B 1 Cell structure and transport

1.1 The world of the microscope

Learning objectives

After this topic, you should know:

- how microscopy techniques have developed over time
- the differences in magnification and resolution between a light microscope and an electron microscope
- how to calculate the magnification, real size, and image size of a specimen.

Living things are all made up of cells, but most cells are so small you can only see them using a microscope. It is important to grasp the units used for such tiny specimens before you start to look at them.

Using units

1 kilometre (km) = 1000 metres (m)

1 m = 100 centimetres (cm)

1 cm = 10 millimetres (mm)

1 mm = 1000 micrometres (μm)

1 μm = 1000 nanometres (nm) – so a nanometre is 0.000 000 001 metres (or written in standard form as 1×10^{-9} m).

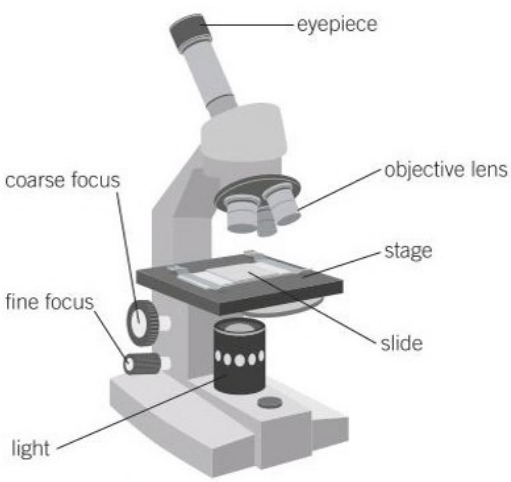


Figure 1 *A light microscope*

The first light microscopes were developed in the mid-17th century. Their development has continued ever since and they are still widely used to look at cells. Light microscopes use a beam of light to form an image of an object and the best can magnify around 2000 times (×2000), although school microscopes usually only magnify several hundred times. They are relatively cheap, can be used almost anywhere, and can magnify live specimens (Figures 1 and 2).

The invention of the electron microscope in the 1930s allowed biologists to see and understand more about the subcellular structures inside cells. These instruments use a beam of electrons to form an image and can magnify objects up to around 2 000 000 times. Transmission electron microscopes give 2D images with very high magnification and resolution. Scanning electron microscopes give dramatic 3D images but lower magnifications (Figure 3). Electron microscopes are large, very expensive, and have to be kept in special temperature, pressure, and humidity-controlled rooms.

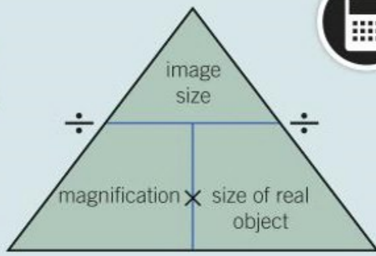
Calculating magnification

You can calculate the magnification you are using with a light microscope very simply. You multiply the magnification of the eyepiece lens by the magnification of the objective lens. So if your eyepiece lens is ×4 and your objective lens is ×10, your overall magnification is:

$$4 \times 10 = \times 40$$

When you label drawings made using a microscope, make it clear that the magnification you give is the magnification at which you looked at the specimen (eg., as viewed at ×40).

Calculating the size of an object



You will want to calculate the size of objects under the microscope. There is a simple formula for this, based on the magnification triangle.

As long as you know or can measure two of the factors, you can find the third.

$$\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$$

For example, if you know you are working at magnification ×40, and the image of the cell you are looking at measures 1 mm, you can work out the actual diameter of the cell:

$$\text{size of real object} = \frac{\text{size of image}}{\text{magnification}}$$

so

$$= \frac{1}{40}\,\text{mm} = 0.025\,\text{mm or } 25\,\mu\text{m}$$

Your cell has a diameter of **25 µm**.

Magnifying and resolving power

Microscopes are useful because they magnify things, making them look bigger. The height of an average person magnified by one of the best light microscopes would look about 3.5 km, and by an electron microscope about 3500 km. There is, however, a minimum distance between two objects when you can see them clearly as two separate things. If they are closer together than this, they appear as one object. 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. A light microscope has a resolving power of about 200 nm, a scanning electron microscope of about 10 nm and a transmission electron microscope of about 0.2 nm – that is approximately the distance apart of two atoms in a solid substance!

1 Name one advantage and one disadvantage of using:
a a light microscope [2 marks] **b** an electron microscope. [2 marks]

2 **a** A student measured the diameter of a human capillary on a micrograph. The image measures 5 mm and the student knows the magnification is ×1000. How many micrometres is the diameter of the capillary? [3 marks]
b A student is told the image of the cell has a diameter of 800 µm. The actual cell has a diameter of 20 µm. At what magnification has the cell been observed? [2 marks]

3 Evaluate the use of an electron microscope and a light microscope, giving one example where each type of microscope might be used. [6 marks]

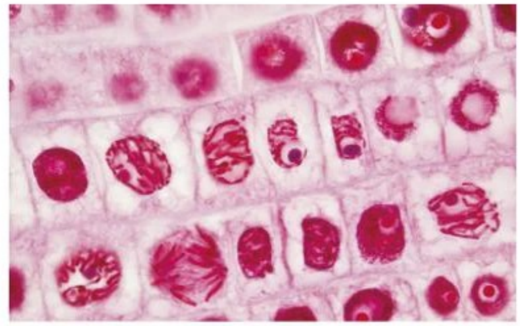


Figure 2 *Onion cells dividing as seen through a light microscope – magnification ×570*

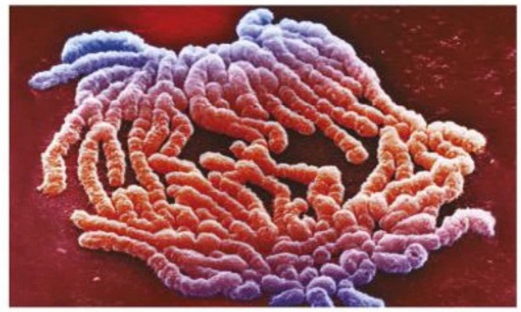


Figure 3 *Chromosomes during cell division seen with a scanning electron microscope – magnification ×4500*

Synoptic links

You can learn more about writing very small or very large numbers in standard form in the Maths skills section in Topic M1b.

For more information on cell division look at Chapter B2.

Study tip

Make sure you can work out the magnification, the size of a cell, or the size of the image depending on the information you are given.

Key points

- Light microscopes magnify up to about ×2000, and have a resolving power of about 200 nm.
- Electron microscopes magnify up to about ×2 000 000, and have a resolving power of around 0.2 nm.
- $\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$

B1.2 Animal and plant cells

Learning objectives

After this topic, you should know:

- the main parts of animal cells
- the similarities and differences between plant and animal cells.

The cells that make up your body are typical animal cells. All cells have some features in common. You can see these features clearly in animal cells.

Animal cells – structure and function

The structure and functions of the parts that make up a cell have been made clear by the electron microscope (Figure 1). You will learn more about how their structure relates to their functions as you study more about specific organ systems during your GCSE Biology course. An average animal cell is around 10–30 μm long (so it would take 100 000–300 000 cells to line up along the length of a metre ruler). Human beings are animals so human cells are just like most other animal cells, and you will see exactly the same structures inside them.

- The **nucleus** – controls all the activities of the cell and is surrounded by the nuclear membrane. It contains the genes on the chromosomes that carry the instructions for making the proteins needed to build new cells or new organisms. The average diameter is around 10 μm.
- The **cytoplasm** – a liquid gel in which the organelles are suspended and where most of the chemical reactions needed for life take place.
- The **cell membrane** – controls the passage of substances such as glucose and mineral ions into the cell. It also controls the movement of substances such as urea or hormones out of the cell.
- The **mitochondria** – structures in the cytoplasm where aerobic respiration takes place, releasing energy for the cell. They are very small: 1–2 μm in length and only 0.2–0.7 μm in diameter.
- The **ribosomes** – where protein synthesis takes place, making all the proteins needed in the cell.

