

5.1.5 RNA and the origin of life

Living things need molecules that have the ability to catalyse reactions that lead to the production of more molecules like themselves so that life can continue.

RNA has both the ability to replicate itself and to act as an enzyme and so one widely held view is that an RNA-dominated world existed on Earth before modern cells formed. This RNA hypothesis suggests that RNA both stored genetic information and catalysed chemical reactions in primitive ‘cells’. DNA took over as the genetic material and proteins became important catalysts much later in evolutionary time.

Support for this view comes from the fact that RNA still catalyses several important reactions in modern-day cells. Perhaps these reactions are the molecular equivalent of fossils from long ago. RNA is a likely molecule to form the basis for a self-replicating set of catalysts but it probably was not the first kind of molecule to do so.

But RNA molecules are difficult to synthesise and build into nucleotides without enzymes, so it has been suggested that the earliest molecules to have both catalytic and information-transferring abilities were chemically simpler ‘RNA-like’ polymers.

Protein catalysts that we know today have a surface with uniquely shaped active site where a given set of substrates can react. In exactly the same way, RNA molecules with appropriately folded shapes can serve as enzymes. For example ribozymes (ribonucleic acid enzymes) are RNA molecules that have the ability to catalyse certain biochemical reactions,

including RNA splicing as genes are expressed and peptide bond formation during the synthesis of protein. Like some proteins, many of these RNA enzymes work by positioning metal ions at their active sites. This feature increases the range of catalytic activities they can perform and explains how they can carry out more reactions than can be accounted for by chemical arrangements of the polynucleotide chain alone.

5.1.6 Micelles

Before cells as we know them today came into existence, they needed to separate themselves and their chemical reactions from the outside environment. To do this they developed a membrane bound compartment to allow the reactions inside the compartment to be different from those outside it. **Micelles** are aggregates formed by self-assembly of amphipathic molecules. Amphipathic structures contain a hydrophilic/polar region (head) and a hydrophobic/non-polar region (tail). In water, micelles form so that the polar region faces the outside surface of the micelle and the non-polar region forms the core.

Modern-day cells have membranes formed of phospholipid bilayers which separate cells from their environment and control what enters and leaves the cell ([Section 6.5](#)). Phospholipids placed in water form micelles, **vesicles** and bilayers.

Early life forms also needed to separate themselves from their environment and the first membrane-like barriers may have formed from fatty acids. Fatty acids are thought to have formed in low concentrations near hydrothermal vents. Fatty acids have hydrophilic heads and hydrophobic tails and they can arrange themselves into micelles. These arrangements may well have formed in the prebiotic environment and been part of the transition from chemical evolution to biological evolution on the early Earth.

KEY POINT

vesicles are structures that consist of a lipid bilayer and form within or outside cells. They form naturally and transport substances inside cells.

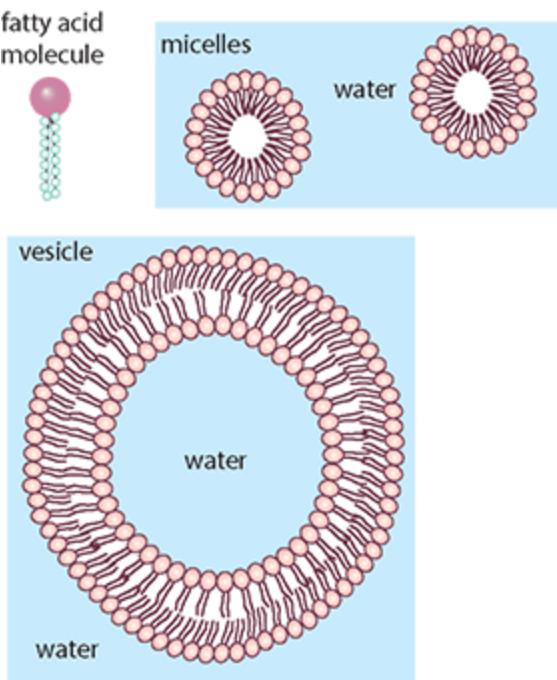


Figure 5.1.4: Micelles form from amphipathic molecules with hydrophobic tails at the centre and hydrophilic head around the outside.

Jack Szostak (b. 1952) is a Canadian American biologist and Nobel laureate who has studied the chemical and physical processes that may have led to this evolution.

The Szostak laboratory in Massachusetts, USA has investigated the formation of micelles and vesicles and discovered that, at low concentrations of fatty acids, micelles form, while at higher concentrations and the correct pH, vesicles will form.

Fatty acid barriers would have been important in an RNA world, especially to separate RNA sequences with different functions from one another. Movement across the fatty acid vesicles would have been possible because fatty acids can enter the vesicle membrane and small molecules including nucleotides can also pass inside. Experiments have shown that vesicles form and

grow rapidly in the presence of micelles. Fatty acid vesicles are very stable and do not appear to change, although their molecules are mobile and will enter and leave the vesicle layer and ‘flip’ between layers. Flipping would have enabled small molecules such as RNA nucleotides to enter the vesicle. Once incorporated into polymers, RNA strands would have been too large to leave through the fatty acid layers.

The membrane may also have been important in the early cell’s ability to store energy by creating a chemical gradient to create ATP in a similar way to the membranes in mitochondria and chloroplasts ([Chapter 3](#)).

Membrane boundaries enable cells to stabilise their internal environment by limiting what can enter and leave the cell. They also allow certain molecules to be accumulated to concentrations that allow biochemical reactions to take place.

5.1.7 Comets

It is unlikely that the early Earth had sufficient organic molecules needed to build all the complex molecules of life. But comets, which arrive regularly on the Earth's surface from space, are a rich source of organic materials.

The core of a comet contains simple molecules such as carbon dioxide and methanol but the Rosetta experiment, which landed a probe on the comet 67P in 2014, discovered that 16 different organic molecules were present. In addition, scientists from NASA discovered the amino acid glycine present in dust from another comet, Wild 2.

It is possible that comets brought these molecules, and others like them, to Earth during a period known as the Late Heavy Bombardment. This period, when many comets landed on Earth, is thought to have occurred between 4.1 and 3.8 billion years ago. Laboratory-based experiments have simulated the high-energy collisions between comets and Earth and discovered that the simple organic molecules found in comets will combine to form a number of amino acids. When amino acids were added to the chemicals from the comet and the experiment repeated, peptide chains were formed. This has led to speculation that comet collisions were key to the formation of organic molecules and ultimately life on Earth.

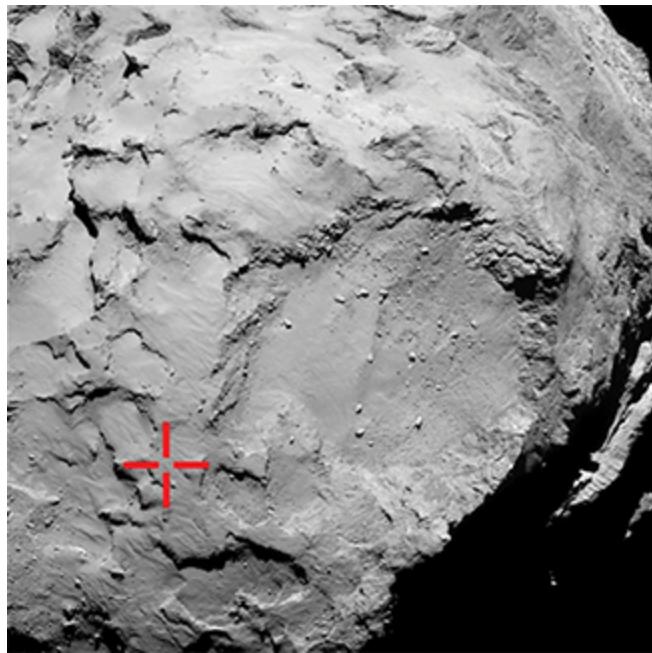


Figure 5.1.5: The comet 67P contained 16 different organic molecules.

NATURE OF SCIENCE

Establishing new theories and gathering evidence

Theories and models have been developed to try to explain how life might have begun on Earth. None of the theories discussed here can ever be proven because we can never observe what happened billions of years ago. Theories such as the clay hypothesis and the deep-sea vent hypothesis are scientists' attempts to explain processes and phenomena using data that are available and experiments that model possible events. Evidence to support a theory can be collected from laboratory experiments that model scientists' ideas and data from other sources. All of these may be helpful to support one theory over another. Any theory can be falsified when evidence does not support it. Science is based on and limited by evidence.

To consider:

- 1** How difficult is it for a scientist to develop a new theory or hypothesis when there is evidence to support an earlier one?
- 2** How do new discoveries, such as the locations of thermal vents, lead to changes in theories?
- 3** How important are new technologies, such as space travel, in learning about the past?

5.1.8 Last universal common ancestor

The last universal common ancestor (LUCA) is the name given to an evolutionary intermediate between the abiotic phase of Earth's history and the first traces of microbes found in rocks that are around 4 billion years old. The idea of a last universal common ancestor of all cells is central to the study of early evolution and the origin of life (Fig 5.1.6), but we can never have definite information about how and where LUCA lived. We can only gather evidence from experiments, the fossil record and studies of present-day genomes. There is evidence that LUCA could have lived in deep underground in iron-sulfur rich hydrothermal vents. LUCA would have been anaerobic and autotrophic, able to produce food in the dark, metal-rich environment around it. Its metabolism probably depended upon hydrogen, carbon dioxide and nitrogen and it would have produced organic compounds from them.

Evidence for LUCA

Evidence for LUCA's existence comes from the universal genetic code and shared genes that exist in all organisms. It is probable that other life forms also evolved but became extinct due to competition from LUCA and its descendants. A team of researchers based in Germany have identified a few hundred genes that definitely belonged to LUCA and can tell us something about how LUCA lived. Geneticists have checked the sequences of nearly 2000 genomes of modern microbes to search for these shared genes and using knowledge of what the genes code for today have suggested that LUCA lived without oxygen and used hydrogen. This provides support for the theory that LUCA was a thermophile (heat-loving) microbe that lived

in and around hydrothermal vents like those found near undersea volcanoes. Other researchers have noticed that LUCA shares this way of life with two groups of present-day microbes: Clostridium sp. (a genus of anaerobic bacteria) and methanogens, a group of Archaea which use hydrogen in their metabolism.

Evidence from the types of proteins that have been identified suggest that LUCA harvested chemicals across a gradient between the hot vent water and colder sea water to make ATP. If this is true, primitive life forms would have had to stay close to hydrothermal vents.

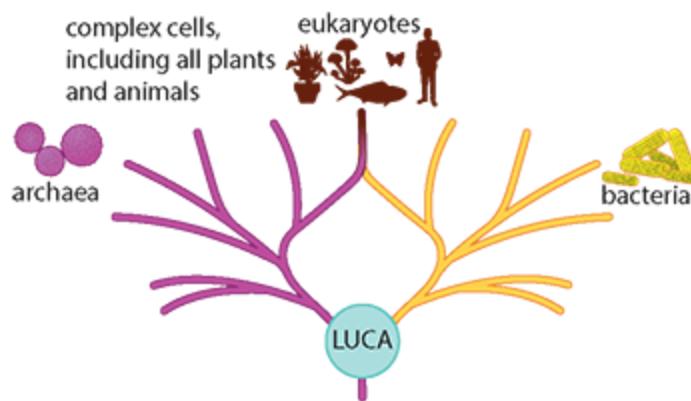


Figure 5.1.6: Scientists propose that LUCA has given rise to all organisms that we know today.

They would have been unable to survive anywhere else because they could not pump ions across a membrane to make ATP, as all organisms can do today. No genes have yet been found that could make amino acids, so the first organisms probably relied on amino acids that form naturally at hydrothermal vents.

EXTENSION

The exact date that LUCA appeared cannot be worked out precisely from the evidence that has been found and analysed. Early microbes used to exchange genes in a process known as **horizontal gene transfer** and some of these genes may have been misinterpreted as coming from the time of LUCA.

TEST YOUR UNDERSTANDING

- 4 State the properties of phospholipids that enable them to form a boundary between cell contents and the outside environment.
- 5 What are the key principles of cell theory?
- 6 Outline the inputs and products of the Miller–Urey experiment
- 7 Why is RNA regarded as being important part of the origin of life?
- 8 What is the main source of evidence for LUCA?

Links

- What features do all cells have in common ([Chapter 5.2](#))
- Boundaries separate cells from their environment, but to what extent must they permit gases, nutrients and waste to cross them? ([Chapter 6](#))

5.2 Cell structure

LEARNING OBJECTIVES

In this section you will:

- recall that living organisms are composed of one or more cells
- understand that unicellular organisms carry out all the functions of life
- recognise that multicellular organisms contain specialised tissues which develop as a result of differentiation
- discover that in multicellular organisms not all cells carry out all the functions of life
- learn that prokaryotic cells have a different structure from eukaryotic cells
- recognise that developments in microscopy have increased our understanding of cell structure
- learn that some cells have an atypical structure.

- understand that the endosymbiotic theory explains the origin of eukaryotic cells
- recall that differentiation is the process for developing specialised tissues

➤ understand that multicellularity has advantages for body size and specialisation

GUIDING QUESTIONS

- How are all cells similar and how do they differ?
- How do compartments in different cells differ between cells?

5.2.1 Cells and their structure

Today, scientists agree that the cell is the fundamental unit of all life forms. An individual cell can perform all the functions of life and anything that is not made of cells, such as viruses, cannot be considered living. Cell theory proposes that all organisms are composed of one or more cells and, furthermore, that cells are the smallest units of life.

Unicellular organisms

By definition, a living organism comprising just one cell has to perform all the necessary functions for survival.

The functions of life are:

- 1 metabolism – all the biochemical reactions of life
- 2 growth – increase in size or number of cells
- 3 response (or sensitivity) – the ability to react to external conditions
- 4 homeostasis – maintenance of a constant internal environment
- 5 nutrition – feeding or making substances needed for metabolism
- 6 reproduction – producing new individuals
- 7 excretion – removal of waste products of metabolism.

A unicellular organism such as *Paramecium* (Figure 5.2.1) needs to **metabolise** organic materials in order to make the chemicals needed to sustain life. It must also be able to **excrete** waste

produced during metabolism and dispose of it. It must be able to detect changes in its environment, so it can respond to more favourable or less favourable conditions. Some unicellular organisms photosynthesise and they have a light spot that enables them to move to a brighter environment to maximise photosynthesis. A unicellular organism must also be able to control its internal environment (**homeostasis**), as large changes in water or salt concentrations may have a detrimental effect on metabolism and other cellular functions. It must also obtain food, whether produced from simple inorganic substances through photosynthesis (as in *Chlorella*; Figure 5.2.2) or ingested as complex organic materials from outside as a source of nutrition. If the species is to survive, an organism must be able to reproduce. This could be either asexual or sexual reproduction.

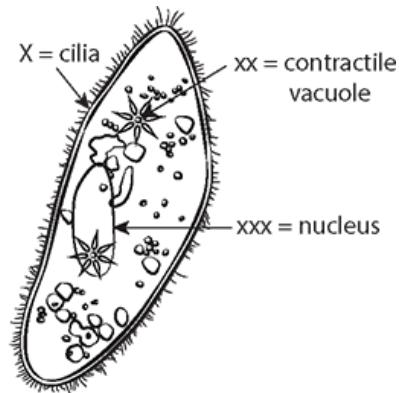


Figure 5.2.1: *Paramecium* carries out all the life functions within its single cell. A paramecium is about 0.5 mm long (x 100 magnification).

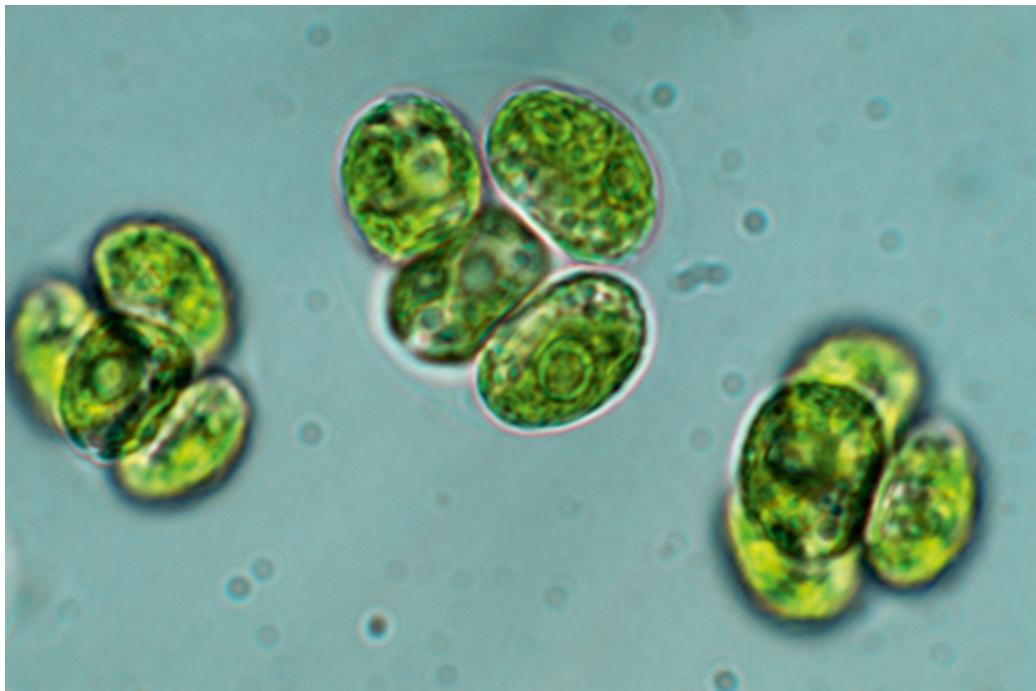


Figure 5.2.2: *Chlorella* is a unicellular organism containing a chloroplast ($\times 1200$ magnification).

