

Chapter 1

Cell structure

All living organisms are made of cells. Cells are the basic units of living things, and most scientists would agree that anything that is *not* made of a cell or cells – for example, a virus – cannot be a living organism.

Some organisms, such as bacteria, have only one cell, and are said to be **unicellular**. Others have millions of cells. Any organism that is made up of more than one cell is said to be **multicellular**.

All cells are very small, but some of them are just large enough to be seen with the naked eye. The unicellular organism *Amoeba*, for example, can just be seen as a tiny white speck floating in liquid if you shake up a culture of them inside a glass vessel. These cells are about 0.1 mm across. However, this is unusually large. Human cells are usually somewhere between 10 µm and 30 µm in diameter (see the box on page 3 for an explanation of ‘µm’). Bacterial cells are much smaller, often about 0.5 µm across. To see most cells, a microscope must be used.

Microscopes

The first microscopes were invented in the mid 17th century. They opened up a whole new world for biologists to study. Now biologists would see tiny, unicellular organisms whose existence had previously only been guessed at. They could also see, for the first time, that large organisms such as plants and animals are made up of cells.

Light microscopes

The early microscopes, like the microscopes that you will use in the laboratory, were **light microscopes**. Light microscopes use glass lenses to refract (bend) light rays and produce a magnified image of an object. Figure 1.1 shows how a light microscope works.

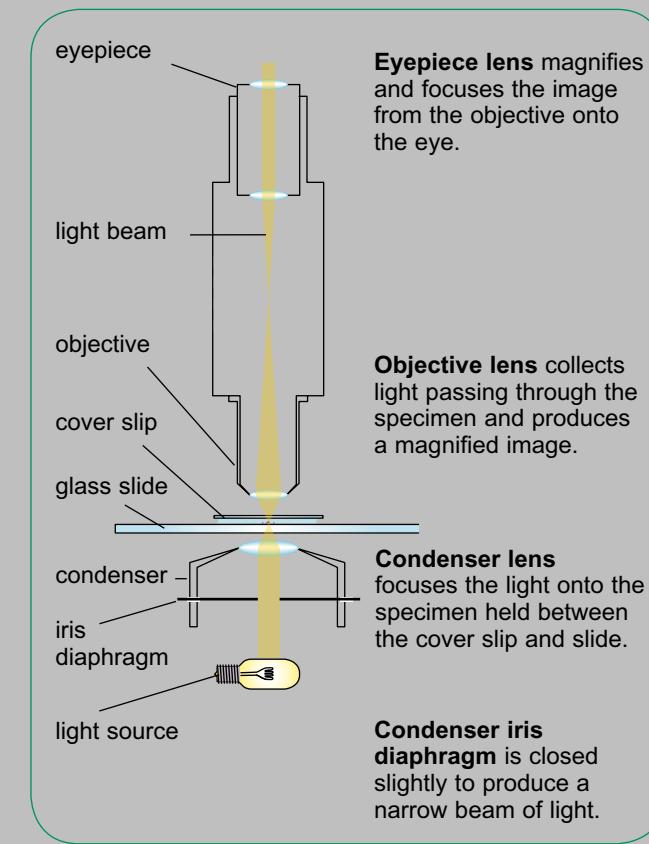


Figure 1.1 How a light microscope works.

The specimen to be observed usually needs to be very thin, and also transparent. To keep it flat, it is usually placed on a glass slide with a very thin glass coverslip on top. For a temporary slide, you can mount the specimen in a drop of water. To make a permanent slide, a liquid that solidifies to produce a clear solid is used to mount the specimen.

The slide is placed on a stage through which light shines from beneath. The light is focused onto the specimen using a **condenser lens**. The light then passes through the specimen and is captured and refracted by an **objective lens**. Most microscopes have three or four different objective lenses, which provide different fields of view and different magnifications. The greater the magnification, the smaller the field of view.

Chapter 1: Cell structure

The light rays now travel up to the **eyepiece lens**. This produces the final image, which falls onto the retina of your eye. The image can also be captured using a digital camera or video camera, and viewed or projected onto a screen.

Many biological specimens are colourless when they have been cut into very thin sections, so a **stain** is often added to make structures within the specimen easier to see (Table 1.1). Different parts of a cell, or different kinds of cells, may take up (absorb) a stain more than others. For example, a stain called methylene blue is taken up more by nuclei than by cytoplasm, so it makes a nucleus look dark blue while the cytoplasm is pale blue. Methylene blue is taken up by living cells, but many other stains cannot get through the cell membrane of a living cell and can only be used on dead cells.

Magnification

Using a microscope, or even just a hand lens, we can see biological objects looking much larger than they really are. The object is **magnified**. We can define magnification as the size of the image divided by the real size of the object.

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

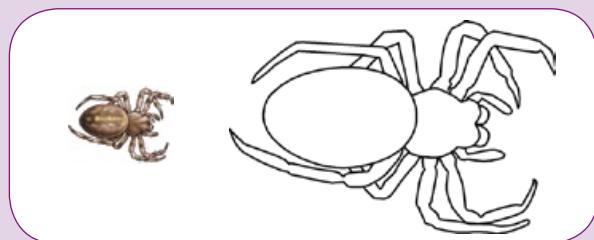
For example, we can calculate the magnification of the drawing of a spider in Worked example 1.

Worked example 1

Calculation of the magnification of a drawing.

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

Below is a ‘real’ spider and a drawing of this spider.



Step 1 Measure the length of the ‘real’ spider. You should find that it is 10 mm long. The length of the spider in the drawing is 30 mm.

Step 2 Now, substitute these numbers into the equation above:

$$\text{magnification} = \frac{30}{10} = \times 3$$

Notice the ‘×’ sign in front of the number 3. This stands for ‘times’. We say that the magnification is ‘times 3’.

Stain	Use	Colours produced
methylene blue	staining living cells	dark blue nucleus, light blue cytoplasm (in bacteria, the whole cell takes up the stain)
iodine solution	staining living plant cells	very dark blue starch grains
acidified phloroglucinol	staining lignin (the substance in the cell walls of xylem vessels)	bright red
acetic orcein	staining nuclei and chromosomes	red
eosin	staining cytoplasm and some organelles (it stains dead cells only and so can be used to distinguish between live and dead sperm cells)	pink
light green	staining plant cell walls	green

Table 1.1 Some stains commonly used in light microscopy.

SAQ

- 1 A person makes a drawing of an incisor tooth. The width of the actual tooth is 5 mm. The width of the tooth in the drawing is 12 mm. Calculate the magnification of the drawing.

Units of measurement

In biology, we often need to measure very small objects. When measuring cells or parts of cells, the most common (and useful) unit is the **micrometre**, written μm for short. The symbol μ is the Greek letter mu. One micrometre is one thousandth of a millimetre.

Even smaller structures, such as the organelles within cells, are measured using even smaller units. These are **nanometres**, written nm for short. One nanometre is one thousandth of a micrometre.

$$1 \mu\text{m} = \frac{1}{1000} \text{ mm}$$

This can also be written 1×10^{-3} mm, or 1×10^{-6} m.

$$1 \text{ nm} = \frac{1}{1000} \mu\text{m}$$

This can also be written 1×10^{-6} mm, or 1×10^{-9} m.

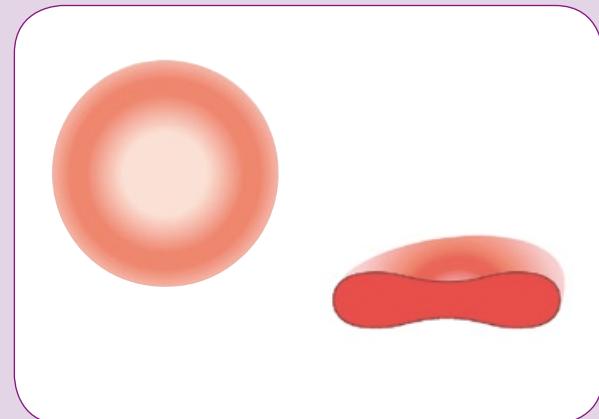
Often, we are dealing with small units, such as μm . It is important to make sure all your measurements are in the same units. It is often best to convert everything into μm before you begin your calculation, as shown in Worked example 2.

SAQ

- 2 This is a **photomicrograph** – a photograph taken using a light microscope. The actual maximum diameter of the cell is 50 μm . Calculate the magnification of the photomicrograph.

Worked example 2

Calculation of magnification and conversion of units.



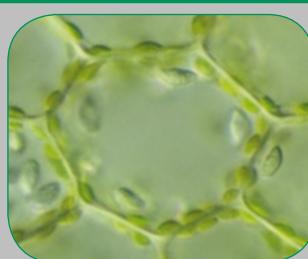
Let us say that we know that the real diameter of a red blood cell is 7 μm and we have been asked to calculate the magnification of the above diagram.

Step 1 Measure the diameter of the cell in the diagram. You should find that it is 30 mm.

Step 2 We have been given its real size in μm , so we need to convert the 30 mm to μm . There are 1000 μm in 1 mm, so 30 mm is $30 \times 1000 \mu\text{m}$.

Step 3 Now we can put the numbers into the equation:

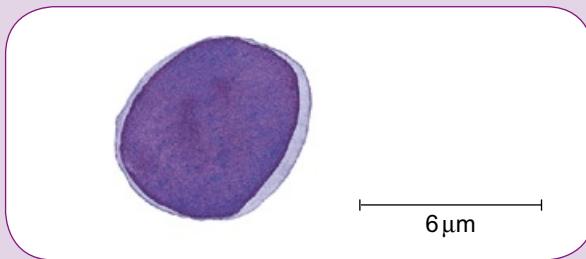
$$\begin{aligned} \text{magnification} &= \frac{\text{size of image}}{\text{real size of object}} \\ &= \frac{30 \times 1000}{7} \\ &= \times 4286 \end{aligned}$$



Worked example 3

Calculating magnification from a scale bar.

This diagram shows a lymphocyte.



We can calculate the magnification of the image of the lymphocyte without needing to measure it or to know anything about its original size. We can simply use the **scale bar**. All you need to do is to measure the length of the scale bar and then substitute its measured length and the length that it represents into the equation. (Remember to convert your measurement to μm .)

Step 1 Measure the scale bar. Here, it is 24 mm.

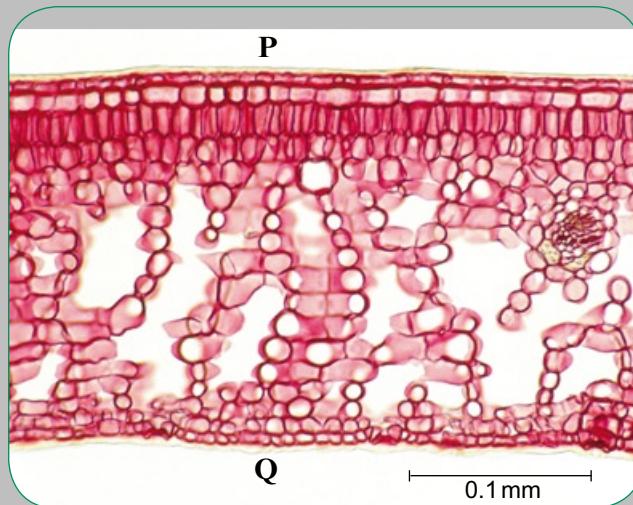
Step 2 Substitute into the equation.

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

$$\begin{aligned}\text{magnification} &= \frac{\text{the length of the scale bar}}{\text{the length the scale bar represents}} \\ &= \frac{24 \times 1000 \mu\text{m}}{6 \mu\text{m}} \\ &= \times 4000\end{aligned}$$

SAQ

- 3 This is a photomicrograph of a transverse section through a leaf. Use the scale bar to calculate the magnification of the photomicrograph.



- 4 If we know the magnification, we can turn the equation around so that we can calculate the real size of something from its magnified image.

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

Use your value for the magnification of the photomicrograph above to calculate the thickness of the leaf between P and Q.

Resolution

Light microscopes have one major disadvantage. They are unable to show objects that are smaller than about 200 nm across ($1 \text{ nm} = \frac{1}{1000} \mu\text{m}$).

You might just be able to pick out such a structure, but it would appear only as a shapeless blur.

The degree of detail that can be seen in an image is known as the **resolution**. The tinier the individual points of information on an image – for example, the pixels on a monitor – the better the resolution. To see the very smallest objects, you need a microscope with very high resolution.

The absolute limit of resolution of a microscope is determined by the wavelength of the radiation that it uses. As a rule of thumb, the limit of resolution is about 0.45 times the wavelength. Shorter wavelengths give the best resolution.

The shortest wavelength of visible light is blue light, and it has a wavelength of about 450 nm. So the smallest objects we can expect to be able to distinguish using a light microscope are approximately $0.45 \times 450 \text{ nm}$, which is around 200 nm. This is the best resolution we can ever expect to achieve using a light microscope. In practice, it is never quite as good as this.

It's important to understand that resolution is not the same as magnification (Figure 1.2). You could project an image from a light microscope onto an enormous screen, so that it is hugely magnified. There is no limit to how much you could magnify it. But your huge image will just look like a huge blur. There won't be any more 'pixels' in your image – just the same ones that were always there, blown up larger.

Magnification with no change in resolution

This is a photograph of a chloroplast in a plant cell taken with an electron microscope.



The photograph is magnified $\times 9$. But there is no extra detail in the photograph. There has been no increase in resolution.



Increase in resolution with no change in magnification



The resolution of the image is increased $\times 10$, by having 10 dots of visual information in each one of the dots (squares) shown on the left. Much more detail of the internal structure of the chloroplast is now shown.



Figure 1.2 Explaining the difference between magnification and resolution.

Electron microscopes

Light is part of the electromagnetic spectrum (Figure 1.3). To get around the limit of resolution imposed by the use of light rays, we can use a different type of wave with a shorter wavelength.

Electron microscopes use beams of electrons instead of light rays (Figure 1.4 and Figure 1.6). Electron beams have much shorter wavelengths than light rays. They therefore have much higher resolution, typically about 400 times better than a light microscope. Using an electron microscope, we can distinguish objects that are only 0.5 nm apart. This means that we can magnify things much more than with a light microscope and still obtain a clear image. With a light microscope, because of the relatively poor resolution, it is only useful to magnify an image up to about 1400 times. With an electron microscope, images remain clear up to a magnification of about 300 000 times.

Some electron microscopes work in a similar way to a light microscope, passing electrons through a thin specimen. They are called **transmission electron microscopes**, TEM for short, and produce images like the one in Figure 1.13.

As with light microscopes, the specimens to be viewed need to be very thin, and to be stained so that the different parts show up clearly in the image that is produced. In electron microscopy, the ‘stains’ are usually heavy metals, such as lead or osmium (Figure 1.5). Ions of these metals are taken up by some parts of the cells more than others.

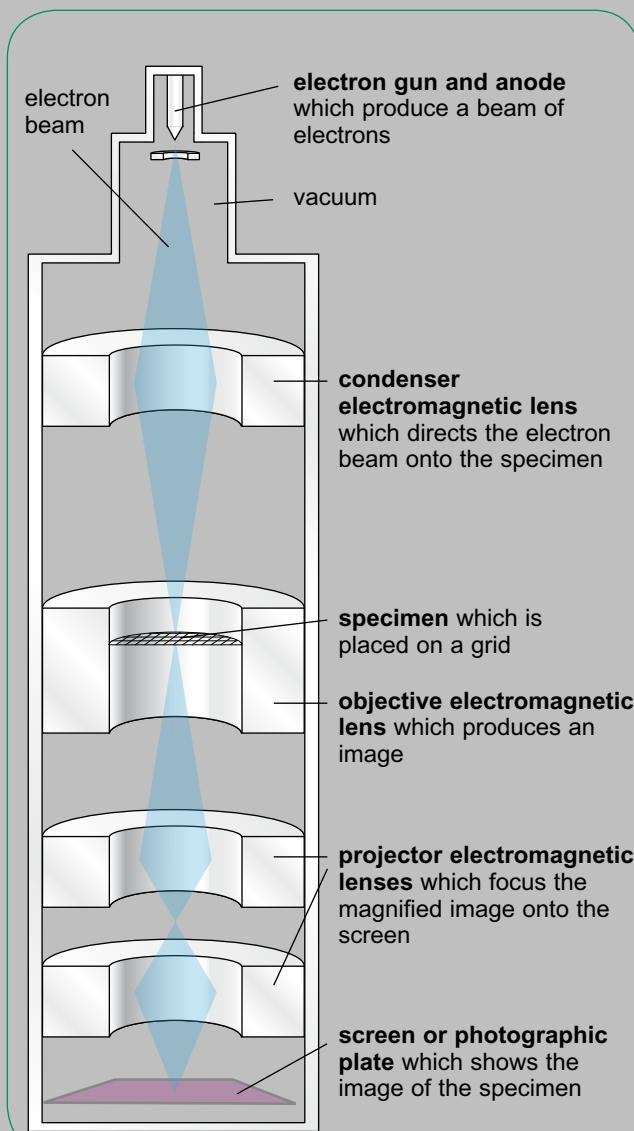


Figure 1.4 How an electron microscope works.