Synoptic link

You will find out more about classifying the living world in Chapter B16.

Go further

The ultrastructure of a cell – the details you can see under an electron microscope – includes structures such as the cytoskeleton, the Golgi apparatus, and the rough and smooth endoplasmic reticulum. They support and move the cell, modify and package proteins and lipids, and produce the chemicals that control the way your body works.

Study tip

Learn the parts of the cells shown on these diagrams, and their functions.

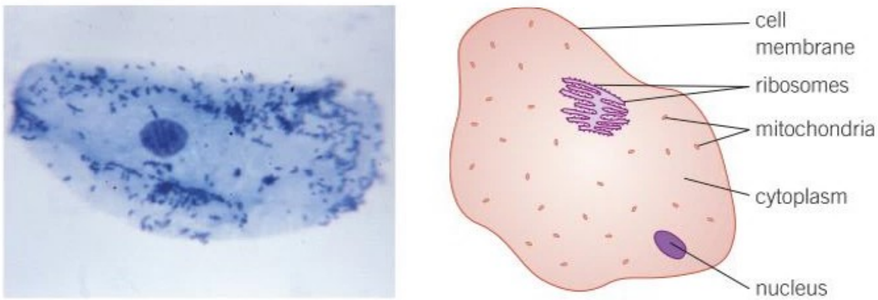


Figure 1 *Diagrams of cells are much easier to understand than the real thing seen under a microscope. This picture shows a simple animal cheek cell magnified ×1350 times under a light microscope. This is the way a model animal cell is drawn to show the main features common to most living cells*

Plant cells – structure and function

Plants are very different organisms from animals. They make their own food by photosynthesis. They do not move their whole bodies about from one place to another. Plant cells are often rather bigger than animal cells – they range from 10 to 100 μm in length.

Synoptic link

For more information on photosynthesis, look at Topic B8.1.

Plant cells have all the features of a typical animal cell, but they also contain features that are needed for their very different functions (Figures 2 and 3). **Algae** are simple aquatic organisms. They also make their own food by photosynthesis and have many similar features to plant cells. For centuries they were classified as plants, but now they are classified as part of a different kingdom – the protista.

Figure 2 *Algal cells contain a nucleus and chloroplasts so that they can photosynthesise*

All plant and algal cells have a **cell wall** made of **cellulose** that strengthens the cell and gives it support.

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

- **Chloroplasts** are found in all the green parts of a plant. They are green because they contain the green substance **chlorophyll**. Chlorophyll absorbs light so the plant can make food by photosynthesis. Each chloroplast is around 3–5 μm long. Root cells do not have chloroplasts because they are underground and do not photosynthesise.
- A **permanent vacuole** is a space in the cytoplasm filled with cell sap. This is important for keeping the cells rigid to support the plant.

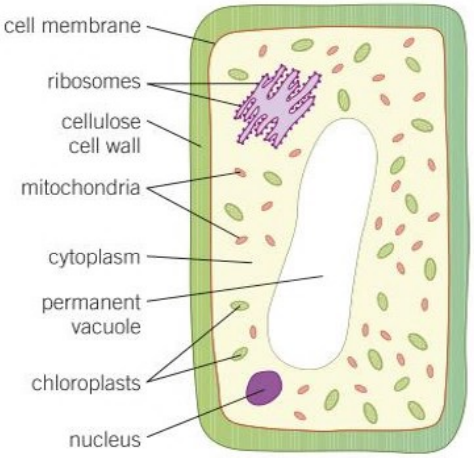


Figure 3 *A plant cell has many features in common with an animal cell, as well as other features that are unique to plants*

1 a Name the main structures you would expect to find in a human cell. [5 marks]
b Name the three extra features that may be found in plant cells but not animal cells. [3 marks]
c Describe the main functions of these three extra structures. [3 marks]

2 Suggest why the nucleus and the mitochondria are so important in all cells. [4 marks]

3 Chloroplasts are found in many plant cells but not all of them. Suggest two types of plant cells that are unlikely to have chloroplasts and in each case explain why they have none. [4 marks]

Looking at cells

Set up a microscope and observe, draw, and label examples of animal cells (e.g., cheek cells, Figure 1), algal cells (e.g., Figure 2) and plant cells (e.g., from onions or *Elodea*). In plant cells you should see the cell wall, the cytoplasm, and sometimes a vacuole. You will see chloroplasts in the *Elodea*, but not in the onion cells because they do not photosynthesise. Always show a scale magnification on your drawings.

Safety: if preparing your own cheek cells, please follow safety procedures.

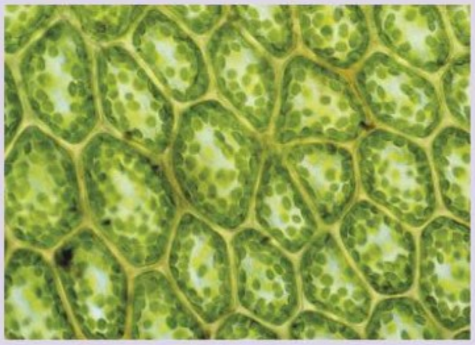


Figure 4 *Some of the common features of plant cells show up well under the light microscope. Here, the features are magnified ×40*

Study tip

Remember that not all plant cells have chloroplasts.

Do not confuse chloroplasts and chlorophyll.

Key points

- Animal cell features common to all cells – a nucleus, cytoplasm, cell membrane, mitochondria, and ribosomes.
- Plant and algal cells contain all the structures seen in animal cells as well as a cellulose cell wall.
- Many plant cells also contain chloroplasts and a permanent vacuole filled with sap.

B1.3 Eukaryotic and prokaryotic cells

Learning objectives

After this topic, you should know:

- the similarities and differences between eukaryotic cells and prokaryotic cells
- how bacteria compare to animal and plant cells
- the size and scale of cells including order of magnitude calculations.

Eukaryotic cells

Animal and plant cells are examples of **eukaryotic cells**. Eukaryotic cells all have a cell membrane, cytoplasm, and genetic material that is enclosed in a nucleus.

The genetic material is a chemical called DNA and this forms structures called chromosomes that are contained within the nucleus. All animals (including human beings), plants, fungi, and protista are eukaryotes.

Prokaryotes

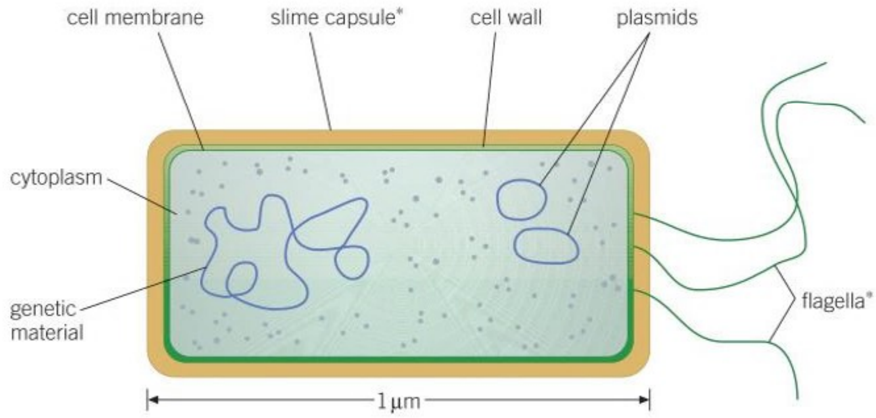
Bacteria are single-celled living organisms. They are examples of prokaryotes. At 0.2–2.0 μm in length prokaryotes are 1–2 orders of magnitude smaller than eukaryotes. You could fit hundreds of thousands of bacteria on to the full stop at the end of this sentence, so you cannot see individual bacteria without a powerful microscope. When you culture bacteria on an agar plate, you grow many millions of bacteria. This enables you to see the bacterial colony with your naked eye.

