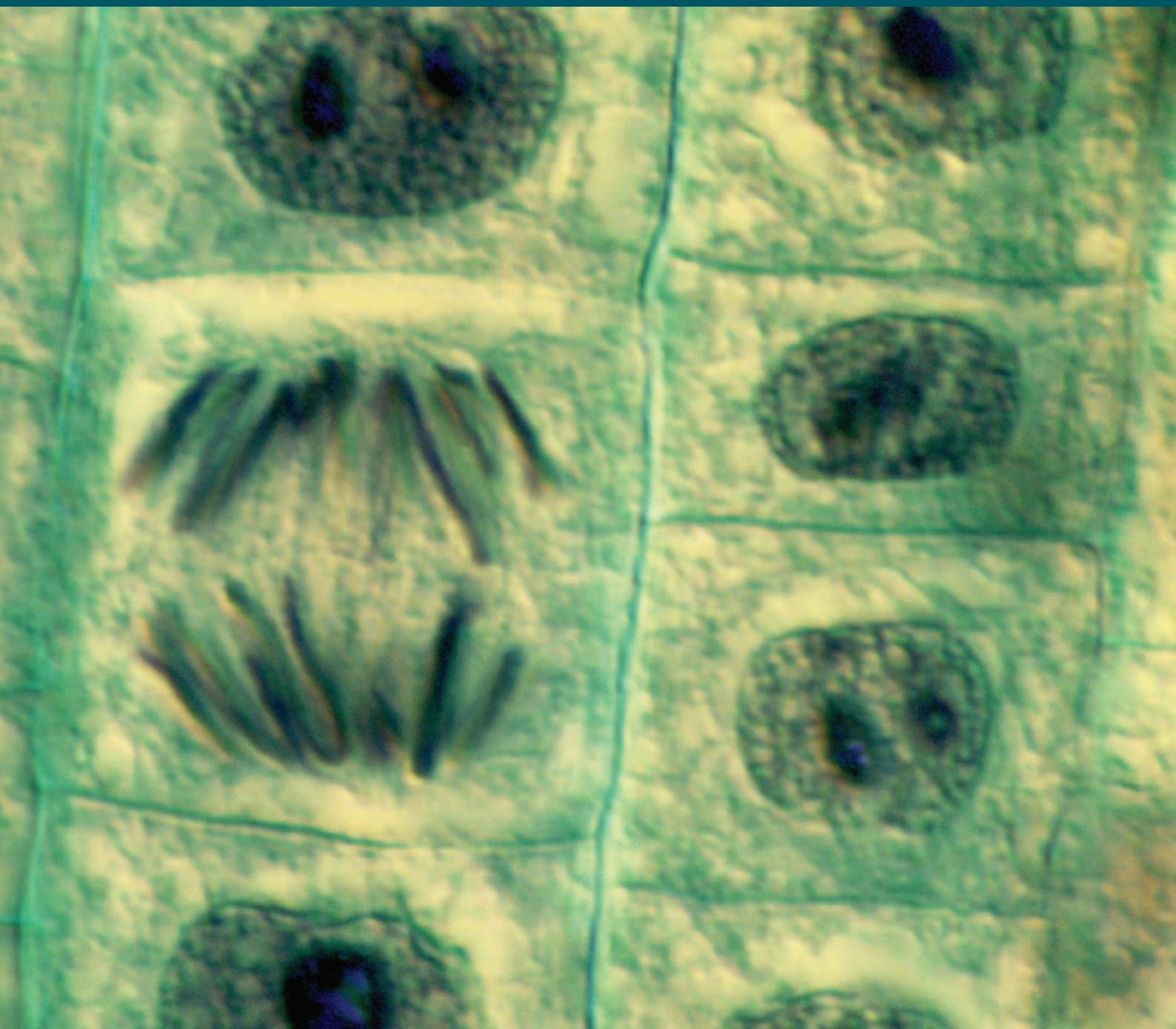
PATTERNS IN NATURE



TIMELINE: a short history of biology

MICROSCOPE BEGINNINGS

1590	*Hans and Zacharias Jansen* made the first **compound microscope** by placing two convex **lenses** in a tube.
1663	*Robert Hooke* introduced the term '**cell**' while observing cork under a light microscope. He also worked at improving a number of scientific devices, including the microscope, telescope and barometer.
1668	*Francesco Redi* conducted an experiment to challenge the theory of '**spontaneous generation**'.
1674–1683	*Anton Van Leeuwenhoek*, a Dutch lens maker: ■ produced *lenses* of higher quality, which allowed for greater magnification (up to 200 times). ■ described 'animacules' (unicells) ■ discovered bacteria.
1758	*John and Peter Dollard* (father and son), spectacle makers, produced the first achromatic (colour-free) *lenses*, making microscopes superior to hand lenses.

THE SCIENTIFIC REVOLUTION

the cell theory

1796	*Edward Jenner* used cowpox in the first successful **vaccine** against the disease **smallpox**.
1801	*Robert Brown* a botanist and naturalist, first described the cell **nucleus** while observing plant cells in an orchid. He also noticed the random movement of pollen grains (Brownian motion).
1836	*Charles Darwin* arrived in Sydney Harbour aboard HMS *Beagle*.
1838	*Matthias Schleiden*, a **botanist**, stated that parts of plants are made of *cells* (not visible to the unaided eye).
1839	*Theodor Schwann*, a **zoologist**, stated that parts of animals are made of *cells*; agreed with Schleiden and they published **the cell theory** in a book, stating that the cell is the basis of the structure of all living things.
1843	*Robert Koch* studied the cause of the disease **anthrax**.
1855	*Rudolph Virchow* introduced the idea that cells reproduce by dividing, stating that all living cells can only arise from other living cells, further challenging the theory of 'spontaneous generation'.

evolution

1856–1858	*Gregor Mendel* began a series of controlled experiments with garden peas, to carry out a statistical study of **heredity**.
1858	*Charles Darwin* and *Alfred Wallace* presented a paper 'A Theory of **Evolution** by **Natural Selection**'.
1859	*Charles Darwin*'s book, *On the Origin of Species*, is published.
1860	The *Huxley–Wilberforce* debate takes place.

germ theory of disease

1861	*Louis Pasteur* published his experiments showing that **fermentation** was caused by something in the air, finally disproving 'spontaneous generation'.
1862	*Louis Pasteur*'s experiments with bacteria showed that infectious diseases are caused by micro-organisms, leading to the *germ theory of disease*.
1863	*Louis Pasteur* introduced **pasteurisation**, a practical application of what he had learnt through his fermentation experiments.
1866	*Gregor Mendel* published his work on *studying plant hybrids*.
1867	*Joseph Lister* made the connection between Pasteur's work on infection and introduced *antiseptic surgery* (published paper).
1880	*Charles Louis Alphonse Laveran* first identified cause of **malaria**: a microscopic organism.
1881	*Pasteur* developed a vaccine against anthrax.

CLASSICAL SCIENCE	disease	1882	*Walther Flemming* discovered nuclear material—termed '**chromatin material**'.
		1882–1893	*Koch* proposed *postulates*: 'rules of engagement' for bacteriologists.
		1885	*Pasteur* used a vaccine against **rabies** on humans for the first time, saving the life of a young boy who had been bitten by a dog.
		1891	*Robert Koch* concluded that malaria was transmitted by mosquitoes.
		1897	*Ronald Ross* demonstrated that female *Anopheles* mosquitoes were the **vectors** *(carriers) of malaria*, by showing that these mosquitoes carried malarial oocysts in their gut tissue.
	genetics	1900	Significance of *Mendel*'s experiments in terms of heredity is noticed after three other scientists get similar results.
		1902	*Walter Sutton* and *Theodore Boveri* independently proposed and demonstrated a connection between **chromosomes** and inheritance. Sutton studied meiosis in grasshoppers. Boveri studied chromosome behaviour and inheritance in sea urchins.
		1911	*Thomas Hunt Morgan* studied *sex-linked inheritance* (Nobel Prize in 1933 for life's work).
		1909	*Wilhelm Johannsen* introduced the term 'gene'.
	microscope advances, microbes and antibiotics	1928	*Alexander Fleming* noticed that the mould *Penicillium* killed bacteria in a petri dish.
		1933	*Ernst Ruska* built the first **electron microscope**.
		1935	*Howard Florey* began to search for a useful medicine to kill germs.
		1938	*Fritz Zernike* invented the **phase contrast microscope** which can be used to observe living, unstained cells.
		1939	*Howard Florey* extracted stable **penicillin** (the first antibiotic).
		1941	*George Beadle* and *Edward Tatum* published the results of their experiments with bread mould, in which they proposed the *one-gene-one-enzyme (protein) hypothesis*.
		1942	Viruses first seen under the electron microscope.
		1945	*Frank McFarlane Burnet* isolated influenza A virus (in Australia) and developed a vaccine.
		1945	*Howard Florey* and *Alexander Fleming* received the Nobel Prize for Physiology and Medicine for their work on penicillin.
CONTEMPORARY SCIENCE	molecular technology, biotechnology and health	1950	*Rosalind Franklin* and *Maurice Wilkins* made a crystal of **DNA** to study its structure.
		1953	*James Watson* and *Francis Crick* put together a model of DNA.
		1955	*Marvin Minsky* invented the *scanning* electron microscope.
		1960	*Frank McFarlane Burnet* and *Peter Medawar* received the Nobel Prize for Physiology and Medicine for their work in *immunology* and *organ transplants*.
		1962	*Vernon Ingram* did further work on genes and proteins leading to the change to the *one-gene-one-polypeptide hypothesis*.
		1962	*Watson, Crick* and *Wilkins* received the Nobel Prize for Chemistry for their discovery of DNA. (Rosalind Franklin died in 1958; her work was acknowledged, but Nobel prize nominations cannot be awarded posthumously.)
		1972	*Niles Eldridge* and *Stephen Jay Gould* put forward the theory of *evolution by punctuated equilibrium*.
		1980	**WHO** declared the disease smallpox eradicated worldwide.
		To present	Genetic and reproductive revolution: in-vitro fertilisation, genetic engineering, cloning and advanced biotechnology.

Note: Dates in many timelines show slight inconsistencies when compared. This is due to inconsistent record-keeping long ago. It is the *sequence of events* that is more important in reflecting the historical developments in science, than the absolute dates.

CHAPTER 1

Cells and the cell theory

Organisms are made of cells that have similar structural characteristics

Introduction

Up until 400 years ago, objects that were too small to be seen with the naked eye could not be examined successfully. Magnifying glasses had been in use since the 13th century, but were still fairly ineffective instruments of observation because of the imperfect shape of the lenses and the low quality of the glass used to produce them.

The study of living things was popular, but at a **macroscopic** level, based on what could be viewed with the naked eye or with the lenses available—living organisms had certainly never been considered at a cellular level. Biologists at that time were called 'natural scientists', suggesting a broad study of nature. Today, biologists study living things not only at a macroscopic level, but also at a **microscopic** (cellular and sub-cellular) level and even at a molecular level. This progress began with the discovery of the microscope.

Characteristics of living organisms

From your studies in junior science, you will be familiar with today's accepted idea that all living things are made of one or more units called cells. This is the most basic characteristic of *living* things. How does one distinguish between something that is *living* and a *non-living* thing? All living things are made of cells, but based on everyday observations without using a microscope what tells us that, for example a beetle is alive but a stone is not?

Certain characteristics or life functions are common to all living things. Living things are made of one or more cells and they can:

- *reproduce*—produce offspring that resemble the parents
- *grow*–increase in size
- *move*—even plants can make some small movements such as opening and closing petals

Figure 1.1 Living or non-living? A beetle as opposed to stones

- *respire*—produce chemical energy by taking in oxygen and combining it with sugar, giving out carbon dioxide as a by-product
- *excrete*—get rid of wastes such as carbon dioxide
- *respond to stimuli* in the environment—such as moving towards food or growing towards light
- *obtain nutrients*
- *die*—death is when all of the above functions cease.

To be *dead*, something must have once been living and when all of its life functions cease, death results. This differs from *non-living* things that are not alive and never were.

These functions of life are easy to picture in complex **multicellular** organisms, such as insects, sunflowers and humans. In **unicellular** organisms (microscopic living things made of only one cell), all of the life functions listed above still occur, but each single cell carries out every function.

The discovery of the cellular basis of living things

1.1

- ***outline the historical development of the cell theory, in particular, the contributions of Robert Hooke and Robert Brown***

Introduction

The statement that *all living things are made of cells* forms the basis of what is currently termed *the cell theory*. The historical development of the cell theory is interwoven with the story of the invention and development of the microscope. Improvements in the design and use of microscopes, as well as progress in techniques to prepare specimens for viewing, play a significant part in advancing our knowledge and understanding of cells.

To study the *historical development* of a theory (see PFA P1 on page ix), we need to know the currently accepted view ('now') and the views in the past ('then'). New ideas are often linked to *advances in technology*, which allow new discoveries to be made (see PFA P3 on page ix).

(The PFAs or Prescribed Focus Areas are different emphases in the Preliminary and HSC biology curriculum designed to increase students' understanding of biology as an ever-developing science. See page ix.)

The cell theory

The cell theory forms the basis of all biology. In its universally accepted form, it states that:

1. All living things are made of cells.
2. Cells are the basic structural and functional unit of organisms.
3. All cells come from pre-existing cells.

However, this has not always been the accepted biological view.

A **scientific theory** is a broad and general idea or *explanation* provided by scientists, and is related to observations and is supported by a large amount of evidence. It is not a fact and cannot be proved; it can only be supported or not supported by evidence. Since an explanation is a product of the mind, it is not a fact and therefore a theory may have to be modified if new evidence arises that no longer supports it.

Theories are tested by examining whether their consequences (predictions) are supported by observation and experiment.

The build up to the proposal of the cell theory is interesting and, in reading this historical account, we as scientists should look for evidence that has been gathered to validate the theory before we accept it (see PFA P2 on page ix).

Biological view prior to the proposal of the cell theory

Before the discovery of the microscopic world

Until the last decade of the 16th century, microscopes did not exist, cells had never been seen and so the living world had not been considered at a cellular level. One of the accepted views was the theory of **spontaneous generation**. This theory predicted that living creatures could arise from inanimate (non-living) material. This idea dated back to the time of Aristotle and the evidence was based on observation. For example it was noticed that maggots (fly larvae) appeared on rotting meat if meat was left exposed for a period of time. In the 1500s, this theory was being challenged, but it was not until the mid 1600s that scientists suggested that the flies that visited the meat contributed to the appearance of the maggots. Francesco Redi (1668) performed an experiment that tested this hypothesis successfully, showing that maggots only appeared in meat that had been exposed to flies in the environment—if the meat was covered, no maggots arose. This is one of the first recorded examples of experimentation being used to oppose a theory—an example of the '**scientific method**' of today (see PFA P3 on page ix).

The idea that the meat 'spontaneously' gave rise to maggots may seem ridiculous now, but seems less so if one considers that people could not see fly eggs in those days. What happened between 1500 and 1668, to encourage people to think differently?

