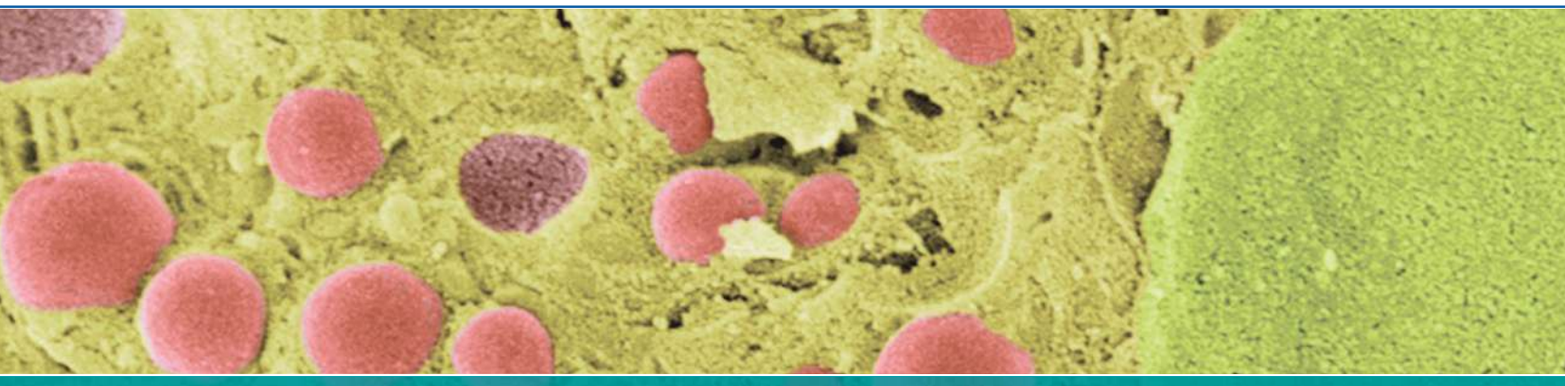


Chapter 1
Cell structure

LEARNING INTENTIONS

In this chapter you will learn how to:

- explain that cells are the basic units of life
- use the units of measurement relevant to microscopy
- recognise the common structures found in cells as seen with a light microscope and outline their structures and functions
- compare the key structural features of animal and plant cells
- use a light microscope and make temporary preparations to observe cells
- recognise, draw and measure cell structures from temporary preparations and micrographs
- calculate magnifications of images and actual sizes of specimens using drawings or micrographs
- explain the use of the electron microscope to study cells with reference to the increased resolution of electron microscopes
- recognise the common structures found in cells as seen with an electron microscope and outline their structures and functions
- outline briefly the role of ATP in cells
- describe the structure of bacteria and compare the structure of prokaryotic cells with eukaryotic cells
- describe the structure of viruses.

BEFORE YOU START

- Make a list of structures that could be found in a cell.
- Try to write down the functions of the structures you have listed.
- Which structures are found in plant cells and which are found in animal cells?
- Are there any cells that are not animal or plant cells?

THINKING OUTSIDE THE BOX

Progress in science often depends on people thinking 'outside the box' – original thinkers who are often ignored or even ridiculed when they first put forward their radical new ideas. One such individual, who battled constantly throughout her career to get her ideas accepted, was the American biologist Lynn Margulis (1938–2011; Figure 1.1). Her greatest achievement was to use evidence from microbiology to help firmly establish an idea that had been around since the mid-19th century – that new organisms can be created from combinations of existing organisms. Importantly, the existing organisms are not necessarily closely related. The organisms form a symbiotic partnership (they live together in a partnership in which both partners benefit). Margulis imagined that one organism engulfed ('ate') another. Normally the engulfed organism would be digested and killed, but sometimes the organism engulfed may survive and even be of benefit to the organism in which it finds itself. This type of symbiosis is known as endosymbiosis ('endo' means inside). A completely new type of organism is created, representing a dramatic evolutionary change.

The best-known example of Margulis' ideas is her suggestion that mitochondria and chloroplasts were originally free-living bacteria (prokaryotes). She suggested that these bacteria invaded the ancestors of modern eukaryotic cells, which are much larger and more complex cells than bacteria, and entered into a symbiotic relationship with the cells. This idea has been confirmed as true by later work. Margulis saw such symbiotic unions as a major driving cause of evolutionary change. Throughout her life, she continued to challenge the traditional view, first put forward by Charles Darwin, that evolution occurs mainly as a result of competition between species.

