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 nm = 1×10^{-9} m). In comparison, the human eye can only resolve down to about 0.1 mm (1 mm = 1×10^{-2} 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*

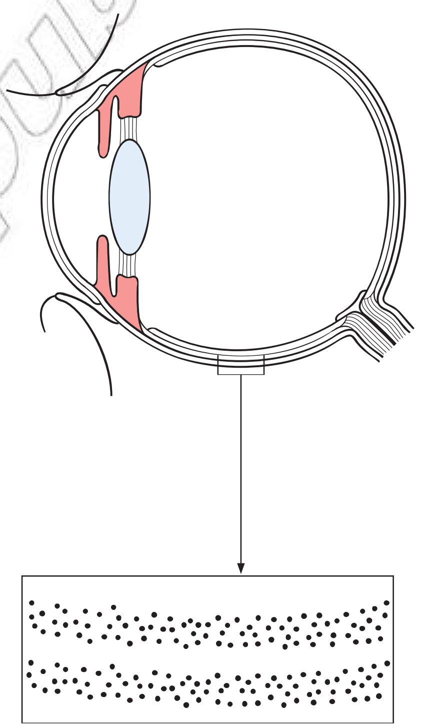


Figure 2.2 *The lines that make up this diagram are actually a mass of dots on the page. The resolving power of your eyes means that you see the dots merged together to make lines because you can't resolve the dots individually. If you magnify the line, you can see the dots. In the same way, what you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

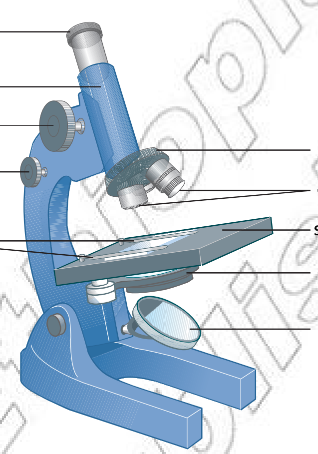


Figure 2.3 *A compound microscope has two sets of lenses (objective and eyepiece lenses) which are used to magnify the specimen. These microscopes are widely used for looking at cells.*

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.

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.

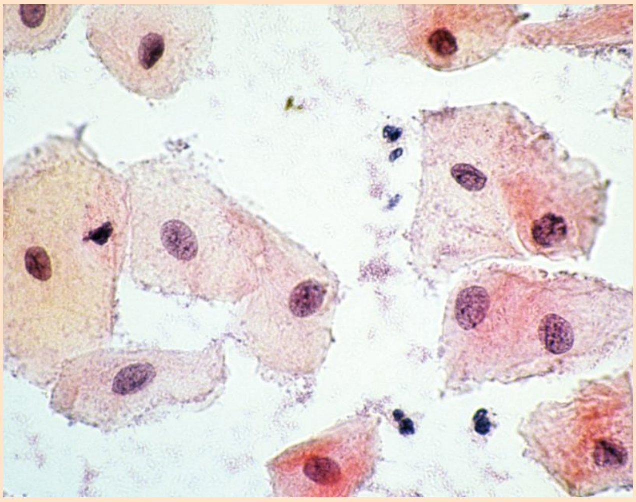


Figure 2.4 *Human cheek cells stained with methylene blue (×100)*

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.

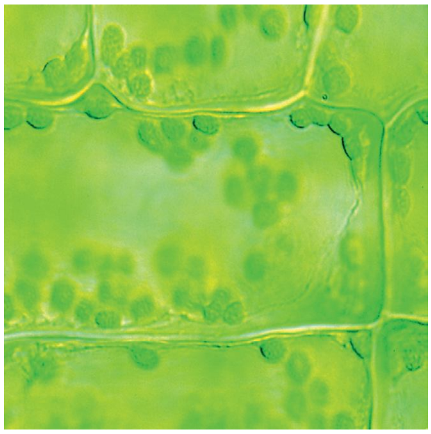


Figure 2.5 (a) *Typical green plant cells seen under the light microscope*

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.

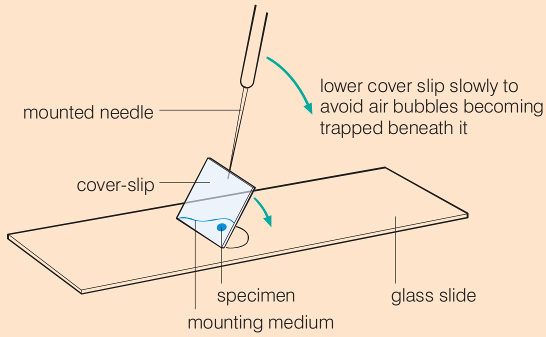
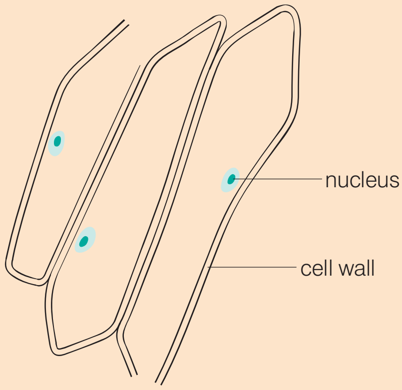


Figure 2.6 *Making a slide*

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).

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.

