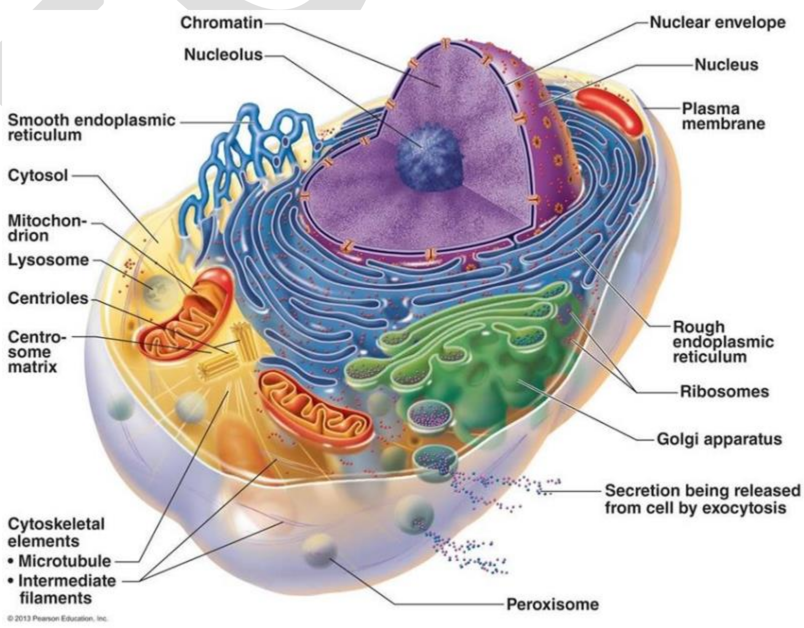
Cambridge AS level Biology

CODE: (9700)

Chapter 01

Cell structure



Why cells?

A cell is a bag allowing life's chemistry to occur, partially separated from the environment. The thin membrane controls exchange and allows controlled material traffic. 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.

Cell biology and microscopy

The study of cells has given rise to an important branch of biology known as **cell biology.** Light and electron microscopes are two types of microscopes, each using radiation to create images of specimens.

Light microscopy

The 19th century saw the 'golden age' of light microscopy, with significant improvements in glass lens quality leading to increased interest among scientists. This fascination in biology led to rapid advancements in microscope design and cytology.

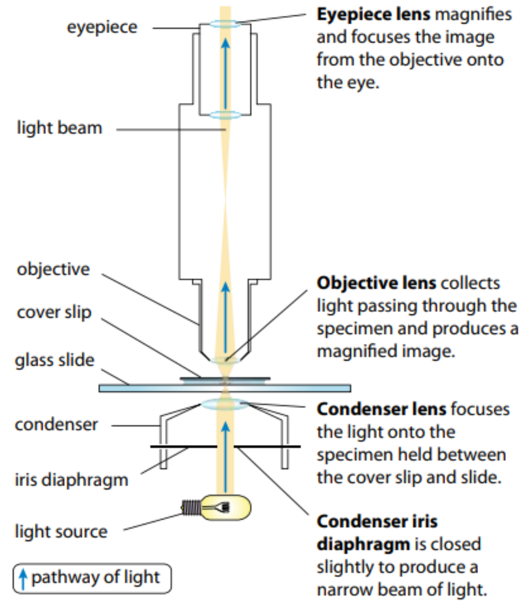


Figure 1.3 How the light microscope works.

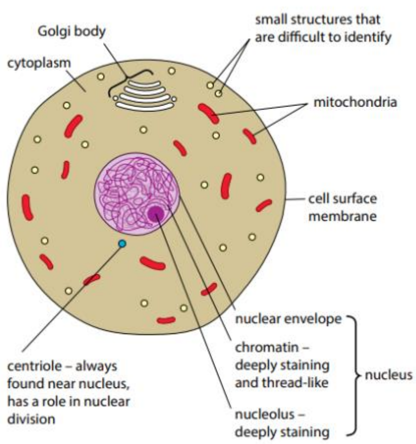
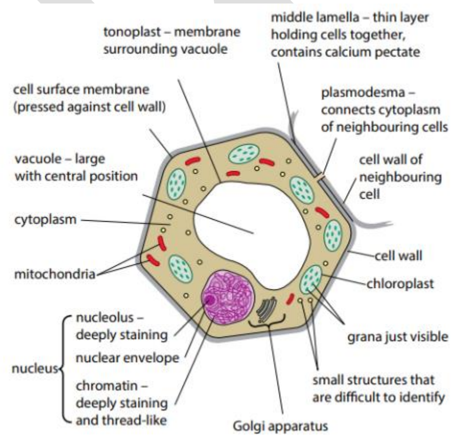
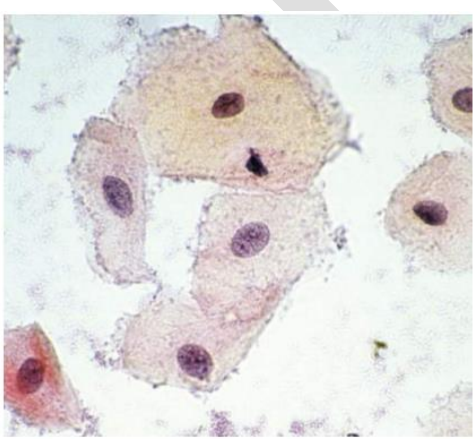


Figure 1.4 Structure of a generalised animal cell (diameter about 20 µm) as seen with a very high quality light microscope.