The invention of the compound microscope

In the late 1500s, scientists, who were using poor quality magnifying glasses to view small or 'minute' objects, tried many things to improve the images that they were viewing. The idea that led to the invention of the first compound microscope was that, to get a larger and clearer image, two convex lenses could be placed one above the other. The lower lens would produce a magnified image of the object and the upper lens would further magnify or enlarge the first image.

Two Dutch lens makers, a father and son named *Hans and Zacharias Janssen*, are credited with having made the first compound microscope in 1590. A **simple microscope** uses only one lens to magnify an object viewed, so the invention of the **compound microscope** relied on the principle of using *two* lenses, kept *a set distance apart*. It consisted quite simply of two convex lenses placed at either end of a wooden tube to keep them the ideal distance apart from each other. These tubes could magnify objects 3 to 9×, were held by hand and formed the basis of the first compound microscopes. (They had not as yet been named microscopes.)

Discovering a compound microscope

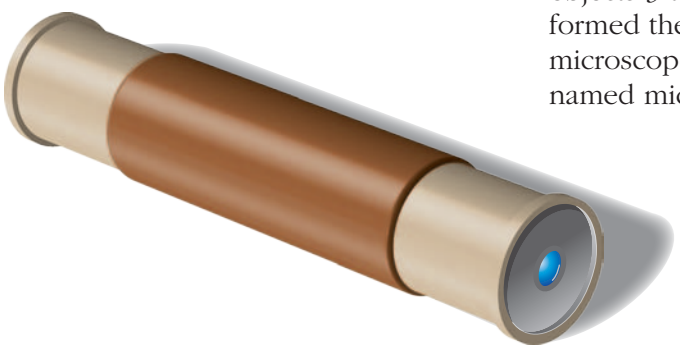


Figure 1.2 The first compound microscope (circa 1595)

Biological studies and technology that led to the proposal of the cell theory

Technology: improvements to the compound microscope

As people across Europe continued to use what are today known as compound microscopes, these instruments were being refined and improved upon all the time. By the early 1620s, most microscopes in use had a magnification of about 30×, but it is recorded that those used in Italy had magnifications of about 150×. This was probably due to the high quality glass that the Italians used, producing lenses of greater clarity. (Italy is still renowned for its high quality glass today.)

For a lens to be effective, it needs to do two things:

1. give an enlarged view of an object
2. make the detail appear clear, giving a precise (not fuzzy), outline to the parts of the object being viewed.

The ability to enlarge an image is termed **magnification**. The ability to show fine detail, distinguishing two very close objects as separate images, is termed **resolution**. A good quality lens is one that has *high magnification* and *high resolution*. The convex shape () of a lens enables it to magnify an object, but to get this shape, one has to grind the glass. Both the quality of the glass used, as well as the manner in which the glass is ground to minimise imperfections, play a role in determining a lens's resolution or resolving power.

During the 17th century, the hand-held tube designed by the Janssens was mounted onto a stand and the design of the microscope as we know it today began to take shape. *Robert Hooke* in England, *Anton van Leeuwenhoek* in Holland, and *Galileo Galilei* in Italy all made noted contributions to improving the design of microscopes.

Robert Hooke's compound microscope was progressive for its time because it used a fine adjustment knob to move the tube holding the lenses up and down. His microscope also had a light source to illuminate the specimen—another lens that concentrated the glow of a candle onto the specimen. Hooke probably had his microscopes built London, but he ground his own lenses. He gave the first demonstration of the use of his microscope to the Royal Society of London in 1663.

Biological view: understanding living things using a microscope

Robert Hooke

In 1665 Robert Hooke produced a book, the first recorded publication to describe observations of living tissue using a microscope. Entitled *Micrographia: physiological studies of minute bodies made by magnifying glasses*, his book included 57 diagrams. It was in this book that he used the term '**cell**' to describe the 'honeycomb' elements (units) of cork. He was looking at dead plant cells which had no contents and clearly resembled small *compartments,* similar to the cells of monks. Hooke's findings were respected, but not universally accepted by scientists at that time.

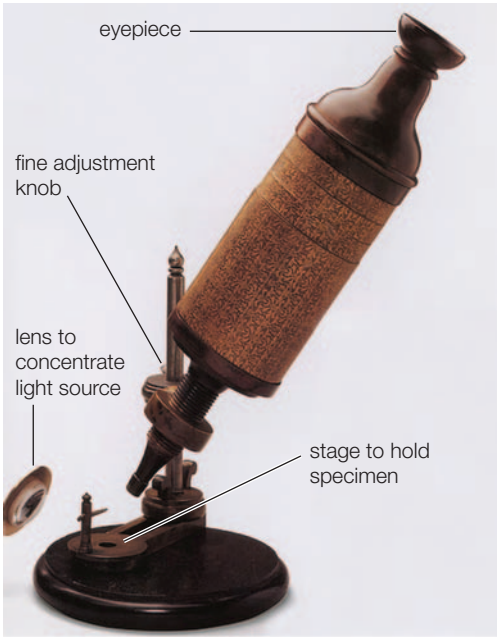


Figure 1.3
Hooke's compound microscope

The low quality lenses in use still distorted images and separated colours, giving a rainbow 'fringe' to the objects being viewed and so many scientists were sceptical about the 'artificial images' created.

Anton Van Leeuwenhoek

Anton Van Leeuwenhoek was a Dutch lens maker whose grinding technique was far superior to that of his contemporaries and so he was able to produce lenses of much higher quality. As a result of his work between 1674 and 1683 with crystal, quartz and even diamond lenses, he developed a **simple microscope** that used a *single*, powerful lens that could magnify up to 300×, perhaps more. The single lens used did not have the usual aberrations associated with lenses at that time. Unfortunately, Van Leeuwenhoek did not record his technique and so similar lenses could not be produced after his death. Starting off in the cloth trade, Van Leeuwenhoek used very many microscopes to study both fabrics and a great variety of living tissue. He discovered many single-celled living things, but because there was no cell theory at the time Van Leeuwenhoek had no framework in which to accurately name or describe his findings. When Van Leeuwenhoek first presented his work to the Royal Society of London they asked Robert Hooke, a member of the society, to confirm these findings, which he did. Evidence of Van Leeuwenhoek's findings are documented in letters to the Royal Society, spanning 50 years. These letters have been translated from Dutch into English and Latin. Van Leeuwenhoek is credited with discovering bacteria, and from his descriptions, may have even seen nuclei.

Figure 1.4
Van Leeuwenhoek's simple microscope

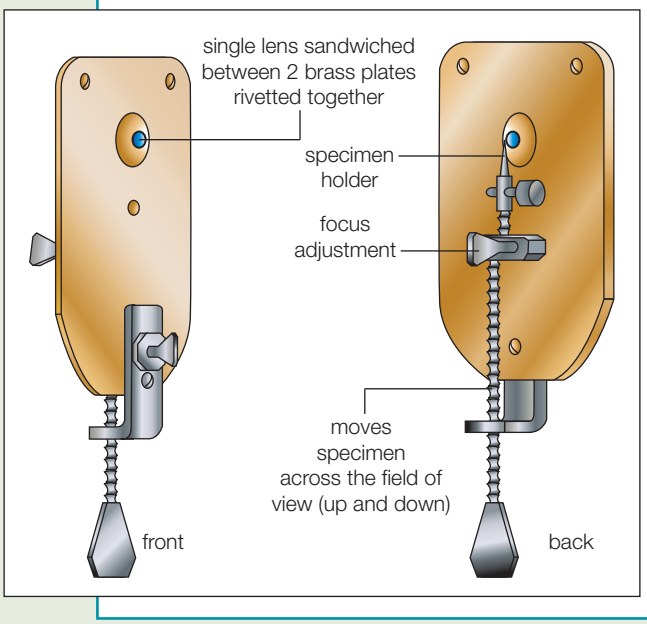


Figure 1.5 Robert Brown

Robert Brown

Robert Brown, a Scottish botanist, is known for his discovery of the cell **nucleus** (plural *nuclei*). Although he first described nuclei seen in the outer layer of cells in orchid plant tissue, he discovered that nuclei were present in a wide variety of plant tissues that he studied. He had no idea at that time of the importance of the nucleus or its function in cells. (Robert Brown is famous in science for his diverse discoveries, including being the first person to observe and describe Brownian motion. He also travelled on a ship with Captain Mathew Flinders to Australia in 1801 and he identified many genera of Australian plants.)

Microscopes as valid scientific instruments

It was about 200 years after the discovery of microscopes, from the time when the first compound *optics* microscopes were in use (1824), that microscopes began to be acknowledged as useful scientific instruments. The lenses of these optics microscopes were achromatic (did not separate colours) and they no longer produced distorted images. There was the added benefit of powerful light sources and precise focusing screws, thereby increasing the precision of the instruments in general. With the improved technology, scientists became less suspicious of the 'artificial images' and observations made were accepted as valid scientific evidence. It is not surprising that, shortly after this time, the *cell theory* was proposed.

Schwann and Schleiden

In 1838, apparently over a cup of coffee after dinner, two German scientists—*Theodor Schwann* and *Matthias Schleiden*, were discussing the results of their microscopic studies of living things. As Schleiden (a botanist) described the regular placement of nuclei that he had observed in plant cells, Schwann (a zoologist) recognised a similarity to the animal cells that he had been studying and they both went right then to Schwann's laboratory to look at his slides. It was the first time that a *common basic structure for all living things* had become evident. A year later (1839) Schwann published a book on plant and animal cells, listing three main conclusions, two of which are still accepted today as the basis for **the cell theory**. Schwann's first two conclusions are summarised below.

1. *The cell is the unit of structure of all living things.*
2. *The cell exists as a distinct entity and as a building block in the construction of organisms.*

Further investigation led to evidence that his third conclusion, *cells form by free-cell formation, similar to the formation of crystals*, is not valid.

Rudolf Virchow

The accepted version of how cells arise is attributed to a German medical scientist, *Rudolf Virchow*. In 1855 his studies led to his statement that: 'Where a cell arises, there a cell must have previously existed'. From this is derived the accepted third statement of the cell theory:

3. *All cells come from pre-existing cells.*

Virchow had not only discovered cell division but, by implying that living things could not arise from non-living elements, had convincingly refuted spontaneous generation. In 1879, *Walther Fleming* confirmed Virchow's observations and named the process of division **mitosis**.

Effect of microscope on disease theory

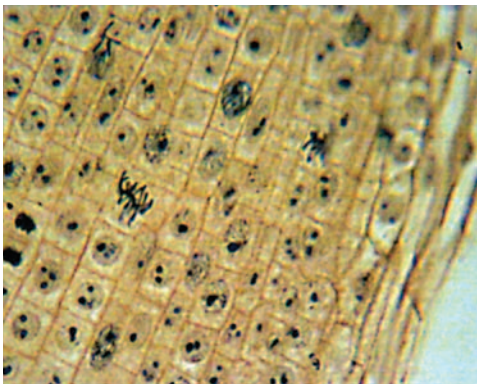
From the time of Hippocrates until the discovery of cells, it was believed that disease resulted from 'imbalance in body humors'. This was replaced with a cell-based theory of disease—look at the timeline (see pages 61–5) to discover the close relationship between the discovery of the cell theory and advances in the understanding of disease.

Collaboration in science: the importance of the contributions of Hooke and Brown

Although the work of other scientists was not formally acknowledged by Schwann in his book, the basic cell theory is today attributed to both Schleiden and Schwann and significance is given to the work of previous scientists such as Hooke and Brown. It was the regular placement of nuclei in plant and animal tissue which suggested to Schleiden and Schwann that all living tissue has a similar, compartmentalised basis.

This compartmental nature of tissue led them directly to the idea that cells are the basic unit of living things. Without the work of Hooke (who, more than 150 years before, had recorded the compartmentalised nature of cork and named these compartments 'cells') and Brown (who had discovered the nucleus six years before Schwann's book was published), Schleiden and Schwann could not have built their cell theory. It is noticeable that it is often the collaborative work between scientists, as well as their building on the work of previous scientists, that leads to a new theory in science.

The cellular basis of life was a major breakthrough in biological thinking and led not only to further studies of cells, but also to a cell-based theory of disease. You will notice in the timeline summary (see pages 64–5) that both the discovery of cells and progress in the study of disease coincided with advances in microscopy (the history of the discovery of disease forms part of the HSC course).

(a) 

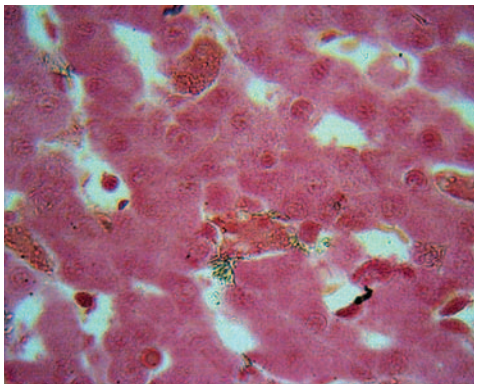
(b) 

Figure 1.6 Photomicrographs: (a) plant and (b) animal cells seen under a light microscope showing the compartmental nature of cells

Evidence to support the cell theory

PFA P1

■ *describe evidence to support the cell theory*

(PFA P1) The evidence to support the cell theory has been described in detail, along with the historical development of the cell theory on pages 67–72. Table 1.1 provides a summary of these findings.

Table 1.1 Summary of evidence for the cell theory

Time frame and/or person	Contribution (discovery or proposal)	Evidence to support finding	Response of scientific community (acceptance or rejection and grounds)
Past: time of Aristotle (380 BC) until the Renaissance (14th to 16th century)	Spontaneous generation: belief that creatures could originate from inanimate (non-living) material.	People relied on observation with the naked eye and drew inferences from what they saw (e.g. rotting meat left exposed developed maggots—fly larvae).	Theory accepted, but was being challenged. (Cells not yet discovered.)
1663 Robert Hooke	Introduced the term 'cell'.	Observed units seen in thin slices of cork using a compound microscope (published in Hooke's book *Micrographia*).	Not well received at first—believed distorted images and colour separation may have given 'artificial images'. Later accepted.

Time frame and/or person	Contribution (discovery or proposal)	Evidence to support finding	Response of scientific community (acceptance or rejection and grounds)
1674–1683 Anton Van Leeuwenhoek	Discovered bacteria. May have seen cells or nuclei.	Viewed microscopic 'animalcules' ('tiny beasties living all around us'); viewed 'globules' in tadpoles and eggs. Findings recorded in letters to the Royal Society of London.	Royal Society asked Robert Hooke to verify these findings, which he did.
1801 Robert Brown	Discovered the nucleus in cells.	Microscopic studies of plants (orchids) and later many other plant tissues revealed that each cell had a nucleus.	Discovery of nucleus noted, but were not aware of its importance.
1838 Schleiden and Schwann	Proposed the cell theory: 1. *All living things are made of cells.* 2. *Cells are the basic unit of organisms.*	Microscopic examination of plant tissue (Schleiden), and animal tissue (Schwann), revealed a common cellular basis for all living tissue. Findings published in Schwann's book, *Microscopic investigations on the accordance in the structure and growth of plants and animals.*	Two of three statements accepted by scientific community and still hold true today.
1855 Rudolf Virchow	Proposed cell theory: 3. *All cells come from pre-existing cells.* This disproved the theory of spontaneous generation.	Studies of living tissue using a microscope showed that cells only arise if other cells are present to give rise to them.	(1879) Walther Fleming confirmed Virchow's observations and named process 'mitosis'.