Figure 1.1: Lynn Margulis: 'My work more than didn't fit in. It crossed the boundaries that people had spent their lives building up. It hits some 30 sub-fields of biology, even geology.'

Questions for discussion

- Can you think of any ideas people have had which were controversial at the time but are now accepted? Try to think of scientific examples. You may also like to consider why the ideas were controversial.
- Can you think of any scientific ideas people have now which are controversial and not accepted by everybody?

1.1 Cells are the basic units of life

Towards the middle of the 19th century, scientists made a fundamental breakthrough in our understanding of how life 'works'. They realised that the basic unit of life is the **cell**.

The origins of this idea go back to the early days of microscopy when an English scientist, Robert Hooke, decided to examine thin slices of plant material. He chose cork as one of his examples. Looking down the microscope, he made a drawing to show the regular appearance of the structure, as you can see in Figure 1.2. In 1665 he published a book containing this drawing.

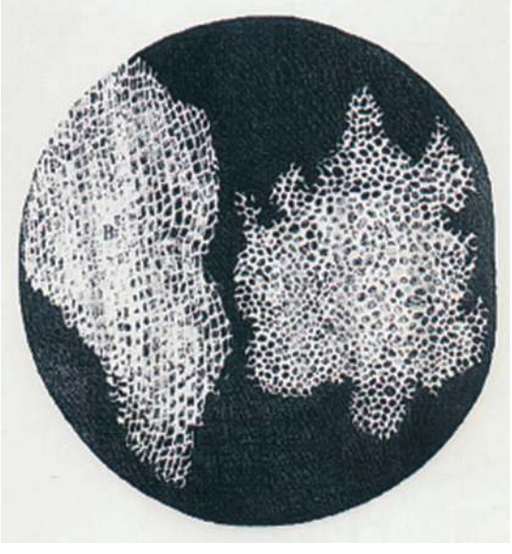


Figure 1.2: Drawing of cork cells published by Robert Hooke in 1665.

If you examine the drawing you will see the regular structures that Hooke called 'cells'. Each cell appeared to be an empty box surrounded by a wall. Hooke had discovered and described, without realising it, the fundamental unit of all living things.

Although we now know that the cells of cork are dead, Hooke and other scientists made further observations of cells in *living* materials. However, it was not until almost 200 years later that a general cell theory emerged from the work of two German scientists. In 1838 Schleiden, a botanist, suggested that all plants are made of cells. A year later Schwann, a zoologist, suggested the same for animals. It was soon also realised that all cells come from pre-existing cells by the process of cell division. This raises the obvious question of where the original cell came from. There are many hypotheses, but we still have no definite answers to this question.

Why cells?

A cell can be thought of as a bag in which the chemistry of life occurs. The activity going on inside the cell is therefore separated from the environment outside the cell. The bag, or cell, is surrounded by a thin membrane. The membrane is an essential feature of all cells because it controls exchange between the cell and its environment. It can act as a barrier, but it can also control movement of materials across the membrane in both directions. The membrane is therefore described as partially permeable. If it were freely permeable, life could not exist, because the chemicals of the cell would simply mix with the surrounding chemicals by diffusion and the inside of the cell would be the same as the outside.

Two types of cell

During the 20th century, scientists studying the cells of bacteria and of more complex organisms such as plants and animals began to realise that there were two fundamentally different kinds of cells. Some cells were very simple, but some were much larger and more complex. The complex cells contained a **nucleus** (plural: **nuclei**) surrounded by two membranes. The genetic material, DNA, was in the nucleus. In the simple cells the DNA was not surrounded by membranes, but apparently free in the cytoplasm.

KEY WORDS

cell: the basic unit of all living organisms; it is surrounded by a cell surface membrane and contains genetic material (DNA) and cytoplasm containing **organelles**

organelle: a functionally and structurally distinct part of a cell, e.g. a ribosome or mitochondrion

nucleus (plural: **nuclei**): a relatively large organelle found in eukaryotic cells, but absent from prokaryotic cells; the nucleus contains the cell's DNA and therefore controls the activities of the cell; it is surrounded by two membranes which together form the nuclear envelope

Organisms made of cells with membrane-bound nuclei are now known as **eukaryotes**, while the simpler cells lacking membrane-bound nuclei are known as **prokaryotes** ('eu' means true, 'karyon' means nucleus, 'pro' means before). Eukaryotes are thought to have evolved from prokaryotes more than two billion years ago. Prokaryotes include bacteria. Eukaryotes include animals, plants, fungi and some other organisms.