Synoptic link

You will learn more about growing colonies of bacteria on agar plates in Topic B5.3. You will learn more about bacteria that cause disease in Topic B5.7, and about bacteria that are important in the environment in Topic B17.2 and Topic B17.3.

Bacteria have cytoplasm and a cell membrane surrounded by a cell wall, but the cell wall does not contain the cellulose you see in plant cells. In prokaryotic cells the genetic material is not enclosed in a nucleus. The bacterial chromosome is a single DNA loop found free in the cytoplasm.

Prokaryotic cells may also contain extra small rings of DNA called plasmids. Plasmids code for very specific features such as antibiotic resistance.



*not always present

Figure 1 *Bacteria come in a variety of shapes, but they all have the same basic structure*

Some bacteria have a protective slime capsule around the outside of the cell wall. Some types of bacterium have at least one flagellum (plural: flagella), that is, a long protein strand that lashes about. These bacteria use their flagella to move themselves around.

Many bacteria have little or no effect on other organisms and many are very useful.

Go further

The plasmids found in bacteria are used extensively in genetic engineering to carry new genes into the genetic material of other organisms, ranging from bananas to sheep.

Some bacteria are harmful. Bacteria can cause diseases in humans and other animals and also in plants. They can also decompose and destroy stored food.

Relative sizes

In cell biology it is easy to forget just how small everything is – and how much bigger some cells are than others. It is also important to remember just how large the organisms built up from individual cells can be. Figure 2 shows you some relative sizes.

Orders of magnitude

Orders of magnitude are used to make approximate comparisons between numbers or objects. If one number is about 10 times bigger than another, it is an order of magnitude bigger. You show orders of magnitude using powers of 10. If one cell or organelle is 10 times bigger than another, it is an order of magnitude bigger or 10^1. If it is approximately 100 times bigger it is two orders of magnitude bigger or 10^2.

If you have two numbers to compare, as a rule of thumb you can work out orders of magnitude as follows:

If the bigger number divided by the smaller number is less than 10, then they are the same order of magnitude.

If the bigger number divided by the smaller number is around 10, then it is 10^1 or an order of magnitude bigger.

If the bigger number divided by the smaller number is around 100, then it is two orders of magnitude or 10^2 bigger.

Example:

A small animal cell has a length of around 10 µm. A large plant cell has a length of around 100 µm.

$$\frac{100}{10} = 10$$

So, a large plant cell is an order of magnitude or 10^1 bigger than a small animal cell.

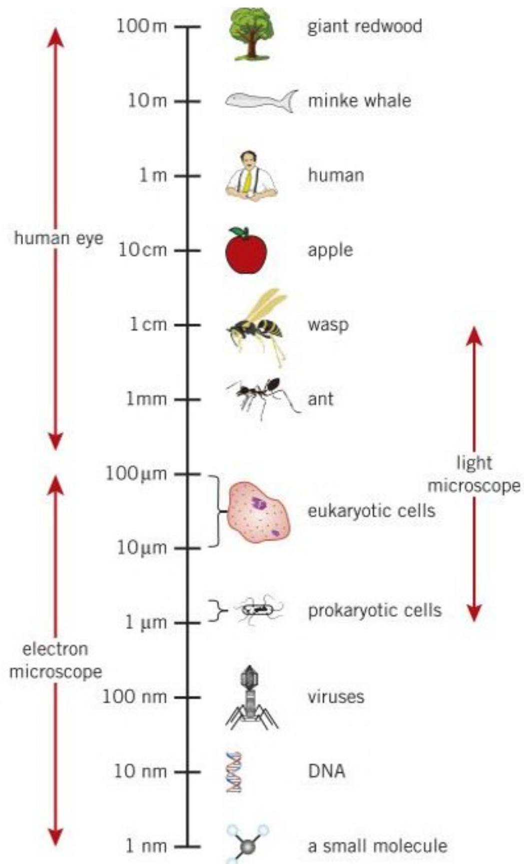


Figure 2 *The relative sizes of different cells and whole organisms and how they can be seen*

Study tip

Be clear about the similarities and differences between animal, plant, and bacterial cells and between eukaryotic cells and prokaryotic cells.

1 **a** Describe the difference between the genetic material in a prokaryotic cell and the genetic material in the eukaryotic cell. [2 marks]

b i Describe what flagella are. [1 mark]

ii Name one use of flagella in a prokaryote. [1 mark]

2 A cell nucleus has an average length of 6 µm. Calculate the order of magnitude comparison between the nucleus of a cell and:

a a small animal cell [2 marks] **b** a large plant cell. [2 marks]

3 Describe the similarities and differences between the features found in prokaryotic and eukaryotic plant and animal cells. [6 marks]

Key points

- Eukaryotic cells all have a cell membrane, cytoplasm, and genetic material enclosed in a nucleus.
- Prokaryotic cells consist of cytoplasm and a cell membrane surrounded by a cell wall. The genetic material is not in a distinct nucleus. It forms a single DNA loop. Prokaryotes may contain one or more extra small rings of DNA called plasmids.
- Bacteria are all prokaryotes.

B1.4 Specialisation in animal cells

Learning objectives

After this topic, you should know:

- how cells differentiate to form specialised cells
- animal cells may be specialised to carry out a particular function
- how the structure of different types of animal cells relates to their function.

Synoptic links

You can find out much more about the organisation of specialised cells into tissues, organs and organ systems in Topic B3.1 and Topic B3.2.

Synoptic link

You can find out more about specialised nerve cells in Chapter B10.

Observing specialised cells

Try looking at different specialised cells under a microscope.

When you look at a specialised cell, there are two useful questions you can ask yourself:

- How is this cell different in structure from a generalised cell?
- How does the difference in structure help the cell to carry out its function?

Although the smallest living organisms are only single cells, they can carry out all of the functions of life. Most organisms are bigger and are made up of lots of cells. Some of these cells become specialised to carry out particular jobs.

As an organism develops, cells differentiate to form different types of specialised cells. Most types of animal cells differentiate at an early stage of development, whereas many types of plant cells retain the ability to differentiate throughout life. As a cell differentiates, it gets different sub-cellular structures that enable it to carry out a particular function. It has become a specialised cell. Some specialised cells, such as egg and sperm cells, work individually. Others are adapted to work as part of a tissue, an organ, or a whole organism.

Nerve cells

Nerve cells are specialised to carry electrical impulses around the body of an animal (Figure 1). They provide a rapid communication system between the different parts of the body. They have several adaptations including:

- Lots of dendrites to make connections to other nerve cells.
- An axon that carries the nerve impulse from one place to another. They can be very long – the axon of a nerve cell in a blue whale can be up to 25 m long! The longest axon in your body runs from the base of your spine to your big toe.
- The nerve endings or synapses are adapted to pass the impulses to another cell or between a nerve cell and a muscle in the body using special transmitter chemicals. They contain lots of mitochondria to provide the energy needed to make the transmitter chemicals.