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

KEY WORD

wavelength *the distance between neighbouring wave crests*

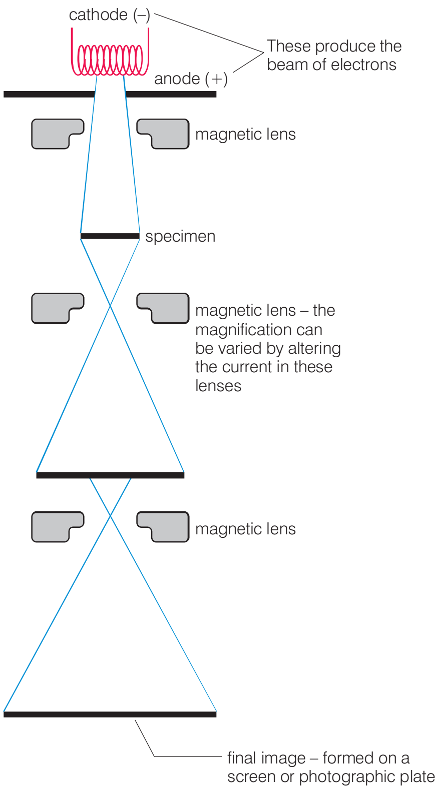


***Figure 2.8** A diagram of an electron microscope and how it works*

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

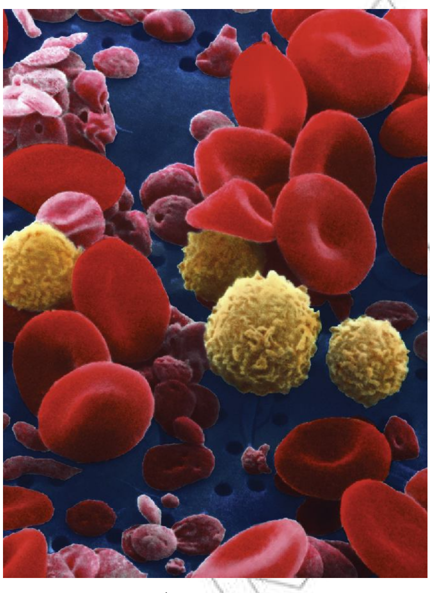
The most common type of electron micrograph you will see is produced by a transmission electron microscope, but the scanning electron microscope produces spectacular images of the surfaces of cells and organisms. It shows the surface of structures, greater depth of focus, and a three-dimensional view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



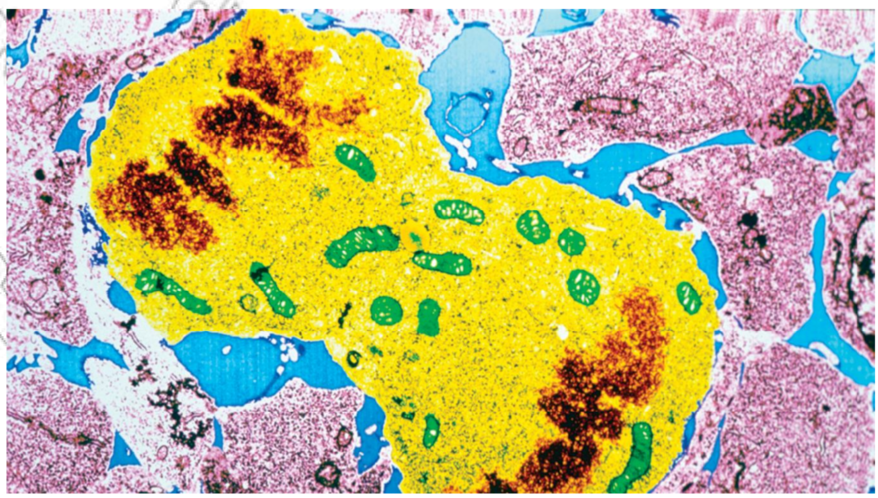


***Figure 2.9** The transmission electron microscope shows the inside details of a cell (right) and the scanning electron microscope can show us three-dimensional shapes (blood cells above).*

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.