KEY WORDS

eukaryote: an organism whose cells contain a nucleus and other membrane-bound organelles

prokaryote: an organism whose cells do not contain a nucleus or any other membrane-bound organelles

1.2 Cell biology and microscopy

The study of cells has given rise to an important branch of biology known as cell biology. Cell biologists study cells using many different methods, including the use of various types of microscope.

There are two fundamentally different types of microscope: the light microscope and the electron microscope. Both use a form of radiation in order to see the specimen being examined. The light microscope uses light as a source of radiation, while the electron microscope uses electrons, for reasons which are discussed later.

Units of measurement

In order to measure objects in the microscopic world, we need to use very small units of measurement, which are unfamiliar to most people. Before studying light and electron microscopy further, you need to become familiar with these units.

According to international agreement, the International System of Units (SI units) should be used. In this system, the basic unit of length is the metre (symbol, m). More units are created by going a thousand times larger or smaller. Standard prefixes are used for the units. For example, the prefix 'kilo' means 1000 times. Thus, 1 kilometre = 1000 metres. The units of length relevant to cell studies are shown in Table 1.1.

The smallest structure visible with the human eye is about 50–100 μm in diameter (roughly the diameter of the sharp end of a pin). The cells in your body vary in size from about 5 μm to 40 μm. It is difficult to imagine how small these cells are, especially when they are clearly visible using a microscope. An average bacterial cell is about 1 μm across. One of the smallest structures you will study in this book is the ribosome, which is only about 25 nm in diameter! You could line up about 20 000 ribosomes across the full stop at the end of this sentence.

1.3 Plant and animal cells as seen with a light microscope

Microscopes that use light as a source of radiation are called light microscopes. Figure 1.3 shows how the light microscope works.

Note: the structure of a light microscope is extension content, and is not part of the syllabus.

Fraction of a metre	Unit	Symbol
one thousandth = 0.001 = 1/1000 = 10^{-3}	millimetre	mm
one millionth = 0.000 001 = 1/1000 000 = 10^{-6}	micrometre	μm
one thousand millionth = 0.000 000 001 = 1/1000 000 000 = 10^{-9}	nanometre	nm

Table 1.1: Units of measurement relevant to cell studies: 1 micrometre is a thousandth of a millimetre; 1 nanometre is a thousandth of a micrometre.

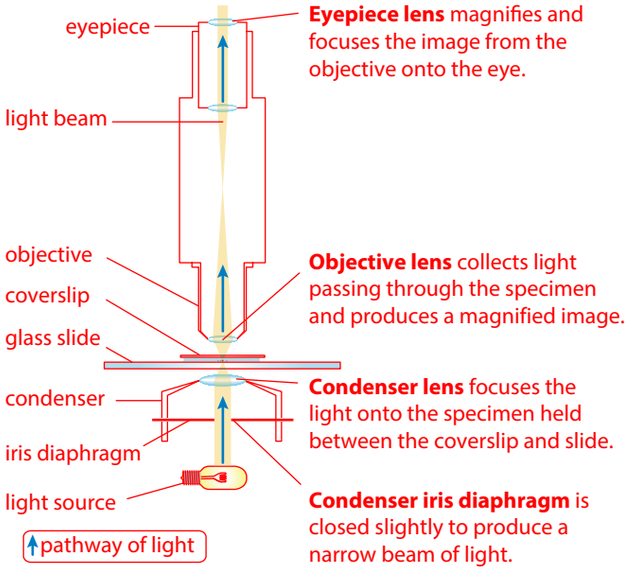


Figure 1.3: How the light microscope works. The coverslip is a thin sheet of glass used to cover the specimen. It protects specimens from drying out and also prevents the objective lens from touching the specimen.