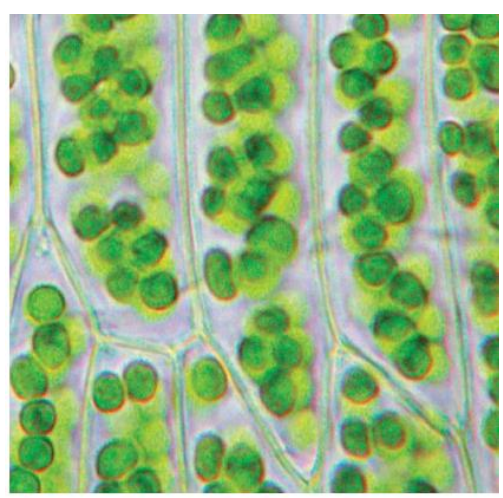


Figure 1.7 Photomicrograph of a cells in a moss leaf (×400).

Animal and plant cells have features in common

In animals and plants, each cell is surrounded by a very thin **cell surface membrane**.

Many of the cell contents are colourless and transparent so they need to be stained to be seen. Each cell has a **nucleus,** which is a relatively large structure that stains intensely and is therefore very conspicuous.

The deeply stained material in the nucleus is called **chromatin** and is a mass of loosely coiled threads. This material collects to form visible separate chromosomes during nuclear division. It contains **DNA** (deoxyribonucleic acid), a molecule which contains the instructions that control the activities of the cell Within the nucleus an even more deeply staining area is visible, the **nucleolus,** which is made of loops of DNA from several chromosomes. The number of nucleoli is variable, with one to five being common in mammals.

The material between the nucleus and the cell surface membrane is known as **cytoplasm.** These have been likened to small organs and hence are known as **organelles.**

Organelles themselves are often surrounded by membranes so that their activities can be separated from the surrounding cytoplasm. This is described as **compartmentalization.**

Since each type of organelle has its function, the cell is said to show a **division of labour**, a sharing of the work between different specialized organelles.

The most numerous organelles seen with the light microscope are usually **mitochondria** (singular: **mitochondrion**)

The use of special stains containing silver enabled the **Golgi apparatus** to be detected for the first time in 1898 by Camillo Golgi. The Golgi apparatus is part of a complex internal sorting and distribution system within the cell.It is also sometimes called the **Golgi body** or **Golgi complex.**

Differences between animal and plant cells

Centrioles Under the light microscope the **centriole** appears as a small structure close to the nucleus.

With a light microscope, individual plant cells are more easily seen than animal cells, because they are usually larger and, unlike animal cells, surrounded by a **cell wall** outside the cell surface membrane.

Plant cells are linked to neighbouring cells through fine strands of cytoplasm called **plasmodesmata** (singular: **plasmodesma**), which pass through pore-like structures in their walls. Movement through the pores is thought to be controlled by the structure of the pores.

Vacuoles

Although animal cells may possess small vacuoles such as phagocytic **vacuoles**. 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.

Chloroplasts

Chloroplasts are found in the green parts of the plant, mainly in the leaves. It is even possible to see tiny ‘grains or grana (singular: **granum**) inside the chloroplasts using a light microscope.

These are the parts of the chloroplast that contain **chlorophyll,** the green pigment which absorbs light during the process of photosynthesis, the main function of chloroplasts.

<u>Points to note</u>

■■ 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.

■■ Vacuoles are not confined to plant cells; animal cells may have small vacuoles, such as phagocytic vacuoles, although these are not usually permanent structures.

Units of measurement

Microscopically, measuring objects requires using small units, such as the International System of Units (SI units). The metre is the basic unit, with additional units created using prefixes like kilo. Relevant units for cell studies are shown in Table 1.1.

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: µ is the Greek letter mu; 1 micrometre is a thousandth of a millimetre; 1 nanometre is a thousandth of a micrometre.

Electron microscopy

By 1900, most structures in Figures 1.4 and 1.5 had been discovered, leading to frustration among microscopists who realized that light microscope design limitations limited the number of structures visible. To understand why this is, it is necessary to know something about the nature of light itself and to understand the difference between **magnification** and **resolution.**

Magnification

Magnification is the number of times larger an image is than the real size of the object.

$$\text{magnification} = \frac{\text{observed size of the image}}{\text{actual size}}$$

or

$$M = \frac{I}{A}$$

Resolution

Look again at Figure 1.9 (page 8). Figure 1.9a is a **light micrograph** (a photograph taken with a light microscope, also known as a **photomicrograph**). Figure 1.9b is an electron micrograph of the same specimen taken at the same magnification (an electron micrograph is a picture taken with an **electron microscope**)

Resolution can be defined as the ability to distinguish between two separate points. If the two points cannot be **resolved**, they will be seen as one point. In practice, resolution is the amount of detail that can be seen – the greater the resolution, the greater the detail.

