Biology

Student Textbook
Grade 9

Federal Democratic Republic of Ethiopia
Ministry of Education

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Biology Student Textbook Grade 9

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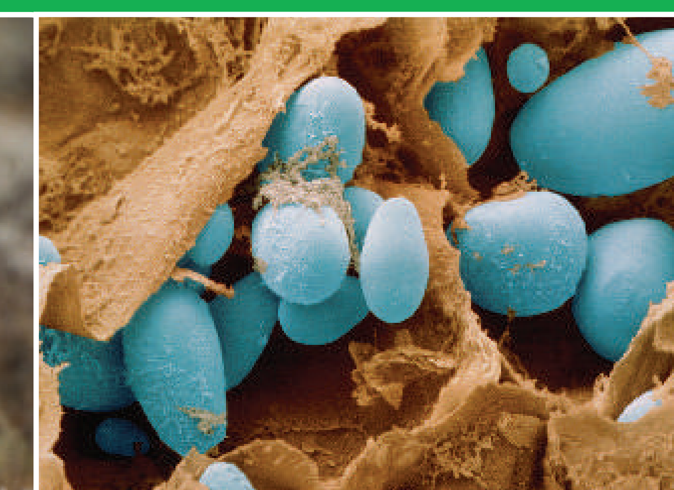


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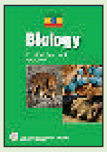

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Biology

Student Textbook
Grade 9

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Biology and technology

Unit 1

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1.1 Renowned Ethiopian biologists

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

- Name at least one renowned Ethiopian biologist.
- Explain the contributions of these Ethopian biologists to international biological knowledge.

Welcome to the study of biology! Biology is the study of life and living organisms. All around you there are many different types of plants, animals and other living organisms. They depend on each other and on the environment where they live. Biologists study both the outer appearance and the internal workings of living things. They study how living organisms interact and where human beings fit into the living world.

All of our biological knowledge comes to us by the work of biologists, scientists who study living organisms. Biology, like all the sciences, moves forward most of the time in small, steady steps. One biologist comes up with an idea. Another carries out more experiments, which either support the new idea or suggest it is wrong. Then more biologists join in until eventually a new idea, or **hypothesis,** is accepted. Like all scientists, biologists publish their new work (called research) in special magazines called **journals**. Before an idea is published in a journal, several other well-known biologists have to read it and check that the research has been done to a high standard. This process is called **peer review**. Sometimes biology takes a great leap forward, when a very gifted biologist comes along with a big new idea!

If you think you would like to be such a biologist, start right now by observing living things around you.

Here in Ethiopia we have some very renowned biologists. Their work is known and important not just here in Ethiopia but around the world. Here are some of their biographies.

KEY WORDS

hypothesis *an idea or statement that explains observed facts and predicts new outcomes*

journal *a regular publication presenting articles on a particular subject*

peer review *evaluation of a person's work done by others in the same field*

***Figure 1.1** Highly magnified image of the parasitic flatworms that cause schistosomiasis*

KEY WORDS

immune reaction *a biological response involving the production of antibodies etc. as a reaction to the presence in the body of bacteria, a poison, or a transplanted organ*

treated water *filtered or disinfected water made safe for consumption*

genetic engineering *the deliberate, controlled manipulation of the genes in an organism, with the intent of making that organism better*

Dr Aklilu Lemma and the battle against bilharzia (schistosomiasis)

Schistosomiasis (also known as bilharziasis) is a common parasitic disease. It affects 200–300 million people in Africa (including Ethiopia), South America, Asia and parts of the Caribbean. It is caused by parasitic flatworms which spend part of their lifecycle in freshwater snails and part in humans. Anyone washing, working or playing in shallow fresh water is at risk. Once inside a person, the parasites mature and produce eggs which are passed out in the urine and faeces. They also infest the blood vessels, liver, kidneys, bladder and other organs. The body sets up an **immune reaction** and an infected person can become weakened and ill for many years.

Some of the most important work in finding a way of controlling this parasite, which is effective but does not cost too much, was carried out by Dr Aklilu Lemma, one of Ethiopia's most renowned biologists.

Dr Aklilu began his work in 1964, when he was investigating the freshwater snails that carry the schistosomiasis parasite around Adwa in northern Ethiopia. He saw women washing clothes in the water and he noticed that downstream of the washing party there were more dead snails than anywhere else he had collected. The women were using the soapberry, Endod (*Phytolacca dodecandra*), to make washing suds. Dr Aklilu collected some live snails from above the washing party and asked one of the women to give him some of her Endod suds. Not long after the suds were put in the snail container, the snails all died. This was the start of years of work for Dr Aklilu.

Back in the laboratory he showed that if the Endod berries were dried, crushed and diluted in water they would kill snails at very low concentrations. Other scientists carried out similar investigations and got the same results. If the freshwater snails can be controlled, the spread of schistosomiasis can be greatly reduced. The World Health Organisation recommended a chemical molluscicide (i.e. a compound that kills molluscs including snails) but it was extremely expensive. Endod works well, it is cheap, it is well known by local people who are likely to use it and it is environmentally friendly as it breaks down naturally within about two days.

***Figure 1.2** Dr Aklilu Lemma, one of Ethiopia's most renowned biologists, with the snail-killing soapberries known locally as Endod*

Dr Aklilu Lemma worked for many years to convince scientists all around the world that his ideas would work. Trials using locally collected Endod showed that using the molluscicide worked. Before the water was **treated**, 50% of children 1–6 years old were infected. After treatment only 7% were infected by the flatworm. Dr Aklilu's results were published in journals around the world. He found the best species of the soapberry plant and developed programmes for local communities to treat their own water. Eventually people were convinced and the use of Endod-based molluscicides is spreading throughout Africa and beyond. Hopefully a combination of Endod water treatment to kill the snails, improved hygiene, clean water wells and medicine for affected people will mean that Ethiopia can be free of this terrible disease. If we succeed it will be largely due to the work of Dr Aklilu Lemma. He has been honoured and recognised in many different ways both in Ethiopia and around the world for his work.

Dr Tewolde Berhan Gebre Egziabher, an ardent lover of nature

Dr Tewolde Berhan Gebre Egziabher was born in 1940. In 2000 he won the Right Livelihood Award (often called the Alternative Nobel Prize) "for his exemplary work to safeguard biodiversity and the traditional rights of farmers and communities to their genetic resources".

During the 1990s Dr Tewolde Berhan was involved in negotiations at the various biodiversity-related meetings, including the Convention on Biological Diversity (CBD) and the Food and Agriculture Organization. Having built a strong and able team of African negotiators, he managed to help achieve progressive, unified policies for Africa, such as recognition of community rights.

Dr Tewolde Berhan was instrumental in securing recommendations from the Organisation of African Unity (OAU) encouraging African countries to develop and implement community rights, a common position on Trade Related Aspects of Intellectual Property Rights, and a clear stance against patents on living materials. He also helped to draft the OAU model legislation for community rights, which is now used across Africa.

In January 2000 Dr Tewolde Berhan acted as chief negotiator on biosafety for the Like-Minded Group, made up of most of the G77 countries, in Montreal. Here he was central to achieving an outcome protecting biosafety and biodiversity and respecting community rights, against strong US-led representations.

Dr Tewolde Berhan also won the United Nations top environmental prize, Champions of the Earth, in 2006.

Professor Tilahun Yilma and his vaccines

Professor Tilahun Yilma is known internationally for the vaccine he developed to help get rid of the terrible cattle disease rinderpest, and for his work on HIV/AIDS vaccines. Rinderpest arrived in Ethiopia in 1888, carried by three infected cattle brought into the country by Italian soldiers. Within a year 90% of the domestic cattle plus many wild animals such as buffalo, giraffe and antelope died. As a result 30–60% of the people starved.

In the 1980s rinderpest became a major problem again. Professor Tilahun worked to develop a vaccine using **genetic engineering**. He was very successful – his vaccine doesn't need refrigeration, it is easily scratched onto the animal's neck or abdomen so cattle don't need injections from vets and it can be made relatively cheaply in large quantities. By 1997 the vaccine was ready for use across Africa,

DID YOU KNOW?

Around 300 million people are affected by schistosomiasis in the tropical and sub-tropical parts of the world – so the work of Aklilu Lemma could make an enormous difference in many other countries as well as Ethiopia. Dr Aklilu recognised this when he said "we found a poor man's medicine for a poor man's disease".

Figure 1.3 *Dr Tewolde Berhan Gebre Egziabher*

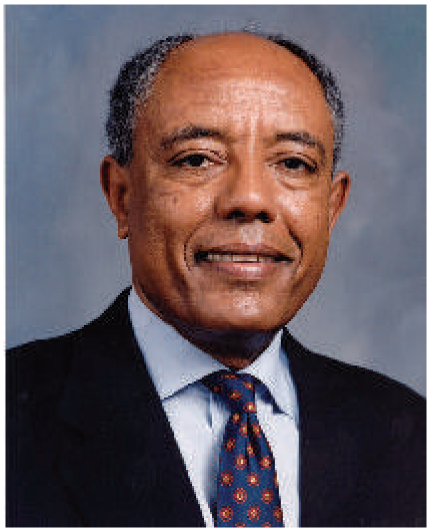


Figure 1.4 *Professor Tilahun Yilma*

including his own country Ethiopia. Now he is working on using similar methods to develop an effective vaccine against HIV/AIDS, which is affecting people all around the world including millions of Africans. Professor Tilahun has been given many international awards and honours over the years. He is also very active in encouraging young scientists and establishing the highest quality research establishments here in Africa.

Figure 1.5 *Professor Yalemtsehay Mekonnen working in the Biomedical Laboratory, Addis Ababa University*

Professor Yalemtsehay Mekonnen: The first female professor from AAU

Professor Yalemtsehay Mekonnen is a biologist and an academic member of staff at the Department of Biology, Faculty of Science, Addis Ababa University. She has worked in this Department for the last 30 years. She received her PhD, specialising in human physiology, from the University of Heidelberg in Germany.

One of her research areas is the assessment of the impact of chemical pesticide hazard on humans. This research covers almost all government farms including the Upper Awash Agricultural farms and some private horticultural farms in the Rift Valley region. The other area of her research is in the use of plants as medicine against human and animal diseases.

Professor Yalemtsehay Mekonnen served as Head of the Department of Biology from 1993 to 1995 and as the Director of the Aklilu Lemma Institute of Pathobiology from February 2003 to October 2007. In leadership positions she was involved and has initated a number of national and international research networks and collaborations. She is a member of many professional societies, such as the Biological Society of Ethiopia, the Safe Environment Association, the Ethiopian Wildlife and Natural History Society, the New York Academy of Sciences and the Third World Organization for Women in Science. She has served as President of the Biological Society of Ethiopia.

She has been awarded research grants and fellowships nationally from the Ethiopian Science and Technology Commission and the Ethiopian Agricultural Research Organization, and internationally from the British Council, the International Foundation for Science, Third World Academy of Sciences, the German Academic Exchange Service and the Alexander von Humboldt Foundation from Germany.

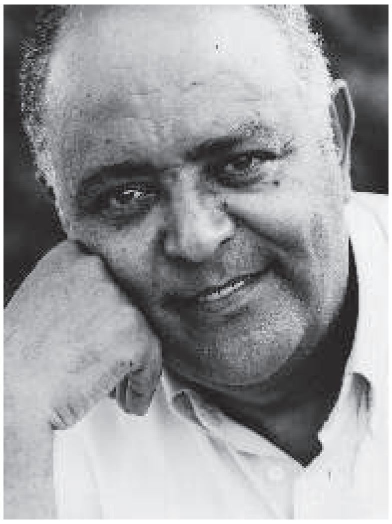


Figure 1.6 *Dr Melaku Worede, an internationally acclaimed plant genetics researcher*

Dr Melaku Worede

Dr Melaku Worede was born in 1936 and he has worked for many years to save the genetic diversity of Ethiopia's domestic plants. He is an internationally acclaimed plant genetics researcher. Dr Melaku set up the Plant Genetic Resources Centre in Addis Ababa. Our country is noted for its great genetic diversity but modern farming methods and problems such as drought can affect this badly. Dr Melaku Worede has preserved many different traditional crop varieties and developed ways of farming that produce high yields without commercial fertilisers. Dr Worede's methods are now widely used both in other areas of Africa and in Asia. He was the first chair of the African Committee for Plant and Genetic Resources and has been Chair of the United Nations Food and Agriculture Organisation's Commission on Plant Genetic Resources. He has also won the Right Livelihood Award (often called the Alternative Nobel Prize) in 1989 for outstanding vision and work and in 2008 he received the Outstanding International Contribution Award from the National Green Award Foundation.

Dr Gebissa Ejeta

When Dr Gebissa Ejeta was born in a small rural village his mother was determined her son would receive a good education. He walked 20 miles to school every Sunday evening, returning home on Friday after a week of studying. It all paid off as he gained a place at Jimma Agricultural and Technical School and then Alemaya College where he took his first degree. He specialises in plant breeding and genetics. Dr Gebissa Ejeta did his research on sorghum – he got his PhD from Purdue University in the USA where he still holds a professorship. He has helped to develop Africa's first commercial hybrid strain of sorghum. This not only needs less water and so is resistant to drought, but it also yields more grain than traditional varieties. Dr Gebissa Ejeta developed other strains of sorghum which are also resistant to the parasitic Striga weed, which can destroy a big percentage of a crop. Dr Ejeta's work has made a very big difference to the food availability in many areas of Ethiopia and other African countries – his varieties yield up to ten times more than the original strains. In 2009 Dr Gebissa Ejeta was awarded the World Food Prize, which is the most important agricultural prize in the world! He has also been awarded the National Hero award of Ethiopia for his work in science and technology.

Figure 1.7 *Dr Gebissa Ejeta who has been honoured for his work in developing new, high yielding strains of sorghum which grow well in our conditions*

These are just some of many renowned Ethiopian biologists who have carried out work of great value both in our own country and across the world. You will have the opportunity to find out more about some of the other scientists with your teacher in activity 1.1.

Here are some more examples of Ethiopian biologists.

- *Professor Beyene Petros* is a biomedical scientist and long serving professor at Addis Ababa University. Professor Beyene Petros, in addition to his distinguished academic career, served as Chairman, Advisory Committee on Health Research and Development, WHO/AFRO, 1997–2000; as vice minster of Education (1991–1993) and many other scientific societies. He has produced more than 43 publications in reputable scientific journals and Published books. Professor Beyene has won Gold Medal Award from Ethiopian Health Association; Fellowships from Fulbright and from Centers for disease control and prevention, Atlanta, USA.
- *Professor Sebsebe Demissew* is a plant taxonomist. He is now the Director of the National Herbarium and the leader of the Ethiopian Flora Project (EFP).

Activity 1.1: Discovering Ethiopian biologists

It is inspiring to know what great work is being done by Ethiopian biologists today. Here you have the opportunity to do some research and find out about some of the people who are active in biology in our country.

- You can choose a biologist from the list on pages 5 and 6, find out more about one of the biologists already mentioned in this chapter or write about a biologist you have discovered for yourself. If you look at the research institutions mentioned in the rest of this chapter you will be able to find lots of Ethiopian biologists to choose from!
- Use any resources you have available. You may find out about Ethiopian biologists in books, magazines, journals, leaflets, in the news or even on the internet if it is available.
- Write a report about your biologist and prepare to give a brief talk on him or her to the rest of the class.

- *Dr Zeresenay Alemseged* discovered a 3.3 million-year-old humanoid child fossil in 2006.
- *Dr Tsehaynesh Meselle* was the Director General of the Ethiopian Health and Nutrition Research Institute (EHNRI) during the writing of this book and leads research in human health, including HIV/AIDS.
- *Dr Berhane Asfaw* is an Ethiopian scientist whose team discovered two 160 000-year-old human skulls, some of the oldest that have ever been found. His discoveries were published in the famous scientific journal *Nature*. They have had a great impact on the study of human evolution around the world.
- *Professor Legesse Negash* is a Professor of Plant Physiology in the Department of Biology, Faculty of Science, Addis Ababa University. He is a pioneer in the propagation of Ethiopia's indigenous trees and is the Founder and Leader of the Center for Indigenous Trees Propagation and Biodiversity Development in Ethiopia. Professor Negash is a winner of several awards, including that from the Stockholm-based International Foundation for Science.
- *Professor Mogessie Ashenafi* works at the University of Addis Ababa and leads international research into food microbiology.
- *Professor Ensermu Kelbessa* is one of the leading systematic botanists who has discovered and named many new plants.

Review questions

Select the correct answer from A to D.

1. Biology is:
   A the study of matter
   B the study of life and living organisms
   C the study of how living organisms interact
   D the study of the way atoms and molecules react together
2. Bilharzia is caused by:
   A snails
   B bacteria
   C viruses
   D parasitic flatworms
3. Dr Tewolde Berhan Gebre Egziabher is a biologist who researches into:
   A HIV/AIDS
   B genetic engineering
   C environmental protection and diversity
   D human evolution

1.2 Biological research in Ethiopia

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

- Explain how scientific institutions contribute to scientific research.
- Name some Ethiopian institutions involved in biological research.
- Explain the activities and contributions of some of these Ethiopian research institutions.

Biologists, like other scientists, do not work alone. A biologist needs equipment, laboratories and other biologists to discuss ideas with and develop theories. Biologists work in many different areas, from plants to animals, and from medicine to classification and genetics. Ethiopia has a number of well-known institutions that are involved in biological research. Our country continues to invest in these institutions and to develop more. Our biologists have international reputations in many fields. Biologists from other African nations and from other continents come to our institutions to take part in the research programmes, and our biologists also travel to other countries. Sharing knowledge across the world is an important part of science and Ethiopia plays her part in this.

Here are some of the institutions that play an important part in biological research in Ethiopia.

Addis Ababa University (AAU) Biology Department

Addis Ababa University (AAU) is a very large university with an international reputation and the Biology Department is no exception. A top university, AAU is one of the major centres of biological research in the country and it is also home to the Aklilu Lemma Institute of Pathobiology (see the next page).

The university entrance is impressive and the Department of Biology contains much modern and high-level equipment to help biologists in their research.

Addis Ababa University is not the only renowned university in Ethiopia. There are many others, including Haramaya University, Mekelle University, Jimma University, Hawassa University, Gonder University and Bahir Dar University. They all have active biology departments where teaching and research takes place.

Figure 1.8 *Addis Ababa University is home to much internationally recognised research.*

Figure 1.9 The AHRI buildings and some of the workers who work there

Armauer Hansen Research Institute (AHRI)

When Armauer Hansen Research Institute (AHRI) was first set up in 1969 it was sited next to a big hospital dedicated to patients with leprosy and it carried out research only into leprosy. However, in the years since 1969 leprosy has become a disease that we can treat quite effectively. Since 1996 AHRI has widened its research to include tuberculosis (TB, which has become a big threat with the rise in HIV/AIDS), leishmaniasis, malaria and HIV/AIDS, as well as leprosy.

Aklilu Lemma Institute of Pathobiology (ALIPB)

The department of pathobiology at Addis Ababa University has been renamed the Aklilu Lemma Institute of Pathobiology (ALIPB) in honour of Professor Aklilu Lemma (see page 2). The institute sets out to be a centre of excellence for biomedical research and training. ALIPB carries out research in five major areas. They have a microbiology research programme into the major infectious diseases, they look into vectors of diseases and how to control them, some of the biologists are focused on human parasitic diseases and others work on animal health and disease. Finally, some of the biologists are carrying out research into Endod and other plants, which may be useful as medicines. The institute also plays an important role in training new Ethiopian pathobiologists. Students with a first degree in biomedical sciences (i.e. biology, human medicine, veterinary medicine, laboratory technology) can apply to do a Masters degree in tropical and infectious diseases at the institute.

Ethiopian Health and Nutrition Research Institute (EHNRI)

The Ethiopian Health and Nutrition Research Institute (EHNRI) is an organisation that carries out research into health and nutrition issues which affect public health. Its role is both to identify problems and to help everyone in the country become aware of how to overcome the problems and improve their levels of nutrition and health. The laboratory facilities at EHNRI are good and are well equipped for research into immunology and viral diseases. At the moment EHNRI is carrying out a lot of work into HIV/AIDS in Ethiopia. For example, biologists working with EHNRI are following the progression of HIV/AIDS in two populations of factory workers (about 2000 people) over a long period of time – the research began in 1994! They are planning to work with more people in the future, and are also hoping to set up trials of a possible HIV vaccine. EHNRI is also very active in the battle against TB and it houses the National TB Reference Laboratory. It is involved in rapid diagnosis of TB. EHNRI is also involved in many other projects including issues such as the nutritional state of mothers and babies in the country as well as infectious diseases.

Ethiopian Institute of Agricultural Research (EIAR) also known as Institute of Agricultural Research (IAR)

Agriculture – farming crops and livestock – is the life force of our country. We must grow food to eat. The EIAR (IAR) is the institute where biologists with a passion for improving agriculture and supporting everyone who cultivates the land or raises livestock in Ethiopia carry out research.

There are five main areas of research. Biologists working on crop technology are working to help us achieve food security and nutritional quality, so that we always have sufficient food. They are looking at different crops and ways of improving the crops we already grow. Other biologists are focusing on our livestock, looking at ways of managing our animals' breeding and feeding programmes to make sure that they grow as quickly and as well as possible. They also look at ways of improving the health of our livestock.

Biologists working on crop technology have improved crops like maize, teff and sorghum. Two of these are shown here.

Another important area of research is with regard to the soil and water. Biologists are looking into ways of improving the fertility of the soil, particularly ways of avoiding buying expensive inorganic fertilisers. Other scientists are also looking at ways to water the land more effectively. Forestry is also an area of research. Biologists are very involved in rehabilitating, restoring and conserving some of our forest ecosystems. Finally, the institute also looks at ways of mechanising farming. Biologists research into the species of crop plants that are most suitable for mechanised harvesting.

The Institute of Biodiversity Conservation (IBC)

Biodiversity – the range of living organisms in an area – is internationally recognised as one of the biggest issues in biology today. Here in Ethiopia we have a tremendous range of biodiversity, particularly in our plants. There are also many species which are found only in Ethiopia (endemic). So in world terms, when it was decided to set up gene banks to conserve the genetic material of as many plants as possible, Ethiopia was given the highest priority. The Institute of Biodiversity Conservation (IBC) started off conserving the genes of Ethiopian plants. Now the institute is involved in the conservation of plants, animals and micro-organisms in Ethiopia. Research into the management of the ecosystem is also an important part of the work.

Current research in the IBC looks at many areas including forest and aquatic plants, medicinal plants, animal genetic resources, biotechnology and safety, and ecosystem conservation. The institute also holds one of the leading gene banks in the whole of Africa with over 300 plant species represented.

Figure 1.10 *Farming is vital to Ethiopia. Biologists with the EIAR work hard to improve our crops, our animals and our soil.*

DID YOU KNOW?

Farming is vital to Ethiopia. About 90% of our exports and around 80% of our economy depends on agriculture.

Figure 1.11 *An agronomist examining sorghum crop*

Figure 1.12 *Scientists have improved crop production of Quncho, an improved teff. It is a hybrid crop now yielding more than 30 quintals per hectare.*

Activity 1.2: Discovering more about research in Ethiopia

There are many great institutions in Ethiopia carrying out biological research. You have learnt a little about some of them. Now you can find out more.

- Investigate the biology department at the university nearest to your school or any other institution with biologists working there. Find out as much as you can about the research they carry out and the biologists who are there.
- Investigate one other biological research institution in Ethiopia. You may choose to find out more about one of the institutions highlighted in this book or you may find another different one.
- Use any resources you have available. You may use books, magazines, journals, leaflets, university prospectuses or reports in the news or even on the internet, if it is available.
- Write a report about your local university biology department and one other Ethiopian research institute and prepare to give a brief talk on them to the rest of the class.

Activity 1.3: Making a table of research institutions

Make a table to summarise the biological research institutions in Ethiopia that are mentioned in this book. Add any that you or your classmates have discovered. Draw a table as shown below and complete it:

Institution	Focus of research

Review questions

Select the correct answer from A to D.

1. EHNRI carries out research into:
   A health and nutrition issues
   B farming
   C biodiversity
   D soil and water
2. Before it widened its research the Armauer Hansen Research Institute studied only:
   A HIV/AIDS
   B tuberculosis
   C leprosy
   D cervical cancer
3. ALIPB is world-renowned for research into:
   A different diseases and their control
   B improved agricultural practices
   C human evolution
   D environmental conservation

Summary

In this unit you have learnt that:

- Biology is the study of life and living organisms.
- Scientific research is based on the ideas of scientists. They design experiments to test these ideas. Results of these experiments are published in peer-reviewed journals, which are read by scientists around the world.
- Ethiopia has some renowned biologists whose work is known both in Ethiopia and internationally. They include Dr Aklilu Lemma, Professor Tilahun Yilma, Professor Yalemtsehay Mekonnen, Dr Melaku Worede, Dr Legesse Woldeyes, Dr Gebissa Ejeta, Dr Berhane Asfaw, Professor Legesse Negash, Professor Mogessie Ashenafi, Professor Ensermu Kelbessa and many others.
- Most biological research is linked to a research institution that has the facilities which are needed. There are a number of well-known Ethiopian biological research institutions.

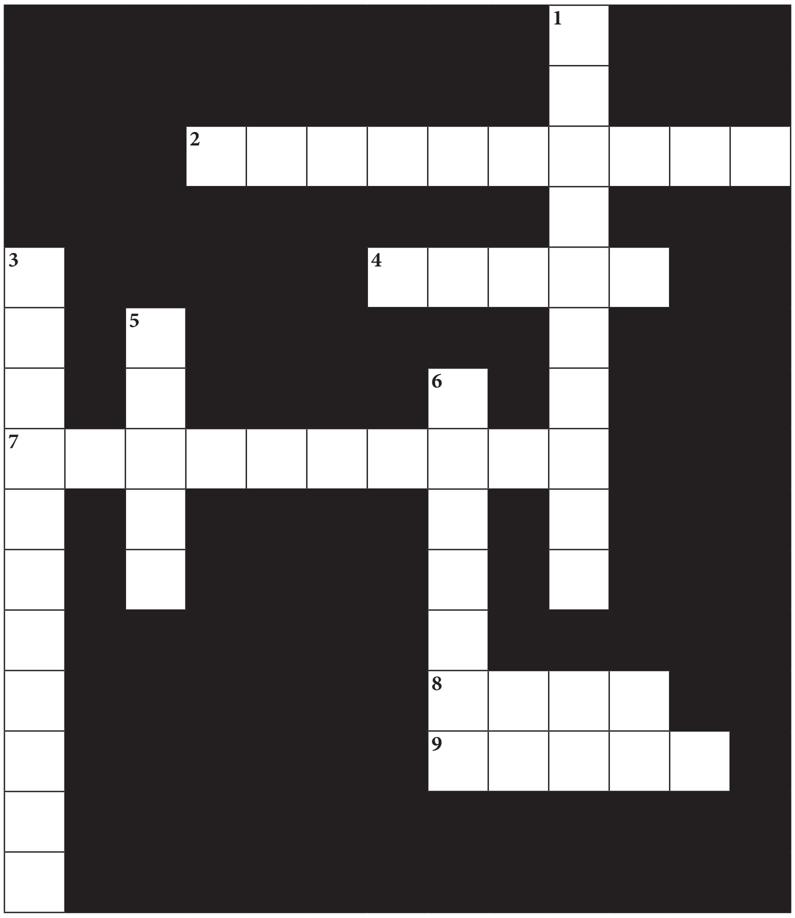
End of unit questions

1. a) Name *two* Ethiopian biologists who have made internationally recognised contributions in their field.

   b) Describe the main work of both of the biologists you have chosen and explain why it is so important.
2. What are the main advantages of using Endod in the battle against bilharzia?
3. Why is Professor Yalemtsehay Mekonnen internationally renowned?
4. What is rinderpest?
5. Why is the work of Dr Gebissa Ejeta so important?
6. Why are scientific institutions important to biological research?
7. a) Name *three* institutions involved in different types of biological research in Ethiopia.

   b) Summarise the areas of biological research carried out by each institution.

