large trees and shrubs by eating them when they are small seedlings. People also affect vegetation by pollution and by climate change. Not all of our impacts are negative – people can also work hard to conserve biodiversity and protect an area, and there has been a great deal of work in Ethiopia with the replanting of indigenous trees by people such as Professor Legesse Negash and his team from Addis Ababa University.

Endemic species

Ethiopia is a country which is internationally recognised for its rich diversity of plant species. We have around 7000 different species of higher plants alone, with up to 800 **endemic** species. An endemic species is an organism that is only found in a particular area – so we have around 800 endemic plants which grow wild in parts of Ethiopia. They are very important to both Ethiopian and world biodiversity! Examples of our endemic species include teff (*Eragrostis teff*), many *Euphorbia* spps, noug or niger seed (*Guizotia abyssinica*), enset (*Ensete ventricosum*), *Ficus vasta* Forssk, zigba, juniper (tid), kererro and sembo trees and many other species.

The history of Ethiopian vegetation

The history of our vegetation in Ethiopia has not been recorded in as much detail as we might wish. Unfortunately, as we are blessed with such a rich and diverse vegetation, we have not as a nation conserved that gift until recent years. But perhaps we are not too late! We have used our resources without thought for the future – in each area of the country the available vegetation has often been destroyed. However, now we are looking at the past and making great efforts for the future. For example, Emperor Zera Yakob (1434–1468) is said to have organised the collection of the seeds of many indigenous trees such as juniper (tid), olive (woira) and podo (zigba) from the Wof-Washa forest near Debre Sina. He had them planted on the Menagesha Mountain. The Menagesha forest is still one of the best preserved in the whole country. Not all efforts at conservation are completely successful! In 1895 Emperor Menelik II ordered the introduction of bahir zaf (blue gum) to try and replace the native vegetation that was disappearing around many settlements. These trees have since covered much of the Ethiopian highlands and, while they are important for our timber trade, recent studies have shown that they have a damaging effect on the soil and that there is a reduced biodiversity of other plants in areas of bahir zaf vegetation. But apart from these efforts, we have used our vegetation in Ethiopia without thought or co-ordinated conservation efforts for many years. Vegetation should be a **sustainable resource** – plants make more plants and grow continuously, so we can harvest them. But no area of vegetation can withstand rapid harvesting without replanting and conservation. It seems that originally around 35% of Ethiopia was covered in forests and lush vegetation. By 1952 only 16% of that forest cover was left.

By 1980 this was down to 3.6%, 2.7% by 1987 and in 1990 only 2.4% of our beautiful country had forest cover – we had lost most of what is one of the most biodiverse ecosystems in the world. Only a very few forests, such as the Anabe and Yegof forests in Wello and the Menagesha forest in Shewa, are well preserved. Scientists think that the way in which land has traditionally been held communally, with no one responsible for the long-term sustainability of the resources, is at least part of the problem. A lack of accountability and responsibility has led to excess felling, woodland and plantation fires, etc. However, there is an increasing awareness in our country of the need to conserve what remains of our magnificent vegetation and where possible restore and preserve it.

Figure 5.7 *Many Ethiopian families are working hard to grow their crops in a way which is sustainable and does not reduce local biodiversity.*

Conservation

Ways in which we can conserve our vegetation are many and varied. It needs as many people as possible to understand what needs to be done and to work together to conserve and restore our magnificent plant heritage. In 1997 Dr Mesfin Tadesse suggested a number of ways in which we might set about conserving our rich vegetation heritage. Over ten years later, many of his ideas are being carried out. The Government of Ethiopia is working with many different groups to encourage the replanting of land with endemic species. Research institutions are looking at indigenous knowledge and using local practices of looking after resources. Much research into our native plants is going on, and more care taken when introducing exotic plants. The National Herbarium at Addis Ababa has become a world-class institution holding information about Ethiopian plants. And the work of many leading scientists like Professor Legesse Negash, means that replanting indigenous tree species is happening faster and faster in more places across our country. One of the most important ways in which we are conserving our vegetation – and our wildlife – is in the setting up of our internationally famous National Parks. You will be looking at these in more detail in the next section and considering their importance for both animals and plants.

Summary

In this section you have learnt that:

- Vegetation has many different uses from food and clothing to building materials and medicines.
- Human activity can have many different impacts on natural vegetation. Human activity often reduces natural vegetation by deforestation, burning, farming etc.
- There are many endemic vegetation species in Ethiopia which include teff (*Eragrostis teff*), many *Euphorbia* spps, noug or niger seed (*Guizotia abyssinica*), enset (*Ensete ventricosum*), *Ficus vasta* Forssk, zigba, juniper (tid), kererro and sembo trees.
- There are a number of different methods of conservation of vegetation which include protecting natural habitats and replanting endemic species.
- Ethiopian vegetation has been affected by human activities through history for a very long time. Some of this activity has been positive, but often we have damaged and destroyed our woodlands and forests.

Activity 5.4: Conserving local vegetation

You are going to carry out a survey of the vegetation in your area. Find out what type of vegetation you have and identify as many plants as possible.

Plan how you might work with others to conserve an area of land, and what indigenous plants would be likely to grow best near your school.

Present your ideas to the rest of the class and vote for the best conservation idea that is suggested.

Review questions

1. Which of the following is not an endemic Ethiopian plant?
   A tid
   B zigba
   C teff
   D maize
2. Which of the following is not a use of vegetation in Ethiopia?
   A building material
   B fuel
   C car building
   D medicines
3. Explain three ways in which people have an effect on the vegetation of Ethiopia.