Technological advances and the development of the cell theory

1.2

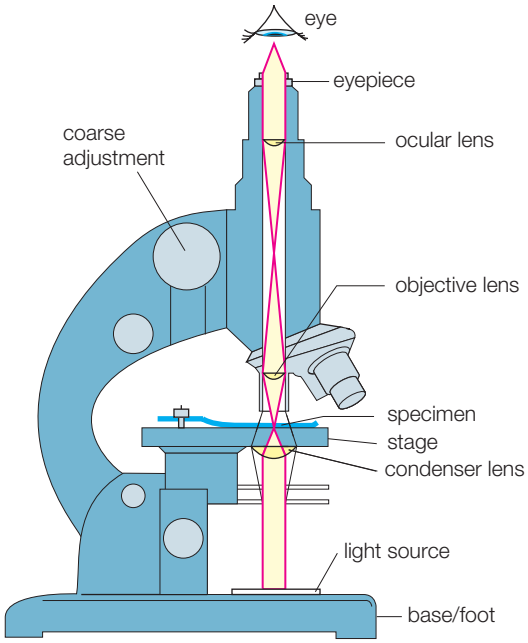
- ***discuss the significance of technological advances to developments in the cell theory***

Continued advances in light microscope technology

Improvements to the light microscope continued and, in the 1870s, **oil-immersion lenses** were introduced by Zeiss and Abbe, enabling a good image of up to 1500× magnification to be seen. By the 1890s the top-level microscopes of the time were fairly similar in their viewing capacity to the current senior school microscopes. Over the next 100 years improvement to the quality of images produced by microscopes has resulted from ongoing research into the technology (see pages 74–8).

Because the microscopes at this stage of the advance in technology were similar to those that you currently use at school, this is an appropriate time for you to become acquainted with the workings of a compound microscope (see classroom activity on next page).

Figure 1.7 The compound microscope



CLASSROOM ACTIVITY

This classroom activity practical is continued on the Student Resource CD and the Teacher Resource CD

Practical introduction to using a microscope

This investigation, although not specified by the Preliminary Course syllabus, is recommended to guide students in the correct use of a compound light microscope. It should also assist their understanding of the size of microscopic fields, magnification and resolution, and the importance of introducing contrast to improve the image that is being viewed.

The microscope is the main technology used to investigate cell structure and functioning. Three main attributes of a microscope that allow you to clearly view a specimen are the *magnification*, *contrast* and *resolution* of a microscope. It is also important for you to understand *measurement* under the microscope. In this introductory practical we will:

- identify parts of a microscope and investigate the functions of each part, including the diaphragm (for contrast)
- investigate magnification and become familiar with microscopic units of measurement
- estimate/calculate the diameter of the fields of view of a microscope
- investigate resolution.

The invention of the electron microscope

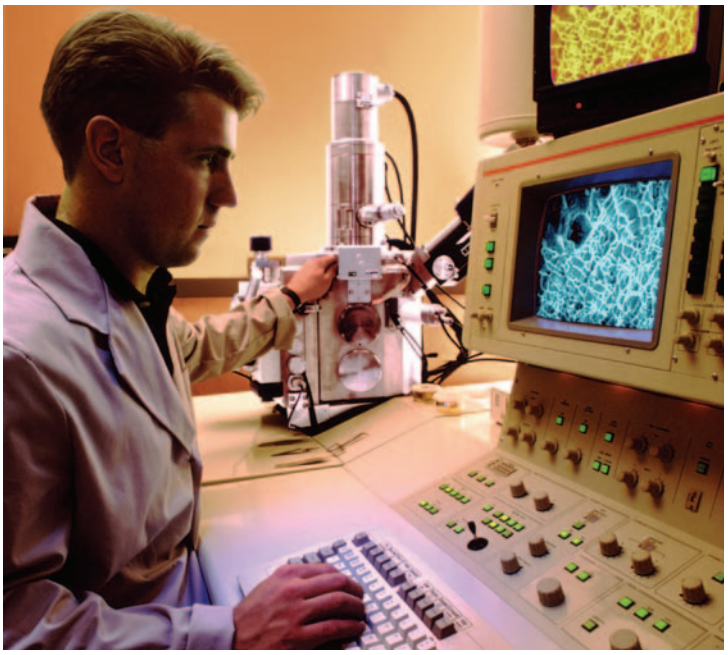
- By the end of the 19th century compound light microscopes had been developed to a point where they were no longer limited by the quality of the lenses—their main limiting factor had become the wavelength of light. The wavelength of visible light (0.5 µm) limits the resolving power of microscopes so that objects closer together than 0.45 µm are no longer seen as separate objects, even if the shortest wavelength of light is used. The best optical microscope cannot effectively magnify larger than 2000×. This led scientists to begin experimenting with forms of energy other than light.
- The next big breakthrough in our knowledge of cells was as a result of the invention (1933) and advancement of the **electron microscope**. With this technology

images are produced using a *beam* of electrons—electrons that are made to behave like light (waves). In 1928, Ernst Ruska and his supervisor Max Kroll built the first electron microscope, but it only had a magnification of 17×. Ruska continued working on the device and by 1933 he had built the first transmission electron microscope that could magnify up to 12000×. Ruska's team continued working on the electron microscope during the second world war, achieving a magnification of one million times.

- The basic principle of the *transmission electron microscope* is similar to that of the compound light microscope, except that the energy source transmitted through the specimen is a beam of electrons instead of a beam of light. Modifications to the design have had to be made because electrons do not normally travel in a manner similar to light, but bounce off anything that they hit, such as air. The electrons must therefore pass through the specimen in a *vacuum*, making it possible to view only non-living, preserved tissue. The electrons are focused by electron *magnets*, rather than by glass lenses, and the image is produced on a screen where it shows up as *fluorescence*, or it may be projected onto a photographic plate.
- The invention of the *scanning electron microscope* followed in 1955. The electron beam causes the specimen to emit its own electrons, producing a three-dimensional image (but it has a low resolution). The picture on the front cover of this textbook was produced by a modern day, scanning electron microscope.

Advantages

The main advantage of the transmission electron microscope is the high magnification and resolution which show an enormous amount of detail. The electron microscope reveals structures at not only the cellular level, but also the sub-cellular level. Many parts of cells (organelles) were seen for the first time after the invention of the electron microscope. Other parts previously seen with the light microscope can be seen in far greater detail, providing increased knowledge of their internal structure. This has led to an understanding of their functions in cells.



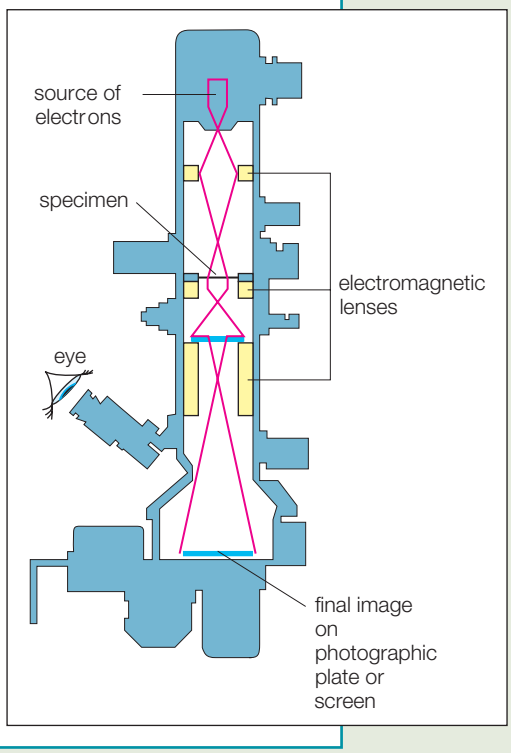


Figure 1.8 The electron microscope

Disadvantages

The main disadvantage of the transmission electron microscope is that the specimen must be placed in a vacuum for viewing, as air would interfere with the flow of electrons. As a result, living tissue cannot be viewed. This leads scientists to question how different the preserved specimens are from living tissue, as a direct comparison cannot be made.

Another difficulty is the size, expense and maintenance: electron microscopes are very large (one microscope fills a small room), must be kept at constant temperature and pressure, and are extremely expensive. As a result, they are not accessible to the general public or to schools. The biology department of a university usually has an electron microscope, but it is in high demand and researchers would need to book time to use it.

Techniques for preparing specimens for viewing

The preparation of tissue for viewing under microscopes has become an integral part of microscopy—as microscopes improved, technology for specimen preparation has had to keep up.

Two main criteria must be met when preparing tissue for viewing under the microscope:

1. The sections must be *thin* enough to allow light or electrons to pass through them.
2. Very thin sections of living tissue are mostly transparent, so the structure is difficult to observe unless some *contrast* is created between the tissue and its background.

While preparing the tissue for viewing, the technique should minimise the alteration of tissue from its living form, otherwise what we view under the microscope may be an *artefact* (aberration or 'artificial image').

To meet these criteria, a four-step process is used to prepare slides involving *fixation, embedding, slicing* and *staining*:

1. fixation: the tissue is placed into a preservative substance that kills it and preserves it, as closely to the living from as possible. In some cells chemical fixation disrupts the cell and its contents, so it is important to study cells prepared in a variety of ways
2. embedding: tissue is embedded in a hard medium such as wax (or an even harder substance such as resin for electron microscopy), to overcome the difficulty of cutting soft tissue into very thin sections
3. slicing or sectioning: a machine called a *microtome* was invented, which could cut much thinner sections of tissue more smoothly than could be done by hand. An *ultramicrotome* has been invented more recently to allow ultra-thin specimens to be cut, suitable for viewing under the electron microscope. The thinner the section, the greater is the clarity of the image being viewed
4. staining: *colour* is produced by a variety of stains to create a contrast between the transparent material and its background or heavy metals may be used to stain tissue for viewing under the electron microscope.

Historical evidence of specimen preparation

Robert Hooke noticed that he could get a clearer view of his cork cells if he cut a section very thinly to allow the light to pass through it.

The use of dyes to stain tissue and improve visibility in specimens began in the late 1770s, but it was in the 1880s that Walther Flemming, using synthetic dyes, named the material that became most strongly stained **chromatin material.** And in 1888 Wilhelm Waldeyer-Hertz named the shortened threads of chromatin, **chromosomes** (chromo = coloured; soma = body).

STUDENT ACTIVITY

Use a table to compare (show the differences and similarities between) the light microscope and the transmission electron microscope. Headings that may be useful as points of comparison are suggested below:

- Energy source
- Focus
- Specimen preparation
- Magnification
- Resolution
- Can live specimens be viewed?
- Image—colour or black and white?
- Advantages and disadvantages

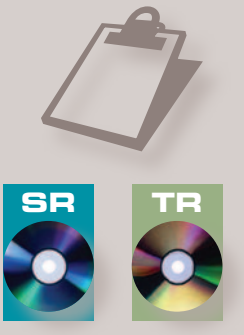


Table for comparison

By using advanced preparation techniques to view tissue under the microscope, our knowledge and understanding of cell structure is further increased.

Current biological research, technology and the cell theory

The electron microscope and further developments in the cell theory

The development of the electron microscope has allowed scientists to study the ultrastructure of cells (parts smaller than can be seen with a light microscope). Electron microscopes are now also linked to computers; this allows the study of sub-cellular structures in enormous detail, providing evidence of their functioning. This technology is also used in the areas of genetics and ecology, providing evidence which has resulted in modern biologists adding a further three statements to the original cell theory. The modern day additions are that:

4. *Cells contain hereditary information which is passed on during cell division.*
5. *All cells have the same basic chemical composition.*
6. *All energy flow (resulting from chemical reactions) of life occurs within cells.*

Further advances in microscopy

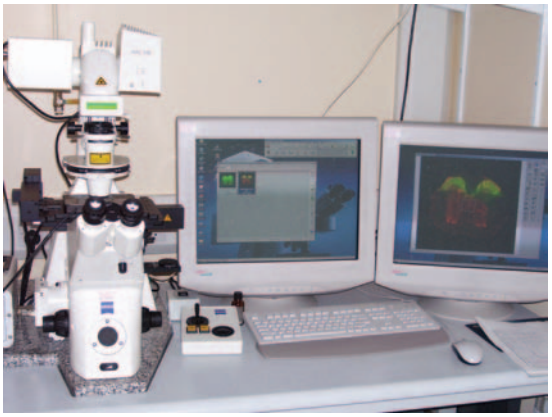
Phase contrast microscopes

These microscopes use an alternate way of creating contrast that does not involve altering the specimen. They take advantage of the fact that when light passes through structures of different densities, it changes *phase* because of the wave-like nature of light. A *phase contrast* in the incoming light is created by the different optical system of the microscope.

Cutting edge technology—contemporary light and electron microscopes

- Current developments in compound light microscopes include link-ups with computers, where the image can now be digitally enhanced. *Confocal microscopes* use laser light to allow a three-dimensional view of a specimen to be built up, similar to medical scans. This has the advantage that the specimen no longer needs to be sliced into sections to be viewed.
- *Synchrotrons* are very recent microscopes that accelerate electrons to a speed close to that of the speed of light. They can be used to study structure at the atomic level and, like most electron microscopes, they control the direction of movement of the electrons with magnets.

At the time of writing, an Australian synchrotron is being built at Monash University and will be about the size of a football field.



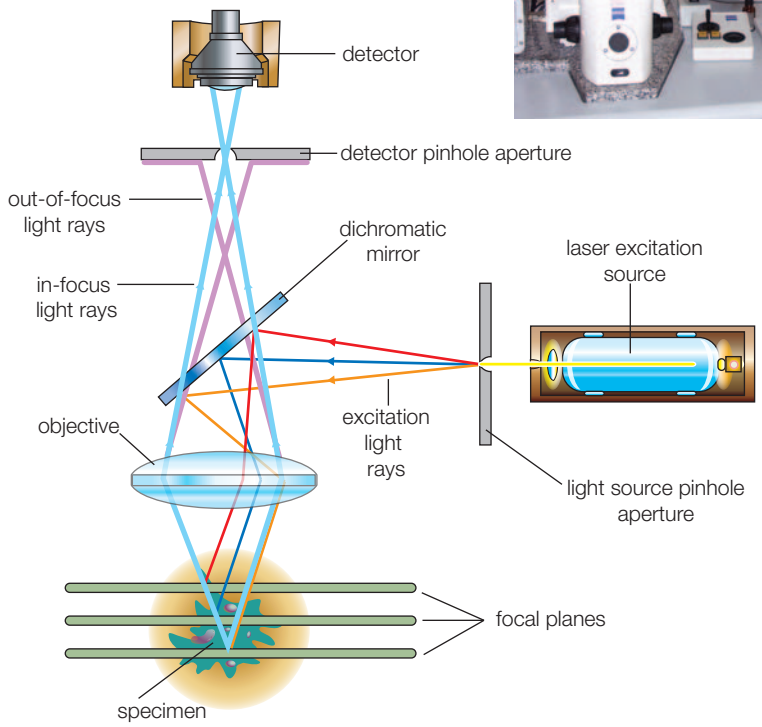


Figure 1.9 A confocal microscope

The impact of technology on the development of the cell theory

SECONDARY SOURCE INVESTIGATION

PFAs

P3

BIOLOGY SKILLS

P11.1
P12.3; 12.4a—f
P13.1a—e
P14.1; 14.3b, d
P15

- ***use available evidence to assess the impact of technology, including the development of the microscope, on the development of the cell theory***

Scientists in the past were limited in their research by the technology available to them. As equipment and techniques became more sophisticated, they could collect new evidence, leading to new biological views/theories.