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 Professor Tilahun Yilma developed a vaccine against this disease (10)

4 The Ethiopian scientist who has helped make food more available with his new breeds of sorghum is Dr Gebissa ***** (5)

7 What type of trees are planted in Ethiopia by Professor Legesse Negash? (10)

8 The Armauer Hansen Research Institute (4)

9 The surname of the Ethiopian scientist who discovered a way to prevent bilharzia (5)

Down

1 A new scientific idea (10)

3 What is studied at the EIAR (IAR)? (11)

5 What is the name of the plant which kills the snails which cause bilharzia? (5)

6 What do we call a special magazine where scientists publish their research? (7)

Cell biology

Unit 2

Contents

2.1 The microscope

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

- Name different types of microscopes.
- Distinguish between the magnification and resolution of a microscope.
- State the functions of different types of microscopes.
- Compare the different resolutions and dimensions of light and electron microscopes.
- Explain and demonstrate basic techniques using a light microscope.
- Explain the purpose of staining cells.
- Use the microscope to study cells.
- Compare the way materials are prepared for the electron microscope and the light microscope.

DID YOU KNOW?

The largest single cell in the world is an ostrich egg – they are about 18 cm long and weigh around 1.2 kg. Most cells are much harder to see!

Figure 2.1 Ostrich with eggs

KEY WORDS

microscope *an instrument for magnifying specimens*

light microscope *a microscope that uses a beam of light to form the image of an object*

electron microscope *a microscope that uses a beam of electrons to form an image*

magnification *increase the size of an object*

resolution *ability to distinguish between two separate points*

resolving power *how much detail the microscope is able to show*

Biologists use different tools to help them study living organisms. One of the most important is the microscope. Many important organisms are very small and biologists need to be able to see them. The building blocks of life are called cells and scientists need to be able to see cells to understand living organisms. Most cells cannot be seen without some kind of magnification. You will be discovering the secrets of cells revealed with the help of a microscope. In this section you will learn more about microscopes and how they work. In the next section you will be learning more about the structure of cells and how they work.

Seeing cells

There are some cells that can be seen very easily with the naked eye. Unfertilised birds eggs are single cells, most cells are much smaller than this. Everything we know about the structure of cells has depended on the development of the **microscope**. For over 300 years we have been able to look at cells, and as microscopes have improved, so has our knowledge and understanding of cell structure. There are two main types of microscopes in use, the **light microscope** and the **electron microscope**. The light microscope uses a beam of light to form the image of an object, while the electron microscope uses a beam of electrons to form an image. You are going to learn about both.

Magnification and resolving power

The reason microscopes are so useful is because they magnify things, making them look bigger. **Magnification** means increasing the size of an object. The best light microscopes will magnify up to around 2000 times. Light microscopes have given us a lot of information about the structure of cells, but in the last 50 years or so we have also been able to use electron microscopes. An electron microscope can give you a magnification of around 2 000 000 times. Using electron microscopes makes it possible for us to learn a lot more about cells and the ways in which they become specialised for particular functions.

The biggest problem with the light microscope is the limited detail it can show. There is a minimum distance between two objects for them to be seen clearly as separate. If they are closer together than this they are seen as one thing. This distance is known as the limit of resolution. **Resolution** is the ability to distinguish between two separate points and it is the **resolving power** of a microscope that affects how much detail it can show. The greater the resolving power of the microscope, the more detail it can show. For the optical light microscope the limit of resolution is approximately 200 nanometres ($1 \text{ nm} = 1 \times 10^{-9} \text{ m}$). In comparison, the human eye can only resolve down to about 0.1 mm ($1 \text{ mm} = 1 \times 10^{-2} \text{ m}$) (see figure 2.2). Objects closer than 0.1 mm are seen as one by human eyes.

The magnification we can get with a light microscope is limited by the resolving power possible using the wavelength of light. To see more detail clearly we need an electron microscope where an electron beam is used to make the image. As the wavelength gets smaller, the resolving power is increased. An electron microscope has a resolving power around a thousand times better than a light microscope, about 0.3 nm. Objects that are 0.3 nm apart can be seen as separate by an electron microscope, demonstrating that the resolving power of an electron microscope is greater than that of a light microscope.

Functions of different types of microscopes

We will now look in more detail at the different types of microscope and how they are used.

The light microscope

To look at a biological specimen using a light microscope you will often use a slide of cells, tissues or individual organisms. These are often very thin slices of biological material that have been specially treated and stained, but you can look at living material directly through a light microscope as well. Often chemicals known as **stains** are added to the tissue on the slide to make it easier to see particular cells, or parts of a cell. When you are looking at stained cell samples it is important to remember that the cells are dead. The cells have been treated with chemicals or 'fixed' so they do not decay. The tissue has also been sliced very thinly. These things can damage or change the cells. Living cells have not been treated in this way, but are less easy to see.

Below is a list of commonly used stains.

Table 2.1 *Application of commonly used stains*

Type of stain	Type of cells	Main organelles stained
Haematoxylin	Animal and plant cells	Nuclei stained blue/ purple or brown
Methylene blue	Animal cells	Nuclei stained blue
Acetocarmine	Animal and plant cells	Staining the chromosomes in dividing nuclei
Iodine	Plant cells	Any material containing starch

How does a light microscope work?

In a light microscope, a specimen is placed on the stage and illuminated (lit) from underneath. The light passes through the specimen and on through the lenses to give an image at the eyepiece lens which is greatly magnified, upside down and right to left.

DID YOU KNOW?

If you magnified an average person by the same amount as the best light microscopes (×2000) they would be about 3.5 kilometres tall. Magnified by an electron microscope (×2 000 000), the average person becomes about 3500 kilometres tall!

KEY WORD

stains *chemicals added to slide tissues to make the cells easier to see*

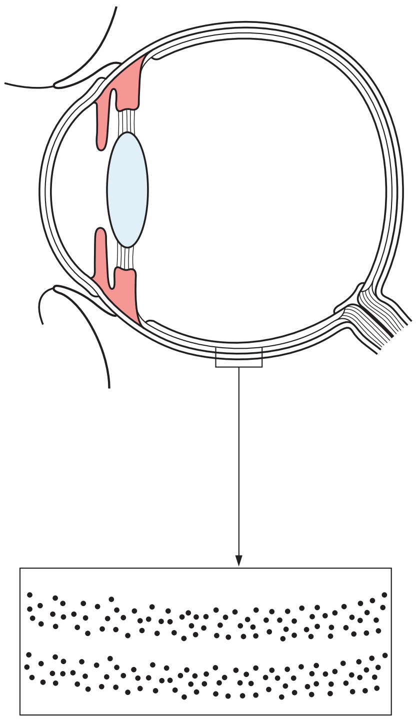


Figure 2.2 *The lines that make up this diagram are actually a mass of dots on the page. The resolving power of your eyes means that you see the dots merged together to make lines because you can't resolve the dots individually. If you magnify the line, you can see the dots. In the same way, what you can see through the light microscope is limited by the resolving power of the microscope itself.*

DID YOU KNOW?

Electron beams have a shorter wavelength than light.

To calculate the magnification of the specimen, you multiply the magnification of the objective lens by the magnification of the eyepiece lens. So if the magnification of the objective lens is ×10, and the eyepiece lens is also ×10, the overall magnification of the microscope is 10 × 10 = ×**100**. If you move the objective lenses round and use the ×40 lens, the overall or total magnification will become 40 × 10 = ×**400**.

DID YOU KNOW?

A light microscope with two lenses – the eyepiece lens and the objective lens – is known as a compound microscope. It produces much better magnification than is possible with a single lens.

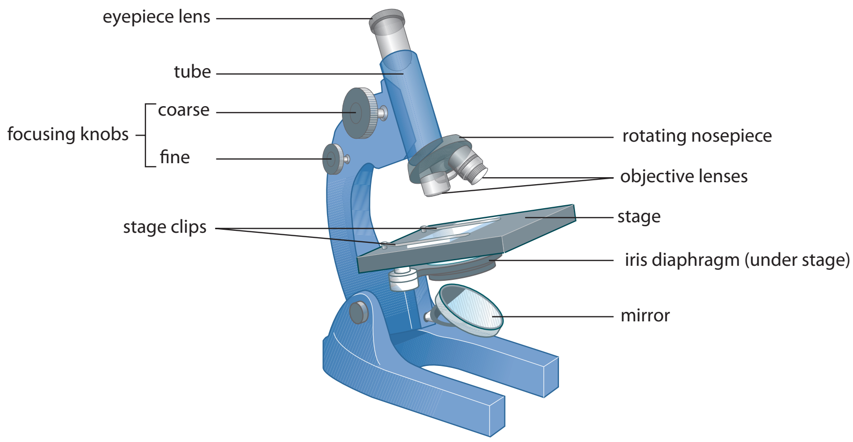


Figure 2.3 *A compound microscope has two sets of lenses (objective and eyepiece lenses) which are used to magnify the specimen. These microscopes are widely used for looking at cells.*

Activity 2.1: Learning to use a microscope

You will need:

- a microscope
- a lamp
- a piece of graph paper
- a prepared slide of stained human cheek cells (see figure 2.4), or look on page 18 to find out how to make a slide for yourself

Method

Remember, microscopes are delicate pieces of equipment so always take care of them and handle them safely.

1. Set up your microscope with the lowest power lens (the smallest lens) in place.
2. Clip the prepared slide into place on the stage using the stage clips. Position the piece of graph paper over the hole in the stage.
3. If your microscope has a built-in lamp, switch it on. If it has a mirror, adjust the angle of the mirror until the specimen is illuminated.
4. Now look through the eyepiece lens and adjust the iris diaphragm until the light is bright but doesn't dazzle you. The illuminated area you can see is known as the field of view.
5. Looking at your microscope from the side (not through the eyepiece lens) and using the coarse focusing knob, move the objective lens down slowly so it is as close as possible to the paper without touching it.
6. Now look through the eyepiece lens again. Turn the coarse focusing knob very gently in the opposite direction to move the objective lens away from the slide. Do this while you are looking through the eyepiece lens and the lines on the graph paper will gradually appear in focus. Once you can see the specimen clearly, use the fine focusing knob to get the focus as sharp as you can.
7. You may find that if you now shut the iris diaphragm down further, so that the hole for the light to pass through gets smaller, you will see the specimen better (the contrast is greater).

8. To use the higher magnifications, rotate the nosepiece so that the next lens clicks into place. Do not adjust the focusing knobs at this point as the specimen should still be in focus and, with the coarse focusing knob in particular, it is very easy to break a slide. It is good to practise this using graph paper, which will not break! If you do need to adjust the focus, use the fine focusing knob only with higher magnifications. Take great care to avoid letting the lens touch the slide/paper. You may want to adjust the iris diaphragm as well.
9. Make simple drawings to show how much of the graph paper you can see at each magnification. This will help you to get an idea of how much the microscope is magnifying what you are seeing. Notice how the appearance of the smooth lines changes as you see them at greater magnification.
10. Return the microscope lenses to their original positions. Now look at a slide of stained human cheek cells and practise focusing on what you see.

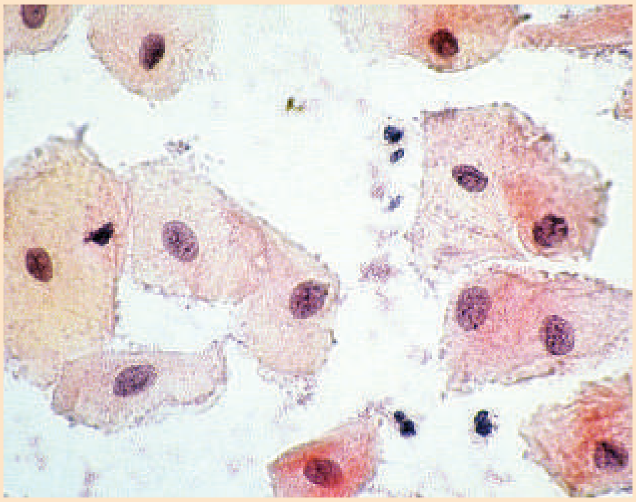


Figure 2.4 *Human cheek cells stained with methylene blue (×100)*

Advantages and disadvantages of the light microscope

One of the biggest advantages of using a light microscope is that we can see living plants and animals or parts of them directly. It is very important to observe living cells. It lets us check if what we see on prepared slides of dead tissue is at all like the real living thing.

Any biologist working in a hospital, industrial or research lab will have a light microscope readily available to use at any time. School and university students around the world also rely on light microscopes to enable them to learn about the living world of cells.

Light microscopes can also be used without electricity, which means they can be used anywhere in the world.

Light microscopes are relatively small and not very heavy, so they can be moved around easily. They are quite delicate so they need to be protected, but with care biologists can even take light microscopes out into the field with them to do their research.

The biggest disadvantage of light microscopes is that their resolving power is limited by the wavelength of light. As you saw earlier, this limits their powers of magnification. Also we can't usually magnify living cells as much as we can dead tissue, which limits what we can learn from living cells.

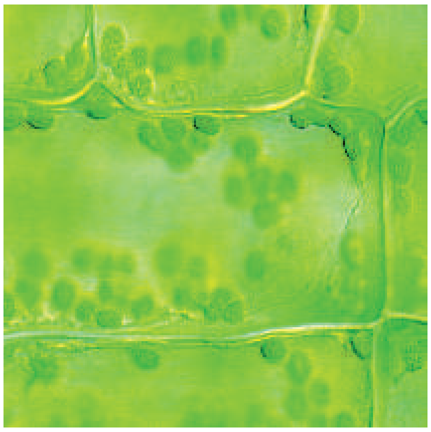


Figure 2.5 (a) *Typical green plant cells seen under the light microscope*

Figure 2.5 (b) Using the light microscope.

Using the light microscope

In the next section of this book you will learn how the light microscope can be used to examine many different types of animal and plant cells. It is important to learn how to mount a specimen on a slide to use with a light microscope. Sometimes you may need to add stain to the specimen so that it can be seen more easily. The activity below explains exactly how to carry out this process.

Activity 2.2: Making a slide of plant cells

The prepared slide you looked at in Activity 2.1 showed animal cells that were dead and stained to make them easier to see. In this activity you are going to learn how to make a slide of living tissue and stain it so that the cells are easier to see.

You will need:

- a microscope
- microscope slides
- cover slips
- forceps
- a mounted needle
- a pipette
- a lamp
- a piece of onion skin
- iodine solution

Method

Remember, microscopes are expensive and delicate pieces of equipment so always take care of them and handle them safely.

Onion cells (the sample taken) do not contain any chlorophyll so they are not coloured. You can look at them as they are, or stain them using iodine, which reacts with the starch in the cells and turns blue-black.

1. Take your piece of onion and remove a small piece of the thin skin (inner epidermis) on the inside of the fleshy part using your forceps. It is very thin indeed and quite difficult to handle.
2. Place the epidermis onto a microscope slide and add a drop of water. Make another identical slide and add a drop of iodine very gently from a pipette.
3. Using the mounted needle (or a sharp pencil), lower the cover slip very gently over the first specimen. Take great care not to trap any air bubbles – these will show up as black ringed circles under the microscope.

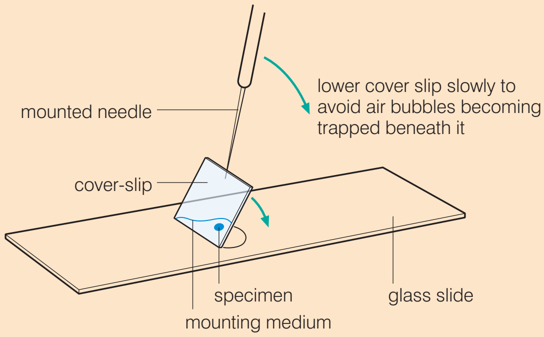


***Figure 2.6** Making a slide*

4. Remove any excess liquid from the slide and place it under the microscope.
5. Repeat this process with the other slide, adding a drop of iodine solution instead of water.
6. Starting with the slide mounted in water and using the lowest power objective lens, follow the procedure for looking at cells described in activity 2.1. Use the higher power lenses to look at the cells in as much detail as possible. You can judge how well you have mounted the tissue – it should be a single layer thick and there should be NO air bubbles!
7. Repeat this process looking at the cells stained with iodine solution. What difference does the stain make?
8. Make a labelled drawing of several of the cells you can see. When you make a drawing of cells, you try and show clearly and simply what is seen under the microscope (see figure 2.7).

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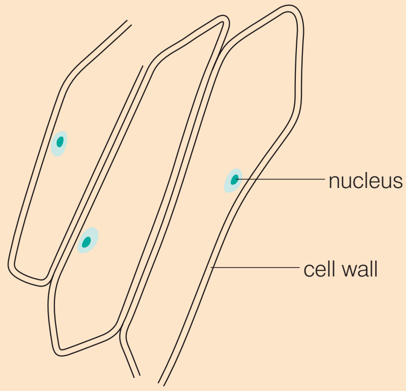
Use a pencil for your drawing and always show the magnification.

(a) mag x100



(b)

***Figure 2.7 (a)** Onion epidermis cells stained with iodine* x100
***(b)** Illustration of some sample onion epidermis cells*

You can get even more information from the light microscope by using the light in different ways. Dark-field illumination, which is where the background is dark and the specimen illuminated, can be useful for showing tiny structures inside cells.

There is one big problem to bear in mind when you are working with microscopes. Unless you are looking at living material, or have the use of a scanning electron microscope (see below), all the cells that you see appear flat and two-dimensional. But cells are actually three-dimensional – spheres, cylinders and strange three-dimensional (3-D) shapes. You need to use your imagination when you look at cells and see them as the living things that they really are.

KEY WORD

wavelength *the distance between neighbouring wave crests*

The electron microscope

The electron microscope was developed in the 1930s and came into regular use in the 1950s. It has greatly increased our biological knowledge. Instead of relying on light with its limit of resolving power, an electron beam is used to form an image. The electrons behave like light waves, but with a much smaller **wavelength**. The resolving power is increased as the wavelength gets smaller, and as a result, the electron microscope can resolve detail down to 0.3 nm.

Samples of material have to be specially prepared for the electron microscope. They are fixed, stained and sliced very thinly in a similar way to the preparation of samples for the light microscope but the materials and stains used are very different.

How does an electron microscope work?

The image in an electron microscope is formed as electrons, which cannot be seen by the human eye, scattered by the biological material, in much the same way as light is scattered in the light microscope. The electron beams are focused by magnetic lenses. A series of magnifications gives you an image. However, you do not simply look into an electron microscope. Complex electronics

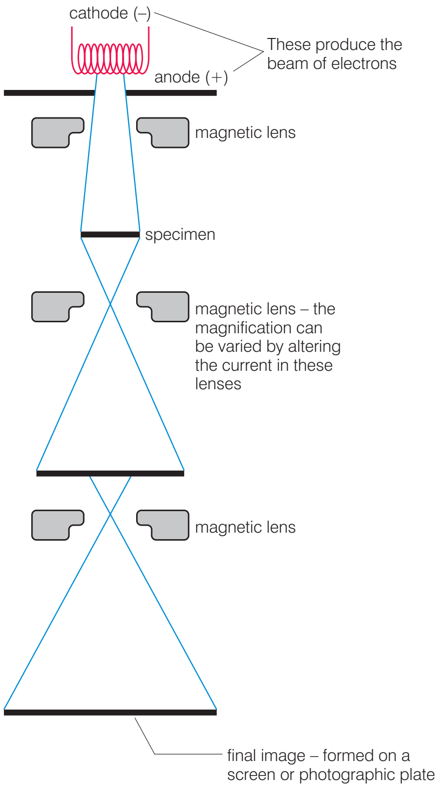


***Figure 2.8** A diagram of an electron microscope and how it works*

produce the image on a television screen, which can then be recorded as a photograph known as an electron micrograph or EM.

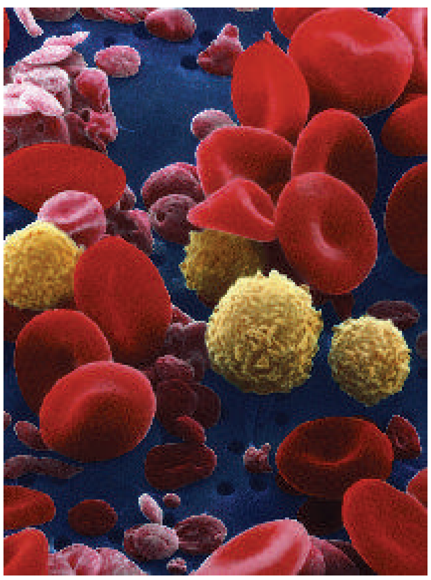
The most common type of electron micrograph you will see is produced by a transmission electron microscope, but the scanning electron microscope produces spectacular images of the surfaces of cells and organisms. It shows the surface of structures, greater depth of focus, and a three-dimensional view of the object (see figure 2.9).

Advantages and disadvantages of the electron microscope

We can see much more detail using an electron microscope than with a light microscope. It gives us much higher magnification and resolution. This is its biggest advantage. Biologists have discovered many structures inside cells since electron microscopes were developed. The electron microscope has also shown us the complicated structures inside cell organelles (see next section) and this helps us understand how they work.

There are several disadvantages to the electron microscope. All the specimens are examined in a vacuum because air would scatter the electron beam. This means it is impossible to look at living material. Some scientists question how useful the images are because the tissue is dead, sliced very thinly, treated with strong chemicals and put in a vacuum before we look at it.

Electron microscopes are very expensive. They take up a lot of space and are usually kept in a separate room. They have to be kept at a constant temperature and pressure and have an internal vacuum. They rely on a constant source of electricity. Few scientists outside of the top research laboratories have access to electron microscopes and so their use for the majority of biologists is limited.



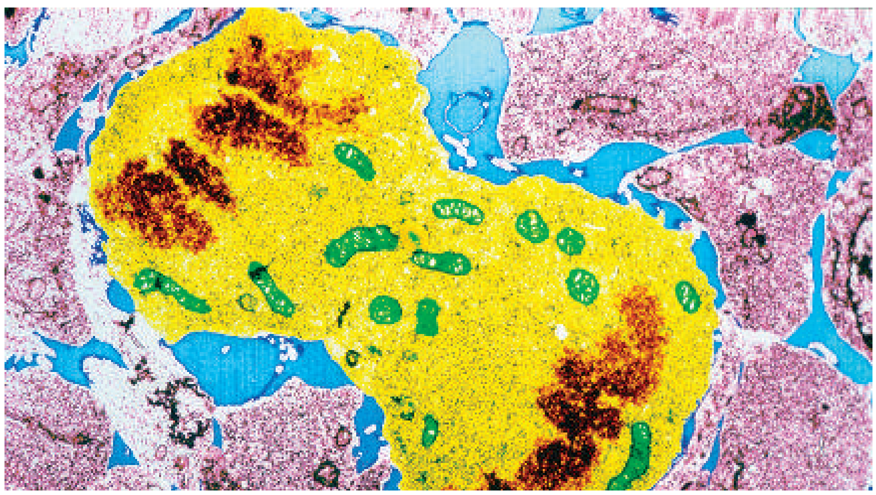


***Figure 2.9** The transmission electron microscope shows the inside details of a cell (right) and the scanning electron microscope can show us three-dimensional shapes (blood cells above).*

Preparing samples for microscopes

Materials must be prepared in different ways depending on what type of microscope you are using.

Tissue has to be prepared and stained in different ways for light and electron microscopes: for light microscopes staining is done using coloured dyes to reflect light, whereas for electron microscopes heavy metals such as lead and uranium are used to reflect electrons. For light microscopes only non-living materials need fixation, while living materials are not fixed: specimens are always fixed with electron microscopes.

Summary

In this section you have learnt that:

- Light microscopes and electron microscopes are widely used by biologists.
- Microscopes magnify both living and dead tissue so you can observe the features of the cells and tissue.
- Magnification involves increasing the size of an object. To work out the magnification of a microscope you multiply the magnification of the objective lens by the magnification of the eyepiece lens.
- Resolution is the ability to distinguish between two separate points.
- The resolving power of a microscope is dependent on the wavelength used, so the resolving power of an electron microscope is around 1000 times greater than the resolving power of a light microscope.
- Using a light microscope takes skill and practice.
- Dead specimens are fixed, stained and sliced before mounting on slides to be observed under the microscope. Living specimens are mounted on slides and stains may be added.
- Stains are used to make parts of cells (e.g. the nucleus) or types of cells show up better under the microscope.
- Tissue has to be prepared carefully before it can be used in the electron microscope. Only dead tissue can be used in the electron microscope.

Review questions

Select the correct answer from A to D.

1. The maximum magnification of a light microscope would make a person:
   A 3.5 m tall
   B 35 m tall
   C 3.5 km tall
   D 35 km tall
2. The largest single cell is:
   A an amoeba
   B a jelly fish
   C an unfertilised ostrich egg
   D an unfertilised human egg
3. Which of the following is not an advantage of the light microscope?
   A It can be used anywhere without electricity.
   B Its resolving power is limited by the wavelength of light.
   C It is relatively light so can be carried out into the field for research.
   D It is relatively cheap.
4. Which of the following is the main advantage of the electron microscope?
   A It's very expensive.
   B Specimens are examined in a vacuum so must be dead.
   C It needs a constant temperature and pressure.
   D It gives a greatly increased magnification and resolution over the light microscope.

2.2 The cell

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

- State the cell theory.
- List the structures of cells and describe their function.
- Draw and label diagrams and compare typical plant and animal cells.
- Describe the types, shapes and sizes of a variety of cells using diagrams.

***Figure 2.10** An organism like this* Paramecium *carries out all the characteristic reactions of life within a single cell.*

The planet we live on is covered with a wide variety of living organisms, including animals, plants and microbes. All living organisms are made up of units called cells. Some organisms, such as amoeba, consist of single cells. Others, such as ourselves, are made up of many millions of cells all working together. Organisms that contain more than one cell are known as multicellular.

Cell theory

Cells were first seen over 300 years ago. In 1665, the English scientist Robert Hooke designed and put together one of the first working optical microscopes. He examined many different things including thin sections of cork. Hooke saw that these sections were made up of many tiny, regular compartments, which he called **cells**.

It took many years of further work for the importance of cells to be recognised. In 1839 Matthias Schleiden and Theodore Schwann introduced an idea known as the **cell theory**. The cell theory states that cells are the basic units of life and by the 1840s this idea was accepted by most biologists.

All living organisms have certain characteristics, which they carry out regardless of whether they have one cell or millions. When we look at cells we can see how all of these functions are carried out.