5.4 Wildlife

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

- State the uses of wildlife.
- Describe the effects of humans on wildlife and its status in Ethiopia.
- List at least five endemic wildlife species of Ethiopia.
- Discuss methods of conservation of wildlife and the uses of National Parks of Ethiopia.
- List at least five national parks of Ethiopia and mention some of the common species that exist in each of the National Parks.

The wildlife of Ethiopia is some of the richest in the world. We have 242 listed mammalian species, which range from huge elephants to tiny elephant shrews. There are around 862 species of birds as well. Insects are another important aspect of Ethiopian wildlife too. This variety of wildlife is useful to people in a number of ways. A rich diversity of animal life is important to maintain our many ecosystems. The wildlife acts as pollinators for our flowering plants and helps to disperse the seeds. Our bees provide the honey for a thriving export business and for the production of tej. The balance of wildlife in different regions helps to maintain the natural balance of the plants as well, with predators keeping down the numbers of herbivores so that they do not destroy all the vegetation. Some of the wildlife acts as a genetic bank for our domestic animals and can be used as a source of genetic diversity. However, one of the most important uses of wildlife in Ethiopia is to generate income from tourism. People from all over the world want to see our amazing wildlife. Animals such as elephants, lions, cheetahs, rhinos, wildebeest and antelopes are an inspiring sight. Our birdlife too brings people from far and wide. From our birds of prey to our pelicans and flamingos, from our parrots to the rare white-winged flufftail, people come to Ethiopia for our rich diversity of birds alone.

Endemic species

We have a high number of endemic species of different types of wildlife. For example, there are 28 species of mammals, which include the Gelada Baboon, the Walia ibex, Menelik's Bushbuck, the Mountain Nyala, Swayne's Hartebeest and the Ethiopian wolf you have looked at before. Endemic bird species include the heavy-headed, thick-billed raven, the wattled ibis, the black-winged lovebird, the white-collared pigeon and the Prince Ruspolis Turaco. We also have six endemic reptiles and around 33 endemic amphibians. These animals and many others are found only within the boundaries of Ethiopia.

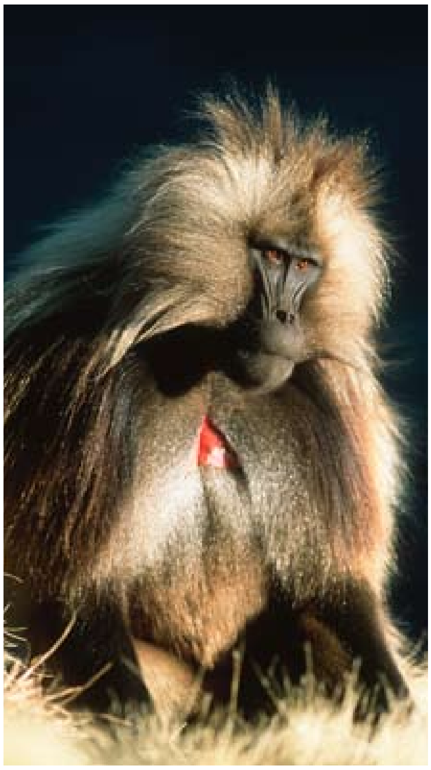


Figure 5.8 *Endemic species such as this Gelada Baboon are just one reason why the biodiversity of wildlife in Ethiopia is so well known.*

Human effect on wildlife

What impact have human beings had on the wildlife of the country? Unfortunately, historically our impact has often been negative. The deforestation which has deprived our country of so much plant biodiversity has also caused many species to be pushed to the verge of extinction. At the moment our Institute of Biodiversity, Conservation (the IBC) is warning that at least four mammal species and two bird species are on the brink of extinction as a result of habitat loss. These are the Walia ibex (there are only about 514 left), Mountain Nyala, Ethiopian wolves and Grevy's zebras, while the white-winged flufftail and the Ankober Serin bird are also badly threatened. The IBC explain that deforestation is one of the main reasons for the decline in wildlife in our country – when the forests go, so does the wildlife. Many animals have been hunted and their numbers greatly reduced. This may be to keep them away from crops or to stop them killing and eating domestic animals, or it may be for sport. Wherever people settle they change the environment and make it more difficult for wildlife to survive.

Activity 5.5: Finding out about endemic species

Ethiopia is renowned for its rich diversity of wildlife and for its endemic species.

Find out as much about our endemic wildlife species as you can. Make a presentation about some of the endemic species of Ethiopia, particularly any that are found in your own area.

Conservation

However, the human impact on wildlife does not have to be negative. There have been many moves in Ethiopia in recent years to conserve our wildlife, and we will be looking at some of these in detail. Conservation involves protecting habitats and managing populations. Another method involves preventing the spread of disease. For example, in the areas where there are still breeding groups of Ethiopian wolves, scientists work hard to keep domestic dogs vaccinated against dangerous diseases such as rabies. When there was an outbreak of rabies in the Web Valley in 2004, the Ethiopian Wolf Conservation Programme captured and vaccinated 72 wolves. This contained and reduced the damage the disease would otherwise have done to these precious populations – and made the local dogs healthier too.

Many of the conservation points which we will discuss for animals apply to vegetation as well. Ethiopia is one of the most enlightened of the African countries in its approach to conservation. In particular, we have set up and maintain a number of National Parks.

