Chapter 1

Cell structure

Background

e-Learning

Objectives

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.

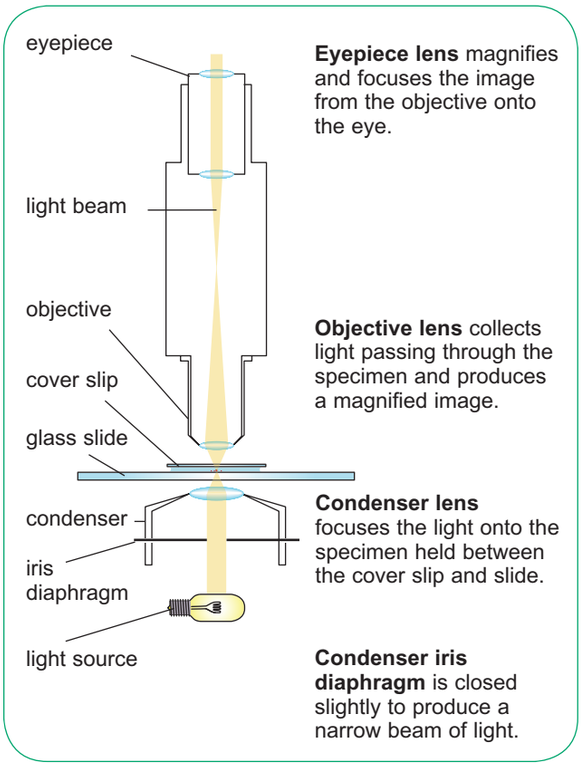


Figure 1.1 How a light microscope works.

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.

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.

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

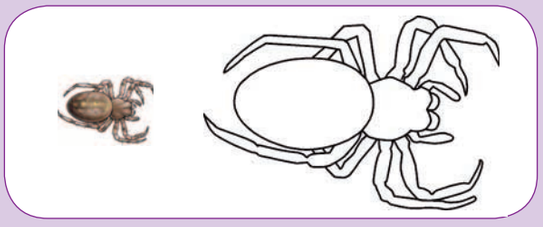
For example, we can calculate the magnification of the drawing of a spider in Worked example 1.

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.

Hint

Answer

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.

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

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

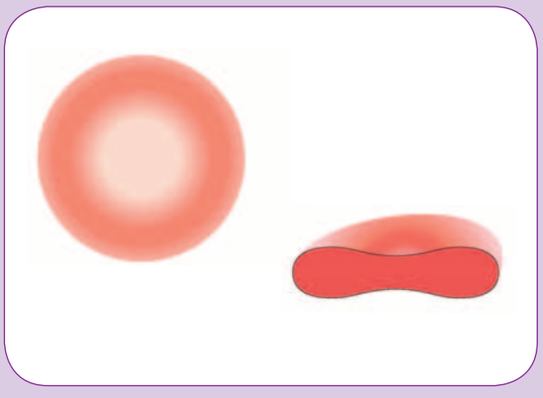
$$1\,nm = \frac{1}{1000}\ \mu m$$

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.

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 30×1000 µm.

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

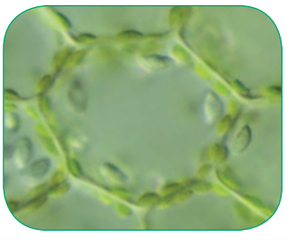
$$\text{magnification} = \frac{\text{size of image}}{\text{real size of object}}$$

$$= \frac{30 \times 1000}{7}$$

$$= \times 4286$$

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.



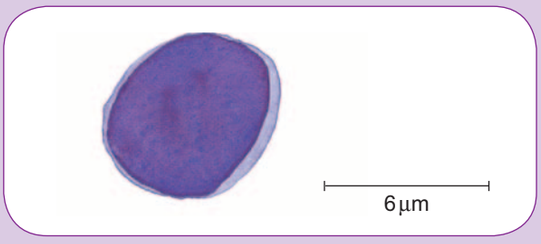
Hint

Answer

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.