Task

This is a complex task that requires high-order thinking skills from students, so a suggested method of tackling this task is given below.

1. Collect relevant information about two things:
   - the advances in technology (such as microscopes and techniques for preparing specimens for viewing)
   - the improvement in understanding of a biological concept (the cell theory) over time. Plot the relevant information on a timeline.
2. Analyse information to enable you to answer the dot point. Using both your timeline and information in the textbook, answer a series of questions which should improve your understanding of the links between the history of the cell theory and the history of the invention and improvement of the microscope.
3. Answering the dot point: a 'scaffold' has been provided on page 80 to assist you with this step.

Introduction

The history of the development of the cell theory is closely linked to the invention and improvement of the microscope. The PFA P1: *Outline the historical development of major biological principles, concepts and ideas* is a precursor to PFA P3: *assessing the impact of technological advances on understanding in biology*, and so we begin our research on the history of the development of the cell theory by using a timeline. The suggestions below will help you to streamline your search for information, so that it is concise and relevant.

PFA P3

Timeline activity

Read pages 65–78 and any additional secondary source information, and then produce a timeline as outlined below. Remember to use a variety of sources and to crosscheck any uncertainty in the accuracy of your information.

- Research the main contributions to the cell theory that each of the following scientists made and the dates of these contributions:
  - —Robert Hooke
  - —Hans and Zacharias Janssen
  - —Anton Van Leeuwenhoek
  - —Matthias Schleiden
  - —Theodor Schwann
  - —Rudolf Virchow
  - —Ernst Ruska.
- Draw a timeline showing the chronological order of the historical development of the cell theory: draw lines on the upper side of the line to list the invention of the technologies; below the line, list the discoveries made that led to the proposal of the cell theory. The earliest date should be on the left of the timeline and the most recent date on the right. Be sure your spacing shows a reasonable approximation of the amount of time elapsed between dates.
- Label the timeline in a logical and legible manner:
  - —record the name, date and contributions of each scientist to the cell theory below the timeline. Some dates may vary slightly in different sources: evaluate the source and use the one you think is most accurate
  - —record the advances in technology made (e.g. improvements to the microscope and specimen preparation techniques) above the timeline.

Answering the dot point

(PFA P3) Use the information summarised in your timeline as a guide to answering the questions below. You will also need to refer to more detailed information (see pages 65–78) to answer some of the questions. You may answer these questions as a rough draft on A4 paper first and then transfer your final answers to the scaffold provided, or you may write them straight onto (or type them on the computer into) the scaffold provided.

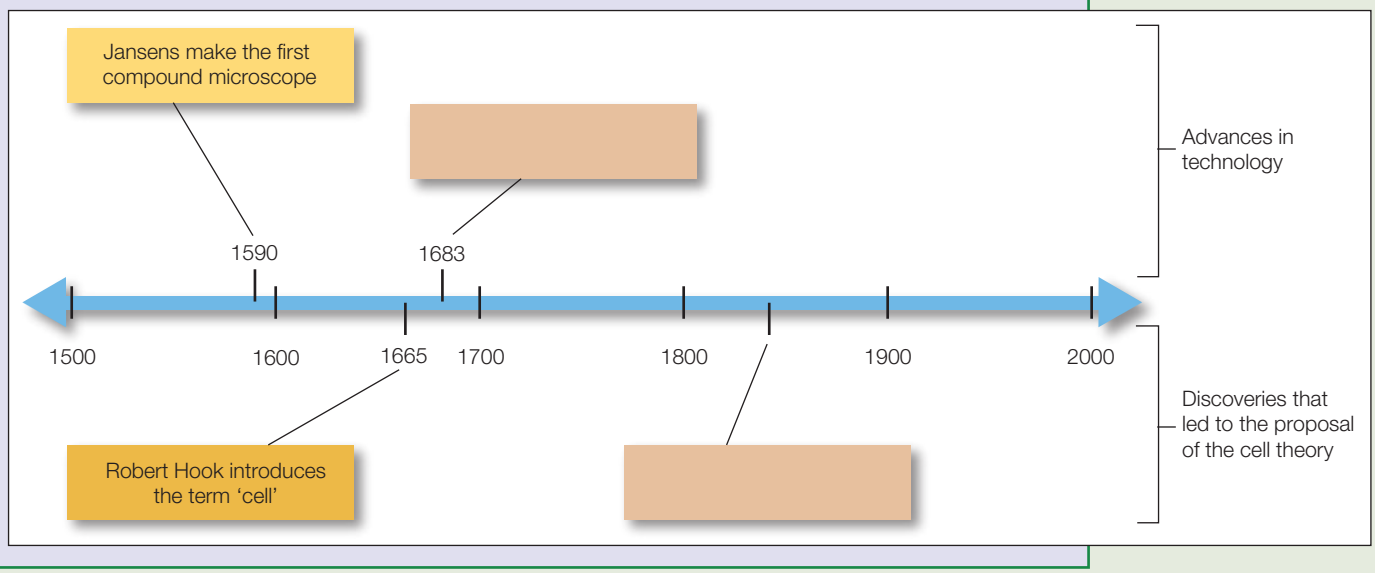
1. Technology

1.1 Identify the technology available PRIOR to the proposal of the cell theory and outline its uses and limitations.

1.2 Identify the technology (microscopes and specimen preparation) available AT THE TIME of the proposal of the cell theory and outline its uses and limitations.

1.3 Identify the most advanced CURRENT technology available and describe

Figure 1.10 Example of how to draw a timeline



four ways in which this technology (microscopes and specimen preparation) is an improvement on the past technology.

2. Knowledge and understanding

2.1 Outline any areas of knowledge and understanding of the cell theory that came about as a result of PAST technology.

2.2 Outline FURTHER areas of knowledge and understanding of the cell theory that resulted from the use of CURRENT technology.

3. Putting the two together

3.1 Explain how the advance in technology allowed the progressive accumulation of knowledge and understanding of the cell theory. (Remember, *explain* means 'relate cause and effect'; that is, show the relationship between the improvement of the microscope and the increased knowledge and understanding about the cell theory.)

3.2 Assess the impact of (1) on (2); that is, 'make a judgment of the value' of the advance in technology on the development of the cell theory.

Table 1.2 The impact of technology on knowledge and understanding

TECHNOLOGY (Identify technology and outline its uses and limitations)	
THEN	**NOW**
PRIOR to: the proposal of the cell theory: *PAST*: at the time of the proposal of the cell theory	*CURRENT*: technology (outline *four ways* in which microscopes and specimen preparation have improved)
IMPROVEMENT (advance) in technology:	
KNOWLEDGE AND UNDERSTANDING	
THEN	**NOW**
PRIOR to: the cell theory *PAST*: at the time of the proposal of the cell theory	*CURRENTLY*:
IMPROVEMENT in (progressive accumulation of) knowledge and understanding:	
PUTTING IT ALL TOGETHER	
Explain how the *advance in technology* allowed the *progressive accumulation of knowledge and understanding* of the cell theory. (Show the relationship between the improvement of the microscope and the increased knowledge and understanding about the cell theory.)	
Assess the *impact of technology* on the *development* of the cell theory.	

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For a sample answer of Table 1.2

Cell structure and functioning

1.3

Introduction: levels of organisation

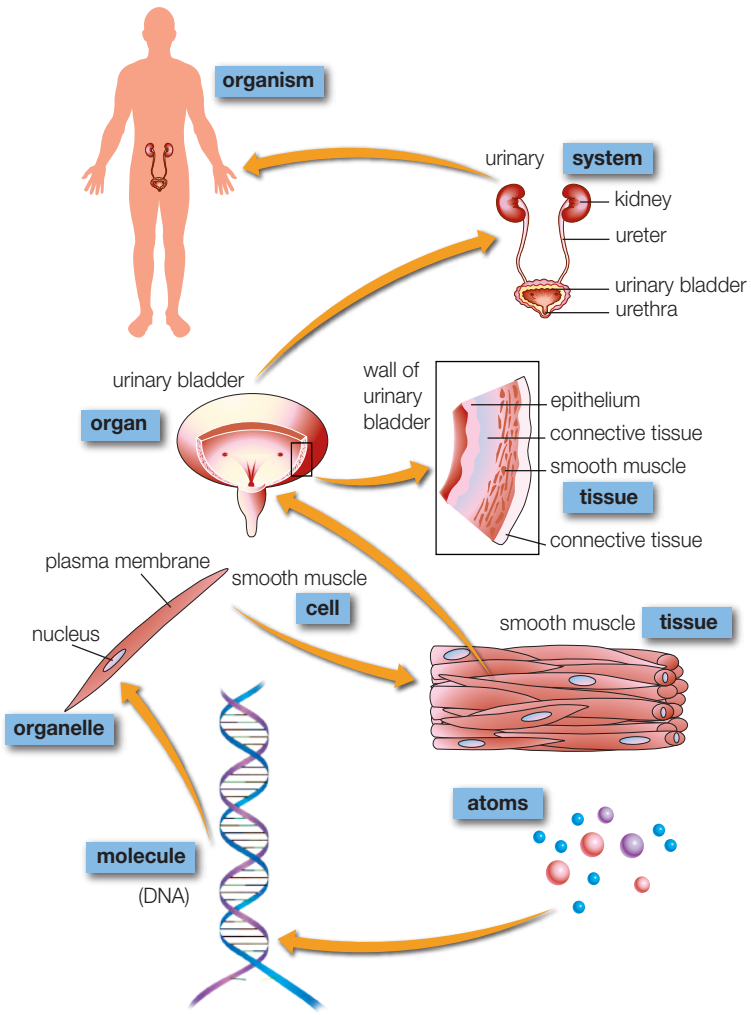
Most living organisms that are seen every day consist of many cells and are termed **multicellular**. However, some living things consist of only *one* cell that carries out all of their life functions. These are said to be **unicellular** and can be seen with a microscope (e.g. Protists such as *Euglena*, *Amoeba* and *Paramecium*, living in pond water, and some disease-causing organisms such as bacteria) (see Fig. 1.11).

The term 'cell' is therefore used to describe the basic unit of any organism, whether it is the only unit or one of many units making up an organism. Table 1.3 shows how the concept of 'cells' fits into the overall organisation of living things.

Table 1.3
An introduction to structural organisation in living things

Level of organisation	Examples
*Multicellular organism	Plant, animal
Systems	Transport system, respiratory system
Organs	Heart, lungs, muscles, roots, stems, leaves
Tissues	Blood tissue, lung tissue, photosynthetic tissue
Cells	Nerve cell, blood cell, muscle cell, *unicellular organism
Organelles	Nucleus, chloroplast, mitochondria, ribosomes
Molecules	Water (H_2O), protein, sugar, lipid, chlorophyll
Atoms	Carbon (C), hydrogen (H), oxygen (O), nitrogen (N)

Diagrams:



* terms are explained in the following text

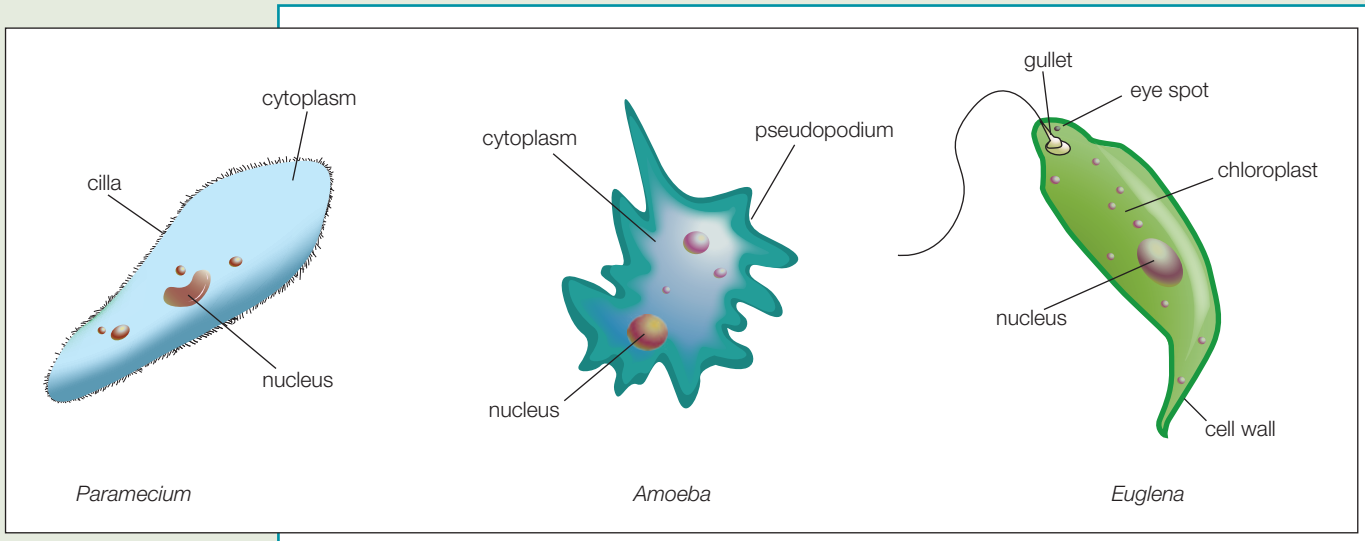


Figure 1.11 Common unicellular organisms that may be seen in a drop of pond water using a light microscope

The structure of cells (as seen using a light microscope)

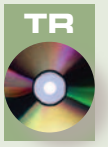
■ *identify cell organelles seen with current light and electron microscopes*

The *general contents* of cells can be studied using the *light microscope*, but if more detailed information is required an *electron microscope* must be used.

Cells vary greatly in shape, size, structure and function. There is, in reality, no such thing as a 'typical' cell. The majority of cells that form the tissues and organs of an organism become highly specialised for particular functions, for example lung tissue and blood tissue. To allow an understanding of the general structure and functioning of cells, a hypothetical or 'typical' cell of plants and one of animals is often studied, as shown in Figures 1.12 and 1.13 (light microscope) and 1.16 (electron microscope).

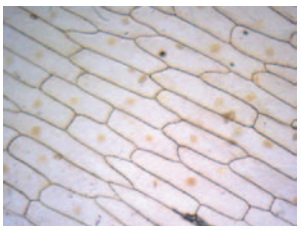
Cells that are found in plants and animals have the same basic features, with some variations. The cell parts discussed below are those that are visible with a light microscope:

- It is in the **protoplasm** of cells that the functions essential to life, such as growth and respiration, are carried out. The **cytoplasm** (that part of the protoplasm outside of the nucleus) consists of a liquid-based background, the cytosol, in which there are *dissolved* chemical substances (e.g. ions such as chloride ions), *suspended* organelles and insoluble granules. Approximately 90 per cent of the cytoplasm is water—the medium in which all cell chemicals are dissolved or suspended.