A National Park is a relatively large area of land which is owned by the Government and is set aside for the protection of vegetation and wildlife and for their appreciation by human beings. A National Park should contain several ecosystems which are not affected by human activities. It is protected legally and there should be staff (rangers) who manage and protect the environment. Visitors can enter the National Parks under carefully controlled conditions for educational, cultural and leisure reasons. Any natural resources within a National Park should not be exploited, although sometimes there may be a need for some building work, and some populations may need to be managed by selective culling to keep the numbers manageable and avoid damaging the ecosystem. When this is necessary, hunting licences may be issued to raise money to help support the park.

By careful management in National Parks, many animals and plants are conserved in Ethiopia and the work is continuing, with local populations becoming more and more involved in protecting our great wildlife diversity. There are some problems – it is not always easy for people to live within a National Park, and some people continue to poach and kill animals even when they are protected. But on the whole, we are making good progress.

Figure 5.9 *This beautiful Nechisar National Park is one of many we have established here in Ethiopia, conserving both vegetation and wildlife. We are setting an example for other countries in Africa and around the world with our focus on conservation.*

Below are listed many of the main National Parks of Ethiopia along with some of the wildlife sanctuaries that have been set up to protect specific species. In each case you can learn about some of the common species of wildlife that exist in each conservation area.

Abijatta-Shalla Lakes National Park is 200 km south of Addis Ababa and it is 887 km^2 in size. More than half of the area is under water in Lake Abijatta and Lake Shalla, but it also includes peaks like Mount Fike, which is 2075 m above sea level. Animals which are found in this beautiful park include flamingos, Great White Pelicans, Grant's Gazelle, Oribi Warthog and Golden Jackals.

Awash National Park is found about 225 km east of Addis Ababa and its southern boundary is formed by the Awash river. Much of it is at an altitude of around 900 m, but it contains a dormant volcano called Fantale which is over 2000 m high. The park is relatively dry, with lots of grassland and acacia woodland. The wildlife supported by this terrain is very varied. There are Beisa oryx, Soemmerrings Gazelle and of course wild pigs. Zebra, dik-dik, Anubis and Hamadryas Baboons, cheetahs, serval and leopards can all be found in this area. The birdlife is also extravagant and varied, including ostriches, Secretary Birds, Carmine Bee-eaters and the Abyssinian Roller.

Figure 5.10 *This amazing bird is a Carmine Bee-eater. This species is protected in the Awash National Park.*

Bale Mountain National Park is not always easy to get to but it contains a mixture of forest and moorland, and some very rare animals such as the Gelada Baboon, Mountain Nyala and Ethiopian wolves. Other species found there include the Giant Mole Rat, Klipspringer, Menelik's Bushbuck and warthogs.

Gambela National Park is one of our newest National Parks. It is big – over 5000 km^2 – with massive grassland plains and it includes the Baro river. The wildlife that can be seen in this park includes enormous Nile perch, crocodiles and hippos as well as waterbuck, Roan Antelope, hyena, lions, elephants, buffalo, zebra, Vervet Monkeys and black-and-white colobus monkeys.

Rift Valley Lakes National Park is in a chain of seven lakes which run from Debre Zeit towards Kenya. This National Park does have some mammals, including Grant's Gazelle and warthogs, but the wildlife for which it is famous is the birdlife, which includes Greater and Lesser Flamingos, a huge colony of Great White Pelicans, fish eagles, spoonbills, Abdim's Storks and ibises.

Mago National Park has an area of over 2000 km^2. Almost 800 km south-west of Addis Ababa on the east bank of the Omo river, this National Park is largely grassland with some forest around the rivers. It is home to 56 species of our famous plains animals, including giraffe, elephants, lions, buffalo, cheetah, zebra, leopard and oryx. This is one of the remaining places where rare Black Rhinos may be found. Vultures are one of the well-known bird species in this area.

Figure 5.11 These spectacular Simien Mountains are home to some of our rarest endemic animals which are protected by their National Park status.

Figure 5.12 The rare Ethiopian wolf which lives in the Bale mountains and is one of our endemic species of animals.

Omo National Park is very big indeed, covering over 4000 km^2. Over 300 species of birds alone are found here. Animal life includes kudu, hartebeest, oryx, Anubis Baboons, lions, cheetahs, buffalo, giraffes and elephants.

Nechisar National Park is between two lakes, Abaya and Chamo. The habitats include dry bush, savannah and a groundwater forest and, although it is only about 500 km^2, almost 200 species of birds have been recorded here, including Red-billed Hornbills, fish eagles, the Abyssinian Ground-hornbill and the Kori Bustard! Animals which can be seen include crocodiles, Burchell's Zebra, bushbucks, Grey Duiker, Grant's Gazelle and the Greater Kudu. This National Park is very important for the conservation of the rare, endemic Swayne's Hartebeest.

Simien Mountains National Park is home to both spectacular scenery and spectacular and rare wildlife. This major mountain range has been declared a World Heritage Site, and it has many peaks above 4000 m. This is not a hot area, and night temperatures are often cold. This is the area of Ethiopia where a number of our endemic species are protected and conserved. You can find Walia ibex, Ethiopian wolves and Gelada Baboons in this amazing and protected region of our country.

Yangudi Rassa National Park is big and is found in the arid northern Rift lowlands. There is a wide variety of vegetation, from semi-desert and scrubland to savannah and even open woodlands. In this conservation area you can find the wild-ass ancestor of our domestic donkeys, and Greater and Lesser Kudu, Grevy's Zebra and cheetah.