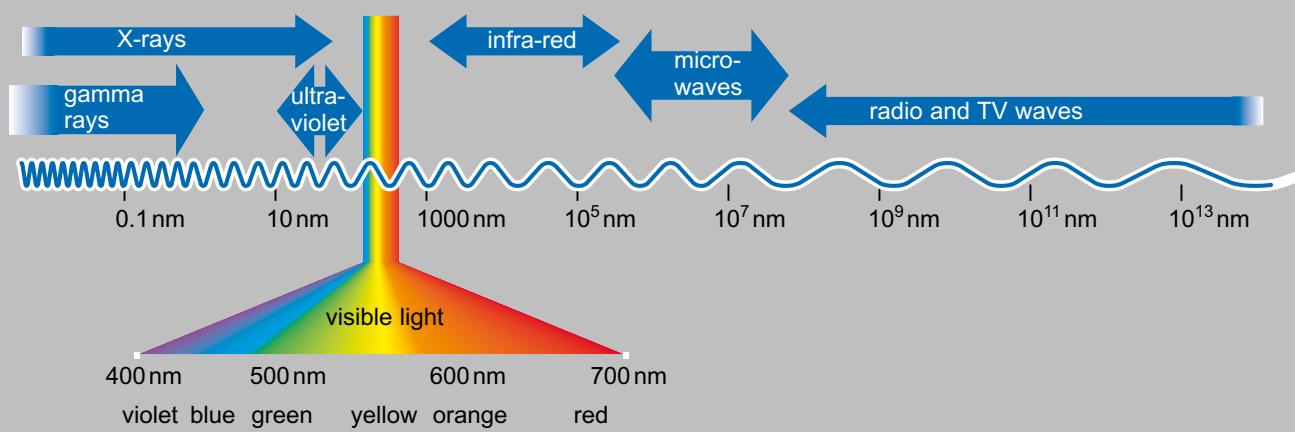


Figure 1.3 The electromagnetic spectrum.

The ions are large and positively charged. The negatively charged electrons do not pass through them, and so do not arrive on the screen. The screen therefore stays dark in these areas, so the structures that have taken up the stains look darker than other areas.

Scanning electron microscopes work by bouncing electron beams off the surface of an object. They give a three-dimensional image, like the one in Figure 1.27. A scanning electron microscope, or SEM, can provide images that can be usefully magnified to almost the same extent as TEM images.

The original images produced by an electron microscope are in black, white and grey only, but false colours are often added using a computer, to make the images look more eye-catching and to help non-specialists to identify the different structures that are visible.



Figure 1.6 Using an electron microscope.

Figure 1.5 These insects are being prepared for viewing in a scanning electron microscope, by having a thin, even layer of gold spattered over them. Gold has large atoms from which electrons will bounce off, giving a clear image of the surface of the insects' bodies.

SAQ

5 Copy and complete the table.

Type of microscope	Best resolution that can be achieved	Best effective magnification that can be achieved
light microscope		
transmission electron microscope		
scanning electron microscope		

Cells

Appearance of cells seen with a light microscope

You are probably already familiar with the structure of animal and plant cells, as they are seen when we use a light microscope. Figure 1.7 is a

photomicrograph of an animal cell, and Figure 1.9 is a photomicrograph of a plant cell.

Figure 1.8 is a diagram showing the structures that are visible in an animal cell using a light microscope, and Figure 1.10 is a similar diagram of a plant cell. In practice, you would probably not see all of these things at once in any one cell.

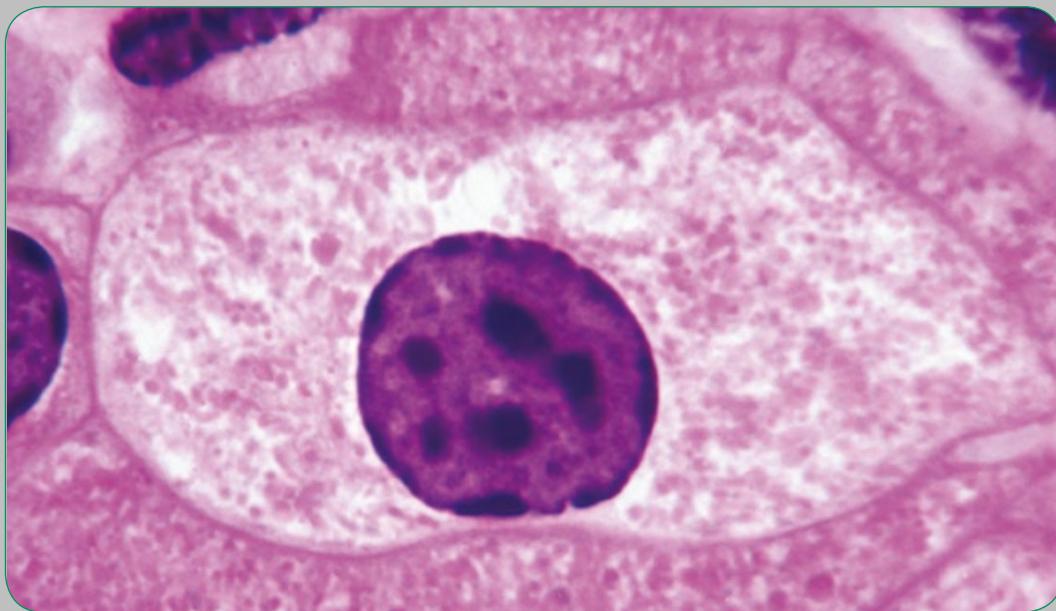


Figure 1.7 Photomicrograph of a stained animal cell ($\times 1800$).

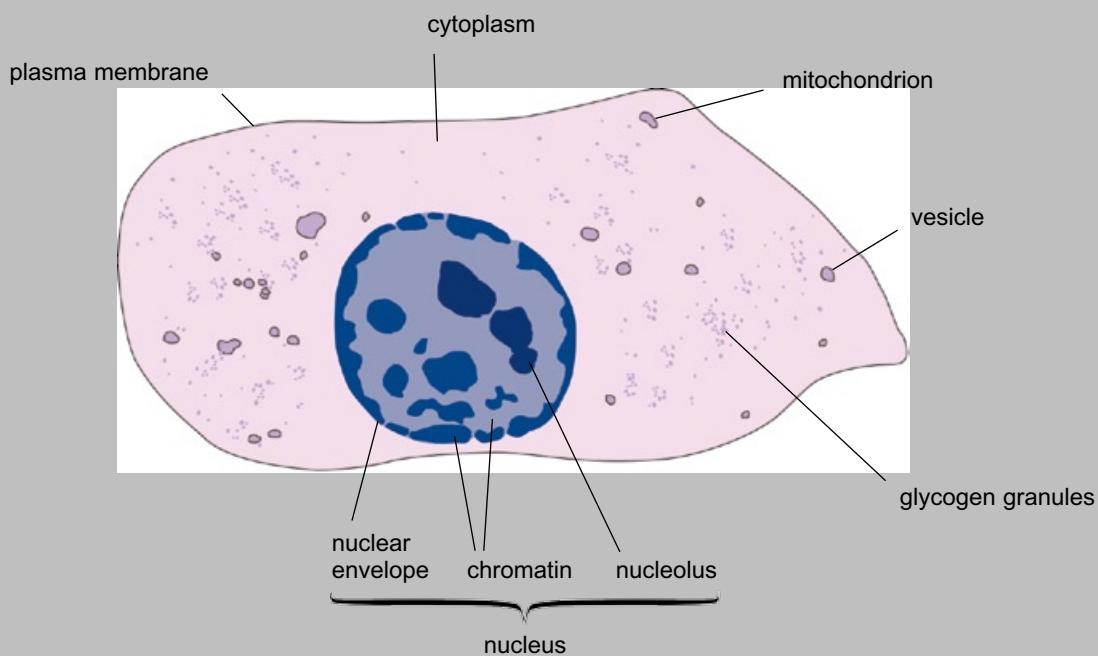


Figure 1.8 A diagram of an animal cell as it appears using a light microscope.



Figure 1.9 Photomicrograph of a cell in a moss leaf ($\times 750$).

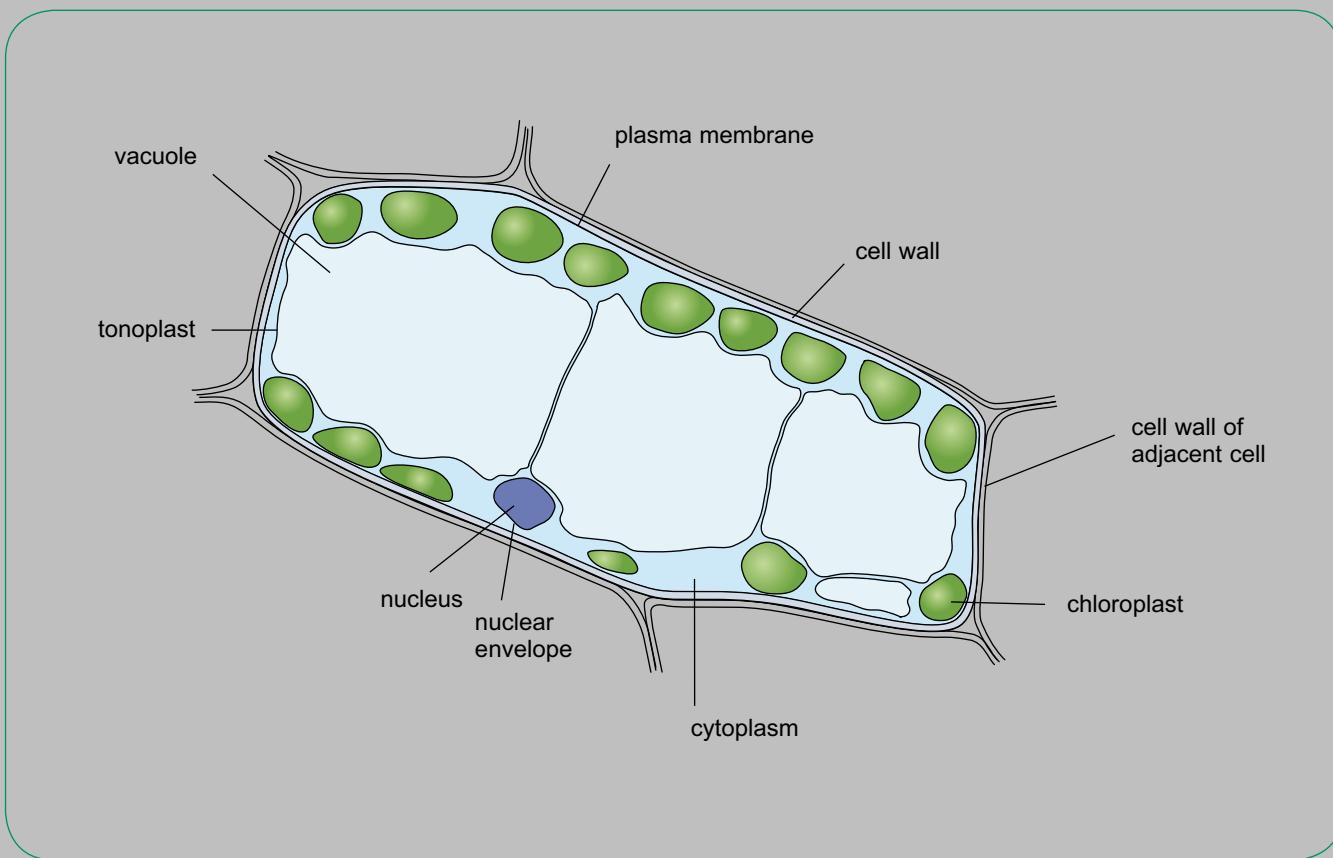


Figure 1.10 A diagram of a plant cell as it appears using a light microscope.

Appearance of cells seen with an electron microscope

As we have seen, electron microscopes are able to resolve much smaller structures than light microscopes. The structure that we can see when we use an electron microscope is called **ultrastructure**.

Figure 1.11 and Figure 1.12 are stylised diagrams summarising the ultrastructure of a typical animal cell and a typical plant cell. Figure 1.13 and Figure 1.15 are electron micrographs of an animal cell and a plant cell. Figure 1.14 and Figure 1.16 are diagrams based on these electron micrographs.

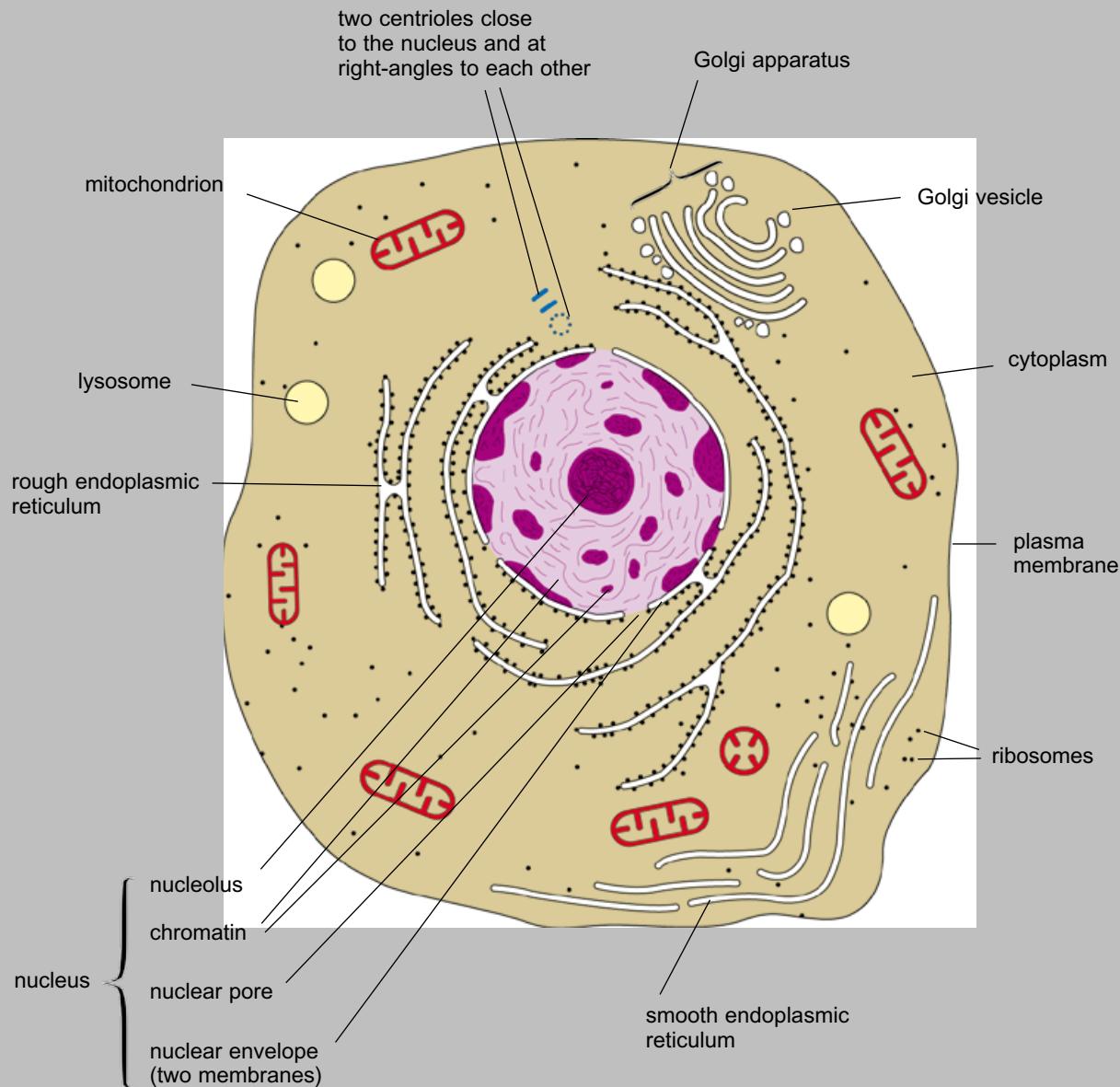


Figure 1.11 Ultrastructure of an animal cell.