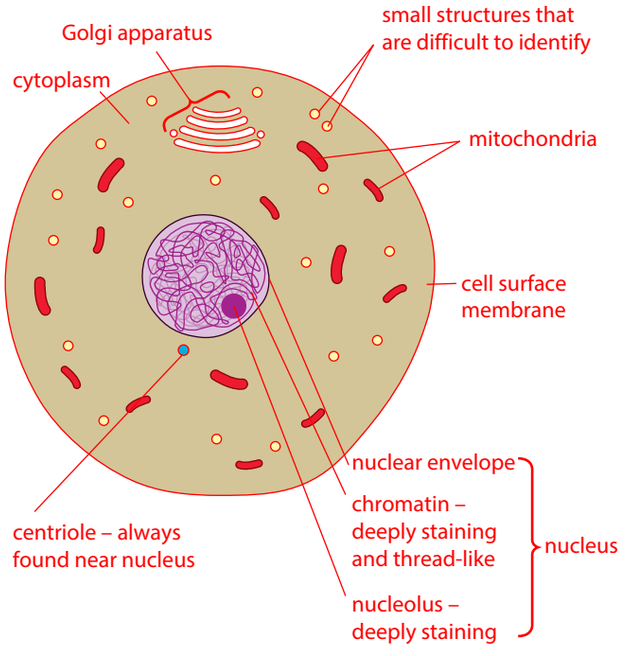


Figure 1.4: Structure of a generalised animal cell (diameter about 20 µm) as seen with a very high quality light microscope.

Figure 1.4 is a drawing showing the structure of a generalised animal cell and Figure 1.5 is a drawing showing the structure of a generalised plant cell, both as seen with a light microscope. (A generalised cell shows all the structures that may commonly be found in a cell.) Figures 1.6 and 1.7 are photomicrographs. A photomicrograph is a photograph of a specimen as seen with a light microscope. Figure 1.6 shows some human cells. Figure 1.7 shows a plant cell taken from a leaf. Both figures show cells magnified 400 times, which is equivalent to using the high-power objective lens on a light microscope. See also Figures 1.8a and 1.8b for labelled drawings of these figures.

Many of the cell contents are colourless and transparent so they need to be stained with coloured dyes to be seen. The human cells in Figure 1.6 have been stained. The chromatin in the nuclei is particularly heavily stained. The plant cells in Figure 1.5 have not been stained because the chloroplasts contain the green pigment chlorophyll and are easily visible without staining.

Question

1 Using Figures 1.4 and 1.5, name the structures that:
   - **a** animal and plant cells have in common
   - **b** are found only in plant cells
   - **c** are found only in animal cells.

Features that animal and plant cells have in common

Cell surface membrane

All cells, including those of both eukaryotes and prokaryotes, are surrounded by a very thin **cell surface membrane**. This is also sometimes referred to as the plasma membrane. As mentioned before, it is partially permeable and controls the exchange of materials between the cell and its environment.

Nucleus

All eukaryotic cells contain a nucleus. The nucleus is a relatively large structure. It stains intensely and

KEY WORD

cell surface membrane: a very thin membrane (about 7 nm diameter) surrounding all cells; it is partially permeable and controls the exchange of materials between the cell and its environment

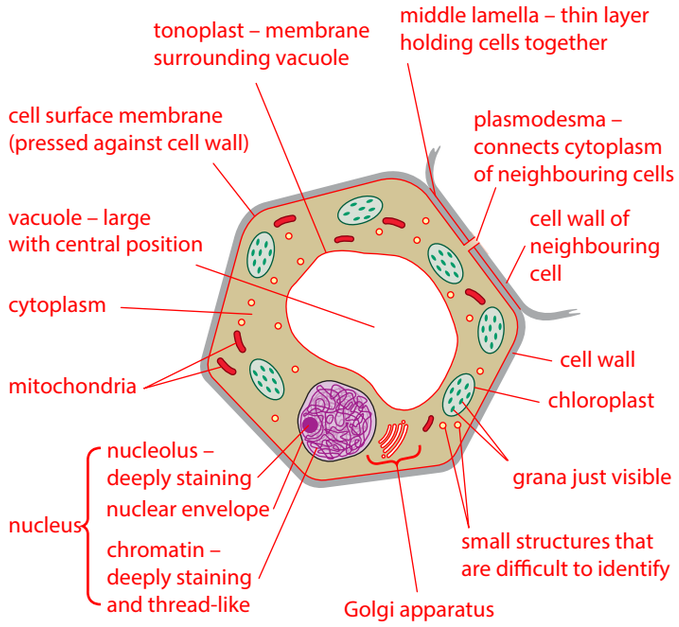


Figure 1.5: Structure of a generalised plant cell (diameter about 40 μm) as seen with a very high quality light microscope.