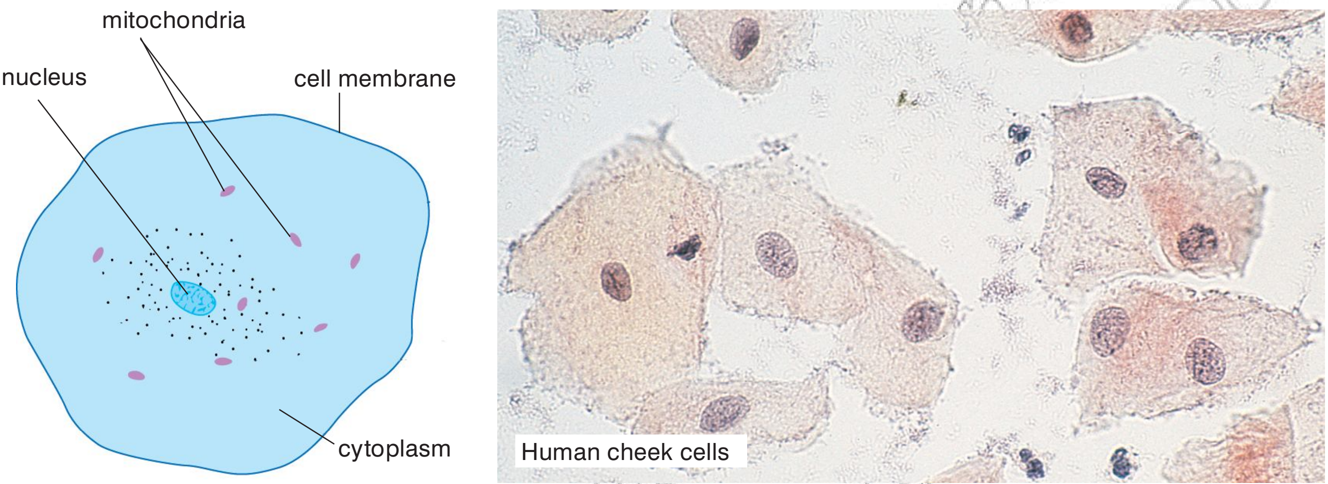


Figure 2.11 *A simple animal cell like this shows the features that are common to almost all living cells. Mitochondria, endoplasmic reticulum and ribosomes cannot be seen easily with a light microscope. They are much clearer using an electron microscope.*

Activity 2.3: Using the microscope to look at animal cells

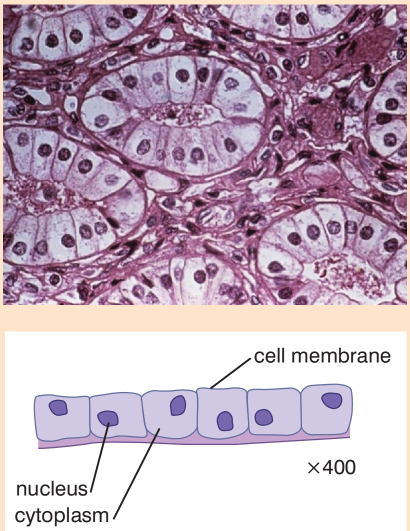


Figure 2.12 *Micrograph and a drawing of simple cuboidal epithelial cells*

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.

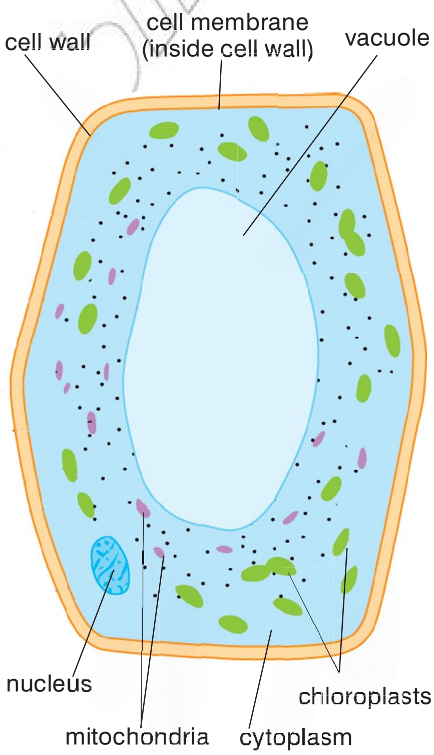


Figure 2.13 *A photosynthetic plant cell has many features in common with an animal cell, but others that are unique to plants.*

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.

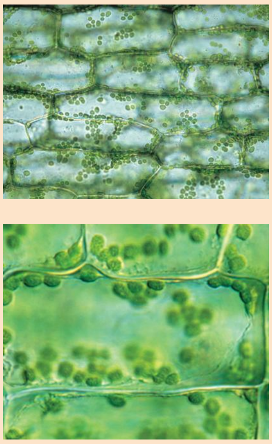


Figure 2.14 *Micrographs of* Elodea *cells under:*

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

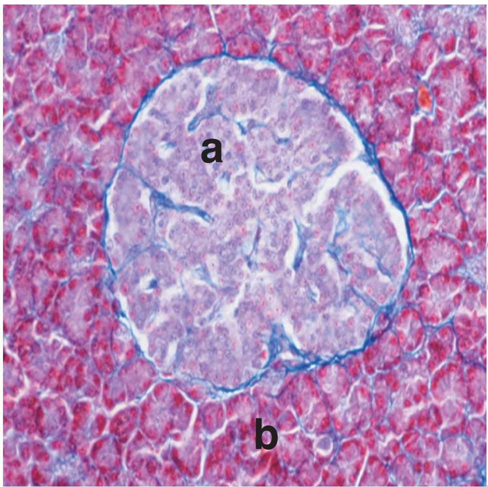


Figure 2.15 Within an organ like the pancreas at least two very different tissues can be seen. The cells in each type of tissue are specialised to make a very different chemical product, and so they take up stains differently, which allows them to be seen.

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.

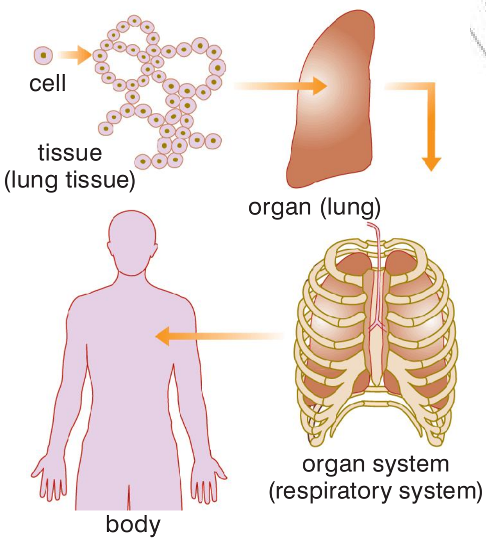


Figure 2.16 Large living organisms have many levels of organisation. As a result, each part of the body is perfectly adapted to carry out its functions.