The seven life processes that are common to most living organisms are:

- **Nutrition** – all living organisms need food to provide them with the energy used by their cells. Plants make their own food by photosynthesis, whereas animals eat other organisms.
- **Respiration** – the process by which living organisms get the energy from their food.
- **Excretion** – getting rid of the waste products produced by the cells.
- **Growth** – living organisms get bigger. They increase in both size and mass, using chemicals from their food to build new material.
- **Irritability** – all living organisms are sensitive to changes in their surroundings.

KEY WORDS

cells *the basic structural and functional units in all living organisms*

cell theory *states that cells are the basic units of life*

nutrition *food substances needed by the body*

respiration *process whereby living organisms obtain energy from their food*

excretion *removal of poisonous waste products produced by cells*

growth *increase in size and mass of an organism*

- **Movement** – all living organisms need to move to get near to things they need or away from problems. Animals move using muscles, plants move more slowly using growth.
- **Reproduction** – producing offspring is vital to the long-term survival of any type of living organism.

Cell structures and functions

There are some basic similarities between all cells, animal and plant alike. For example, almost all cells have a **nucleus**, a **cell membrane**, **mitochondria**, **ribosomes**, **endoplasmic reticulum** and **cytoplasm**. Other features are often seen in plant cells, particularly from the green parts of the plants, but not in animal cells. This has led scientists to develop a picture of the basic structure of an unspecialised animal cell and an unspecialised green plant cell. Although there are not many cells which are quite this simple, the idea of unspecialised animal and plant cells gives us a very useful base point with which to compare other, more specialised cells.

Structures and functions in unspecialised animal cells

All cells have some features in common and we can see them clearly in typical unspecialised animal cells (like the ones on the inside of your cheek). They contain small units called **organelles**. Many of these organelles contain enzymes and chemicals to carry out specialised jobs within the cell.

- The **nucleus** controls all the activities of the cell. It also contains the instructions for making new cells or new organisms in the form of long threads known as **chromosomes**. This is the genetic material. You will find out more about this in Grade 10.
- The **cytoplasm** is a liquid gel in which most of the chemical reactions needed for life take place. About 70% of the cytoplasm of a cell is actually water! The cytoplasm contains all the other organelles of the cell where most of the chemical reactions take place.
- The **cell membrane** forms a barrier like a very thin 'skin' around the outside of the cell. The membrane controls the passage of substances such as carbon dioxide, oxygen and water in and out of the cell. Because it lets some substances through but not others it is known as selectively permeable.
- The **mitochondria** (singular: mitochondrion) are the powerhouse of the cell. They carry out most of the reactions of respiration, whereby energy is released from the food in a form your cells can use. Whenever cells need a lot of energy – such as muscle cells and secreting cells – you will see a lot of mitochondria.

KEY WORDS

irritability *sensitivity of an organism to changes in surroundings*

movement *the need to get near to or away from things*

reproduction *the production of offspring to ensure the survival of a type of organism*

nucleus *controls all cell activity and contains chromosomes*

cell membrane *outer layer of living cell that controls the movement of substances in and out*

mitochondria *carry out cellular respiration*

ribosomes *organelles involved in protein synthesis*

endoplasmic reticulum *links the nucleus of a cell with the cell membrane*

cytoplasm *liquid gel which contains all the organelles of a cell*

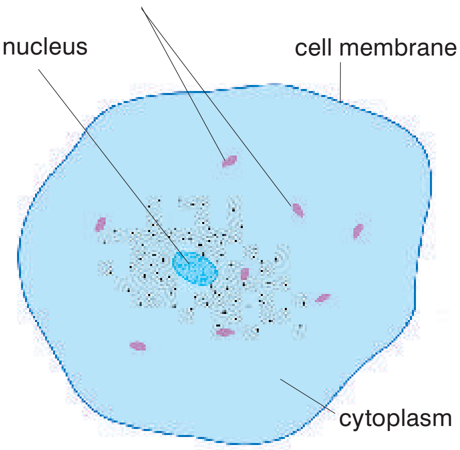
organelles *the small units inside a cell*

chromosome *strand of DNA carrying genetic information*

DID YOU KNOW?

Human beings contain an enormous number of cells. Estimates range from 10 million million cells (10^{12}) to 100 million million (100^{12}) cells – no one has counted accurately!

- The **endoplasmic reticulum** is a three-dimensional system of tubules that spreads right through the cytoplasm. It links the nucleus with the cell membrane.
- The **ribosomes** are found on the endoplasmic reticulum in your cells. They are vital for protein synthesis, the process by which your body makes all the enzymes that control the reactions of your cells.



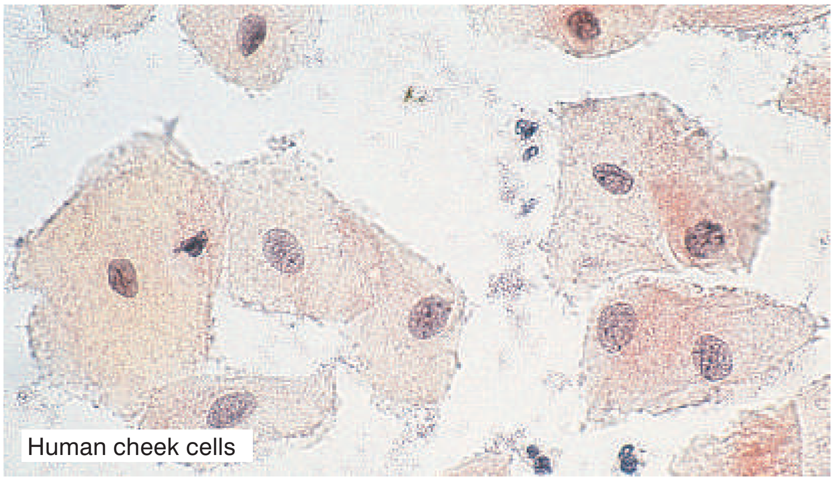
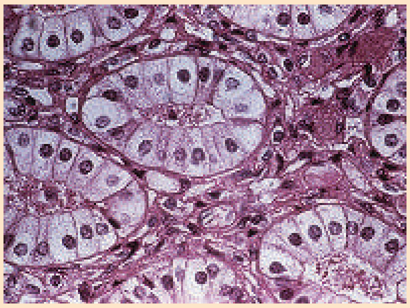


Figure 2.11 *A simple animal cell like this shows the features that are common to almost all living cells. Mitochondria, endoplasmic reticulum and ribosomes cannot be seen easily with a light microscope. They are much clearer using an electron microscope.*

Activity 2.3: Using the microscope to look at animal cells



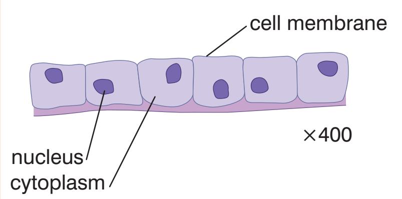


Figure 2.12 *Micrograph and a drawing of simple cuboidal epithelial cells*

You will need:

- a microscope
- a lamp
- prepared microscope slides of human cheek cells/ epidermal cells

Method

Remember, microscopes are expensive and delicate pieces of equipment so always take care of them and handle them safely.

1. Use the instructions for using the microscope, which you learnt in the previous section. You will be provided with slides of human cheek cells and simple epithelial cells.
2. Human cheek cells and simple epithelial cells are very similar to your diagram of an unspecialised animal cell. Draw some of the cells you see and label them as well as you can. Remember you will NOT see ribosomes and mitochondria under normal light microscopes.

Why do cells have organelles?

All of the processes of life take place within a single cell. Imagine 100 mixed reactions going on in a laboratory test tube – chemical chaos and probably a few explosions would be the result! But this is the level of chemical activity going on in a cell at any one time. Cell chemistry works because each reaction is controlled by an enzyme, a protein designed to control the rate of a very specific reaction and ensure that it takes place without becoming mixed up with any other reaction. What is more, the **enzymes** involved in different chemical processes are usually found in different parts of the cell. So, for example, most of the enzymes controlling the reactions of respiration are found in the mitochondria. The enzymes controlling the reactions of photosynthesis are found in the chloroplasts and the enzymes involved in protein synthesis are found on the surface of the ribosomes. These cell compartments or organelles help to keep your cell chemistry well under control.

KEY WORDS

enzyme *protein molecule that acts as a catalyst in cells*

cell wall *outer layer in plant cells and bacteria that is freely permeable*

cellulose *complex carbohydrate that makes up plant cell walls*

vacuole *a fluid-filled cavity inside a cell*

Structures and functions in unspecialised plant cells

Plants are very different from animals – they do not move their whole bodies about and they make their own food by photosynthesis. So, whereas plant cells have all the features of a typical animal cell – nucleus, cell membrane, cytoplasm, mitochondria, endoplasmic reticulum and ribosomes – they also have structures that are needed for their very different way of life.

The **cell wall** is made mainly of a carbohydrate called **cellulose**, which strengthens the cell and gives it support. It is found outside the cell membrane. The cell wall structure contains large holes so substances can move freely through it in either direction – it is freely permeable.

Many (but not all) plant cells also have other features.

- Chloroplasts are found in all of the green parts of the plant. They contain the green pigment chlorophyll, which gives the plant its colour. As a result of the chlorophyll they can absorb energy from light to make food by photosynthesis.
- A permanent **vacuole** is a space in the cytoplasm filled with cell sap, a liquid containing sugars, mineral ions and other chemicals dissolved in water. The vacuole is important for keeping the cells rigid to support the plant. The vacuole pushes the cytoplasm against the cell wall, which keeps the whole structure firm. A permanent vacuole is often a feature of mature (adult) plant cells.

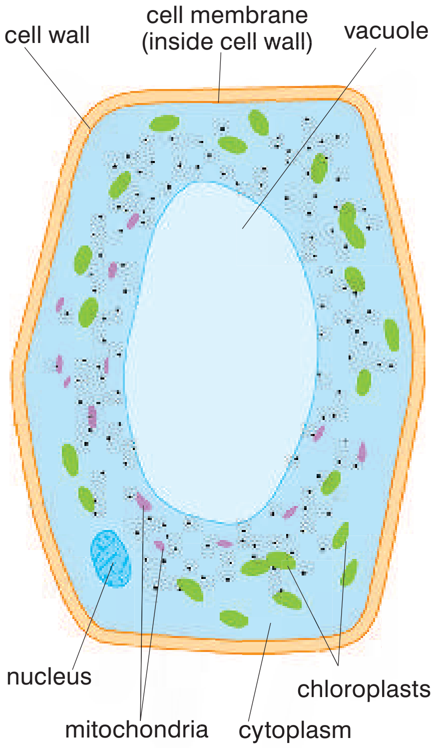


Figure 2.13 A photosynthetic plant cell has many features in common with an animal cell, but others that are unique to plants.

Activity 2.4: Making a slide of plant cells

The prepared slides you have looked at show animal cells that are dead and stained to make them easier to see. In this activity you are going to look at one of a number of different types of plant cells – either (a) onion (as you used in the previous section), (b) red pepper or (c) pondweed.

You will need:

- a microscope
- microscope slides
- cover slips
- forceps
- mounted needles
- pipette
- a lamp
- a piece of (a) onion, (b) red pepper or (c) pondweed, e.g. *Elodea* or Canadian pondweed

Method

Remember, microscopes are expensive and delicate pieces of equipment so always take care of them and handle them safely.

Activity (a) – onion cells

Onion cells do not contain any chlorophyll so they are not coloured. You can look at them as they are, or stain them using iodine, which reacts with the starch in the cells and turns blue-black.

1. Take your piece of onion and remove a small piece of the epidermis using your forceps. Use the method for preparing a slide given in the previous section. You may use iodine to stain the cells.
2. Remove any excess liquid from the slide using tissues and place under the microscope.
3. Starting with the low power lens, follow the procedure for looking at cells described on pages 16–17. Use the higher power lenses to look at the cells in as much detail as possible. Then make a labelled drawing of several of the cells you can see.

Activity (b) – red pepper

Repeat the instructions for the onion cells except this time remove a thin epidermal layer of the pepper. Again these cells do not contain chlorophyll, but they are red so you do not need to use iodine on them.

Activity (c) – pondweed such as *Elodea* (Canadian pondweed)

These plant cells contain chloroplasts. If you watch very carefully when you have the cells under a high power of magnification you may well see the chloroplasts moving about in the living cytoplasm of the cell.

1. Take a single leaf from a piece of pondweed and cut a very small section about 2 mm^2.
2. Place the leaf sample onto a microscope slide and add a drop of water.
3. Using the mounted needle (or a pencil!) lower the cover slip very gently over the specimen, taking care not to trap air bubbles.
4. Remove any excess liquid from the slide using tissues and place under the microscope. Starting with the low power lens, follow the procedure for looking at cells described on pages 16–17.
5. Use the higher power lenses to look at the cells in as much detail as possible. Then make a labelled drawing of several of the cells you can see.

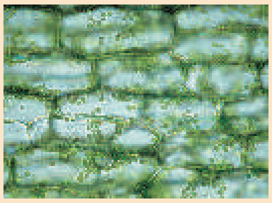
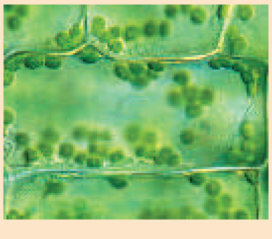


Figure 2.14 Micrographs of Elodea cells under:

***a**) low power (x250)*



***b**) high power lenses (x1260)*

Cell specialisation in humans

Looking at the structure of simple unspecialised cells gives us a good basic understanding of how a cell works. But in multicellular organisms like human beings, most cells become **specialised** – that is, they are adapted to carry out a particular function in your body.

When an egg and a sperm combine to form an embryo, a single cell is formed. This cell divides many times (you will learn more about this in Grade 10) to form a mass of similar **undifferentiated cells**. Each of these cells (known as **embryonic stem cells**) carries all of the genetic information of the individual. As the embryo develops, the cells become **differentiated** – they specialise to carry out a particular function. For example, some cells differentiate to become **red blood cells** and carry oxygen, some become muscle cells and others become **neurones** (nerve cells). This differentiation takes place as some of the genetic material (**genes**) in the nucleus of the cells is switched on and others are switched off. Scientists are still not quite sure what causes these changes to take place, but it seems to be at least partly down to the position of the cells in the embryo itself.

The specialised cells which form as cells differentiate are often grouped together to form a **tissue** – for example in humans

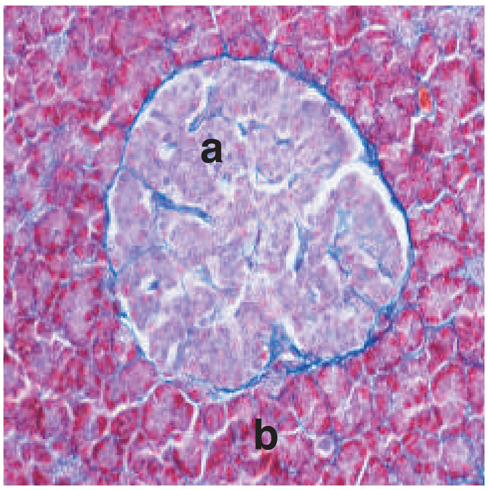


Figure 2.15 *Within an organ like the pancreas at least two very different tissues can be seen. The cells in each type of tissue are specialised to make a very different chemical product, and so they take up stains differently, which allows them to be seen.*

a) The cells that are stained pink make hormones that help to control the sugar levels in the blood.

b) The cells that are stained red make enzymes needed to digest the food in the gut.

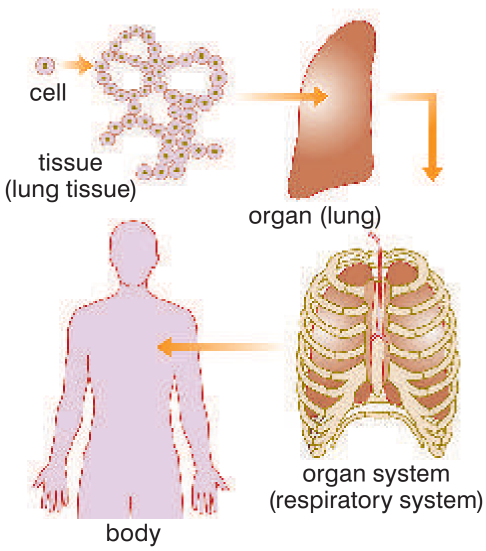


Figure 2.16 *Large living organisms have many levels of organisation. As a result, each part of the body is perfectly adapted to carry out its functions.*

KEY WORDS

specialised cells *adapted to carry out a particular bodily function*

undifferentiated cells *cells that have not yet assumed their final functional characteristics*

embryonic stem cells *cells from the early embryo that have the potential to form almost any other type of cell*

differentiated cells *special cells which carry out specific functions*

red blood cells *types of blood cell that carry oxygen around the body*

neurones *nerve cells*

genes *units of inheritance*

tissue *a group of cells that performs specific functions*

DID YOU KNOW?

Some scientists are working with human embryonic stem cells in an attempt to grow new adult tissues. The hope is that these can be used to replace diseased tissue in people with serious illnesses. So far progress is slow, partly because scientists are not sure how to persuade human embryonic stem cells to differentiate into the tissues they want, and partly because there are ethical issues about using cells from human embryos.

KEY WORDS

organ *a part of the body that carries out special functions*

epithelial cells *cells arranged in one or more layers to form part of a covering or lining of a body surface*

alveoli *microscopic air sacs in the lungs with a large surface area*

microvilli *minute hair-like structures that increase the surface area of a cell*

meiosis *cell division that reduces the chromosome numbers and forms the sex cells*

sperm *male sex cell*

acrosome *a thin sac at the head of a sperm cell containing enzymes which dissolve the protective layers of an egg cell*

connective tissue joins bits of the body together, while nervous tissue carries information around the body and muscle tissue contracts to move the body about.

In many living organisms, including people, there is another level of organisation. Several different tissues work together to do different jobs and form an **organ** such as the heart, the kidneys or the lungs. In turn different organs are combined in organ systems to carry out major functions in the body such as transporting the blood or reproduction. Examples include the cardiovascular system (the heart, lungs and blood vessels) and the digestive system.

Specialised cells

When cells become specialised to carry out one main function as part of a tissue or organ their structure is often very different to that of a 'typical' plant or animal cell. The structure is modified or adapted to suit the very specialised job the cell is doing. For example, cells that use a lot of energy have many mitochondria, whereas cells that are important for diffusion will have a large surface area and cells that produce lots of proteins have many ribosomes as well as mitochondria.

By looking carefully at specialised cells you can see how their structure is adapted to their function. Below are some examples of the specialised cells you will find in the human body.

Epithelial cells

Sometimes the specialisation is not to be very specialised! **Epithelial cells** play many very important roles in the human body. They are usually arranged in thin sheets of epithelial tissue (which are often only one cell thick) and they cover your internal and external surfaces. So your skin is made up of epithelial cells, and your gut, your respiratory system, your reproductive system and many other organ systems of your body are all lined with epithelial cells.

Epithelial cells have many different functions, and their basic structure may be adapted to make them more efficient at their job. Many epithelial cells are there to protect the tissues underneath from damage or infection. They have a very basic simple cell structure, such as in your skin. Epithelial cells often allow the diffusion of materials from one area of your body to another – they line the air sacs (**alveoli**) of your lungs, and the gut wall as well as many glands which secrete hormones or enzymes. Epithelial cells may be flattened, thin columns or have tiny, hair-like projections known as **microvilli** on them to increase the surface area of the cell. This is seen in places like the gut, where diffusion is very important. Some epithelial cells found in the respiratory and the reproductive systems have small hair-like cilia, which move and beat and can be used to move substances through a tube. In your airways ciliated epithelial cells move mucus and microbes away from your lungs, whereas in the female reproductive system ciliated epithelium helps to move the ovum towards the uterus.

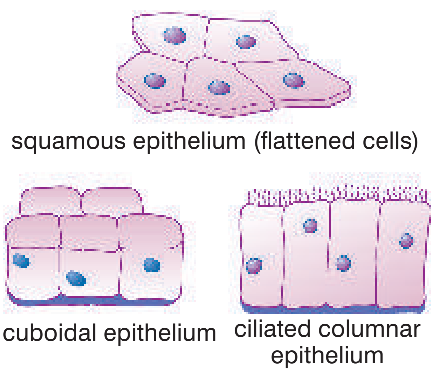


Figure 2.17 *Epithelial cells are found all over your body, lining the body spaces, organs and tubes inside you as well as forming your skin.*

Reproductive cells – the eggs and sperm

The reproductive cells in your body are specialised to perform very different functions when you reproduce (you will learn more about this in Grade 10). If you are female your body contains **ova** or egg cells found in your ovaries. These female sex cells have only half the number of chromosomes found in normal body cells (you will learn more on **meiosis** in Grade 10, a form of cell division that halves the number of chromosomes in your cells). Egg cells have a large nucleus containing genetic information from the woman. They have a protective outer coat to make sure only one sperm gets through to fertilise the egg, and a store of food in the cytoplasm for the developing embryo. In humans, this food store is quite small, but in animals such as birds it is very large – it forms the yolk of the egg.

A small number of relatively large egg cells are released by the ovaries over a woman's reproductive life.

If you are male, once you have gone through puberty your body will produce millions of male sex cells known as **sperm**. Like the egg cells, sperm have only half the chromosome number of normal body cells. Sperm cells are usually released a long way from the egg they are going to fertilise. They need to move through the female reproductive system to reach an egg. Then they need to be able to break into the egg. They have several adaptations to make all this possible. Sperm have long tails containing muscle-like proteins so they can swim towards the egg. The middle section of a sperm is full of mitochondria which provide the energy for the tail to work. They have a special sac known as the **acrosome**, which stores digestive enzymes used for breaking down the outer layers of the egg. Finally, the sperm has a large nucleus containing the genetic information to be passed on to the offspring. Sperm cells are much smaller than egg cells, but they are produced in their millions every day.

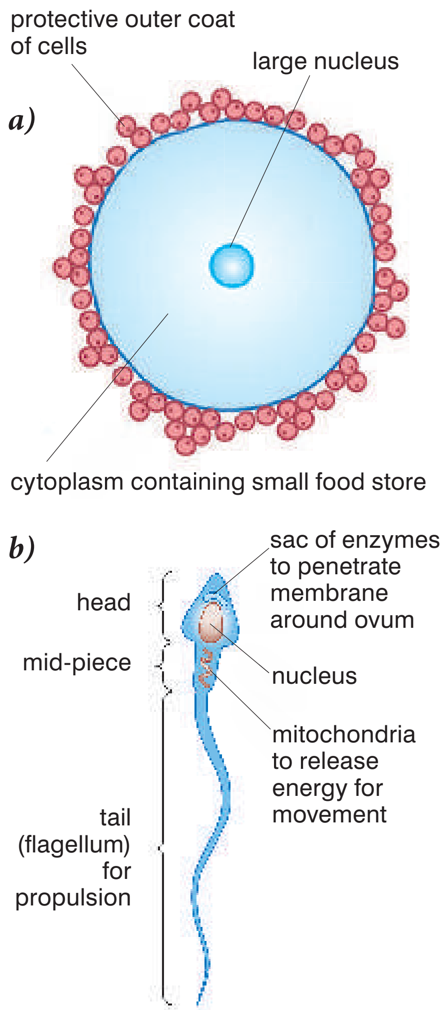
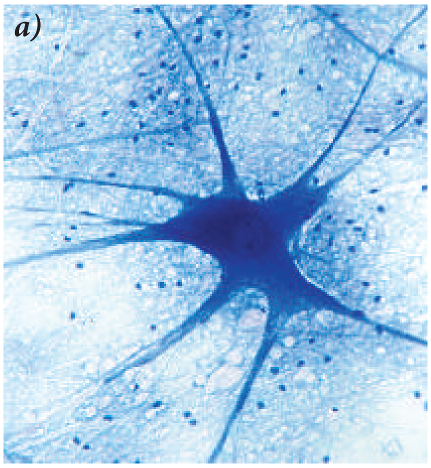


***Figure 2.18 a)** Egg and **b)** sperm cells show very clear adaptations to their much specialised functions.*

Nerve cells (neurones)

Nerve cells or neurones are part of the communication and control system of your body. Electrical nerve impulses pass along them at great speed carrying information from one part of your body to another. So, nerve cells have some clearly specialised features that make this possible. Whatever the type of nerve cell, they have a cell



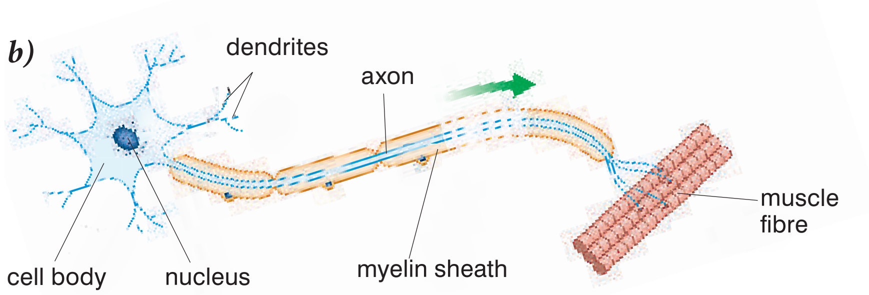
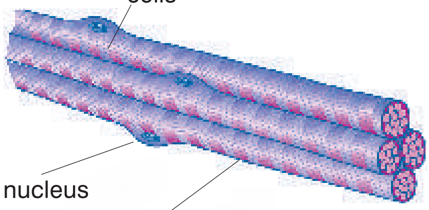


***Figure 2.19** Nerve cells are very different from epithelial cells – but they play a very different role in your body.*

KEY WORDS

dendrites *short, arm-like protuberances of a nerve cell*

axon *extension of a neuron that transmits messages*



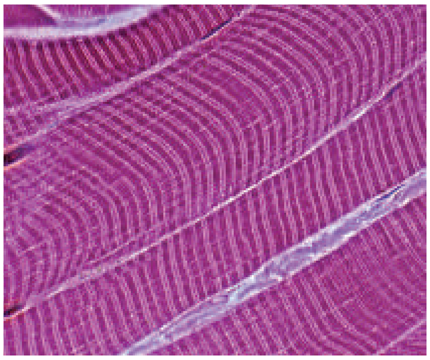


Figure 2.20 *Striated muscle has dark and light stripes under the microscope.*

KEY WORDS

muscle cells *elongated contractile cells that form muscle*

muscle fibres *strands of protein that enable muscles to contract*

body containing the nucleus, **dendrites** that communicate with neighbouring nerve cells and nerve fibres (called the **axon**) that can carry the nerve impulse long distances. The nerve fibres are often covered by a protective myelin sheath that allows the nerve impulses to travel faster. You will find out more about nerve cells in Grade 10.

Muscle cells

Your muscles are responsible for movement in your body. They are made up of very specialised **muscle cells** or **muscle fibres**. These are very long thin (elongated) cells which can contract and relax. When they are relaxed they can be stretched, and when they contract they shorten powerfully. The muscle cells contain two proteins, actin and myosin, and it is these which enable the muscle cells to contract. The most common muscle in the body is striated or striped muscle, and these proteins are arranged so that the muscle cell looks striped. Muscle cells also contain lots of mitochondria which provide the energy for them to contract. The muscle cells are always found in bundles and they all contract together. You will find out more about muscle and its role in your body in Grade 10.