Multicellular organisms and differentiation

Multicellular organisms such as animals, plants and fungi are made of many cells and can be much larger and more complex than simple unicellular organisms. Becoming multicellular has enormous advantages. An organism can grow in size and its cells can undergo **differentiation**, that is, each cell can take on specific functions, so the organism can grow in complexity as well as size. Differentiation involves the expression of some genes from the organism's genome in the cell, but not others.

A multicellular organism may have specialised nerve cells for communication and interaction with the outside, and muscle cells for movement. It may also have special reproductive cells and secretory cells that produce enzymes for digestion. New properties emerge as a result of differentiation. Different cell

types interact with each other to allow more complex functions to take place. For example, nerve cells may interact with muscle cells to stimulate movement.

How do cells in the same organism behave in different ways when they all arose from the same parent cell and so have the same genome (genetic make-up)? In a particular organism, nerve cells and muscle cells all have the same genes, but look and behave very differently. The logical answer is that in some cells certain genes are expressed that are not expressed in other cells, and vice versa. For example, a pancreatic cell will express genes for the production of digestive enzymes or insulin, but a skin cell will not. Differentiation involves the expression of some genes from the organism's genome in the cell, but not others ([Chapter 4](#)).

Prokaryotic cells

Living things are divided into two types – prokaryotes and eukaryotes – according to the structure of their cells. Prokaryotic cells are usually much smaller than eukaryotic cells and have a much simpler structure. Prokaryotes are thought to be the first cells to have evolved. Bacteria are all prokaryotic cells.

Prokaryotic cells are so called because they have no nucleus ('prokaryote' comes from the Greek, meaning 'before the nucleus') and their cell functions do not take place in separate compartments in the cytoplasm. From the mid-20th century, when the electron microscope was developed, it became possible to study the internal detail of cells. Figures 5.2.3 and 5.2.4 show the main features of a typical prokaryotic cell.



Figure 5.2.3: The bacterium *Escherichia coli* is a typical prokaryotic cell. (Coloured transmission electron micrograph, $\times 30\,000$ magnification.)

- The **cell wall** surrounds the cell. It prevents the cell from bursting and is composed of peptidoglycan, which is a mixture of carbohydrate and amino acids.
- The **plasma membrane** controls the movement of materials into and out of the cell. Some substances are pumped in and out using active transport.
- **Cytoplasm** inside the membrane contains all the enzymes for the chemical reactions of the cell. It also contains the genetic material.
- The chromosome is found in a region of the cytoplasm called the nucleoid. The DNA is not contained in a nuclear envelope and it is also ‘naked’, that is, not associated with any proteins. Bacteria also contain additional small circles of DNA called plasmids. Plasmids replicate independently and may be passed from one cell to another. They also may transmit resistance to antibiotics ([Chapter 10](#)).

- The **cytoskeleton** is a network of protein fibres which form a scaffolding to give the cell shape and allow substances to be directed through the cell.
- Ribosomes are found in all prokaryotic cells, and they synthesise proteins. They can be seen in very large numbers in cells that are actively producing protein. Prokaryotes have 70S ribosomes, which are smaller than those found in eukaryotes.
- A **flagellum** is present in some prokaryotic cells. A flagellum, which projects from the cell wall, enables a cell to move.
- Some bacteria have **pili** (singular **pilus**). These structures, found on the cell wall, can connect to other bacterial cells, drawing them together so that genetic material can be exchanged between them.

EXTENSION

Ribosome sizes

The ‘S’ (Svedberg) unit is used to define the size of a ribosome. It is a measure of the behaviour of particles during sedimentation. 70S and 80S ribosomes are different in size and so take different times to sediment when they are centrifuged. They are said to have different sedimentation coefficients.

Prokaryotic cells are usually much smaller in volume than more complex cells because they have no nucleus. Their means of division is also simple. As they grow, their DNA replicates and separates into two different areas of the cytoplasm, which then

divides into two. This is called binary fission. It differs slightly from mitosis in eukaryotic cells ([Chapter 6](#)).

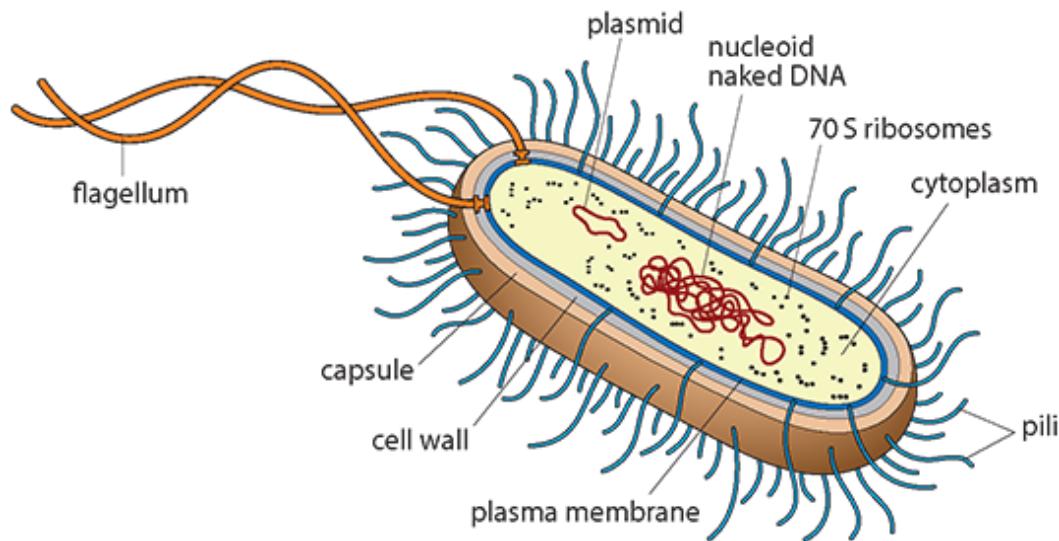


Figure 5.2.4: The structure of a typical prokaryotic cell.

Eukaryotic cells

Eukaryotic organisms have cells that contain a nucleus. Animals, plants, fungi and protocista all have eukaryotic cells.

The complexity of a eukaryotic cell cannot be fully appreciated using a compound light microscope. But in images made using an electron microscope, which has a much higher resolution, the fine details of many different organelles are visible (for more on microscopy, [Section 5.2.3](#)). Figure 5.2.5 shows what can be seen of animal and plant cells using a light microscope; compare these images with the electron micrographs and interpretive drawings in Figures 5.2.11–5.2.14.

Electron micrographs like the ones on p. 200 reveal far more detail. Eukaryotic cells contain structures called **organelles**, each of which forms a ‘compartment’ in which specific functions take place. This compartmentalisation enables a eukaryotic cell to

carry out various chemical reactions or processes in separate parts of the cell, which all form part of the same system.

Different types of cell have different organelles in different proportions, depending on the role of the cell.

The largest and most obvious structure in a eukaryotic cell is the **nucleus**, which contains the cell's chromosomes. Chromosomes are composed of DNA combined with histone protein, forming a material known as chromatin. The nucleus is surrounded by a double-layered membrane, the **nuclear envelope**. Small gaps in the envelope, called nuclear pores, are visible and it is through these that material passes between the nucleus and the rest of the cell. A distinctive feature of the nucleus is the darkly staining **nucleolus**. This is the site of ribosome production.

Associated with the nuclear envelope is a series of membranes known as the **endoplasmic reticulum** (ER). Ribosomes attach to this network to form rough endoplasmic reticulum (rER), the site of protein synthesis. As proteins are produced, they collect in the spaces between the membranes, known as the **cisternae**. From here they can be transported in vesicles to other parts of the cell such as the Golgi apparatus. ER that has no ribosomes attached is known as smooth endoplasmic reticulum (sER). The membranes of sER have many enzymes on their surfaces. Smooth ER has different roles in different types of cell: in liver cells, it is where toxins are broken down; in the ovaries, it is the site of estrogen production. Smooth ER also produces phospholipids for the construction of membranes and lipids for use in the cell.

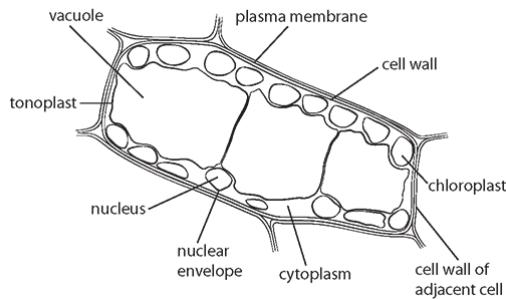
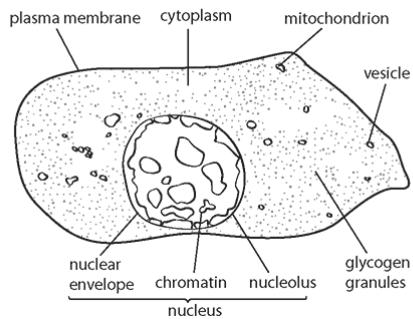
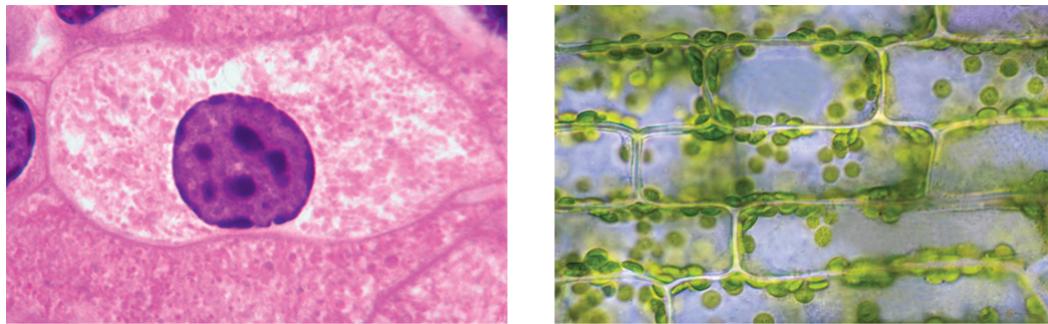


Figure 5.2.5: Photographs and interpretive drawings to show typical animal and plant cells as they appear using a light microscope.

The **Golgi apparatus** is similar in appearance to the sER, composed of stacks of flattened, folded membranes. It processes proteins made in the rER, collecting, packaging and modifying them, and then releasing them in vesicles for transport to various parts of the cell or for secretion from the cell. The pancreas contains many secretory cells, which have large areas of Golgi apparatus (Figure 5.2.14).

Eukaryotic cells also contain **mitochondria** (singular **mitochondrion**). These are elongated structures surrounded by a double membrane that are found throughout the cytoplasm. Mitochondria are known as the cell's 'powerhouses' because they are the site of aerobic respiration. The inner membrane is folded to form **cristae**, which greatly increase the surface area

for the production of ATP in the cell. Cells that respire rapidly, such as muscle cells, have numerous mitochondria.

Lysosomes are spherical organelles with little internal structure, which are made by the Golgi apparatus. They contain hydrolytic enzymes for breaking down components of cells. They are important in cell death, in breaking down old organelles and, in white blood cells, digesting bacteria that have been engulfed by phagocytosis. Plant cells do not normally contain lysosomes.

Centrioles are tube-like structures composed of the protein tubulin. They are involved in organising microtubules in the cytoplasm (Figure 5.2.6) and the location of the centriole controls the position of the nucleus and other structures in the cell. Centrioles are also involved in the formation of the spindle during cell division and in the completion of cytokinesis ([Section 6.5](#))

The cytoskeleton is a network of protein filaments which connect different areas of the cell (Figure 5.2.6). Its primary function is to support the cell and maintain its shape. It is also involved in cell signalling ([Section 7.1](#)), and serves as a highway for the transport of materials and movement of organelles inside the cell. Three types of filament are present, actin microfilaments, intermediate filaments and microtubules made of polymers of tubulin.

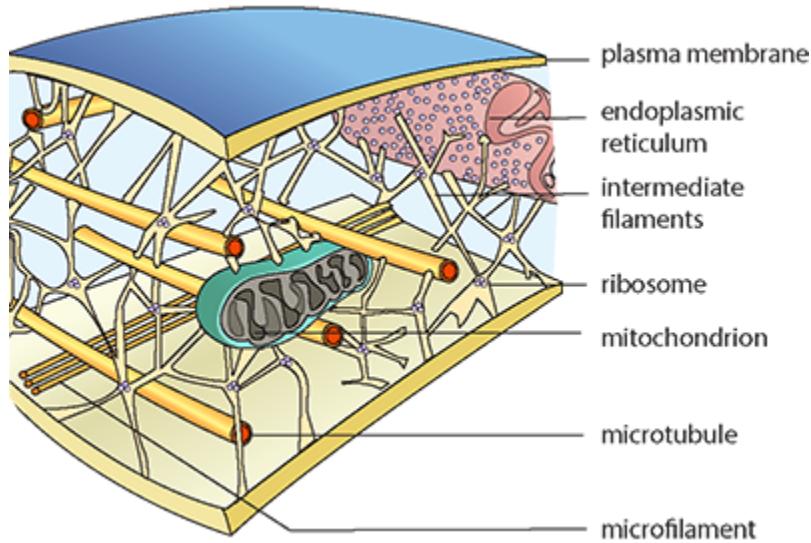


Figure 5.2.6: The cytoskeleton supports cell shape and enables transport within the cell.

Ribosomes are the site of protein synthesis in cells. They may be free in the cytoplasm or attached to the rER. They are made of RNA and protein but they do not have a membrane around them. Eukaryotic cells contain 80S ribosomes, which are larger than those found in prokaryotes.

As in prokaryotic cells, the plasma membrane controls the movement of materials into and out of the cell, and the gel-like cytoplasm, which fills much of the volume of the cell, provides a medium for many metabolic reactions.

Plant cells have three additional structures. All plant cells have an outer cellulose cell wall and most have a large central **vacuole** which contains sap. Some plant cells, such as palisade mesophyll cells (see Figures 5.2.16 and 5.2.17 in the section on electron microscopy), contain chloroplasts. The **chloroplasts** are found in cells exposed to the light, as they are the sites of photosynthesis. Chloroplasts have a double membrane and are about the same size as bacteria. Both chloroplasts and mitochondria have their

own DNA and ribosomes and are able to reproduce independently of the cell.

Fungi are also eukaryotes and they also have cell walls but these are built of different materials. Fungal cell walls are made of a matrix of chitin, glucans and protein. Fungal cells are linked together to form threads called hypha.

The large central vacuole contains water and salts. The membrane that surrounds it is under pressure from within and exerts a force on the cytoplasm, which in turn exerts a force on the cell wall, making the cell turgid and firm. The outer cell wall is composed of cellulose and other carbohydrates such as lignin and pectin, giving plant cells further support and a more rigid structure than animal cells. The cell walls and turgidity of plant cells give strength and support to tissues like leaves, holding them in the optimum position to catch the energy from sunlight for photosynthesis.

Although they are both types of eukaryotic cell, there are several key differences between animal and plant cells. These are summarised in Table 5.2.1.

Differences between prokaryotic and eukaryotic cells

Comparisons of images of prokaryotic and eukaryotic cells show numerous differences between them. These are summarised in Table 5.2.2. Note the difference in size of ribosomes between prokaryotic and eukaryotic cells and the presence of compartments in eukaryotes.

EXAM TIP

If you are asked to make comparisons in an exam question, use a table to organise your information clearly and neatly.

Animal cells	Plant cells	Fungal cells
cell wall absent	cellulose cell wall present	cell wall made of chitin present
small vacuoles sometimes present	large central vacuole present in mature cells	large central vacuole
no chloroplasts	chloroplasts often present	no chloroplasts
cholesterol in plasma membrane	no cholesterol in plasma membrane	no cholesterol
centrioles present to aid mitosis	centrioles absent	centrioles absent
store food reserves as glycogen	store food reserves as starch	store food reserves as glycogen

Table 5.2.1: Differences between animal, plant and fungal cells.