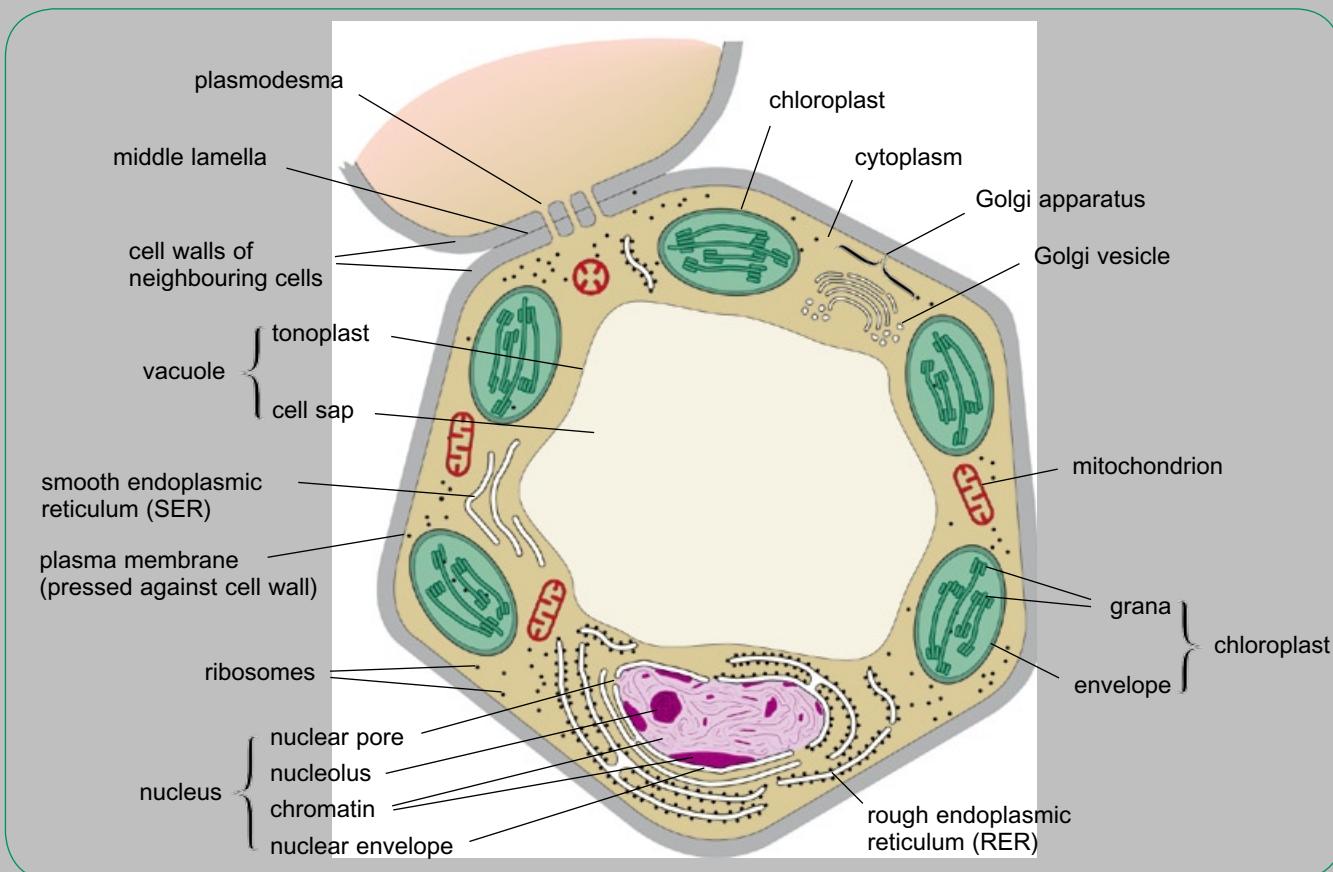


Figure 1.12 Ultrastructure of a plant cell.

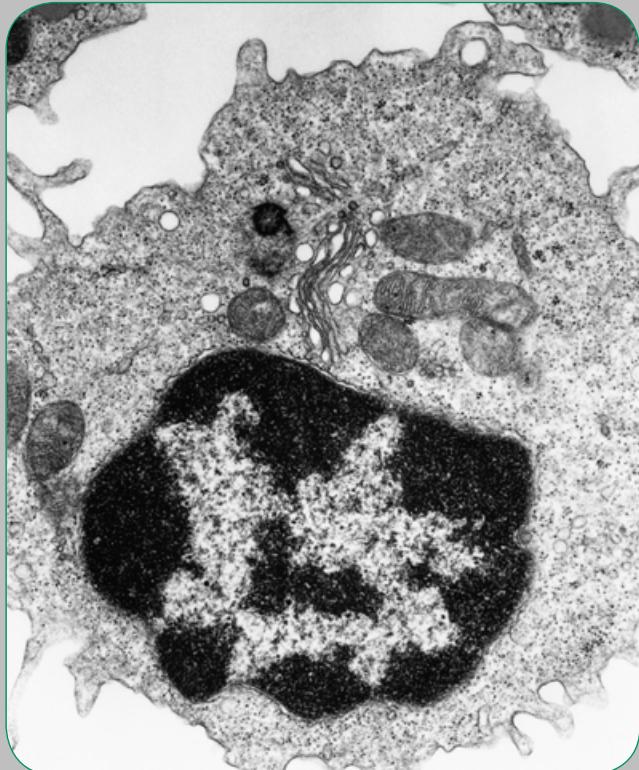


Figure 1.13 Transmission electron micrograph of a white blood cell ($\times 15000$).

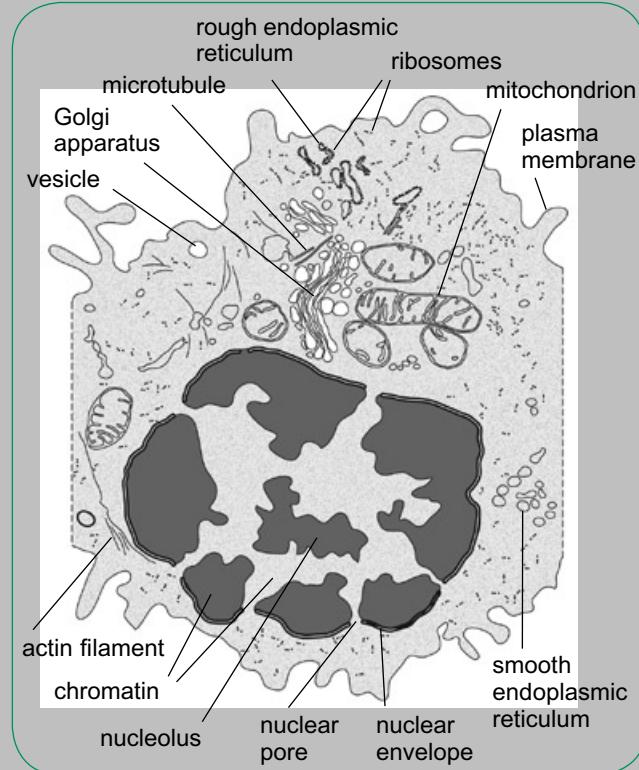


Figure 1.14 Drawing of an animal cell made from the electron micrograph in Figure 1.13.

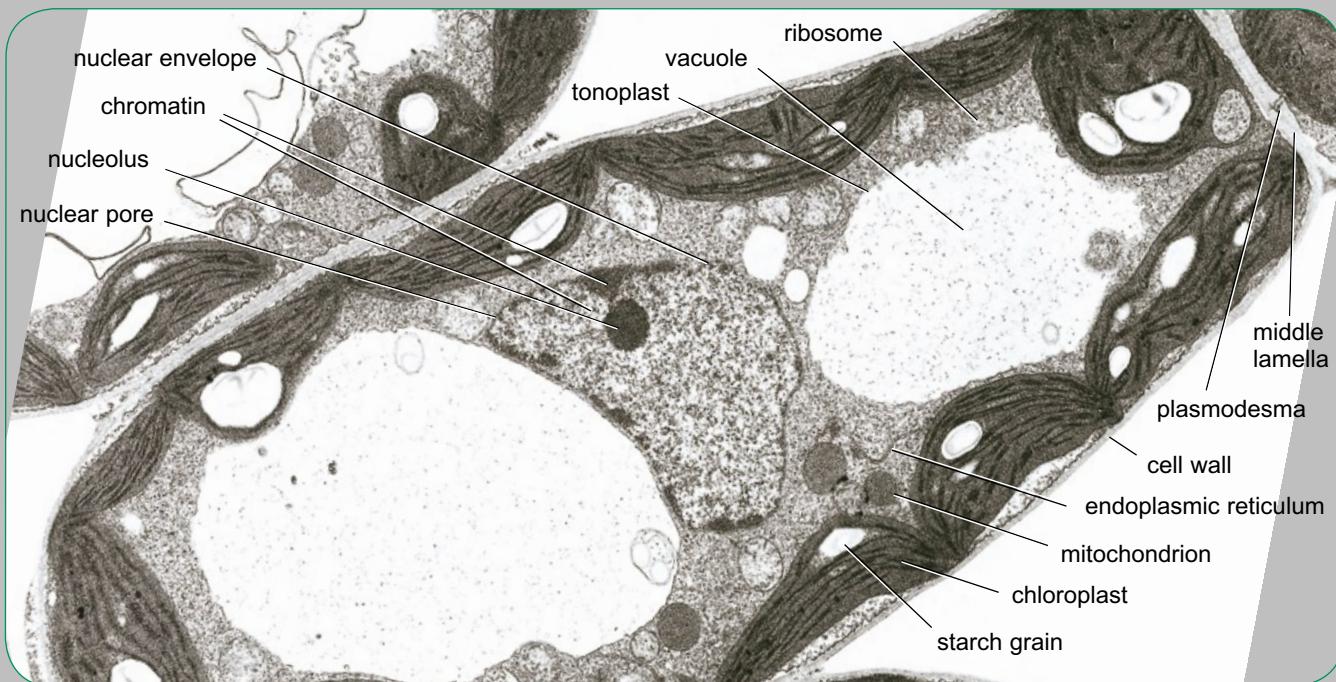


Figure 1.15 Electron micrograph of a plant cell ($\times 5600$).

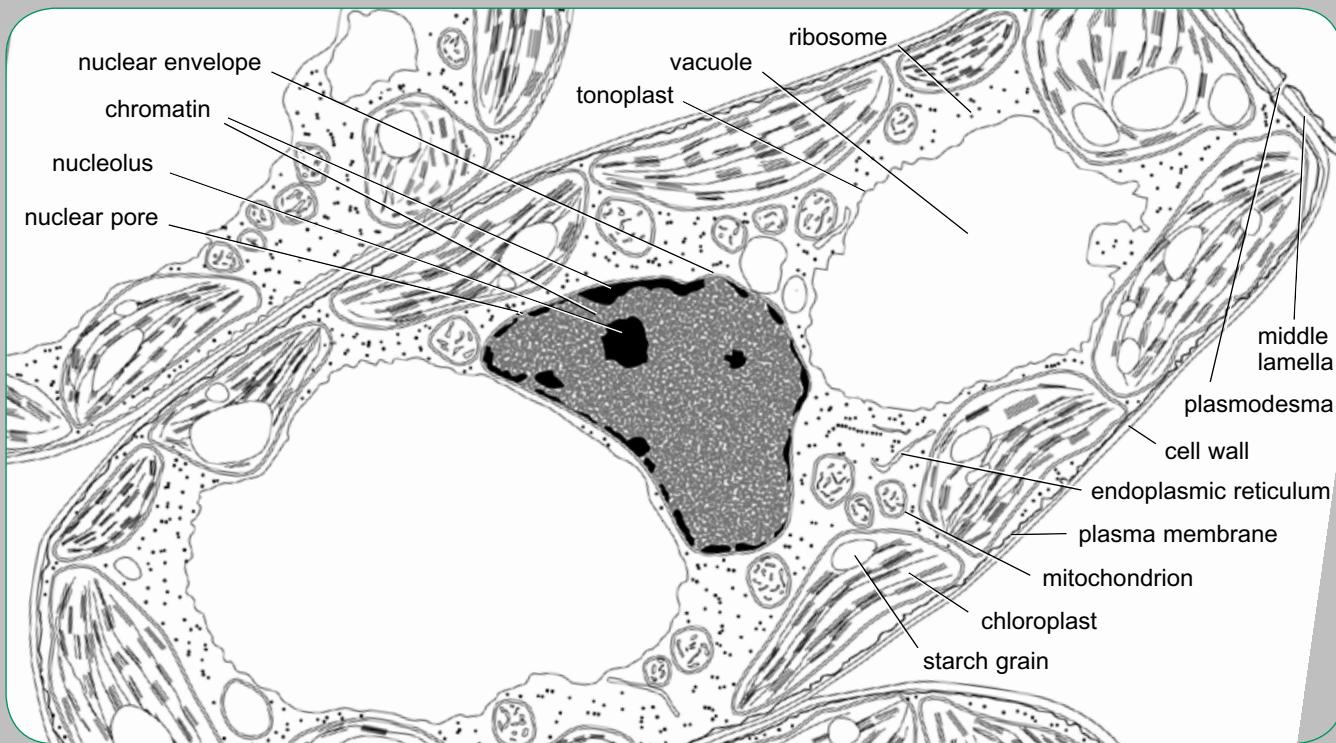


Figure 1.16 Drawing of a plant cell made from the electron micrograph in Figure 1.15.

SAQ

6 State whether the electron micrographs in Figure 1.13 and Figure 1.15 were made using a transmission electron microscope (TEM) or a scanning electron microscope (SEM). How can you tell?

7 Make a list of all the structures within a cell that are visible with an electron microscope but cannot be clearly seen with a light microscope.

Structure and function of organelles

The different structures that are found within a cell are known as **organelles**.

Nucleus

Almost all cells have a **nucleus**. Two important exceptions are red blood cells in mammals, and phloem sieve tubes in plants.

The nucleus is normally the largest cell organelle. It has a tendency to take up stains more readily than the cytoplasm, and so usually appears as a dark area (Figure 1.17).

The nucleus is surrounded by two membranes with a small gap between them. The pair of membranes is known as the **nuclear envelope**. There are small gaps all over the envelope, called **nuclear pores**.

The nucleus contains **chromosomes**.

Chromosomes are long molecules of DNA. In a non-dividing cell, they are too thin to be visible as individual chromosomes, but form a tangle known as **chromatin**, often darkly stained.

DNA carries a code that instructs the cell about making proteins, and the DNA in the lighter-staining parts of the chromatin can be used for transcription, the first stage of protein synthesis. During transcription, the information on DNA is

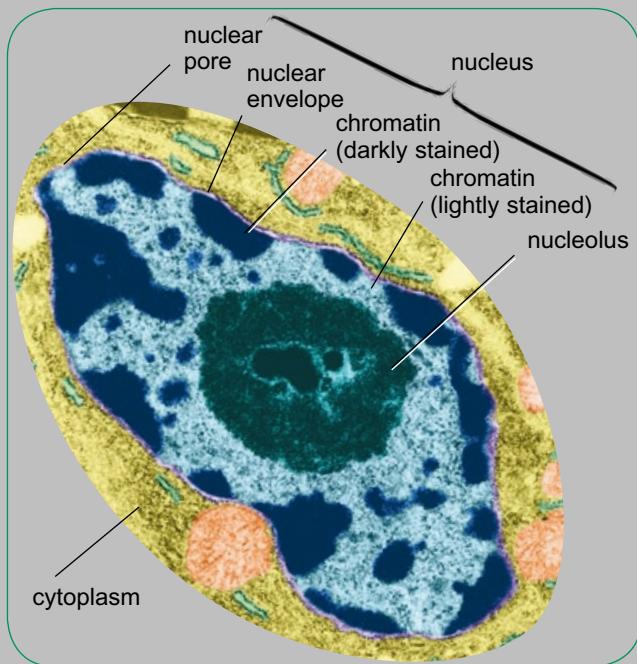


Figure 1.17 Transmission electron micrograph of a nucleus ($\times 10\,000$).

copied onto molecules of messenger RNA, which travel out of the nucleus, through the nuclear pores, into the cytoplasm.

An especially darkly staining area in the nucleus, the **nucleolus**, contains DNA that is being used to make **ribosomes**, the tiny organelles where protein synthesis takes place.

Endoplasmic reticulum

Within the cytoplasm of every eukaryotic cell, there is a network of membranes, known as the **endoplasmic reticulum**. Some of these membranes have ribosomes attached to them, forming **rough endoplasmic reticulum**, RER for short (Figure 1.18). Some do not, and these form **smooth endoplasmic reticulum**, SER. The RER is usually continuous with the nuclear envelope.

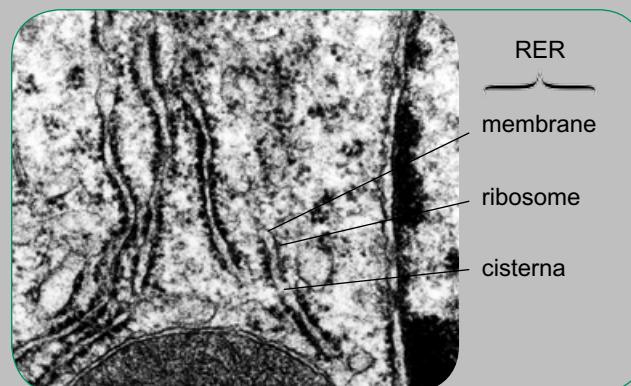


Figure 1.18 Transmission electron micrograph showing endoplasmic reticulum ($\times 40\,000$).

The enclosed spaces formed by the membranes are called **cisternae**. The membranes keep these spaces isolated from the cytoplasm.