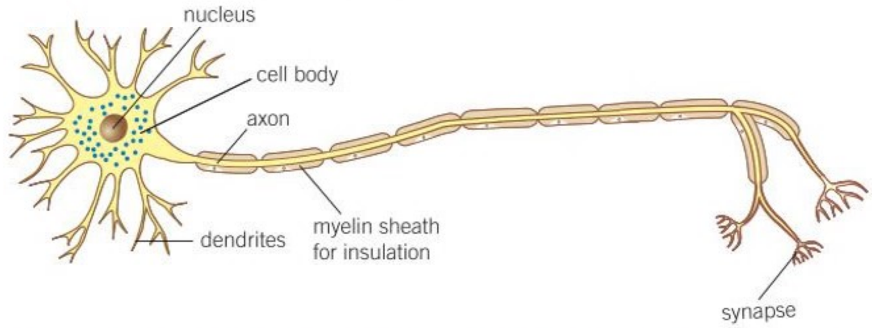


Figure 1 *A nerve cell is specialised to carry electrical impulses from one part of the body to another*

Muscle cells

Muscle cells are specialised cells that can contract and relax. Striated (striped) muscle cells work together in tissues called muscles (Figure 2). Muscles contract and relax in pairs to move the bones of the skeleton, so vertebrates can move on land and in water, and in some cases fly. Smooth muscle cells form one of the layers of tissue in your digestive system and they contract to squeeze the food through your gut.

Striated muscle cells have three main adaptations:

- They contain special proteins that slide over each other making the fibres contract.
- They contain many mitochondria to transfer the energy needed for the chemical reactions that take place as the cells contract and relax.
- They can store glycogen, a chemical that can be broken down and used in cellular respiration by the mitochondria to transfer the energy needed for the fibres to contract.

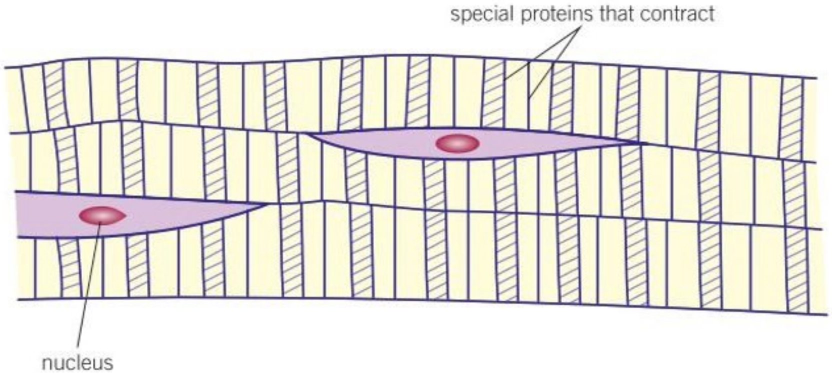


Figure 2 *A striated muscle cell is specialised to contract and relax*

Sperm cells

Sperm cells are usually released a long way from the egg they are going to fertilise. They contain the genetic information from the male parent. Depending on the type of animal, sperm cells need to move through water or the female reproductive system to reach an egg. Then they have to break into the egg.

Sperm cells have several adaptations to make all this possible (Figure 3):

- A long tail whips from side to side to help move the sperm through water or the female reproductive system.
- The middle section is full of mitochondria, which transfer the energy needed for the tail to work.
- The acrosome stores digestive enzymes for breaking down the outer layers of the egg.
- A large nucleus contains the genetic information to be passed on.

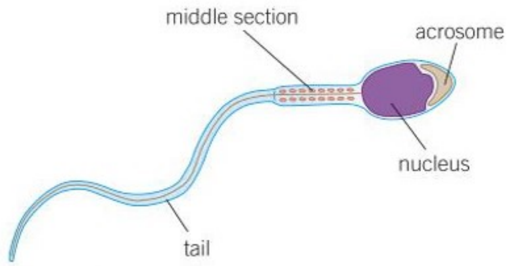


Figure 3 *A sperm cell*

1 Name one adaptation for each of the following specialised animal cells. Describe how this adaptation helps the cell carry out its function:

a nerve cell [2 marks]

b muscle cell [2 marks]

c sperm cell [2 marks]

2 Cone cells are specialised nerve cells in the eye. They contain a chemical that changes in coloured light. As a result of the change, an impulse is sent along another nerve cell to the brain. Cone cells usually contain many mitochondria. Suggest why this is an important adaptation. [4 marks]

3 Describe the features you would look for to decide on the function of an unknown specialised animal cell. [6 marks]

Key points

- As an organism develops, cells differentiate to form different types of cells.
- As an animal cell differentiates to form a specialised cell it acquires different sub-cellular structures to enable it to carry out a certain function.
- Examples of specialised animal cells are nerve cells, muscle cells, and sperm cells.
- Animal cells may be specialised to function within a tissue, an organ, organ systems, or whole organisms.

B1.5 Specialisation in plant cells

Learning objectives

After this topic, you should know:

- how plant cells may be specialised to carry out a particular function
- how the structure of different types of plant cells relates to their function.

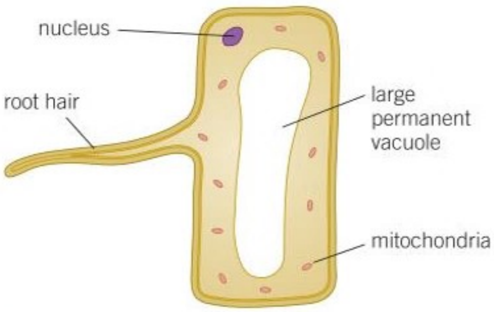


Figure 1 *A root hair cell*

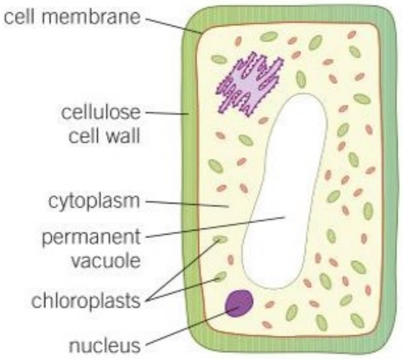


Figure 2 *A photosynthetic plant cell*

Synoptic link

You will learn much more about photosynthesis in Chapter B8.

Animals are not the only organisms to have cells specialised for a particular function within a tissue or an organ. Plants also have very specialised cells with clear adaptations for the job they carry out. Here are four examples.

Root hair cells

You find root hair cells close to the tips of growing roots. Plants need to take in lots of water (and dissolved mineral ions). The root hair cells help them to take up water and mineral ions more efficiently. Root hair cells are always relatively close to the xylem tissue. The xylem tissue carries water and mineral ions up into the rest of the plant. Mineral ions are moved into the root hair cell by active transport (Topic B1.9).

Root hair cells (Figure 1) have three main adaptations:

- They greatly increase the surface area available for water to move into the cell.
- They have a large permanent vacuole that speeds up the movement of water by osmosis from the soil across the root hair cell.
- They have many mitochondria that transfer the energy needed for the active transport of mineral ions into the root hair cells.

Photosynthetic cells

One of the ways plants differ from animals is that plants can make their own food by photosynthesis. There are lots of plant cells that can carry out photosynthesis – and lots that cannot. Photosynthetic cells (Figure 2) usually have a number of adaptations including:

- They contain specialised green structures called chloroplasts containing chlorophyll that trap the light needed for photosynthesis.
- They are usually positioned in continuous layers in the leaves and outer layers of the stem of a plant so they absorb as much light as possible.
- They have a large permanent vacuole that helps keep the cell rigid as a result of osmosis (Topic B1.8). When lots of these rigid cells are arranged together to form photosynthetic tissue they help support the stem. They also keep the leaf spread out so it can capture as much light as possible.

Xylem cells

Xylem is the transport tissue in plants that carries water and mineral ions from the roots to the highest leaves and shoots. The xylem is also important in supporting the plant. The xylem is made up of xylem cells (Figure 3) that are adapted to their functions in two main ways:

- The xylem cells are alive when they are first formed but a special chemical called lignin builds up in spirals in the cell walls. The cells die and form long hollow tubes that allow water and mineral ions to move easily through them, from one end of the plant to the other.