Structure	Eukaryotic cell	Prokaryotic cell
nucleus	usually present, surrounded by a nuclear envelope and containing chromosomes and a nucleolus	no nucleus, and therefore no nuclear envelope or nucleolus
mitochondria	usually present	never present
chloroplasts	present in some plant cells	never present
endoplasmic reticulum	usually present	never present

cytoskeleton	contains three components: microtubules, intermediate filaments and microfilaments	present but contains slightly different proteins to those found in eukaryotes
ribosomes	relatively large, about 30 nm in diameter, or 80S	relatively small, about 20 nm in diameter, or 70S
chromosomes	DNA arranged in long strands, associated with histone proteins	DNA present, not associated with proteins, circular plasmids may also be present
cell wall	always present in plant cells, made of cellulose, never present in animal cells	always present, made of peptidoglycan
flagella	sometimes present	some have flagella, but these have a different structure from those in eukaryotic cells

Table 5.2.2: Differences between prokaryotic and eukaryotic cells. The unit ‘S’ is a Svedberg unit, used to compare sizes of cell organelles.

NATURE OF SCIENCE

New techniques enable new discoveries to be made

Until the 1990s it was believed that prokaryotic cells did not contain a cytoskeleton but information gathered from bioinformatics, structural data and new methods of cell imaging have provided more convincing evidence that both bacteria and archaea have active cytoskeletons with proteins that are similar to tubulin and actin found in eukaryotes.

You can read more about this in the *Journal of Cell Biology*. (Wickstead, B., & Gull, K. (2011). The evolution of the cytoskeleton. *The Journal of Cell Biology*, 194(4), 513–525).

Atypical cells

Extensive examination of many organisms and millions of different types of cell has found that most eukaryotic cells have a similar structure and pattern. But a few cell types have some differences that make them atypical. One example is fungi, whose structures consist of long threads called hyphae (Figure 5.2.7), which have many nuclei but are not divided into separate cells by cell walls.

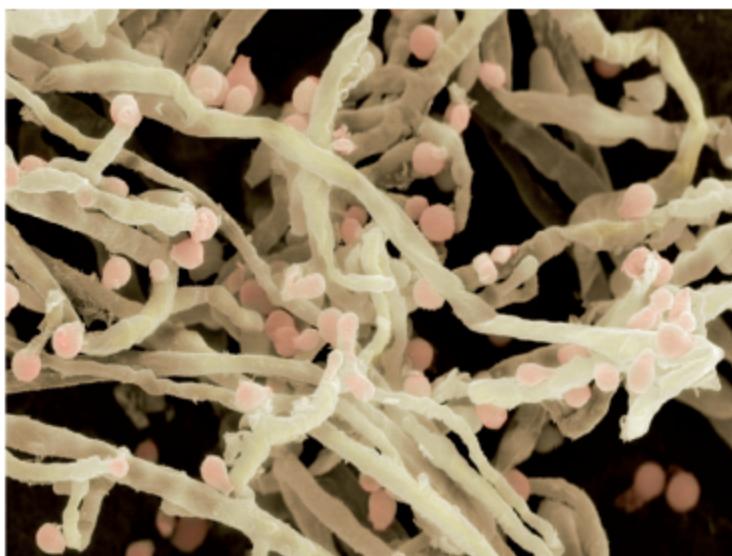


Figure 5.2.7: Fungal hyphae grow through material that nourishes the fungus. In this scanning electron micrograph the thread like structures are the hyphae and the pale pink spheres are the reproductive spores ($\times 2000$).

Another example is skeletal muscle, which is composed of muscle fibres that are much larger than a single cell and contain several hundred nuclei (Chapter 9). Bone cells are also unusual because they have a matrix of extracellular material around them that seems to be greater than the cells themselves. Mammalian erythrocytes (red blood cells) are also atypical as they do not contain nuclei once they have matured and have been released into the bloodstream, which means that they cannot carry out all the functions of life at this stage of their life cycle.

Xylem and phloem

Cells in some organisms have a structure which is atypical but which allows them to perform their functions within the organism. Xylem and phloem are the two components of a plant's transport system. They are found in vascular bundles in stems and leaves. Although they both develop from living, dividing cells they do not have a typical cell structure and once they are mature they cannot divide. Their development begins in the apical meristems, which are specific parts of a plant in buds and root tips where cell growth and differentiation can occur.

Meristem cells are totipotent and can produce all the cells and organs in a mature plant. Xylem cells are arranged end to end, forming tubes of tissue that transport water and minerals from the roots to other parts of the plant. Mature xylem is dead and consists simply of cell walls, thickened with lignin, with no separations between adjacent cells, and no cell contents or

cytoplasm (Figure 5.2.8). These cells can neither divide nor metabolise.

Phloem carries dissolved food molecules, mainly in the form of sugars, around the plant. Phloem is living tissue and like xylem is part of the vascular bundles. The main part of the phloem has tubular cells, known as sieve tubes, which have lost most of their organelles but remain alive (Figure 5.2.9).

Beside each one is a companion cell that is responsible for keeping the sieve element alive. The ends of each sieve tube cell are perforated so that solutes can pass between adjacent cells.

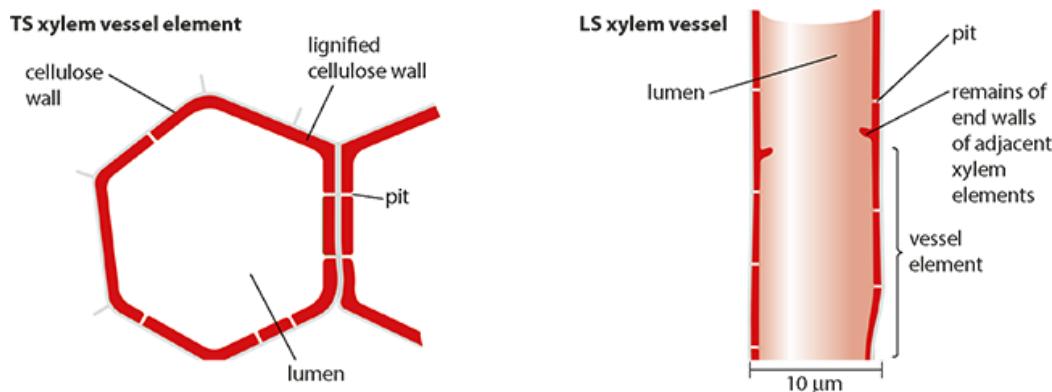


Figure 5.2.8: Cross-sections and longitudinal sections of xylem tubes. LS, longitudinal section; TS, transverse section.

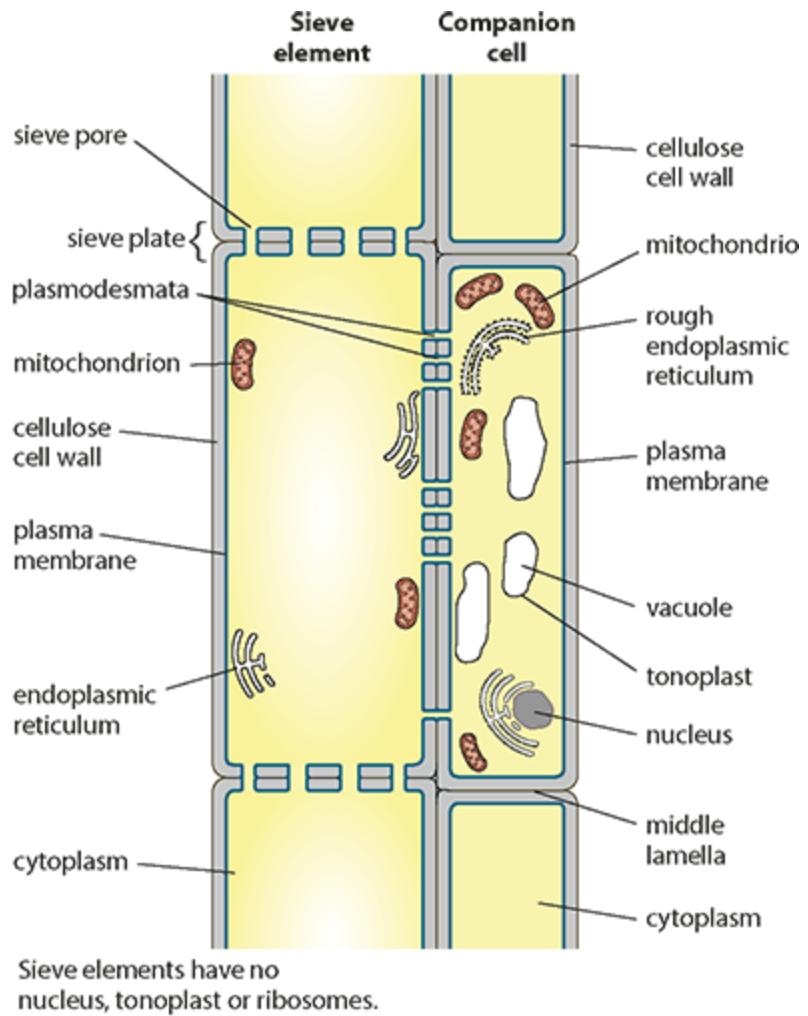


Figure 5.2.9: A phloem sieve tube element and its companion cell.

The features of xylem and phloem are outlined in Table 5.2.3.

Xylem	Phloem
composed of a column of dead cells, once mature, cell end walls removed	composed of a column of living cells with perforated walls between them
continuous tube of cells enables an unbroken column of water (held together by	living cells enable substances to be loaded by active transport

cohesive forces) to move inside the xylem	
thickened with lignin to withstand negative pressure as water vapour is lost in transpiration	associated with companion cells which carry out cell functions and supply energy for active transport into the phloem
transports water and minerals passively from roots to leaves	transports sugars, amino acids, hormones to all parts of the plant by mass flow

Table 5.2.3: The features of xylem and phloem.

5.2.2 The endosymbiosis theory

The theory of endosymbiosis explains how eukaryotic cells could have developed from a simple cell or prokaryote. The theory suggests that some organelles found inside eukaryotes were once free-living prokaryotes, and that the relationship is a form of endosymbiosis. There is evidence to suggest that some prokaryotes were engulfed by larger cells, and were retained inside their membranes where they provided some advantages to the larger cell (Figure 5.2.10).

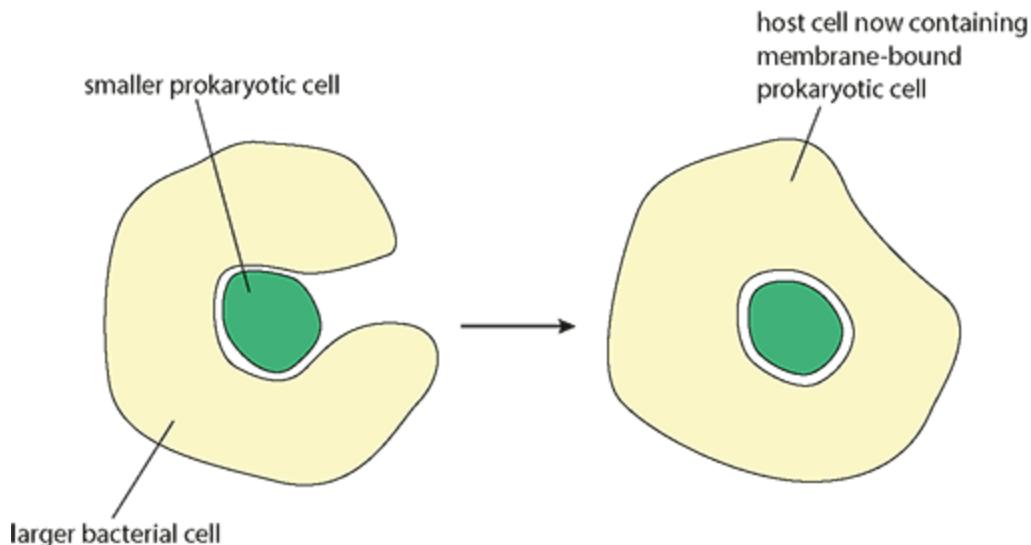


Figure 5.2.10: Organelles such as chloroplasts may have originated from free-living prokaryotes that were engulfed by larger cells.

Evidence for this theory includes the fact that two important organelles, mitochondria and chloroplasts, share many characteristics with prokaryotic cells. Both chloroplasts and mitochondria:

- contain ribosomes that are smaller than those found in other parts of eukaryotic cells but are identical in size to those

found in bacteria

- contain small circular pieces of DNA resembling bacterial plasmids in their basic structure
- have their own envelope surrounding them, on the inner membrane of which are proteins synthesised inside the organelle, suggesting that they may have used this ability long ago when they were independent organisms
- can replicate themselves by binary fission.

This evidence supports the theory that these organelles are modified bacteria that were taken in by phagocytosis, early in the evolution of eukaryotic cells. Here they became useful inclusions. The double outer envelope of chloroplasts and mitochondria may have originated from the bacterial plasma membrane together with the membrane of an engulfing phagocytic vesicle. Perhaps some of the enclosed bacteria carried pigment molecules on their membranes and used light energy to make organic molecules and release oxygen; these may have become chloroplasts. It may be that others became efficient at using the oxygen molecules for aerobic energy production, and these became mitochondria.

KEY POINT

endosymbiosis symbiosis means ‘life together’ and endo means ‘inside’ so endosymbiosis describes a relationship taking place inside a cell.

TEST YOUR UNDERSTANDING

- 9 List three differences between prokaryotic and eukaryotic cells.

- 10** State one advantage a cell gains from having organelles.
- 11** Outline the function of the endoplasmic reticulum.
- 12** What is the evidence for the theory of endosymbiosis?

Cell differentiation and multicellularity

Multicellular organisms have cells which perform different functions. Cells which differentiate to carry out the same function form groups called **tissues**. Tissues contain cells which have changed and developed to carry out their roles, for example muscle tissue develops the enzymes and contractile proteins needed for contraction. Tissues enable multicellular organisms to function more efficiently than they would if all their cells carried out the same jobs and specialised tissues develop by cell differentiation.

Cell differentiation is the process in which a cell undergoes changes in gene expression to become a more specific type of cell. Differentiation allows multi-cellular organisms to produce different cell types and body shapes. The process of cell differentiation is controlled by genes, and the interaction of genes with the environment.

NATURE OF SCIENCE

How strong and reliable is a theory?

A theory is a proposed explanation for observations of the natural world. Theories are made using scientific methodology and usually bring together several facts and hypotheses. The theory of endosymbiosis will always remain a theory because we cannot go back in time and observe whether our theory is true. Nevertheless, some theories can be

regarded as better and more reliable than others. Scientists collect evidence and make observations to explain and support their theories. The more evidence that is gathered to support the theory, the more likely it becomes to be accepted as reliable. Scientists have gathered a lot of reliable evidence to support the theory of endosymbiosis and today it is generally accepted as a good explanation of how eukaryotic cells could have arisen.

To consider:

- 1 Think about other theories in biology. Are they strong and reliable or could they easily be disproved?

All the cells in a multicellular organism have the same set of genes, even though the cells have many differences in their structure and their jobs. There are about 25,000 genes in a human cell but not all these genes are switched on, or expressed, in every cell. There are just over 200 cell types in a human body and, as a cell develops into a liver cell or a nerve cell, different genes are switched on or off. As different genes are expressed, cells differentiate into all the different types that we can observe. Controlling gene expression is crucial to development. Cell differentiation is triggered by environmental factors that affect gene expression. These factors may be in the internal environment, for example as a cell develops in an embryo its position will determine which genes are expressed. In other cases, hormones can influence what form a cell will take. Or the influences may be in the external environment where available nutrients, salinity, and temperature affect differentiation. For example, in Himalayan rabbits, the genes that code for fur colour are turned on and off depending on temperature. Cold conditions lead to the expression of darker pigmentation. The colder areas

of the rabbits' bodies, their paws, nose and ears are black while their body fur is white.

Cells which have not differentiated and retain the ability to develop into many different cell types are known as stem cells ([Section 8.1.2](#)).

Evolution of Multicellularity

As Fig 5.1.5 shows multicellular organisms have evolved and developed along many different lines. Many fungi, eukaryotic algae and all plants and animals are multicellular which gives these organisms many advantages over single-celled organisms. A multicellular organism can grow to a larger size than a single celled organism because it is not limited by diffusion of substances into its cells. A single-celled organism is limited by its surface area to volume ratio. A large single cell cannot absorb and transport nutrients efficiently because, as it grows larger, its surface area to volume ratio decreases ([Section 6.4.1](#)).

Multicellular organisms with many different cell types can become more complex as different cells take on different jobs. They can also have longer life spans because if one cell dies the whole organism does not die.