All living cells carry out the characteristic functions of life. As a result, they all have some features in common. But as you have seen there are many ways in which cells become specialised to carry out particular functions in your body. As you study more about the way the human body works in this book, you will discover more examples of specialised cells and their importance in the healthy functioning of your body.

Activity 2.5: Observing different human cells

You will need:

- a microscope
- a lamp
- prepared microscope slides of different human cells – ciliated epithelia, nervous tissue, muscle fibres, sperm and ova if possible

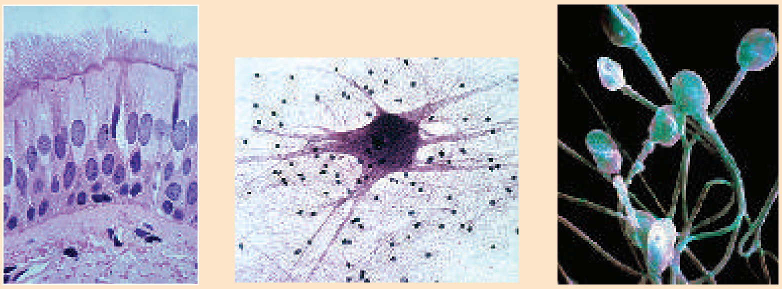
Method

Remember, microscopes are expensive and delicate pieces of equipment so always take care of them and handle them safely.

You will not see mitochondria and ribosomes with a light microscope.

1. Set up your microscope with the lowest power lens (the smallest lens) in place.
2. Clip a prepared slide into place on the stage using the stage clips and observe it using the microscope as described in activity 2.1 on pages 16–17.

3. To use the higher magnifications, rotate the nose piece so that the next lens clicks into place. DO NOT TOUCH the focusing knobs as the specimen should still be in focus and – with the coarse focusing knob in particular – it is very easy to break the slide. If you do need to adjust the focus, use the fine focusing knob only and the higher powers of magnification. Take great care to avoid letting the lens touch the slide. You may want to adjust the iris diaphragm as well.
4. It takes time to be able to understand and interpret what you see under the microscope – the cells you see won't be as clear as the diagrams in your books because those have been drawn by experts using the best possible specimens! Draw some of the cells you see and label them as well as you can. Remember you will NOT see ribosomes and mitochondria under normal light microscopes.



ciliated epithelium   motor neurone   spermatozoa

***Figure 2.21** Micrographs of specialised cells*

Summary

In this section you have learnt that:

- All living organisms are based on units known as cells.
- There are seven life processes that are common to all living organisms: nutrition, respiration, excretion, growth, irritability (response to stimuli), movement and reproduction.
- Unspecialised animal cells all have the following structures and organelles: a cell membrane, cytoplasm, nucleus, mitochondria, endoplasmic reticulum and ribosomes. Each of these has a characteristic structure and carries out clear functions in the working of the cell.
- Unspecialised plant cells all have the same basic structures and organelles as an animal cell. In addition, they have a cellulose cell wall, and may have a permanent vacuole. In the green parts of a plant all the cells contain chloroplasts, which in turn contain chlorophyll. Each of these has a characteristic structure and carries out clear functions in the working of the cell.

KEY WORDS

diffusion *movement of particles from an area of high concentration to an area of low concentration along a concentration gradient*

osmosis *movement of water from an area of high concentration to an area of low concentration along a concentration gradient through a partially permeable membrane*

active transport *movement of substances against a concentration gradient using energy from respiration*

concentration *a way of measuring how many particles of a substance are in one place*

- In multicellular organisms like human beings the cells of the embryo differentiate to form specialised cells, which carry out particular functions in the body.
- Cells specialised to carry out a particular function are grouped together to form a tissue, tissues group together to form an organ, several different organs working together form an organ system and organ systems working together make up the body of a complex multicellular organism.
- There are many different specialised cells in the human body. They include epithelial cells, sperm cells, egg cells, nerve cells and muscle cells. A close look at their specialisation shows how they are adapted to their functions.

Review questions

Select the correct answer from A to D.

1. Which of the following is not an organelle within a cell?
   A nucleus
   B chloroplast
   C mitochondria
   D cytoplasm
2. Which of the following is not one of the seven life processes that characterise living things?
   A movement
   B language
   C reproduction
   D respiration
3. One of these is a tissue in the human body. Which one?
   A heart
   B stomach
   C muscle
   D uterus

2.3 The cell and its environment

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

- Describe the permeability of the cell membrane.
- Describe the process of diffusion and its importance in living organisms.
- Demonstrate diffusion experimentally.
- Explain the process of osmosis and its importance in living organisms.
- Demonstrate osmosis experimentally.
- Show that plant cells become flaccid when they lose water and turgid when they absorb water by osmosis.
- Explain plasmolysis and turgor pressure.
- Explain passive and active transport across cell membranes.
- Discuss the advantages and disadvantages of diffusion, osmosis and active transport for moving substances into and out of cells.

Your cells need to take in substances, such as oxygen and glucose, and to get rid of waste products and chemicals that are needed elsewhere in your body. In human beings, just like all other living organisms, dissolved substances can move into and out of your cells across the cell membrane in three different ways – by **diffusion**, by **osmosis** and by **active transport**. In this section you will look at each of these methods of transport in turn.

Diffusion

When you go home from school you will probably know if there is a meal cooking before you get there. How? Because the smell reaches you by diffusion. Diffusion happens when the particles of a gas, or any substance in solution, spread out.

Diffusion is the net (overall) movement of particles from an area of high concentration to an area of lower concentration. **Concentration** is a way of measuring how much (how many particles) of a substance is in one place.

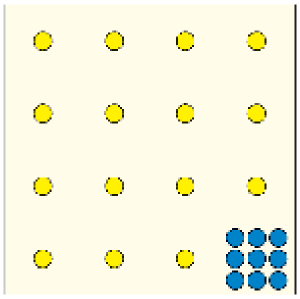
Diffusion takes place because of the random movements of the particles of a gas or of a substance in solution in water. All the particles are moving and bumping into each other and this moves them all around. Although the molecules are moving in both directions, there are more particles moving in the area of high concentration, and so the net (overall) movement is away from the area of high concentration towards the area of low concentration.

Imagine an empty classroom containing a group of boys and a group of girls. If everyone closes their eyes and moves around briskly but randomly, people will bump into each other and scatter until the room contains a mixture of boys and girls. This gives you a good working model of diffusion.

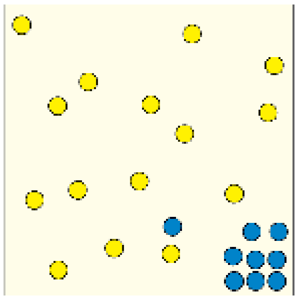
DID YOU KNOW?

Some sharks can sense one part blood in 10 or even 100 million parts of sea water – it's not a good idea to bleed in the sea!

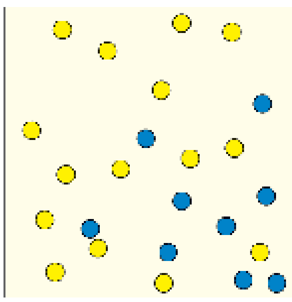
Figure 2.22 *The blood from an injured fish or animal will spread through the water by diffusion. Fish like this piranha will follow the trail of diffusing blood to some easy prey!*



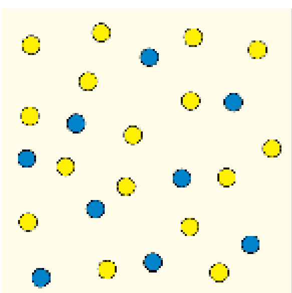
At the moment of adding blue particles to yellow mixture they are not mixed at all.



As the particles move randomly the blue ones begin to mix with the yellow ones.



As the particles move and spread they bump into each other and keep spreading as a result of all the random movement.



Eventually the particles are completely mixed and diffusion is complete.

Figure 2.23 *The random movement of particles results in substances spreading out or diffusing from an area of higher concentration to an area of lower concentration.*

Activity 2.6: Demonstrating diffusion

You will need:

- stopwatch or timer

Method

If your classroom or school yard is suitable, try the idea described on page 33.

1. All the boys stand in one corner (a high concentration of boys). All the girls stand in another corner (a high concentration of girls).
2. Your teacher starts a timer for 30 seconds and you move around slowly with your eyes closed until the timer tells you to stop.
3. Open your eyes and observe what is happening, then start the timer again and move slowly with your eyes closed again. Repeat until the area contains an even mixture of boys and girls.

Activity 2.7: Detecting diffusion

You will need:

- stopwatch or timer

Method

1. Your teacher will open a bottle of a strongly scented chemical such as ammonia or spray some perfume at the front of your class.
2. Start timing as the spray is released, and then put your hand up when you can smell the scent. You'll see a wave of hands moving from the front to the back and sides of the class as the molecules spread out by diffusion.
3. Time how long it takes to reach the last person.

Rates of diffusion

Diffusion is a relatively slow process. A number of different factors affect the rate at which it takes place.

If there is a big difference in concentration between two areas, diffusion will take place quickly. However, when a substance is moving from a higher concentration to one which is just a bit lower, the movement towards the less concentrated area will appear to be quite small. This is because although some particles move into the area of lower concentration by random movement, at the same time other identical particles are leaving that area by random movement.

the overall or **net** movement = particles moving in – particles moving out

In general the bigger the difference in concentration the faster the rate of diffusion will be. This difference between two areas of concentration is called the **concentration gradient** and the bigger the difference the steeper the gradient will be.

Concentration isn't the only thing that affects the rate of diffusion. An increase in temperature means the particles in a gas or a solution move more quickly. This in turn means diffusion will take place more rapidly as the random movement of the particles speeds up.

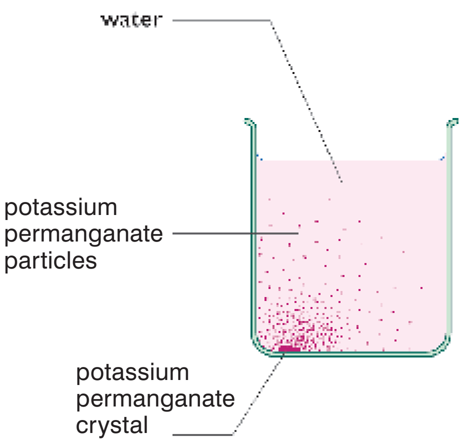
Always remember that diffusion is **passive** – it takes place along a concentration gradient from high to low concentration and uses up no energy.

KEY WORDS

net *amount remaining after certain adjustments have been made*

concentration gradient *difference between an area of high concentration and an area of low concentration*

passive *uses no energy*



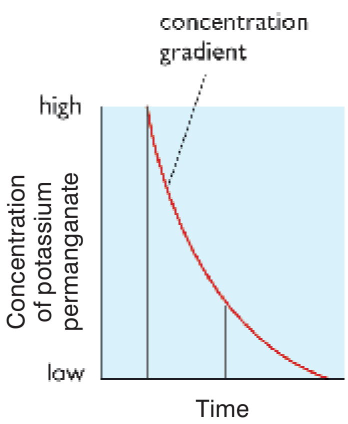


Figure 2.24 *This diagram shows how the overall movement of particles in a particular direction is more effective if there is a big difference (a steep concentration gradient) between the two areas. This is why so many body systems are adapted to maintain steep concentration gradients.*

Activity 2.8: The effect of temperature on diffusion

Potassium manganate(VII) (potassium permanganate) forms purple crystals that dissolve in water. This activity demonstrates both simple diffusion and the impact of temperature on the rate of diffusion.

You will need:

- two identical beakers (100, 200 or 250 cm^3)
- cold water
- warm/hot water
- two crystals of potassium manganate(VII)
- a stopwatch

Method

1. Half fill one beaker with cold water.
2. Put exactly the same amount of warm or hot water in the second beaker. (N.B. if the water is hot, be careful how you handle it.)
3. Drop a crystal of potassium manganate(VII) in each beaker at the same time. Simultaneously start the stop-watch.
4. Time how long it takes the purple colour to reach different points in your beaker, and (if possible) the total time it takes for the liquid to become purple.
5. Write up your investigation and explain your results in terms of diffusion and the effect of temperature on the movement of particles.

DID YOU KNOW?

Many moths rely on diffusion to find a mate. The female moths produce a powerful chemical known as a pheromone to attract males. Pheromone molecules spread through the air by diffusion, sometimes helped by breezes. Male moths can pick up these molecules as far as five miles away from the female – and then fly up the concentration gradient until they reach their mate!

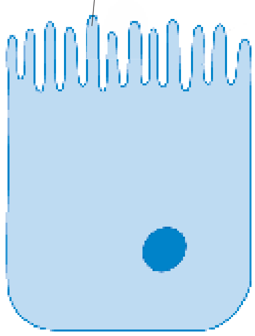


Figure 2.25 *An increase in the surface area of a cell membrane means more diffusion can take place.*

KEY WORDS

partially permeable *allows the passage of some substances but not all*

solvent *liquid in which a solute is dissolved*

solute *chemical that is dissolved in a solvent*

Diffusion in living organisms

Many important substances can move across your cell membranes by diffusion. The oxygen that you need for respiration passes easily from the air into your lungs into your blood and then into your body cells by diffusion. Similarly the waste carbon dioxide produced by your cells passes out easily by diffusion. Simple sugars like glucose and amino acids from the breakdown of proteins in your gut can also pass through your cell membranes by diffusion.

Because diffusion can be a relatively slow process, individual cells may be adapted to make diffusion easier and more rapid. As movement of substances into and out of cells takes place across the cell membrane, the most common adaptation is to increase the surface area of the cell membrane over which diffusion occurs. Only so many particles of a substance such as oxygen can diffuse over a given surface area, so increasing the surface area means there is more room for diffusion to take place. By folding up the membrane of a cell the area over which diffusion can take place is greatly increased and so the amount of substance moved by diffusion is also greatly increased. Tissues and organs show similar adaptations to make sure that diffusion takes place as quickly as possible – the air sacs of the lungs, the villi of the small intestine and the thin, flat leaves of plants are just three examples of this.

Osmosis

Diffusion takes place where particles can spread freely from one place to another. However, the solutions inside a cell are separated from those outside the cell by the cell membrane, which does not let all types of particles through. Only the smallest particles can pass through freely. Because the membrane only lets some types of particles through, it is known as **partially permeable**.

Partially permeable cell membranes allow water to move across them. It is important to remember that a dilute solution of (for example) sugar contains a *high* concentration of water (the **solvent**) and a *low* concentration of sugar (the **solute**). A concentrated sugar solution contains a relatively *low* concentration of water and a *high* concentration of sugar.

Osmosis is a special type of diffusion where only water moves across a partially permeable membrane, from an area of high concentration of water to an area of lower concentration of water.

A cell is basically a solution inside a partially permeable bag (the cell membrane). The cell contents contain a fairly concentrated solution of salts and sugars. Water moves from a high concentration of water particles (a dilute solution) to a less concentrated solution of water particles (a concentrated solution) across the membrane of the cell. The sugars and salts cannot cross the membrane. In other words, osmosis takes place. Take care when you define osmosis. Make it clear that it is only water that is moving across the membrane, and get your concentrations right!

The internal concentration of your cells needs to stay the same all the time for the reactions of life to take place. Yet animal and plant cells are bathed in liquid which can be at very different concentrations to the inside of the cells. This can make water move into or out of the cells by osmosis. So osmosis is very important for all living organisms, including human beings.

Cell membranes aren't the only partially permeable membranes. There are artificial ones too, and these can be used to make a model cell (see the specimen investigation below). By changing the concentration of the solutions inside and outside your model cell, you can see exactly why osmosis is so important in living organisms – and why it is so critical if things go wrong!

There are a number of ways in which you can show how osmosis takes place in living cells. One is described for you here and written out as a specimen investigation. Other ways of investigating osmosis in cells are presented for you to try.

KEY WORDS

isotonic *solutions of equal solute concentration*

hypertonic *a solution with a greater solute concentration than another*

hypotonic *a solution with a lesser solute concentration than another*

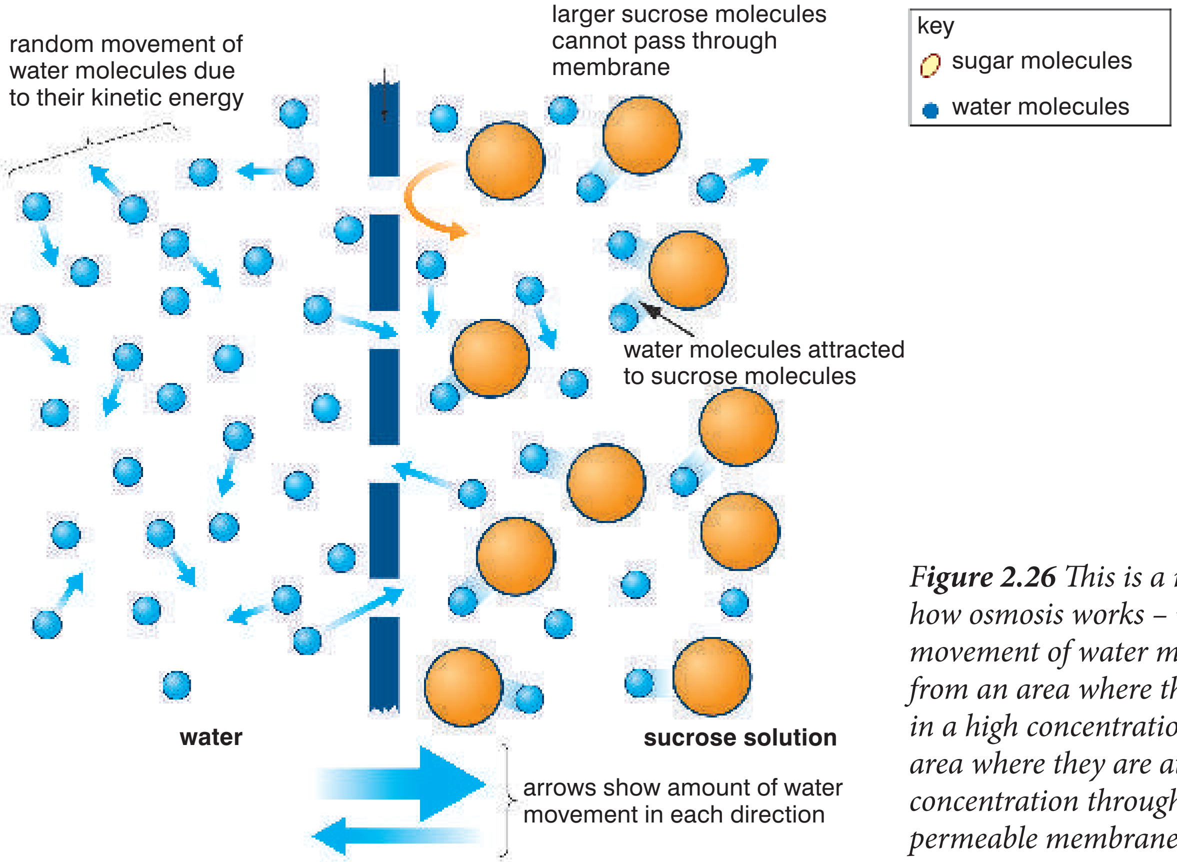


Figure 2.26 This is a model of how osmosis works – with a net movement of water molecules from an area where they are in a high concentration to an area where they are at a lower concentration through a partially permeable membrane.

If the concentration of the solutions on both sides of a cell membrane are the same they are **isotonic**.

If the concentration of the solution on the outside of the cell membrane is higher than the concentration of the solution inside the cell it is **hypertonic**.

If the concentration of the solution on the outside of the cell membrane is lower than the concentration of the solution inside the cell it is **hypotonic**.

Specimen investigation: Demonstrating osmosis in model cells

You will need:

- two sets of the equipment shown in figure 2.27 to make model cells in different situations
- wax crayon (coloured pencil) or small stickers

Method

1. In set A, put concentrated sucrose (sugar) solution in the Visking tubing bag, and water surrounding it in the beaker.
2. In set B, put water in the Visking tubing bag and concentrated sucrose solution surrounding it in the beaker.
3. In both cases, mark the starting level of the liquid on the capillary tubing using the pencil or stickers and observe the state of the Visking tubing bag.
4. Leave the model cells for 30 minutes or longer.
5. Observe the level of water in the capillary tubing and the state of the Visking tubing.

Apparatus

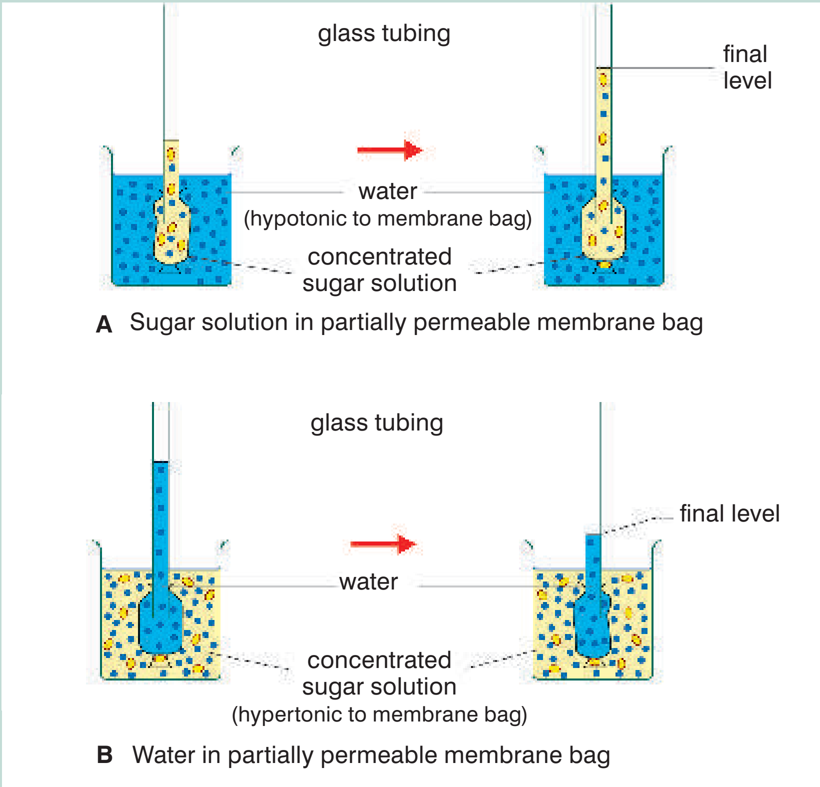


Figure 2.27 *Using bags of partially permeable membrane to make model cells you can clearly see the effect of osmosis as water moves across the membrane from a dilute to a concentrated sugar solution.*

Results

In set A, the liquid level had risen up the glass tubing and the membrane bag was full and tight.

In set B, the liquid level in the glass tubing had dropped and the membrane bag was less full and soft.

Conclusion

In a model cell, if the concentration of water is higher outside the selectively permeable membrane bag than it is on the inside, water will move into the model cell by osmosis (set A). This is why the liquid level rose and the bag filled. If the concentration of water is higher inside the membrane bag than outside, water will leave the model cell by osmosis (set B). This is why the liquid level fell and the bag was emptier. This mimics what happens in real cells.

Activity 2.9: Using potato cups as osmometers

You can use simple potatoes to demonstrate osmosis. A system that shows or measures osmosis is an osmometer.

You will need:

- three raw potatoes and one cooked potato (or three raw half potatoes and one cooked half potato)
- four containers e.g. beakers, bowls
- strong sugar solution/sugar
- water

Method

1. Take each potato or half potato and cut one end to make it flat. Peel the layer directly above the flat end (see figure 2.28).
2. Hollow out the other end of the potato to make a cup (see figure 2.28).
3. Set up the experiment as shown in figure 2.28. A is your control.
4. In B place sugar or strong sugar solution in the cup, with water in the container. If you use sugar solution in the cup, mark the level before you start the experiment.
5. In C place water in the potato cup and mark the level. Place strong sugar solution in the container.
6. In D you will be given a cooked potato, or you must cook it yourself before starting the experiment. Place sugar or strong sugar solution in the cup. Mark the level. Place water in the container.
7. Leave the investigations for several hours or overnight.
8. Record your results carefully.
9. Write up the investigation and make some conclusions. Explain your results in terms of osmosis.

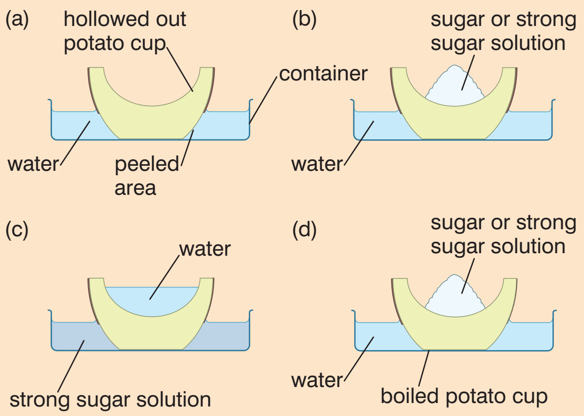


Figure 2.28 *Potato cup osmometers. You can use these to show that osmosis takes place.*

By varying the strength of the sugar solutions you use in osmometers B and C you can investigate how the strength of the solution affects the rate and amount of osmosis.

Osmosis in animals

Osmosis is an important way of moving water in and out of the cell when needed. If a cell uses up water in its chemical reactions, the cytoplasm becomes more concentrated. The external solution is hypotonic and more water will immediately move in by osmosis. Similarly if the cytoplasm becomes too **dilute** because water is produced during chemical reactions. The external solution becomes hypertonic and water will leave the cell by osmosis, restoring the balance.

However osmosis can also cause some very serious problems in animal cells. If the solution outside the cell is much more dilute than the cell contents (hypotonic) then water will move into the cell by osmosis, diluting the cytoplasm. The cell will swell and may eventually burst.

On the other hand, if the solution outside the cell is much more concentrated than the cell contents (hypertonic) then water will

KEY WORD

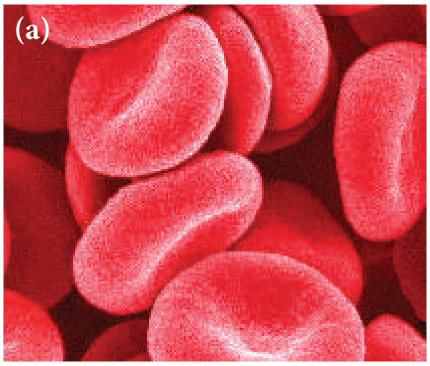
dilute *to make less concentrated*

KEY WORD

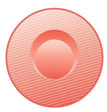
homeostasis *maintenance of a constant internal environment*

move out of the cell by osmosis, the cytoplasm will become too concentrated and the cell will shrivel up. Once you understand the effect osmosis can have on cells, the importance of **homeostasis** and maintaining constant internal conditions will become clear. You will learn more about this later in your course.

(a)



When the concentration of your body fluids is the same as your red blood cell contents, equal amounts of water enter and leave the cell by random movement and the cell keeps its shape.