- The spirals and rings of lignin in the xylem cells make them very strong and help them withstand the pressure of water moving up the plant. They also help support the plant stem.

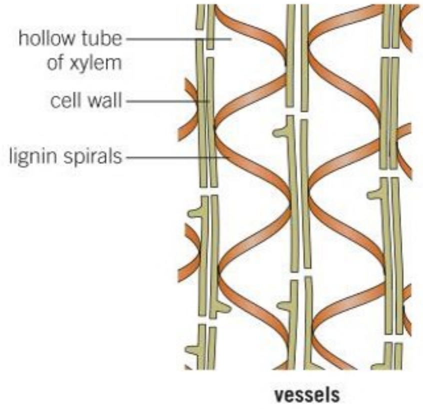


Figure 3 *The adaptations of xylem cells*

Synoptic link

You will learn more about the movement of water up the xylem and the process of transpiration in Chapter B4.

Phloem cells

Phloem is the specialised transport tissue that carries the food made by photosynthesis around the body of the plant. It is made up of phloem cells that form tubes rather like xylem cells, but phloem cells do not become lignified and die. The dissolved food can move up and down the phloem tubes to where it is needed. The adaptations of the phloem cells (Figure 4) include:

- The cell walls between the cells break down to form special sieve plates. These allow water carrying dissolved food to move freely up and down the tubes to where it is needed.

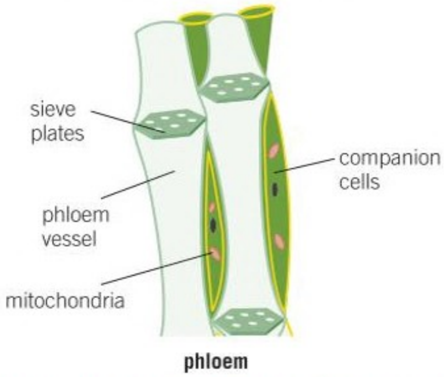


Figure 4 *The adaptations of phloem cells*

- Phloem cells lose a lot of their internal structures but they are supported by companion cells that help to keep them alive. The mitochondria of the companion cells transfer the energy needed to move dissolved food up and down the plant in phloem.

1 Name one adaptation for each of the following specialised plant cells. Describe how this adaptation helps the cell carry out its function:
   a root hair cell [2 marks]
   b xylem cell [2 marks]
   c phloem cell [2 marks]
   d photosynthetic cell [2 marks]

2 Suggest why a cell within the trunk of a tree cannot carry out photosynthesis. [2 marks]

3 Describe the features you would look for to decide on the function of an unknown specialised plant cell. [6 marks]

Key points

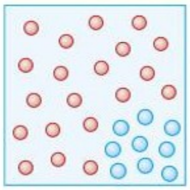
- Plant cells may be specialised to carry out a particular function.
- Examples of specialised plant cells are root hair cells, photosynthetic cells, xylem cells, and phloem cells
- Plant cells may be specialised to function within tissues, organs, organ systems, or whole organisms.

B1.6 Diffusion

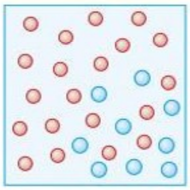
Learning objectives

After this topic, you should know:

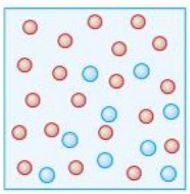
- how diffusion takes place and why it is important in living organisms
- what affects the rate of diffusion.



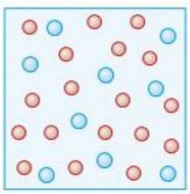
At the moment when the blue particles are added to the red particles they are not mixed at all



As the particles move randomly, the blue ones begin to mix with the red ones



As the particles move and spread out, they bump into each other. This helps them to keep spreading randomly



Eventually, the particles are completely mixed and diffusion is complete, although they do continue to move randomly

Figure 1 *The random movement of particles results in substances spreading out, or diffusing, from an area of higher concentration to an area of lower concentration*

Study tip

Particles move randomly, but the net movement is from a region of high concentration to a region of low concentration.

Your cells need to take in substances such as glucose and oxygen for respiration. They also need to get rid of waste products, and chemicals that are needed elsewhere in your body. Dissolved substances and gases can move into and out of your cells across the cell membrane. One of the main ways in which they move is by **diffusion**.

Diffusion

Diffusion is the spreading out of the particles of a gas, or of any substance in solution (a solute). This results in the net movement (overall movement) of particles. The net movement is from an area of higher concentration to an area of lower concentration of the particle. It takes place because of the random movement of the particles (molecules or ions). The motion of the particles causes them to bump into each other, and this moves them all around.

Imagine a room containing a group of boys on one side and a group of girls on the other. If everyone closes their eyes and moves around briskly but randomly, they will bump into each other. They will scatter until the room contains a mixture of boys and girls. This gives you a good model of diffusion (see Figure 1).

Rates of diffusion

If there is a big difference in concentration between two areas, diffusion will take place quickly. Many particles will move randomly towards the area of low concentration. Only relatively few will move randomly in the other direction.

However, if there is only a small difference in concentration between two areas, the net movement by diffusion will be quite slow. The number of particles moving into the area of lower concentration by random movement will only be slightly more than the number of particles that are leaving the area.

net movement = particles moving in – particles moving out

In general, the greater the difference in concentration, the faster the rate of diffusion. This difference between two areas of concentration is called the concentration gradient. The bigger the difference, the steeper the concentration gradient and the faster the rate of diffusion. In other words, diffusion occurs *down* a concentration gradient.

Temperature also affects the rate of diffusion. An increase in temperature means the particles in a gas or a solution move around more quickly. When this happens, diffusion takes place more rapidly as the random movement of the particles speeds up.

Diffusion in living organisms

Dissolved substances move into and out of your cells by diffusion across the cell membrane. These include simple sugars, such as glucose, gases such as oxygen and carbon dioxide, and waste products such as urea from the breakdown of amino acids in your liver. The urea passes from the liver cells into the blood plasma and is excreted by the kidneys.

The oxygen you need for respiration passes from the air in your lungs into your red blood cells through the cell membranes by diffusion. The oxygen moves down a concentration gradient from a region of high oxygen concentration to a region of low oxygen concentration.

Oxygen then also moves by diffusion down a concentration gradient from the blood cells into the cells of the body where it is needed. Carbon dioxide moves out from the body cells into the red blood cells and then into the air in the lungs by diffusion down a concentration gradient in a similar way. The diffusion of oxygen and carbon dioxide in opposite directions in the lungs is known as gas exchange.

Individual cells may be adapted to make diffusion easier and more rapid. The most common adaptation is to increase the surface area of the cell membrane (Figure 2). By folding up the membrane of a cell, or the tissue lining an organ, the area over which diffusion can take place is greatly increased. Therefore the rate of diffusion is also greatly increased, so that much more of a substance moves in a given time.