We also have a number of wildlife sanctuaries which are similar to National Parks but focus on the conservation of particular species.

Some examples of these include:

Harar Wildlife Sanctuary is an area of almost 7000 km^2 in the Misraq Hararghe Zone of the Oromia region, which was set up to conserve and protect our native elephant sub-species, *Loxodonta Africana oleansie*. The area is also home to the black-maned lion.

Kuni-Muktar Mountain Nyala Sanctuary is a protected area which has been set up to protect the Mountain Nyala (*Tragelaphus nyala*), an extremely rare endemic animal in Ethiopia. There are fears that there are only between 70 and 200 of these animals left in Ethiopia, and so it is vital to conserve them. Sadly, there are still people in our country who want to hunt these animals for trophies, and so they need a great deal of protection.

Senkelle Swayne's Hartebeest Sanctuary is close to the Lake Rift Valley National Park and it is dedicated to the protection of this rare hartebeest. There are over a thousand of these protected animals in the sanctuary.

In Ethiopia many people are working to conserve our vegetation and wildlife. On a large scale we have National Parks and wildlife sanctuaries. On a smaller scale many individuals and villages are working to conserve the environment. For our country to succeed, people must be able to live side by side with our great Ethiopian biodiversity of vegetation and wildlife in a sustainable way.

Summary

In this section you have learnt that:

- The wildlife in Ethiopia has many uses from food to encouraging tourism, and from maintaining genetic diversity to providing the original species for our domestic animals.
- Human beings have had a major impact on wildlife and their status in Ethiopia. For many years people have threatened the wild life, hunting animals and often destroying their habitat, e.g. in deforestation. However, increasingly people are protecting and conserving wildlife.
- There are many endemic wildlife species of Ethiopia including Gelada Baboon, the Walia ibex, Menelik's Bushbuck, the Mountain Nyala, Swayne's Hartebeest, the Ethiopian wolf, the heavy-headed, thick-billed raven, the wattled ibis, the black-winged lovebird, the white-collared pigeon and the Prince Ruspolis Turaco.
- There are a number of methods of conservation of wildlife including restoring lost habitat, e.g. replanting forests. Setting up National Parks or reserves where the habitat is protected and the animals are also protected from hunting and poaching is an effective way of conserving threatened species and wildlife biodiversity.
- Ethiopia has many National Parks which are important in the conservation of our endemic wildlife species and others. They include Abijatta-Shalla Lakes National Park, Awash National Park, Bale Mountain National Park, Gambala National Park, Rift Valley Lakes National Park, Mago National Park, Omo National Park, Nechisar National Park, Simien Mountains National Park and Yangudi Rassa National Park.

Review questions

1. Which of the following is not an example of endemic Ethiopian wildlife?

   A Ethiopian wolf

   B cheetah

   C Walia ibex

   D white-winged flufftail

2. Which of the following is a sanctuary rather than a National Park in Ethiopia?

   A Bale

   B Gambala

   C Senkelle

   D Simien

KEY WORDS

pollution *the contamination of the natural environment by harmful substances as a result of human activities*

pollutant *a harmful substance*

hydrocarbons *substances containing only hydrogen and carbon. Fossil fuels are made of hydrocarbons*

particles *very small pieces of solid or liquid matter*

global dimming *a worldwide reduction of the sunlight reaching the Earth's surface, caused by particulate air pollution*

carbon dioxide *a gas produced by living organisms as a waste product of respiration, and as a result of burning wood and fossil fuels*

carbon cycle *the global cycle of movement of carbon, in all of its forms, involving all living things and all parts of the environment*

5.5 Air

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

- Explain the causes of air pollution.
- Explain the effects of air pollution.
- Define global warming.
- State the causes of global warming.
- Explain the methods of preventing global warming.

Clean air is essential for our bodies to live as it supplies the oxygen for cellular respiration. We breathe air into and out of our lungs all the time from our birth to our death. Unfortunately, some of our other activities release substances that pollute the air and are harmful to humans, plants and animals.

Pollution is the contamination of the natural environment by harmful substances as a result of human activities. Pollution can happen on a very small, local scale – every time you drop litter, or a dog fouls the street, the local environment is polluted. On the other hand, pollution happens on a very large scale too, affecting whole countries – acid rain, global warming and the ozone hole are all examples of the effects of large-scale air pollution you will be learning about here.

A **pollutant** can be defined as something that contaminates the air, soil and water. In this section we will be concentrating on substances which pollute the air.

What is in air pollution?

Air pollution comes in various forms, each of which has serious implications for our health and well-being as well as for the whole environment.

One type of air pollution is **smoke** produced by burning fuel for energy. Much of the fuel we use is fossil fuel – coal, oil or gas, or electricity produced by burning them. Fossil fuels contain chemicals known as **hydrocarbons**. When these fuels are burnt, tiny **particles** of unburnt hydrocarbons are released into the air. Diesel smoke is a good example of this. The particles are very small pieces of matter. This type of pollution is sometimes referred to as 'black carbon' pollution. The exhaust from burning fuels in cars, homes and industries is a major source of pollution in the air. Even the burning of wood on our fires can release significant quantities of soot into the air causing local air pollution. Smoke pollution worldwide is thought to be causing **global dimming**, blocking out some of the light from the sun.

Another major cause of air pollution is the production of **carbon dioxide**. Carbon dioxide is produced by living organisms as a waste product of respiration. It is used by plants in the process of photosynthesis. Carbon dioxide is also produced as a result of burning wood and fossil fuels.