5.2.3 Developments in microscopy

Light microscopes

Light microscopes, also called optical microscopes, enable us to see magnified images of objects placed on the microscope stage (Figure 5.2.11). Visible light is passed through the specimen and a system of lenses produces magnified images which can be seen by looking through the eyepiece. One of the few cells large enough to be visible to the unaided eye is the mature human ovum, which has a diameter of approximately 150 µm. However, most cells are much smaller than this, and can only be seen using a microscope. The most powerful light microscopes can magnify up to 2000 times and reveal some internal structures such as the nucleus (Figure 5.2.1), but to see greater detail more powerful microscopes such as the electron microscope, which magnifies cell structures up to 500 000 times must be used.

The advantage of light microscopes is that they can be used to examine whole specimens or sections of them, and either living or dead material. There are many staining and lighting techniques that can be used to show specimens in colour so that physical and biological features can be seen. Images can be photographed or videoed or computerised for later examination. Light microscopes are small and relatively inexpensive.

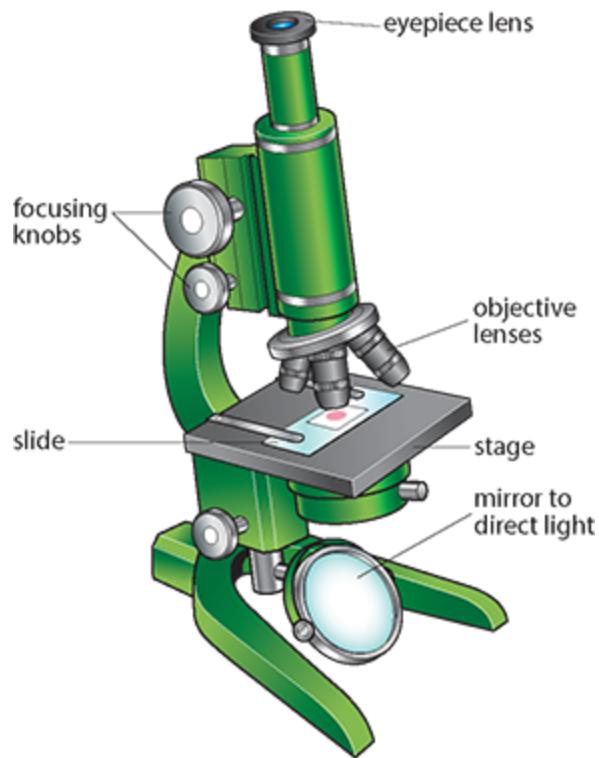


Figure 5.2.11: Typical compound light microscope.

Magnification and scale

Knowing the sizes of objects viewed under the microscope can be very useful, for example, a scientist might want to compare the relative sizes of pollen grains from plants in the same genus to help identify different species or to identify the range of sizes in a population of unicellular organisms.

Magnification is defined as the ratio of the size of the image to the size of the object:

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

KEY POINT

magnification refers to how many times larger an object appears compared with its actual size. It is calculated from the ratio of length of image to the length of the object.

With a compound microscope (as shown in Figure 5.2.11), the magnification is the product of both lenses, so if a microscope has a $\times 10$ eyepiece and $\times 40$ objective, the total magnification is $\times 400$.

Printed images of structures seen with a microscope usually show a scale bar or give the magnification, so that the size of an object can be calculated. For example, the magnification of the micrograph in Figure 5.2.12 is given as $\times 165$.

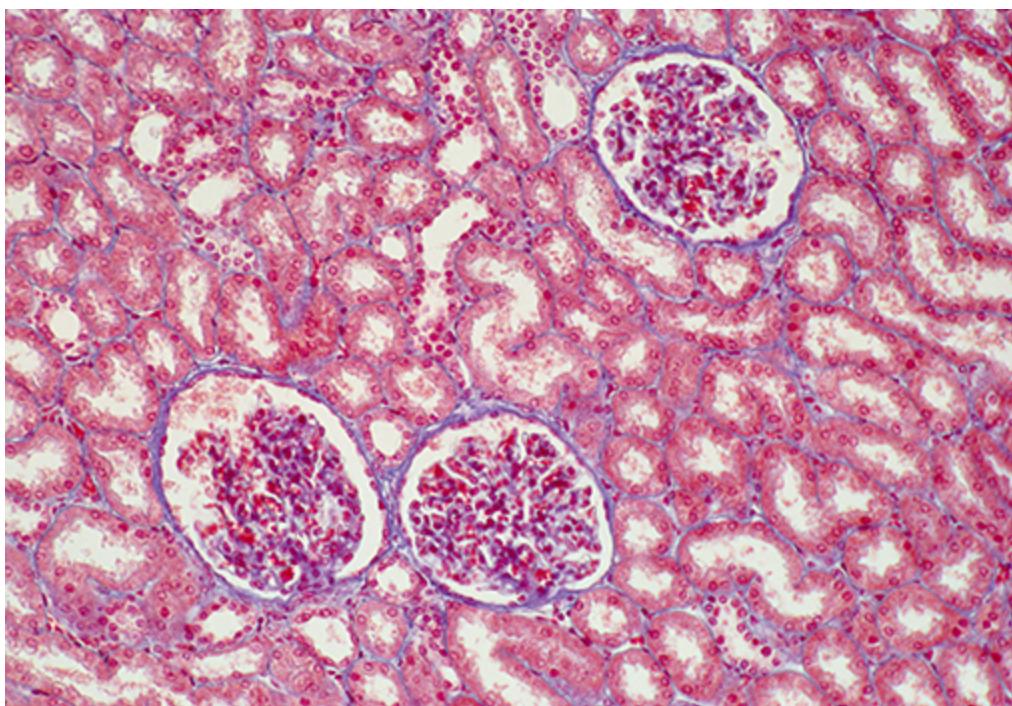


Figure 5.2.12: Coloured light micrograph of a section through the cortex of a kidney ($\times 165$).

In Figure 5.2.12, there are three spherical glomeruli present. In the image, each one is approximately 25 mm across. You can check this using a ruler. Thus:

$$\begin{aligned}\text{actual size of glomerulus} &= \frac{\text{size of image}}{\text{magnification}} \\ &= \frac{25 \text{ mm}}{165} \\ &= 0.15 \text{ mm}\end{aligned}$$

In photographs produced by an electron microscope, most measurements are expressed in micrometres. A micrometre (μm) is 10^{-3} mm, so 1 mm is 1000 μm .

So, the diameter of the glomerulus = $0.15 \times 1000 = 150 \mu\text{m}$.

WORKED EXAMPLE 5.2.1

The image below represents a red blood cell. The scale bar shows 2 μm . From this, you can calculate both the size of the cell and the magnification of the image.

Size of the cell

Step 1 Use a ruler to measure the length of the cell (its diameter in this case). This is 30 mm.

Step 2 Use a ruler to measure the length of the scale bar. This is 9 mm.

Step 3 Use the ratio of these two values to work out the actual length of the cell.

$$\frac{2 \mu\text{m}}{9000 \mu\text{m}} = \frac{\text{actual length of cell}}{30000 \mu\text{m}}$$

(Remember to convert all the units to μm . $1 \text{ mm} = 1000 \mu\text{m}$.)

Answer

Rearranging the equation:

$$\begin{aligned}\text{actual length of cell} &= 2 \mu\text{m} \times \frac{30\,000 \mu\text{m}}{9000 \mu\text{m}} \\ &= 6.7 \mu\text{m}\end{aligned}$$

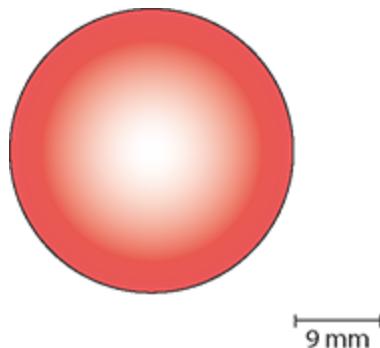
Magnification of the image

Use the formula:

$$\text{magnification} = \frac{\text{measured length of the cell}}{\text{actual length of the cell}}$$

So in the case:

$$\begin{aligned}\text{magnification} &= \frac{30\,000 \mu\text{m}}{6.7 \mu\text{m}} \\ &= \times 4500\end{aligned}$$



If you are given a value for the magnification, you can measure the length of the object in the image and then rearrange the equation to work out the actual length of the object.

KEY POINT

SI units – International System

1 metre (m) = 1 m

1 millimetre (mm) = 10^{-3} m

1 micrometre (μm) = 10^{-6} m

1 nanometre (nm) = 10^{-9} m

1 centimetre cubed = 1 cm^3

1 decimetre cubed = 1 dm^3

1 second = 1 s

1 minute = 1 min

1 hour = 1 h

concentration is measured in mol dm^{-3}

New techniques in light microscopy

Fluorescent and phosphorescent stains are non-protein molecules that absorb light at a specific wavelength and re-emit it at a longer wavelength from the visible part of the spectrum. In this way they produce coloured images. The technique of fluorescence microscopy has become an essential tool in biology and the biomedical sciences. Biomolecules such as proteins, antibodies and peptides can have fluorescent molecules added to them and these labelled molecules can be seen in the microscope (Figure 5.2.13). Different stains are used so that different parts of the same cell can be distinguished easily. In Figure 5.2.13 DNA in the cell nuclei can be distinguished from other cell structures.

KEY POINTS

fluorescent able to emit light immediately; usually visible under a light source such as UV light.

phosphorescent refers to a molecule that can store absorbed light for some time and release it later.

Phosphorescence is also used to monitor the delivery of medicine and drugs. Medications carrying fluorescent markers can be tracked as they move to specific tissues in the body.

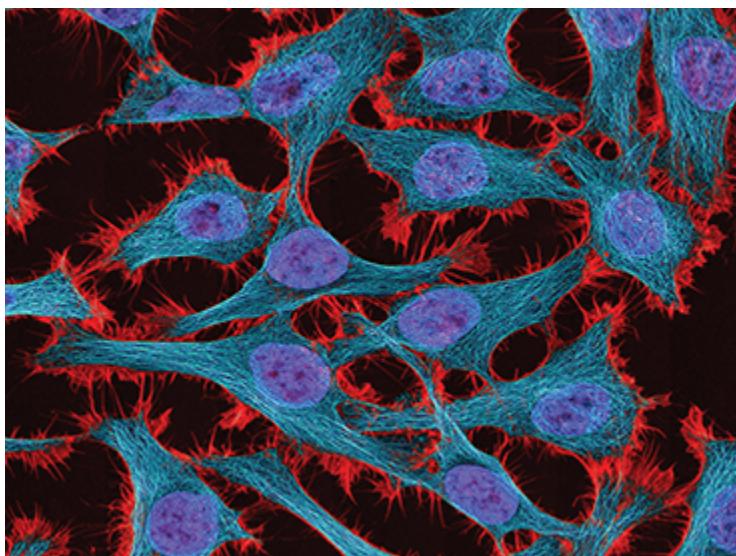


Figure 5.2.13: Fluorescence image of HeLa cells. Actin molecules are stained in red and the cell nuclei are stained blue. Microtubules in the cell are stained with cyan.

Electron microscopy

Electron microscopes use a beam of electrons, instead of light, to produce an image. The **resolution (resolving power)** of an electron microscope is much better than that of a light microscope because of the shorter wavelength of electrons

compared to light. Resolving power is the ability of the microscope to separate objects that are close together so that more detail can be seen. Figure 5.2.5 shows us the appearance of an animal cell and a plant cell. Different organelles and structures can be seen clearly and we can recognise the cell membranes and the plant cell wall. The diagrams (Figures 5.2.15 and 5.2.17) made from the electron micrographs help us to identify the various parts of the cells.

Only non-living material can be observed in an electron microscope and specimens must be specially prepared with heavy metals or coated with carbon or gold. Viruses can only be seen with these microscopes, so the structure of viruses was unknown until the invention of these microscopes in the 20th century ([Section 5.3](#)).

EXAM TIP

You should be able to recognise the organelles and structures present in cells and label diagrams like those shown in figures 5.2.14 and 5.2.16 with their names.

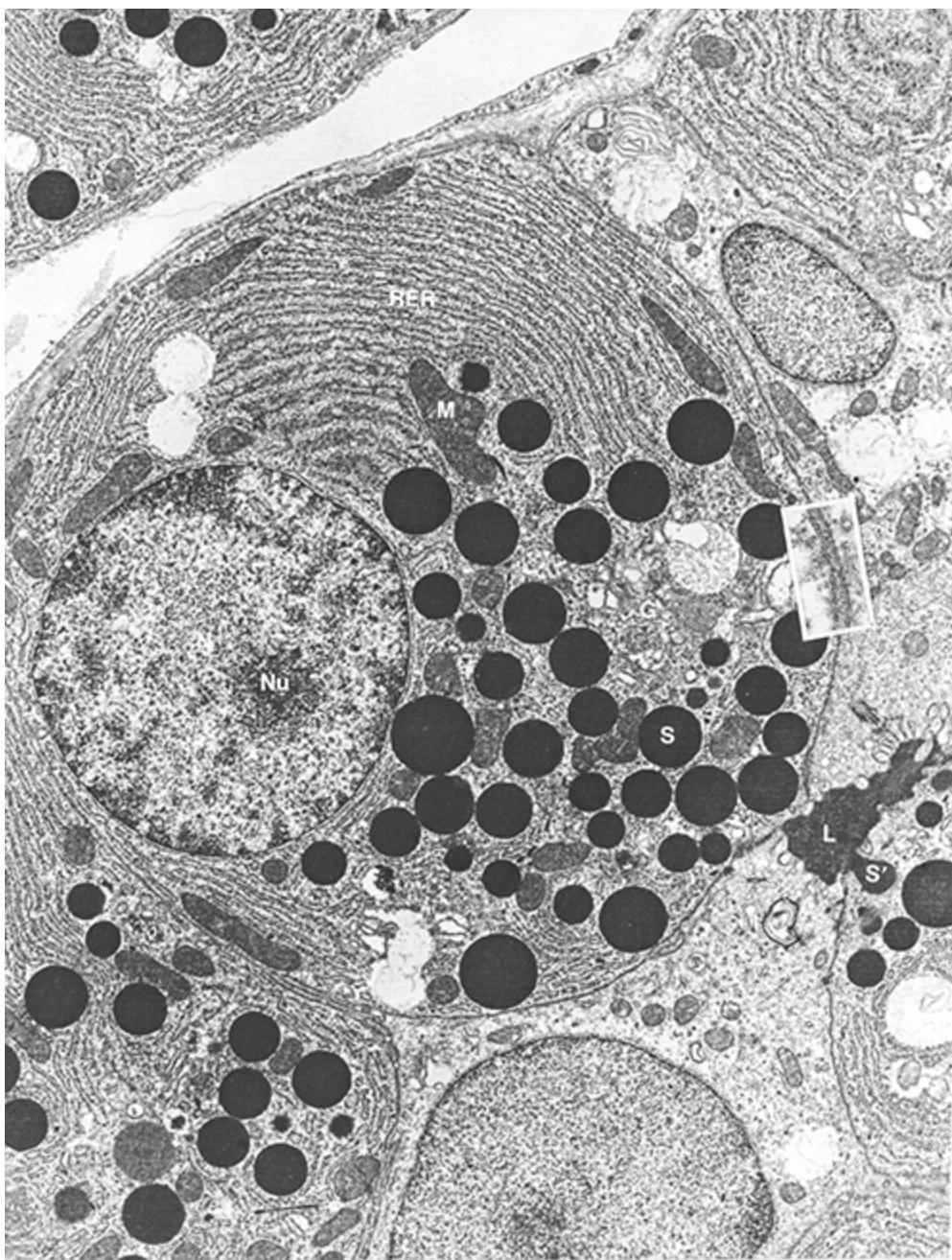


Figure 5.2.14: Electron micrograph of an exocrine cell from the pancreas ($\times 12\,000$).

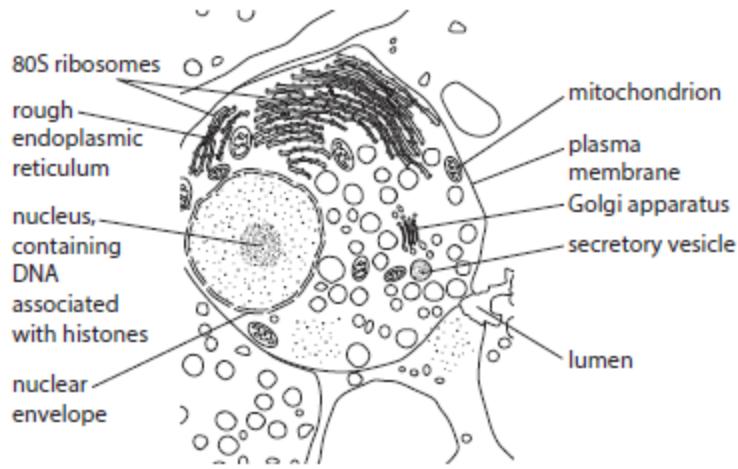


Figure 5.2.15: Interpretive drawing of some of the cell structures visible in Figure 5.2.14.