RER is where most protein synthesis takes place. Protein synthesis happens on the ribosomes that are attached to the membranes. As the protein molecules are made, they collect inside the cisternae. From here, they can be transported to other areas in the cell – to the Golgi apparatus, for example (page 14).

SER has different roles in different cells. For example, in cells in the ovary and testis it is the site of production of steroid hormones such as oestrogen and testosterone. In liver cells, it is the place where toxins are broken down and made harmless.

Golgi apparatus

In many cells, a stack of curved membranes is visible, enclosing a series of flattened sacs. This is the **Golgi apparatus** (Figure 1.19). Some cells have several Golgi apparatuses.

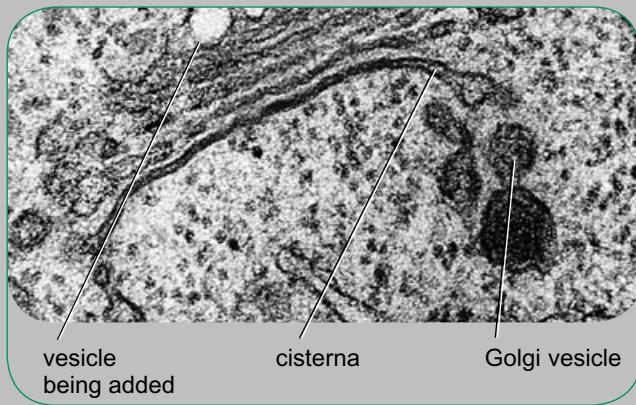


Figure 1.19 Transmission electron micrograph showing a Golgi apparatus ($\times 35\,000$).

The Golgi apparatus is not a stable structure; it is constantly changing. At one side, tiny membrane-bound **vesicles** move towards the Golgi apparatus and fuse together, forming a new layer to the stack. At the other side, the sacs break down, forming vesicles that move away from the Golgi apparatus (Figure 1.20).

The vesicles that fuse with the Golgi apparatus have come from the endoplasmic reticulum. They contain proteins that were made there. In the Golgi apparatus, these proteins are packaged and processed, changing them into the required product.

Some of the processed proteins are then transported, in the vesicles that bud off from the Golgi apparatus, to the plasma membrane. Here, the vesicles fuse with the membrane and deposit the proteins outside the cell, in a process called **exocytosis**. The production of useful substances in a cell and their subsequent release from it is called **secretion**.

Some vesicles, however, remain in the cell. Some of these contain proteins that function as digestive enzymes, and such vesicles are called **lysosomes**.

Lysosomes

Lysosomes are tiny bags of digestive enzymes. They are surrounded by a single membrane. They are usually about $0.5\,\mu\text{m}$ in diameter. Their main function is to fuse with other vesicles in the cell that contain something that needs to be digested – for example, a bacterium which has been brought into the cell by endocytosis (Chapter 2). They also help to destroy worn-out or unwanted organelles within the cell. The enzymes in the lysosome break down the large molecules in the bacterium or organelle, producing soluble substances that can disperse into the cytoplasm. The head of a sperm cell contains a special type of lysosome called an **acrosome**, whose enzymes digest a pathway into an egg just before fertilisation takes place.

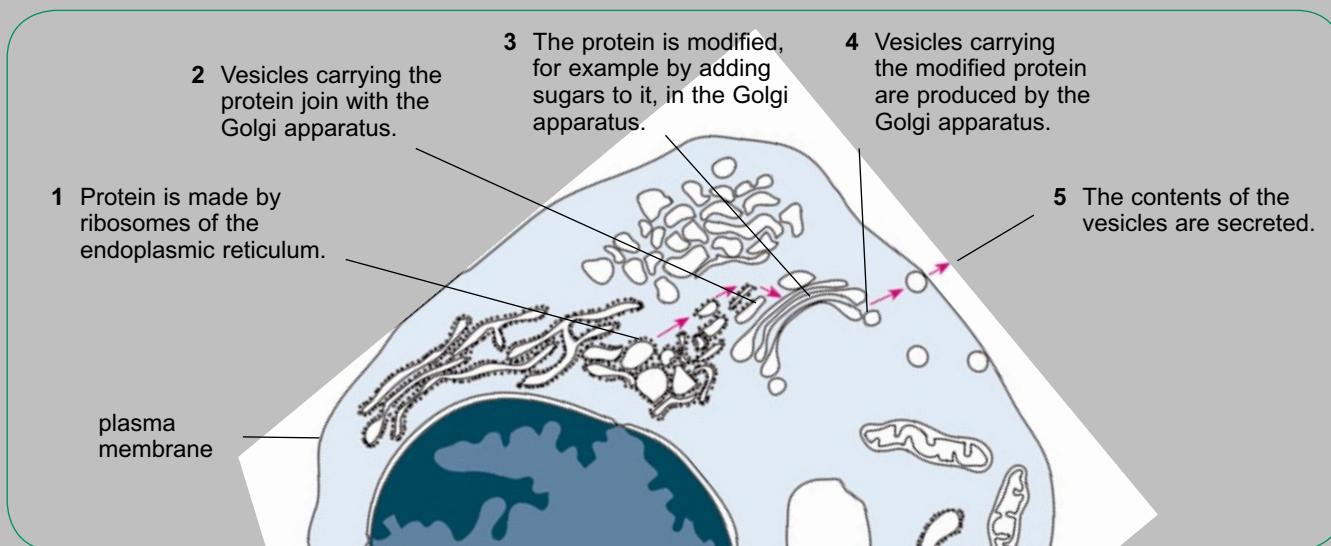


Figure 1.20 Function of the Golgi apparatus.

Chloroplasts

Chloroplasts are found in some plant cells, but never in animal cells (Figure 1.21). They are the site of photosynthesis.

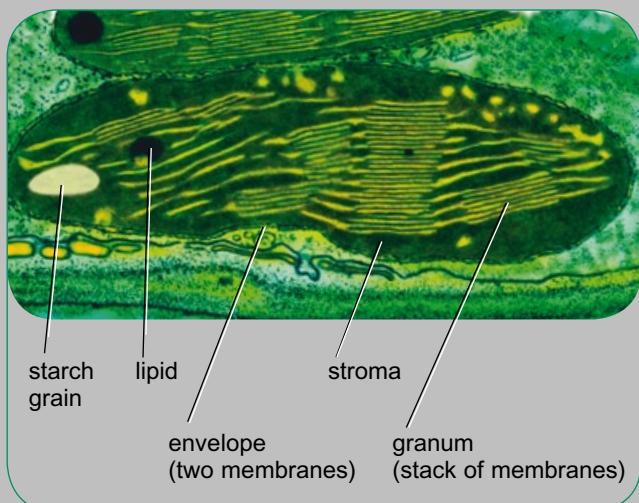


Figure 1.21 Transmission electron micrograph of a chloroplast ($\times 27\,000$).

A chloroplast has a double membrane, called an **envelope**, surrounding it. These membranes isolate the reactions that take place inside the chloroplast from the rest of the cell.

Inside the chloroplast, there are membranes called **grana** (singular: **granum**). In places, the grana form stacks called **thylakoids**. The grana contain chlorophyll, and this is where the light-dependent reactions of photosynthesis take place. In these reactions, light energy is captured by chlorophyll and used to split water molecules to provide hydrogen ions, which are then used to make ATP and a substance called reduced NADP. The ATP and reduced NADP are then used to make carbohydrates, using carbon dioxide from the air, in the light-independent reactions. The light-independent reactions take place in the ‘background material’ of the chloroplast, called the **stroma**.

Chloroplasts often contain **starch grains**. Starch is a carbohydrate that is used as an energy store in plants.

Mitochondria

Mitochondria are found in both plant and animal cells. Like chloroplasts, they are surrounded by a double membrane, also known as an envelope (Figure 1.22).

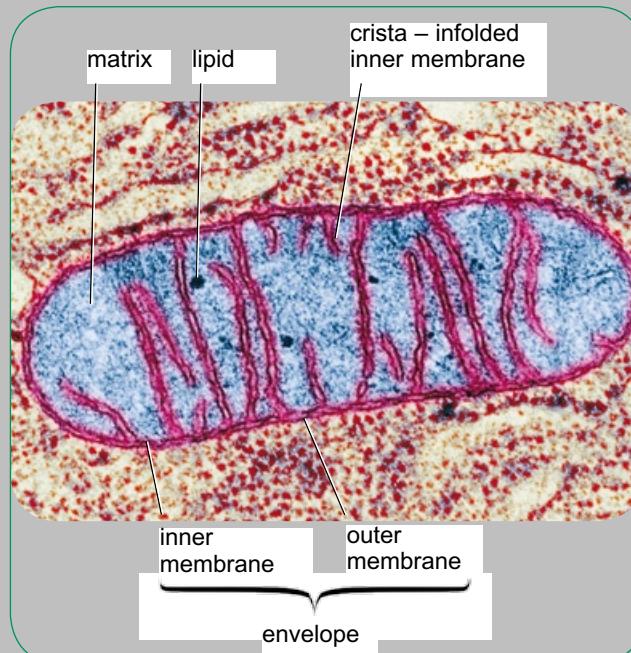


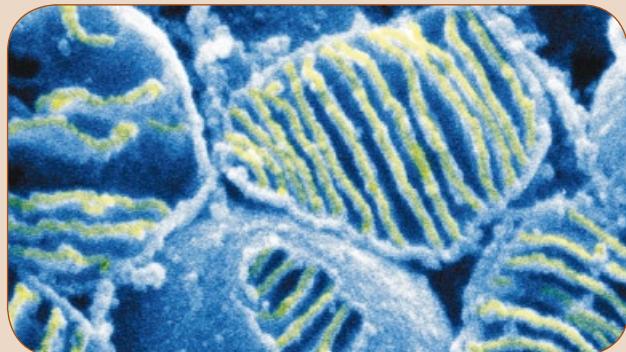
Figure 1.22 Transmission electron micrograph of a section through a mitochondrion ($\times 46\,000$).

Mitochondria are the site of **aerobic respiration** in a cell. Here, oxygen and energy-containing molecules produced from glucose are used to make **ATP**. ATP is the energy currency of a cell, necessary for every energy-using activity that it carries out. Each cell has to make its own ATP. Cells that use a lot of energy, such as muscle cells, therefore contain a lot of mitochondria.

The inner membrane of the mitochondrion is folded to form **cristae**. Here, ATP is made in a process that has many similarities with the production of ATP on the membranes inside a chloroplast. The ‘background material’ of the mitochondrion, called the **matrix**, is the site of the stages of aerobic respiration called the Krebs cycle.

Faulty mitochondria

Mitochondria are unusual organelles. Like chloroplasts they have two membranes around them rather than just one, and they contain their own DNA. Mitochondria and chloroplasts have evolved from prokaryotic cells that ‘invaded’ eukaryotic cells early in their evolutionary history – perhaps 2 billion years ago – and made themselves invaluable by providing enzymes and pathways that help the cell to survive. They have become an integral part of their host cells.



Scanning electron micrograph of a group of mitochondria ($\times 60\,000$).

All the mitochondria in your cells have been produced from a few mitochondria that were in your mother’s egg cell. The genes in mitochondria are passed down the maternal line. When a cell divides (Chapter 3), the mitochondria are shared out between the daughter cells.

The DNA in human mitochondria contains 37 different genes. These genes are not as well protected as those in the nucleus and are particularly prone to mutation. Some of these mutations are harmful, and mitochondria with mutant genes have been linked to a number of human diseases. However, mitochondria are not self-sufficient in DNA, and they rely on proteins that are produced following the code on the DNA in the nucleus. So faults in mitochondria are not necessarily caused by the mitochondria’s own genes, but could be a result of a mutation in the nuclear DNA. This is borne out by the fact

that more than 80% of diseases that are linked to faulty mitochondria do not follow a maternal inheritance pattern. This includes some cases of male infertility, caused by a lack of ATP generation in sperm cells, and also a tendency towards the development of type 2 (late onset) diabetes.

But about 1 in every 5000 people are thought to carry mutations in their mitochondrial DNA, and this can sometimes lead to very serious health problems, such as liver, kidney or brain damage. Often, a fetus that has inherited these faulty mitochondria from its mother does not survive and the mother has a miscarriage. Work is in progress to find methods of removing these faulty mitochondria from the mother’s egg and replacing them with healthy mitochondria taken from a donor egg. The mother’s nucleus would still be present in the egg, so the child would still be genetically hers – except for the genes in her mitochondria.

Licences to carry out such work in the UK are granted by the Human Fertilisation and Embryology Authority. The HFEA has a general ruling that embryos cannot be genetically altered in such a way that the altered genes would be passed on to their own offspring one day – they cannot pass along the ‘germ line’ from one person to their offspring. Initially, this ruling was thought to exclude the substitution of a mother’s mitochondria with someone else’s, because mitochondria contain genes. However, in 2006, the HFEA ruled that this would be allowable, and they have granted a licence for research work to be carried out on the technique. Professor John Burn, from the Newcastle Institute of Clinical Genetics, which is the first institution to receive such a licence, says: ‘My belief is that what we are doing is changing a battery that doesn’t work for one that does. The analogy is with a camera: changing the battery won’t affect what’s on the film, and changing the mitochondria won’t affect the important DNA.’

Vacuole

A vacuole is a membrane-bound organelle that contains liquid. Mature plant cells often have large vacuoles that contain cell sap. The membrane surrounding the vacuole is known as the **tonoplast**. Cell sap contains a variety of substances in solution, especially sugars, pigments and also enzymes.

Plasma (cell surface) membrane

Every cell is surrounded by a **plasma membrane**, sometimes known as the **cell surface membrane**. This is a thin layer made up of lipid (fat) molecules and protein molecules. Its role is to control what enters the cell and what leaves it. You can read about the movement of substances through the plasma membrane in Chapter 2.

Centrioles

Centrioles are found in animal cells but not in plant cells. Centrioles make and organise tiny structures called **microtubules**, which are made of a protein called **tubulin** (Figure 1.23). During cell division, microtubules form the **spindle**, and are responsible for moving the chromosomes around in the cell, and pulling them to opposite ends of the cell. Plant cells also use microtubules during cell division, but they are not organised by centrioles.

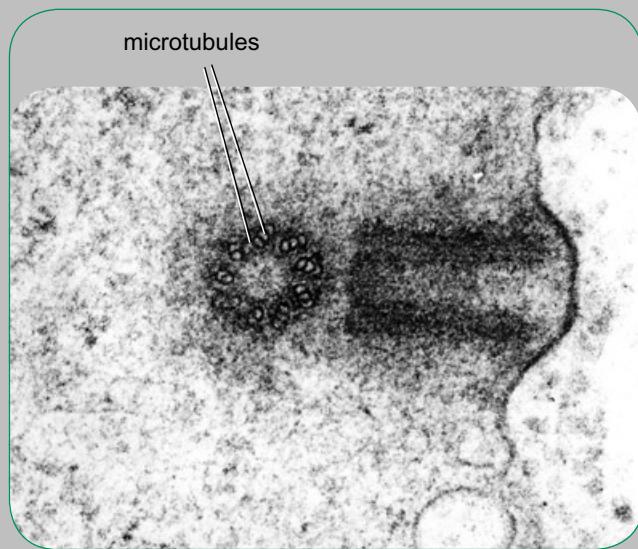


Figure 1.23 Transmission electron micrograph showing the two centrioles of an animal cell (at right angles to each other) ($\times 126\,000$).

Cilia and flagella

Cilia and flagella (singular: cilium and flagellum) are long, thin extensions from the surface of a cell, which can produce movement. They are found in some animal cells, and rarely in plant cells – some primitive plants such as liverworts and mosses produce male gametes that swim using flagella.

Cilia and flagella have the same basic structure. The term ‘cilia’ is used for relatively short structures, usually found in large numbers, whereas ‘flagella’ are longer and normally found in ones or twos.

Cilia and flagella contain microtubules, always arranged in a $9 + 2$ arrangement – that is, with two microtubules in the centre surrounded by a ring made up of nine pairs of microtubules (Figure 1.24 and Figure 1.25). Movement is produced by these microtubules sliding against each other. The movement causes the cilium or flagellum to bend and then straighten. Cilia in a group of ciliated cells usually all move in harmony with each other, looking like a field of wheat as wind sweeps over it.

The movement of cilia can move fluids over the surface of the cell. For example, in the lining of the bronchus, cilia sweep mucus up to the throat, where it is swallowed. Flagella, however, usually cause the cell to swim through a liquid.