Teaching analogy

(a)



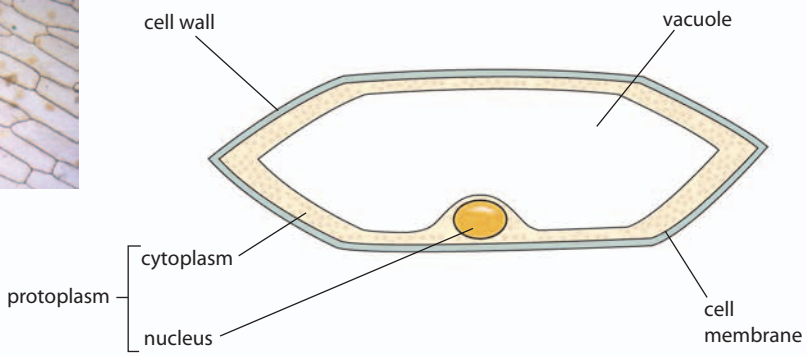


Figure 1.12 Cells of multicellular organisms that can be seen using a compound light microscope: (a) non-photosynthetic plant cells (onion)

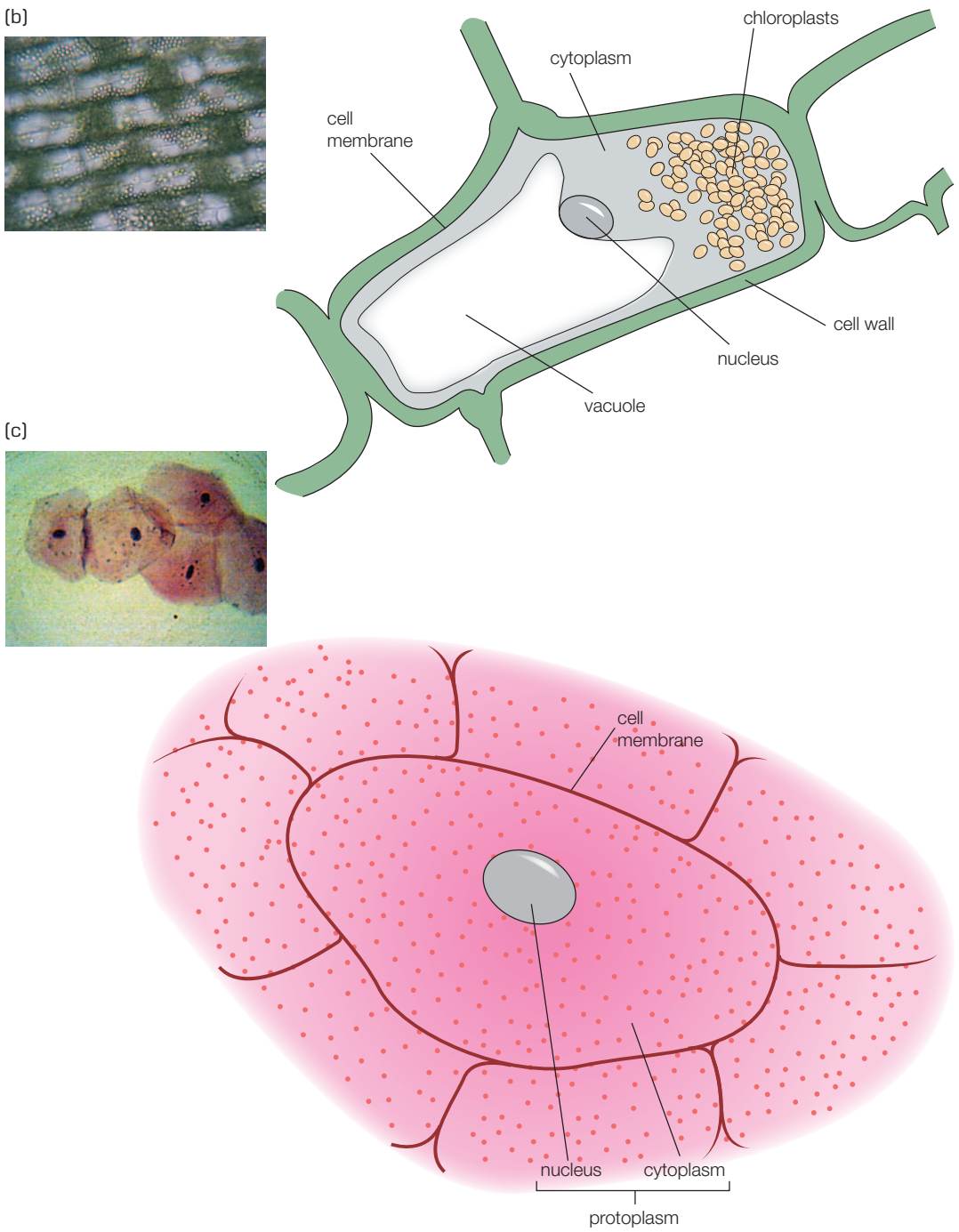


Figure 1.12 Cells of multicellular organisms that can be seen using a compound light microscope: (b) photosynthetic plant cells (pond weed); (c) animal cells (cheek cells)

- The **nucleus** (plural *nuclei*) appears as a large, spherical, oval or sometimes elongate structure in the cytoplasm. It is colourless, transparent and slightly more jelly-like than the rest of the cell. Most organisms have one nucleus per cell.
- The **cell membrane** (alternate names are the *plasma membrane, cytoplasmic membrane* or *plasmalemma)* surrounds the cell contents in all cells and separates the cell contents from its surroundings. It controls the passage of water and other chemical substances into and out of cells.

Plant cells

Plant cells have some additional structures which can be viewed under a light microscope. These structures are

exclusive to plant cells and therefore not usually found in animal cells.

- **Chloroplasts** are organelles that are green in colour, due to the presence of a pigment called *chlorophyll*. Chloroplasts are responsible for **photosynthesis**—the manufacturing of sugar in plants, using the energy of sunlight. Chloroplasts are not present in all plant cells, they are only found in the green tissue of plants that can photosynthesise. Under the light microscope, they appear as green, disc-shaped structures, smaller than the nucleus. An electron microscope is needed to see the detailed interior.
- **Vacuoles** in plant cells are large, permanent, fluid-filled sacs in the cytoplasm of mature cells. Each vacuole consists of a watery solution called **cell sap**, surrounded by single membrane, the *tonoplast*. Cell sap contains substances such as mineral salts, sugars and amino acids dissolved in water. It may also contain dissolved pigments that give cells their colour, for example the reds, pinks and purples seen in some flower petals. Besides having a storage function, vacuoles play a very important role in providing *support* to plant cells. By filling up with water, the vacuole pushes outwards with the cytoplasm, exerting a pressure on the cell wall, keeping it firm. As a result of the outward pressure of the cell contents and the resisting pressure of the cell wall, the cell becomes firm or **turgid**. (Small, temporary vesicles may sometimes be found in animal cells, but these do not play a role in cell support, so permanent vacuoles that give turgidity are considered to be a feature excusive to plant cells.)

Figure 1.13 is a comparative diagram of a plant and an animal cell. To compare two things, both the similarities and differences must be

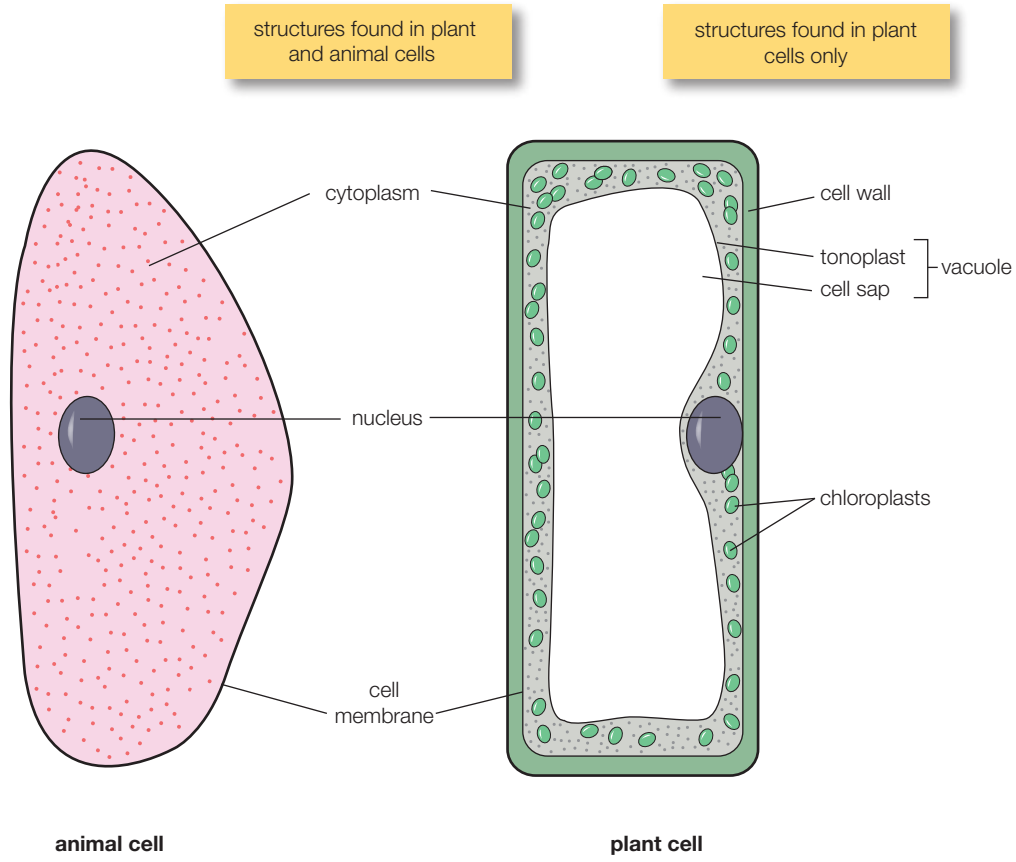


Figure 1.13 Comparative diagram of typical plant and animal cells as seen under a light microscope

examined. When this is done using diagrams, the features common to both are labelled down the centre and the features that are different are labelled on the outside.

The nucleus is one of the largest organelles visible with the light microscope. Chloroplasts and vacuoles in plant cells are also large enough to be seen with a light microscope, but all other organelles are much smaller and appear as granules of various sizes in the cytoplasm, if viewed under a light microscope.

Table 1.4 Comparison of organelles visable with light and electron microscopes

School light microscope (10–200×)	Top technology light microscope (800–2 000×)	Electron microscope (60–2 000 000×)
■ Cell wall ■ Cell membrane ■ Nucleus and nuclear membrane ■ Chloroplast ■ Vacuole: tonoplast and cell sap ■ Cytoplasm	All structures in previous column as well as: ■ Golgi body ■ mitochondria ■ nucleolus ■ (special staining required for all)	All structures in previous two columns as well as: ■ endoplasmic reticulum ■ ribosomes ■ lysosomes ■ centrosome ■ cytoskeleton (special staining needed for this)

Observing plant and animal cells using a light microscope

■ ***perform a first-hand investigation to gather first-hand information using a light microscope to observe cells in plants and animals and identify nucleus, cytoplasm, cell wall, chloroplast and vacuoles***

FIRST-HAND INVESTIGATION

BIOLOGY SKILLS

P12.1; 12.2; 12.4
P13.1

Background

The microscope

The practical introduction to using a microscope (see page 74) helped students to review parts of a microscope, safe work practice in microscopy, inversion of image, as well as giving them a clearer understanding of magnification, calculating the size of a microscope's field of view and the use of the diaphragm. This knowledge should be applied when completing this investigation.

The specimens to be viewed

You are required to examine both plant and animal cells under the microscope and gather first-hand information. This investigation involves:

- preparing your own slides for the plant tissue to be viewed, using the wet mount technique described and illustrated below
- using permanent prepared slides of animal cells such as cheek cells and blood cells, that have been made in commercial laboratories for you. (As a matter of OH&S, we no longer prepare our own slides of this tissue, to avoid the risk of transmitting infections between students.)

(*Note to teacher*: A demonstration of how to prepare a wet mount can be done on a plastic sheet on the overhead projector, as all materials are transparent and can be viewed easily.)

Preparing a wet mount

The technique will be described on the next page, in the *method* of the practical and your teacher may also demonstrate this technique to you. Figure 1.14 illustrates the technique.

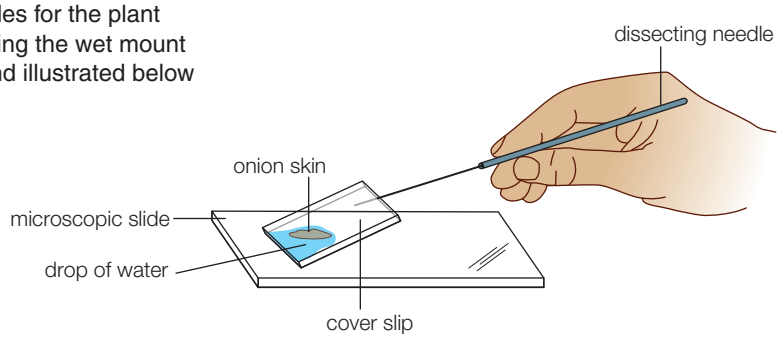
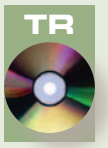


Figure 1.14 Diagram showing technique for lowering coverslip on to a wet mount



General resources

Recording your results

- Accurately present your information by selecting and drawing two to three cells of each type viewed under the microscope. Remember to calculate and state the magnification for each diagram. It is not essential to draw the circular field of view around the cells, but this sometimes helps to remind you that this is a representation of a microscopic section.
- The photomicrographs and diagrams provided (see Fig. 1.12) should help you to find and recognise the tissues that you are looking for.

Drawing cells seen under the microscope

Scientific drawing skills apply—use a sharp pencil and draw single, solid lines. Each diagram should be large enough (approximately 6 to 7 cm in size) to clearly show all structures visible inside the cells, have detailed and accurate labels (see Table 1.4). Label lines should be parallel if possible, should never cross each other and should have no arrowheads, but touch the actual structure being labelled (see Figs 1.12 and 1.13).

Practical task

Aim

To investigate the structure of plant and animal cells under a light microscope.

Equipment

- One compound light microscope per student if possible
- Glass microscope slides, coverslips, dissecting needle, razor blade or scalpel
- 50 mL beaker, water, dropper, stains such as iodine or toluidine blue, paper towel, lens tissue, oil for oil immersion
- Onion, elodea (water plant), leaves of agapanthus
- Prepared slides of cheek cells, blood cells

Method

1. Plant cells

Working in pairs, one student prepares a wet mount of a section of onion tissue, while the other student prepares a wet mount of a piece of pond weed (elodea). Follow the procedure for preparing a wet mount as demonstrated by your teacher (see Fig. 1.14).