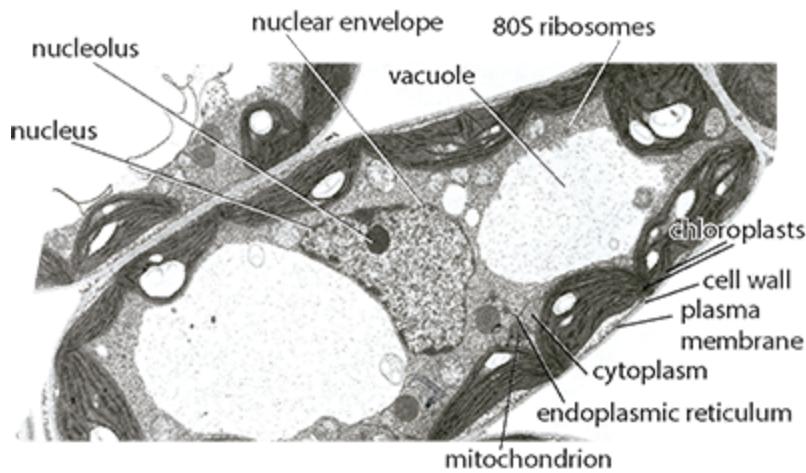


Figure 5.2.16: Electron micrograph of a palisade mesophyll plant cell ($\times 5600$).

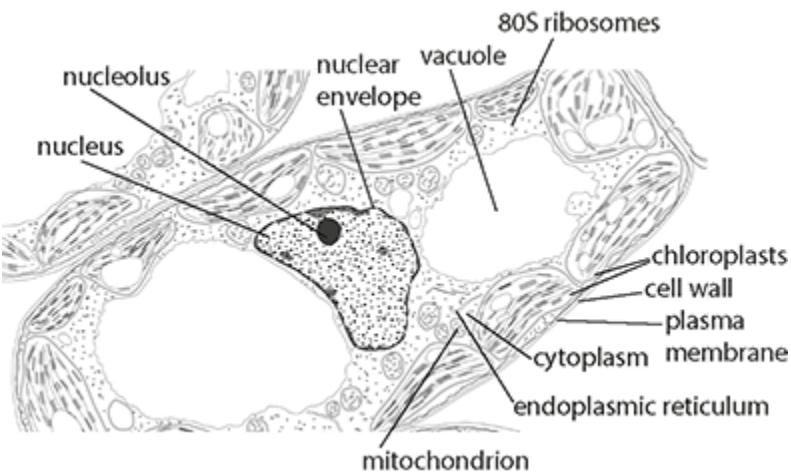


Figure 5.2.17: Drawing of a palisade mesophyll plant cell made from the electron micrograph in Figure 5.2.16.

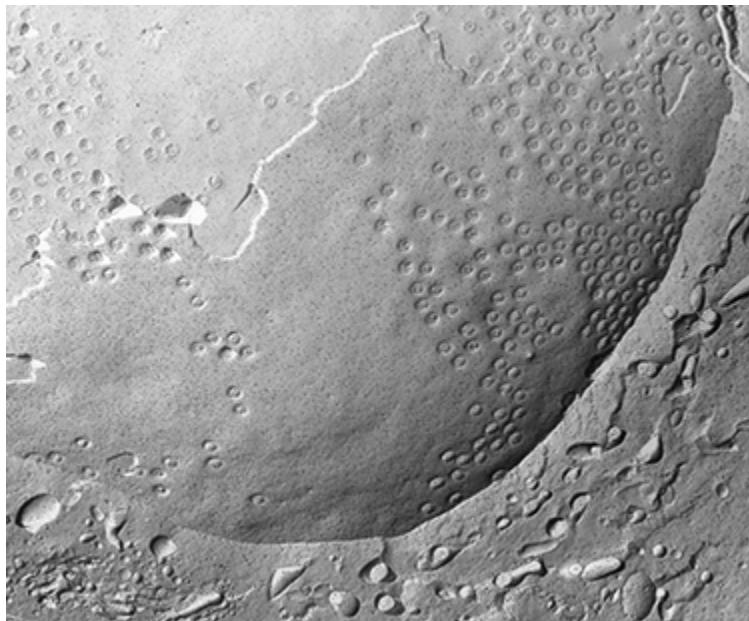


Figure 5.2.18: Freeze-fracture image of cell nuclear membrane.

There are two main types of electron microscope: the transmission electron microscope (TEM) and the scanning electron microscope (SEM). A TEM was the first electron microscope to be built. It produces clear images of very thin sections of material. A beam of electrons passes through a

specimen and is scattered, producing an image that can be viewed on a screen. A SEM directs a focused beam of electrons across a specimen and, as electrons are bounced off the surface, detailed images of the external shape and composition of the specimen appear. A SEM can create images of larger specimens and give a good idea of their real shape.

Electron microscopes produce black and white images that are often artificially coloured so that certain features can be seen more clearly, and different techniques are used to study different aspects of the living world.

Freeze-fracture electron microscopy is a technique that was developed in the 1960s. It has helped us to understand the structure of membranes more clearly. The technique involves rapidly freezing a specimen and then cracking it along a line through the tissues. Specimens will fracture along their weakest parts, usually the membranes or the surfaces of cell organelles. If the broken surfaces are shadowed with a film of platinum, a replica of the surface can be made and viewed in a TEM (Figure 5.2.18).

Until recently, even electron microscopes could not distinguish individual molecules and X-ray crystallography was always used to work out the structure and arrangement of atoms in molecules. But now, a newer technique, **cryogenic electron microscopy** (cryo-EM), is proving so successful that the majority of new molecular structures are worked out using it. Cryogenic electron microscopy allows scientists to work out the structures of biomolecules, especially proteins, without the need to produce crystals of them first. The technique was developed in the 1970s, but has become more useful as new software and algorithms have been developed and used to work out the structure of thousands of biomolecules. This type of microscope is used on

samples that are cooled to cryogenic temperatures (temperatures at which molecules cease moving) and embedded in amorphous ice, which has no crystalline structure of its own. In 2020, the Electron Microscopy Data Bank (EMDB), a database for molecular structures, added its 10 000th entry, and the vast majority of structures had been worked out using cryo-EM.

Table 5.2.4 compares the main features of different types of microscope.

	Light microscope	Transmission electron microscope	Scanning electron microscope
	uses light to produce images	uses electron beams to produce images	uses electron beams to produce images
Maximum resolution	200 nm	1 nm	1 nm
Maximum magnification	×2000	up to ×1 000 000	×200 000
Preparation of material	thin sections of material mounted on slides, living organisms can be examined	very thin sections of material supported on metal grids, living organisms cannot be examined	very thin sections of material supported on metal grids, living organisms cannot be examined
Stain used	coloured	heavy metals	carbon or gold

	dyes		coating
Image	viewed directly through eyepiece lens	viewed on a screen or photographic plate	viewed on a screen or photographic plate

Table 5.2.4: Comparison of light microscopes with the transmission electron microscope (TEM) and scanning electron microscope (SEM).

TEST YOUR UNDERSTANDING

- 13** Calculate how many cells of $100\text{ }\mu\text{m}$ will fit along a 1 mm line.
- 14** What property of fluorescent stains makes them useful in microscopy?

NATURE OF SCIENCE

Scientific advance follows technical innovation: the electron microscope

A typical animal cell is $10\text{--}20\text{ }\mu\text{m}$ in diameter, which is about one-fifth the size of the smallest particle visible to the naked eye. Robert Hooke was the first scientist to see and describe cells, although he didn't know what they were. Later, Anton van Leeuwenhoek, who built one of the first microscopes in 1674, was able to see living cells of *Spirogyra* and bacteria.

It was not until good light microscopes became available in the early part of the 19th century that plant and animal tissues were seen as groups of individual cells and Schleiden and

Schwann in 1838 were able to see sufficient structure to propose cell theory, which incorporated the work of their predecessors.

Animal cells are tiny and colourless so it was not until the end of the 19th century, when staining techniques were first used, that it was possible to see a little more detail of cell contents. In the early 1940s, far more powerful electron microscopes were used for the first time and organelles and greater complexity of cell structure could be studied. Developments proceeded more rapidly in the 20th century, because international communication allowed for more efficient collaboration, not only in the designing and building of microscopes but also in the discussion and understanding of what could be observed.

A light microscope can resolve (view separately) cell details that are about 0.2 µm apart. Resolution is limited by the wavelength of light so that bacteria and mitochondria (500 nm or 0.5 µm) are the smallest objects that can be seen. An electron microscope uses a beam of electrons to probe specimens and in theory it should be able to resolve structures that are 0.002 nm apart (a resolution 10 000 times that of a light microscope). For biological material this reduces to about 0.2 nm but, even so, an electron microscope allows a resolution which is 100 times better than a light microscope.

New techniques in microscopy such as electron microscopy such as cryo-EM are improving our understanding of cells at the molecular level and new labelling techniques using phosphorescent pigments and light microscopes have improved our knowledge of how cell structures are organised.

Technology has improved the range and precision of human senses in examining cells and led to a greater understanding of cells and how they function.

To consider:

- 1 Discuss other areas of science where technology has been important in improving human understanding of the natural world.
- 2 Why has international communication and collaboration been so important in technological advances?

THEORY OF KNOWLEDGE

Perception and interpretation: can we believe what we see?

Our own perception is a crucial source of knowledge. The way we see things depends on the interpretation of the information that our sense organs relay to our mind. What we perceive may be a selective interpretation.

When examining microscope images we must remember that preparing cells by staining them and taking sections through them will alter their appearance. Images we view through microscopes or on screens will be influenced by these methods as well as our own expectations about what we are looking at.

To consider:

- 1 Look at the shapes of the mitochondria in the electron micrographs in Figures 5.2.16 and 5.2.13. Why do some appear cylindrical and others circular?

- 2** Plant cells have a single central vacuole. Study the plant cell in Figure 5.2.17. How many vacuoles can you see? How can you explain this?

Links

- Why do cells have different structures? ([Chapter 6](#))
- What advantages does compartmentalisation give to eukaryotes? ([Chapter 6](#))
- How does cell structure help with classification and building evolutionary relationships? ([Chapter 11](#))

5.3 Viruses

LEARNING OBJECTIVES

In this section you will:

- › learn that viruses are acellular, have no metabolism and need to be inside a host cell to replicate themselves
- › discover that viruses are much smaller than prokaryotic cells
- › learn that viruses contain RNA or DNA, have a protein coat and that some have a viral envelope
- › understand that viruses have different structures and modes of infection
- › recognise lytic and a lysogenic cycles of different viruses
- › recognise that the wide diversity of viruses suggests they have several origins, although all are obligate parasites
- › learn that there are several hypotheses to explain the origins of viruses
- › Understand that viruses such as HIV and influenza virus evolve very rapidly.

GUIDING QUESTIONS

- How are viruses similar to and different from living organisms?
- How diverse are viruses?

5.3.1 The structure of viruses

Viruses are not considered to be living things. They are said to be **acellular** because they have no metabolism and can only replicate inside a host cell. A virus consists of DNA or RNA enclosed inside a protective protein coat known as a **capsid**. Viruses vary in their structure, and the shape of the capsid varies between different types of virus. Capsid shape is one method used to classify viruses. Genes that are present in viral genetic material code for the capsid. The simplest viruses contain just enough DNA or RNA to code for four proteins, whereas the most complex can code for up to 200 proteins. Viral proteins self-assemble to form a capsid (Figure 5.3.1).

Some viruses are able to surround themselves with an envelope which is derived from their host cell's plasma membrane, endoplasmic reticulum or nuclear membrane. This **viral envelope** contains proteins coded for by both the virus genome and the host cell genome and can give the virus better protection from the host's immune system. Proteins in the envelope may include **glycoproteins**. These are proteins that have carbohydrate groups covalently bonded to their amino acid chains. Glycoproteins act as receptor molecules and can make it easier for viruses to bind to and enter host cells. Many enveloped viruses depend on their envelope to infect new cells and to enable them to survive for longer periods outside a host cell.

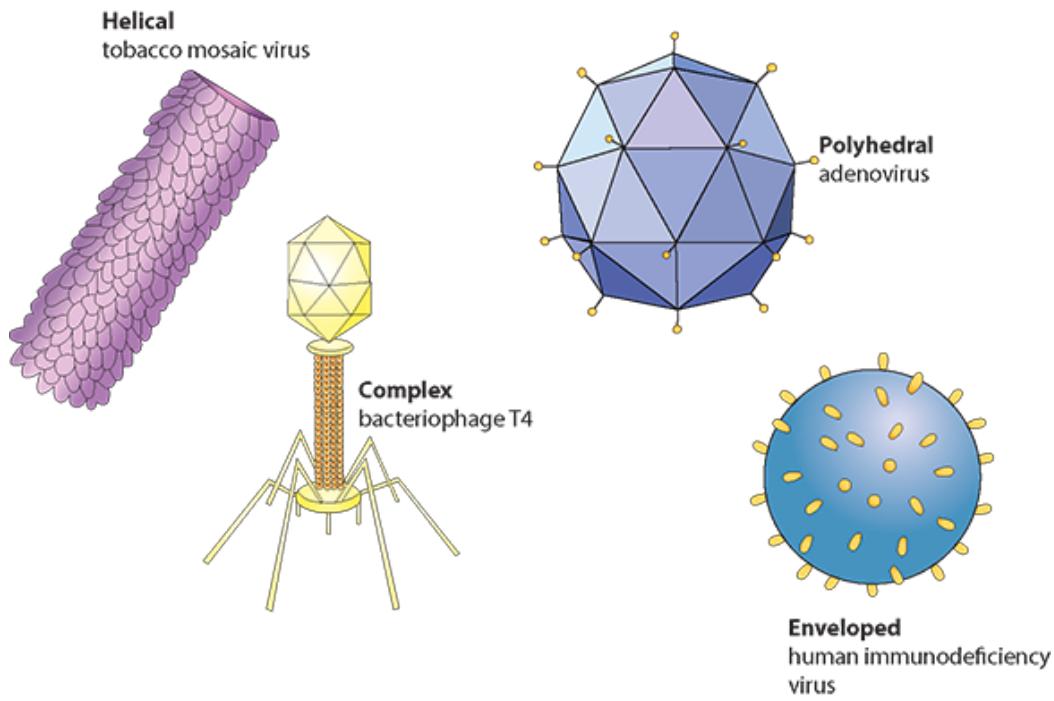


Figure 5.3.1: Virus capsids may be helical, polyhedral, complex or enveloped.

SCIENCE IN CONTEXT

Viruses and disease

Viruses are thought to cause approximately 60% of human infections, some like the common cold are mild while others such as Ebola and polio are serious and potentially fatal. Many thousands of viruses are known and more are emerging every year. The rise of zoonoses, diseases that pass from animals to humans, are causing particular concern.

The most common viral illnesses are infections of the digestive and respiratory systems. In developed countries, viruses are responsible for about 30% of all infectious gastroenteritis and it is estimated that adults have between two and five colds per year, while young children may have twice as many.

Viruses pass from an infected person directly to a new host by physical contact or in a cough or sneeze, or indirectly when a person picks up a virus from a contaminated surface. Viruses can be transmitted indirectly, because many can survive outside the body for short periods of time. Their survival time depends on the virus and the environment. Temperature, humidity and level of UV light can all cause viruses to degrade. But some retain their power to infect for several days or even longer on surfaces such as clothes, utensils or furniture. Viruses can be transferred from a contaminated surface via hands to food or into a person's mouth.

Respiratory viruses that cause influenza and the common cold are often found on surfaces that have been touched by infected people. Viruses may survive for up to 18 hours on places such as door handles, light switches, keyboards and phones and be transferred to the hands of a new host. During the coronavirus pandemic public health authorities advised strict hygiene measures to prevent the spread of viruses. These included masks, to prevent droplets being coughed or sneezed out, frequent hand washing to remove any viruses picked up from contaminated surfaces and sanitisation of surfaces likely to be touched by infected people.

To consider:

- 1** What effect has international travel had on the spread of virus diseases across the world?
- 2** How effective are public health campaigns in raising people's awareness of the need for hygiene to prevent disease?

KEY POINTS

lytic cycle reproduction by viruses that use a host cell to manufacture more viruses; the viruses then burst out of the cell e.g. bacteriophage lambda

lysogenic cycle incorporation of the viral genome into the host cell genome and infection from inside the cell e.g. HIV

Infection and replication

Viruses are much smaller than prokaryotic cells (Figure 5.3.2). They infect both prokaryotic and eukaryotic cells in a similar way. A viral surface protein binds with a receptor on the host cell surface and the virus enters the host cell and releases its nucleic acid from the capsid or envelope. Viruses then use the host cell machinery for their reproduction. They use host cell ribosomes to produce their proteins and many viruses modify host cell transcription and translation mechanisms to favour the production of viruses over normal cell activities.