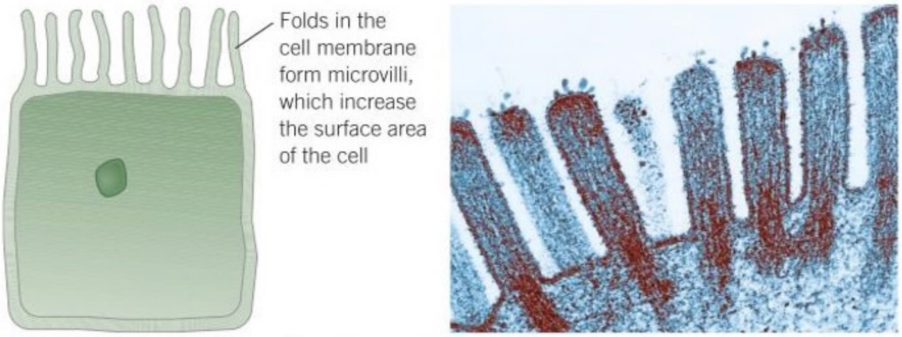


Figure 2 *An increase in the surface area of a cell membrane means diffusion can take place more quickly. This is an intestinal cell – magnification × 57 600*

1 Define the process of diffusion in terms of the particles involved. [2 marks]

2 a Explain why diffusion takes place faster when there is an increase in temperature. [3 marks]

b Explain why so many cells have folded membranes along at least one surface. [2 marks]

3 Describe the process of diffusion occurring in each of the following statements. Include any adaptations that are involved.

a Digested food products move from your gut into the bloodstream. [3 marks]

b Carbon dioxide moves from the blood in the capillaries of your lungs to the air in the lungs. [3 marks]

c Male moths can track down a mate from up to 3 miles away because of the special chemicals produced by the female. [3 marks]

Synoptic link

You will learn more about the excretion of urea by the kidney in Topic B12.2.

You will learn more about gas exchange in Topic B4.5.

Key points

- Diffusion is the spreading out of particles of any substance, in solution or a gas, resulting in a net movement from an area of higher concentration to an area of lower concentration, down a concentration gradient.
- The rate of diffusion is affected by the difference in concentrations, the temperature, and the available surface area.
- Dissolved substances such as glucose and urea and gases such as oxygen and carbon dioxide move in and out of cells by diffusion.

B1.7 Osmosis

Learning objectives

After this topic, you should know:

- how osmosis differs from diffusion
- why osmosis is so important in animal cells.

Study tip

Remember, any particles can diffuse from an area of high concentration to an area of low concentration, provided they are **soluble** and **small** enough to pass through the membrane.

Osmosis in organisms refers only to the diffusion of *water* molecules through the partially permeable cell membrane.

Investigating osmosis

You can make model cells using bags made of partially permeable membrane (see Figure 1). You can find out what happens to them if the concentrations of the solutions inside or outside the 'cell' change.

Diffusion takes place when particles can spread out freely from a higher to a lower concentration. However, the solutions inside cells are separated from those outside by the cell membrane. This membrane does not let all types of particles through. Membranes that only let some types of particles through are called **partially permeable membranes**.

How osmosis differs from diffusion

Partially permeable cell membranes let water move across them. Remember:

- A **dilute** solution of sugar contains a *high* concentration of water (the solvent). It has a *low* concentration of sugar (the solute).
- A **concentrated** sugar solution contains a relatively *low* concentration of water and a *high* concentration of sugar.

The cytoplasm of a cell is made up of chemicals dissolved in water inside a partially permeable cell membrane. The cytoplasm contains a fairly concentrated solution of salts and sugars. Water moves from a dilute solution (with a high concentration of water molecules) to a concentrated solution (with fewer water molecules in a given volume) across the membrane of the cell.

This special type of diffusion, where only water moves across a partially permeable membrane from a dilute solution to a concentrated solution is called **osmosis**.

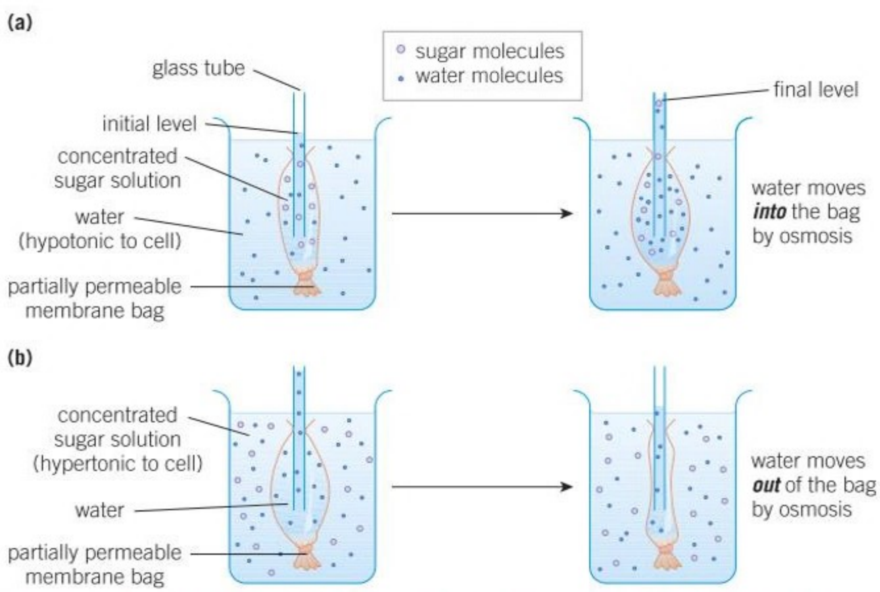


Figure 1 *A model of osmosis in a cell. In* (a) *the model cell is in a hypotonic solution. In* (b) *the model cell is in a hypertonic solution*

The concentration of solutes inside your body cells needs to stay at the same level for them to work properly. However, the concentration of the solutions outside your cells may be very different to the concentration inside them. This concentration gradient can cause water to move into or out of the cells by osmosis (see Figure 1).

- If the concentration of solutes in the solution outside the cell is **the same** as the internal concentration, the solution is **isotonic** to the cell.
- If the concentration of solutes in the solution outside the cell is **higher** than the internal concentration, the solution is **hypertonic** to the cell.
- If the concentration of solutes in the solution outside the cell is **lower** than the internal concentration, the solution is **hypotonic** to the cell.

Osmosis in animals

If a cell uses up water in its chemical reactions, the cytoplasm becomes more concentrated. The surrounding fluid becomes hypotonic to the cell and more water immediately moves in by osmosis.

If the cytoplasm becomes too dilute because more water is made in chemical reactions, the surrounding fluid becomes hypertonic to the cell and water leaves the cell by osmosis. Osmosis restores the balance in both cases.

However, osmosis can also cause big problems. If the solution outside the cell becomes much more dilute (hypotonic) than the cell contents, water will move in by osmosis. The cell will swell and may burst. If the solution outside the cell becomes much more concentrated (hypertonic) than the cell contents, water will move out of the cell by osmosis. The cytoplasm will become too concentrated and the cell will shrivel up and can no longer survive. Once you understand the effect osmosis can have on cells, the importance of maintaining constant internal conditions becomes clear.

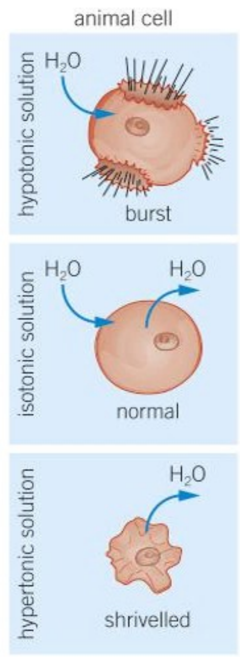


Figure 2 *Osmosis can have a dramatic effect on animal cells*

Study tip

When writing about osmosis, be careful to specify whether it is the concentration of water or of solutes that you are referring to.

Make sure you understand exactly what is meant by the terms isotonic, hypertonic, and hypotonic.

1 a Explain the difference between osmosis and diffusion. [2 marks]
b Explain how osmosis helps to maintain the cytoplasm of plant and body cells at a specific concentration. [2 marks]

2 a Define the following terms:
i isotonic solution [1 mark]
ii hypotonic solution [1 mark]
iii hypertonic solution. [1 mark]
b Explain why it is so important for the cells of the human body that the solute concentration of the fluid surrounding the cells is kept as constant as possible. [4 marks]

3 Animals that live in fresh water have a constant problem with their water balance. The single-celled organism called *Amoeba* has a special vacuole in its cell. The vacuole 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. [4 marks]

Key points

- Osmosis is a special case of diffusion. It is the movement of water from a dilute to a more concentrated solution through a partially permeable membrane that allows water to pass through.
- Differences in the concentrations of solutions inside and outside a cell cause water to move into or out of the cell by osmosis.
- Animal cells can be damaged if the concentration outside the cell changes dramatically.