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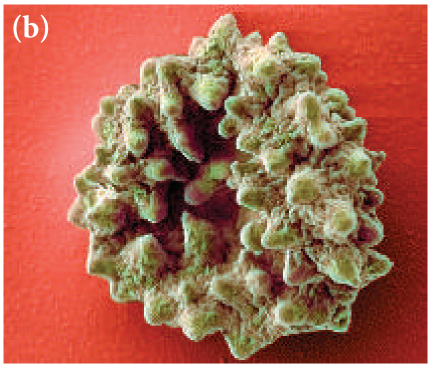
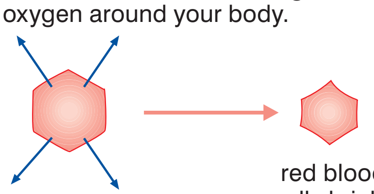
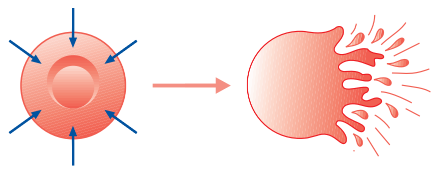


If the concentration of the solution around the red blood cells is higher than the concentration of substances inside the cell, water will leave the cell by osmosis. This makes it shrivel and shrink so it can no longer carry oxygen around your body.



(c)



If the concentration of your body fluids is lower than your red blood cell contents water enters the cells by osmosis so your red blood cells swell up, lose their shape and eventually burst!

Figure 2.29 *Keeping your body fluids at the right concentration is vital. When you realise what can happen to your red blood cells if things go wrong, you can see why!*

Activity 2.10: How does osmosis affect animal cells?

You can show the effect on animal cells of water moving in or out by osmosis with this simple experiment using egg yolks.

You will need:

- two beakers
- water
- strong salt solution made by dissolving salt in water
- two egg yolks

Method

1. Fill one beaker with water and one with strong salt solution.
2. Very carefully crack one egg open and separate the yolk from the white. Do not break the yolk. Place the yolk carefully in the beaker of water.
3. Very carefully crack the other egg open and separate the yolk from the white. Do not break the yolk. Place the yolk carefully in the beaker of salt solution.
4. Immediately observe the yolks very carefully. Draw them or describe what they look like. Measure them if you can.
5. Leave the yolks in the water and salt solution for at least an hour. Then observe and record any changes in the appearance of the yolks.
6. Write up your experiment and explain what you have observed in terms of osmosis.

Osmosis in plants

Plants rely on osmosis to support their stems and leaves. Water moves into plant cells by osmosis, making the cytoplasm swell and press against the plant cell walls. The pressure builds up until no more water can enter the cell, which is hard and rigid. This swollen state is called **turgor**. It keeps the leaves and stems of the plant rigid and firm. So for plants it is important that the fluid surrounding the cells always has a higher concentration of water (it is a more dilute solution of chemicals or hypotonic) than the cytoplasm of the cells, to keep osmosis working in the right direction.

To understand the difference between animal and plant cells when it comes to water moving in by osmosis, imagine blowing up a balloon. As more and more water moves in the balloon gets bigger and bigger and eventually bursts. This models an animal cell placed in pure water or a very dilute solution of salts. Now imagine a balloon sealed into a cardboard box. As the balloon inflates it fills the box and then presses out against the box walls. Eventually you simply cannot force any more air into the balloon. The box feels very rigid and the balloon does not burst. This models a plant cell placed in pure water or a very dilute solution of salts.

If the surrounding fluid becomes more concentrated than the contents of the plant cells (hypertonic), then water will leave the cells by osmosis. The vacuole shrinks and the cell becomes much less rigid – it is **flaccid**. If water continues to leave the cell by osmosis, eventually the cytoplasm pulls away from the cell walls and the cell goes into a state known as **plasmolysis**.

As you have seen, in normal conditions water moves into plant cells by osmosis and keeps them rigid. This in turn helps to keep the plant upright. But if conditions are very dry, the plant cannot take enough water up through the roots from the soil. The cells are no longer rigid and the plant wilts. Many of the chemical reactions slow down and so the plant survives until more water is available. But only for so long – if the osmotic situation is not put right fairly quickly, most plants will die.

KEY WORDS

turgor *when the cytoplasm of a plant cell is pushed hard against the cell wall by the vacuole which is filled with water*

flaccid *floppy, limp*

plasmolysis *when the cytoplasm of a plant cell shrinks away from the cell wall due to osmotic movement of water*

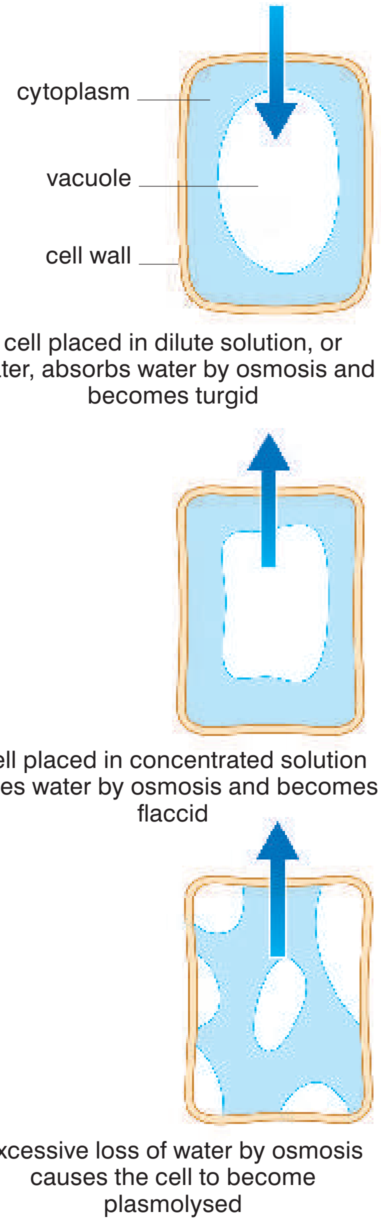


Figure 2.30 *Osmosis plays an important role in maintaining the rigid structure of plants.*

Activity 2.11: How does osmosis affect plant cells?

You will need:

- onion epidermis – red onion is best because the cytoplasm is red so you can see the effects of osmosis much better
- a microscope
- two microscope slides and cover slips
- mounted needle
- 1M sucrose solution
- two small beakers, one labelled 'water' and the other labelled 'sucrose solution'
- two dropping pipettes
- tissue/filter paper

Method

1. Using one of your pipettes, place a drop of water on one of the microscope slides and then place the pipette in the beaker of water.
2. Using the other pipette, place one drop of sucrose solution on the other microscope slide and then place the pipette in the beaker of sucrose solution.
3. Either collect or prepare a piece of epidermis and place it on the drop of water on your microscope slide.
4. Add another drop of water on top of your piece of epidermis and, using the mounted needle, carefully lower the cover slip into place. Blot any excess water using tissues.
5. Now collect or prepare a piece of epidermis and place it on the drop of sucrose solution on your microscope slide.
6. Add another drop of sucrose solution on top of your piece of epidermis and, using the mounted needle, carefully lower the cover slip into place. Blot any excess liquid using tissues or filter paper.
7. Examine both of your slides carefully under the microscope. Look for any differences between them. Draw and label a representative few cells from each slide.
8. Take the slide which has the cells in sucrose solution. Replace the sucrose solution with water and observe any changes in the cells. To do this, place some drops of water on one side of the slide beside the cover slip. Place some tissue or filter paper next to the cover slip on the other side (see figure 2.31) and the sucrose solution will be drawn up into the absorbent paper, pulling the water under the cover slip. You may need to repeat this several times to make sure the cells are now in almost pure water.

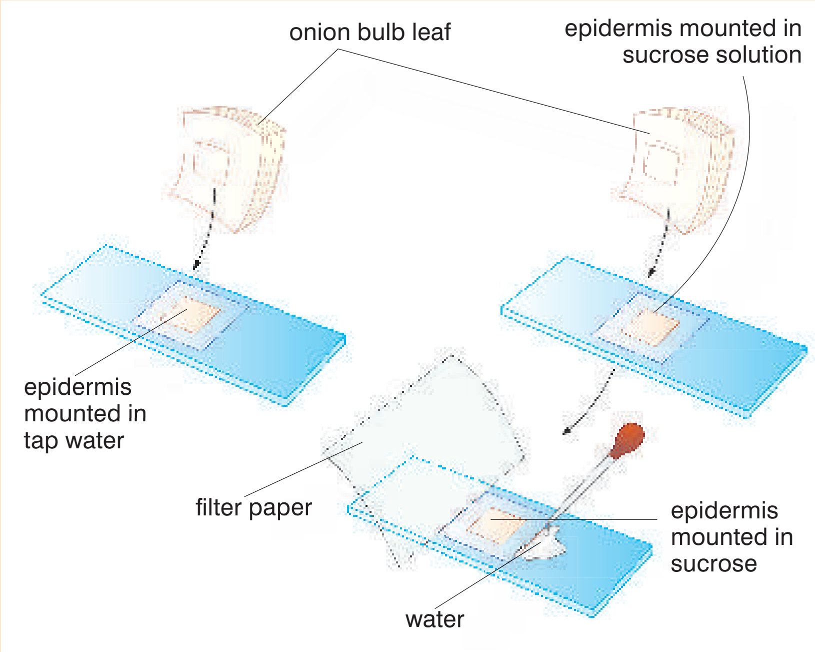


***Figure 2.31** Using this simple technique you can change the solution surrounding your plant epidermis cells as many times as you want to.*

9. Examine the cells again carefully and observe any changes in the cells after the sucrose solution has been replaced by water.
10. Write up your investigation fully, including your drawings and explain your observations are in terms of osmosis.

To carry out activity 2.11 you need to have a microscope. However, you do not need a microscope to measure the effects of osmosis on plant tissue, as you will see if you carry out activity 2.12.

Activity 2.12: How does osmosis affect potato tissue?

There are two alternative ways of carrying out this same experiment. Potato is the most common vegetable chosen but you could use others such as sweet potato or yam and compare the results you obtain. The basic equipment is the same for both methods.

You will need:

- a potato
- a cork borer or apple corer and a sharp knife or scalpel
- a tile or chopping board
- three test tubes or beakers
- tweezers
- a balance if possible (sensitive to 0.1 g)
- a ruler
- filter paper
- 1M sucrose solution
- marker pen

Method A

1. If you have a cork borer or apple corer, cut three cylinders out of your potato. Trim the skin off the top and bottom and cut them all to approximately the same length. If not, cut three long blocks from your potato (approximately 5 cm x 1 cm x 1 cm) and trim off any skin from the top and bottom.
2. Half fill one boiling tube with tap water and label it. Half fill another with 1M sucrose solution and label it. Leave the third tube empty.
3. You are going to be measuring changes in your potato cylinders, so make sure that you know exactly which cylinder you are going to place in which boiling tube before you start measuring! Draw out tables like those given below to record your observations.
4. Measure the length of each cylinder as accurately as you can and record the measurement.
5. Gently blot each potato cylinder with filter paper to remove excess moisture. If you have a balance available, find and record each mass carefully.
6. Place one cylinder in your tube of water, one in 1M sucrose solution and one in the air. Leave them for a minimum of 30 minutes.
7. Using the tweezers, remove each cylinder of potato and blot it dry if necessary.

Table 1: Investigating the effect of osmosis on potato cylinders: length (mm)

Tube	**Starting length (mm)**	**Final length (mm)**	**Change in length (mm)**	**% change in length**	**Condition (Flexible/stiff)**
Water					
Sucrose solution					
Nothing (air)					

Table 2: Investigating the effect of osmosis on potato cylinders: mass (g)

Tube	**Starting mass (g)**	**Final mass (g)**	**Change in mass (g)**	**% change in mass**	**Condition (Flexible/stiff)**
Water					
Sucrose solution					
Nothing (air)					

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8. Measure each tube in turn and record the final length in your table.
9. Observe the appearance of the cylinder compared to a freshly cut one and record it on your table.
10. Calculate the change in length from the start to the finish. This may be positive or negative, depending on whether the potato has lost or gained length.

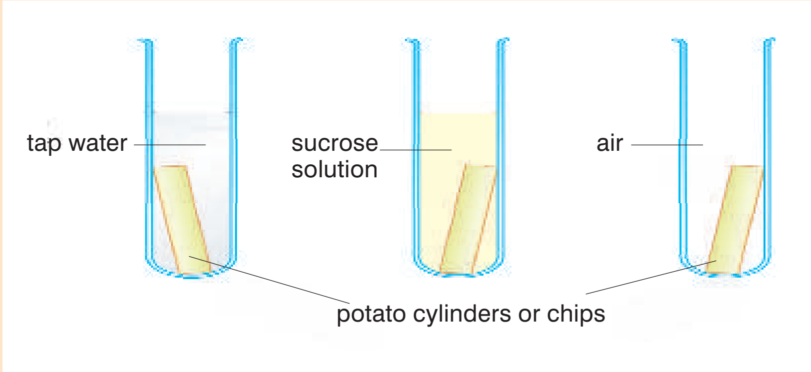

Figure 2.32 *Apparatus for investigating the effects of osmosis on plant tissue*

11. Calculate the percentage change in length for each cylinder and enter it on your table:

$$\% \text{ change} = \frac{\text{change in length}}{\text{starting length}} \times 100$$

12. If you have measured the mass, calculate the percentage change in mass for each cylinder and enter it on your table:

$$\% \text{ change} = \frac{\text{change in mass}}{\text{starting mass}} \times 100$$

13. Write up your investigation, explaining your observations in terms of osmosis and the concentrations of the liquids surrounding the potato cylinders. Make suggestions for any ways in which you feel the investigation might be improved and the results made more reliable. Do you think that measuring the length or finding the mass of the potato is the most reliable method to use?

DID YOU KNOW?

When you sprinkle salt on bitter fruit or vegetables before using them in cooking, water moves out of the plant cells by osmosis and dissolves the salt crystals. This is why you are left with floppy fruit and salty liquor!

Method B (this requires a balance)

Follow method A as far as point 3. In this second method you are only going to investigate changes in mass, so you will only need one table for your results.

3. When you have cut and dried your three cylinders of potato, cut each into a number of smaller discs.
4. Weigh each pile of discs, and then place them into the different boiling tubes and leave them for a minimum of 30 minutes.
5. Using the tweezers, remove all the discs from one tube, blot them dry if necessary and weigh. Record your results in the table.
6. Repeat this for the other two tubes.
7. Calculate the percentage change in mass for each cylinder and enter it on your table:

$$\% \text{ change} = \frac{\text{change in mass}}{\text{starting mass}} \times 100$$

8. Write up your investigation as before.
9. Why do you think that you cut each cylinder into a number of small discs before starting this experiment?

Active transport

There are three main ways in which substances are moved into and out of cells. Diffusion is the passive movement of substances and it depends on a concentration gradient in the right direction to work. Osmosis depends on a concentration gradient of water and a partially permeable membrane. Only water moves in osmosis. However, sometimes the substances needed by your body have to be moved against a concentration gradient, or across a partially permeable membrane, or both. The only way you can do this is to use energy produced by respiration. The process is known as active transport.

Active transport allows cells to move substances from an area of low concentration to an area of high concentration, completely against the concentration gradient. As a result the cells can absorb ions from very dilute solutions. It also makes it possible for them to move substances like sugars and ions from one place to another through the cell membranes.

It takes energy for the active transport system shown in figure 2.33 to carry a molecule across the membrane and then return to its original position. That energy comes from cellular respiration. Scientists have shown in a number of different cells that the rate of respiration and the rate of active transport are closely linked. In other words, if a cell is making lots of energy, it can carry out lots of active transport. Cells like root hair cells and your gut lining cells, which are involved in a lot of active transport, usually have lots of mitochondria to provide the energy they need.

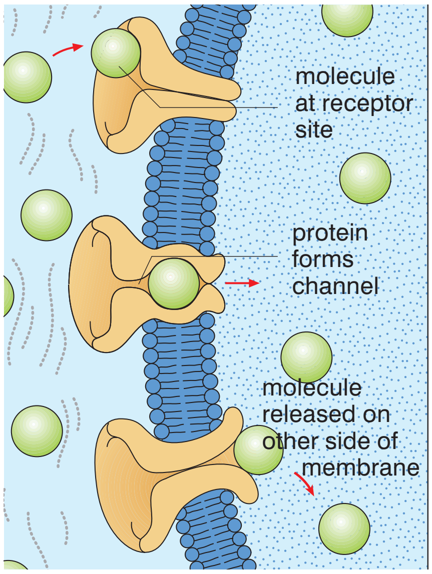

Figure 2.33 *Sometimes it is worth using up energy when a resource is particularly valuable and its transport is really important!*

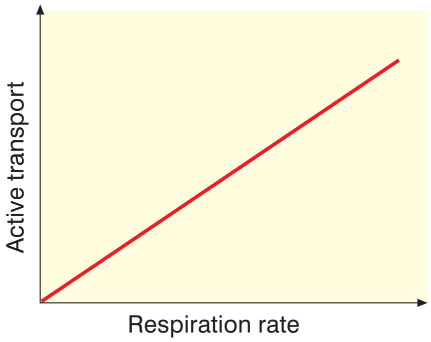

Figure 2.34 *The rate of active transport depends on the rate of respiration.*

The importance of active transport

Active transport is widely used in cells. There are some situations where it 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.

Glucose is always moved out of your gut and kidney tubules into your blood, even when it is against a large concentration gradient, so this relies on active transport.

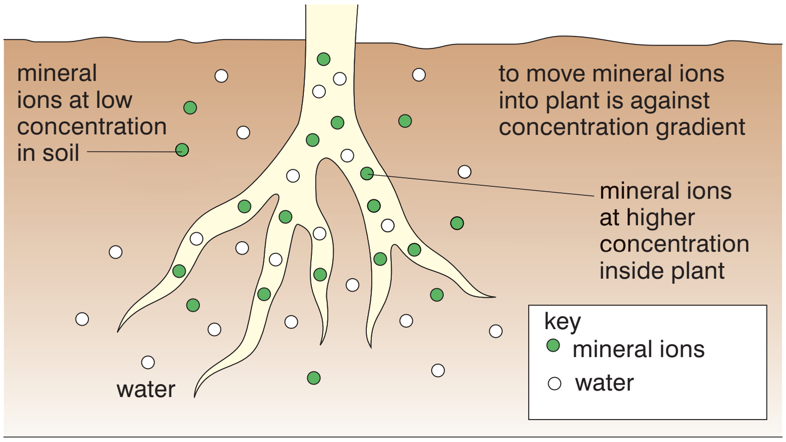

Figure 2.35 *It takes the use of energy in active transport to move mineral ions against a concentration gradient like this.*

Figure 2.36 *These flamingos have salt glands that depend on active transport to move salt out of the body.*

The cells of all living organisms contain sodium chloride and other chemicals in solution. This means they can always be prone to water moving into them by osmosis. If they are immersed in a solution with a lower concentration of salts than the body cells they will tend to gain water. If in a more concentrated solution, water is lost. Either way can spell disaster. Here are just a few of the different ways in which living organisms attempt – largely successfully – to beat osmosis! Active transport is usually an important part of the solution.

Fish that live in fresh water have a real problem. They need a constant flow of water over their gills to get the oxygen they need for respiration. But water moves into their gill cells and blood by osmosis at the same time. Like all vertebrates, fish have kidneys which play a big part in osmoregulation. So freshwater fish produce huge amounts of very dilute urine, which gets rid of the excess water which gets into their bodies. They also have special salt absorbing glands which use active transport to move salt against the concentration gradient from the water into the fish – rather like the situation in plant root cells.

Some marine birds and reptiles – such as flamingos and green turtles – have the opposite problem. They take in a great deal of salt in the sea water they drink, and their kidneys cannot get rid of it all. The solution is special salt glands which are usually found near the eyes and nostrils. Sodium ions are moved out of the body into the salt glands which then produce a very strong salt solution – up to six times more salty than their urine! The sodium ions have to be moved against a very big concentration gradient, and so active transport is involved in the survival of these marine creatures.

It isn't just animals that have this problem. Mangrove swamps can only survive in the salty water where they grow because many of the species of mangroves have salt glands in the leaves. They remove the excess salt that gets into their systems by active transport through these glands.

Summary

In this section you have learnt that:

- Diffusion is the net (overall) movement of particles from an area of high concentration to an area of lower concentration.
- Diffusion takes place because of the random movements of the particles of a gas or of a substance in solution in water.
- Diffusion is important in many processes taking place in animals and plants. Examples include gaseous exchange in the lungs, the absorption of digested food from the gut and the entry of carbon dioxide into the leaves of plants.
- Osmosis is a special type of diffusion where only water moves across a selectively permeable membrane, from an area of high concentration of water to an area of lower concentration of water.
- Cell membranes are selectively permeable so osmosis occurs frequently in plant and animal cells.
- Osmosis can be very useful to plants and animals, but it can cause many difficulties.
- Both osmosis and diffusion can be demonstrated experimentally in the laboratory.

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- When plant cells lose water by osmosis they become flaccid. When plant cells absorb water by osmosis they become turgid.
- In active transport substances are moved against a concentration gradient or across a selectively permeable membrane.
- Active transport uses energy produced by cellular respiration.
- Cells which carry out a lot of active transport often have many mitochondria to provide the energy they need.
- Active transport is very important in cells and whole organisms, for example in the movement of mineral ions into plant roots and in the movement of excess salt out of the body via the salt glands in some marine creatures.

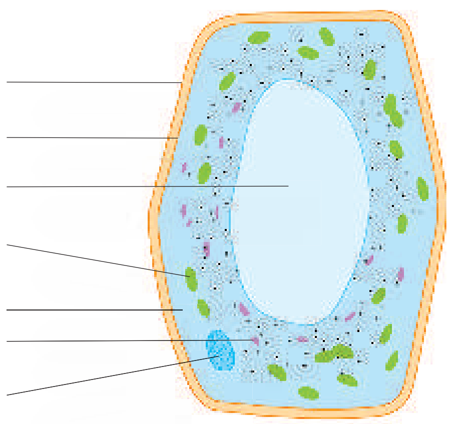
Review questions

1. a) Why do sharks find an injured fish – or person – so easily?
   b) What is meant by the net movement of particles?
   c) What factors most affect the rate of diffusion?
2. a) How does osmosis differ from diffusion?
   b) Why is it so important for animals to keep the concentration of their body fluids constant?
   c) Plants don't have skeletons – instead, osmosis is an important part of the plant support system. How does osmosis keep plant stems rigid?
3. a) Explain how active transport works in a cell.
   b) Give some examples of a situation when a substance cannot be moved into a cell by osmosis or diffusion, and how active transport solves the problem.
   c) The processes of diffusion and osmosis do not need energy to take place. Why does the organism have to provide energy for active transport and where does it come from?

End of unit questions

1. a) Why have microscopes been so important in developing our understanding of cells?
   b) Write a set of instructions that could be handed out with a microscope to make sure that students use it properly.
2. What is the cell theory and who were the first scientists to have the idea?
3. What happens in the cytoplasm of a cell?
4. What are enzymes and why are they so vital in the cell?
5. Why are organelles important in the structure of a cell?
6. The diagram opposite shows an unspecialised plant cell from a blade of grass.
   a) Copy the diagram and use words from the list given below to help you label it.

      cell membrane   cell wall   chloroplast   cytoplasm
      nucleus   vacuole   mitochondria



b) Name two parts of this grass cell that you would never see in an animal cell.

7. Make a table to show the similarities and differences in structure between unspecialised animal cells and unspecialised plant cells.

8. How is a sperm cell specialised for its role in reproduction?

9. Read the following information about *Chlamydomonas* and then answer the questions below.

   Chlamydomonas is a single-celled organism that lives under water. It has an eyespot that is sensitive to light and it can move itself about. In fact, it 'swims' towards the light using long flagella. It has a large chloroplast and uses the light to photosynthesise, and it stores any excess food as starch. When it is mature and has been in plenty of light it will reproduce by splitting in two.

   a) *Chlamydomonas* is a living organism. What features of *Chlamydomonas* in this description show you this is true?

   b) For many years scientists were not sure whether to classify *Chlamydomonas* as an animal or a plant. Now it is put in a separate group altogether!

      i) What features suggest that *Chlamydomonas* is an animal cell?

      ii) What features suggest that *Chlamydomonas* is a plant cell?

10. a) Why do cells become specialised in the human body?

    b) Choose two different types of cells and explain how they are adapted for the job they do in your body.

    c) Describe the different levels of organisation in the human body from cells to the whole body.

11. a) Explain using a diagram what would happen if you set up an experiment with a partially permeable bag containing strong sugar solution in a beaker full of pure water.

    b) Explain using a diagram what would happen if you set up an experiment using a partially permeable bag containing pure water in a beaker containing strong sugar solution.

12. Animals which live in fresh water have a constant problem with their water balance. The single-celled organism called an amoeba has a special vacuole in every cell. It fills with water and then moves to the outside of the cell and bursts. A new vacuole starts forming straight away. Explain in terms of osmosis why the amoeba needs one of these vacuoles.

13. Experiments on osmosis are often carried out using potato cylinders. You have been asked to find out if sweet potato or bread fruit would be a good alternative.

    Describe in detail how you might find out if either of these would be better than the traditional potato.

14. You have to produce some revision sheets on diffusion, osmosis and active transport in living organisms. Use the examples given here and in the unit to help you make the sheets as lively and interesting as possible. Use any methods that help YOU to remember things – and save the sheets to help you when exams are approaching!

Copy this table into your exercise book (or your teacher may give you a photocopy). Draw a pencil line through each of the words in the list below as you find it.

Words go up and down in both directions

M	I	C	R	O	S	C	O	P	E	C	A
A	D	H	I	V	P	E	V	E	B	T	F
G	I	O	B	A	E	L	S	T	A	I	N
N	F	S	O	C	R	L	D	U	N	S	V
I	F	M	S	U	M	A	I	L	C	S	A
F	U	O	O	G	E	N	E	O	E	U	C
Y	S	S	M	R	O	S	C	O	P	E	U
C	I	I	E	L	E	C	T	R	O	N	O
E	O	S	N	U	C	L	E	U	S	T	L
L	N	E	A	X	E	T	U	L	O	S	E
R	E	S	O	L	U	T	I	O	N	E	D

Word search: In this table you will find 15 words linked to cell biology.

They are:

microscope	sperm	magnify	tissue
ribosome	electron	solute	stain
resolution	cell	gene	diffusion
nucleus	osmosis	vacuole	

Human biology and health Unit 3

Contents

Section	Learning competencies
3.1 Food and nutrition (page 51)	• List the major nutrients needed by the human body and their sources. • List the main sources of some of the vitamins and minerals needed by the human body. • Carry out laboratory tests to identify different nutrient groups in a food sample. • Explain the concept of a balanced diet and what it involves. • Define nutrition and malnutrition and describe the effects of malnutrition on the human body. • Understand the concept of height/weight tables and how they can be used to help maintain a healthy body mass. • Analyse a local diet and if necessary suggest ways in which it might be improved to become more balanced.
3.2 The digestive system (page 69)	• Label a diagram of the human digestive system. • Describe the functions of the structures of the human digestive system. • Define enzymes and describe their role in the process of digestion. • Describe the structure of the teeth and explain their importance. • Describe the processes of digestion in the mouth, stomach and small intestine. • Demonstrate that starch digestion begins in the mouth using saliva and bread. • Explain how the products of digestion are absorbed and assimilated by the body. • Discuss constipation, care with canned, bottled and packed foods and food hygiene as issues of digestive health.
3.3 The respiratory system (page 82)	• Explain the importance of breathing in humans. • Describe the structure and functions of the human respiratory system. • Examine the structure of a lung from an animal such as a cow or sheep. • Explain the mechanism of breathing using a lung model. • Explain the process of gas exchange. • Demonstrate the presence of CO_2, water vapour and heat in exhaled air. • Compare the composition of inhaled and exhaled air. • List the factors which affect breathing and explain how they affect it. • Explain the effects of cigarette smoking and inhaling gaya, suret and shisha on health and on the economy of the family. • List the methods of maintaining the hygiene of breathing. • Describe the steps followed during artificial respiration and be able to demonstrate these steps.
3.4 Cellular respiration (page 99)	• Explain cellular respiration and describe the formation of ATP and its importance to the body. • Define and compare aerobic and anaerobic respiration, and explain their importance in cells.