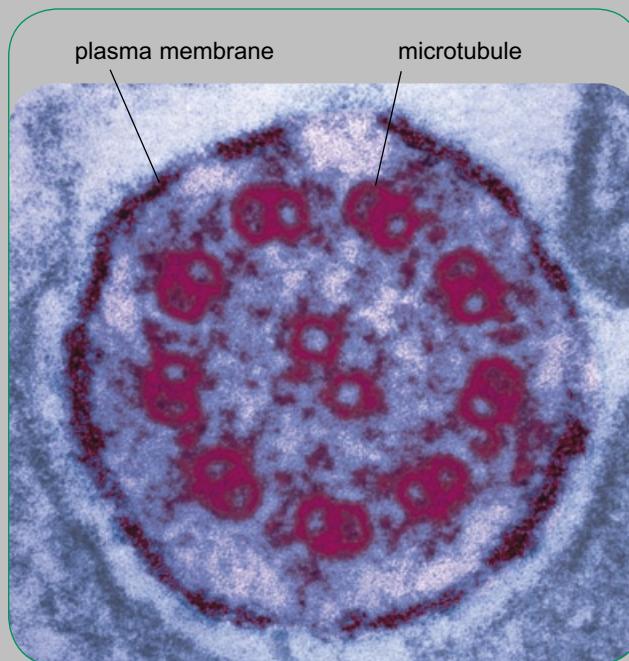


Figure 1.24 Transmission electron micrograph of a transverse section of a cilium or flagellum ($\times 265\,000$).

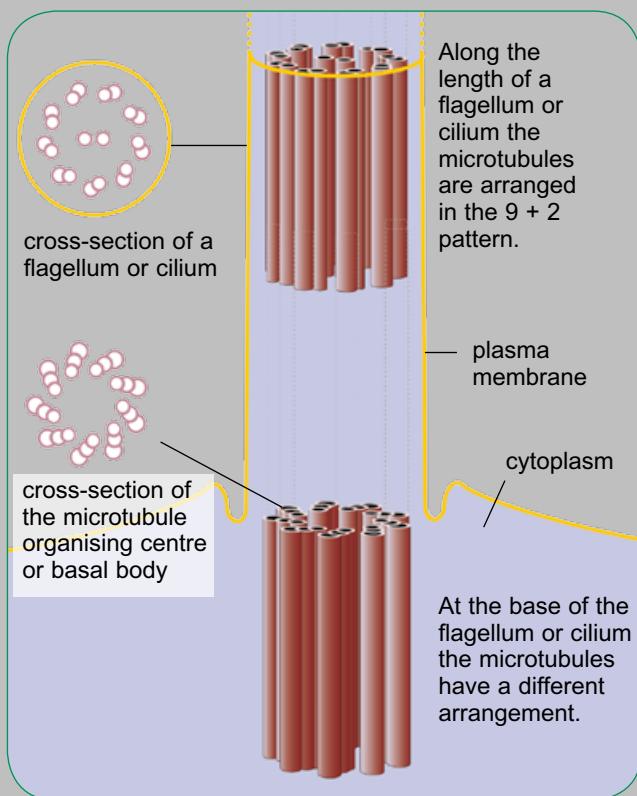


Figure 1.25 Cilia and flagella.

The cytoskeleton

All plant and animal cells contain a network of protein filaments, called **microfilaments**, that act as a ‘skeleton’ helping to support the cell and to determine its shape. Together with microtubules, these filaments make up the **cytoskeleton** (Figure 1.26).

The cytoskeleton provides mechanical strength for the cell, and also helps to direct movement of organelles within the cell. It provides ‘tracks’ along which organelles can be moved. The microtubules can act as ‘motors’, using energy from ATP to pull organelles along the tracks from one place to another. The cytoskeleton can also help the whole cell to move.

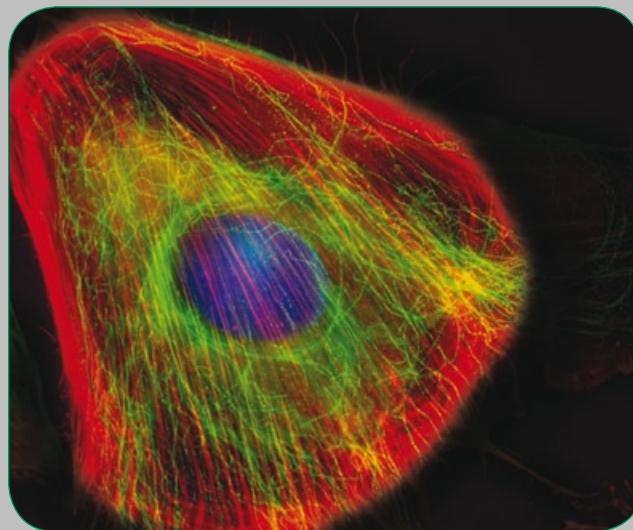


Figure 1.26 Light micrograph showing the cytoskeleton in a kidney cell. Microtubules are stained green, microfilaments red and the nucleus blue ($\times 500$).

Cell walls

Plant cells are always surrounded by a **cell wall** (Figure 1.27 and Figure 1.28). This is not an organelle, because it is not inside the cell.

Plant cell walls are made of long strands of a carbohydrate called **cellulose**. The cellulose fibres are very strong, and are arranged in a criss-cross manner, held together by a matrix that contains **pectin**. This composite structure has tremendous resistance to stretching forces that might act on it – for example, if the cell has taken up a lot of water and is expanding. The cell wall holds firm, preventing the cell from bursting.

Pectin is also found in the **middle lamella** that cements one cell to another (Figure 1.28).

SAQ

- 8 Draw a table to compare the structures visible in an animal cell and a plant cell, when they are viewed through an electron microscope.

Hint

Answer

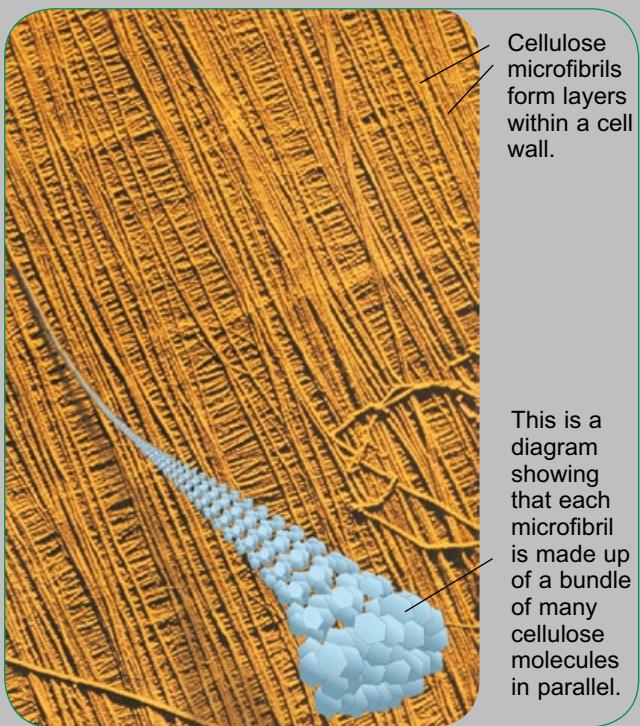


Figure 1.27 Scanning electron micrograph and diagram showing the structure of a plant cell wall (background electron micrograph $\times 600\,000$). Notice that the microfibrils lie in different directions in different layers, which greatly increases the mechanical strength of the cell wall.

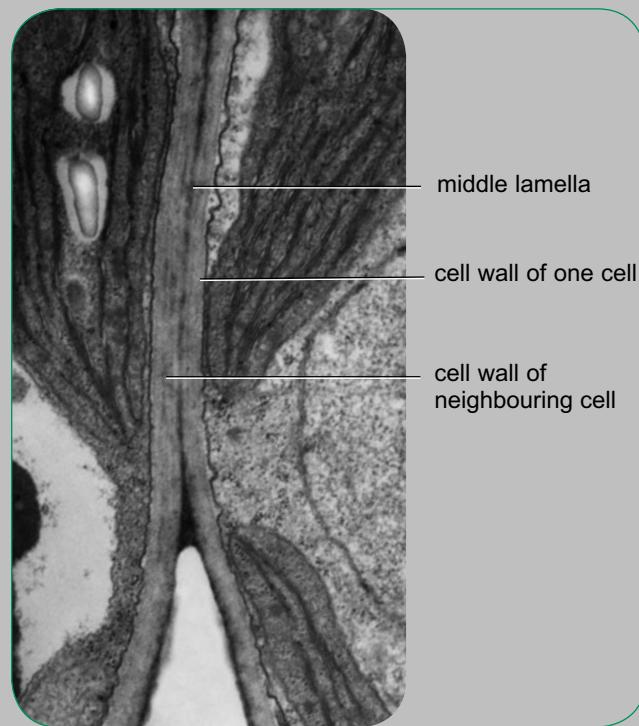


Figure 1.28 Transmission electron micrograph of plant cell walls. Where two plant cells lie next to each other, a structure called the middle lamella holds the adjacent walls firmly together ($\times 18\,000$).

Prokaryotic cells

Prokaryotic means ‘before nucleus’. Prokaryotes are single-celled organisms that do not have nuclei. Cells that do have nuclei are said to be **eukaryotic**.

The structure of a prokaryotic cell

Figure 1.29 shows the structure of a typical prokaryotic cell. The most obvious difference between this cell and a eukaryotic cell is the lack of a nucleus. The prokaryote’s DNA lies free in the cytoplasm.

In eukaryotic cells, the DNA is organised into several chromosomes, in which a long strand of DNA is associated with proteins called **histones**. This is not the case in prokaryotes. The DNA is not usually associated with histones (although histones are present in Archaea), and it is circular rather than linear as in eukaryotes.

This arrangement of the DNA is so different that some people think we should not use the

term ‘chromosome’ to describe it. However, it has now become common for scientists to talk about bacterial chromosomes, despite the fact that they are not the same as the chromosomes in eukaryotic cells.

Prokaryotes also lack complex membrane-bound organelles, such as mitochondria, chloroplasts and endoplasmic reticulum. They do have ribosomes, but these are smaller than in eukaryotic cells, and they are always free in the cytoplasm rather than attached to membranes.

Prokaryotes are surrounded by a cell wall, but its structure is not at all like that of plant cells. The prokaryote cell wall is made up of fibres of **peptidoglycan**. Like plant cell walls, this cell wall stops the cell bursting if it expands.

Table 1.2 summarises the differences and similarities between eukaryotic cells and prokaryotic cells.

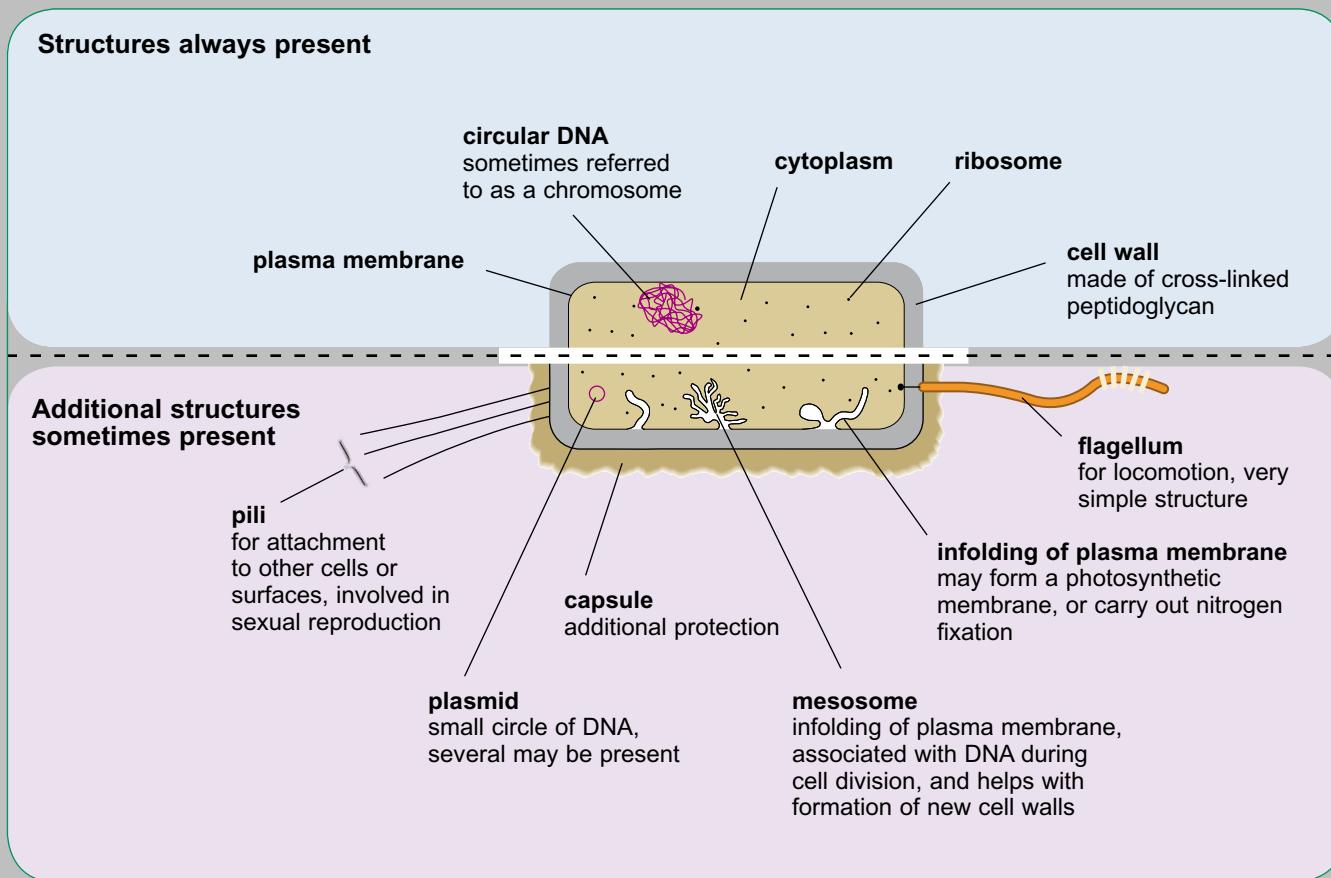


Figure 1.29 The structure of a typical prokaryotic cell.

Structure	Eukaryotic cell	Prokaryotic cell
nucleus	usually present, surrounded by a nuclear envelope and containing a nucleolus	no nucleus, and therefore no nuclear envelope or nucleolus
mitochondria	usually present	never present
chloroplasts	present in some plant cells	never present
endoplasmic reticulum	always present	never present
ribosomes	relatively large, about 30 nm in diameter	relatively small, about 20 nm in diameter
cytoskeleton	always present, made up of microtubules and microfilaments	no cytoskeleton
chromosomes	DNA arranged in several long strands, associated with histones	DNA circular, not associated with histones
cell wall	cellulose cell walls present in plant cells	cell wall always present, made of peptidoglycan
cilia and flagella	sometimes present	some have flagella, but these have a different structure from those in eukaryotic cells

Table 1.2 Comparison of the ultrastructure of eukaryotic and prokaryotic cells.

Summary

- All living organisms are made of a cell or cells. Cells and their contents are usually measured in micrometres (μm). One micrometre is one thousandth of a millimetre.
- Light microscopes have much less resolving power than electron microscopes and so the images obtained from light microscopes can only be usefully magnified up to about 1400 times, compared with 300000 times for an electron microscope.
- The greater resolving power of the electron microscope enables us to see the ultrastructure of a cell – that is, the small organelles that it contains, and their internal structure.
- The following formula can be used to calculate magnifications or the real sizes of objects being viewed:
$$\text{magnification} = \frac{\text{size of image}}{\text{real size of object}}$$
- Specimens to be viewed using a microscope are often stained to make parts of them look darker, or different colours.
- Plant and animal cells are eukaryotic cells, with a nucleus surrounded by an envelope. The nucleus contains the DNA, in the form of chromosomes. All cells are surrounded by a partially permeable plasma membrane.
- Plant and animal cells contain ribosomes for protein synthesis, endoplasmic reticulum for the storage and transport of substances made in the cell, Golgi apparatus for processing and packaging proteins the cell has made, lysosomes containing digestive enzymes and mitochondria to produce ATP by aerobic respiration.
- Plant cells sometimes also contain chloroplasts, where photosynthesis takes place, and they may have a large vacuole containing cell sap. They are surrounded by a fully permeable cellulose cell wall.
- Animal cells contain a pair of centrioles, which organise the microtubules in the cell – for example, when forming the spindle during cell division. Animal cells may also have cilia or flagella, which contain microtubules in a 9 + 2 arrangement and can produce movement.
- Microtubules and microfilaments form the cytoskeleton, holding the cell in shape and helping to move organelles around inside the cell.
- Bacteria are prokaryotic cells, which do not have a nucleus. Their DNA is not associated with histones, and is present as a circular strand. Prokaryotic cells lack complex membrane-bound organelles such as mitochondria. They have smaller ribosomes than eukaryotic cells. They always have a cell wall, but this is made of peptidoglycan and not cellulose.

Questions

1 a The drawing shows an animal cell nucleus as seen using an electron microscope.

i Name the structure labelled W. [1]

ii The actual diameter of the nucleus, measured along the line XY, is $7 \mu\text{m}$.

Calculate the magnification of the nucleus. Show your working. [2]

b Each part of a cell is specialised to carry out a particular function.

Below is a list of parts of a cell, labelled A to F. Each of the list of statements, numbered 1 to 6, refers to one of these parts of the cell.