The basis of many experiments is to put plant tissue into different concentrations of salt solutions or sugar solutions. You can even use squash to give you the sugar solution. If plant tissue is placed in a hypotonic solution, water will move in to the cells by osmosis. If it is placed in a hypertonic solution, water will move out by osmosis. These changes can be measured by the effect they have on the tissue sample.

- Suggest why salt and sugar are used in osmosis experiments. How could you decide which gives the clearest results?
- Potato is commonly used as the experimental plant tissue. It can be cut into cylinders, rectangular 'chips' or smaller discs. Suggest why potato is so often used as a test plant tissue.
- Sweet potato and beetroot are other common sources of plant tissue for osmosis experiments – suggest possible advantages and disadvantages of using them. How could you determine which is the best experimental plant tissue?

Measuring changes in mass is a widely used method for investigating the uptake or loss of water from plant tissues by osmosis. You must take care not to include any liquid left on the outside of the plant tissue in your measurements as this can have a big effect on your results.

- Evaluate the possible advantages and disadvantages of cylinders, chips, or discs for assessing the effect of osmosis on plant tissue. How would you determine which method is the most effective?
- Investigate the effect of surface area on osmosis.
- Explain how you think the surface area of the plant tissue samples might affect osmosis.
- Plan an investigation to see if your ideas are right.
- Show your plan to your teacher and then carry out your investigation.

Safety: Take care when using cutting instruments.

Go further

Scientists have discovered ways of measuring the turgor pressure inside individual cells using very tiny probes. The pressures inside the root or leaf cell of a plant are far higher than human blood pressure, or even the pressure in a car tyre.

1 Define the term osmosis. [1 mark]

2 Students carried out an investigation into the effects of osmosis on plant tissues, placing three sets of beetroot cylinders in three different sugar solutions for 30 mins. One set had gained mass, another lost mass and the third set did not change. One student thought the last experiment hadn't worked. Another disagreed. Explain the results in terms of osmosis in plant cells. [6 marks]

3 Suggest and explain why osmosis is so important in the structural support systems of plants. [6 marks]

Key points

- Osmosis is important to maintain turgor in plant cells.
- There are a variety of practical investigations that can be used to show the effect of osmosis on plant tissues.

B1.9 Active transport

Learning objectives

After this topic, you should know:

- how active transport works
- the importance of active transport in cells.

People with cystic fibrosis have thick, sticky mucus in their lungs, gut and reproductive systems. This causes many different health problems and it happens because an active transport system in their mucus-producing cells does not work properly. Sometimes diffusion and osmosis are not enough.

All cells need to move substances in and out. Water often moves across the cell boundaries by osmosis. Dissolved substances also need to move in and out of cells. There are two main ways in which this happens:

- Substances move by diffusion, down a concentration gradient. This must be in the right direction to be useful to the cells.
- Sometimes the substances needed by a cell have to be moved against a concentration gradient, across a partially permeable membrane. This needs a special process called **active transport**.

Moving substances by active transport

Active transport allows cells to move substances from an area of low concentration to an area of high concentration. This movement is *against* the concentration gradient. As a result, cells can absorb ions from very dilute solutions. It also enables cells to move substances, such as sugars and ions, from one place to another through the cell membrane.

Energy is needed for the active transport system to carry a molecule across the membrane and then return to its original position. This energy is produced during cell respiration. Scientists have shown in a number of different cells that the rate of respiration and the rate of active transport are closely linked (Figure 1).

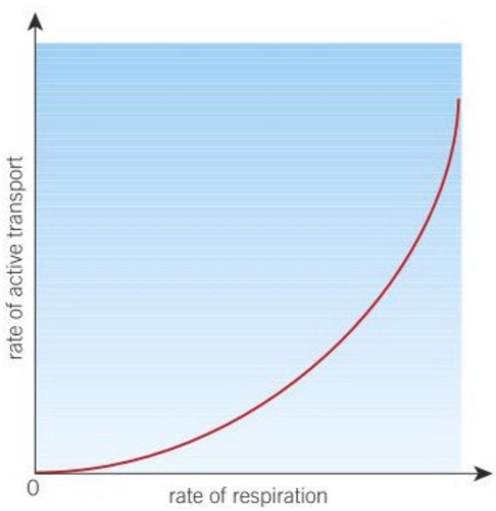


Figure 1 *The rate of active transport depends on the rate of respiration*

In other words, if a cell respires and releases a lot of energy, it can carry out lots of active transport. Examples include root hair cells in plants and the cells lining your gut. Cells involved in a lot of active transport usually have many mitochondria to release the energy they need.

The importance of active transport

Active transport is widely used in cells. There are some situations where it is particularly important. For example, mineral ions in the soil, such as nitrate ions, are usually found in very dilute solutions. These solutions are more dilute than the solution within the plant root hair cells. By using active transport, plants can absorb these mineral ions, even though it is against a concentration gradient (see Figure 2).

Sugar, such as glucose, is always actively absorbed out of your gut and kidney tubules into your blood. This is often done against a large concentration gradient.

For example, glucose is needed for cell respiration so it is important to get as much as possible out of the gut. The concentration of glucose in your blood is kept steady, so sometimes it is higher than the concentration of glucose in your gut. When this happens, active transport is used to move the glucose from your gut into your blood against the concentration gradient.

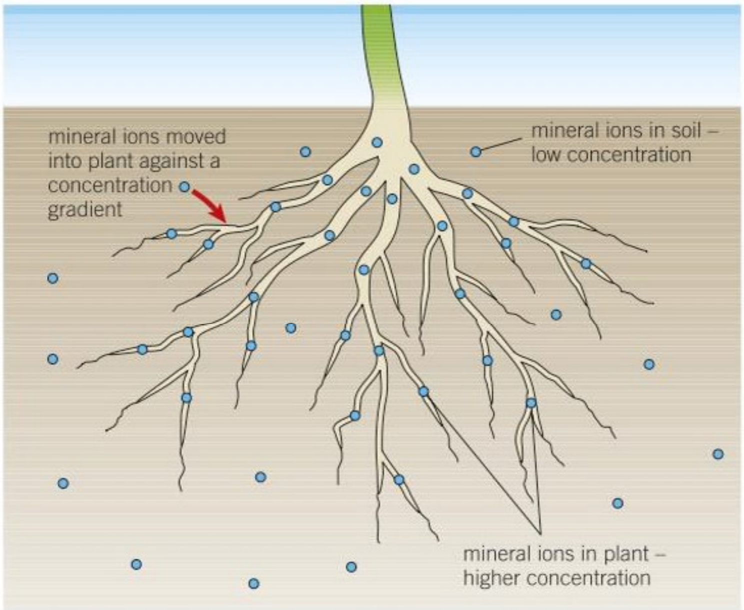


Figure 2 *Plants use active transport to move mineral ions from the soil into the roots against a concentration gradient*

Figure 3 *Some crocodiles have special salt glands in their tongues. These remove excess salt from the body against the concentration gradient by active transport. That's why members of the crocodile species Crocodylus porosus can live in estuaries and even the sea*

1 Describe how active transport works in a cell. [4 marks]

2 **a** Describe how active transport differs from diffusion and osmosis. [3 marks]

b Explain why cells that carry out a lot of active transport also usually have many mitochondria. [2 marks]

3 Explain fully why active transport is so important to:

a marine birds such as albatrosses that have special salt glands producing very salty liquid [2 marks]

b plants. [3 marks]

Synoptic links

You can find out more about cystic fibrosis in Topic B14.7, and about the absorption of glucose in the gut in Topic B3.6 and about the absorption of solutes in the kidney in Topic B12.3.