A. Onion cells (see Fig 1.12a)

- Remove the onion skin and carefully lift a thin section of onion tissue from the surface of one of the layers.
- Cut a piece about 1 cm^2 in area and place this in a drop of water plus iodine (stained) or water (unstained) on the glass microscope slide.
- Carefully lower the coverslip using a dissecting needle, to avoid the formation of air bubbles.
- Place a piece of paper towel over the coverslip and slide to dry any excess water or stain. (*Note*: There are no chloroplasts in white onion cells, but you should be able to view all other plant cell structures visible with a school microscope listed in Table 1.4 on page 85.)

B. Pond weed—elodea (see Fig 1.12b)

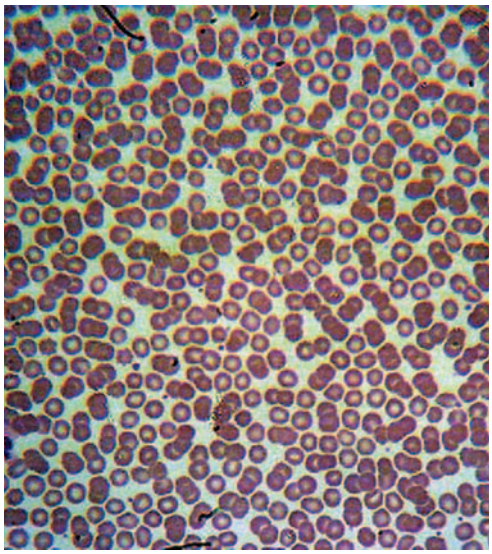
- Follow the instructions above for an unstained wet mount. Pond weed is thin enough for light to pass through and you should be able to view chloroplasts clearly.
- View under low power, then under higher power. You will need to place drop of oil on top of the coverslip to view the cells under the highest power. Remember that your microscope is **parfocal**, so it is not necessary to adjust the focus before changing to a higher magnification, but make sure you use the fine adjustment knob only, when bringing the specimen into focus.

Draw the cells seen in both parts A and B.

2. Animal cells

C. Cheek cells

- Using a prepared slide of stained cheek cells, observe and draw these as seen under high power or under oil immersion, as instructed by your teacher.
- Label the cheek cells (see Table 1.4 for suggested labels).
- Record your magnification.

(a) 

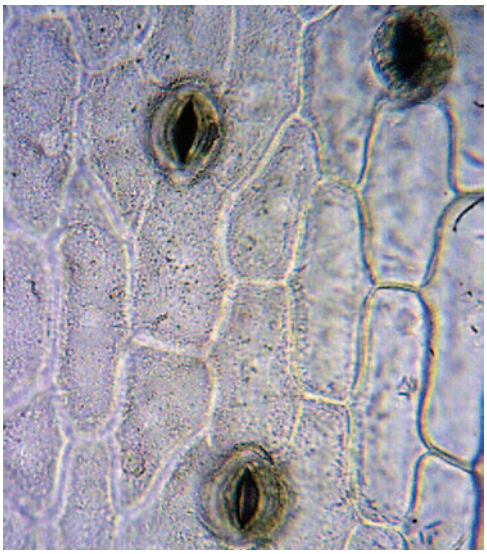
(b) 

Figure 1.15 Photomicrographs taken under a compound light microscope: (a) blood cells; (b) agapanthus—surface view of epidermal cells and stomates

Further investigations for students who finish early:

(a) blood cells

(b) surface view of leaf of epidermal cells showing guard cells and stomates an agapanthus leaf: scour the surface of the leaf into 1 cm^2 sections with a scalpel blade and then place transparent sticky tape over the leaf surface to lift the uppermost layer (epidermis). Place these cells attached to the sticky tape in a drop of water on a microscope slide, as described for the unstained onion and complete the wet mount as described. Draw and label this surface view of epidermal cells of agapanthus. Breathing pores called stomates should be visible amongst the epidermal cells

(c) pond water: place a drop of pond water on a microscope slide. Cover with a coverslip and view under low power to find cells and then under high power to draw (see Fig. 1.11). Record your magnification.

1.4 The ultrastructure of cells (electron microscope)

■ *describe the relationship between the structure of cell organelles and their function*

In order to look at cells and their organelles in detail, photographs that have been produced using an electron microscope are studied. These photographs are called **electron micrographs** and they reveal the structure of these sub-cellular components which have been greatly magnified—termed the *ultrastructure* of cells.

The structure of each organelle is closely related to its function within the cell.

In any cell, membranes are extremely important structures which not only separate one cell from another, but may also separate organelles within a cell from the surrounding cytoplasm.

(a)

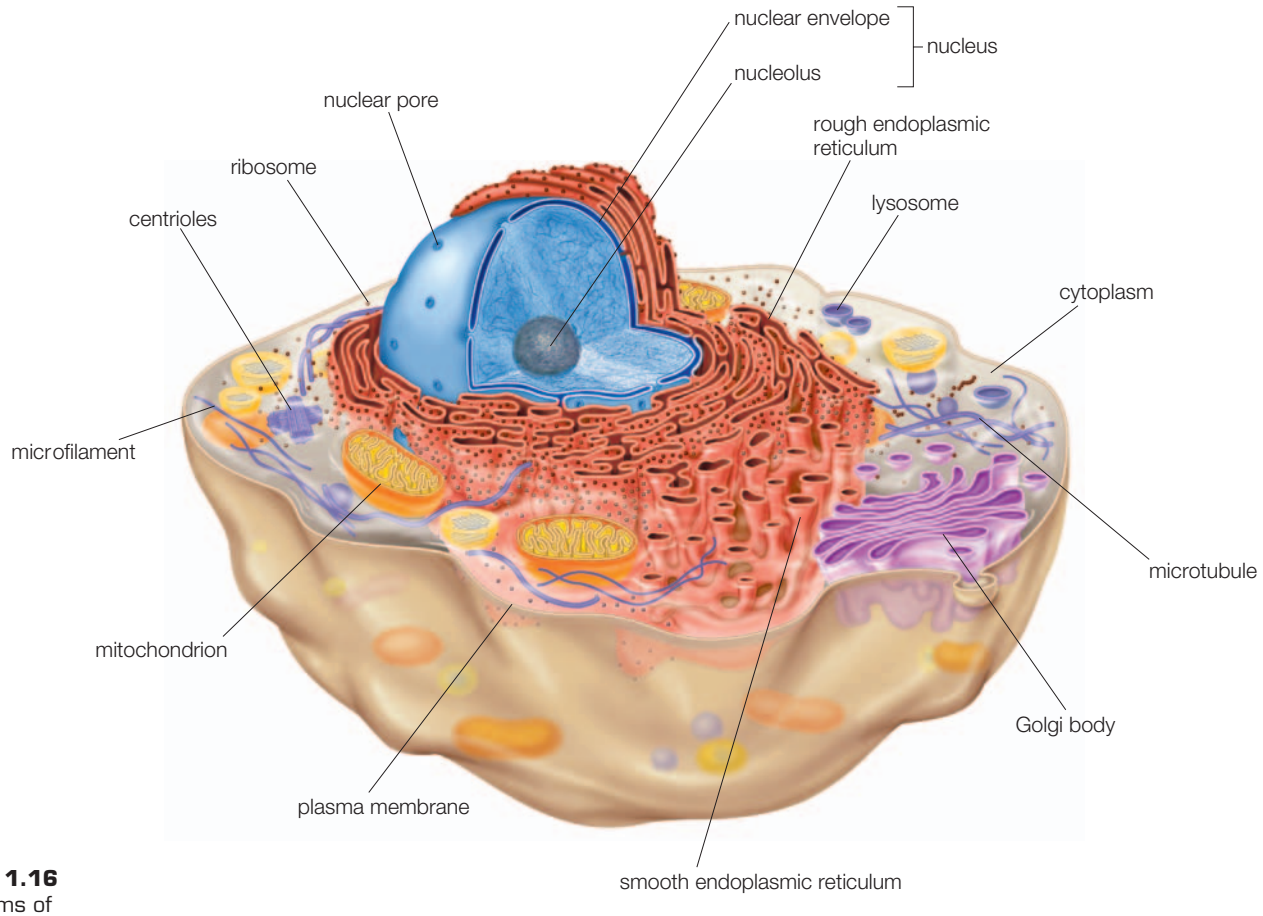
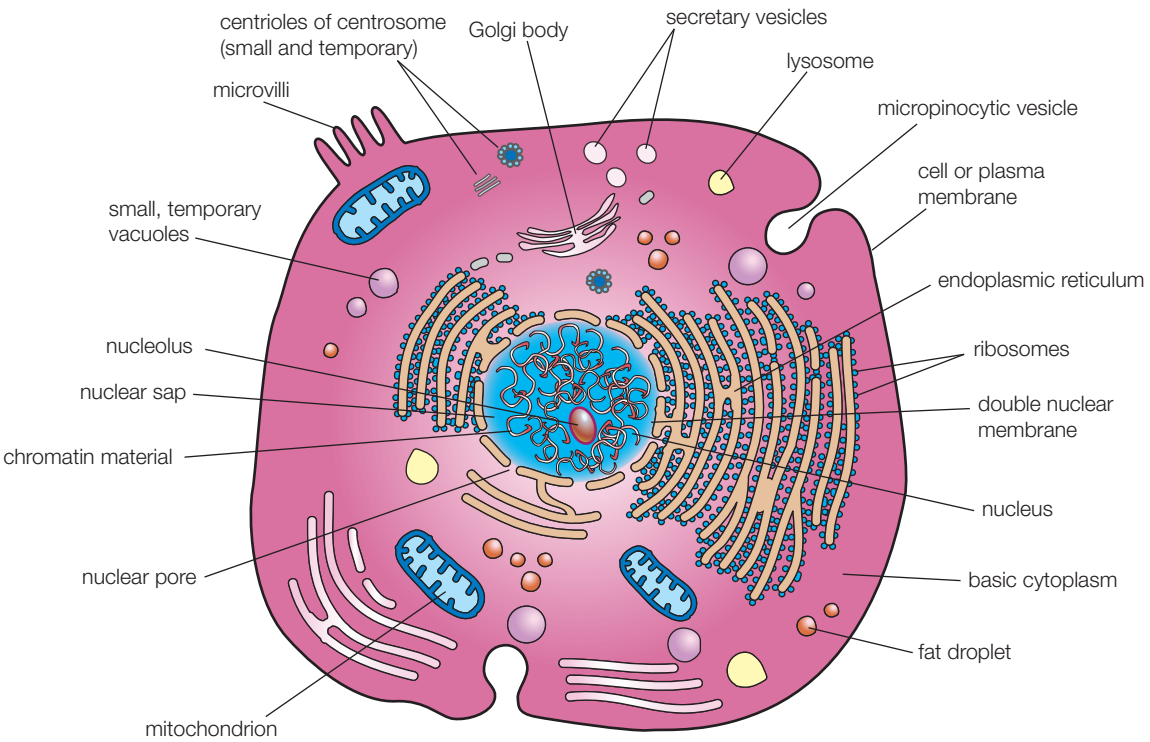
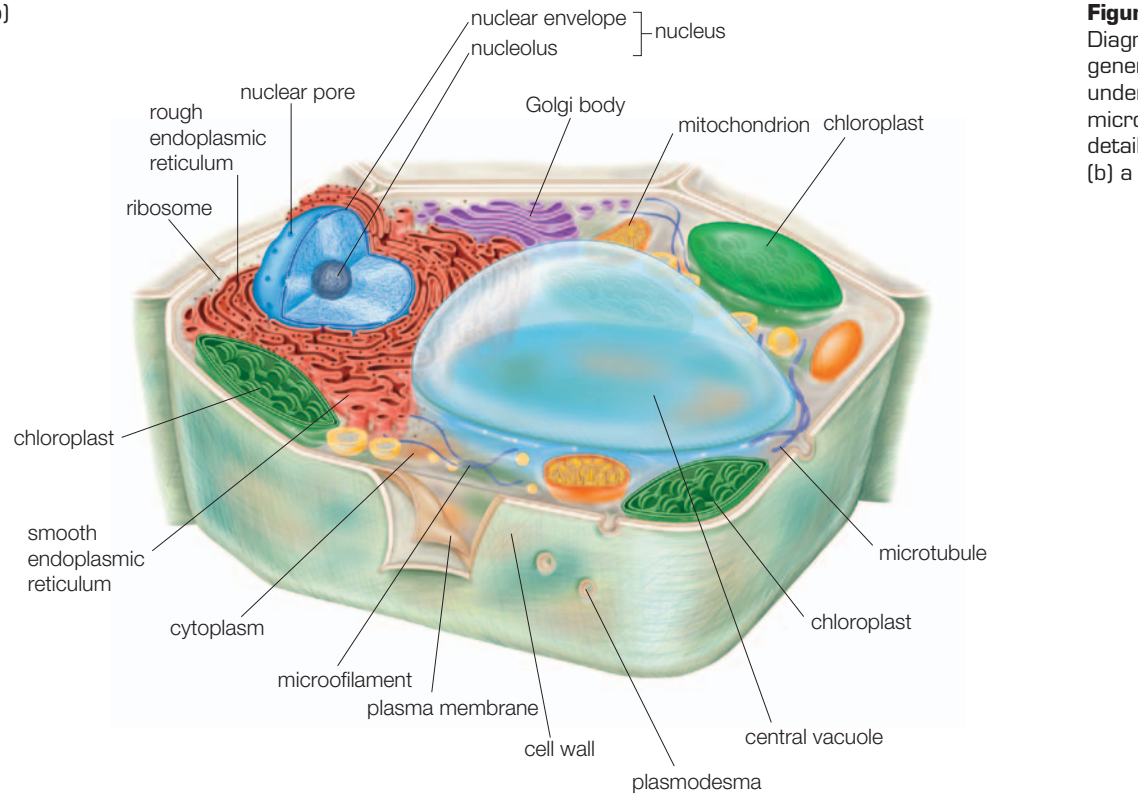


Figure 1.16 Diagrams of generalised views under the electron microscope showing details of organelles: (a) an animal cell



(b)