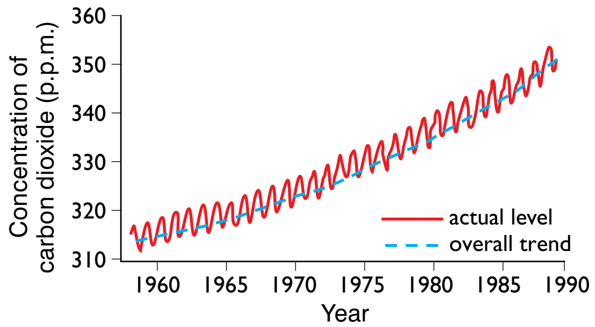


Figure 5.13 *This graph shows how carbon dioxide levels in the air have been steadily increasing. The variations through the year show the difference in the plants taking up carbon dioxide in summer and winter. The measurements are taken at the top of a mountain in Hawaii.*

For millions of years the levels of carbon dioxide released by living things into the atmosphere have been matched by the plants taking it out and the gas dissolving in the seas. As a result the level in the air stayed about the same from year to year. You learnt about this **carbon cycle** in grade 9.

Why is carbon dioxide increasing?

But now the amount of carbon dioxide produced is increasing fast as the result of human activities. Around the world people are burning huge amounts of fossil fuels in cars, planes and also in power stations to generate electricity. This speed means that the natural sinks cannot cope, and so the levels of carbon dioxide are building up.

Carbon dioxide in the atmosphere is important because of the greenhouse effect. It traps some of the heat from the sun and keeps the surface of the Earth warm enough for life as we know it. But the build-up of carbon dioxide gas in the atmosphere from human activities seems to be adding to this greenhouse effect and causing global warming. Although plants take in carbon dioxide and release oxygen, the release of carbon dioxide from human activities is higher than the plants can process. The situation is made worse because all around the world large-scale deforestation is taking place. We are cutting down trees over vast areas of land for timber and to clear the land for farming. In this case, the trees are felled and burned in what is known as 'slash-and-burn' farming. The land produced is only fertile for a short time, after which more forest is destroyed. No trees are planted to replace those cut down.

Deforestation increases the amount of carbon dioxide released into the atmosphere as burning the trees leads to an increase in carbon dioxide levels from combustion. The dead vegetation left behind decays as it is attacked by decomposing micro-organisms, which releases more carbon dioxide.

Normally trees and other plants use carbon dioxide in photosynthesis. They take it from the air and it gets locked up in plant material like wood for years. So when we destroy trees we lose a vital carbon dioxide 'sink'. Dead trees don't take carbon dioxide out of the atmosphere.

Methane is another greenhouse gas that causes air pollution and the levels of this gas are rising too. It has two major sources. As rice grows in swampy conditions, known as paddy fields, methane

DID YOU KNOW?

Cows produce methane all through the day from both ends! A single cow can release from 100–400 litres of methane per day – that's a lot of greenhouse gas.

KEY WORDS

carbon monoxide *a pollutant gas produced as a result of burning fossil fuels*

sulphur dioxide *a pollutant gas produced as a result of burning fossil fuels*

nitrogen oxides *pollutant gases produced as a result of burning fossil fuels*

acid rain *rain with a low pH containing sulphuric acid and nitric acid as a result of dissolving airborne pollutant gases*

is released. Rice is the staple diet of many countries so as the population of the world has grown so has the farming of rice.

The other source of methane is cattle. Cows produce methane during their digestive processes and release it at regular intervals.

In recent years the number of cattle raised to produce cheap meat for fast food like burgers has grown enormously, and so the levels of methane in the atmosphere are rising. Many of these cattle are raised on farms produced by deforestation.

Global warming

So as a result of human activities the amount of carbon dioxide (and methane) in the air is continuing to increase. This build-up acts like a blanket and traps heat close to the surface of our Earth. This causes the temperature at the surface of the Earth to rise. This in turn may have many effects on our climate and health – and it is also thought to contribute to the increased hurricane activity which has affected some areas of the world in recent times.

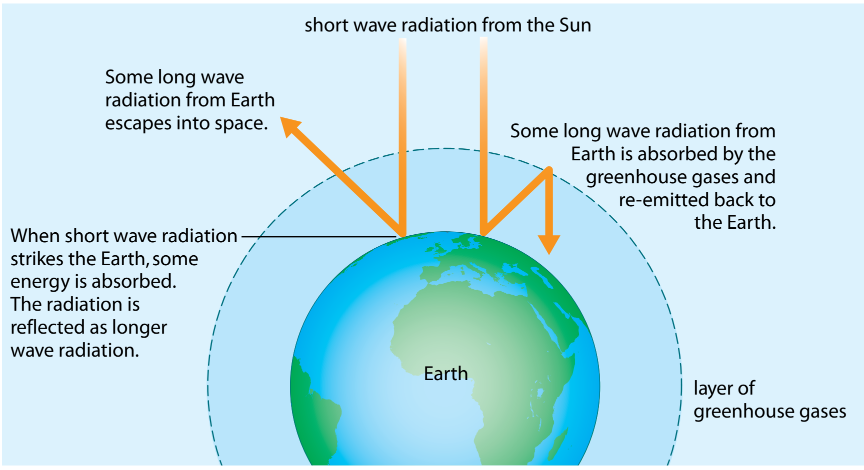


Figure 5.14 Most scientists believe that global warming is a result of the build-up of air pollutants such as carbon dioxide. The pollution is produced all over the world. Here in Ethiopia we are already feeling the effects.