The ways in which two important viruses, **bacteriophage lambda**, a virus which infects bacteria, and **human immunodeficiency virus** (HIV) which infects cells of the human immune system, enter their host cells are described shown in Figures 5.3.3 and 5.3.4 .

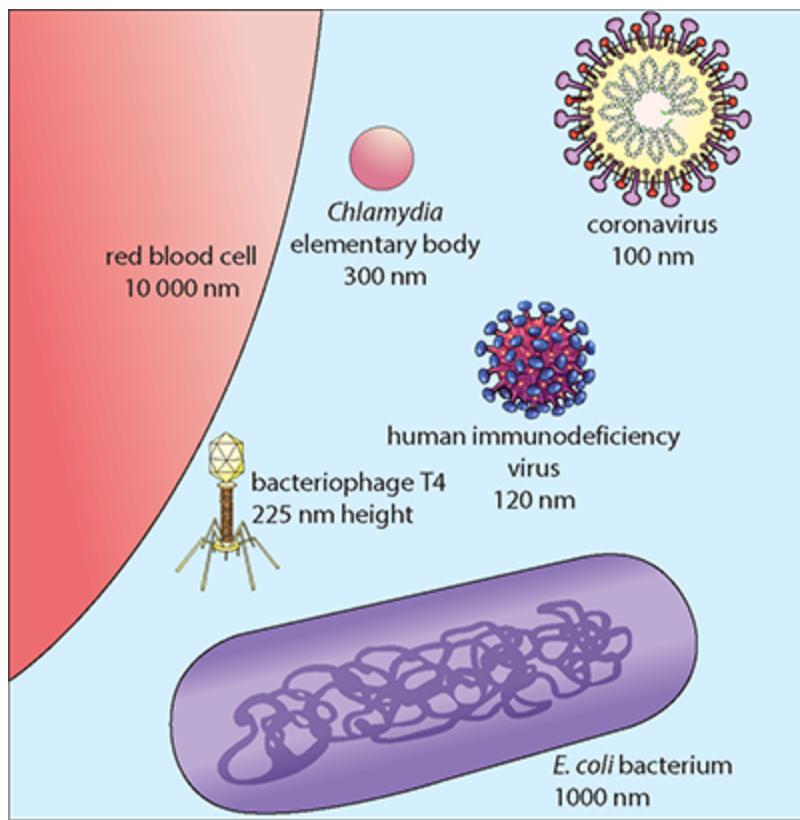


Figure 5.3.2: Relative sizes of prokaryotic cells, eukaryotic cells and viruses.

Bacteriophage lambda is a virus that infects *E. coli* bacteria. It has a lytic lifecycle. It is a complex virus with an icosahedral head, a tail and tail fibres and double-stranded DNA as its genetic material (Figure 5.3.1).

The stages of the life cycle of bacteriophage λ (Figure 5.3.3) include absorption and penetration into the bacterium, followed by synthesis of proteins and replication of viral DNA using the bacterial enzymes. The viral genetic material is enclosed in new capsids and finally the host cell wall breaks, releasing new viruses that go on to infect more bacterial cells.

Human immunodeficiency virus infects cells of the human immune system that have specific CD4 protein receptors on their

membranes. The cells that have these receptors are called the helper T cells, which communicate with other cells involved in antibody production to fight infections ([Chapter 10](#)). Without treatment, the numbers of these cells fall to such low levels that the body is unable to resist infections and may succumb to acquired immunodeficiency syndrome (AIDS). HIV is an enveloped retrovirus (Figure 5.3.1) containing a capsid, inside which are single-stranded RNA and viral enzymes. The envelope contains glycoproteins that attach to particular CD4 receptors on the host cell plasma membrane. The envelope fuses with the plasma membrane and the HIV contents are released into the host cell. The virus RNA is released along with viral enzymes. One of these is **reverse transcriptase**, an enzyme that converts the single-stranded RNA into double-stranded DNA. Another viral enzyme, integrase, then integrates the double-stranded DNA into the host cell genome. This virus has a lysogenic lifecycle. The host cell transcribes the viral genes and new viruses are produced and assembled. New viruses bud out through the plasma membrane of the host cell (Figure 5.3.4) and are released to infect more helper T cells.

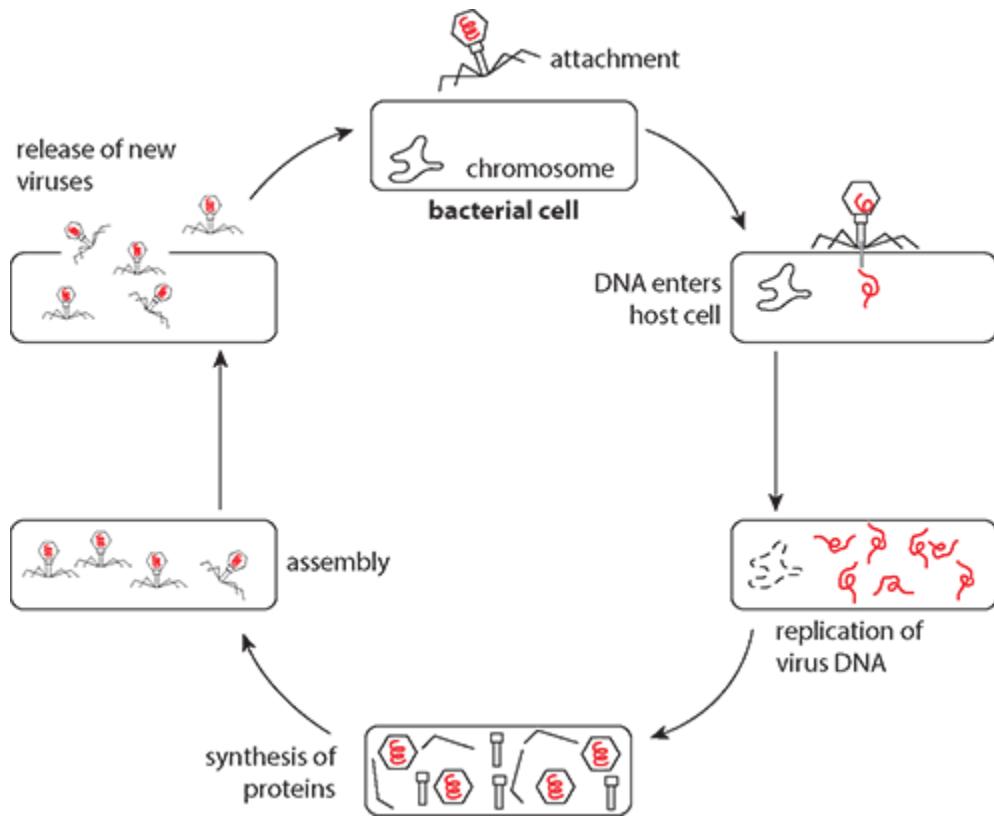


Figure 5.3.3: Stages in the lifecycle of bacteriophage lambda.

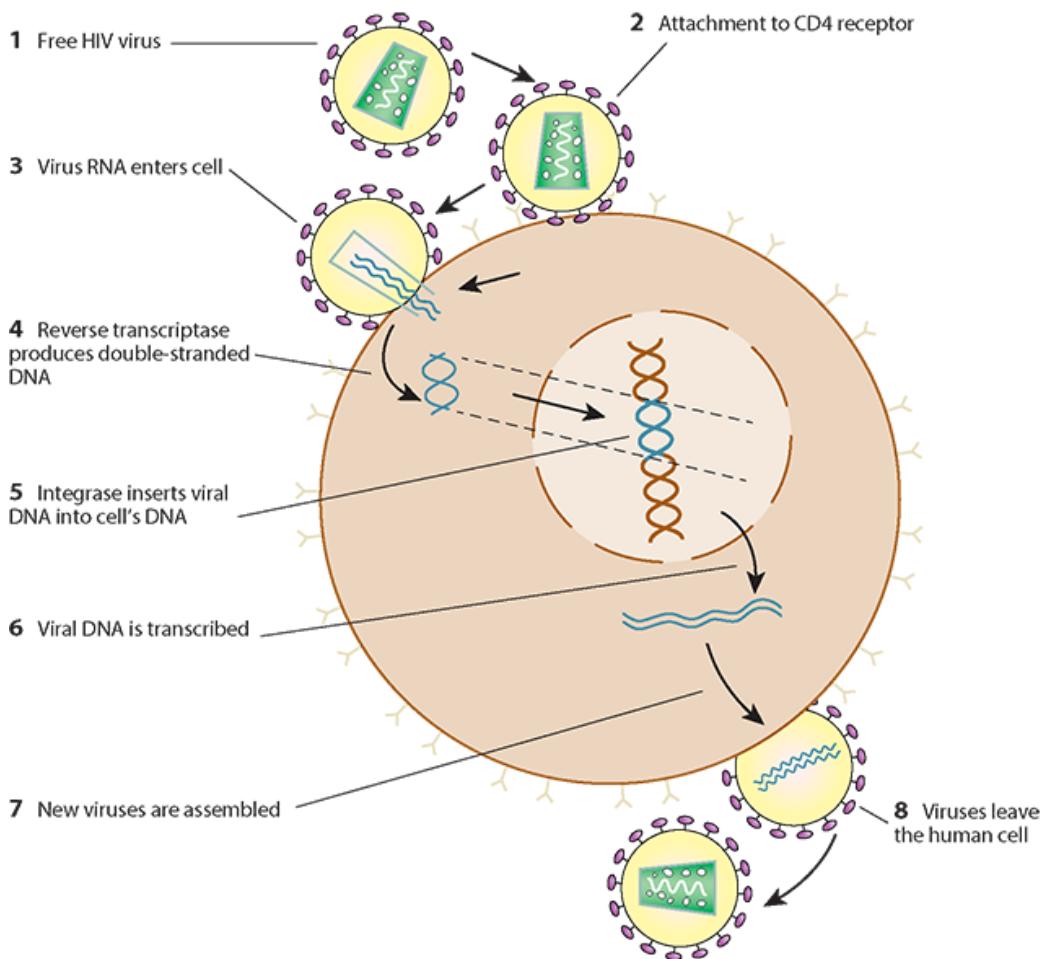


Figure 5.3.4: Life cycle of HIV.

Similar immunodeficiency viruses also affect other species including monkeys, apes and cats, but none of these viruses can cross the species barrier and infect humans, nor can HIV infect any other species that do not have the correct receptors on their plasma membranes.

TEST YOUR UNDERSTANDING

- 15** Explain why most biologists do not consider viruses to be living organisms.

16 Outline the difference between a capsid and a viral envelope.

17 Suggest one advantage of a viral envelope.

5.3.2 Diversity and origins of viruses

Viruses are a diverse group: some have RNA as their genetic material while others have DNA; some have single-stranded genetic material and some doubled-stranded genetic material, as we can see by comparing T4 phage and HIV. Their replication strategies are also very different. But all viruses have some key similarities: they are very small, with few being larger than 200 nm, no virus has ribosomes, so none can produce their own proteins and all viruses must replicate themselves inside a host cell. Table 5.3.1 summarises the features of some common viruses.

Virus	Size	Genetic material	Envelope	Host
Poliovirus	30 nm	single-stranded RNA	no	humans are the only natural host
Influenza	90 nm	single-stranded RNA	yes	mammals: each species has its own specific virus
Herpes simplex	150 nm	double-stranded DNA	yes	primarily human cells but can infect a range of different species
HIV	120 nm	single-stranded RNA	yes	humans, other types of immunodeficiency viruses infect other species

Coronavirus	100 nm	single-stranded RNA	yes	different coronaviruses infect humans, bats, rats, cattle and birds
Bacteriophage T4	225 nm tall	single-stranded DNA	no	<i>E. coli</i> bacteria

Table 5.3.1: Features of some common viruses.

Viruses are a very diverse group and this suggests that they may have several possible origins. Viruses all share a very extreme form of obligate parasitism as their mode of life and it is possible that this developed as a result of convergent evolution. But their genetic code is the same as living organisms. These differences and similarities have led to several hypotheses about the origins of viruses, as follows.

The **virus first hypothesis** proposes that viruses existed before cells and may have been the first ‘entities’ capable of replicating themselves. These very early viruses may have become more complex over time and eventually developed the ability to synthesise membranes and cell walls, so that cells could form from them. It is generally accepted that RNA was the first replicating material so perhaps today’s single-stranded viruses arose from early RNA molecules? Some researchers have proposed that the nucleus of eukaryotic cells evolved from a DNA virus that became engulfed by a developing cell. Support for this theory comes from the fact that viruses can infect cells from all three domains: the Archaea, Bacteria and Eukarya.

The **progressive hypothesis or cellular origin hypothesis** suggests that viruses originated through a progressive process.

The hypothesis describes how pieces of genetic material that were able to move within a genome became able to leave one cell and enter another. Retroviruses, the group that includes HIV, contain the enzymes reverse transcriptase and integrase that enable them to enter a host cell's genome and then leave the cell when new viruses have been produced. This behaviour is very similar to that of a component of the human genome known as a retrotransposon. Some retrotransposons can code for reverse transcriptase and integrase. Within a cell these elements can move to new locations within a human genome. It may be that if additional structural protein genes were acquired by these elements in the past, they could have become able to leave one cell and 'infect' another. Support for this theory comes from the fact that viruses are assembled within host cells.

The **regressive hypothesis** suggests that viruses may have originated by a regressive or reductive process. Support for this theory includes the fact that some bacteria have evolved in this way and are now also obligate intracellular parasites. One example is *Chlamydia* spp. This bacterium has evolved from a free-living ancestor and has its own metabolism, but can only reproduce inside a host cell. Researchers propose that existing viruses may have evolved over time and that once-complex viruses lost the genes for independent life and kept only those which were required for a parasitic mode of existence. This theory is supported by one particular group of very large DNA viruses that includes the smallpox virus and a recently discovered mimivirus, which infects amoebae. These viruses have complex genomes: pox viruses have 200 000 base pairs and mimivirus 1.2 million base pairs. This is far more than other viruses such as poliovirus, which contains only 7500 bases. These large viruses are less dependent on their hosts for replication and can produce their own mRNA within the host

cell cytoplasm. The regressive hypothesis suggests that similar large viruses were once free living but developed first a symbiotic relationship with their hosts and eventually lost genes that were previously present.

KEY POINTS

progressive hypothesis (or cellular origin hypothesis) is a theory that proposes viruses may have evolved from DNA or RNA fragments from the genes of another organism.

regressive hypothesis is a theory proposing that viruses are derived from fragments of cellular organisms via a reductive process.

virus first hypothesis is a theory proposing that viruses existed before cells and may have been the first ‘entities’ capable of replicating themselves.

INTERNATIONAL MINDEDNESS

Fighting a new virus: COVID-19 research

In 2019 a new strain of coronavirus emerged, which spread rapidly across the world in 2020. Called SARS-CoV-2, the virus causes lung infections with a high temperature, a continuous cough and a loss or change to the sense of smell. The virus spreads primarily through droplets when an infected person coughs or sneezes. The COVID-19 pandemic has led to loss of human life worldwide and presents an unprecedented challenge to public health.

Scientists around the world mobilised to use their skills to help fight COVID-19 disease. While many politicians used almost military terms to describe the fight against the virus as

a ‘biotechnology arms race’, scientists responded in a completely different way. Politicians may have closed national borders but, in science, expert researchers from many countries worked together and focused on COVID-19 research with an urgency never seen before.

Many other research projects were put on hold and features that are typical of research, such as academic credit, were set aside. The results of studies from all over the world were quickly posted online and became available months ahead of published reports in scientific journals. Researchers identified and shared hundreds of genome sequences from the virus. More than 200 clinical trials were organised to bring together laboratories and medical facilities around the world.

Dr Francesco Perrone, an Italian scientist, said ‘I never hear scientists – true scientists, good quality scientists – speak in terms of nationality. My nation, your nation. My language, your language. My geographic location, your geographic location. This is something that is really distant from true top-level scientists.’

By August 2020, vaccines were being trialled and more than 150 countries were engaged in discussions to establish a global initiative to work with vaccine manufacturers and provide countries all over the world equal access to safe and effective vaccines. ‘Equal access to a COVID-19 vaccine is the key to beating the virus and paving the way for recovery from the pandemic,’ said Stefan Löfven, Prime Minister of Sweden. ‘This cannot be a race with a few winners, making sure all countries can benefit from fair and equitable distribution of vaccine doses is vital.’

Vaccine trials took place all over the world and the first mass vaccination programmes began in early 2021.

To consider:

- 1** Institutional and international cooperation has been key in the work to combat COVID-19. Is it possible that the landscape of global research in the search for medical treatments has changed forever?
- 2** Discuss the importance of international collaboration in research into SARS-CoV-2 and other disease-causing viruses.