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

$$\text{magnification} = \frac{\text{the length of the scale bar}}{\text{the length the scale bar represents}}$$

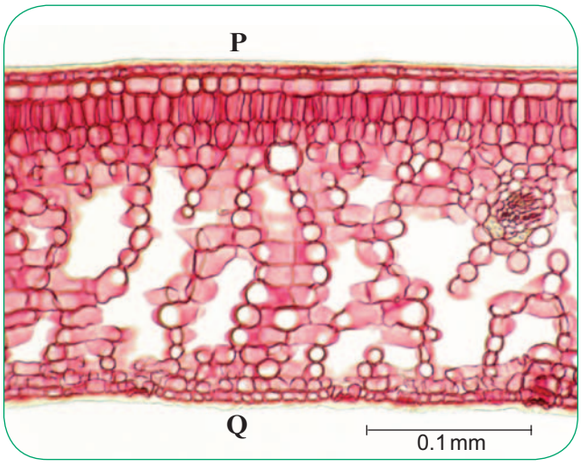
$$= \frac{24 \times 1000\,\mu\text{m}}{6\,\mu\text{m}}$$

$$= \times 4000$$

SAQ

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

Hint



Answer

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.

Hint

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

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

Answer

Resolution

Light microscopes have one major disadvantage. They are unable to show objects that are smaller than about 200 nm across (1 nm = $\frac{1}{1000}$ mm). 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 × 450 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.

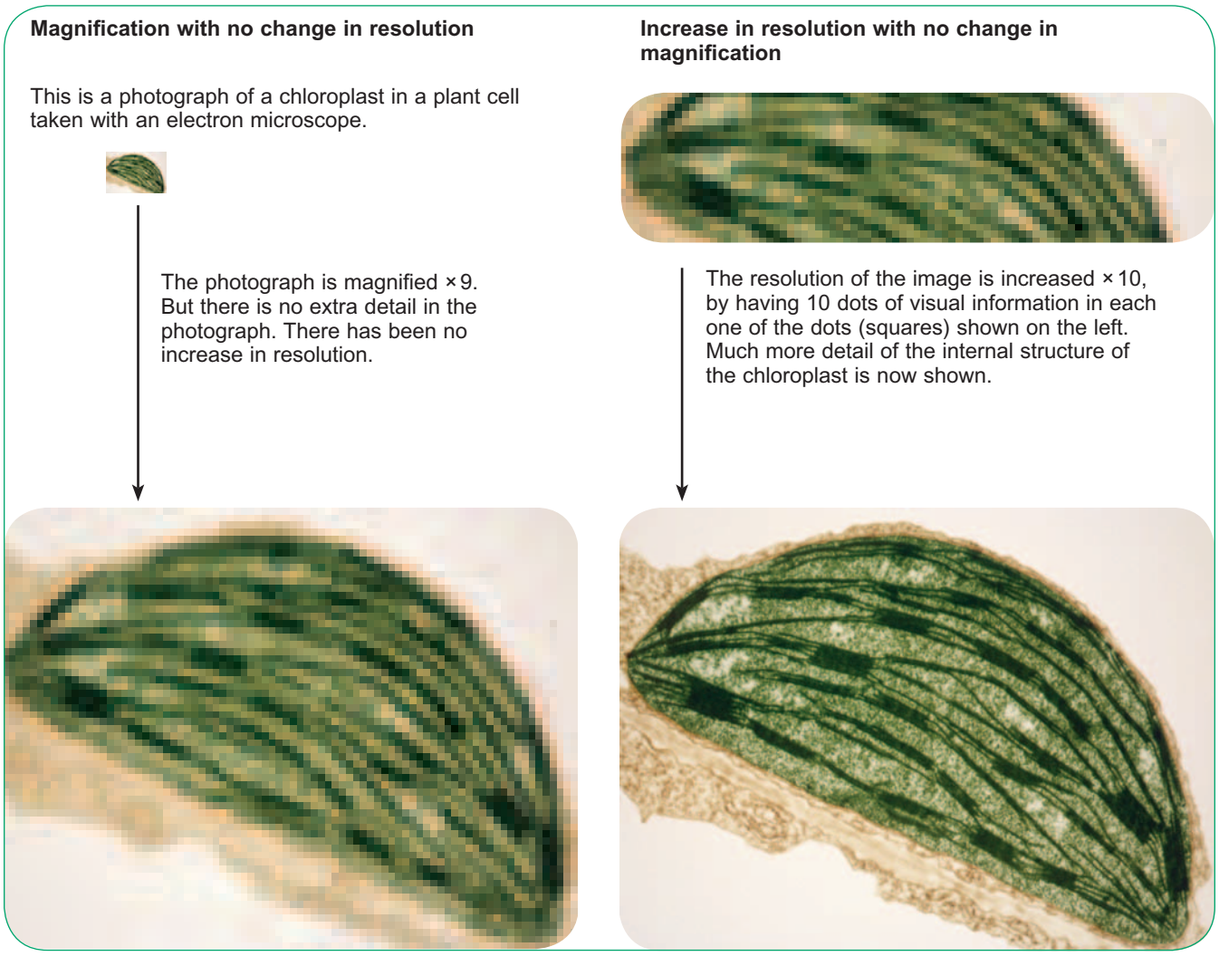


Figure 1.2 Explaining the difference between magnification and resolution.