Resolution is the ability to distinguish between two objects very close together; the higher the resolution of an image, the greater the detail that can be seen.

Magnification is the number of times greater that an image is than the actual object;
magnification = image size ÷ actual (real) size of the object.

The electromagnetic spectrum

Light's wave nature, ranging from 400nm to 700nm, allows the human eye to distinguish between different wavelengths, which in the brain are converted into color differences. The whole range of different wavelengths is called the **electromagnetic spectrum.**

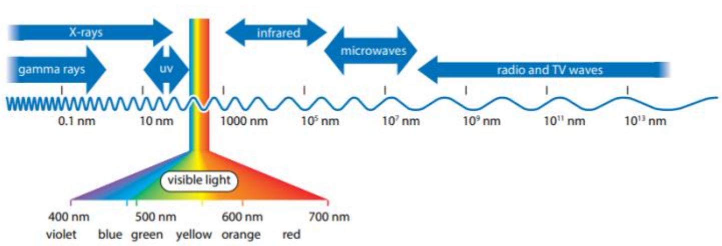


Figure 1.11 Diagram of the electromagnetic spectrum (the waves are not drawn to scale). The numbers indicate the wavelengths of the different types of electromagnetic radiation. Visible light is a form of electromagnetic radiation. The arrow labelled uv is ultraviolet light.

Figure 1.12 shows a mitochondrion, ribosomes, and 400nm wavelength light. The mitochondrion can interfere with light waves, but ribosomes are too small. The limit of resolution is about half the wavelength of the radiation used to view the specimen. The best resolution using a light microscope is 200nm, with a maximum magnification of 1500 times.

If an object is transparent, it will allow light waves to pass through it and therefore will still not be visible. This is why many biological structures must be stained before they can be seen.

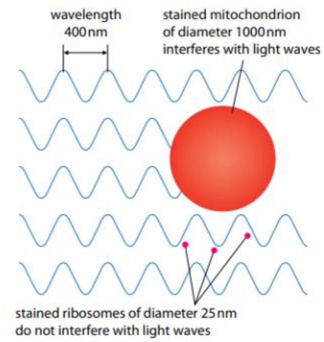


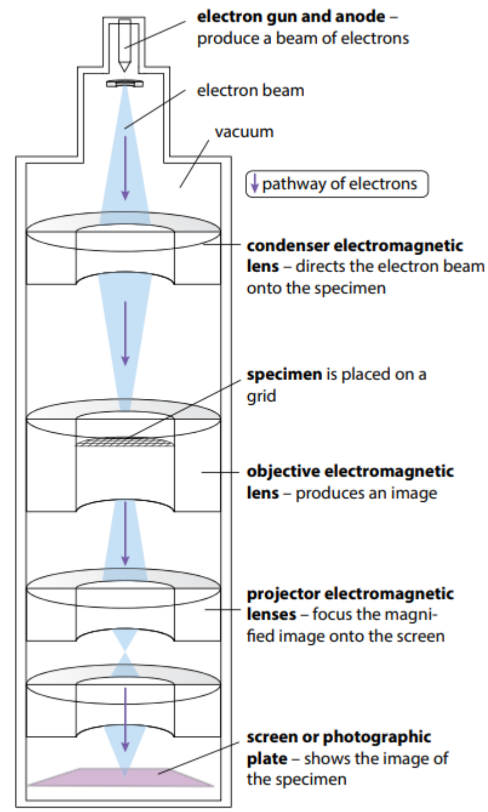
Figure 1.12 A mitochondrion and some ribosomes in the path of light waves of 400 nm length.

The electron microscope

Biologists discovered that light microscopes couldn't see anything smaller than 200nm due to the limitations of light. They decided to use shorter wavelength radiation, such as ultraviolet light or X-rays, instead. Electrons, negatively charged particles orbiting an atom's nucleus, have a shorter wavelength due to their energy gain. This makes electrons an ideal form of microscope.

Transmission and scanning electron microscopes

Two types of electron microscopes are now in common use. The **transmission electron microscope**, or **TEM,** was the type originally developed. Here the beam of electrons is passed **through** the specimen before being viewed. Only those electrons that are **transmitted** (pass through the specimen) are seen. This allows us to see thin sections of specimens, and thus to see inside cells. In the **scanning electron microscope (SEM),** on the other hand, the electron beam is used to scan the surfaces of structures, and only the reflected **beam** is observed.



Viewing specimens with the electron microscope

An electron microscope uses a fluorescent screen to project electron beams, resulting in a black-and-white image. Stains used to improve contrast in biological specimens contain heavy metal atoms, causing the resulting image to resemble an X-ray photograph. False-colour images can be created using a computer.

Electron microscopy is challenging due to the need for a vacuum, dehydration of specimens, and the presence of air molecules, which scatter electrons and prevent sharp pictures. Efforts are made to preserve lifelike material for examination.

Ultrastructure of an animal cell

The fine (detailed) structure of a cell as revealed by the electron microscope is called its ultrastructure.

Figure 1.16 shows the appearance of typical animal cells as seen with an electron microscope, and Figure 1.17 is a diagram based on many other micrographs.