Another air pollutant is **carbon monoxide**, also produced by the burning of fossil fuels. It is produced by cars as well as by home water heaters, paraffin lamps and fires if they are not functioning properly. Carbon monoxide is very dangerous because it combines irreversibly with haemoglobin in your blood, reducing the oxygen-carrying capacity. There is carbon monoxide in cigarette smoke, which is why it is so dangerous to smoke if you are pregnant because you can deprive your unborn baby of oxygen. Carbon monoxide poisoning can eventually lead to death and, because the gas has no colour or smell, there is no way of knowing if it is leaking into your home from a faulty lamp.

Acid rain

Acid rain is the result of another form of air pollution. When fossil fuels are burned carbon dioxide is released into the atmosphere as a waste product. However, carbon dioxide is not the only waste gas produced. Fossil fuels often contain sulphur impurities. When these burn they react with oxygen to form sulphur dioxide gas. At high temperatures, for example, in car engines, nitrogen oxides are also released into the atmosphere.

Sulphur dioxide and **nitrogen oxides** pollute the air and can cause serious breathing problems for people if the concentration gets too high. They form a haze of pollution known as smog, which can be a real problem in big cities where there are millions of motor vehicles.

They are also involved in the formation of acid rain. This pollutes land and water over a wide area.

The sulphur dioxide and nitrogen oxides dissolve in the rain and react with oxygen in the air to form dilute sulphuric acid and nitric acid. This makes the rain more acidic – it is known as **acid rain**.

The effect of acid rain

Not surprisingly, acid rain has a damaging effect on the environment. If it falls onto trees, the acid rain can cause direct damage. It may kill the leaves and, as it soaks into the soil, even the roots of the tree may be destroyed. In some parts of the world, huge areas of woodland are dying as a result of acid rain.

Acid rain has an indirect effect on our environment as well as its very direct effect on plants such as trees. As acid rain falls into lakes, rivers and streams the water in them becomes acidic. If the concentration of acid gets too high, plants and animals can no longer survive. Many lakes and streams have become dead, no longer able to support life.

It is not only living things that are damaged by acid rain. The weak acid attacks the material of buildings and statues, reacting with any calcium carbonate (limestone or marble) and even with metals.

Acid rain is a difficult form of air pollution to pin down and control. It is formed by pollution from factories. It also comes from the cars and other vehicles we use every day. The source of the gases is pretty widespread. The worst effects of acid rain are often not felt by the country that produced the pollution in the first place. The sulphur and nitrogen oxides are carried high in the air by the prevailing winds. As a result, it is often relatively 'clean' countries that get the pollution and the acid rain from their dirtier neighbours. Their own clean air goes on to benefit someone else!

DID YOU KNOW?

Normal rain has a pH of around 5. It is slightly acidic because of carbon dioxide from animals breathing out being dissolved in the water. Acid rain has been measured with a pH of 2.0 – more acidic than vinegar!

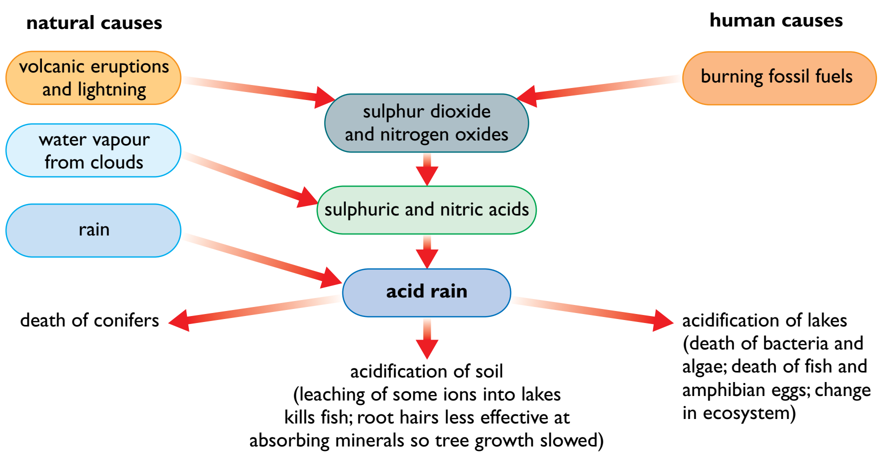


Figure 5.15 *Air pollution in one place can cause acid rain – and serious pollution problems – somewhere else entirely. Depending on the prevailing winds, it can even be in another country!*

One of the ways in which air pollution is affecting the African environment is to kill life in the seas that surround our continent. For example, the beautiful coral reefs are very vulnerable to air pollution in two ways. Firstly, the temperature of the seas is going up as a result of global warming. Just a small rise is enough to kill off the algae on which the coral polyps feed, and so in turn the polyps die and the coral reefs begin to bleach and die as well. Secondly, acid rain falls into the sea and the change in pH affects the calcium salts dissolved in the water and breaks down the coral skeleton itself. Without the coral, many of the unique reef ecosystems of the world will be destroyed forever – so controlling air pollution is very important indeed.

Air pollution in our homes

It may surprise you to learn that air pollution also needs to be considered inside our homes, offices and schools. Some of these pollutants can be created by indoor activities such as smoking and cooking. Fumes from cars come in through the windows. And when the air is polluted, whether inside or out, you cannot avoid breathing it in. One particular problem is air pollution in the home from the use of paraffin lamps to give us light in the evening.