Study tip

Do not refer to movement *along* a concentration gradient. Always refer to movement as *down* a concentration gradient (from higher to lower) for diffusion or osmosis and *against* a concentration gradient (from lower to higher) for active transport.

Key points

- Active transport moves substances from a more dilute solution to a more concentrated solution (against a concentration gradient).
- Active transport uses energy released from food in respiration to provide the energy required.
- Active transport allows plant root hairs to absorb mineral ions required for healthy growth from very dilute solutions in the soil against a concentration gradient.
- Active transport enables sugar molecules used for cell respiration to be absorbed from lower concentrations in the gut into the blood where the concentration of sugar is higher.

B1.10 Exchanging materials

Learning objectives

After this topic, you should know:

- how the surface area to volume ratio varies depending on the size of an organism
- why large multicellular organisms need special systems for exchanging materials with the environment.

Synoptic links

You will use the idea of surface area to volume ratio when you study the adaptations of animals and plants for living in a variety of different habitats in Topics B16.7 and B16.8.

For many single-celled organisms, diffusion, osmosis, and active transport are all that is needed to exchange materials with their environment because they have a relatively large surface area compared to the volume of the cell. This allows sufficient transport of molecules into and out of the cell to meet the needs of the organism.

Surface area to volume ratio

The surface area to volume ratio is very important in biology. It makes a big difference to the way animals can exchange substances with the environment. Surface area to volume ratio is also important when you consider how energy is transferred by living organisms, and how water evaporates from the surfaces of plants and animals.

Surface area to volume ratio

The ratio of surface area to volume falls as objects get bigger. You can see this clearly in Figure 1. In a small object, the surface area to volume (SA:V) ratio is relatively large. This means that the diffusion distances are short and that simple diffusion is sufficient for the exchange of materials.

As organisms get bigger, the surface area to volume ratio falls. As the distances between the centre of the organism and the surface get bigger, simple diffusion is no longer enough to exchange materials between the cells and the environment.

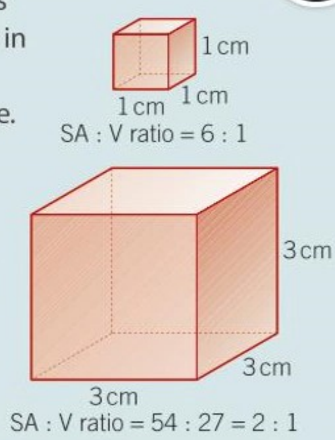


Figure 1 *Relationship of surface area to volume*

Getting bigger

As living organisms get bigger and more complex, their surface area to volume ratio gets smaller. This makes it increasingly difficult to exchange materials quickly enough with the outside world:

- Gases and food molecules can no longer reach every cell inside the organism by simple diffusion
- Metabolic waste cannot be removed fast enough to avoid poisoning the cells.

In many larger organisms, there are special surfaces where the exchange of materials takes place. These surfaces are adapted to be as effective as possible. You can find them in humans, in other animals, and in plants.

Synoptic links

You will find out much more about gas exchange in the lungs in Topic B4.5, and about the adaptations of the small intestine in Topic B3.2.

You can find out more about the transpiration stream in Topic B4.8.

Adaptations for exchanging materials

There are various adaptations to make the process of exchange more efficient. The effectiveness of an exchange surface can be increased by:

- having a large surface area over which exchange can take place
- having a thin membrane or being thin to provide a short diffusion path
- in animals, having an efficient blood supply moves the diffusing substances away from the exchange surfaces and maintains a steep concentration (diffusion) gradient
- in animals, being **ventilated** makes gas exchange more efficient by maintaining steep concentration gradients.

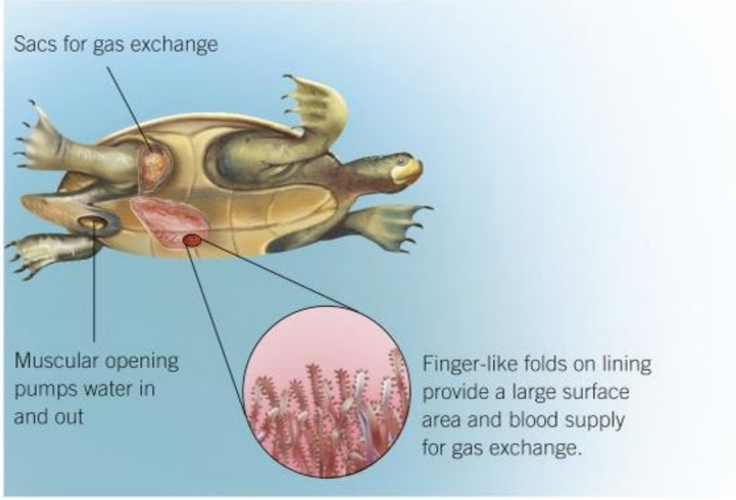


Figure 2 *Fitzroy river turtles can get oxygen from the water through a specialised excretory opening*

Examples of adaptations

Different organisms have very different adaptations for the exchange of materials. For example, the Australian Fitzroy river turtle (locally known as the bum-breathing turtle) can 'breathe' underwater (Figure 2). Inside the rear opening are two large sacs lined with finger-like folds which provide a large surface area and rich blood supply for gas exchange. The muscular opening pumps water in and out, ventilating the folds and maintaining a steep concentration gradient for gas exchange.

The human surface area to volume ratio is so low that the cells inside your body cannot possibly get the food and oxygen they need, or get rid of the waste they produce, by simple diffusion. Air is moved into and out of your lungs when you breathe, ventilating the millions of tiny air sacs called **alveoli**. The alveoli have an enormous surface area and a very rich blood supply, for effective gas exchange. The villi of the small intestine also provide a large surface area, short diffusion paths and a rich blood supply to make exchange of materials more effective.

Fish need to exchange oxygen and carbon dioxide between their blood and the water in which they swim. This happens across the gills, which are made up of stacks of thin filaments, each with a rich blood supply. Fish need a constant flow of water over their gills to maintain the concentration gradients needed for gas exchange. They get this by pumping water over the gills using a flap that covers the gills called the operculum.

Plant roots have a large surface area, made even bigger by the root hair cells, to make the uptake of water and mineral ions more efficient. Water constantly moves away from the roots in the transpiration stream, maintaining a steep concentration gradient in the cells.

Plant leaves are also modified to make gas and solute exchange as effective as possible. Flat, thin leaves, the presence of air spaces in the leaf tissues, and the **stomata** all help to provide a big surface area and maintain a steep concentration gradient for the diffusion of substances such as water, mineral ions, and carbon dioxide.

Key points

- Single-celled organisms have a relatively large surface area to volume ratio so all necessary exchanges with the environment take place over this surface.
- In multicellular organisms, many organs are specialised with effective exchange surfaces.
- Exchange surfaces usually have a large surface area and thin walls, which give short diffusion distances. In animals, exchange surfaces will have an efficient blood supply or, for gaseous exchange, be ventilated.

1 Describe two adaptations of an effective exchange surface. [2 marks]

2 Compare the gas exchange system of fish with that of the Australian Fitzroy river turtle shown in Figure 2. [5 marks]

3 **a** Explain how the surface area to volume ratio of an organism affects the way it exchanges materials with the environment. [2 marks]

b Describe the adaptations you would expect to see in effective exchange surfaces and explain the importance of each adaptation. [6 marks]