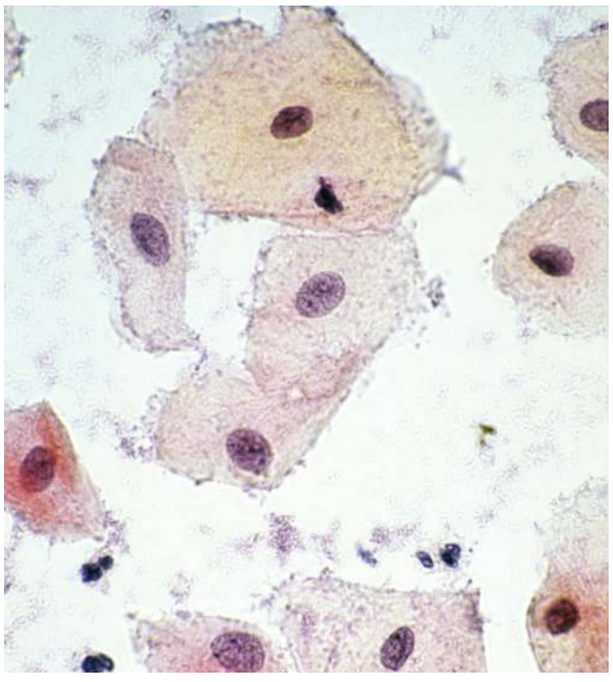


Figure 1.6: Cells from the lining of the human cheek (×400). Each cell shows a centrally placed nucleus, which is typical of animal cells. The cells are part of a tissue known as squamous (flattened) epithelium.

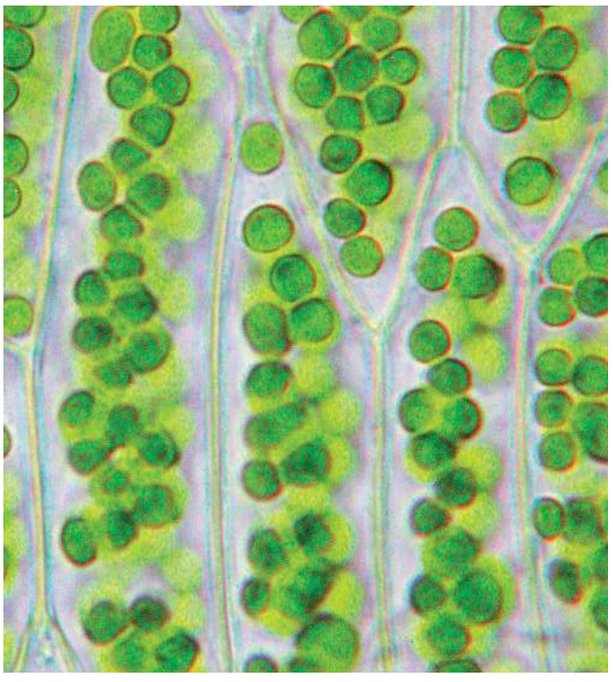


Figure 1.7: Cells in a moss leaf (×400). Many green chloroplasts are visible inside each cell. The grana are just visible as black grains inside the chloroplasts ('grana' means grains). Cell walls are also clearly visible (animal cells lack cell walls).

is therefore very easy to see when looking down the microscope. The deeply staining material in the nucleus is called **chromatin** ('chroma' means colour). Chromatin is a mass of coiled threads. The threads are seen to collect together to form **chromosomes** during nuclear division (Chapter 5, Section 5.2, Chromosomes). Chromatin contains DNA (deoxyribonucleic acid), the molecule which contains the instructions (genes) that control the activities of the cell (Chapter 6).

Inside the nucleus an even more deeply staining area is visible, the **nucleolus**. This is made of loops of DNA from several chromosomes. The number of nucleoli is variable, one to five being common in mammals. One of the main functions of nucleoli is to make ribosomes.