Burning paraffin produces many poisonous chemicals in the air including benzene, carbon monoxide and lead from the wick as well as particles of soot. We may breathe these substances into our lungs every day.

Air pollution can affect our health in many ways with both short-term and long-term effects. Examples of short-term effects include irritation to the eyes, nose and throat, and upper respiratory infections such as bronchitis and pneumonia. Other symptoms can include headaches, nausea and allergic reactions. Long-term health effects of air pollution can include chronic respiratory disease, lung cancer, heart disease and even damage to the brain, nerves, liver or kidneys. Young children are particularly vulnerable. In some cases the pollution of the air in our homes can lead to death. In some places people are using solar power to store electricity during the day, which can then be used at night. This is a safe and pollution-free way of lighting our homes.

Another form of air pollution has led to the depletion of the ozone layer in the atmosphere. Ozone is a gas which is found in the atmosphere of the Earth. It absorbs some of the ultraviolet radiation from the sun. Ultraviolet radiation damages and burns the skin and can cause the development of skin cancers. The ozone layer protects life on Earth from the worst of this damage. For over 50 years people, particularly in the more economically developed countries, used chemicals called CFCs (chlorofluorocarbons) in fridges and freezers as a refrigerant, and in aerosol sprays as the propellant. They did not realise that CFCs can damage the ozone layer. By the time scientists made this discovery, it was too late. Air pollution by CFCs had caused the ozone layer around the Earth to get thinner, particularly over the Antarctic at certain times of the year. This thin area is often referred to as the 'ozone hole'. Levels of ultraviolet light reaching the surface of the Earth have increased as a result and levels of skin cancers and eye problems caused by ultraviolet light have also increased. However, once people realised the damage this was doing, the use of CFCs has been banned and fridges and freezers containing these compounds are disposed of very carefully. Within about 50 years the ozone hole will heal itself – already levels of atmospheric ozone are higher again. This is one form of air pollution that has been overcome.

People have become more aware of the problems caused by air pollution. In many countries in the world steps are being taken to stop the damage to our environment from air pollution. One of the biggest causes of air pollution is cars and other vehicles. Car exhausts contain carbon dioxide, carbon monoxide, sulphur dioxide and oxides of nitrogen. All of these gases have both a direct and an indirect effect on human health. Around the world people are working hard to reduce the levels of sulphur dioxide and nitrogen oxides in car exhausts. More and more cars are being fitted with catalytic converters. Once hot, these remove the acidic gases before they are released into the air.

Preventing air pollution in Ethiopia

In Ethiopia we do not contribute greatly to air pollution as our way of life is often relatively simple. Relatively few people own cars, and the majority of people cook and heat their homes using traditional fuels such as wood or animal dung. However, burning forests down during deforestation has a bad effect on air pollution levels. In Ethiopian towns and cities, more air pollution is produced than in the countryside. As more people move to cities, the number of vehicles increases and the use of electricity and fuels such as kerosene for cooking also increases. It is important that we take care to keep our pollution levels as low as possible. For example, the use of solar energy to charge batteries so that we can light our homes with clean electricity in the evenings reduces the risk of air pollution from paraffin lamps. This is an important step we can take to protect the health of our children – and it reduces the risk of fires as well. In the meantime, we have to live with the effects of climate change and ozone depletion that is the result of air pollution elsewhere in the world.

Many countries are passing laws which control the amount of air pollution that is allowed by factories and the generation of electricity. People are trying to prevent many types of air pollution, through personal, careful, attention to our interactions with the environment. Individuals can make a difference by reducing the amount of electricity they use, by switching off lights when they are not needed and reducing the level of the air conditioning. People walk or cycle sometimes instead of using cars or buses. In cities people buy local produce with as little packaging as possible – that reduces the fuel used to get food to them, and the chemicals processed to make the packaging. All of these things can make a real difference in the long term, and the more people who help the better. Here in Ethiopia we have a relatively clean country – let us all work hard to keep it that way, and to conserve our wonderful vegetation and wildlife, so that we can be an example to the world.

Summary

In this section you have learnt that:

- Air pollution is caused in a number of ways including by smoke, by carbon dioxide and carbon monoxide from the burning of fossil fuels, by sulphur dioxide and nitrogen oxides causing acid rain and by benzene, lead and soot in homes and offices from paraffin lamps.
- Air pollution has a number of effects on both the environment and on individuals. These include global dimming, global warming, acid rain as well as problems such as asthma, lung infections and cancer for individuals.
- Global warming is an increase in the temperature at the surface of the earth as a result of an increased greenhouse effect.
- Global warming is caused by an increase in the levels of greenhouse gases such as carbon dioxide and methane in the atmosphere. As a result more heat is trapped by the atmosphere and the temperature at the surface of the earth increases.
- Methods of preventing global warming include reducing the use of fossil fuels and managing the farming of cattle and rice. Stopping deforestation and replanting trees can also help by using up some of the carbon dioxide.
- Ozone depletion caused by the use of CFCs has caused an increase in harmful ultraviolet light reaching the surface of the earth. As the use of CFCs has been controlled, the ozone hole in the atmosphere is getting smaller as the damage is repaired.