A nucleus

B mitochondrion

C plasma membrane

D chloroplast

E smooth endoplasmic reticulum

F ribosomes

1 where some lipids, including steroids, are made

2 controls entry of substances into the cell

3 controls the activities of the cell

4 where polypeptides are made

5 where photosynthesis takes place

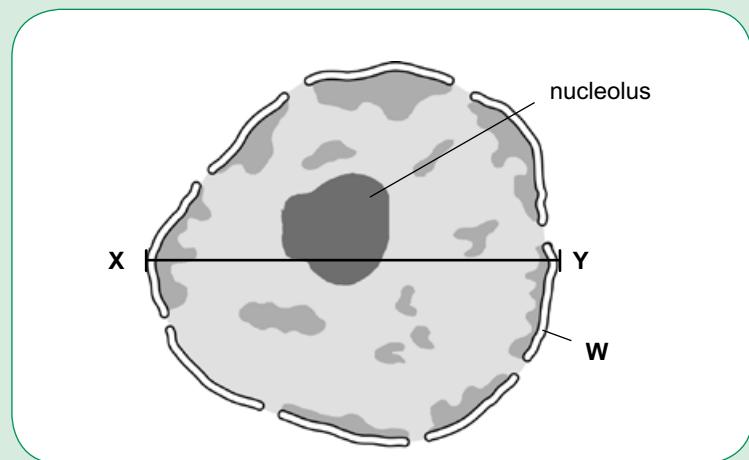
6 where aerobic respiration takes place

Match a statement to part of the cell. For example, 3 matches with A.

[5]

OCR Biology AS (2801) January 2003

[Total 8]

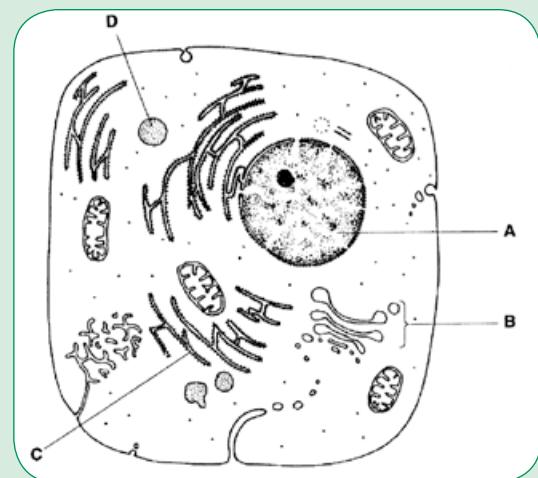


2 a The drawing shows an animal cell as seen under an electron microscope.

Complete the following table by:

- identifying the parts of the cell A to E
- naming the part of the cell responsible for the function stated. The first one has been done for you.

Function	Part of cell	Label
controls activities of the cell	nucleus	A
attaches to mRNA in protein synthesis		
produces secretory vesicles		
contains digestive enzymes		



[6]

b Outline the structure and functions of the cytoskeleton.

[4]

OCR Biology AS (2801) January 2005

[Total 10]

continued

- 3** With reference to both light and electron microscopy, explain and distinguish between the terms *magnification* and *resolution*.

OCR Biology AS (2801) January 2002

[Total 4]

- 4** The table below compares the features of typical eukaryotic and prokaryotic cells.
Copy and complete the table by placing one of the following, as appropriate, in each empty box: a tick (**✓**), a cross (**✗**) or the words 'sometimes present'

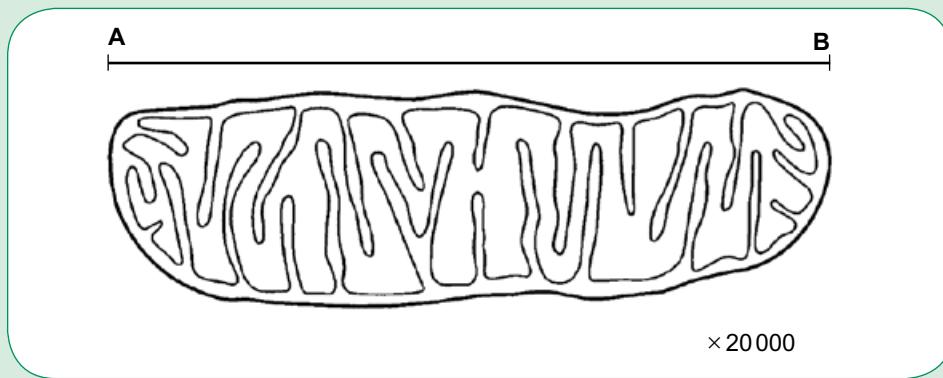
Feature	Eukaryotic cell	Prokaryotic cell
cell wall	sometimes present	✓
nuclear envelope	✓	
Golgi apparatus		✗
flagellum	sometimes present	
ribosomes		✓
carries out respiration	✓	
chloroplast	sometimes present	

OCR Biology AS (2801) January 2001

[Total 6]

Answer

- 5 a** The diagram shows a drawing of an organelle from a ciliated cell as seen with an electron microscope.



- i** Name the organelle shown in the diagram. [1]
- ii** State the function of this organelle. [2]
- iii** State why ciliated cells contain relatively large numbers of these organelles. [1]
- iv** Calculate the actual length as shown by the line AB in the diagram.
Express your answer to the nearest micrometre (μm).
Show your working. [2]

- b** An image shown to the same magnification as the diagram above could be produced using a light microscope. Explain why such an image would be of little use when studying cells. [2]

OCR Biology AS (2801) January 2006

[Total 8]

Chapter 2

Cell membranes

Every living cell is surrounded by a membrane. This is called the **plasma membrane**, or the **cell surface membrane**. The plasma membrane defines the limits of the cell. It separates the cell's contents from its external environment, and it controls what can pass from this environment into the cell, and from the cell into the external environment. It is partially permeable.

Membranes are also found inside cells. Some organelles are surrounded by a single membrane – for example, lysosomes. The nucleus, mitochondria and chloroplasts each have two membranes around them, making up an **envelope**. Most eukaryotic cells also have an extensive network of membranes within their cytoplasm, forming the rough endoplasmic reticulum, the smooth endoplasmic reticulum and the Golgi apparatus (Figure 2.1). Like the plasma membrane, these membranes

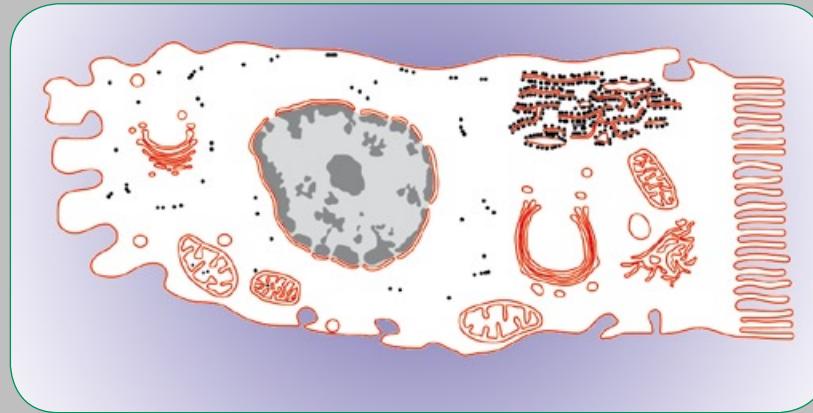


Figure 2.1 Membranes in an animal cell (shown in red).

inside the cell are partially permeable, and therefore able to control what can pass through them. They separate what happens inside the organelle from what is happening in the rest of the cell.

Table 2.1 summarises the functions of membranes around and inside cells. You will find out more about some of these functions in this chapter.

Function	Example
Membranes are partially permeable, controlling what passes through them.	The plasma membrane allows small or uncharged particles to pass through it; protein channels and transporters control the passage of larger or charged particles.
Membranes produce different compartments inside cells.	Mitochondria are surrounded by two membranes, which isolate the reactions taking place inside from the reactions taking place in the cytoplasm.
Membranes are important in cell signalling.	A substance produced by one cell docks into a receptor in the plasma membrane of another, causing something to happen in the second cell.
Membranes can allow electrical signals to pass along them.	The membrane of the axon of a motor neurone transmits action potentials from the central nervous system to a muscle.
Membranes provide attachment sites for enzymes and other molecules involved in metabolism.	The inner membrane of a mitochondrion contains molecules needed for the production of ATP. The inner membrane of a chloroplast contains chlorophyll needed for photosynthesis.

Table 2.1 Functions of membranes.

Structure of cell membranes

All cell membranes have a similar structure. They are normally between 7 nm and 10 nm thick, which makes them invisible with a light microscope but visible using an electron microscope. They are formed from a double layer of molecules called phospholipids, in which many different kinds of **proteins** are situated.

Phospholipid bilayer

Phospholipid molecules have an unusual property. Their heads have a tiny charge, and this attracts them to water molecules. But their tails don't have a charge, and they are repelled from water molecules. We say that the heads of the phospholipids are **hydrophilic** ('water-loving') and the tails are **hydrophobic** ('water-hating') (Figure 2.2).

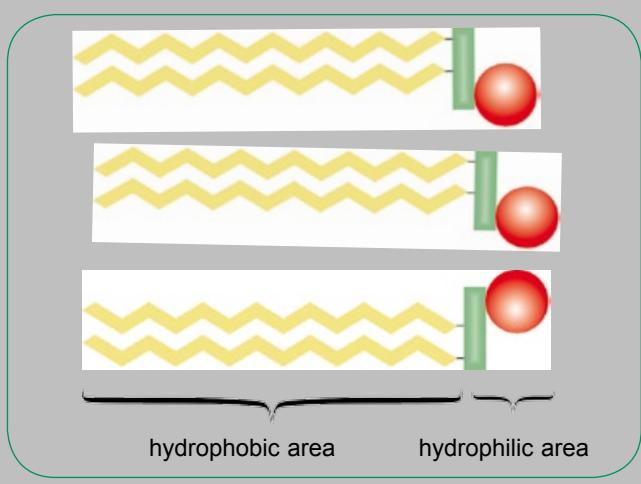


Figure 2.2 Phospholipid molecules.

The cytoplasm inside a cell contains a lot of water, and so does the fluid outside cells. (This is true whether the cell is the single cell of a unicellular organism, or one cell of many in the body of a multicellular organism.) The hydrophilic heads of phospholipid molecules are therefore drawn to these fluids, while the hydrophobic tails are repelled by them. This causes the phospholipids to arrange themselves in a double layer, with heads facing outwards and tails facing inwards. This is called a phospholipid bilayer (Figure 2.3).

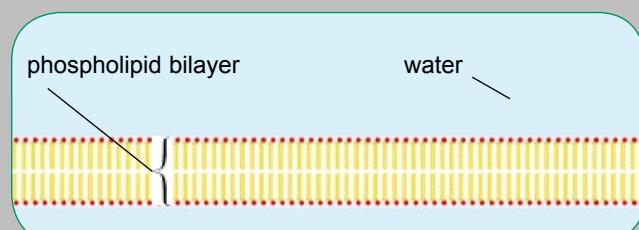


Figure 2.3 A phospholipid bilayer.

Other components of cell membranes

Membranes also contain another type of lipid. This is **cholesterol**. Cholesterol molecules lie alongside the phospholipids, helping to make up the bilayer.

There are also many different protein molecules in cell membranes. They are much larger than phospholipid molecules. Some of the protein molecules lie in the membrane, protruding from both sides. Others float in just the outer layer or the inner layer (Figure 2.4).

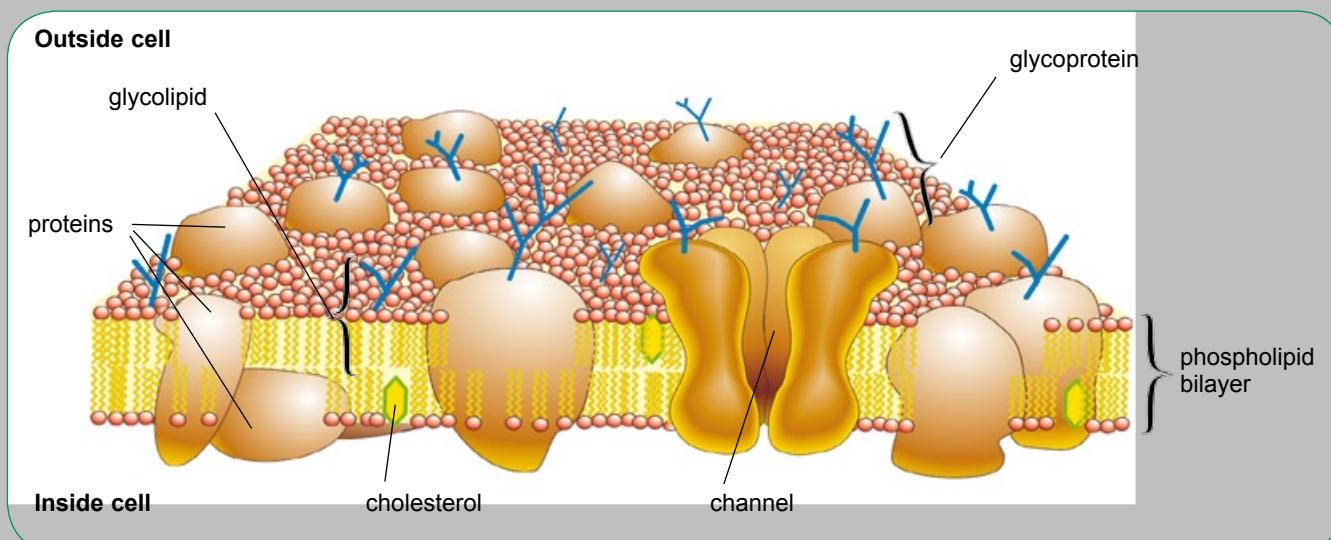


Figure 2.4 Part of a cell surface membrane.

Many of the lipid molecules and protein molecules have short strings of **sugar** molecules attached to them, forming **glycolipids** and **glycoproteins**.

Figure 2.4 shows the structure of a plasma (cell surface) membrane, including all of these components. This is called the **fluid mosaic model** of membrane structure. The term ‘fluid’ refers to the fact that the molecules in the membrane are in constant motion, moving around within their own layer (they don’t normally swap sides). The term ‘mosaic’ refers to the way the membrane would look if viewed from above, with a mosaic pattern formed by the protein molecules that are scattered throughout.

Table 2.2 summarises the roles of the different components of cell membranes.

SAQ

- 1 What is the difference between the outer surface and the inner surface of a plasma membrane?

Cell signalling

A cell must stay in contact with its environment and with other cells in order to survive. Cells must be able to react to changes in their environment. In a multicellular organism, cells in one part of the body must be able to communicate with cells in other parts. A cell therefore needs to be able to pick up ‘signals’ at its surface to which it may need to respond.

Signals arrive at the plasma membrane from outside the cell as particular substances – for example, a hormone – or changes in electrical potential – as happens in nerve impulses. A receptor in the cell’s plasma membrane picks up these signals, and brings about actions within the cell. This process is known as **cell signalling**.

You will meet several different examples of cell signalling as you continue through your Biology course, especially in the context of coordination by hormones and nerve impulses. Cell signalling has potential implications for medicine. For example, why do liver cells in some people not respond to insulin as they should? (This is the cause of type 2 diabetes.) Why do cancer cells not respond to signals that should stop them dividing? Answers to these questions may help to bring about cures or treatments for these and other diseases.

Component	Roles
phospholipid	<ul style="list-style-type: none">• forms the bilayer which is the fundamental basis of the membrane in which all other components are embedded• provides a barrier to water-soluble (hydrophilic) substances, such as ions and molecules that carry a charge
cholesterol	<ul style="list-style-type: none">• helps to maintain the fluidity of the membrane, preventing it from becoming too stiff when temperatures are low, or too fluid when temperatures are high
protein and glycoprotein	<ul style="list-style-type: none">• form channels through which hydrophilic substances can pass; the channels can be opened and closed• act as transporters that can move substances across the membrane up their concentration gradients, with the use of energy from ATP• act as receptor sites, allowing specific molecules from outside the cell, such as hormones, to bind with them and then set up responses within the cell• act as recognition sites, because their precise structure may be specific to a particular type of cell or to a particular individual• act as enzymes

Table 2.2 Roles of the components of cell membranes.

Mechanisms of cell signalling

Figure 2.5 shows three different ways in which cell signalling can occur. In Figure 2.5a, the signal is a chemical that attaches to a protein or glycoprotein acting as an ion channel. When the chemical attaches to the receptor, it makes the channel open and let ions into the cell, bringing about a response.

Figure 2.5b shows a slightly more complex mechanism of cell signalling. Here, the receptor in the plasma membrane interacts with another molecule, a **G-protein**. When the signal molecule

attaches to the receptor, the G-protein is activated. The G-protein then activates an enzyme, which brings about a reaction inside the cell.