While there is some evidence to support all three theories there is no definite answer to explain the origin of viruses. It may be that modern viruses arose in different ways by many different mechanisms. Research in the fields of structural biology, genomics and virology continues to try to gather more evidence and no single hypothesis may be the correct one.

5.3.3 Rapid evolution in viruses

Viruses evolve by natural selection in the same way as cellular organisms. Natural selection and evolution occur when there are genetic differences in a population and those individuals with favourable characteristics become more likely to inherit them and survive and reproduce ([Chapter 11](#)). Variation and evolution of viruses happens rapidly and regularly, for example new strains of influenza virus appear each year.

Viruses evolve in two main ways:

- 1** By recombination of genetic material

If two viruses infect a cell at the same time, they can exchange genetic material to produce new viruses with different properties, new strains of influenza virus arise like this.

- 2** As mutations occur in their DNA or RNA sequences

RNA viruses have a very high rate of mutation and this can lead to the evolution of drug-resistant strains.

Viral evolution is usually rapid because of their fast rate of reproduction. Viruses that infect animals are able to evolve much more quickly than their hosts. Some viruses, for example HIV, have a very high mutation rate so they can produce a more variable population very quickly. They also produce very large populations of virus and they have a very short lifecycle. Large populations tend to have more individuals with random mutations and if these are useful to the virus, for example if they make the virus more infectious or resistant to drug treatments, natural selection will enable these to survive.

Evolution of influenza viruses

Viruses exchange genetic material by recombination. If two viruses infect the same cell at the same time many viral genomes will be produced inside the cell at the same time.

If this happens, recombination can occur, either by similar regions of the genomes breaking and reconnecting with other fragments or by a process called reassortment when viruses exchange segments of DNA or RNA. (Fig 5.3.5.)

Influenza viruses evolve rapidly by **reassortment**. They have eight RNA segments and if two different viruses, perhaps strain X and strain Y, infect a cell together, new viruses may have a mixture of segments from both X and Y (Figure 5.3.5). Various combinations can be made. The two strains may originally have infected different organisms, for example H1N1 strain of swine flu that caused a pandemic in 2009 was found to have RNA segments that originated from human, bird and pig viruses from two continents. Reassortments had occurred naturally over many years and in a series of stages to produce this virus and several other strains.

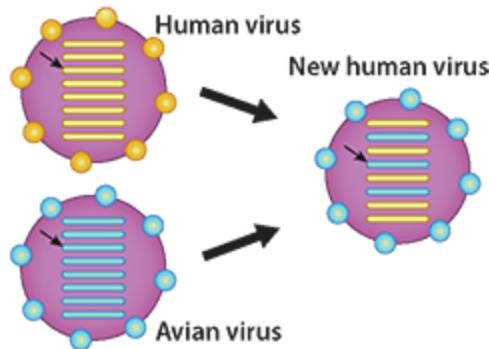


Figure 5.3.5: Influenza viruses evolve by reassortment of their RNA segments to produce new strains which may originate in different species.

KEY POINT

reassortment only occurs in viruses that have their genetic material divided into segments. It is the exchange of intact genes within the entire segment, which occurs when a cell is infected by more than one strain at the same time. It is not to be confused with the reassortment that occurs in the genetics of living organisms ([Chapter 4](#)).

Evolution of HIV viruses

HIV is an RNA virus and RNA viruses tend to have higher rates of mutation than DNA viruses. The reason is that RNA viruses use RNA polymerases to copy their genetic material, unlike DNA viruses that use the host cell's DNA polymerase to do so. DNA polymerases proofread new DNA that is produced and edit out any mistakes. RNA polymerases do not do this so any mutations in the new RNA remain and while some will be harmful, others will be of benefit to the virus.

Some HIV viruses have developed a mutation that can provide resistance to drug treatments that are used to treat the disease. One treatment that is used is a drug called nevirapine that blocks reverse transcriptase, the enzyme that viruses use to copy their RNA genomes to DNA. Without this enzyme the virus cannot reproduce and cannot permanently infect a cell. Most HIV viruses are blocked by nevirapine but a few have a mutation in the genes for reverse transcriptase which alters the enzyme's binding site so that the drug cannot inhibit it. These resistant viruses will survive and reproduce and can re-establish a resistant population of HIV.

Today a new method of treatment for HIV is used. It is known as HAART or highly active antiretroviral therapy. It uses a combination of three or more drugs because it is less likely that a

population of HIV viruses will carry mutations to all three drugs at the same time. Multi-drug resistant strains will eventually evolve but this treatment will slow down the rate of evolution of these viruses.

TEST YOUR UNDERSTANDING

- 18** How does the bacterium *Chlamydia* support the regressive hypothesis of viral origin?
- 19** Outline the ‘virus first’ hypothesis of viral origin.
- 20** Summarise the reasons for the rapid evolution of viruses.

Links

- Why are viruses used as vectors in genetic modification? ([Chapter 4](#))
- How does the Hershey–Chase experiment support the idea that DNA is the hereditary material? ([Chapter 4](#))

SELF-ASSESSMENT CHECKLIST

Think about the topics covered in this chapter. Which parts are you most confident with? Which topics require some extra practice?

I can...	Subsection	Needs more work	Nearly there	Confident to move on
explain the importance of organic molecules and boundaries in the origin of life	5.1.1			
outline the principles of cell theory	5.1.2			
outline the Miller–Urey experiment and its importance	5.1.3			
describe how the deep-sea vent hypothesis provided evidence for early molecules and their energy sources	5.1.4			

outline the properties of RNA that make it important in the origin of life	5.1.5			
describe how micelles form and suggest how protocells may have originated	5.1.6			
outline the endosymbiosis theory	5.2.2			
state that living organisms are composed of cells and list all the functions of life	5.2.1			
state that in multicellular organisms cells are differentiated and that all cells do not carry out all the functions of life	5.2.1			
describe the atypical structure of xylem and phloem	5.2.1			

describe the similarities and differences between prokaryotic and eukaryotic cells	5.2.1				
identify the components of different types of cell in micrographs	5.2.1, 5.2.3				
summarise how developments in microscopy have helped us understand cell structure	5.2.3				
describe the key features of a virus	5.3.1				
state that all viruses contain genetic material and are protected in a capsid	5.3.1				
describe how some viruses have a viral envelope and outline the benefits this gives	5.3.1				
	5.3.1				

describe the structure of some different viruses and outline the lytic and lysogenic life cycles of bacteriophage lamda and HIV				
explain the similarities and differences between viruses that suggest several origins	5.3.2			
outline the hypotheses which try to explain the origin of viruses	5.3.2			
summarise the reasons for the rapid evolution of viruses.	5.3.3			

REFLECTION

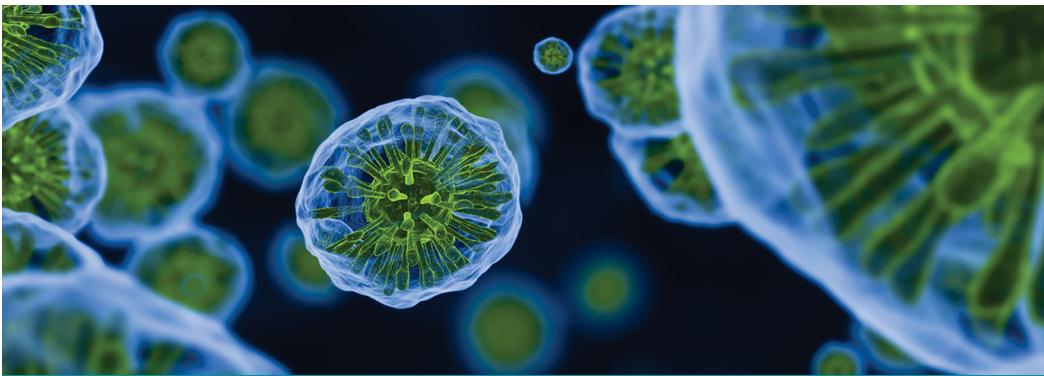
Can I explain the importance of looking at life at the microscopic level to someone else? If not, what do I need to review?

What are your first thoughts about this chapter? Are they positive or negative?

How do you feel this topic relates to real-life situations and problems?

EXAM-STYLE QUESTIONS

You can find questions in the style of IB exams in the digital coursebook.



› Chapter 6

Cell function

B2.1, B2.2, B2.3

INTRODUCTION

Membranes enclose the contents of the cell. There is much activity at membrane surfaces, especially at the plasma membrane where it contacts the extracellular space.

Membranes surround organelles inside eukaryotic cells and are important in separating different substances and reactions that take place in organelles. Some substances can cross membranes while others cannot, and the cell controls the amount of water that it contains by regulating what can cross its membranes by diffusion and active transport. Cells must retain a suitable surface area to volume ratio if these

mechanisms are to operate. So, after cells have grown, cell division is needed to increase the surface area of the cell.

6.1 Membranes and organelles

LEARNING OBJECTIVES

In this section you will:

- learn that all cells are surrounded by a phospholipid bilayer that forms due to amphipathic properties of the molecules
 - understand that the phospholipid layer contains other molecules including proteins, glycoproteins and integral proteins
 - discover that integral proteins act as receptors and enzymes and are involved in transport across membranes, while glycoproteins are used for cellular recognition or attachment
 - learn that cholesterol in animal cells and sterols in plant cell membranes reduce membrane fluidity and permeability
 - recognise that organelles are membrane-bound structures that form compartments with specific functions and that separation confers advantages such as isolating metabolic processes
 - learn that prokaryotic cells do not contain organelles
- recognise the relationship between fatty acid and cholesterol content of bilayers and their fluidity

- understand that membrane fluidity affects endocytosis and exocytosis
- understand that organelles interact due to the fluid nature of the phospholipid bilayer
- learn that rough endoplasmic reticulum supports ribosomes and packages proteins
- distinguish between the function of attached and free ribosomes
- recognise the role of the Golgi apparatus
- recognise that coated vesicles aid transport between different parts of the cell
- recall that mitochondria have two membranes and are adapted for aerobic respiration
- discover that compartmentalisation permits organelles, including mitochondria and chloroplasts to isolate enzyme systems, generate high quantities of protons and synthesise ATP
- learn that chloroplasts have three membranes that provide compartmentalisation to isolate enzymes and synthesise ATP. Membranes of the chloroplast also support photosynthetic pigments.

GUIDING QUESTIONS

- Why do phospholipids form bilayers?

- How do proteins integrate into membranes?
- Why is compartmentalisation within cells important?

6.1.1 Membrane structure

All membranes, wherever they occur in cells, have the same basic structure. Membranes are usually between 7 and 10 nm thick, and are composed of two layers of phospholipid, which form a bilayer. **Phospholipids** are made up of a polar, hydrophilic area containing a phosphate group bonded to glycerol, and a non-polar, lipophilic area containing fatty acids. In the bilayer, the lipophilic or hydrophobic (water-hating) parts all point towards each other, and the hydrophilic (water-loving) areas point outwards. Phospholipids are amphipathic molecules as they contain hydrophilic and hydrophobic parts as Figure 6.1.1 shows.

It is the different properties of each end of the phospholipid molecule that cause the phospholipids to arrange themselves in this way. The hydrophilic ‘heads’ of the molecules always appear on the outside of the membrane where water is present, while the hydrophobic ‘tails’ orientate inside the double layer, away from water.

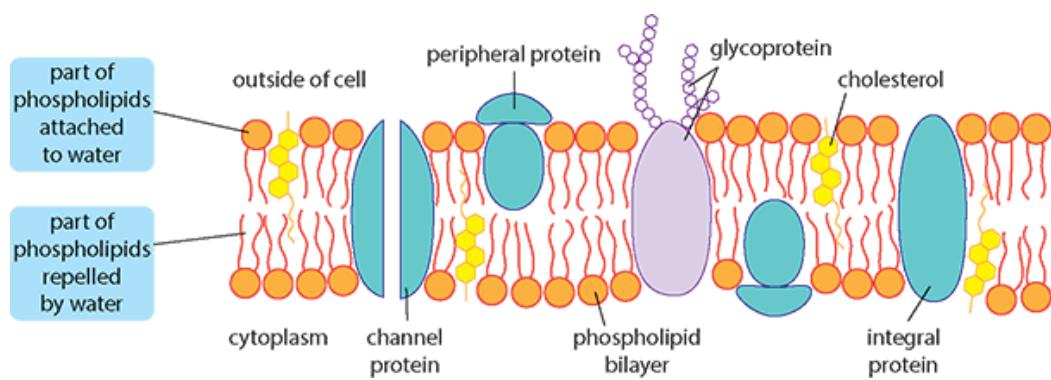


Figure 6.1.1: A plasma membrane contains structures which produce a dynamic matrix.

The structure of a membrane is called a ‘mosaic’ because, just as a mosaic picture is made up of many small, separate pieces, so the surface of the membrane is composed of the heads of many separate phospholipid molecules. The whole structure is flexible or ‘fluid’ because the phospholipids can float into a position anywhere in the membrane. Cell membranes are dynamic, fluid structures because most of their molecules are able to move about in the plane of the membrane. Research using radioactively labelled phospholipids shows that these molecules move not only within their own layer, but also between the two layers of the membrane.

The phospholipid bilayer contains other molecules that form a part of the dynamic matrix. Embedded in the membrane bilayer are different molecules that contribute to the functions of membranes (Figure 6.1.1).

- Cholesterol is often present in animal cells and is most commonly found in the plasma membrane. Plant cell membranes have similar molecules called **sterols** which serve the same function. One end of the cholesterol or sterol molecule associates with the polar heads of phospholipid molecules while other parts of it are embedded in the membrane next to the non-polar fatty acid chains. This interaction makes the membrane less ‘fluid’, more rigid and less permeable to water-soluble molecules.

There are also different types of protein in the bilayer. Membrane proteins have many different structures and positions in the bilayer. They also have different functions:

- **Integral proteins** are embedded in the bilayer. Part of their surface is hydrophobic and remains embedded in the centre of the membrane. Some extend through the membrane and have hydrophilic parts which project between the phosphate

heads. Some integral proteins are enzymes immobilised within the membrane structure and perfectly placed to carry out sequences of metabolic reactions.

- **Peripheral proteins** are hydrophilic and are attached to the membrane's surface. Most of them are attached to the surface of an integral protein. Many of the proteins on the outer surface are glycoproteins, that is, they have carbohydrate groups attached to them. Some of them serve as hormone-binding sites and have special shapes to recognise the specific hormones or antigens to which the cell will respond. Others are important in cell to cell communication and adhesion.
- **Channel proteins** are integral proteins that span the bilayer, acting as channels for ions and molecules to pass by passive transport, or forming pumps that use active transport to move molecules into or out of the cell.
- **Aquaporins** are a special class of channel proteins that act as channels for the transfer of water, and in some cases, small solutes across the membrane.
- **Glycolipids** are lipids which are attached to a carbohydrate by a glycosidic bond. They maintain the stability of the cell membrane and allow cells to recognise other cells. This is vital to the immune response and in allowing cells to make connections to one another to form tissues

EXAM TIP

You must be able to draw and label a simple diagram like the one shown in Figure 6.1.1 to show the range of membrane proteins, including glycoproteins, and cholesterol or sterol.

6.1.2 Organelles

All cells contain a number of different structures that enable them to stay alive and function (see also [Section 5.2](#)). Organelles are special structures that have their own specific roles in the cell. Membrane-bound organelles, such as mitochondria and chloroplasts, form compartments so that metabolic processes can be separated from one another, material can be stored and certain molecules can be concentrated. The cell wall, cell membrane, cytoskeleton and cytoplasm are not organelles, but vesicles such as the Golgi apparatus and lysosomes are considered to be organelles because of their contents.

Membrane-bound organelles are only found in eukaryotic cells. Prokaryotes do not contain membrane-bound organelles, but they do have ribosomes that carry out protein synthesis and a plasma membrane that encloses their cytoplasm.

Advantages of separating the cell into compartments

The nucleus and cytoplasm are separated by the nuclear envelope, the membrane which encloses the nucleus. This separation means that gene transcription (copying DNA to mRNA) can occur in the nucleus and is separated from translation (production of polypeptides from mRNA) that occurs in the cytoplasm. Modifications of mRNA such as the removal of introns can take place before the mRNA meets ribosomes and the translation process begins. The translation of modified mRNA produces the correct amino acid sequences needed to make a functional protein. Prokaryotes which do not have a separate nucleus have mRNA that meets ribosomes as soon as it is produced.

The cytoplasm contains many organelles which separate the functions of the cell into compartments. Within a compartment metabolites and enzymes can be concentrated so that enzyme-controlled reactions such as respiration can take place more quickly and efficiently than if the reactants were spread through the cytoplasm. Certain biochemical processes such as the digestion of unwanted materials can take place within an enclosed vacuole without affecting other parts of the cell.