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.

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.

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*

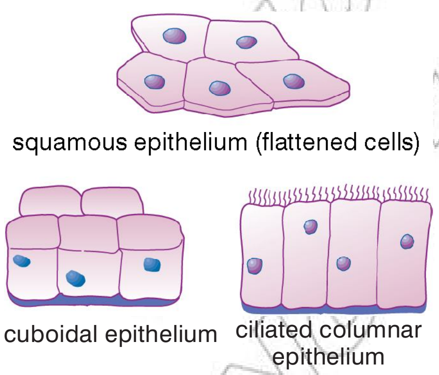


Figure 2.17 *Epithelial cells are found all over your body, lining the body spaces, organs and tubes inside you as well as forming your skin.*

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.

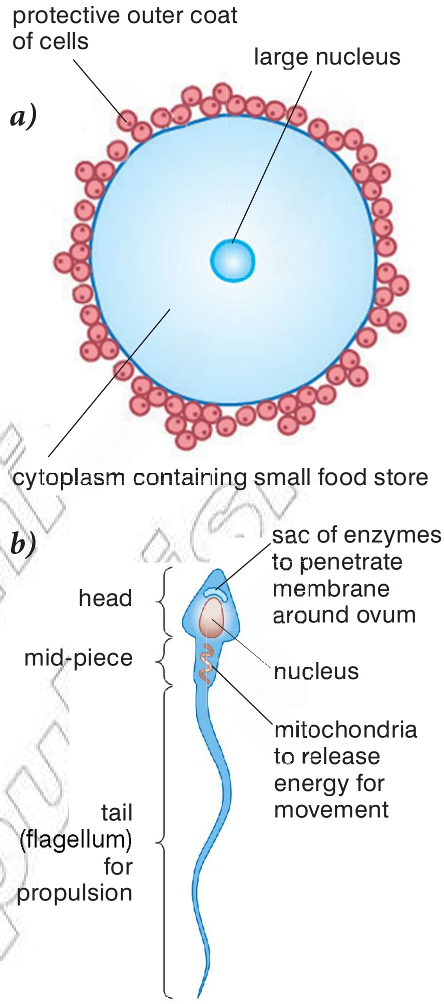
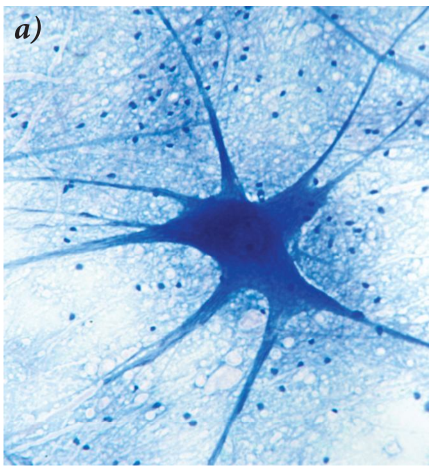


***Figure 2.18 a)** Egg and **b)** sperm cells show very clear adaptations to their much specialised functions.*

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



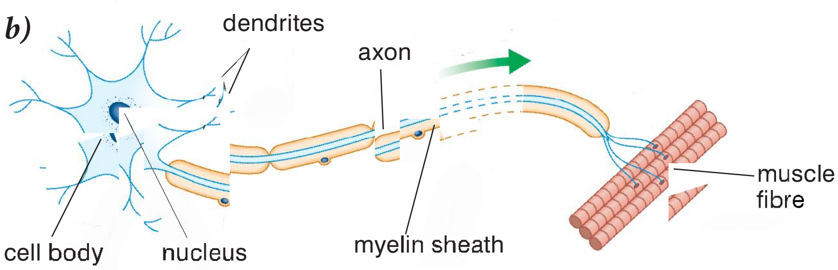


***Figure 2.19** Nerve cells are very different from epithelial cells – but they play a very different role in your body.*

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.

KEY WORDS

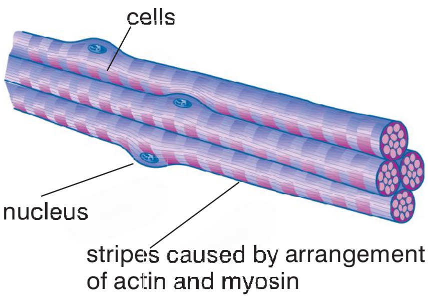
dendrites *short, arm-like protuberances of a nerve cell*

axon *extension of a neuron that transmits messages*

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.



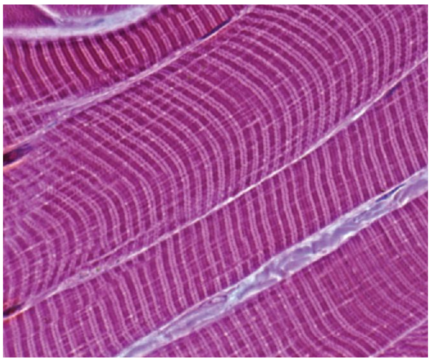


Figure 2.20 *Striated muscle has dark and light stripes under the microscope.*

KEY WORDS

muscle cells *elongated contractile cells that form muscle*

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

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

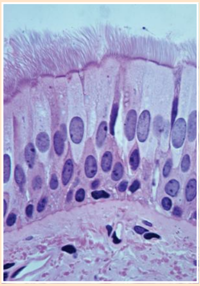
Method

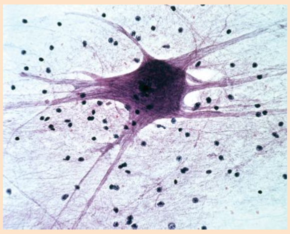
Remember, microscopes are expensive and delicate pieces of equipment so always take care of them and handle them safely.