Figure 2.5c shows a third type of signalling, this time involving a receptor that is also an enzyme. The receptor is made up of two parts. When the signal molecule arrives, it slots into both of these parts, connecting them to one another and forming them into an active enzyme. The enzyme then brings about reactions inside the cell.

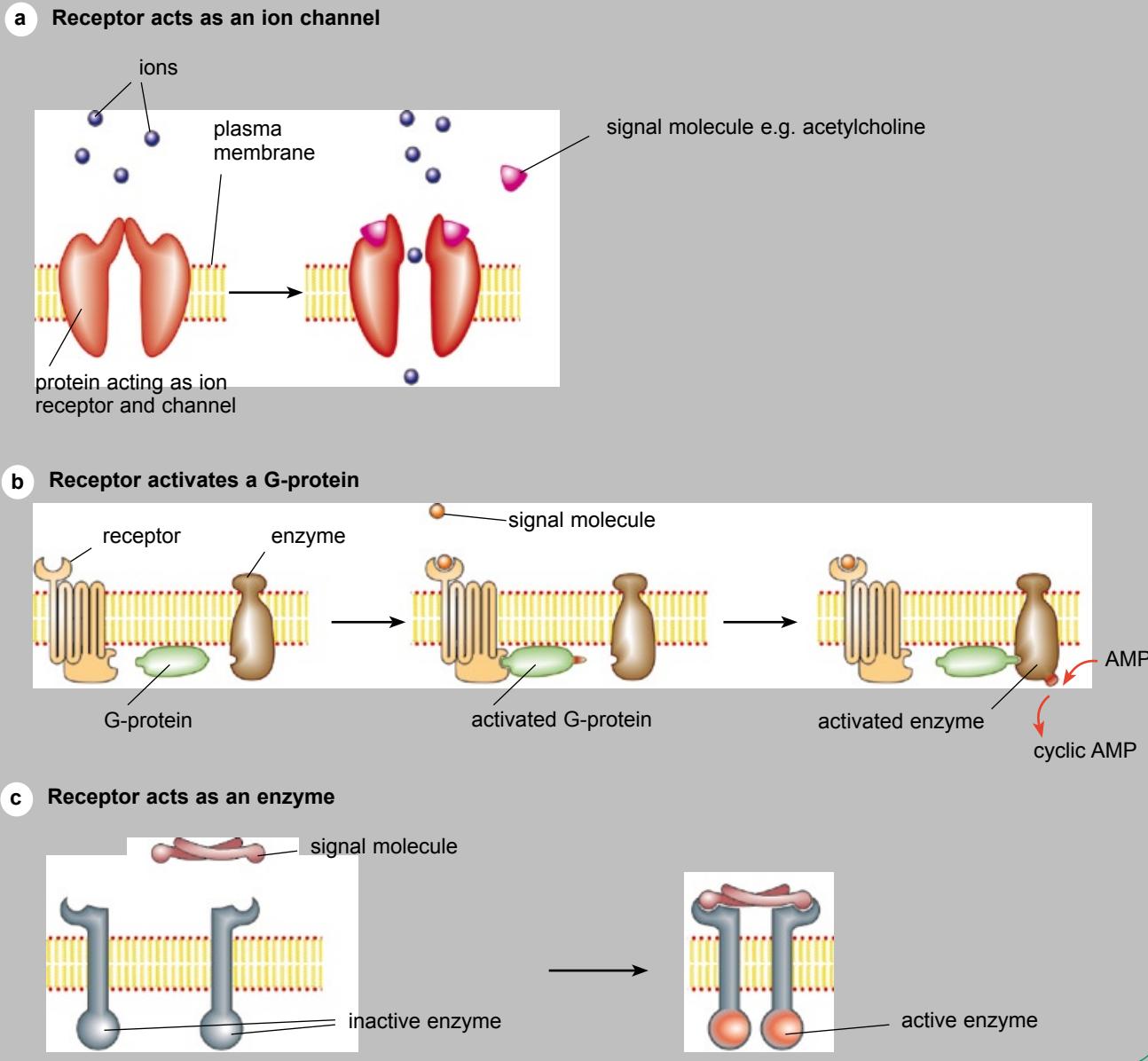


Figure 2.5 Mechanisms of cell signalling: **a** receptor acts as an ion channel; **b** receptor activates a G-protein; **c** receptor acts as an enzyme.

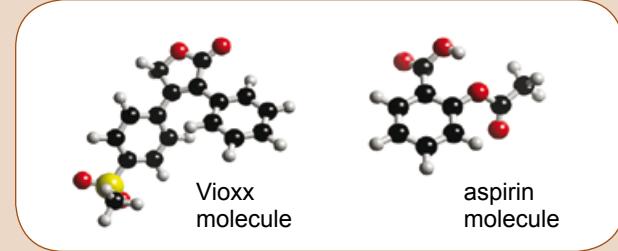
Aspirin and Vioxx

Aspirin seems to have become a wonder drug. Cheap and widely available, not only does it help to relieve pain, but people who are at risk of developing a blood clot in an artery or vein – perhaps because they have atherosclerosis, or are going on a long plane journey – are sometimes recommended to take half an aspirin tablet daily. This is because aspirin reduces the tendency of blood to clot.

Aspirin has these effects because it blocks some important cell-signalling pathways. One of these pathways involves chemicals called prostaglandins. Prostaglandins are made in cells in practically all the tissues in the body, especially after injury. They pass out of the cell and slot into receptors in the membranes of several different kinds of cells, activating G-proteins and bringing about various effects in those cells. For example, some nerve cells respond to prostaglandins by sending pain signals to the brain. Prostaglandins also cause inflammation, where blood capillaries become leaky and allow fluid and white blood cells into the damaged area.

Pain and inflammation in a damaged tissue are useful responses. The pain tells you to take care of that part of your body, and not to do any more damage to it. Inflammation brings white blood cells that can attack and destroy any invading bacteria that have managed to get into the wound. Swelling provides a cushion around the damaged area, helping to protect it while it heals.

But you don't always appreciate these responses of your body to damage! Inflammation has its harmful side, sometimes causing damage to healthy tissue. We would like to be free of pain and to be able to reduce the swelling caused by inflammation. Aspirin does both by stopping the production of prostaglandins. It acts by inhibiting an enzyme inside cells called COX-2, which produces prostaglandins from a lipid called arachidonic acid. With COX-2 out of action, prostaglandin production stops, and inflammation and pain are reduced.



Arachidonic acid is also the starting point for making a substance called thromboxane. Thromboxane stimulates platelets to stick together and form blood clots. Aspirin also inhibits the production of thromboxane, which is how it is able to reduce the risk of blood clots forming.

Unfortunately, aspirin also inhibits another enzyme called COX-1, and this enzyme helps to produce the protective layer of mucus that lines the stomach. So taking aspirin makes it more likely that the strong acid in the stomach could damage its walls. People with stomach ulcers are advised not to take aspirin.

As we learn more about the complex metabolic pathways that produce enzymes like COX-1 and COX-2, and about the cell-signalling mechanisms involving prostaglandins and other chemicals, it is becoming possible to produce new drugs that have more narrow-ranging effects than aspirin. One such drug, called Vioxx, was developed to inhibit COX-2 but not COX-1. The idea was that it would reduce pain and inflammation without affecting the stomach lining. The drug went through all the normal testing procedures without difficulty, and was widely prescribed for pain caused by arthritis. However, it was eventually realised that patients taking Vioxx were at an increased risk of developing heart disease. No-one knows quite why this happens. Although the increased risk was very small – 1.5% of people taking Vioxx developed heart problems, compared with 0.78% taking a placebo – it was enough to cause Vioxx to be withdrawn.

Now drug companies are trying to find out more about how COX-1 inhibitors affect cell signalling, hoping that they can find a Vioxx-like substance that will have no harmful side-effects.

Movement across cell membranes

Many substances move into and out of cells through their plasma membranes. Some of these substances move passively – that is, the cell does not have to use energy to make them move. Passive processes include **diffusion**, **facilitated diffusion** and **osmosis**. Other substances are actively moved by the cell, which uses energy to make them move up their concentration gradients. This is called **active transport**.

Diffusion

Particles are constantly moving around randomly. They hit each other and bounce off in different directions. Gradually, this movement results in the particles spreading evenly throughout the space within which they can move. This is **diffusion**.

If there are initially more particles in one place than another, we say there is a **concentration gradient** for them. Diffusion is the net movement of molecules or ions down their concentration gradient – that is, from a place where they are in a high concentration to a place where they are in a lower concentration.

There are usually a large number of different kinds of particles bouncing around inside and outside a cell, on both sides of its plasma membrane. Some of these particles hit the plasma membrane. If they are small – like oxygen and carbon dioxide molecules – and do not have an electrical charge, they can easily slip through the phospholipid bilayer.

Oxygen enters a cell like this. Inside the cell, aerobic respiration constantly uses up oxygen, so the concentration of oxygen inside the cell is low. If there is more oxygen outside the cell, then there is a concentration gradient for oxygen. Oxygen molecules on both sides of the plasma membrane are moving freely around, and some of them hit the plasma membrane and pass through it. This happens in both directions, but because there are more oxygen molecules in a given volume *outside* the cell than *inside*, more of them will pass through the membrane from outside to inside rather than in the opposite direction. The overall effect is for oxygen to move from outside the cell, through the plasma membrane, into the cytoplasm.

Facilitated diffusion

Oxygen and carbon dioxide have small molecules with no electrical charge, and can easily pass through the phospholipid bilayer. However, many other molecules or ions may be too big, or too highly charged, to do this. For example, chloride ions, Cl^- , have an electrical charge and cannot pass through the phospholipid bilayer.

Cells therefore need to provide special pathways through the plasma membrane which will allow such substances to pass through. Such pathways are provided by **channel proteins**. These proteins lie in the membrane, stretching from one side to the other, forming a hydrophilic channel through which ions can pass. The ions pass through by diffusion, down their concentration gradient. This process is called **facilitated diffusion**. It is just like ordinary diffusion, except that the molecules or ions only get through the membrane if they happen to bump into a channel (Figure 2.6).

Each channel formed by a protein will allow only a specific ion or molecule to pass through. The protein can change its shape, making the channel either open or closed. As we have seen, this is used in cell signalling.

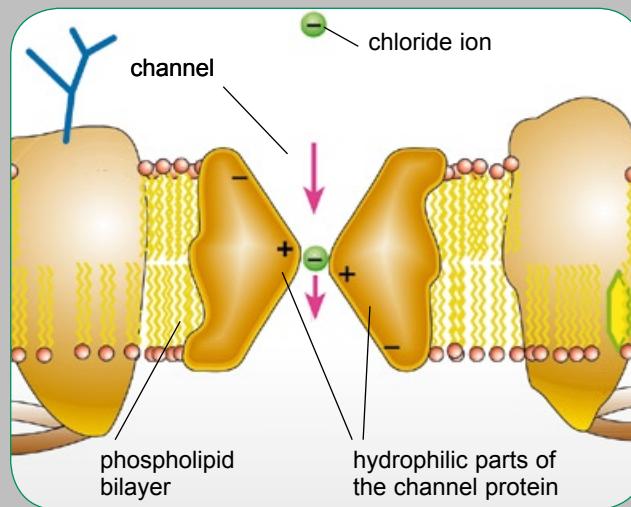


Figure 2.6 Facilitated diffusion.

SAQ

- Explain under what circumstances carbon dioxide might diffuse into a palisade cell in a leaf, and how the process takes place.

Osmosis

Water molecules, although they carry a charge (Chapter 7), are very small. They are therefore able to pass through the lipid bilayer by diffusion. This movement of water molecules, down their diffusion gradient, through a partially permeable membrane, is called **osmosis**.

It is not correct to use the term ‘concentration’ to describe how much water there is in something. Concentration refers to the amount of solute present. Instead, the term **water potential** is used. The symbol ψ (psi) can be used to mean water potential.

The water potential of a solution is a measure of how much water the solution contains in relation to other substances, and how much pressure is being applied to it. A solution containing a lot of water, and under pressure, is said to have a **high water potential**. A solution containing a lot of dissolved substances (solutes) and little water, and not under pressure, has a **low water potential**. You can think of water potential as being the tendency for water to leave a solution.

By definition, pure water at normal atmospheric pressure is given a water potential of 0. The more

solute you dissolve in the water, the lower its water potential gets. Therefore, a solution of sugar has a water potential which is less than 0 – that is, it has a negative water potential.

Just as we don’t normally talk about the ‘concentration’ of water, we don’t normally use the term ‘concentration gradient’ either. Instead, we use the term **water potential gradient**. Water tends to move *down* a water potential gradient, from where there is a lot of water to where there is less of it (Figure 2.7). It diffuses out of a dilute solution (a lot of water – high water potential) and into a concentrated solution (a lot of solute – low water potential).

Why is this important? The cells in your body are surrounded by watery fluids. Blood cells, for example, float in blood plasma. Water can move freely through the plasma membrane of the blood cells, but most of the substances dissolved in the water cannot. If there is a water potential gradient between the contents of a cell and the blood plasma, then water will move either into or out of the cell. If a lot of water moves like this, the cell can be damaged.

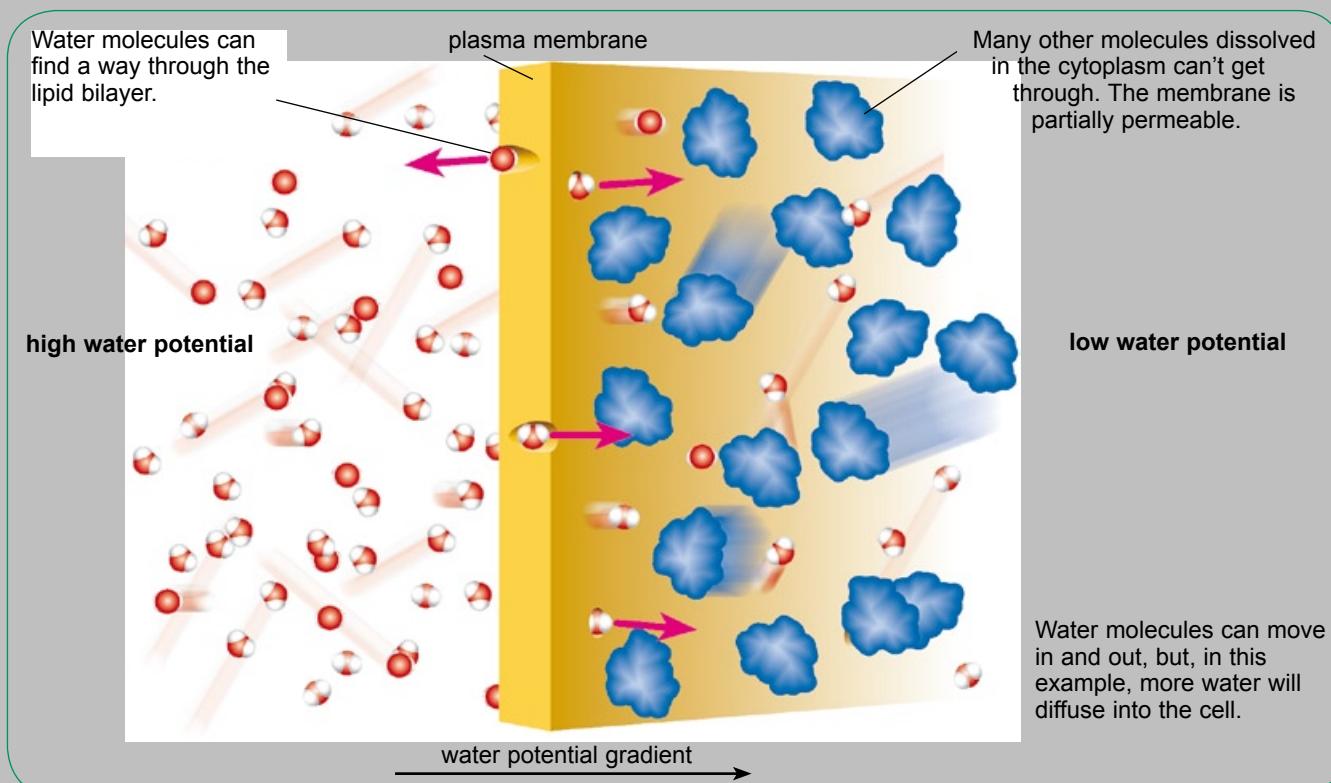


Figure 2.7 How osmosis occurs.

Osmosis and animal cells

Figure 2.8 shows what happens when animal cells are placed in solutions with water potentials higher or lower than the water potential of the cytoplasm inside the cells. If the solution outside the cell has a higher water potential than the cytoplasm, then water enters the cell by osmosis. If the water potential gradient is very high, so much water may enter that the cell bursts.

If the water potential gradient is in the other direction, then water leaves the cell by osmosis. The cell may shrink, sometimes becoming ‘star-shaped’, described as being ‘crenated’. The concentration of the solutes in the cytoplasm increases, and this may adversely affect metabolic reactions taking place inside the cell.