Cytoplasm

All the living material inside the cell is called **protoplasm**. It is also useful to have a term for all the living material outside the nucleus; it is called **cytoplasm**. Therefore, cytoplasm + nucleus = protoplasm.

Cytoplasm is an aqueous (watery) material, varying from a fluid to a jelly-like consistency. Using a light microscope, many small structures can be seen within it. These have been likened to small organs and are therefore known as organelles (meaning 'little organs'). An organelle can be defined as a functionally and structurally distinct part of a cell. Organelles are often, but not always, surrounded by one or two membranes so that their activities can be separated from the surrounding cytoplasm. Organising cell activities in separate compartments is essential for a structure as complex as an animal or plant cell to work efficiently.

Mitochondria (singular: mitochondrion)

The most numerous organelles seen with the light microscope are usually **mitochondria** (singular: **mitochondrion**). Mitochondria are only just visible using a light microscope. Videos of living cells, taken with the aid of a light microscope, have shown that mitochondria can move about, change shape and divide. They are specialised to carry out aerobic respiration.

Golgi apparatus

The use of special stains containing silver resulted in the Golgi apparatus being discovered in 1898 by Camillo Golgi. The Golgi apparatus collects and processes molecules within the cell, particularly proteins.

Note: you do not need to learn this structure. It is sometimes called the Golgi body or Golgi complex.

KEY WORDS

chromatin: the material of which chromosomes are made, consisting of DNA, proteins and small amounts of RNA; visible as patches or fibres within the nucleus when stained

chromosome: in the nucleus of the cells of eukaryotes, a structure made of tightly coiled chromatin (DNA, proteins and RNA) visible during cell division; the term 'circular DNA' is now also commonly used for the circular strand of DNA present in a prokaryotic cell

nucleolus: a small structure, one or more of which is found inside the nucleus; the nucleolus is usually visible as a densely stained body; its function is to manufacture ribosomes using the information in its own DNA

protoplasm: all the living material inside a cell (cytoplasm plus nucleus)

cytoplasm: the contents of a cell, excluding the nucleus

mitochondrion (plural: **mitochondria**)**:** the organelle in eukaryotes in which aerobic respiration takes place

cell wall: a wall surrounding prokaryote, plant and fungal cells; the wall contains a strengthening material which protects the cell from mechanical damage, supports it and prevents it from bursting by osmosis if the cell is surrounded by a solution with a higher water potential

Differences between animal and plant cells

One of the structures commonly found in animal cells which is absent from plant cells is the centriole. Plant cells also differ from animal cells in possessing cell walls, large permanent vacuoles and chloroplasts.

Centrioles

Under the light microscope the centriole appears as a small structure close to the nucleus (Figure 1.4). Centrioles are discussed later in this chapter.

Cell walls and plasmodesmata

With a light microscope, individual plant cells are more easily seen than animal cells. This is because they are usually larger and, unlike animal cells, are surrounded by a **cell wall**. Note that the cell wall is an extra

structure which is outside the cell surface membrane. The wall is relatively rigid because it contains fibres of cellulose, a polysaccharide which strengthens the wall. The cell wall gives the cell a definite shape. It prevents the cell from bursting when water enters by osmosis, allowing large pressures to develop inside the cell (Chapter 4, Section 4.5, Movement of substances across membranes). Cell walls may be reinforced with extra cellulose or with a hard material called lignin for extra strength (Chapter 7). Cell walls are freely permeable, allowing free movement of molecules and ions through to the cell surface membrane.

Plant cells are linked to neighbouring cells by means of pores containing fine strands of cytoplasm. These structures are called **plasmodesmata** (singular: **plasmodesma**). They are lined with the cell surface membrane. Movement through the pores is thought to be controlled by the structure of the pores.

Vacuoles

Vacuoles are sac-like structures which are surrounded by a single membrane. Although animal cells may possess small vacuoles such as phagocytic vacuoles (Chapter 4, Section 4.5, Movement of substances across membranes), which are temporary structures, mature plant cells often possess a large, permanent, central vacuole. The plant vacuole is surrounded by a membrane, the **tonoplast**, which controls exchange between the vacuole and the cytoplasm. The fluid in the vacuole is a solution of pigments, enzymes, sugars and other organic compounds (including some waste products), mineral salts, oxygen and carbon dioxide.