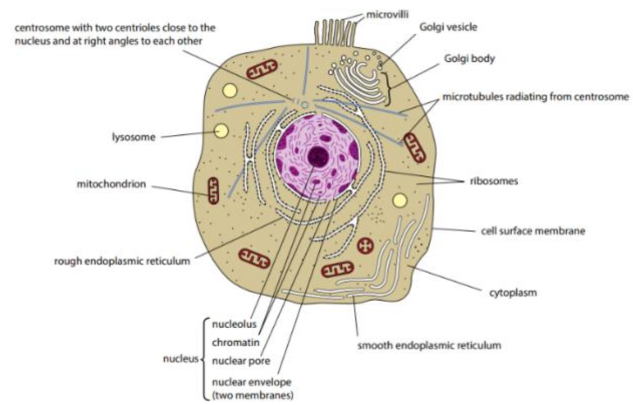


Figure 1.17 Ultrastructure of a typical animal cell as seen with an electron microscope. In reality, the ER is more extensive than shown, and free ribosomes may be more extensive. Glycogen granules are sometimes present in the cytoplasm.

Structures and functions of organelles

Compartmentalization and division of labour within the cell are even more obvious with an electron microscope than with a light microscope. We will now consider the structures and functions of some of the cell components in more detail.

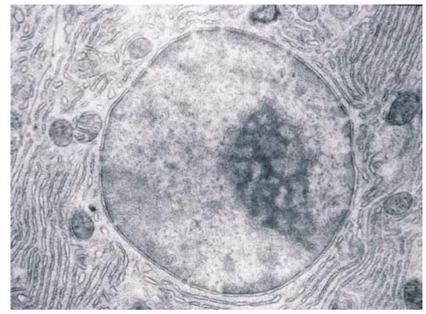


Figure 1.18 Transmission electron micrograph of the nucleus of a cell from the pancreas of a bat (×7500). The circular nucleus is surrounded by a double-layered nuclear envelope containing nuclear pores. The nucleolus is more darkly stained. Rough ER (page 15) is visible in the surrounding cytoplasm.

Nucleus

The **nucleus** (Figure 1.18) is the largest cell organelle. It is surrounded by two membranes known as the **nuclear envelope.** The outer membrane of the nuclear envelope is continuous with the endoplasmic reticulum.

The nuclear envelope has many small pores called **nuclear pores**. These allow and control exchange between the nucleus and the cytoplasm

Endoplasmic reticulum and ribosomes

When cells were first seen with the electron microscope, biologists were amazed to see so much detailed structure. The existence of much of this had not been suspected. This was particularly true of an extensive system of membranes running through the cytoplasm, which became known as the **endoplasmic reticulum** (ER) (Figures 1.18, 1.19 and 1.22).

There are two types of ER: rough ER and smooth ER. **Rough ER** is so-called because it is covered with many tiny organelles called ribosomes.

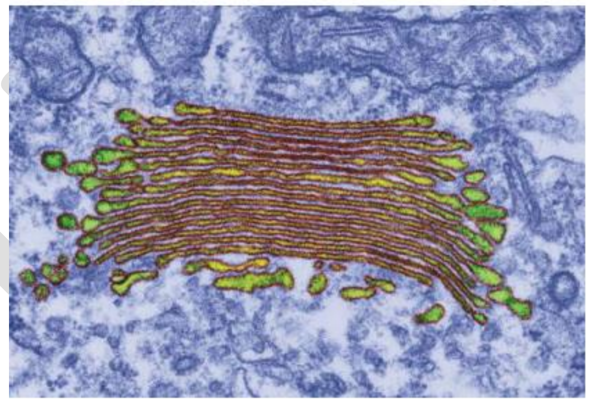


Figure 1.20 Transmission electron micrograph of a Golgi body. A central stack of saucer-shaped sacs can be seen budding off small Golgi vesicles (green). These may form secretory vesicles whose contents can be released at the cell surface by exocytosis (page 87).

The Golgi body, composed of RNA and protein, is part of the secretory pathway, allowing proteins to be exported from the cell via Golgi vesicles, which are formed by ribosomes on the rough ER.

Smooth ER, so called because it lacks ribosomes, has a completely different function. It makes lipids and steroids, such as cholesterol and the reproductive hormones oestrogen and testosterone.

Golgi body (Golgi apparatus or Golgi complex)

The **Golgi body** is a stack of flattened sacs (Figure 1.20). More than one Golgi body may be present in a cell. The stack is constantly being formed at one end from vesicles which bud off from the ER and broken down again at the other end to form **Golgi vesicles.**

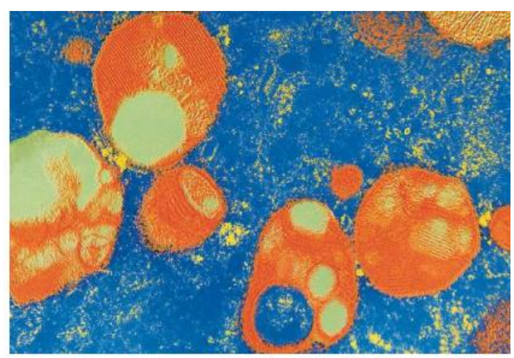


Figure 1.21 Lysosomes (orange) in a mouse kidney cell (×55000). They contain cell structures in the process of digestion, and vesicles (green). Cytoplasm is coloured blue here.