3.5 The circulatory system (page 104)	• Explain how oxygen and nutrients are transported in the blood. • Indicate the structures of the heart on a diagram/model. • Explain the functions of the structures of the heart. • Examine a mammalian heart using fresh or preserved specimens. • Take your own pulse, counting the heartbeats using your fingers. • List the three types of blood vessels. • Explain the functions of the blood vessels. • Name the components of the blood. • Tell the functions of the components of the blood. • List the four blood groups. • Indicate the compatibility of the four blood groups. • Explain the causes and prevention of anaemia and hypertension.

3.1 Food and nutrition

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

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

KEY WORD

heterotrophs *organisms that feed on other organisms*

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

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

KEY WORDS

macronutrients *food you need in large amounts*

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

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

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

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

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

glucose *sugar made by plants during photosynthesis*

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

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

The human diet

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

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

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

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

Carbohydrates

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

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

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

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

The simple sugars

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

$$(CH_2O)_n$$

The best-known simple sugar is glucose, which has the chemical formula $C_6H_{12}O_6$. There are lots of other simple sugars, including **fructose**, the sugar found in fruit.

KEY WORD

fructose *a sugar found in sweet fruits and honey*

condensation reaction *when two simple sugars combine to form a double sugar, removing a molecule of water*

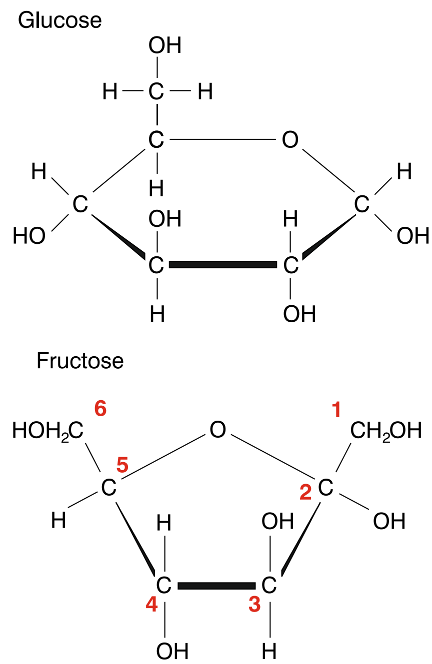


Figure 3.2 Glucose and the other simple sugars are fairly complicated molecules – they are often arranged in rings rather than simple chains.

The double sugars

Double sugars are made up of two simple sugars joined together, and sucrose (the substance you know as sugar) is one of the most common. It is formed by a molecule of glucose joining with a molecule of fructose. When two simple sugars join together to form a double sugar, a molecule of water (H_2O) is removed. This type of reaction where water is produced is known as a **condensation reaction** (see figure 3.3).

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

Table 3.1 *Sources of disaccharides*

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

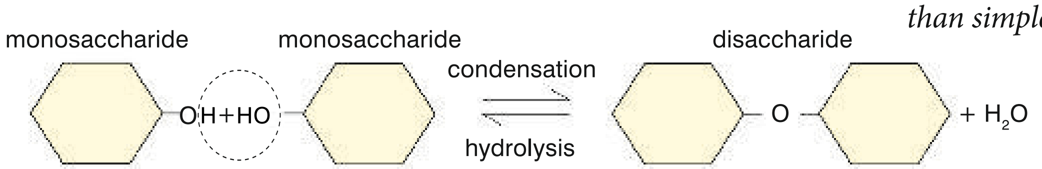


Figure 3.3 The formation of sucrose. The condensation reaction between the two simple sugars results in a double sugar and a molecule of water.

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

The complex sugars

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

KEY WORDS

complex sugars *when many single sugar units join to form a long chain*

glycogen *carbohydrate energy store found in animals*

cellulose *the main constituent in plant cell walls*

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

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

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

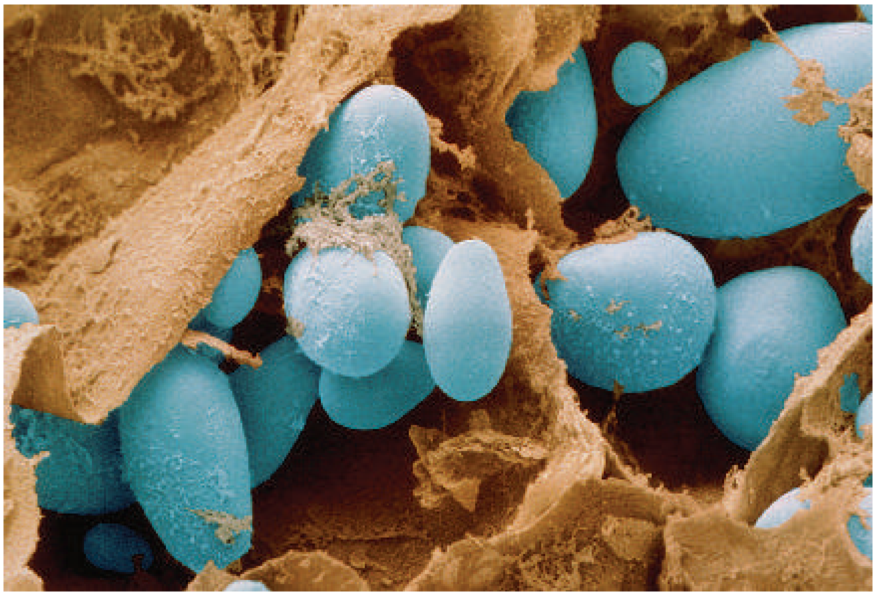


Figure 3.4 *Starch grains found in potato cells are larger than those found in most plants.*

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

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

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

Activity 3.1: Starch test

You will need:

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

Method

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

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

Figure 3.5 *The reaction of iodine with starch solution*

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

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

You will need:

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

Method

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

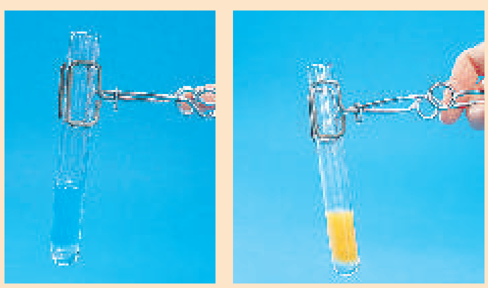


Figure 3.6 *Results of the Benedict's test for simple sugars before and after heating*

Proteins

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

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

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

KEY WORDS

nitrogen *a colourless, tasteless, odourless, gaseous chemical element*

amino acid *building block of protein*

peptide link *when amino acids are joined together in a condensation reaction and a molecule of water is lost*

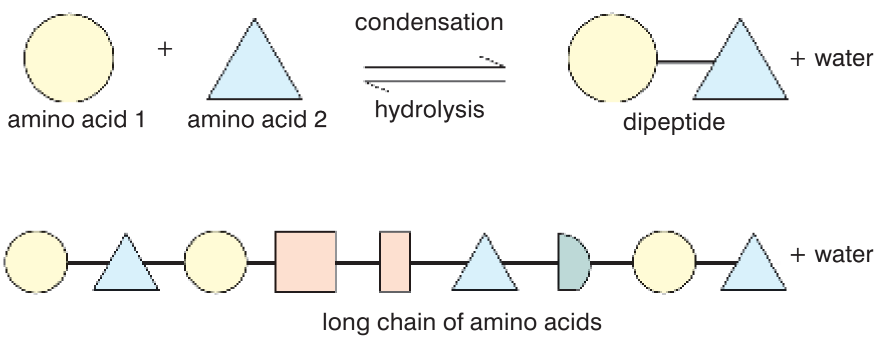


Figure 3.7 *Amino acids are the building blocks of proteins and they can be joined in a seemingly endless variety of ways to produce an almost infinite variety of proteins.*

Amino acids dissolve in water, but the properties of the proteins that are produced vary greatly. Some proteins are insoluble in water and are very tough, which makes them ideally suited to structural functions within living things. These proteins are found in connective tissue, in tendons and the matrix of bones (collagen), in the structure of muscles, in the silk of spiders' webs and silkworm cocoons and as the keratin that makes up hair, nails, horns and feathers.

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

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

DID YOU KNOW?

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

KEY WORD

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

Activity 3.3: Biuret test for proteins

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

You will need:

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

Figure 3.8 *Results of the Biuret test for proteins*

Method

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

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

KEY WORDS

lipids *general name for fats and oils*

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

oils *viscous liquid at room temperature*

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

saturated *fat with no double bonds in the structure*

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

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

double bonds *created when atoms share two electrons*

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

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

Fats and oils

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

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

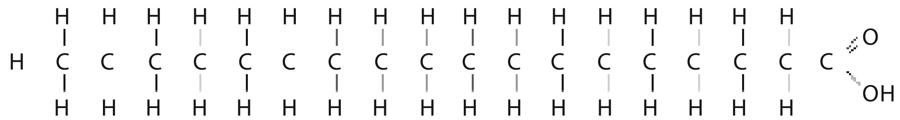
All lipids are insoluble in water, but dissolve in organic solvents. This is important because when they are present in your cells they do not interfere with the many reactions that go on in the cytoplasm, because the reacting chemicals are all dissolved in water.

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

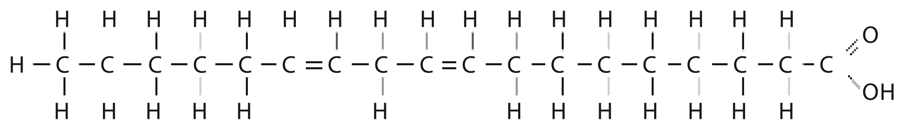
Just like the carbohydrates, the chemical elements that go into all lipids are carbon, hydrogen and oxygen. There is, however, a considerably lower proportion of oxygen in lipid molecules. Fats and oils are made up of combinations of two types of organic chemicals, fatty acids and **glycerol**.

Glycerol is always the same, with the chemical formula $C_3H_8O_3$. On the other hand, there is a wide range of fatty acids. Over seventy different ones have been extracted from living tissues and the nature of the lipid depends a lot on which fatty acids are in it. All fatty acids have a long hydrocarbon chain – a pleated backbone of carbon atoms with hydrogen atoms attached. There are two main ways in which fatty acids vary; the length of the carbon chain can differ, and the fatty acid may be **saturated** or **unsaturated**.

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



Stearic ac id



Linoleic ac id

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

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

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

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

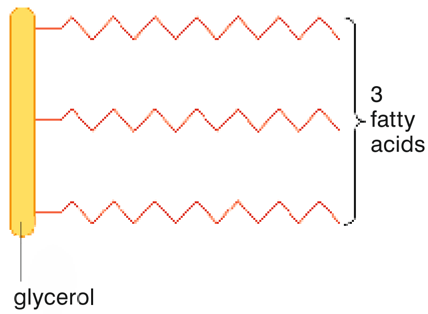


Figure 3.11 *It is the combination of fatty acids in a triglyceride that decides what it will be like. Saturated fatty acids give solid fats like butter, whereas unsaturated fatty acids produce a liquid like corn oil.*

Activity 3.4: Test for lipids

a) Filter paper test

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

You will need:

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

Method

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

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

b) Emulsion test

You will need:

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

Method

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

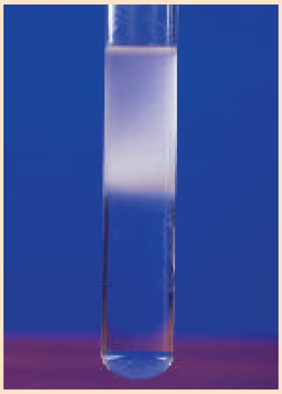


Figure 3.12 *Results of the ethanol test for fats*

Minerals

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

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

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

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

KEY WORDS

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

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

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

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

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

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

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

KEY WORDS

night blindness *inability to see clearly in dim light due to vitamin A deficiency*

beri-beri *deficiency disease from lack of vitamin B*

DID YOU KNOW?

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

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

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

Vitamins

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

Vitamin B_1, found in yeast extract and cereals, is needed for the reactions of cellular respiration to take place. If you don't eat enough of it you get a condition called **beri-beri**, when your muscles waste away and you become paralysed. It can be fatal.

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

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

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

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

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

KEY WORDS

scurvy *a disease caused by lack of vitamin C in the diet*

retinol *vitamin A*

calciferol *vitamin D*

thiamine *vitamin B1*

Activity 3.5: Testing for vitamin C

You will need:

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

Method

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

Discussion

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

Investigation

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

Activity 3.5a: Copy and complete

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

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

KEY WORDS

urea *the main component of urine*

hydrolysis reaction *chemical reaction of a compound with water*

nutrition *the obtaining of food in order to survive*

The role of water

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

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

Fibre in the diet

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

Why is a balanced diet important?

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

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

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

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

KEY WORDS

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

undernutrition *too little food is eaten*

overnutrition *too much food is eaten*

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

Table 3.4 *Daily energy needs*

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

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

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

DID YOU KNOW?

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

DID YOU KNOW?

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

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

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

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

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

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

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

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

Lunch: kei wot with injera and orange or banana

Dinner: shiro wot with injera and fresh green pepper

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

Activity 3.6: A diet diary

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

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

Summary

In this section you have learnt that:

- A balanced diet contains carbohydrates, proteins, lipids, minerals, vitamins and water in the right proportions to keep your body functioning effectively. Fibre is also important.
- Carbohydrates are the main energy supply for the body. Carbohydrates are found as simple sugars, double sugars and complex sugars.
- Iodine is used to test for the presence of starch and Benedict's solution for the presence of simple reducing sugars.
- Proteins are used as the building blocks of the body. They are made up of small units called amino acids.
- The Biuret test using 5% sodium hydroxide solution and 1% copper sulphate solution is used to show the presence of protein in the food.
- Lipids are fats and oils. They provide energy for the body. They are made up of fatty acids and glycerol.
- The translucent smear test and the ethanol test identifies lipids in foods.
- Iron is needed in the body for the production of haemoglobin to carry oxygen in the red blood cells. Lack of iron in your diet causes anaemia.
- Calcium is needed for healthy bones and teeth. Lack of calcium in your diet can cause rickets.
- Vitamins are needed in small amounts for your cells to work properly. Vitamins A, B_1, C and D are all vital for health.
- Malnutrition is when your diet is unbalanced. This can result from too little food, when you are at risk of deficiency diseases, and also too much food, which can give rise to obesity.

DID YOU KNOW?

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

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

Review questions

Select the correct answer from A to D.

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

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

3.2 The digestive system

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

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

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

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

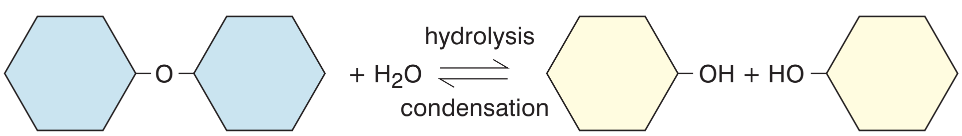


***Figure 3.17** The large food molecules are broken down by hydrolysis reactions – the opposite of the condensation reactions by which they are built up in the first place.*

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

DID YOU KNOW?

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

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

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

More about enzymes

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

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

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

Activity 3.7: Investigating the activity of amylase

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

You will need:

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

Method

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

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

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

KEY WORDS

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

The working of the gut

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

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

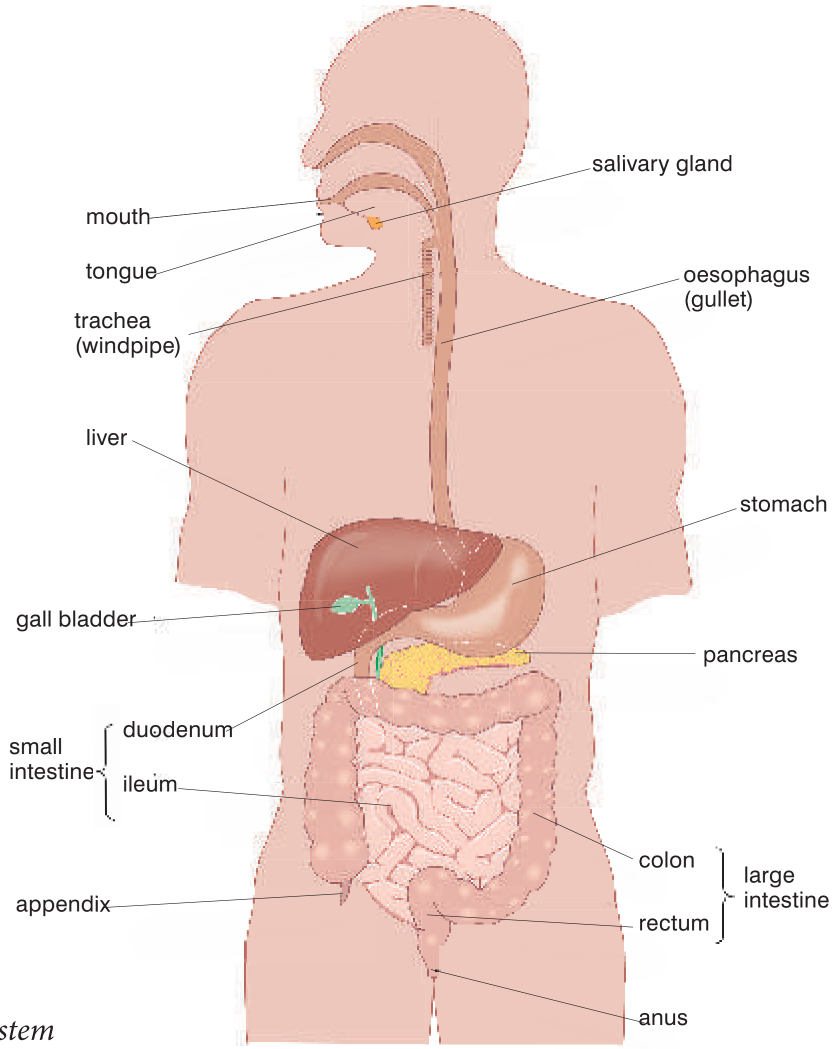


Figure 3.19 *The human digestive system*

Teeth have evolved to be very strong – in fact the **enamel** that covers them is the strongest substance made by the human body. Teeth are needed for a variety of different jobs – gripping food, tearing food and chewing food, for example. The shape of different teeth means they are ideally suited to their different functions. Because humans have a very varied diet (we are omnivores so we eat animals and plants) we also have a variety of different types of teeth. The incisors and canines are used for biting while the premolars and molars are used for chewing and crushing food.

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

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

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

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

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

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

If they are available:

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

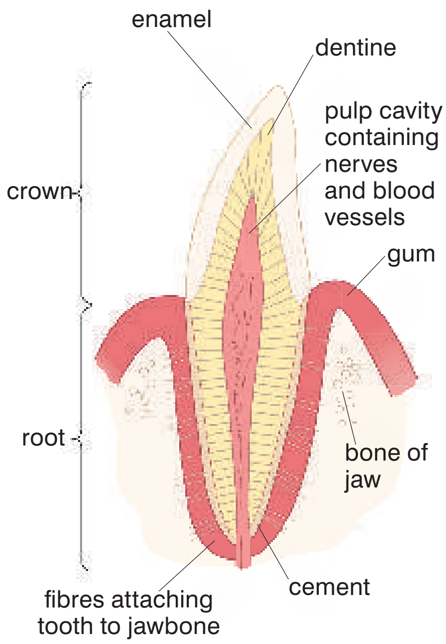


***Figure 3.20** The structure of teeth makes them very well adapted to their various functions.*

KEY WORDS

dentine *living layer underneath tooth enamel*

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

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

periodontal disease *bacterial infection of the gums*

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

DID YOU KNOW?

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

KEY WORDS

carbohydrase *an enzyme in saliva*

bolus *a saliva-coated chunk of chewed food*

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

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

peristalsis *wavelike muscle contractions to move food along*

Moving the food on

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

When your food is swallowed it travels down the **oesophagus** or gullet, squeezed along by muscular contractions known as **peristalsis**. As a result you can eat at any angle you like – even standing on your head – because food does not rely on gravity to arrive in your stomach. Peristalsis is not confined to your oesophagus – it is important all the way through your gut to move the food through as it is digested, to mix the food with the digestive enzymes produced in the various parts of the gut and to continue the physical break-up of the food. The walls of your gut have a layer of circular muscles forming rings around it and a layer of longitudinal muscles that run the length of the gut. Waves of alternate contraction and relaxation of the different muscles (see figure 3.22) move food through from one end of the gut to the other.

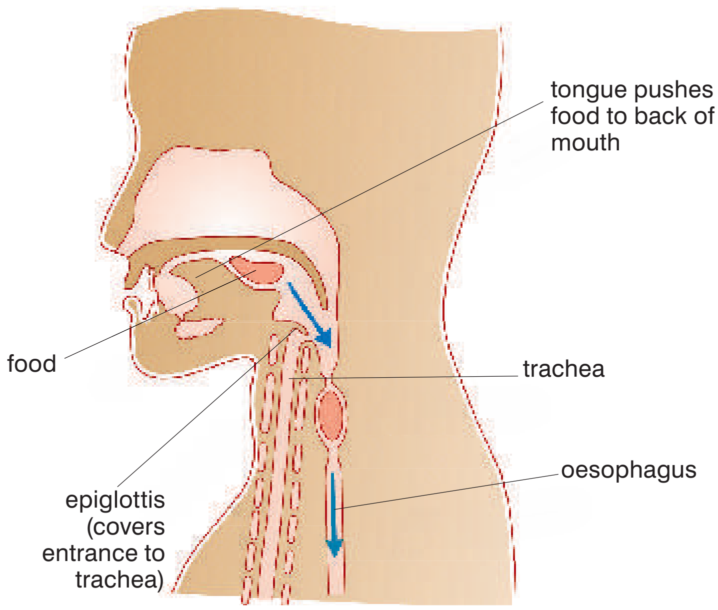


Figure 3.22 *The swallowing reflex means you don't get food down into your lungs – and you can't breathe in while you are swallowing food.*

Stomach churning activity

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

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

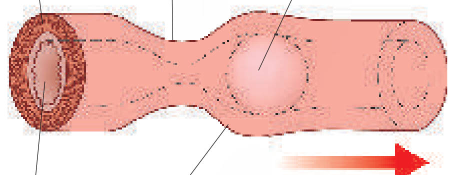


***Figure 3.23** Muscular action in your gut pushes the food along.*

KEY WORDS

sphincter *ring of muscle*

stomach *muscular bag that produces protease enzymes to digest protein*

pepsin *enzyme that breaks down proteins*

hydrochloric acid *produced in the stomach to kill bacteria*

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

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

Bile

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

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

Enzymes

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

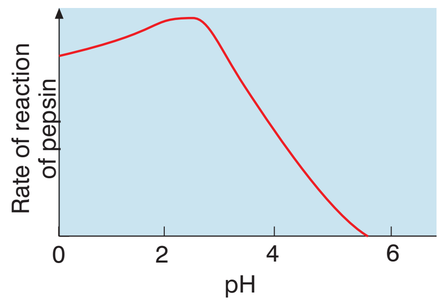


***Figure 3.24** The protein-digesting enzymes of the stomach only work at their best in low pH, so the acid made by the stomach wall is very important.*

KEY WORDS

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

lipase *enzyme that breaks down fats*

absorption *the process whereby the body absorbs food molecules*

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

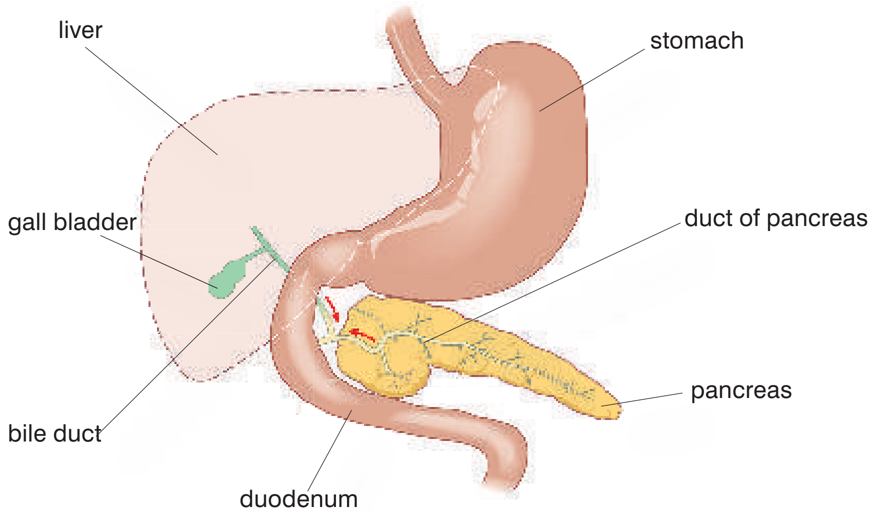


Figure 3.25 *The liver and pancreas are important to the successful digestion of food in the small intestine in a number of ways.*

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

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

Table 3.5 *Enzymes of the human digestive system*

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

Once the food molecules have been digested, giving glucose, amino acids, fatty acids and glycerol, they are absorbed by your body (**absorption**). They leave the small intestine by diffusion and go into the blood supply to be carried around the body to the cells that need them. The lining of the small intestine is specially adapted to allow as much diffusion as possible and as rapidly as possible. It has many finger-like projections of the lining (called **villi**) to increase the surface area for diffusion, and each individual villus in turn is covered in even smaller projections called microvilli. The villi also have a rich blood supply that carries away the digested food molecules and maintains a steep diffusion gradient. The diffusion distances are very small, and the whole process takes place in a water-based solution. All of these factors make the absorption of the digested food molecules from the small intestine into the blood supply very efficient. The glucose molecules and amino acids go directly into the blood. The fatty acids and glycerol move initially into the lacteals, which are part of the lymph system. The lymphatic fluid with its load of fatty acids and glycerol then eventually drains into the blood as well. Once the digested food molecules have all been taken into the blood they are taken in the **hepatic portal vein** to the liver, which processes some of the food (see section 3.5). The remaining products of digestion are carried around the body to the cells where they are needed. They are built up into the molecules required by the cells. This is known as **assimilation**.