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.

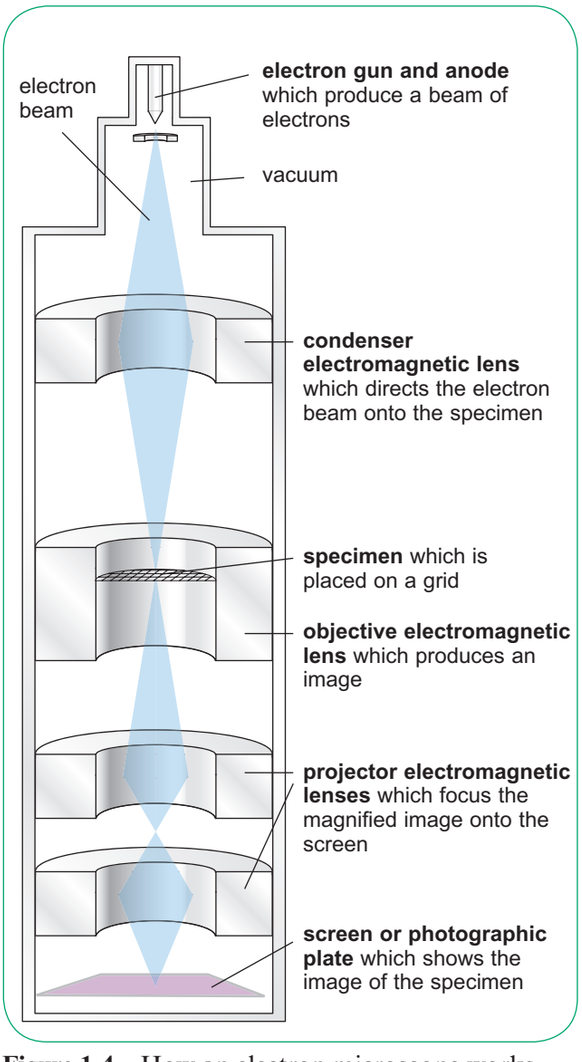


Figure 1.4 How an electron microscope works.

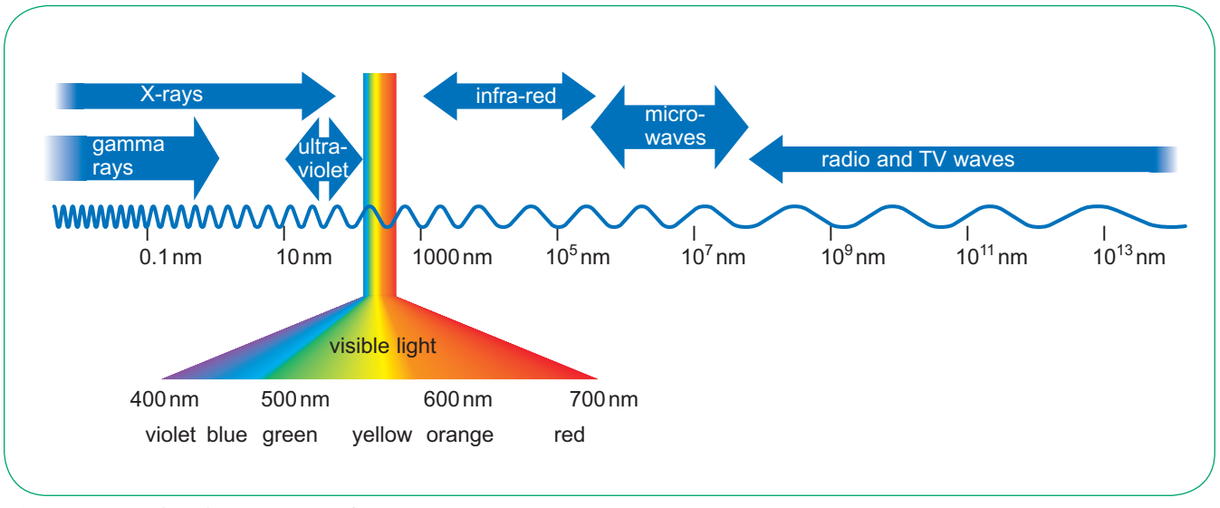


Figure 1.3 The electromagnetic spectrum.