Lysosomes

Lysosomes are spherical sacs with no internal structure, 0.1-0.5µm in diameter, containing digestive enzymes. They break down unwanted structures and whole cells, like mammary glands after lactation. In white blood cells, they digest bacteria. Enzymes can be released outside the cell.

Mitochondria

<u>Structure</u>
The inner of these is folded to form finger-like **cristae** which project into the interior solution, or **matrix**. The space between the two membranes is called the **intermembrane space**. The outer membrane contains a transport

protein called **porin,** which forms wide aqueous channels allowing easy access of small, water-soluble molecules from the surrounding cytoplasm into the intermembrane space.

Function of mitochondria and the role of ATP

ATP, the universal energy carrier, is the energy-carrying molecule found in all living cells. Reactions occur in solution in the matrix and inner membrane (cristae), with enzymes providing hydrogen and electrons. The flow of electrons along the membranes generates **ATP** molecules. **ATP** leaves the mitochondrion and spreads rapidly to all parts of the cell. Its energy is released by breaking down **ADP,** which can be recycled into a mitochondrion for conversion during aerobic respiration.

The endosymbiont theory

In the 1960s, it was discovered that mitochondria and chloroplasts contain ribosomes, like those found in bacteria, and small, circular DNA molecules. These ancient bacteria now live in larger cells typical of animals and plants, like those found in cytoplasm.
This is known as the **endosymbiont theory**. 'Endo' means 'inside' and a 'symbiont' is an organism which lives in a mutually beneficial relationship with another organism.

Cell surface membrane

The cell surface membrane is extremely thin (about 7nm). However, at very high magnifications, at least × 100 000, it can be seen to have three layers, described as a **trilaminar appearance.**

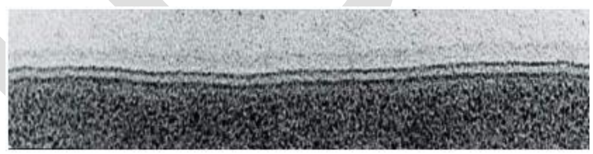


Figure 1.23 Cell surface membrane (×250 000). At this magnification the membrane appears as two dark lines at the edge of the cell.

Microvilli

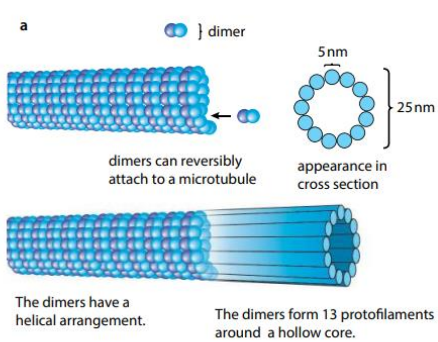
Microvilli, finger-like extensions of cell surface membrane, increase membrane surface area, useful for absorption in gut and kidney reabsorption.

Microtubules and microtubule organizing centers (MTOCs)

Microtubules, small, rigid tubes in the cytoplasm, make up the cytoskeleton and determine cell shape. Made of tubulin, they consist of α-tubulin and beta-tubulin. These molecules combine to form dimers, which are joined to form protofilaments. These protofilaments form a cylinder with a hollow center.

Microtubules serve multiple functions in cellular structures, including supporting secretory vehicles, forming an intracellular transport system, holding membrane-bound organelles, and acting as a spindle during nuclear division and centriole structure.

The assembly of microtubules from tubulin molecules is controlled by special locations in cells called **microtubule organizing centers (MTOCs).**



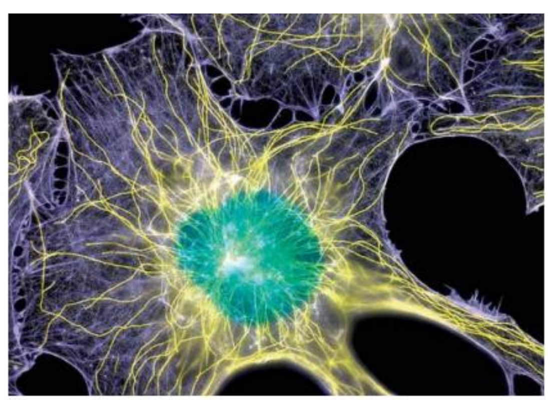


Figure 1.24 **a** The structure of a microtubule and **b** the arrangement of microtubules in two cells. The microtubules are coloured yellow.

Centrioles and centrosomes

The extra resolution of the electron microscope reveals that just outside the nucleus of animal cells there are two centrioles and not one as it appears under the light microscope (compare Figures 1.4 and 1.17). They lie close together and at right angles to each other in a region known as the centrosome.

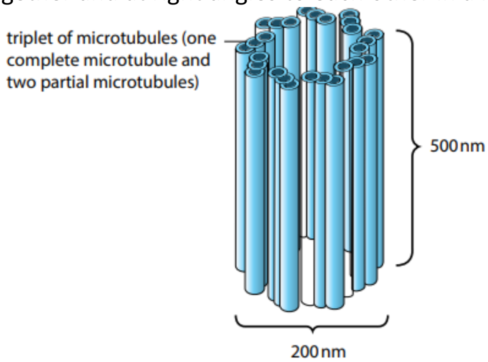


Figure 1.25 The structure of a centriole. It consists of nine groups of microtubules arranged in triplets.