In plants, vacuoles help to regulate the osmotic properties of cells (the flow of water inwards and outwards) as well as having a wide range of other functions. For example, the pigments which colour the petals of certain flowers and the parts of some vegetables, such as the red pigment of beetroots, may be found in vacuoles.

Chloroplasts

Chloroplasts are organelles specialised for the process of **photosynthesis**. They are found in the green parts of the plant, mainly in the leaves. They are relatively large organelles and so are easily seen with a light microscope. It is even possible to see tiny 'grains' or **grana** (singular: **granum**) inside the chloroplasts using a light microscope (Figure 1.7). These are the parts of the chloroplast that contain chlorophyll, the green pigment which absorbs light during the process of photosynthesis. Chloroplasts are discussed further in Chapter 13 (Section 13.2, Structure and function of chloroplasts).

KEY WORDS

plasmodesma (plural: **plasmodesmata**): a pore-like structure found in plant cell walls; plasmodesmata of neighbouring plant cells line up to form tube-like pores through the cell walls, allowing the controlled passage of materials from one cell to the other; the pores contain ER and are lined with the cell surface membrane

vacuole: an organelle found in eukaryotic cells; a large, permanent central vacuole is a typical feature of plant cells, where it has a variety of functions, including storage of biochemicals such as salts, sugars and waste products; temporary vacuoles, such as phagocytic vacuoles (also known as phagocytic vesicles), may form in animal cells

tonoplast: the partially permeable membrane that surrounds plant vacuoles

chloroplast: an organelle, bounded by an envelope (i.e. two membranes), in which photosynthesis takes place in eukaryotes

photosynthesis: the production of organic substances from inorganic ones, using energy from light

grana (singular: **granum**): stacks of membranes inside a chloroplast

IMPORTANT

- You can think of a plant cell as being very similar to an animal cell but with extra structures.
- Plant cells are often larger than animal cells, although cell size varies enormously.
- Do not confuse the cell wall with the cell surface membrane. Cell walls are relatively thick and physically strong, whereas cell surface membranes are very thin. Cell walls are freely permeable, whereas cell surface membranes are partially permeable. All cells have a cell surface membrane, but animal cells do not have a cell wall.
- Vacuoles are not confined to plant cells; animal cells may have small vacuoles, such as phagocytic vacuoles, although these are not usually permanent structures.

PRACTICAL ACTIVITY 1.1

Making temporary slides

A common method of examining material with a light microscope is to cut thin slices of the material called 'sections'. The advantage of cutting sections is that they are thin enough to allow light to pass through the section. The section is laid ('mounted') on a glass slide and covered with a coverslip to protect it. Light passing through the section produces an image which can then be magnified using the objective and eyepiece lenses of the microscope.

Biological material may be examined live or in a preserved state. Prepared slides contain material that has been killed and preserved in a life-like condition.

Temporary slides are quicker and easier to prepare and are often used to examine fresh material containing living cells. In both cases the sections are typically stained before being mounted on the glass slide.

Temporary preparations of fresh material are useful for quick preliminary investigations. Sometimes macerated (chopped up) material can be used, as when examining the structure of wood (xylem). A number of temporary stains are commonly used. For example, iodine in potassium iodide solution is useful for plant specimens. It stains starch blue-black and will also colour nuclei and cell walls a pale yellow. A dilute solution of methylene blue can be used to stain animal cells such as cheek cells.

Viewing specimens yourself with a microscope will help you to understand and remember structures. Your understanding can be reinforced by making a pencil drawing on good quality plain paper. Remember always to draw what you see, and not what you think you should see.

Procedure

Place the biological specimen on a clean glass slide and add one or two drops of stain. Carefully lower a cover over the specimen to protect the microscope lens and to help prevent the specimen from drying out. Adding a drop of glycerine and mixing it with the stain can also help prevent drying out.

- Suitable animal material: human cheek cells obtained by gently scraping the lining of the cheek with a finger nail
- Suitable plant material: onion epidermal cells, lettuce epidermal cells, *Chlorella* cells, moss slip leaves

(See Practical Investigation 1.1 in the Practical Workbook for additional information.)