KEY WORDS

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

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

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

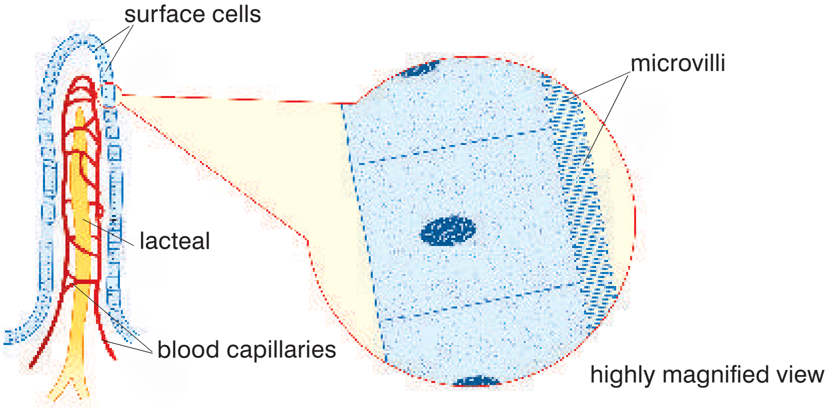


Figure 3.26 *Millions of villi make it possible for all the digested food molecules to be transferred from the small intestine into the blood by diffusion.*

The end of the story

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

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

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

DID YOU KNOW?

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

DID YOU KNOW?

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

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Activity 3.8: Timing food through your system

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

KEY WORDS

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

diarrhoea *loose, watery faeces*

salmonella *bacteria that causes food poisoning*

Issues of digestive health

Constipation

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

Diarrhoea

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

Food hygiene

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

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

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

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

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

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

Summary

In this section you have learnt that:

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

Review questions

Select the correct answer from A to D.

1. Enzymes are made of:

   A carbohydrates
   B vitamins
   C proteins
   D fats

2. Which of the following does NOT affect the activity of an enzyme?

   A pH
   B temperature
   C the surface area of the reactants
   D light levels

3. Extracellular enzymes work:

   A outside of your cells
   B inside your cells
   C inside your mitochondria
   D only in your mouth

4. Which part of a tooth contains the living nerves?

   A enamel
   B dentine
   C cement
   D pulp cavity

5. The finger-like projections in the small intestine are known as:

   A bilirubin
   B microvilli
   C sphincters
   D villi

3.3 The respiratory system

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

- Explain the importance of breathing in humans.
- Describe the structure and functions of the human respiratory system.
- Examine the structure of a lung from an animal such as a cow or sheep.
- Explain the mechanism of breathing using a lung model.
- Explain the process of gas exchange.
- Demonstrate the presence of CO_2, water vapour and heat in exhaled air.
- Compare the composition of inhaled and exhaled air.
- List the factors which affect breathing and explain how they affect it.
- Explain the effects of cigarette smoking and inhaling gaya, suret and shisha on health and on the economy of the family.
- List the methods of maintaining the hygiene of breathing.
- Describe the steps followed during artificial respiration and be able to demonstrate these steps.

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

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

The human respiratory system

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

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

KEY WORDS

carbon dioxide *colourless, odourless gas formed during respiration and a widely produced greenhouse gas*

trachea *major airway connecting the larynx with the lungs*

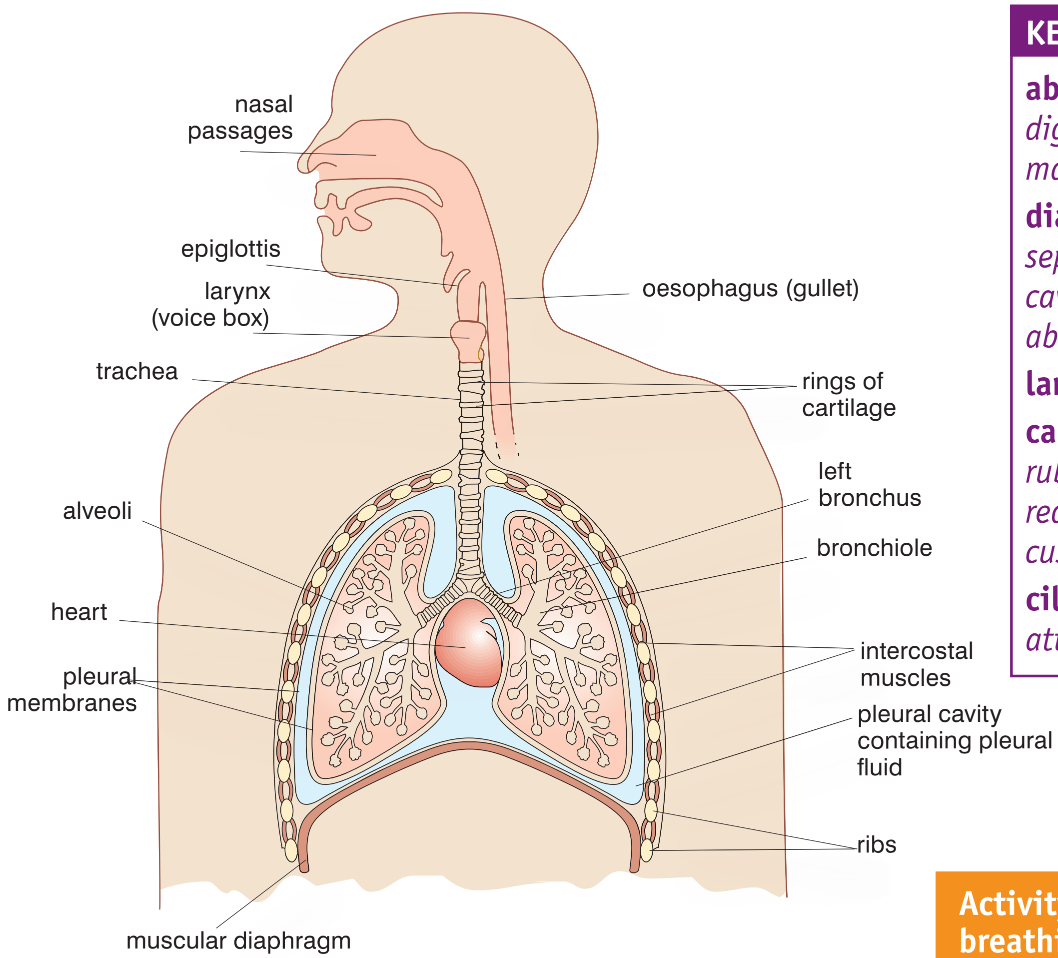


Figure 3.29 *The respiratory system supplies your body with vital oxygen and removes poisonous carbon dioxide. The lungs are in the upper part of the body – the thorax. The* ***abdomen*** *contains the digestive system and many other body organs. The* ***diaphragm*** *is a sheet of muscle separating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

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

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

KEY WORDS

abdomen *contains the digestive system and many body organs*

diaphragm *muscle separating the chest cavity from the abdomen*

larynx *voice box*

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

cilia *tiny moving hairs attached to cells*

Activity 3.9: The breathing structures of a mammal

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

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

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

DID YOU KNOW?

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

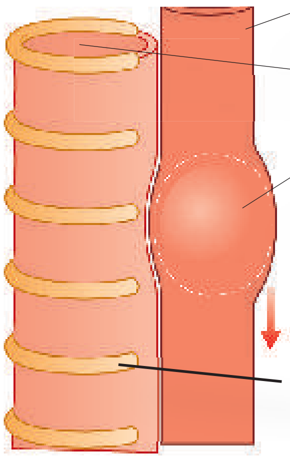


Figure 3.30 *The incomplete cartilage rings that support your trachea are a useful adaptation when it comes to swallowing your food successfully.*

KEY WORDS

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

bronchioles *small air tubes in the lung*

alveoli *tiny air sacs in a lung*

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

Activity 3.10: Looking at the tissues of the respiratory system

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

You will need:

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

Method

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

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

How is air brought into your lungs?

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

The breathing movements are brought about by two different sets of muscles that change the pressure in the chest cavity. When we breathe in, our ribs move up and out, and the muscles of the diaphragm contract so that it flattens from its normal domed shape. The intercostal muscles between the ribs contract, pulling them upwards and outwards at the same time as the diaphragm muscles contract to flatten the diaphragm. These two movements increase the volume of your chest (thorax). Because the same amount of gas is now inside a much bigger space, the pressure inside the chest drops. This in turn means the pressure inside the chest is lower than the pressure of the air outside. As a result air moves into the lungs.

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

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

KEY WORDS

ventilation *moving air into and out of the lungs*

intercostal muscles *muscles used in breathing*

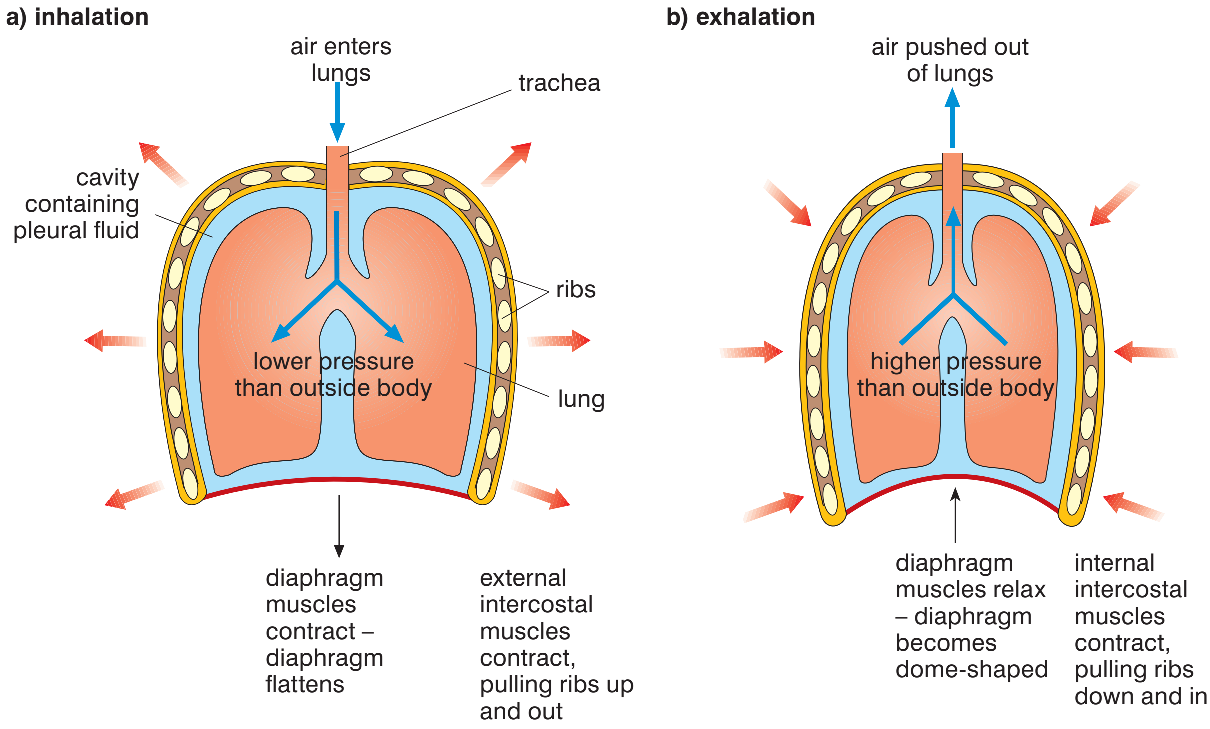


Figure 3.31 *Breathing movements bring about changes in the air pressure in your chest that result in air moving into and out of your lungs. The movements of your diaphragm are hidden but the movements of the ribs can be seen and felt easily.*

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

Activity 3.11: Investigating breathing movements

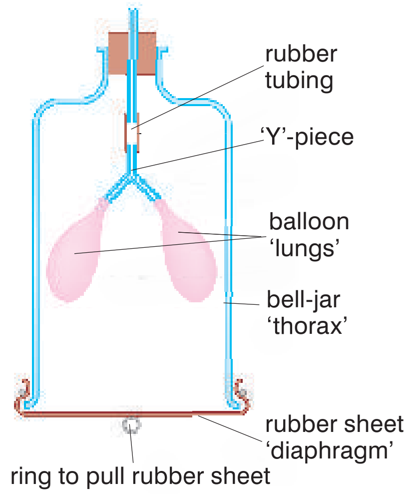


Figure 3.32 *Bell-jar model of the thorax*

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

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

The process of gaseous exchange

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

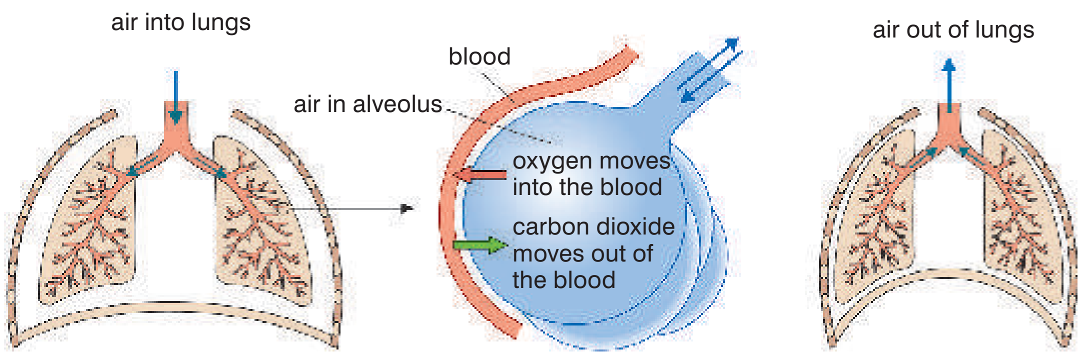


Figure 3.33 *An exchange of gases between the blood and the air takes place in the lungs.*

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

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

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

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

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

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

DID YOU KNOW?

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

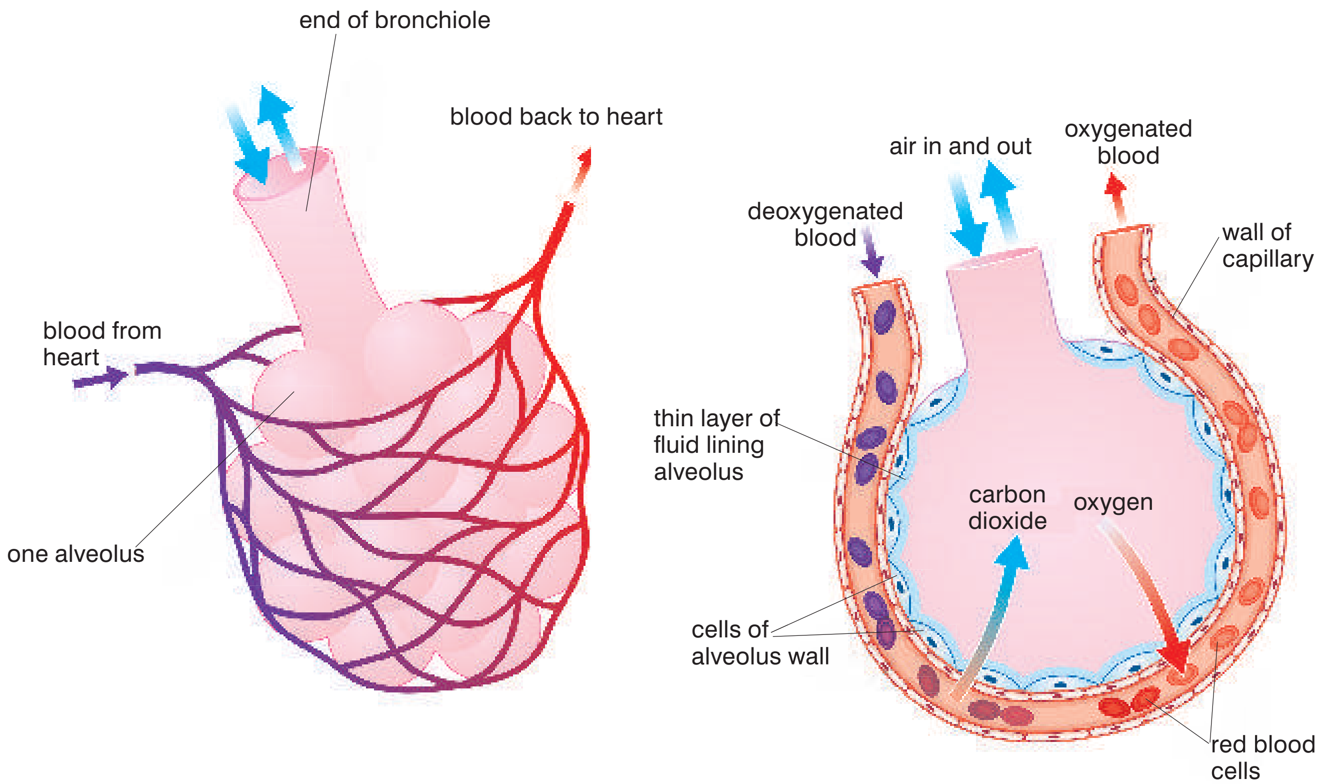


__Figure 3.34__ The alveoli are the site of very efficient gas exchange in the lungs.

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

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

Activity 3.12: Demonstrating the presence of carbon dioxide (CO_2) in exhaled air

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

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

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

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

You will need:

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

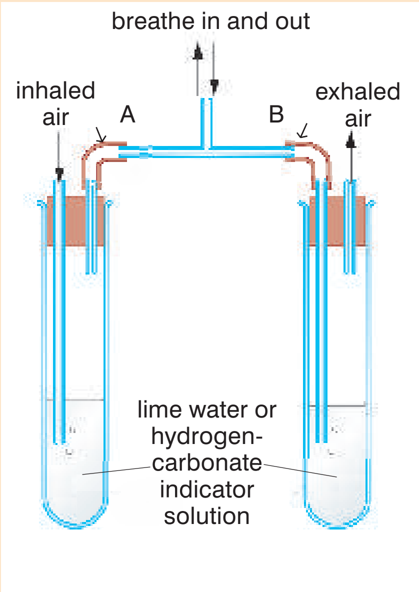


Figure 3.35 Using relatively simple apparatus it is possible to see differences between the air we breathe in and the air we breathe out.

Method

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

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

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

What affects your breathing rate?

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

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

Exercise

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

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

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

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

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

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

KEY WORDS

tidal volume *the amount of air breathed in*

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

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

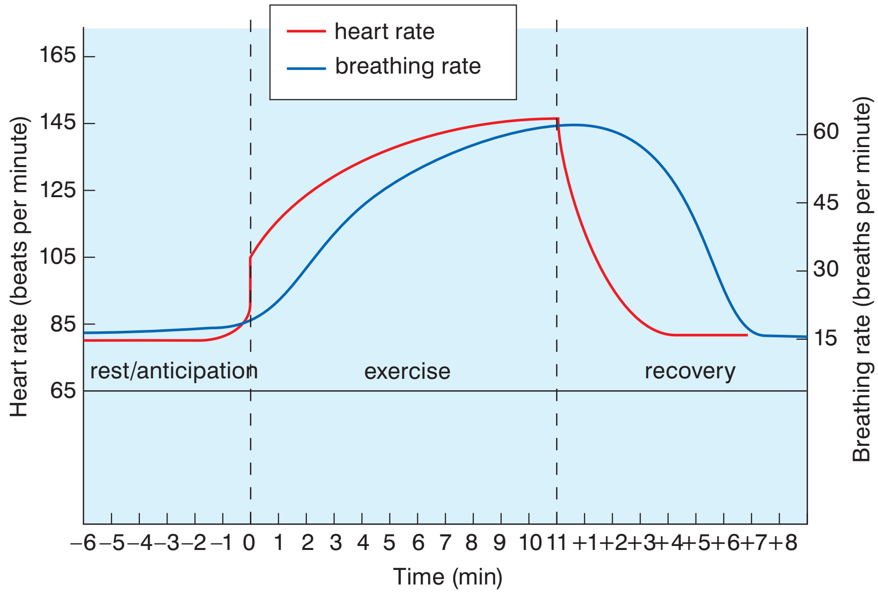
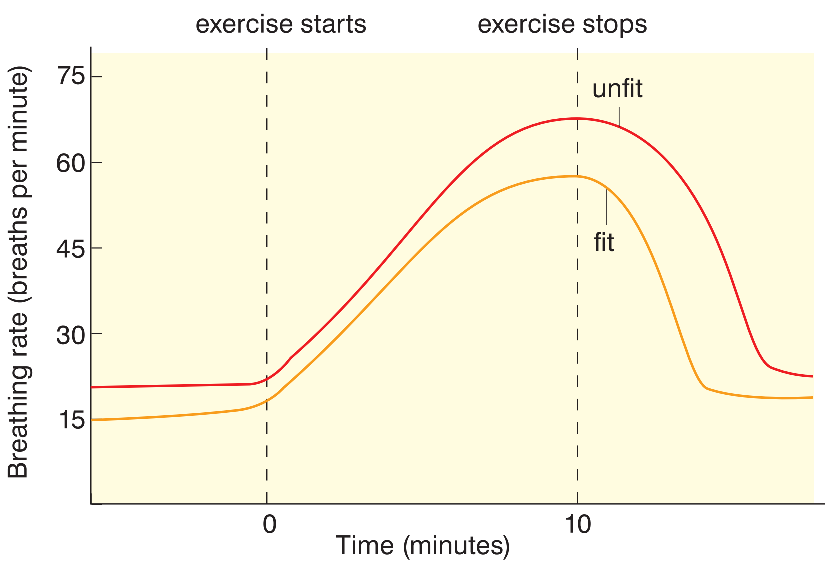


Figure 3.36 *During exercise the breathing rate increases to supply the muscles with the oxygen needed and remove the extra carbon dioxide produced.*

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

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

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



Activity 3.15: Investigating the effect of exercise on breathing rate

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

You will need:

- stopwatch or clock with clear second hand

Method

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

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

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

Anxiety

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

Drugs

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

Environmental factors

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

Altitude

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

Weight

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

KEY WORD

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

Smoking

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

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

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

Nicotine is the addictive drug found in tobacco smoke.

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

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

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

KEY WORDS

nicotine *addictive drug found in tobacco smoke*

carbon monoxide *poisonous gas found in smoke*

Smoking-related diseases

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

KEY WORDS

bronchitis *inflammation and infection of the bronchi*

chronic obstructive pulmonary diseases (COPD) *reduction of surface area of the lungs due to breakdown of the alveoli*

lung cancer *disease linked to smoking*

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

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

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

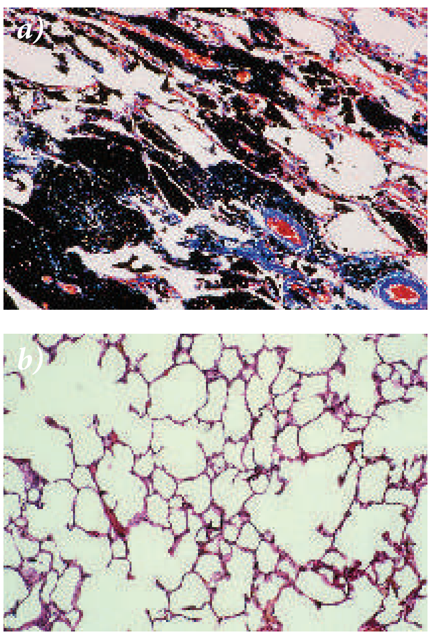


Figure 3.38 *The difference in the appearance of the lungs of a smoker (a) compared to a non-smoker (b) is obvious even to the untrained eye.*

Activity 3.16: Demonstration of the tar in cigarette smoke

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

You will need:

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

Method

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

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

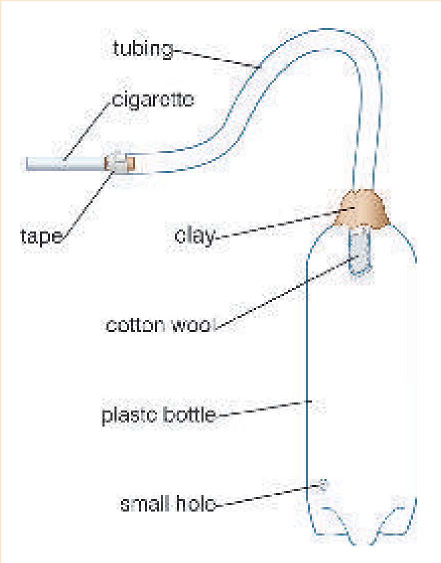


Figure 3.39 *Equipment needed to set up a plastic bottle smoking machine*

Smoking and the family

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

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

Breathing hygiene

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

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

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

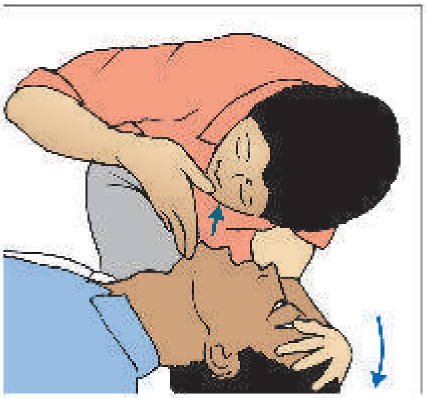
If a dentist or doctor is going to examine a patient, they may wear a mask over their mouth and nose. This prevents them passing on infections to you, and also helps prevent them getting an infection from you – this is good breathing hygiene.

When breathing fails

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

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

Call for help



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

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

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

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

   Look along the chest to check for breathing movement.
   Listen for the sounds of breathing.
   Feel for breath on your cheek.

   Observe for at least 5 seconds before you decide the person is not breathing. **Call for help. NEVER use artificial respiration on a casualty who is breathing**.
5. **Make sure the airway is open and the head is tilted back. Pinch the casualty's nostrils closed with one hand. Keep the chin lifted with the other hand.**
6. **Use a clean piece of cloth over the mouth to avoid the transfer of HIV through contact and other infections. Take a deep breath and then seal your mouth around the person's mouth. Breathe out firmly into the person's mouth until you see the chest rise. This will show you that you are getting air into their lungs.**
7. **Remove your lips and let the chest fall naturally.**
8. **Repeat these steps at about 12 breaths per minute – a steady rate. The colour should return and the person may begin breathing for themselves. If not, continue until medical help arrives.**

Summary

In this section you have learnt that:

- The breathing system takes air into and out of the body to supply oxygen and remove carbon dioxide.
- The respiratory system is made up of the mouth and nose, larynx, trachea, bronchi, bronchioles and alveoli. The lungs are surrounded by the pleural membranes and enclosed in the thorax.
- The movement of air is brought about by the intercostal muscles moving the ribs and the diaphragm.
- Breathing movements cause changes in the volume and pressure of the chest that bring about ventilation of the lungs.
- In the lungs oxygen from the air diffuses into the bloodstream at the same time as carbon dioxide from the blood diffuses out of the bloodstream into the air. This is known as gas exchange.
- The alveoli provide a very large, moist surface area, richly supplied with blood capillaries to allow the most efficient possible gas exchange.
- The rate of breathing is affected by a number of factors including exercise, anxiety, drugs, environmental factors, altitude, body weight and smoking.
- Nicotine is the addictive drug found in tobacco.
- Tobacco smoke also contains carbon monoxide, which reduces the oxygen carrying capacity of the blood.
- In pregnant women carbon monoxide deprives the foetus of oxygen and can lead to low birthweight babies and stillbirths.
- Tobacco smoke contains tar and other chemicals, which contribute to lung cancer, bronchitis, emphysema and disease of the heart and blood vessels.

Review questions

Select the correct answer from A to D.