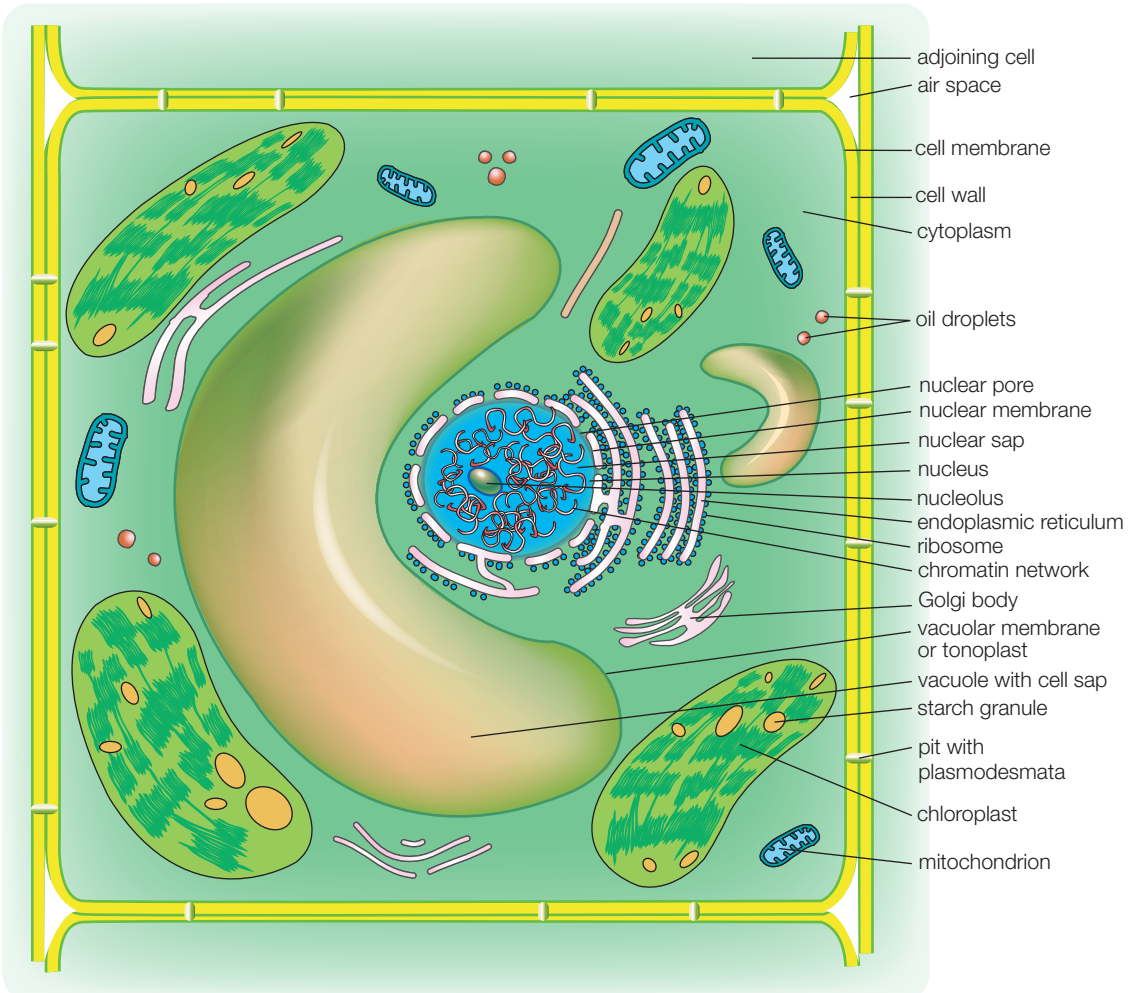


Figure 1.16 Diagrams of generalised views under the electron microscope showing details of organelles: (b) a plant cell

In the cells of multicellular organisms and many unicellular organisms, each organelle within a cell is surrounded by its own membrane, which may be either a single or a double membrane. *Cells* with membrane-bound organelles are termed **eucaryotic cells** (alternate spelling *eukaryotic*) and the *organism* is classified as a *eucaryote*. This name refers to the fact that the genetic material is contained within a nucleus, separated from the cytoplasm by a double nuclear membrane. (Derived from the Greek '*eu*' meaning '*true or proper*' and '*karyon*' meaning '*nucleus*').

With the use of the electron microscope, primitive cells called **procaryotic cells** (alternate spelling *prokaryotic*) were discovered. (Greek '*pro*' = before, '*karyon*' = nucleus). These organisms, for example bacteria, do not have their genetic material separated from the cytoplasm by a membrane, they simply have a strand of genetic material floating within the cytoplasm. Further studies with the electron microscope showed that procaryotes do not have any membrane-bound organelles, their sub-cellular components float within the cytoplasm.

Membranes—selective boundaries

The cell membrane is a *selective* barrier, permitting the passage of only certain molecules into or out of cells. This property gives the cell membrane the feature of being *selectively permeable*. (This will be dealt with in greater detail in the following chapter). Both plant and animal cells have a cell membrane. The membranes surrounding organelles are also selective in allowing only certain substances to pass between the cytoplasm and the organelle.

The nucleus—the control and information centre

- The nucleus stores the information needed to control all cell activities. It is therefore essential for the nucleus to be able to communicate with the surrounding cytoplasm.
- Electron micrographs reveal that the nucleus is surrounded by a *double* **nuclear membrane** or **nuclear envelope**, pierced by tiny **pores**. These pores regulate the passage of substances between the nucleus and cytoplasm, allowing communication between them.
- The **nucleoplasm** or **nuclear sap** is the liquid background of the nucleus in which the *chromatin* material is found. Chromatin is made up of *protein* and *nucleic acid*.
- The nucleic acid **DNA** is a very large chemical that holds, in a coded form, all the genetic information (the 'blueprint') necessary to control the cell's functioning. It is this DNA which contains the hereditary information of an organism that gets passed from one generation to the next. Within one organism, the information stored in the DNA of each cell is the same. Before a cell divides, the information on the DNA must be copied so that it can be transmitted (passed on) to newly formed cells.
- The chromatin material separates into short, thick separate rod-shaped structures called **chromosomes,** which become visible in dividing cells. ('chromo' = coloured, 'soma' = 'body'—so named because chromosomes take up stains easily when being prepared for microscopy.) Each species of organism has its own particular number of chromosomes; for example, humans have 46 chromosomes, a platypus has 52, a lettuce has 18 and a camel has 70!
- The **nucleolus** is a dense, granular region commonly seen within the nucleoplasm and it contains a large amount of nucleic acid—some DNA, but mostly RNA. The nucleolus is responsible for the manufacture of organelles called ribosomes, essential 'machinery' of the cell.

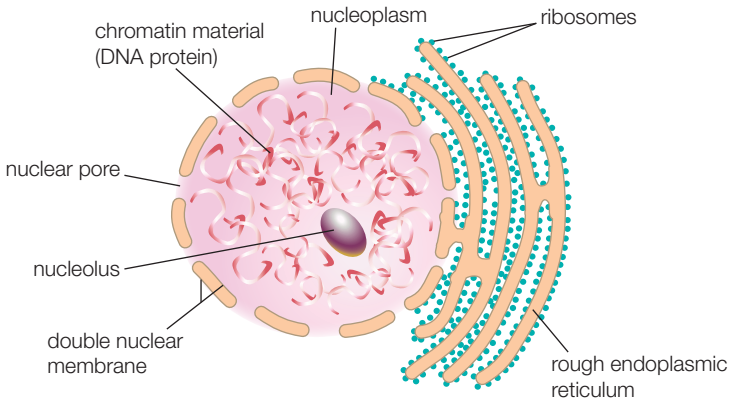


Figure 1.17 Diagram of nucleus and associated ER and ribosomes

It is important to remember that the view of cell organelles revealed by a transmission electron microscope is a section cut through the organelle. From these micrographs it is possible to build up a *three-dimensional* view of each organelle (see Table 1.5 on page 95). Scanning electron microscopes give an *external* view of the surface of these organelles.

Endoplasmic reticulum—transport and processing of proteins and lipids

The outer nuclear membrane is usually continuous with a network of flattened, interconnected membranes—the **endoplasmic reticulum (ER)**. The ER provides a connection of pathways between the nucleus and the cell's environment, allowing intracellular transport (transport within a cell). The immense folding of the sheets of membrane increases its surface area. ER may have ribosomes attached (rough ER) or may have no ribosomes (smooth ER). The main function of ER is *transport*, but it also plays a role in *processing* cell products: rough ER folds and processes proteins products made by the cell and it can also synthesise lipids; smooth ER is the main site of lipid production, essential for membrane repair and manufacture. ER may also transport substances from one cell to another in plant cells, passing through channels in the cell wall called cell pits.

Ribosomes—protein synthesis

These small organelles appear as dense granules in electron micrographs of cells. Their small size and rounded shape increase their surface area for easy interaction with chemicals during their functioning. Each is made of the chemicals RNA and protein, and their function is protein synthesis. Ribosomes are the 'machinery' that carries out the genetically coded instructions of DNA to *produce* any *proteins* necessary for cell functioning and structure. Ribosomes may be found free in the cytoplasm or scattered over the surface of ER. Newly synthesised proteins pass from the ribosomes into the ER where the folding of the protein occurs.

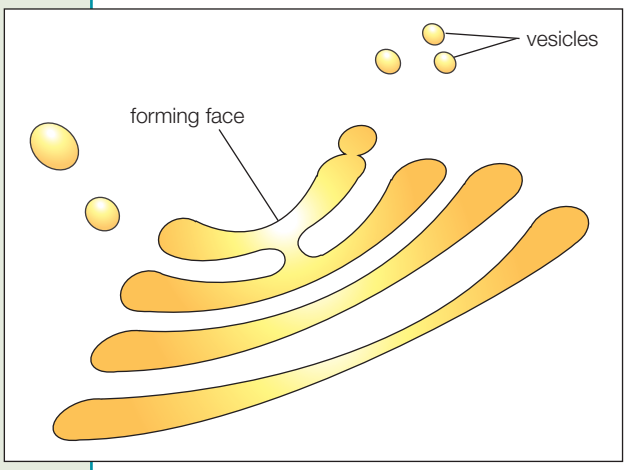
Golgi bodies—packaging and sorting the products

Although the Golgi body is also made of flat membranes, it differs from ER in that it does not have ribosomes attached and the membranes are often in stacks of four to ten. The Golgi body is easily recognisable by its curved shape on one surface, where *vesicles* can be seen budding off. This surface is called the *forming face* and the vesicles are evidence of the secretory function of Golgi bodies. The opposite surface may be convex or flat in shape.

Golgi bodies process, package and 'sort' cell products. They are involved in adding proteins and carbohydrates to cell products and they also provide

a membrane around the cell products to 'package' them. The membranes provided by Golgi bodies vary and serve as a 'packaging label'. Features of the membrane are used to 'sort' these products, determining where they will end up—they may be transported within the cell to wherever they are required or they may be secreted out of the cell.

Figure 1.18 Golgi body and vesicles



Lysosomes—digestion and destruction

One example of the products of Golgi bodies are lysosomes. These are little fluid-filled sacs, most commonly seen in animal cells. They are surrounded by a single membrane and the vesicle is filled with digestive enzymes, for intracellular digestion. Lysosomes commonly break down worn out cell organelles, so that the materials can be recycled and used to make new organelles. The membrane is essential to prevent the enzyme from digesting the normal cell contents.

Mitochondria—cellular respiration: production and storage of energy (ATP)

- Mitochondria are the 'powerhouses' of a cell, producing energy by the process of **chemical respiration**.
- Mitochondria (singular = *mitochondrion*) are usually rod-shaped, but may be round, they vary in both shape and size. Mitochondria are smaller than the nucleus and chloroplasts, but larger than ribosomes.
- The number of mitochondria in a cell depends on how much energy the cell needs to carry out its functions. Less active cells contain few mitochondria, whereas very active cells have hundreds or even thousands of mitochondria (e.g. active liver cells contain 1000 to 2000 mitochondria).
- Just as machines in a factory need electrical energy in order to work, so cells need energy, in the form of a chemical called ATP (adenosine triphosphate), to work. Mitochondria combine oxygen with sugars during the process of chemical respiration to release energy in a form (ATP) that the cell can use.
- Each mitochondrion is surrounded by a **double membrane**: the *outer membrane* gives the mitochondria its shape and allows the passage of small substances into and out of mitochondria. The *inner membrane* is folded into fine, finger-like ridges or **cristae**—this increases the surface area for the attachment of groups of enzymes that are responsible for making energy for the cell. The groups of enzymes appear as knob-like particles on the inside of the cristae.
- The central space in a mitochondrion is filled with fluid and is termed the **matrix**. It contains mitochondrial DNA and enzymes that give mitochondria the unusual feature of being able to replicate (make copies of) themselves. The mitochondria divide by pinching off and then growing, something that usually occurs in very active cells or cells that are about to divide. This ability of mitochondria to reproduce themselves is extremely useful in evolutionary studies.

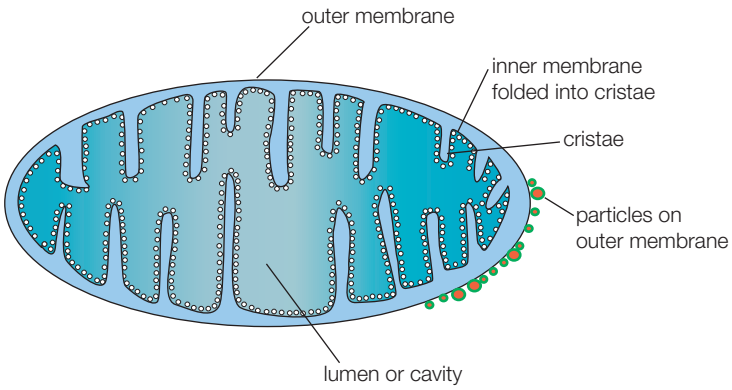


Figure 1.19
Simplified scheme of mitochondrion in longitudinal section

Chloroplasts—photosynthesis

- Chloroplasts belong to a group of organelles called *plastids* which are biconvex in shape and vary in colour. Plastids that are red, yellow and orange are called *chromoplasts* and they contribute to the colour of some flowers and fruit. Some plastids are white (e.g. leucoplasts in potatoes). Chloroplasts are green plastids which carry out the process of **photosynthesis**.
- Chloroplasts are larger than mitochondria, but they are similar in that they also contain their own DNA and the number of chloroplasts per cell varies.
- Chloroplasts are not found in all plant cells, only in green cells that photosynthesise; for example, they are not present in cells of roots, but are common in leaves.
- Chloroplasts are surrounded by a *double membrane* which allows substances to pass between the cytoplasm and the chloroplast but, unlike mitochondria, the inner membrane of the chloroplast is not folded (see Fig. 1.20).
- The liquid background of the chloroplast is called the stroma and it is here that stacks of membranes called **thylakoids** are found. Each stack or *group* of thylakoids is termed a **granum** (plural: *grana*) and the green pigment, **chlorophyll**, is found on these membranes.
- The layering of the membranes increases the surface area over which chlorophyll occurs, allowing a large amount of sunlight to be absorbed for the process of photosynthesis. This captured energy of sunlight is then used by the plant to make food. All the enzymes needed for photosynthesis are present in the stroma and food made during photosynthesis is stored in the stroma as starch grains.

Cytoskeleton—keeps organelles in place

Organelles are not randomly scattered within a cell, their distribution is organised and they are held in place by a network of tiny microtubules and microfilaments called the cytoskeleton, which extends throughout the cytoplasm.