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		

Answer

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.

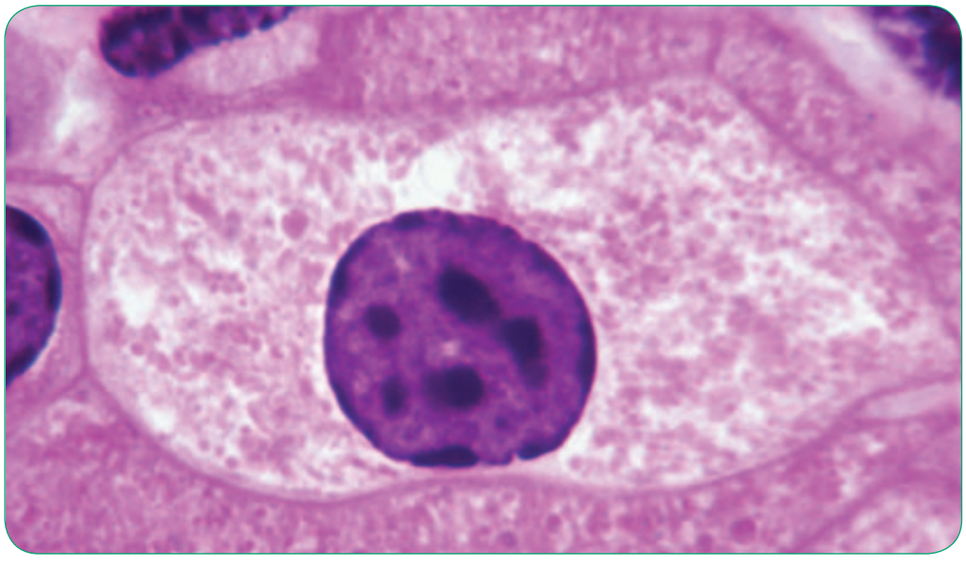


Figure 1.7 Photomicrograph of a stained animal cell (×1800).

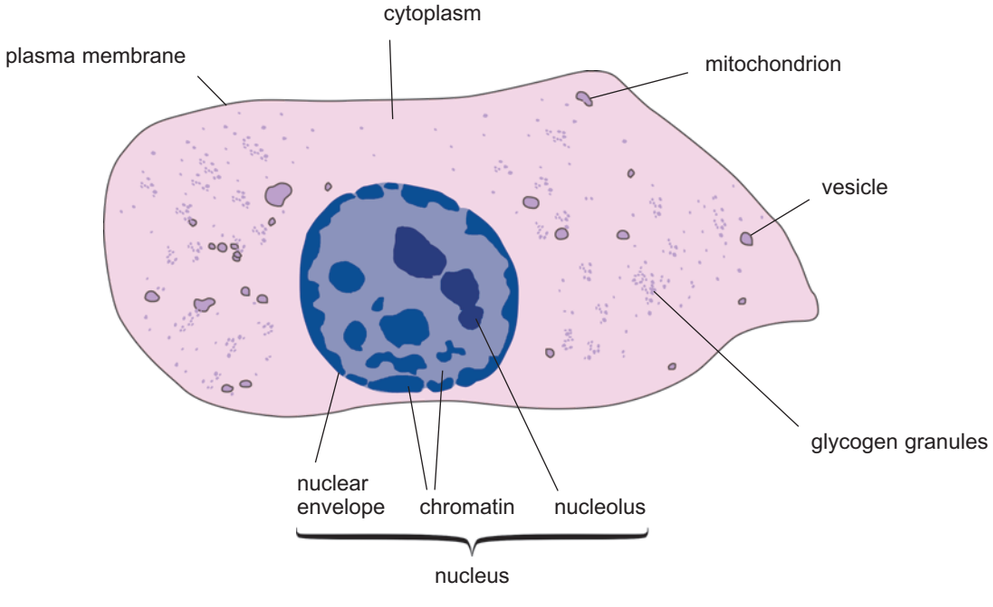


Figure 1.8 A diagram of an animal cell as it appears using a light microscope.