Figure 1.26 Centrioles in transverse and longitudinal section (TS and LS) (×86 000). The one on the left is seen in TS and clearly shows the nine triplets of microtubules which make up the structure.

Ultrastructure of a plant cell

Animal cell structures, except centrioles and microvilli, are found in plant cells. Plant cell structures not found in animal cells include cell walls, large central vacuoles, and chloroplasts.

Chloroplasts

Chloroplasts, elongated with a diameter of 3-10 µm, are surrounded by two membranes and replicate independently of cell division, like mitochondria. They replicate by dividing into two.

Chloroplasts, crucial for photosynthesis, demonstrate the interplay between structure and function, making a brief comprehension of their function essential for comprehending their structure.

Photosynthesis, the light-dependent stage, involves the absorption of light energy by chlorophyll, a green pigment, and the splitting of water into hydrogen and oxygen. This process requires electron transport in membranes, which are organized into thylakoids and grana, which contain photosynthetic pigments and electron carriers. Both membranes and chloroplasts can change orientation to maximize light absorption.

Chloroplasts store sugars in starch grains and lipid droplets, which are used for membranes or membrane breakdown. They have protein synthesis machinery, including 70S ribosomes and a circular DNA strand. Chloroplasts originated as endosymbiotic bacteria, photosynthetic blue-green bacteria, and have their protein synthesis machinery.

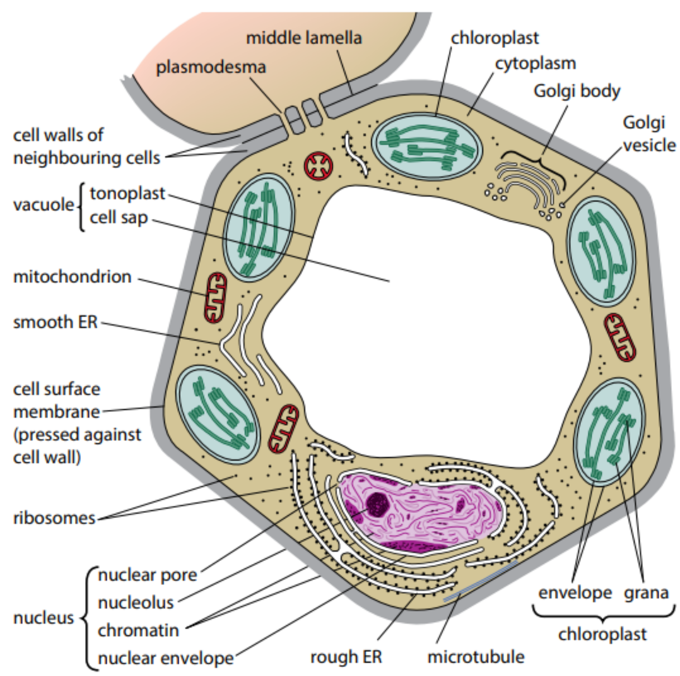


Figure 1.29 Chloroplasts (×16 000). Thylakoids (yellow) run through the stroma (dark green) and are stacked in places to form grana. Black circles among the thylakoids are lipid droplets. See also Figure 13.6, page 291. Chloroplast X is referred to in Question 1.2.

Two fundamentally different types of cells

Organisms that lack nuclei are called **prokaryote**s ('pro' means before; 'karyon' means nucleus). They are, on average, about 1000 to 10,000 times smaller in **volume** than cells with nuclei, and are much simpler in structure – for example, their DNA lies free in the cytoplasm. Organisms whose cells possess nuclei are called eukaryotes ('eu' means true). Their DNA lies inside a nucleus. Eukaryotes include **animals, plants, fungi** and a group containing most of the unicellular eukaryotes known as **protoctists.**

A generalized **prokaryotic cell** is shown in Figure 1.30. A comparison of prokaryotic and **eukaryotic cells** is given in Table 1.2

Prokaryotes	Eukaryotes
average diameter of cell is 0.5–5 µm	cells commonly up to 40 µm diameter and commonly 1000–10 000 times the volume of prokaryotic cells
DNA is circular and lies free in the cytoplasm	DNA is not circular and is contained in a nucleus – the nucleus is surrounded by an envelope of two membranes
DNA is naked	DNA is associated with protein, forming structures called chromosomes
slightly smaller (70S) ribosomes (about 20 nm diameter) than those of eukaryotes	slightly larger (80S) ribosomes (about 25 nm diameter) than those of prokaryotes
no ER present	ER present, to which ribosomes may be attached
very few cell organelles – no separate membrane-bound compartments unless formed by infolding of the cell surface membrane	many types of cell organelle present (extensive compartmentalisation and division of labour): ■ some organelles are bounded by a single membrane, e.g. lysosomes, Golgi body, vacuoles ■ some are bounded by two membranes (an envelope), e.g. nucleus, mitochondrion, chloroplast ■ some have no membrane, e.g. ribosomes, centrioles, microtubules
cell wall present – wall contains murein, a peptidoglycan (a polysaccharide combined with amino acids)	cell wall sometimes present, e.g. in plants and fungi – contains cellulose or lignin in plants, and chitin (a nitrogen-containing polysaccharide similar to cellulose) in fungi

Table 1.2 A comparison of prokaryotic and eukaryotic cells.