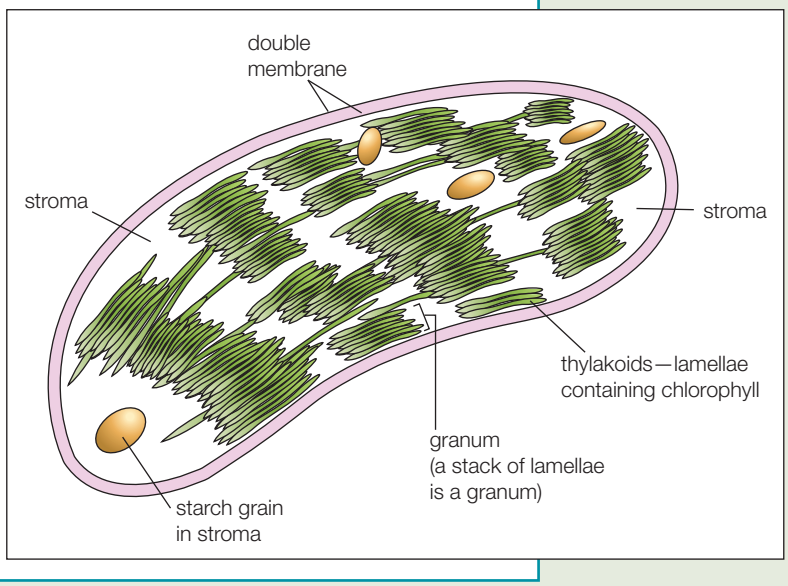


Figure 1.20
Simplified scheme of chloroplast seen in longitudinal section

Centrioles—spindle production in cell division

A dense, granular structure, the centrosome, is often found near the nucleus in animal cells. It consists of two centrioles, which play an important role in the formation of spindle fibres when a cell divides (this will be referred to in Chapter 5).

Plant cell wall—shape and support

The cellulose cell wall that surrounds plant cells differs from the cell membrane beneath it, because the cell wall is not really selective in terms of what substances it does or does not allow into the cell. Its structure allows it to provide strength and support. The cell wall is built up of strands of cellulose fibres which have a little elasticity and are somewhat flexible, giving cell walls their characteristic feature of being able to resist the outward pressure of the vacuole and cell contents in a well-watered plant cell, conferring turgidity to the cell. Some cell walls are thickened with additional chemicals such as *lignin*, which could make the walls hard and woody (e.g. in tree trunks), or the chemical *suberin* for waterproofing (e.g. in cork or the waxy cuticle of leaves).

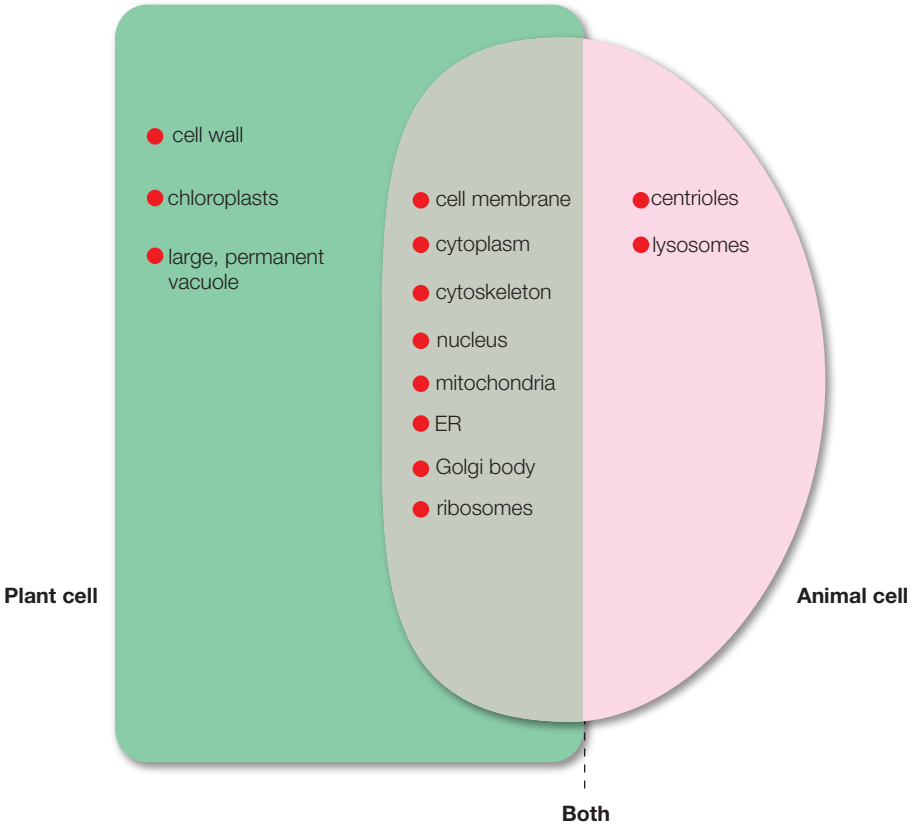


Figure 1.21
Summary of structures found in plant and animal cells

Electron micrographs of cell organelles

- ***process information from secondary sources to analyse electron micrographs of cells and identify mitochondria, chloroplasts, Golgi bodies, lysosomes, endoplasmic reticulum, ribosomes, nucleus, nucleolus and cell membranes***

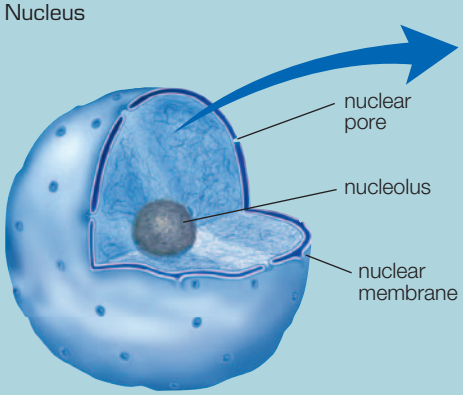
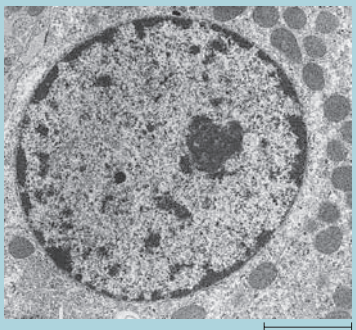
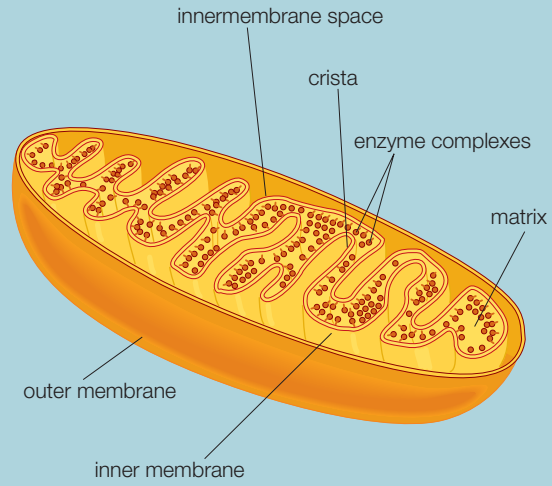
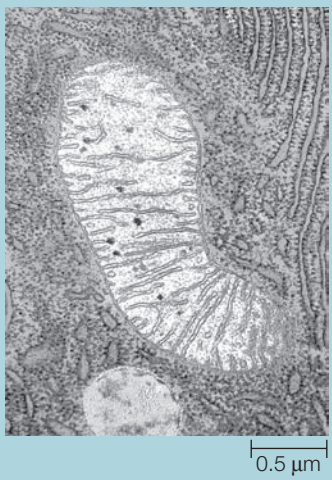
SECONDARY SOURCE INVESTIGATION

BIOLOGY SKILLS

P12.3; P12.4

Table 1.5 shows a series of micrographs of the organelles of plant and animal cells, as seen using a transmission electron microscope. Draw a scientific diagram of the organelles shown in each micrograph, label the parts listed in the column next to the micrographs and then select any two features labelled on your diagram and describe how their structure relates to the function of the organelle of which it forms a part.

Table 1.5 Identifying cell organelles and relating structure to function

Three-dimensional view of organelle	Micrograph of organelle	Identify and label these parts on the micrograph
Nucleus 		■ double nuclear membrane ■ nuclear pore ■ chromatin ■ nucleolus ■ nuclear sap
Mitochondrion 		■ outer membrane ■ inner membrane ■ matrix ■ crista ■ particles adhering to crista

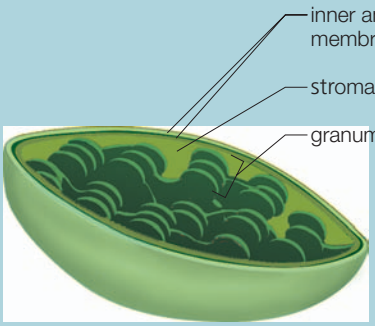
continued . . .

SR TR

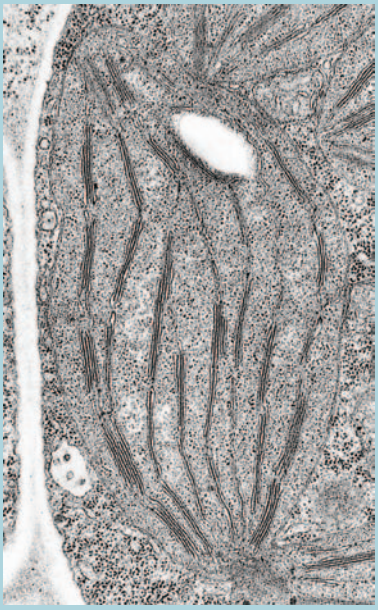
Student worksheet

Three-dimensional view of organelle

Chloroplast



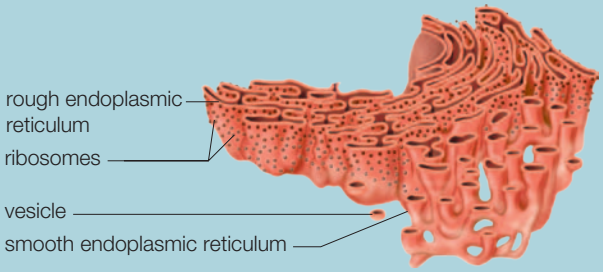
Micrograph of organelle

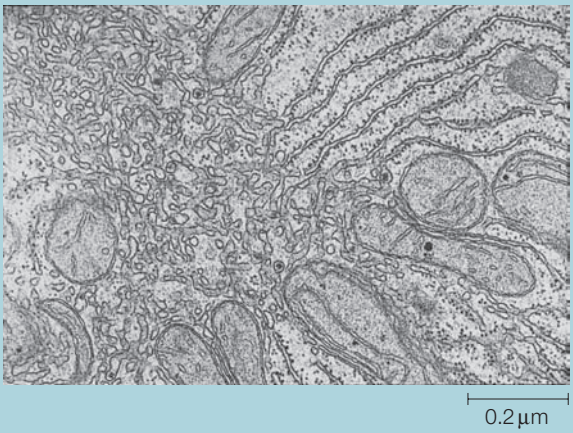


Identify and label these parts on the micrograph

- double membrane
- stroma
- lamella
- granum
- cholorophyll
- starch grain

Endoplasmic reticulum and ribosomes





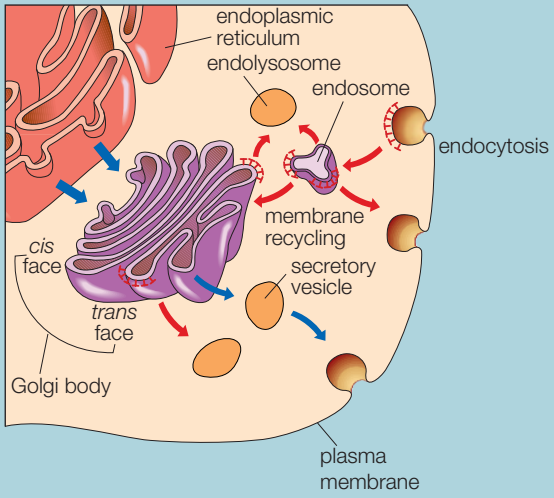
- flattened membranes
- ribosomes
- rough endoplasmic reticulum
- smooth endoplasmic reticulum

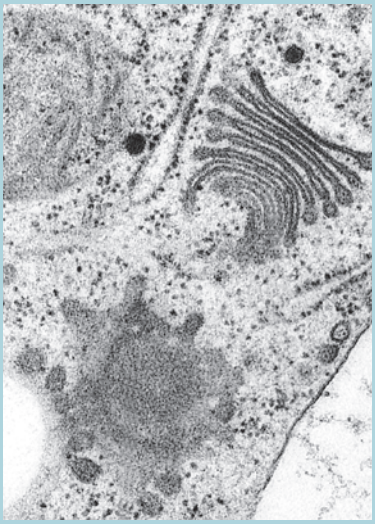
Three-dimensional view of organelle

Micrograph of organelle

Identify and label these parts on the micrograph

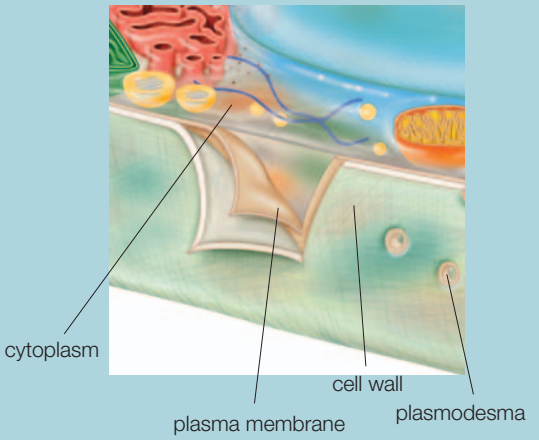
Golgi body and lysosomes

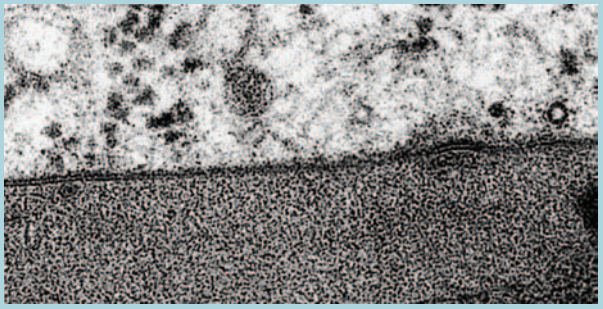




- membranes of Golgi
- convex forming face
- vesicles budding off
- lysosome

Cell membrane and cell wall





- cell membrane
- cell wall
- cytoplasm

REVISION QUESTIONS

1. (a) Clarify what is meant by a scientific *theory*.
   (b) Describe how you would go about validating a scientific theory.
   (c) State the cell theory.
2. Before the development of the cell theory, it was commonly believed that living organisms could arise by spontaneous generation.
   (a) Outline the theory of spontaneous generation.
   (b) Describe experimental evidence that was used to discount this theory.
   (c) Explain the role that the invention of the microscope played in the dismissal of the theory of spontaneous generation.
3. Describe the contributions of Robert Hooke and Robert Brown in the development of the cell theory. (Find a reliable way of remembering which 'Robert' did what!)
4. Discuss why biologists have continued to use light microscopes since the invention of the electron microscope.

Table 1.6

5. Put the following words into order of size, from smallest to largest: organelles, molecules, cells, atoms and organisms.
6. Compare the detail seen with a light microscope in plant and animal cells. As a guide use the table below. (Copy out a larger version or print it from the Student Resource CD.)

Table 1.6 Parts of cells visible under a light microscope

Part of cell	Plant cell	Animal cell
Boundary		
Organelles		
Cell shape		
Vacuoles		

7. State whether the each of the following photographs shows plant or animal cells. Justify your answers.