Review questions

1. Which of these chemicals has caused the formation of the 'ozone hole'?

   A sulphur dioxide

   B carbon dioxide

   C CFCs

   D nitrogen oxides

2. Which air pollutants can lead to global warming?

   A carbon dioxide and carbon monoxide

   B carbon dioxide and methane

   C methane and sulphur dioxide

   D methane and nitrogen oxides

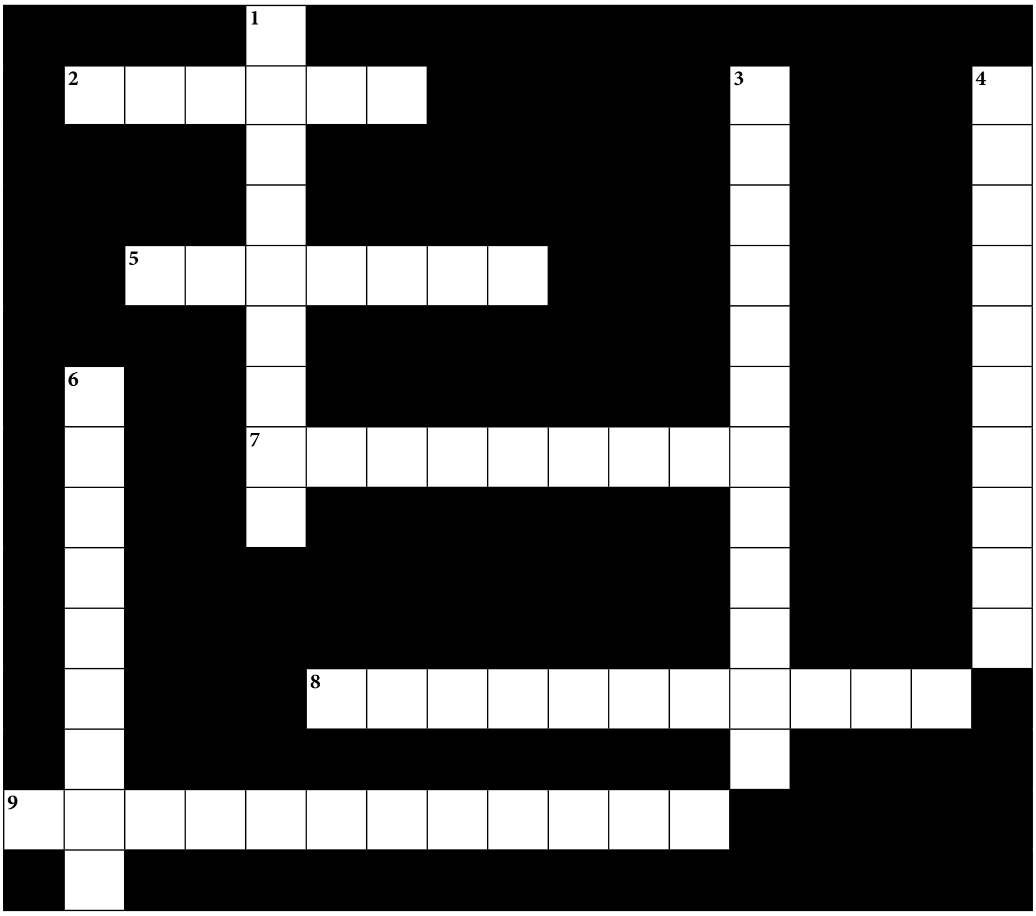
3. How can air pollution affect us in our homes?

End of unit questions

1. Which of the following is a non-renewable resource?
   A eggs
   B teff
   C sweet potato
   D oil
2. Which of the following is a renewable resource?
   A gold
   B coal
   C meat
   D gas
3. Which of these statements describes conservation?
   A Farming an area intensively.
   B The protection and preservation of our natural environment.
   C The rapid loss of habitats.
   D None of the above.
4. Which of the following statements does not explain why biodiversity is important?
   A Biodiversity produces genetic variety.
   B Biodiversity maintains the balance of an ecosystem.
   C Biodiversity reduces the spread of disease.
   D Biodiversity establishes a monoculture.
5. What is biodiversity?
6. Why is biodiversity important?
7. Which of these is not an example of how humans can affect the natural vegetation?
   A classification
   B deforestation
   C burning
   D farming
8. Which of these is not a way of conserving our natural vegetation?
   A protecting natural habitats
   B replanting endemic species
   C farming sustainably
   D slash and burn deforestation

9. Give three ways in which our rich plant diversity can be conserved.
10. Which of the following is not an endemic Ethiopian species of animal?
    A Mountain Nyala
    B Ethiopian wolves
    C Gelada Baboon
    D Roan Antelope
11. Which of these methods is not an effective way of conserving wildlife?
    A setting up National Parks
    B intensive farming
    C controlling hunting
    D restoring lost habitat
12. Explain three ways in which people have an effect on the wildlife of Ethiopia.
13. Give three ways in which our rich wildlife diversity can be conserved and explain why it is so important.
14. Which of these pollutants causes most problems in Ethiopian homes?
    A sulphur dioxide
    B carbon dioxide
    C benzene, lead and soot
    D nitrogen oxides
15. What damage has been caused by CFCs?
    A global warming
    B thinning of the ozone layer
    C acid rain
    D global dimming
16. How do scientists think that human activities are causing global warming?

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

2 Type of baboon endemic to Ethiopia (6)

5 No longer in existence (7)

7 Capable of being produced indefinitely, not used up (9)

8 Cultivation of a single crop (11)

9 The act of preserving, guarding or protecting part of the natural world (13)

DOWN

1 An area which focuses on the conservation of a particular species (9)

3 A measure of the wealth of species in a given place (12)

4 Plant life (10)

6 The contamination of the natural environment by harmful substances, often as a result of human activities (9)

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