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.

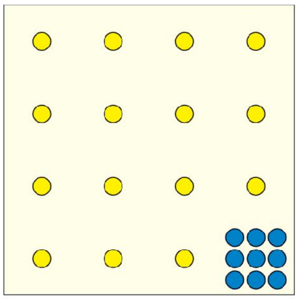
Diffusion takes place because of the random movements of the particles of a gas or of a substance in solution in water. All the particles are moving and bumping into each other and this moves them all around. Although the molecules are moving in both directions, there are more particles moving in the 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.

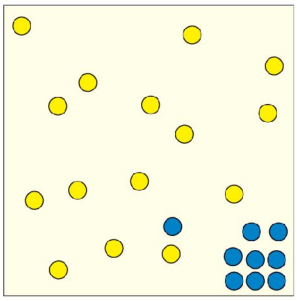
DID YOU KNOW?

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!

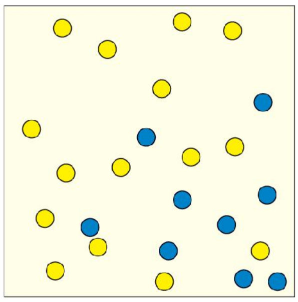
Figure 2.22 *The blood from an injured fish or animal will spread through the water by diffusion. Fish like this piranha will follow the trail of diffusing blood to some easy prey!*



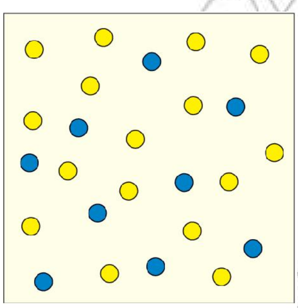
At the moment of adding blue particles to yellow mixture they are not mixed at all.



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*

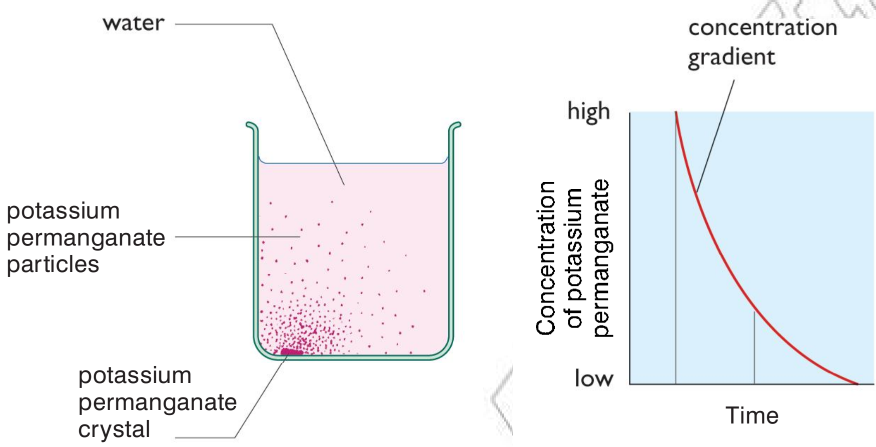


Figure 2.24 This diagram shows how the overall movement of particles in a particular direction is more effective if there is a big difference (a steep concentration gradient) between the two areas. This is why so many body systems are adapted to maintain steep concentration gradients.

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!

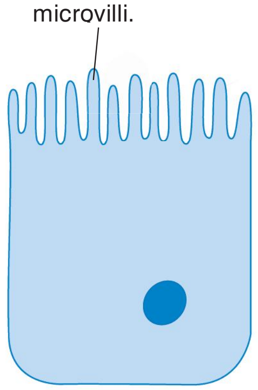


Figure 2.25 *An increase in the surface area of a cell membrane means more diffusion can take place.*