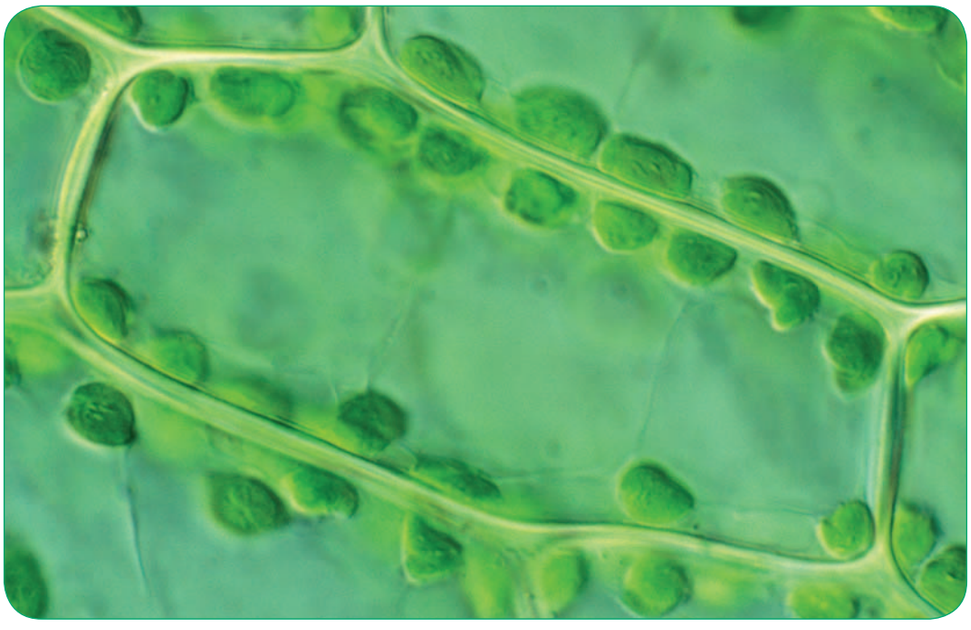


Figure 1.9 Photomicrograph of a cell in a moss leaf (× 750).

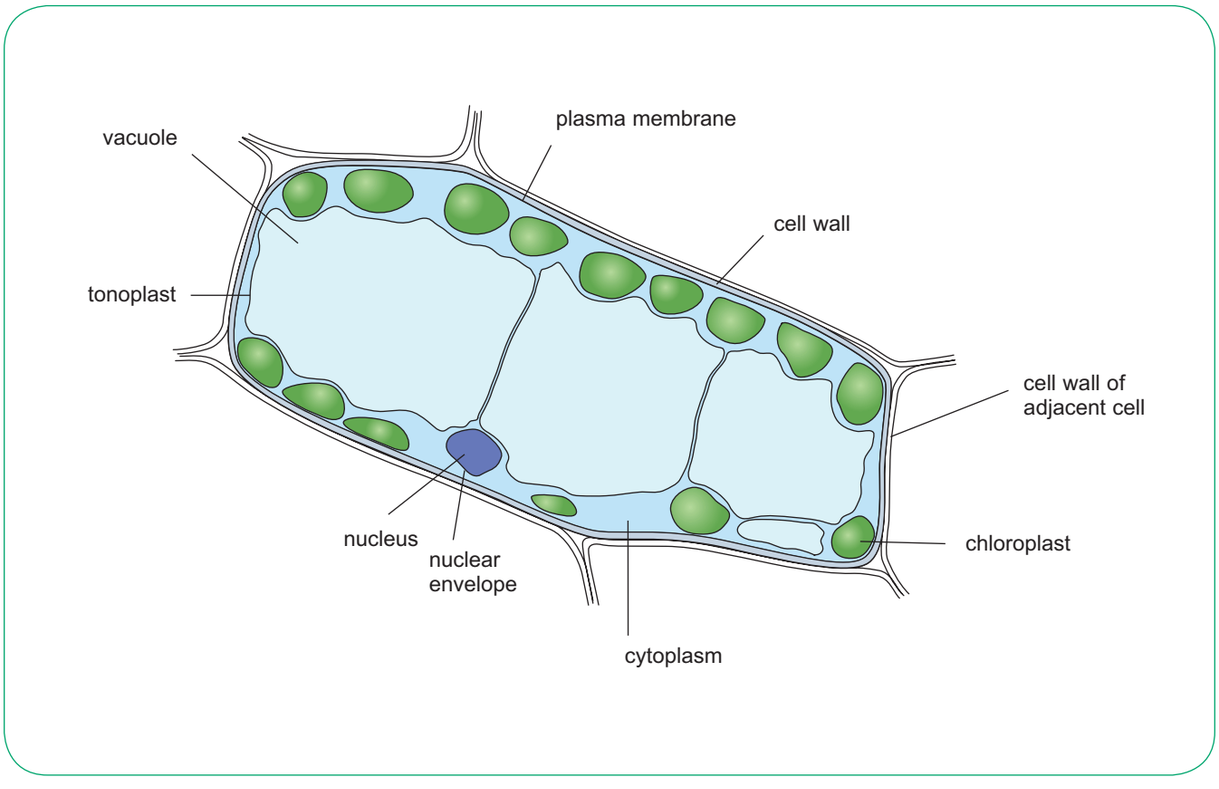


Figure 1.10 A diagram of a plant cell as it appears using a light microscope.