Lysosomes are small spherical organelles that contain hydrolytic (digestive) enzymes, including proteases, amylases, nucleases and lipases.. The enzymes must be kept separated from the contents of the cytoplasm, because the pH inside the lysosome is different from that of the cytoplasm and would damage cell structures. The function of lysosomes is to engulf and break down unwanted macromolecules and respond to and destroy invading particles, such as bacteria or viruses, that enter the cell. They are also capable of destroying a cell if they burst and release their enzymes; they are sometimes called the cell's 'suicide packets'.

NATURE OF SCIENCE

Using models to represent the real world: alternative models of membrane structure

The fluid mosaic model that we accept today was not the first scientifically accepted explanation of membrane structure. In 1935 Hugh Davson and James Danielli proposed the first model that attempted to describe the structure of the bilayer and the proteins in it (Figure 6.1.2a). They proposed that the membrane consisted of two layers of protein that enclosed a phospholipid bilayer. The model was known as a 'lipoprotein sandwich'. But the model wrongly assumed that all

membranes were the same, with a constant lipid to protein ratio. This is not true. The model also could not explain how certain hydrophilic substances could pass through the hydrophobic centre of the membrane.

Later research found that membrane proteins are insoluble and thus have hydrophobic surfaces. This means that they could not form a continuous layer around the outside of a membrane. More recent fluorescent tagging of membrane proteins also showed that they are mobile and can occupy different positions in a membrane and do not form a static layer. In addition, freeze fracturing, a technique to cut open and expose the inner surfaces of a biological specimen, was used to split open the membrane and showed that there are irregular rough surfaces inside the membrane. These rough surfaces are interpreted as being trans-membrane proteins and indicate that proteins are not only found on the outside of membranes.

The discoveries led to a new model being proposed by Singer and Nicolson in 1972. According to this model, proteins were embedded within the lipid bilayer and do not exist as separate layers. This model is known as the fluid mosaic model and it is still the model that is most widely accepted today (Figure 6.1.2b).

To consider:

- 1 Models are used to explain patterns that are not directly observable. They cannot be proven but can be falsified when their predictions do not agree with current evidence. How important are the two models of membranes to our understanding of their structure?

- 2** Why were the new techniques of electron microscopy, fluorescent marking and freeze fracturing crucial to the development of the fluid mosaic model of membranes?
- 3** Could a new model eventually replace the fluid mosaic model?

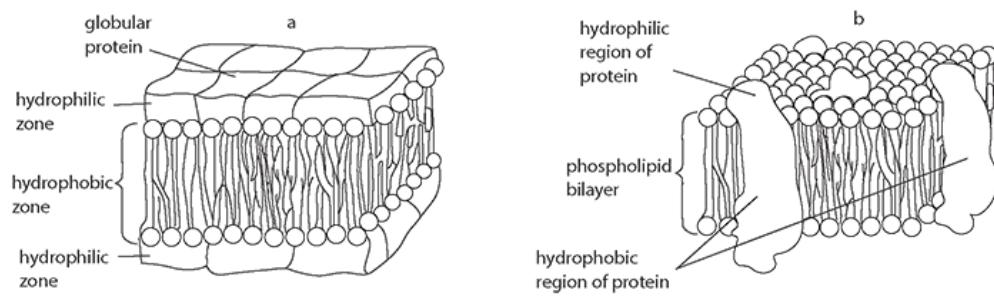


Figure 6.1.2: Diagrams showing **a** the Davson Danielli ‘sandwich’ model of membrane structure and **b** the later fluid mosaic model that is accepted by scientists today.

Membrane fluidity

Fatty acids in lipid bilayers are the main component of cellular membranes. There are many different fatty acids which vary in structure, and the distribution of different lipids in membranes varies between organisms, cell types, organelles and membranes. Lipid composition affects the physical properties of a membrane, for example, unsaturated fatty acids in phospholipids reduce membrane rigidity and affect processes that take place as the membrane changes shape.

Membrane fluidity is affected by the type of fatty acids that are present; saturated fatty acids make the membrane less fluid, while unsaturated fatty acids make it more fluid. (Fig 6.1.3). Saturated fatty acids have higher melting points than unsaturated

molecules and make membranes stronger at higher temperatures. They have no double bonds in their hydrocarbon chains ([Chapter 1](#)) and this results in a strong, tight membrane. Polyunsaturated fatty acids have more than one double bond in their hydrocarbon chains and this creates a bend in the molecule which increases fluidity. The correct ratio of saturated to unsaturated fatty acids will keep the membrane fluid at different temperatures. For example, microorganisms can adjust the fatty acid composition of their membranes in response to heat stress in their environment.

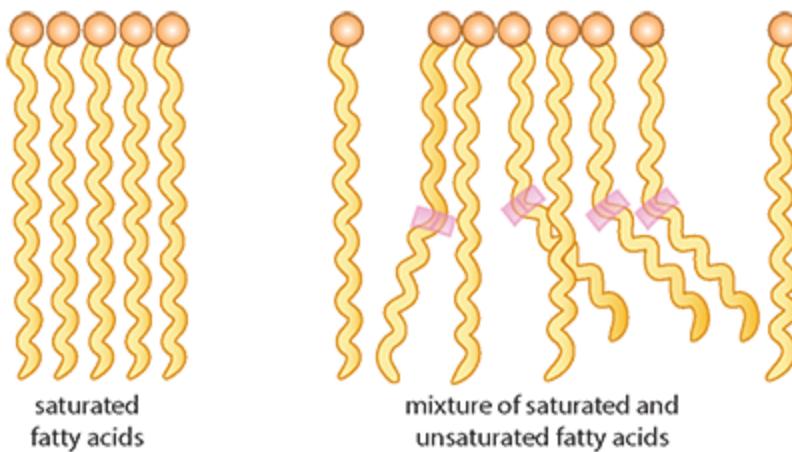


Figure 6.1.3: Saturated fatty acids produce a stable, stronger membrane at high temperatures. Unsaturated fatty acids increase the fluidity of the membrane.

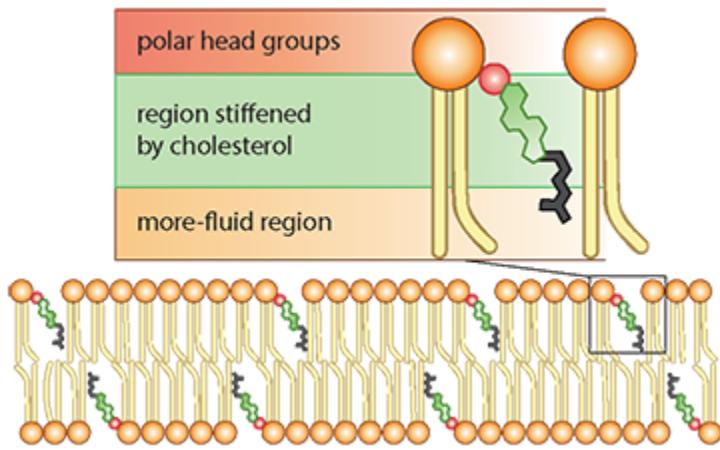


Figure 6.1.4: Cholesterol between phospholipid molecules stiffens the membrane at higher temperatures and prevents it from melting.

Membrane fluidity also affects the functioning of other molecules in the membrane. Binding to some peripheral proteins and movement of enzymes within the membrane depend on its fluidity. Functions such as cell signalling and endocytosis and exocytosis (described here) can be regulated by the fluidity of the cell membrane.

Cholesterol makes up 30% of the lipids in the membranes of animal cells and it also affects their fluidity. Its presence stabilises and stiffens membranes at higher temperatures and increases their melting points. At low temperatures it is positioned between phospholipids and prevents them aggregating and becoming stiff at lower temperatures. (Figure 6.1.4)

Membranes and the protein channels which are present in them also have important functions in the transmission of nerve impulses. You can read more about gated ion channels for

neurotransmitters and about sodium potassium pumps which maintain membrane potentials in [Chapter 6.2.3](#) and in [Chapter 7](#).

Importance of membranes in cell adhesion

A certain group of surface glycoproteins are known as cell adhesion molecules (CAMs). They are involved in helping cells stick to each other and to their surroundings. They are very important in maintaining the structure and function of tissues.

Cell adhesion molecules are found on a cell's surface and form different types of bonds and junctions so that they can join:

- Cells to cells
- Cells to extracellular matrix (chains of sugar and protein molecules with other structural proteins such as collagen which surround cells and make tissues more stable)
- Extracellular matrix to the cell cytoskeleton

CAMS help in processes including:

- The adhesion of cells to one another to provide organized tissue structure
- The transmission of cues and signals from outside the cell across the membrane
- The movements of certain cells by regulating the cell that they adhere to.

As well as acting as a molecular glue, CAMS have important roles in growth, contact inhibition and apoptosis.

There are four different forms of CAM,

- integrins that connect cells to the extracellular matrix to give integration,
- immunoglobulins CAMS which act as adhesion molecules in the nervous system,
- cadherins responsible for cell to cell adhesion
- selectins which bind to cell surface carbohydrates and are involved in the way cells respond to inflammation

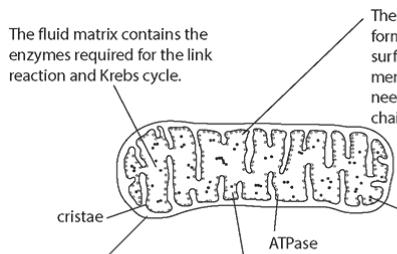
CAMS may bind with the same CAMS (homophilic binding) or the CAM of one cell may bind with different CAMS (heterophilic binding) on another cell.

Mitochondria and chloroplasts

Two of the most important organelles found in cells are mitochondria and chloroplasts.

Mitochondria are found in all eukaryotic cells, but only organisms that photosynthesise contain chloroplasts. Figure 6.1.5 shows diagrams of the two organelles, drawn from electron micrographs (see also [Section 2.3](#)).

Both organelles are enclosed in two layers of membrane which separate their contents from the cytoplasm of the cell. Both have important roles in transforming energy and generating ATP, and both have their own ribosomes, DNA and enzymes. Chloroplasts and mitochondria can also move, change their shape and divide independently of the cell cycle by simple fission. Both these organelles are thought to have originated by endosymbiosis ([Section 5.2](#)) and they have retained some independence from the cell which contains them.



The outer membrane encloses the mitochondrion and keeps it separate from the cytoplasm.

The inner membrane is folded to form cristae, which increase the surface area for reactions. This membrane contains the proteins needed for the electron transfer chain and also ATP synthase.

The space between the inner and outer membranes, known as the intermembrane space, is important in chemiosmosis as it is small and enables a high concentration of protons to accumulate.

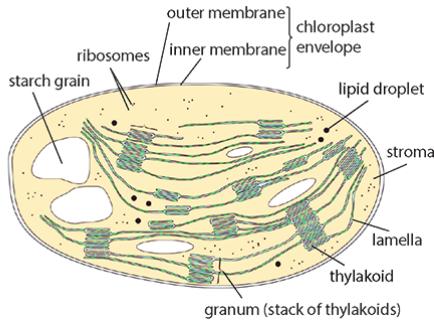


Figure 6.1.5: Diagrams to show the detailed structures of a mitochondrion and a chloroplast.

WORKED EXAMPLE 6.1

Recognising and identifying cells

1 Diagrams of cells

You must be able to recognise prokaryotic and eukaryotic cells from electron micrographs and draw diagrams of eukaryotic cells to show their structure and organelles. Look at Figure 6.1.6, which is a diagram of a cell.

a To identify the type of cell, first check: is it a prokaryote or a eukaryote?

- If the cell has organelles it is a eukaryote. In this case we can see a nucleus with a membrane, as well as mitochondria and other organelles.

b Is the cell a plant or an animal cell?

- If the cell has a cell wall, large vacuole and chloroplasts then it is a plant cell.

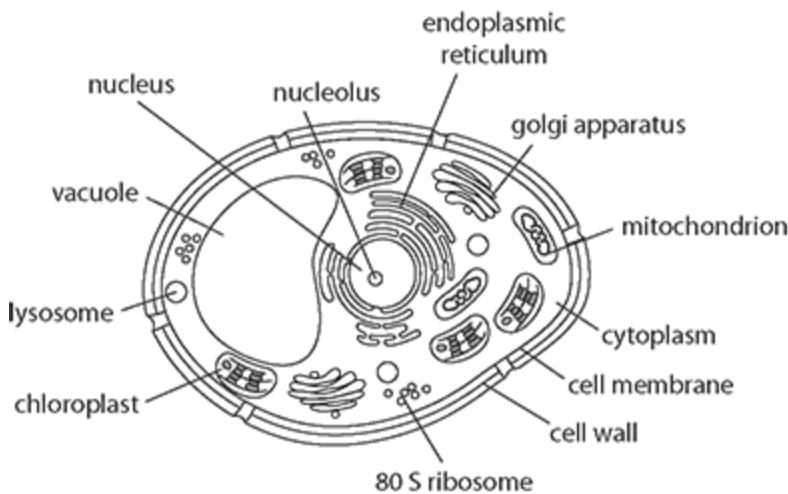


Figure 6.1.6: Diagram of a cell.

2 Electron micrographs of cells

In electron micrographs such as Figure 6.1.7 you must be able to identify organelles including mitochondria, chloroplasts, the Golgi apparatus, rough and smooth endoplasmic reticula and ribosomes.

- a** Can you identify the cell membrane in this photograph?
 - It appears at the top left-hand corner of the image.
- b** Notice the mitochondria (the structures coloured purple), they are not all the ‘sausage shape’ that you see in diagrams. Think about why this is.
- c** This cell contains a large amount of endoplasmic reticula (the structures coloured green), is it rough and grainy?

- If it is, this indicates that the cell is manufacturing protein and that ribosomes are attached. If it is smooth there are no ribosomes attached.
- d There are pale blue lipid droplets present in the cell.
- The cell is storing lipids in droplets to be used in the production of testosterone. The lipids are separated from the rest of the cytoplasm inside a membrane.
- e Look at the nucleus. Notice the nuclear membrane that surrounds it. What can you see inside it?
- The darker areas are uncoiled chromosomes and are called chromatin.
 - At higher magnifications it is possible to see that the nuclear membrane is double and has pores through it.

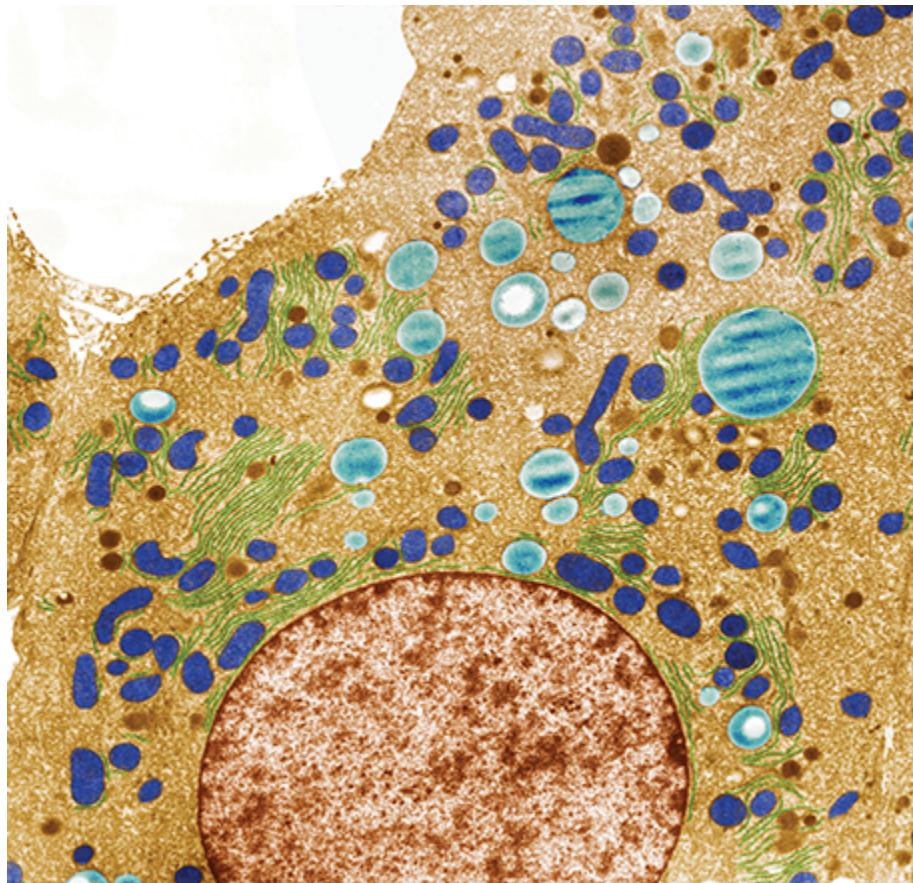


Figure 6.1.7: Coloured electron micrograph of a testis cell.

3 Prokaryotic cells

You should be able to draw a diagram of a prokaryotic cell (Figure 6.1.8) of a rod-shaped bacterium and label the structures it contains.