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*

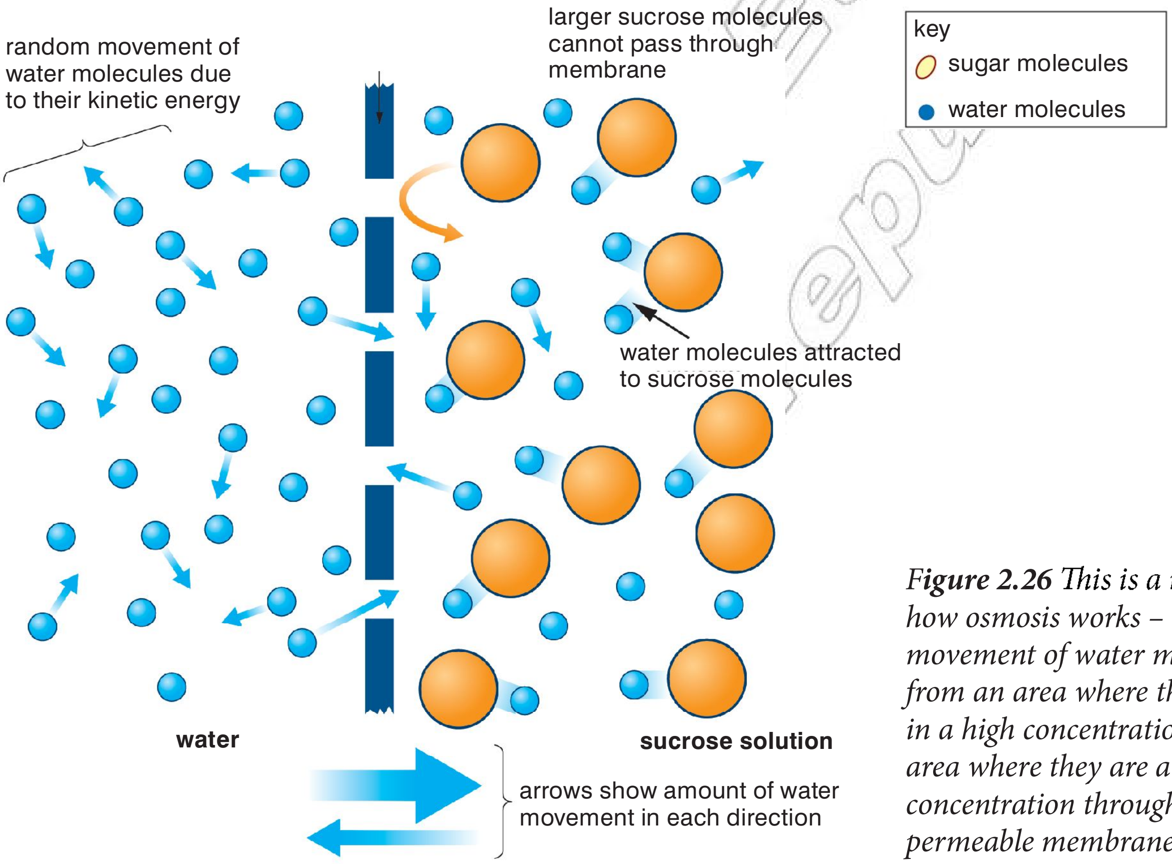


Figure 2.26 This is a model of how osmosis works – with a net movement of water molecules from an area where they are in a high concentration to an area where they are at a lower concentration through a partially permeable membrane.

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

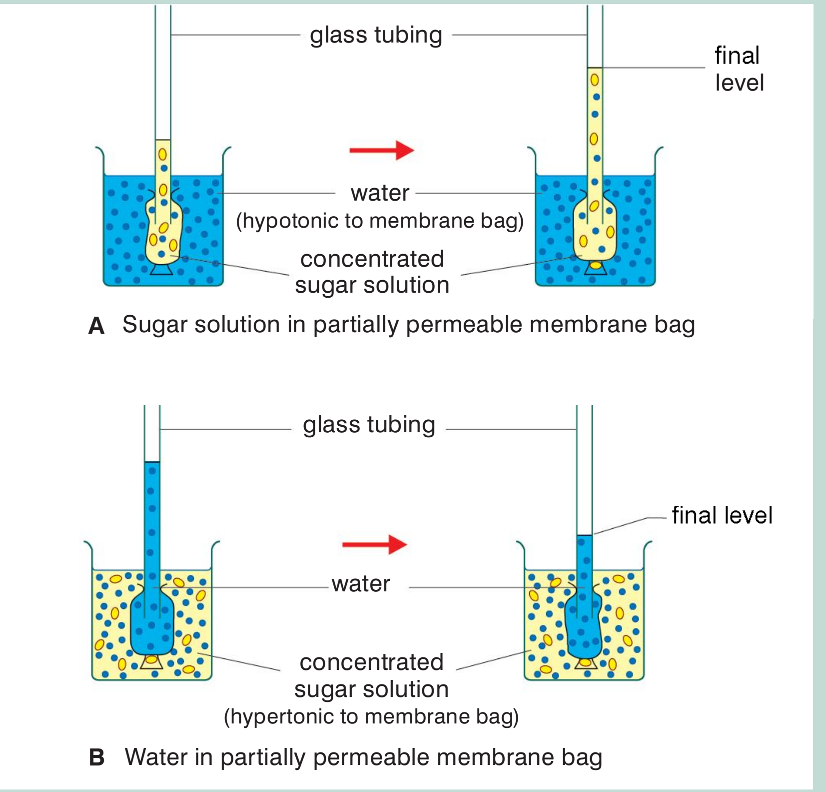


Figure 2.27 *Using bags of partially permeable membrane to make model cells you can clearly see the effect of osmosis as water moves across the membrane from a dilute to a concentrated sugar solution.*

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.