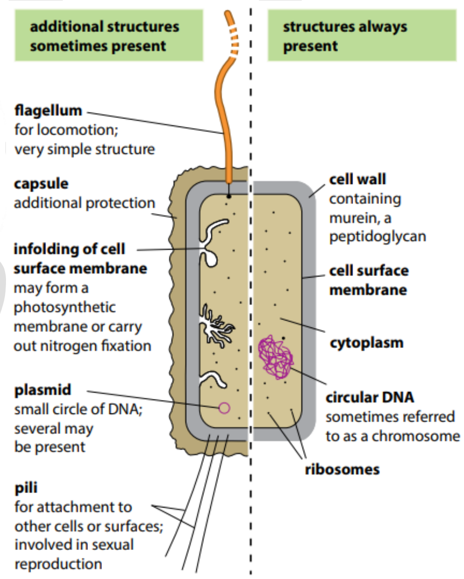


Figure 1.30 Diagram of a generalised bacterium showing the typical features of a prokaryotic cell.

Viruses

In 1852, a Russian scientist discovered that certain diseases could be transmitted by agents that could pass through filters, indicating the existence of viruses, which are smaller, simpler organisms on the boundary between living and non-living. They are much simpler in structure Most consist only of:

■A self-replicating molecule of DNA or RNA which acts as its genetic code

■A protective coat of protein molecules.

Figure 1.31 shows the structure of a simple virus. It has a very symmetrical shape. Its protein coat (or **capsid**) is made up of separate protein molecules, each of which is called a **capsomere.**

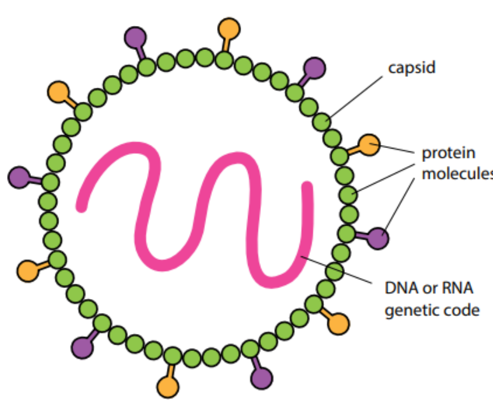
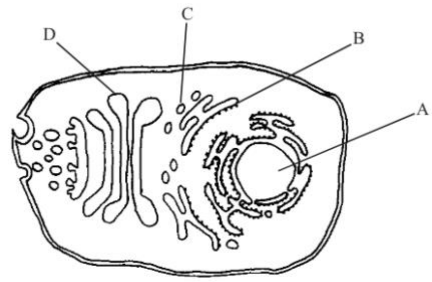


Figure 1.31 The structure of a simple virus.

Revision questions

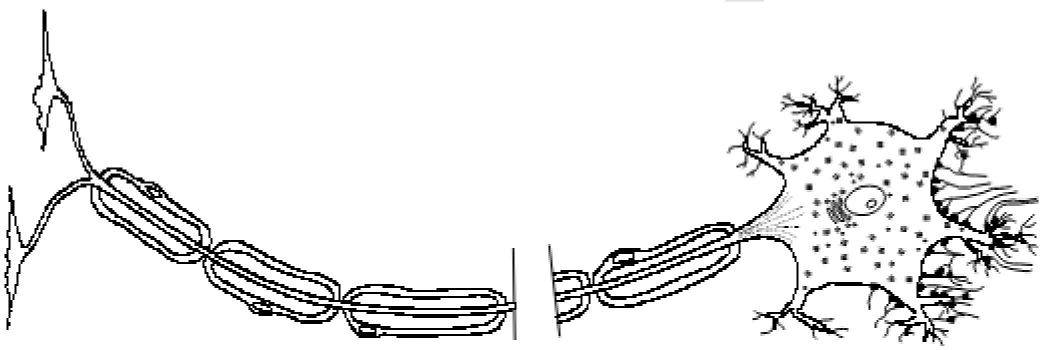


1) The diagram shows some of the cell structures involved in the secretion of an extracellular enzyme

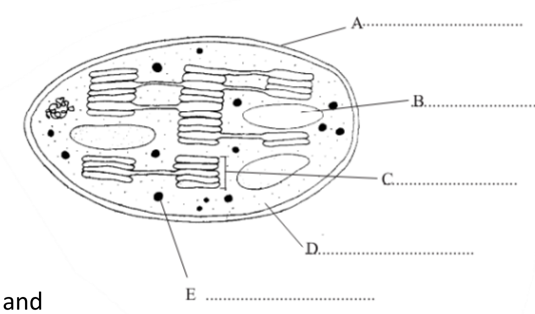
(a) Identify A, B, C, and D.
(b) Outline the role of each of the following in this process. (A, B, C, D)

2) The diagram shows a cell from the proximal (first) convoluted tubule in the nephron of the kidney
(a) Label two features on the diagram that help the cell to take up glucose from the glomerular filtrate
(b)Explain how the two features of the cell help in the uptake of glucose from the glomerular filtrate.