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.

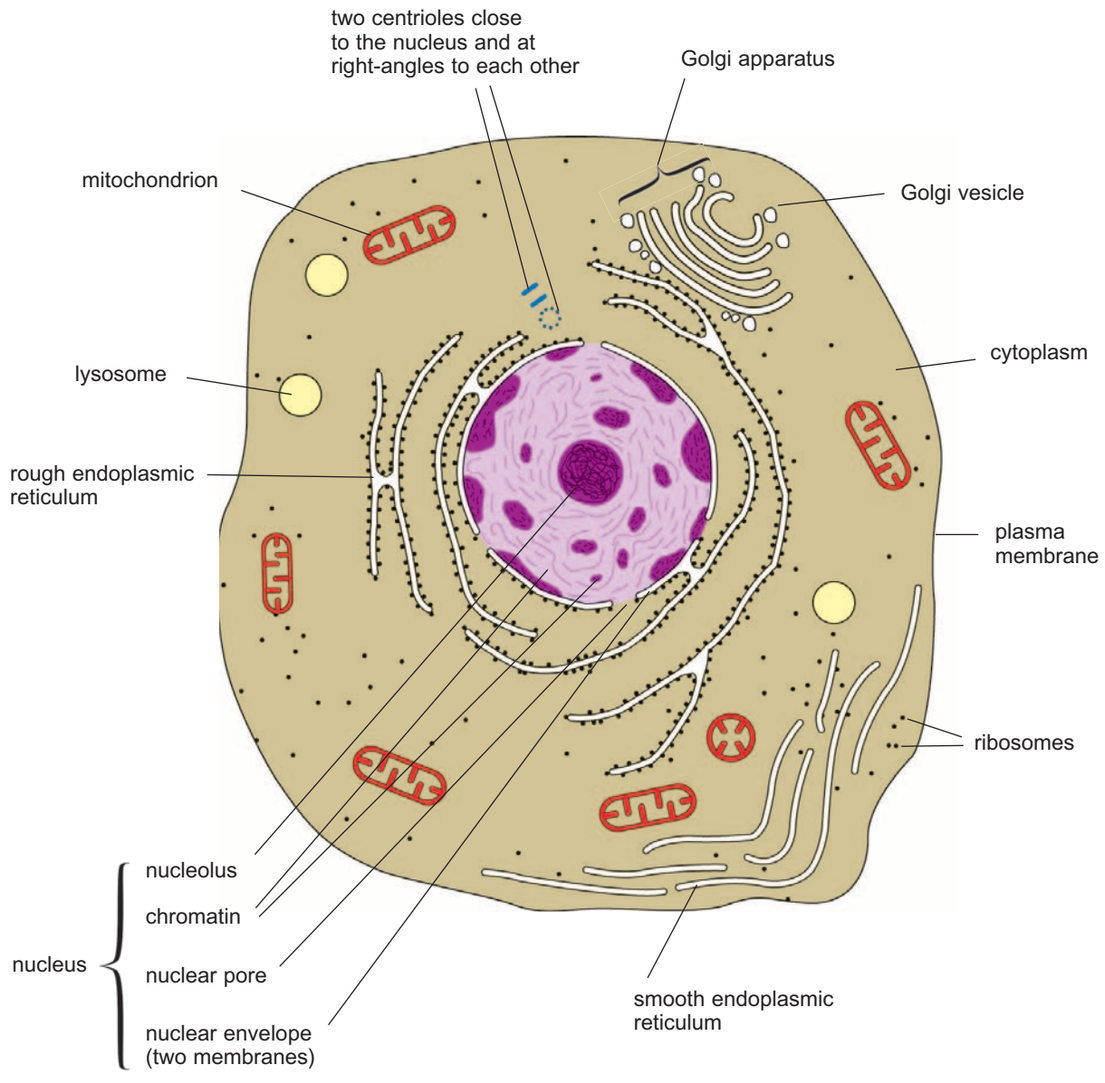


Figure 1.11 Ultrastructure of an animal cell.