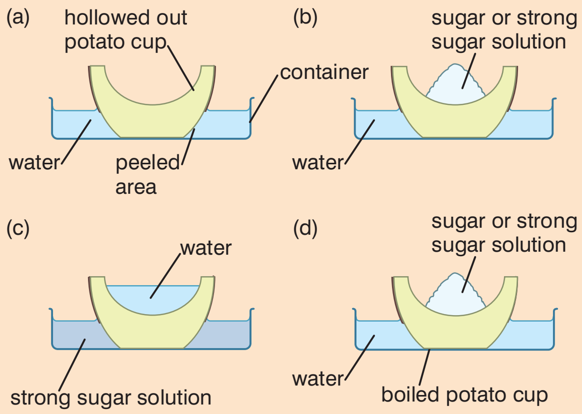


***Figure 2.28** Potato cup osmometers. You can use these to show that osmosis takes place.*

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

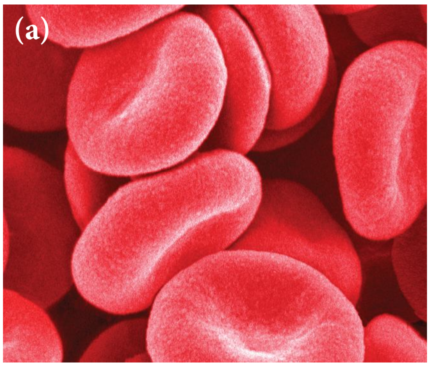
KEY WORD

dilute *to make less concentrated*

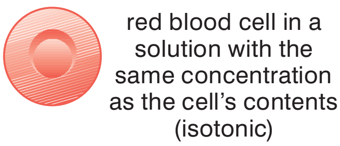
KEY WORD

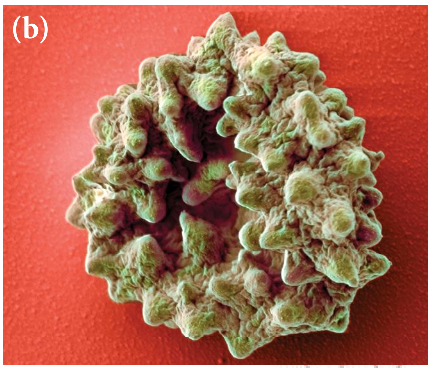
homeostasis *maintenance of a constant internal environment*

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.

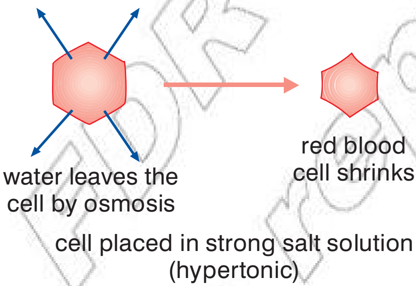


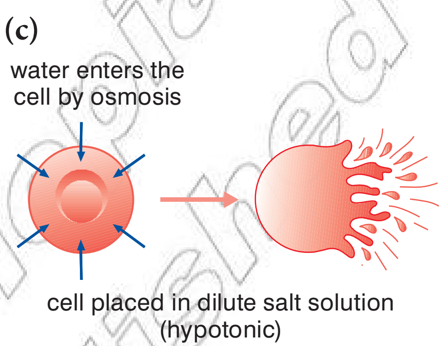
When the concentration of your body fluids is the same as your red blood cell contents, equal amounts of water enter and leave the cell by random movement and the cell keeps its shape.





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.





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*

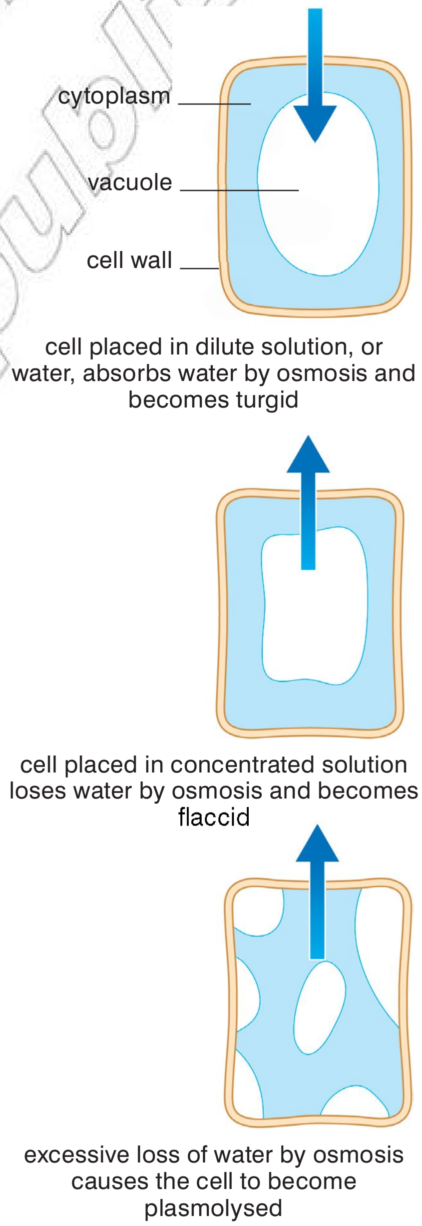


***Figure 2.30** Osmosis plays an important role in maintaining the rigid structure of plants.*

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.

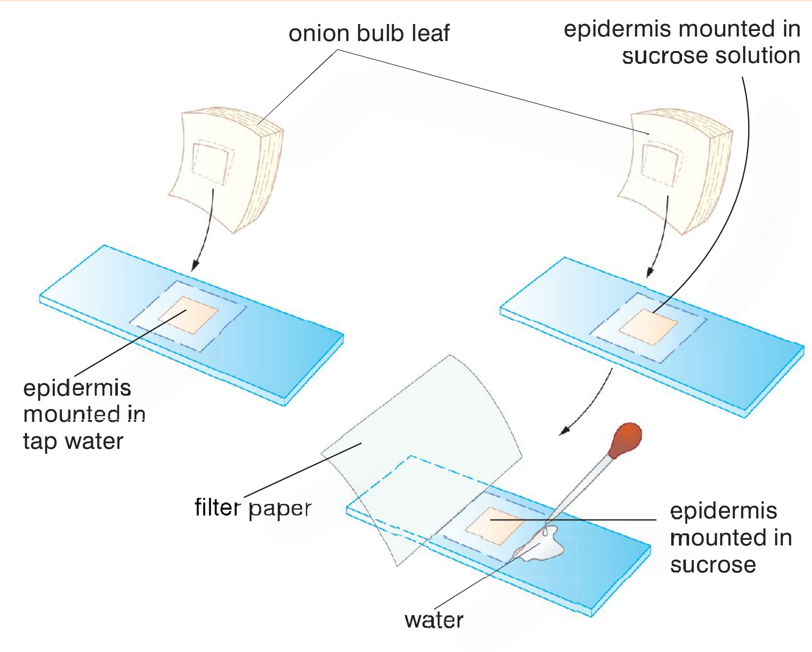


Figure 2.31 *Using this simple technique you can change the solution surrounding your plant epidermis cells as many times as you want to.*

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)					

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.