Osmosis and plant cells

Figure 2.9 shows what happens when plant cells are placed in solutions with water potentials higher or

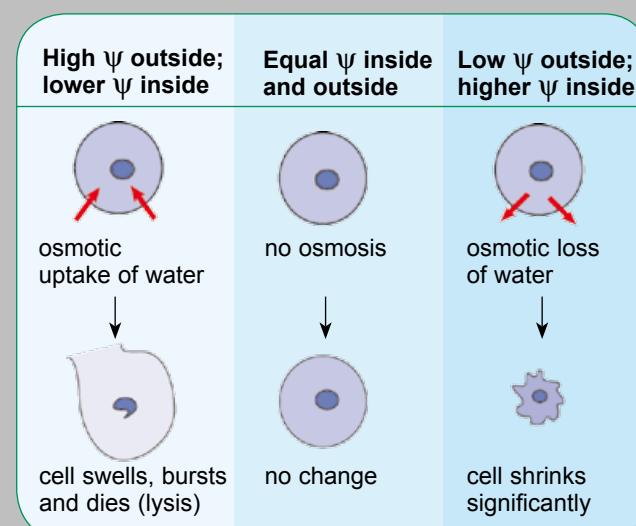
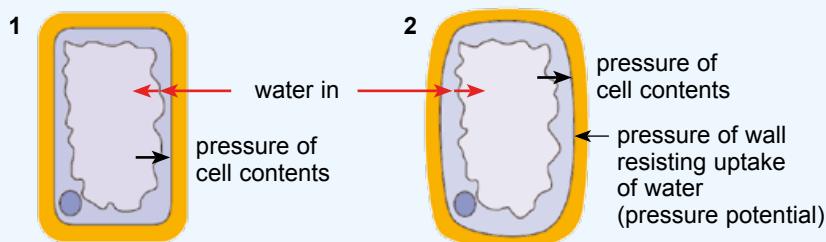


Figure 2.8 Osmosis and animal cells.

lower than the water potential of the cytoplasm in the cells.

A plant cell in a solution that is less concentrated than the cell solution absorbs water by osmosis



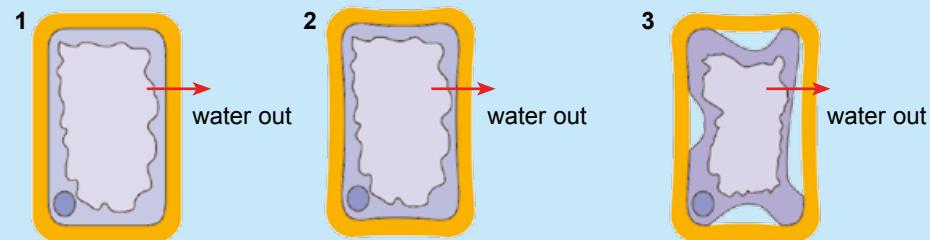
Water diffuses into the cell through the partially permeable plasma membrane. The cell contents expand. The contents will push out on the wall.

The wall pushes back on the cell contents. The force of the wall pushing on the cell contents is called the pressure potential. The cell is turgid.



As more water enters, ψ of the cell solution rises. Eventually, ψ inside equals ψ outside and there is no further net uptake of water. The cell has reached equilibrium. The cell is fully turgid.

A plant cell in a solution that is more concentrated than the cell solution loses water by osmosis



Water diffuses out of the cell through the partially permeable plasma membrane.

The contents do not push out on the walls. The cell is said to be flaccid.

The plasma membrane is eventually pulled away from the wall in places. The cell is plasmolysed. External solution now fills the gap between wall and plasma membrane.



Some parts of the membrane are resistant to pulling away from the wall. If the membrane is torn at these points, the cell dies.

Figure 2.9 Osmosis and plant cells.

Water moves into or out of the cell, down its water potential gradient, just as in an animal cell. The cell wall does not directly affect this movement, because it is fully permeable to water and to most of the solutes dissolved in it.

If the cell is put into water, then – just as in an animal cell – water enters by osmosis. But this time the cell does not burst. This is because, as it swells, it has to push out against the strong cell wall. The cell wall resists expansion of the cell, exerting a force called **pressure potential**. The cell becomes full and stiff, a state called **turgor**.

If a plant cell is put into a concentrated solution, then water leaves it by osmosis. The cell therefore shrinks. If a lot of water is lost, the contents no longer press outwards on the cell wall, and the cell loses its turgor. It is said to be **flaccid**.

The strong cell wall cannot cave in very much, so as the volume of the cell gets smaller and smaller, the plasma membrane may eventually pull away from the cell wall. The plasma membrane is often damaged in this process. A cell in this state is said to be **plasmolysed**. The cell usually dies.

Active transport

So far, we have looked at three ways in which substances can move down a concentration gradient (or a water potential gradient) from one side of the plasma membrane to the other. The cell does not have to do anything to make this happen, except perhaps to open a channel to allow facilitated diffusion to take place. These methods are all passive.

However, there are many instances where a cell needs to take up, or get rid of, substances whose concentration gradient is in the ‘wrong’ direction. This is usually the case with **sodium ions** and **potassium ions**. Most cells need to contain a higher concentration of potassium ions, and a lower concentration of sodium ions, than the concentration outside the cell. To achieve this, cells constantly pump sodium ions out and potassium ions in, up their concentration gradients. This requires energy input from the cell, so it is called **active transport** (Figure 2.10).

Active transport is carried out by **transporter proteins** in the plasma membrane, working in close association with ATP which supplies the energy. The ATP is used to change the shape of the transporter proteins. The shape

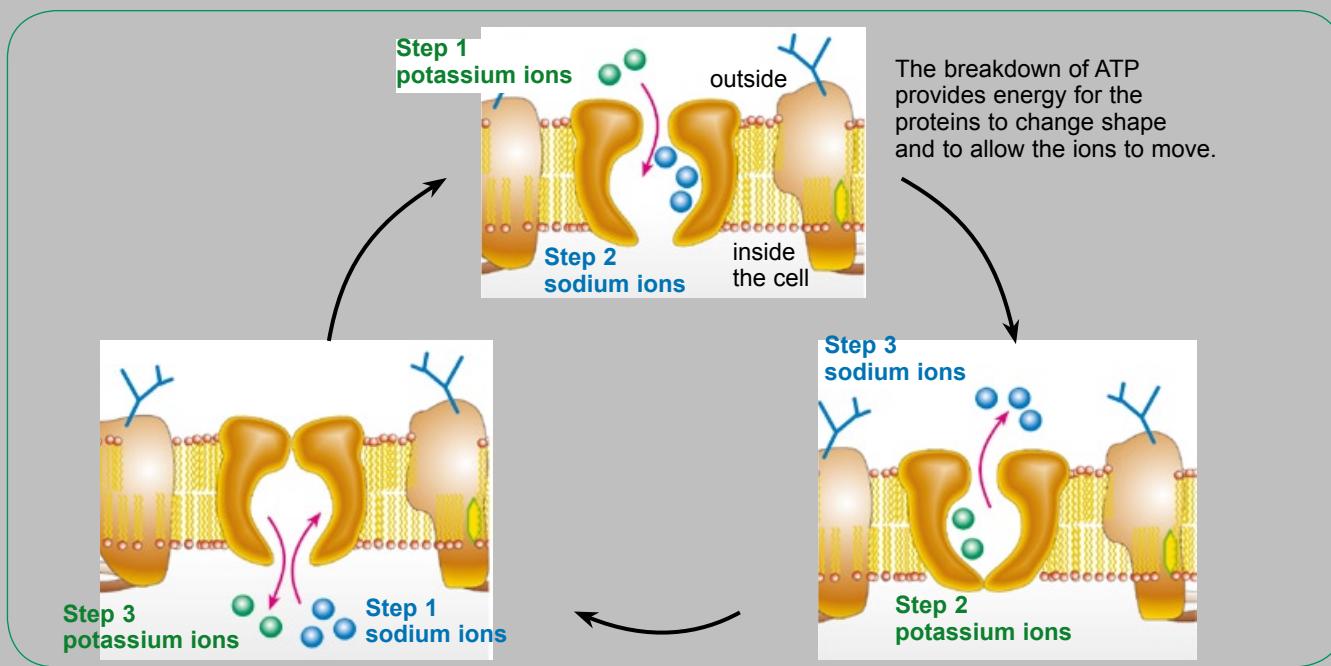


Figure 2.10 An example of active transport – the sodium–potassium pump. Start at step 1 for each ion in turn, and work your way round clockwise. Potassium ions are green and sodium ions are blue.

change moves three sodium ions out of the cell and two potassium ions in. This is going on all the time in most of your cells, and is called the **sodium–potassium pump**. It is estimated that more than a third of the ATP produced in your cells by respiration is used as fuel for the sodium–potassium pump.

Exocytosis and endocytosis

All the mechanisms of movement across membranes that we have looked at so far involve individual ions or molecules moving. Cells can also move substances in bulk across the membrane.

Moving substances *out* of a cell in this way is called **exocytosis** (Figure 2.11). The substance to be released from the cell is contained in a tiny membrane-bound sac called a **vesicle**. The vesicle is moved to the plasma membrane along microtubules. The membrane around the vesicle fuses with the plasma membrane, emptying the vesicle's contents outside the cell.

Moving substances *into* a cell in this way is called **endocytosis**. A good example is the way that

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- 3 Suggest what might be moved out of a cell in the pancreas by exocytosis.

a phagocyte (a type of white blood cell) engulfs a bacterium. The cell puts out fingers of cytoplasm around the bacterium, which fuse with one another to form a complete ring around it. The bacterium is therefore enclosed in a vacuole, surrounded by a membrane. Enzymes can then be secreted into the vacuole to digest it.

Cells can also move bulk liquids into the cell by endocytosis. The process is the same – fingers of cytoplasm surround a small volume of liquid and form a vacuole around it.

Endocytosis and exocytosis are both active processes, requiring the cell to use energy to make them happen.

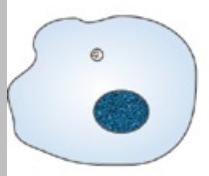
How temperature affects membrane permeability

If you cut some pieces of beetroot, wash them and place them in water, the water will remain colourless. If, however, you heat the beetroot pieces, then some of their red colour comes out and the water goes red. Why does this happen?

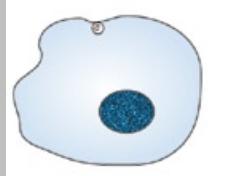
The red colour in beetroot cells is caused by molecules of a red pigment. The pigment is held in by their cell membranes, which are not permeable to it. However, if you heat the cells, then their membranes become much more permeable. This happens because of the effects of a rise in temperature on the phospholipids and proteins in

Exocytosis

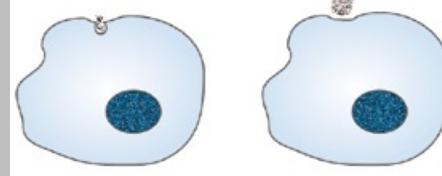
- 1 Vesicle moves towards plasma membrane.



- 2 Vesicle joins with plasma membrane.

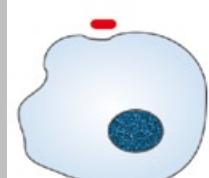


- 3 Vesicle contents released – the vesicle membrane is now part of the plasma membrane.

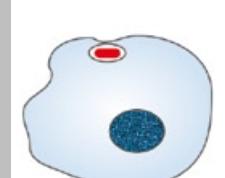


Endocytosis

- 1 The cell spreads around an object or area of the solution outside the cell.



- 2 The area enclosed becomes a vesicle.



- 3 The contents of the vesicle are absorbed into the cytoplasm and the vesicle membrane is recycled.

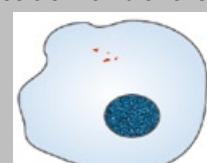


Figure 2.11 Exocytosis and endocytosis.

the cell membranes.

As the phospholipid molecules get hotter, they vibrate more and more. They move much more than previously, leaving temporary gaps in the membrane through which the pigment molecules can pass.

The protein molecules, too, vibrate more and more as the temperature increases. They may vibrate so much that they begin to come apart and lose their shapes. This, too, leaves gaps in the cell membrane. Very low temperatures, on the other hand, *decrease* membrane permeability. The phospholipids vibrate much less, packing together

tightly and only rarely providing pathways between themselves through which molecules might pass. Protein channels remain in place, but transporter proteins may not work very well, because the low temperatures make it difficult for the cell to provide ATP needed for active transport. Moreover, at low temperatures all molecules and ions will be moving around less, so few of them will hit the membrane and pass through it.

Summary

- Every cell is surrounded by a selectively permeable plasma membrane, which controls what passes through it. The plasma membrane also has important roles in cell signalling.
- Many organelles are also surrounded by membranes; these membranes help to isolate the metabolic reactions inside the organelle from those outside it, and provide extra surface area for the attachment of enzymes and other molecules.
- Membranes are made of a phospholipid bilayer in which proteins are embedded. This is known as the fluid mosaic model. The membranes also contain cholesterol, glycolipids and glycoproteins, each of which has its own functions.
- Cells are able to send and receive signals – for example, in the form of molecules such as hormones. Such signals are received by the plasma membrane; the arrival of a signal may bring about a response in the cell.
- Substances that have small, uncharged molecules can diffuse passively through the phospholipid bilayer. Larger molecules and charged ions pass through channels formed by proteins. If they are diffusing passively down their concentration gradient, this is known as facilitated diffusion.
- Water molecules can move freely across most membranes, by diffusion, down their water potential gradient. This is known as osmosis.
- Cells placed in a solution that has a lower water potential than the cell contents lose water by osmosis, so their volume decreases. Animal cells may become crenated, whilst the cell membrane in plant cells may pull away from the cell wall as the cytoplasm shrinks.
- Cells placed in a solution that has a higher water potential than the cell contents gain water by osmosis, so their volume increases. Animal cells may burst, but plant cells do not because of the strong cell wall that surrounds them.
- Substances can also be moved across membranes against their concentration gradient, using energy in the form of ATP produced by the cell. This is called active transport, and takes place through carrier proteins in the membrane.
- Substances can be moved in bulk across a membrane by exocytosis or endocytosis.
- An increase in temperature increases the movement of the molecules in a membrane, increasing the membrane's permeability.

Questions

- 1 a** Red blood cells of mammals respond to changes in the concentration of salts in the fluid that surrounds them. If they are placed in a solution that has a lower concentration of salts than blood plasma, they swell and may burst. This bursting is known as haemolysis.
Explain why red blood cells may burst when they are placed in a solution that has a lower concentration of salts than blood plasma. [3]

- b** An experiment was carried out in which red blood cells were placed in salt solutions of different concentrations. The percentage of cells which were destroyed by haemolysis was recorded. The results are shown in the graph.

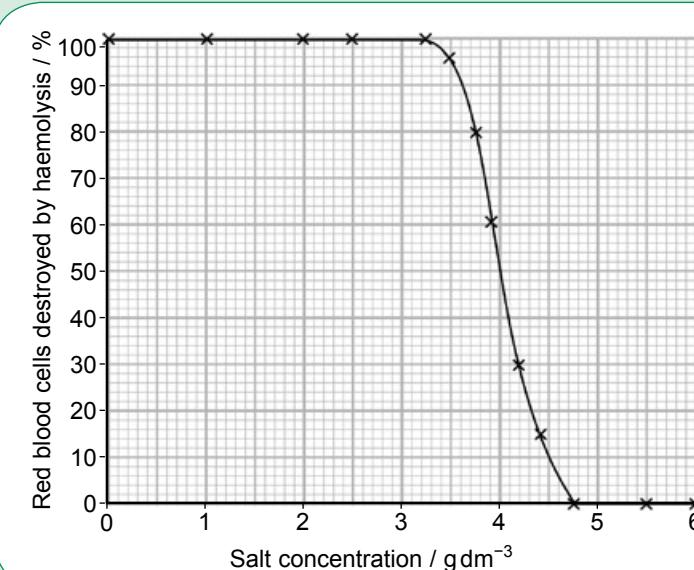
The graph shows that the red blood cells do not all haemolysate at the same salt concentration.

- Using the graph, state the salt concentration at which the percentage of haemolysed red blood cells is equal to those that are not haemolysed.
 - Suggest why different red blood cells haemolysate at different salt concentrations.
- c** An experiment was carried out to investigate the uptake of potassium ions by carrot tissue. The experiment was carried out as follows:

- A carrot was cut into discs of uniform size.
- The discs were divided into four groups.
- Equal volumes of a solution containing potassium ions were added.

The temperature remained constant at 21 °C and the experiment was carried out for the same length of time in each case. The experiment was carried out in different oxygen concentrations.

The results are shown in the table.



- | oxygen concentration / arbitrary units | 0 | 4 | 11 | 20 |
|--|---|----|----|-----|
| rate of uptake of potassium ions / arbitrary units | 7 | 27 | 92 | 100 |
- Using the information given in the table, state the main process by which potassium ions enter the carrot cells. [1]
 - Give a reason for your answer to i. [1]
 - Suggest an explanation for the uptake of potassium ions in the absence of oxygen. [1]