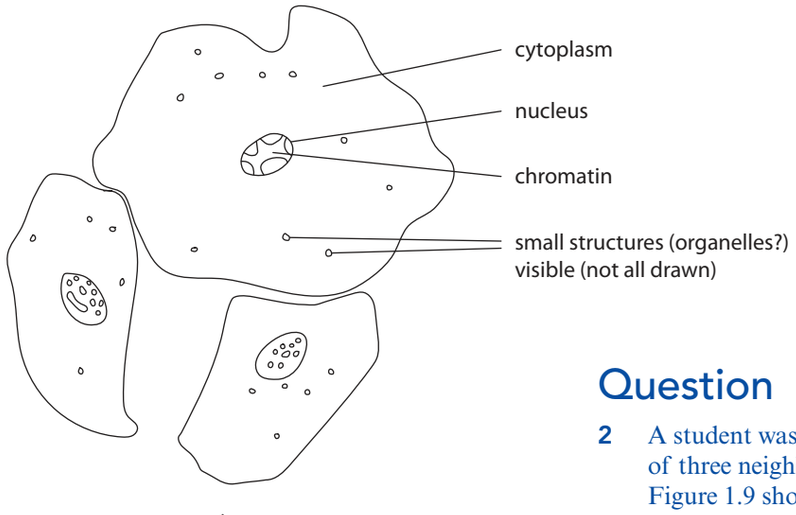
PRACTICAL ACTIVITY 1.2

Biological drawing

To reinforce your learning, you will find it useful to make labelled drawings of some of your temporary and permanent slides, as well as labelled drawings of photomicrographs.

Practical Activity 7.1 in Chapter 7 provides general guidance on biological drawing. Read the relevant sections of Practical Activity 7.1 before answering the question below, which is relevant to this chapter. Figures 1.8a and b show examples of good drawing and labelling technique based on Figures 1.6 and 1.7. Note that it is acceptable to draw only a representative portion of the cell contents of Figure 1.7, but add a label explaining this.

a



b

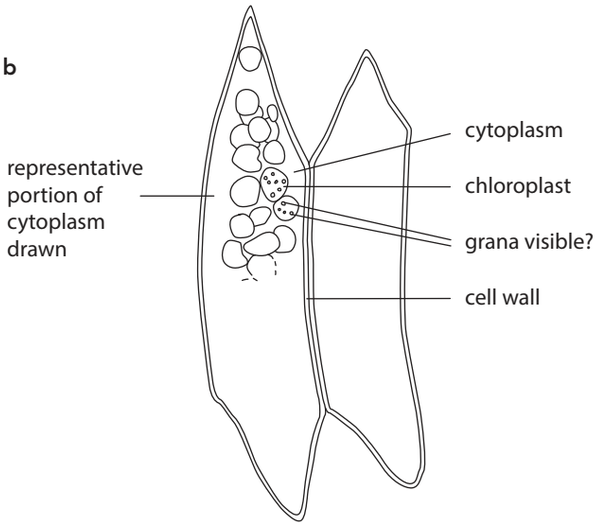


Figure 1.8: Examples of good drawing technique: **a** high-power drawing of three neighbouring animal cells from Figure 1.6; **b** high-power drawing of two neighbouring plant cells from Figure 1.7.

Question

2 A student was asked to make a high-power drawing of three neighbouring cells from Figure 1.6. Figure 1.9 shows the drawing made by the student.

Using Practical Activity 7.1 to help you, suggest how the drawing in Figure 1.9 could be improved.

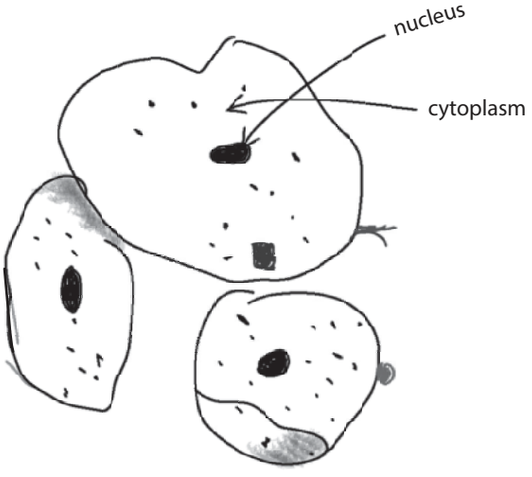


Figure 1.9: A student's high-power drawing of three neighbouring cells from Figure 1.6.

(See Practical Investigation 1.1 in the Practical Workbook for additional information.)