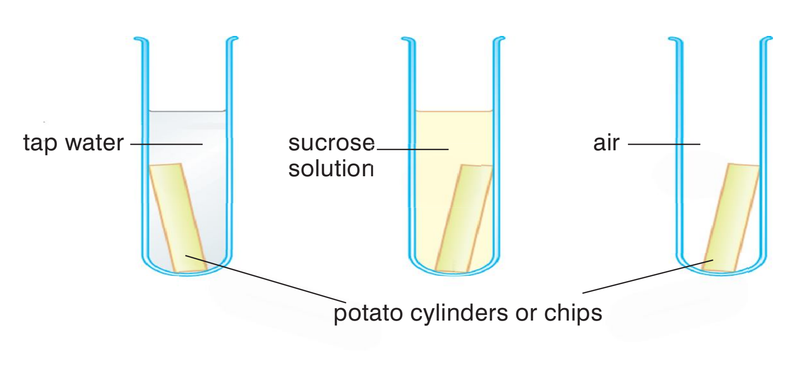


Figure 2.32 Apparatus for investigating the effects of osmosis on plant tissue

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.

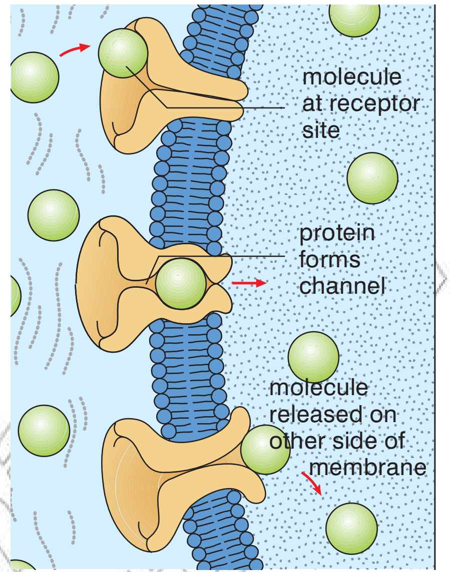


Figure 2.33 *Sometimes it is worth using up energy when a resource is particularly valuable and its transport is really important!*

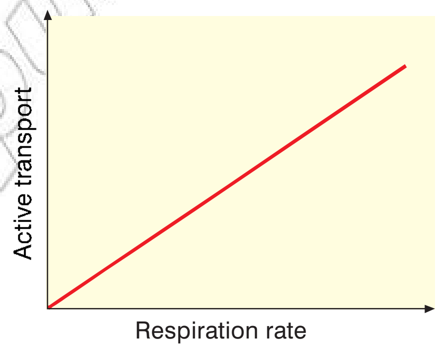


Figure 2.34 *The rate of active transport depends on the rate of respiration.*

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.

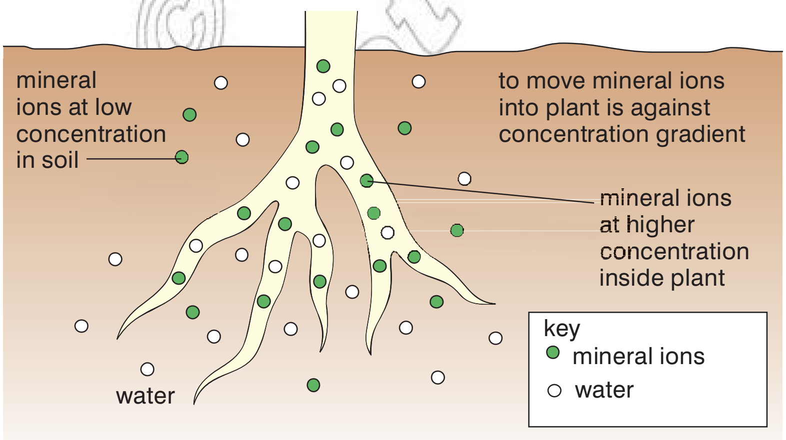


Figure 2.35 *It takes the use of energy in active transport to move mineral ions against a concentration gradient like this.*

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.

- 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.

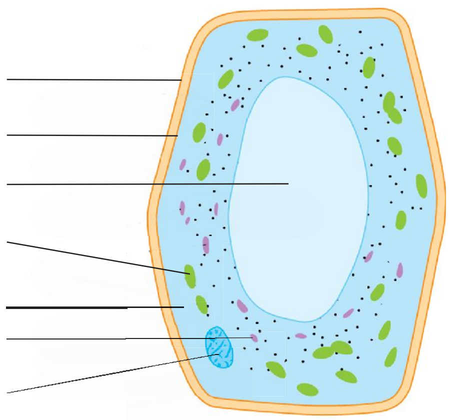
Review questions

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	