1. The organ of your body where gas exchange takes place is the:

   A liver
   B lungs
   C trachea
   D heart

2. The role of the cilia on the epithelium of the trachea is to:

   A move dirt and mucus away from the lungs
   B move dirt and mucus down the trachea into the lungs
   C to produce mucus
   D to prevent food getting into the lungs

3. Which of the following is not part of the respiratory response to exercise?

   A breathing faster
   B producing more oxygen
   C breathing deeper
   D producing more carbon dioxide

4. Which of the following is NOT a constituent of cigarette smoke?

   A oxygen
   B nicotine
   C carbon monoxide
   D tar

3.4 Cellular respiration

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

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

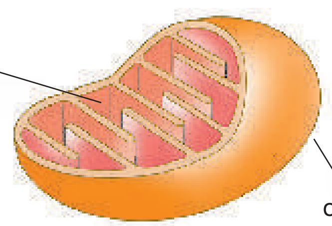
Aerobic respiration

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

The reaction can be summed up as follows:

glucose + oxygen → carbon dioxide + water + energy (ATP)

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



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

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

KEY WORDS

aerobic *respiration using oxygen*

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

adenosine diphosphate (ADP) *an inorganic phosphate compound*

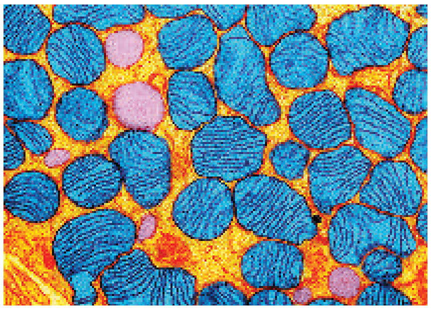


Figure 3.42 *Mitochondria are the powerhouses that provide energy for all the functions of a cell.*

KEY WORDS

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

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

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

DID YOU KNOW?

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

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

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

$$\text{ADP} + \text{P}_i \underset{\text{energy required}}{\overset{\text{energy produced}}{\rightleftarrows}} \text{ATP}$$

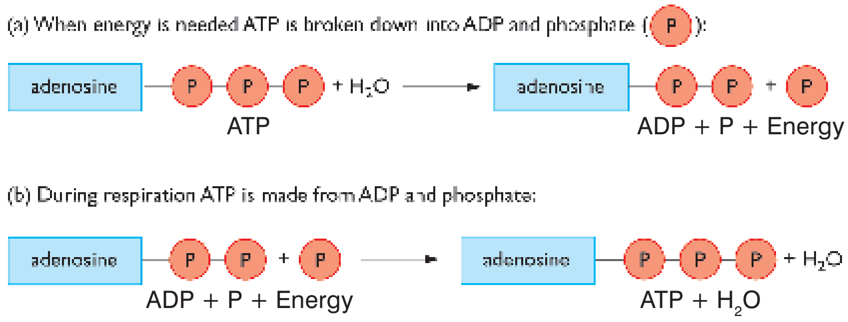


Figure 3.43 *ATP is the energy currency of the cell.*

The importance of ATP to the body

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

anabolism + catabolism = metabolism

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

Anaerobic respiration

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

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

Anaerobic respiration:

glucose → lactic acid + energy (ATP)

Oxygen debt repayment:

lactic acid + oxygen → carbon dioxide and water

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

KEY WORDS

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

lactic acid *product of anaerobic respiration in animal cells*

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

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

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

You will need:

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

Method

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

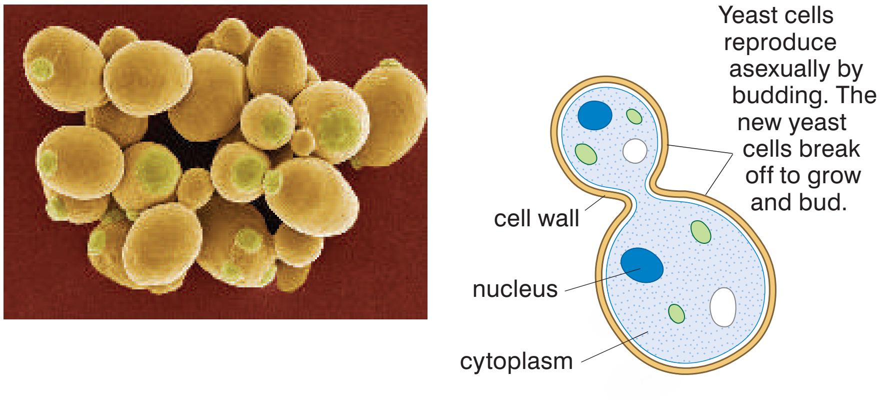


Figure 3.45 *Yeast cells – these microscopic organisms have been useful to us for centuries.*

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

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

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

$$\textbf{glucose} \rightarrow \textbf{ethanol} + \textbf{CO}_2 + \textbf{energy (ATP)}$$

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

Summary

In this section you have learnt that:

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

Review questions

Select the correct answer from A to D.

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

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

   A ADP

   B carbon monoxide

   C ATP

   D gas

2. Which of the following is not a commercial use for anaerobic respiration?

   A production of biogas from human waste

   B beer making

   C yoghurt production

   D bread making

3.5 The circulatory system

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

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

KEY WORDS

surface area to volume ratio *amount of surface area per unit of volume*

blood circulation system *system of blood vessels transporting blood around the body via the heart*

blood vessels *pipes throughout the body carrying blood*

heart *the pump inside the body that moves blood through the vessels*

blood *the medium which transports nutrients around the body*

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

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

DID YOU KNOW?

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

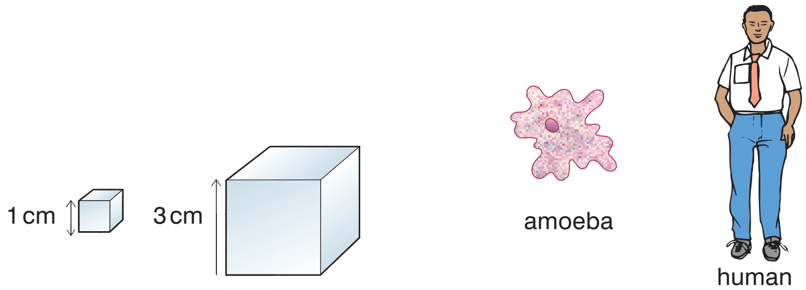


Figure 3.46 *The surface area to volume ratio of the small cube is three times bigger than that of the large cube – imagine the difference between an amoeba and you.*

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

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

A double circulation

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

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

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

The blood vessels

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

KEY WORDS

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

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

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

arteries *carry blood away from the heart*

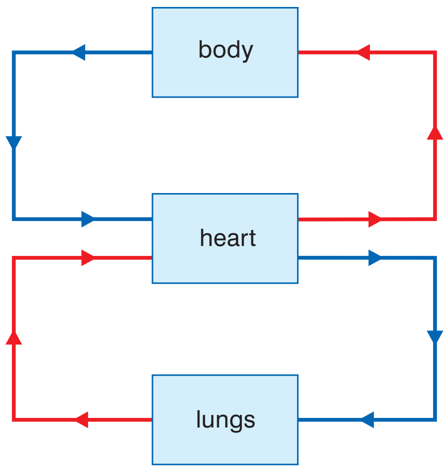


Figure 3.47 *The two separate circulation systems supply the lungs and the rest of the body.*

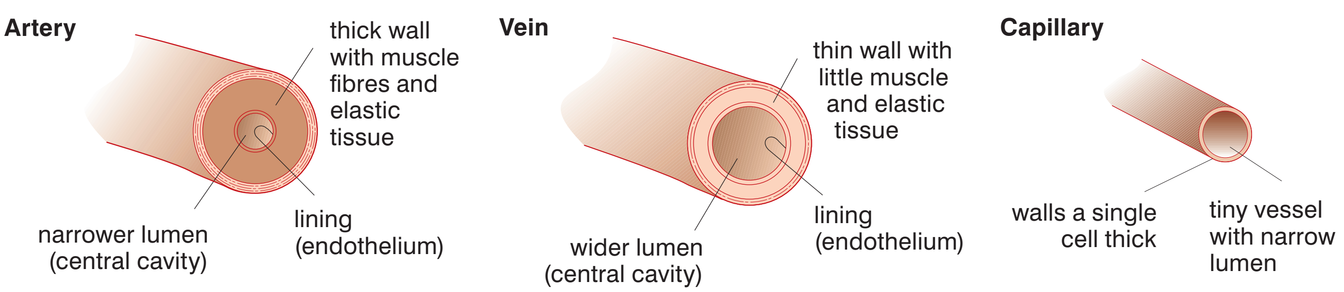


Figure 3.48 *Arteries, veins and capillaries – different blood vessels for different functions in the body.*

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

DID YOU KNOW?

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

KEY WORDS

veins *carry blood towards the heart*

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

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

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

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

Activity 3.18: Investigating the role of valves in veins

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

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

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

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

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

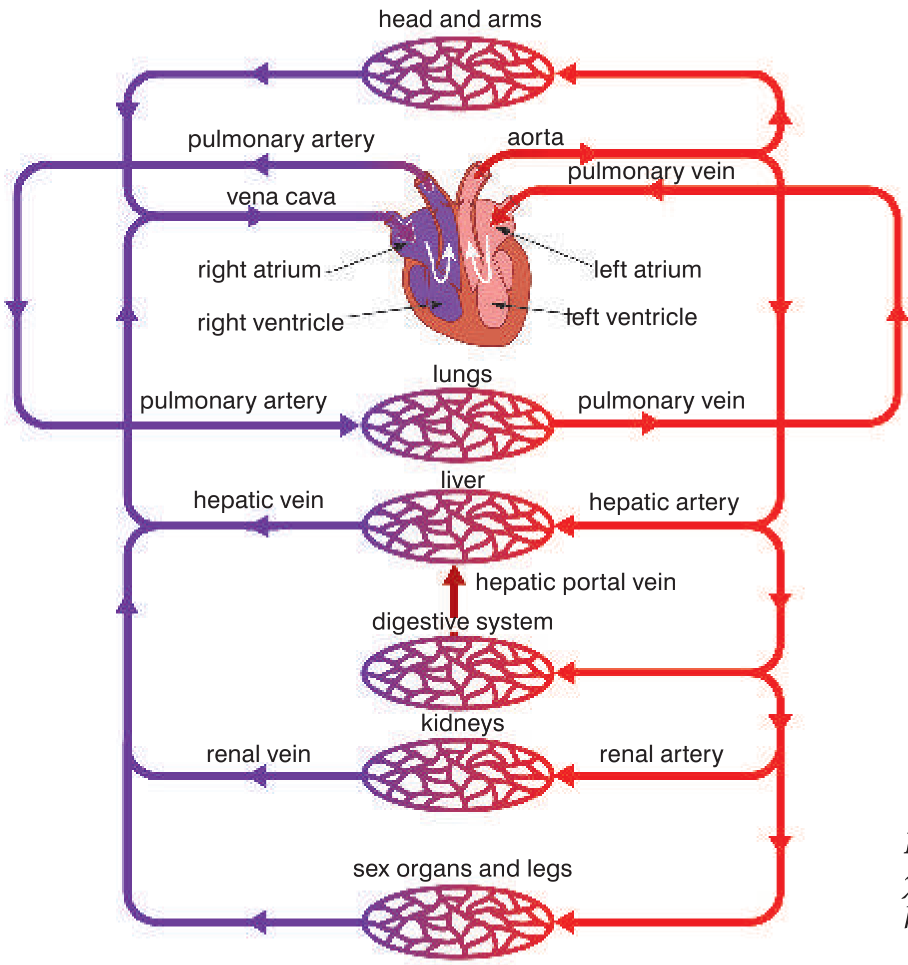


Figure 3.50 *This diagram shows you the main components of the human circulatory system.*

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

The human heart

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

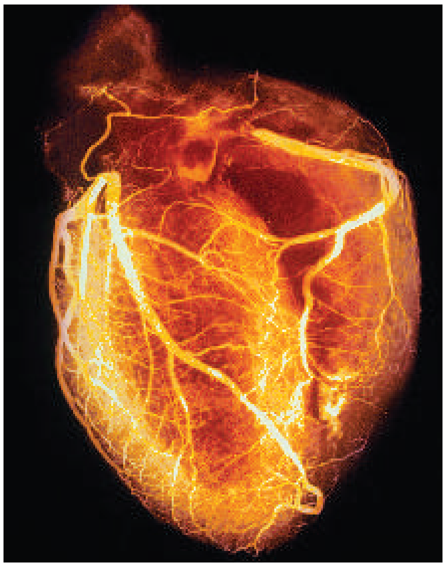
The walls of the heart are almost entirely muscle. These muscular walls are supplied with blood by the **coronary arteries**, so that they have a constant supply of glucose and oxygen and the carbon dioxide produced is not allowed to build up in the tissue. The deoxygenated blood is carried away in the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

KEY WORDS

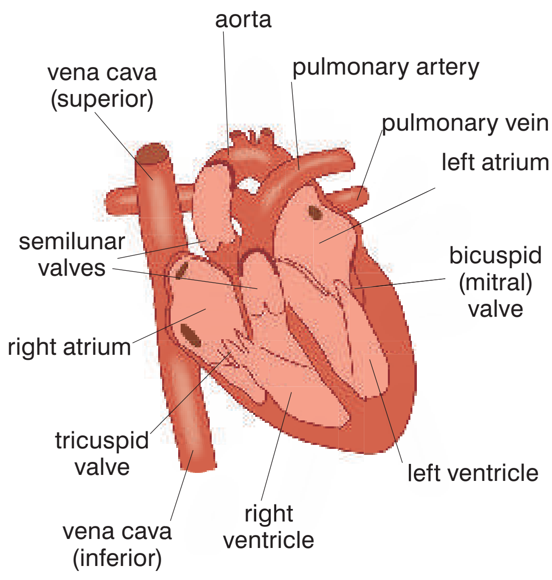
cardiac muscle *contracting muscle of the heart*

coronary arteries *supply blood to the cardiac muscles*

atria *top chambers of the heart*

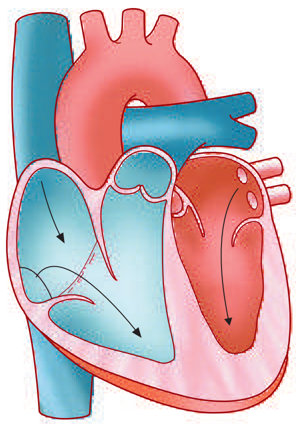


a) External view to show coronary arteries

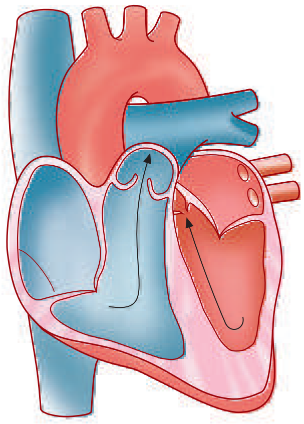


b) Vertical section through the heart

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



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



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

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

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

The working of the heart

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

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

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

Diastole is when the heart muscles relax and it fills with blood. **Systole** is when the heart muscles contract and force the blood out of the heart.

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

KEY WORDS

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

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

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

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

Activity 3.19: Examining a mammalian heart

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

You will need:

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

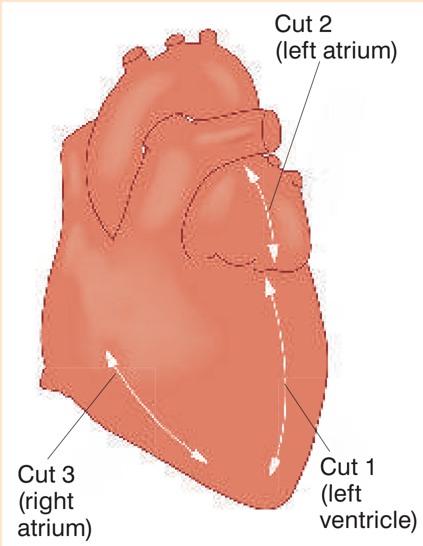


***Figure 3.53** Guide to dissecting a mammalian heart*

Method

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

The flexible heart

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

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

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

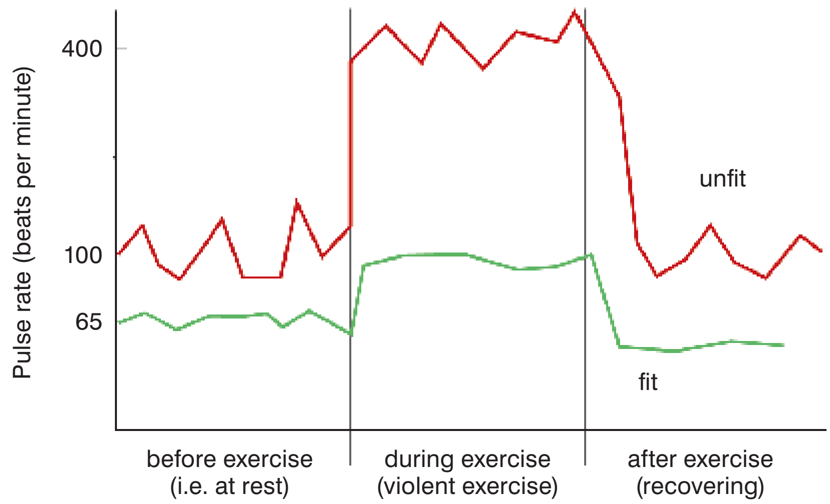


Figure 3.54 A fit heart responds quickly to exercise and returns rapidly to its resting rate when exercise is finished. People with less fit hearts can feel them racing for several minutes after they stop exercising!

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

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

You will need:

- stopwatch or clock with clear second hand

Method

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

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

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

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

DID YOU KNOW?

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

KEY WORD

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

DID YOU KNOW?

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

The blood

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

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

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

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

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

$$\textbf{haemoglobin} + \textbf{oxygen} \underset{\textbf{low oxygen concentration}}{\overset{\textbf{high oxygen concentration}}{\rightleftharpoons}} \textbf{oxyhaemoglobin}$$

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

The red blood cells have a unique shape – they form biconcave discs. This is another adaptation to their function. The shape gives them a large surface area to volume ratio for the diffusion of oxygen into and out of the cell. It also means they are relatively thin, giving short diffusion distances, which again makes the exchange of gases more efficient.

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

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

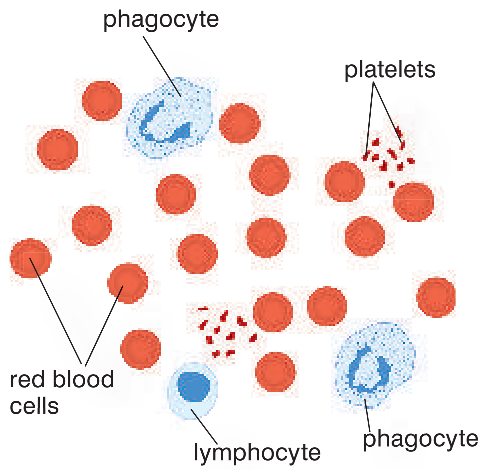


Figure 3.55 *Mixed together with plasma these different types of cells make up our blood.*

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

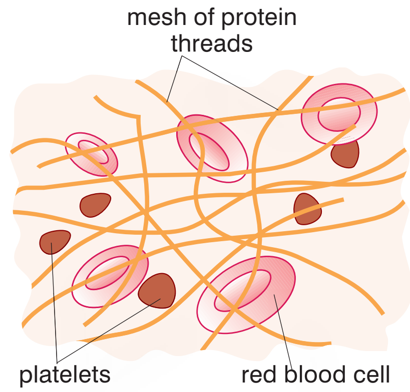


Figure 3.56 *Without platelets, clotting would not occur and we could bleed to death from a simple cut.*

Human blood groups

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

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

KEY WORDS

red blood cells *carry oxygen around the body*

haemoglobin *red pigment inside red blood cells*

oxyhaemoglobin *bright red product that forms in the blood when oxygen from the lungs combines with haemoglobin*

anaemia *deficiency disease from lack of iron*

white blood cells *form part of the body's defence against microbes*

KEY WORDS

phagocytes *white blood cells that engulf invading bacteria*

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

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

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

Table 3.7 *Antigens and antibodies of different blood groups*

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

If the blood from different blood groups is mixed together, there may be a reaction between the antigen and the complementary antibody which makes the red blood cells stick together (agglutinate). This means they cannot work properly. They block the capillaries and even larger blood vessels. Most of the time this is not important since everyone keeps their own blood in their own circulatory system. But if someone loses a lot of blood in an accident, an injury, when giving birth or during an operation then they may need a blood transfusion. This is when blood taken from one person is given to another to save their life. Before a transfusion it is vital to know the blood groups of both the person giving the blood (the donor) and the person receiving the blood (the recipient). This means the right type of blood can be given to prevent agglutination. The blood groups must be compatible. It is not usually the case that only one type of blood can be given, simply that blood containing a particular antigen must not be mixed with blood containing the matching antibody. For example, blood group O has no antigens so it can be given to anyone, but someone who has blood group O has both antibodies so they can only receive group O blood! On the other hand someone with blood group AB which has no antibodies can receive any type of blood! Figure 3.57 summarises the compatibilities of the different blood groups.

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

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

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

Two common problems of the circulatory system

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

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

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

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

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

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

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

Hypertension in Ethiopia

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

Treatment of hypertension

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

KEY WORD

hypertension *high blood pressure*

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

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

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

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

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

Now squeeze the rubber tubing gently to narrow it.

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

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

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

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

Summary

In this section you have learnt that:

- The body transport system consists of the blood vessels (the pipes), the heart (the pump) and the blood (the medium).
- Human beings have a double circulation – the pulmonary circulation to the lungs and the systemic circulation to the body.
- The three main types of blood vessels are the arteries, veins and capillaries and they are each adapted for a different function.
- The heart is mainly made of muscle.
- It pumps blood around the body in response to the needs of the tissues.
- Blood enters the atria of the heart, which contract to force blood into the ventricles. When the ventricles contract blood leaves the heart to go to the lungs (from the right) and around the body (from the left).
- Valves control the flow of blood in the heart.
- The blood has four main components:
  1 – Plasma, which transports dissolved food molecules, carbon dioxide and urea.
  2 – Red blood cells, which transport oxygen.
  3 – White blood cells, which defend against attack by microbes.
  4 – Platelets, which help clot the blood.
- Oxygen is carried by haemoglobin, which becomes oxyhaemoglobin in a reversible reaction.
- Tissue fluid is forced out of the blood in the capillaries and bathes the cells of the body. Exchange of substances by diffusion between the blood and the cells takes place through the tissue fluid.
- When the tissue fluid passes into the lymph system it becomes lymph. Lymph eventually returns to the blood enriched with antibodies.
- There are four main blood groups: A, B, AB and O. They are not all compatible and they must be matched carefully before a blood transfusion.
- Anaemia and hypertension are two diseases of the circulatory system which are particularly common in Ethiopia.

Review questions

Select the correct answer from A to D.

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

KEY WORDS

diuretics *chemicals which increase the output of urine*

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

End of unit questions

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

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

Part of the blood	Description

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

    a) For each substance say where in the body it enters the plasma.

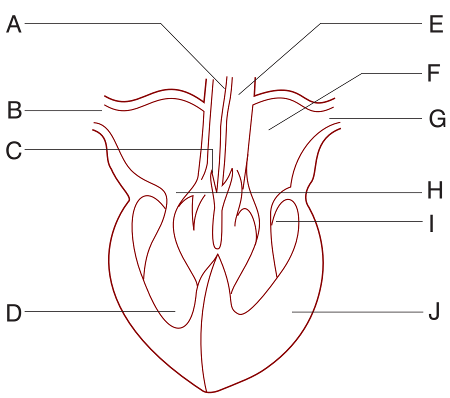
    b) For each substance say where it is transported to, and what happens to it when it gets there.

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

    a) Draw and label a typical red blood cell.

    b) Explain how red blood cells carry oxygen around your body and release it in the tissues where it is needed.

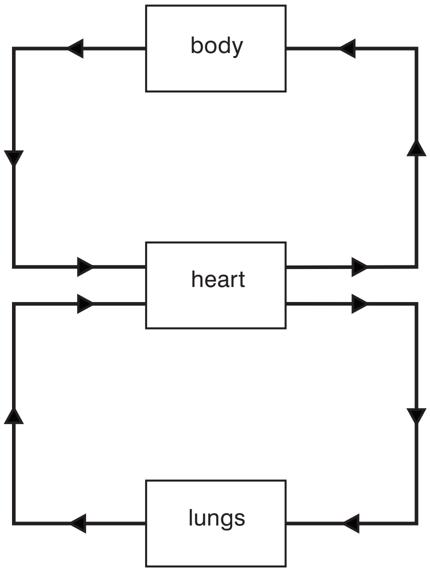
    c) How are red blood cells adapted for their role in your body?



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

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

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



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

    a) Copy the diagram and shade it blue in the areas where the blood is deoxygenated and red in the areas where you would expect oxygenated blood.

    b) What happens to the blood in the body?

    c) What happens to the blood in the lungs?

    d) Why is it called a double circulation?

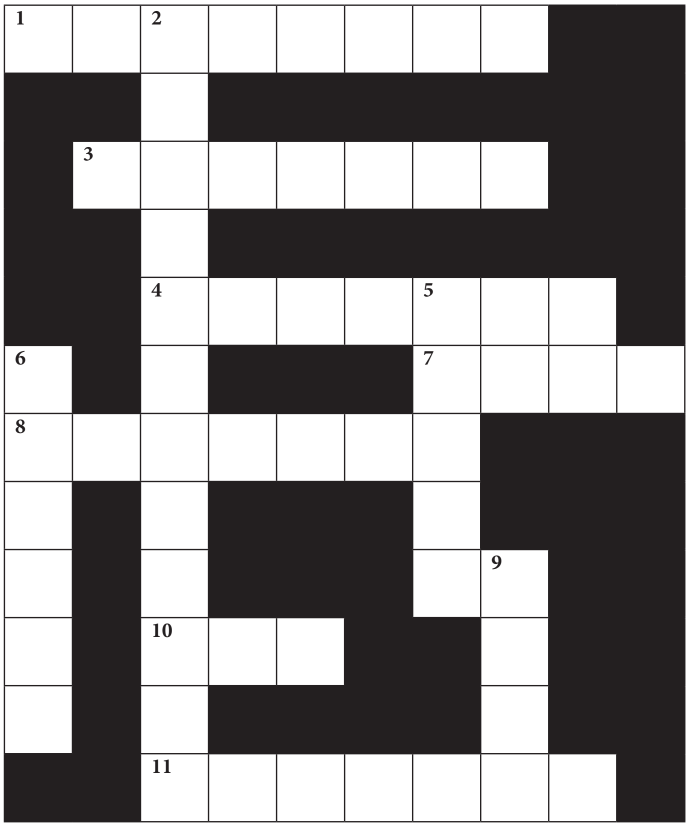
21. a) Name the three main types of blood vessel.

    b) Describe the job of each type of blood vessel in the body.

    c) Draw an annotated diagram of each type of blood vessel, using the annotations to describe how the blood vessel is adapted to its function.

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

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



Across

1 The addictive drug in cigarettes (8)

3 The food group needed for body building and growth (7)

4 Too much food can cause excess fat called ******* (7)

7 The organ in which gas exchange takes place (4)

8 The gas carried around the body in the red blood cells (6)

10 The form in which energy is needed in the cell (3)

11 Food in the digestive system is broken down by ******* (7)

Down

2 The main food group used to supply energy to the body (12)

5 The region of the small intestine where digested food is absorbed into the blood (5)

6 The chemical used to test for starch (6)

9 Greenish liquid formed in the liver and stored in the gall bladder (4)

Index