3) The diagram shows a voluntary motor neuron.



a) State one way in which (i) an autonomic motor neuron, and (ii) a sensory neuron differs in structure from the voluntary motor neurone.
b) Explain how each of the following features increases the efficiency of nerve impulse transmission
(i) myelinated axon
(ii) Nissl granules



3)The diagram shows the structure of a chloroplast
(a) Name structures labelled A to E on the diagram.
(b) Describe where in the chloroplast:
(i) the light-dependent reaction takes place.
(ii) the light-independent reaction takes place
(c) Describe three similarities in the structure of chloroplasts and mitochondria
(d) Suggest why each of the following is present in both chloroplasts and mitochondria.
(i) phosphorylase enzymes.
(ii) ribosomes

4) The table below compares the process of diffusion, facilitated diffusion and active transport. Complete the table by filling in the blanks, using the words yes or no.

	Process		
Description	Simple Diffusion	Facilitated Diffusion	Active Transport
Is ATP required?	No		
Are protein carrier molecules involved?	No		Yes
Direction of transport is always down concentration gradient		Yes	

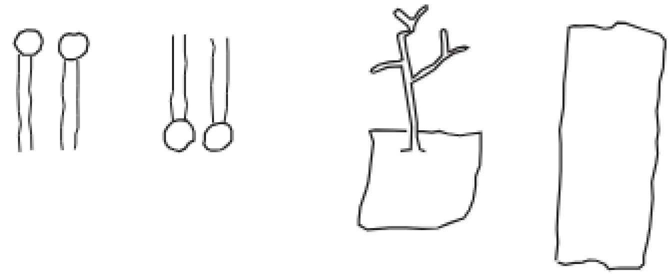
5) The table below describes the structure and function of organelles in eukaryotic cells. Complete the table by filling in the empty boxes A, B, C, D and E

Organelle	Structure/Feature	Function of feature
Nucleus	Nucleoli present	A
B	Inner membrane folded into cristae	C
D	Vesicles containing hydrolytic enzyme	Breakdown of old organelles. Cell lysis.
Smooth endoplasmic reticulum	Consists of flattened membrane- bound sacs called cisternae	E

6) The table below refers to a bacterial cell, a liver cell and a palisade mesophyll cell and to the structures which may be found inside them.
If a feature is present in the cell, place a tick in the appropriate box and if a feature is absent from the cell, place a cross (×) in the appropriate box.

Feature	Bacterial cell	Liver cell	Palisade cell
Nuclear membrane			
Vacuole			
Cell wall			
Microvilli			
Chloroplasts			
Mesosomes			
Glycogen granules			

7) The diagram below shows some of the components of the plasma membrane



(a) (i) Using the information shown and your knowledge, draw a diagram to show the structure of the plasma membrane.

(ii) On your diagram label the components drawn and indicate the outer surface of the membrane.

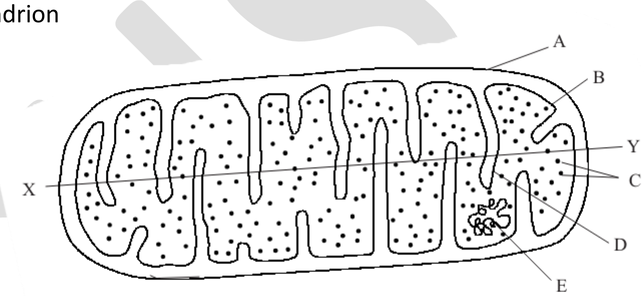
(b) State two functions of the proteins in the plasma membrane.

(c) Explain how the following substances cross the plasma membrane.

(i) carbon dioxide.

(ii) glucose.

8) The diagram below shows the structure of a mitochondrion



(a) Name structures A to E

b) State where the following are situated in the mitochondrion

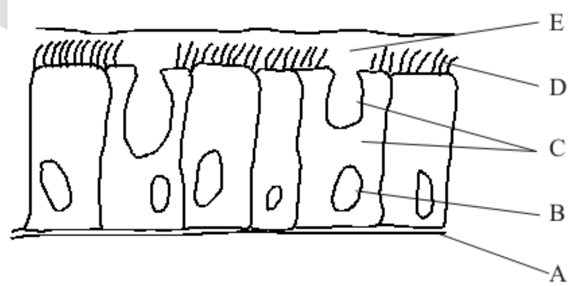
(i) The enzymes involved with oxidative phosphorylation and electron transport.

(ii) The enzymes involved with the Krebs cycle.

(iii) Why does the mitochondrion contain RNA?

(c) The magnification of the diagram is 130,000 times. Calculate the actual length of the mitochondrion. Express your answer in µm. Make your measurements along the axis XY.

9) The diagram below shows a vertical section through a simple columnar epithelium



(a) (i) Name structures A to E.

(ii) State two sites in the body where this type of epithelium can be found.

(iii) What are the functions of D and E?

(b) (i) How does a compound epithelium differ from a simple epithelium?

(ii) Name two types of compound epithelium and state one site in the body where each is found.