CHAPTER 3

Cell structure

The basic unit of structure and function in living organisms is the cell. The cell is a self-sustaining chemical system. All the chemical reactions necessary for it to maintain its existence occur in its protoplasm. In order to maintain its chemical integrity, the cell must be physically separated from the environment and yet capable of exchanging material with it. The cell membrane forms this boundary. The efficiency of exchange decreases with an increase in size of the cell, so there is an upper limit to how large a cell can grow. Most cells, therefore, can be seen only when viewed with a microscope.

OBJECTIVES

→ Recognise that prokaryotic and eukaryotic cells have many features in common, which is a reflection of their common evolutionary past.
→ Recall that prokaryotic cells lack internal membrane-bound organelles, do not have a nucleus, are significantly smaller than eukaryotes, usually have a single circular chromosome and exist as single cells.
→ Understand that eukaryotic cells have specialised organelles to facilitate biochemical processes:
  – photosynthesis (chloroplasts)
  – cellular respiration (mitochondria)
  – synthesis of complex molecules including proteins (rough endoplasmic reticulum), carbohydrates, lipids and steroids (smooth endoplasmic reticulum), pigments, tannins and polyphenols (plastids)
  – the removal of cellular products and wastes (lysosomes).
→ Explain, using an example, how the arrangement of internal membranes can control biological processes (e.g. folding of membranes in mitochondria increases the surface area for enzyme-controlled reactions).
→ Identify the following structures from an electron micrograph: chloroplast, mitochondria, rough endoplasmic reticulum and lysosome.
→ Compare the structure of prokaryotes and eukaryotes.
→ Describe the structure of the cell membrane (including protein channels, phospholipids, cholesterol and glycoproteins) based on the fluid mosaic phospholipid bilayer model.
→ Describe how the cell membrane maintains relatively stable internal conditions via the passive movement (diffusion, osmosis) of some substances along a concentration gradient.

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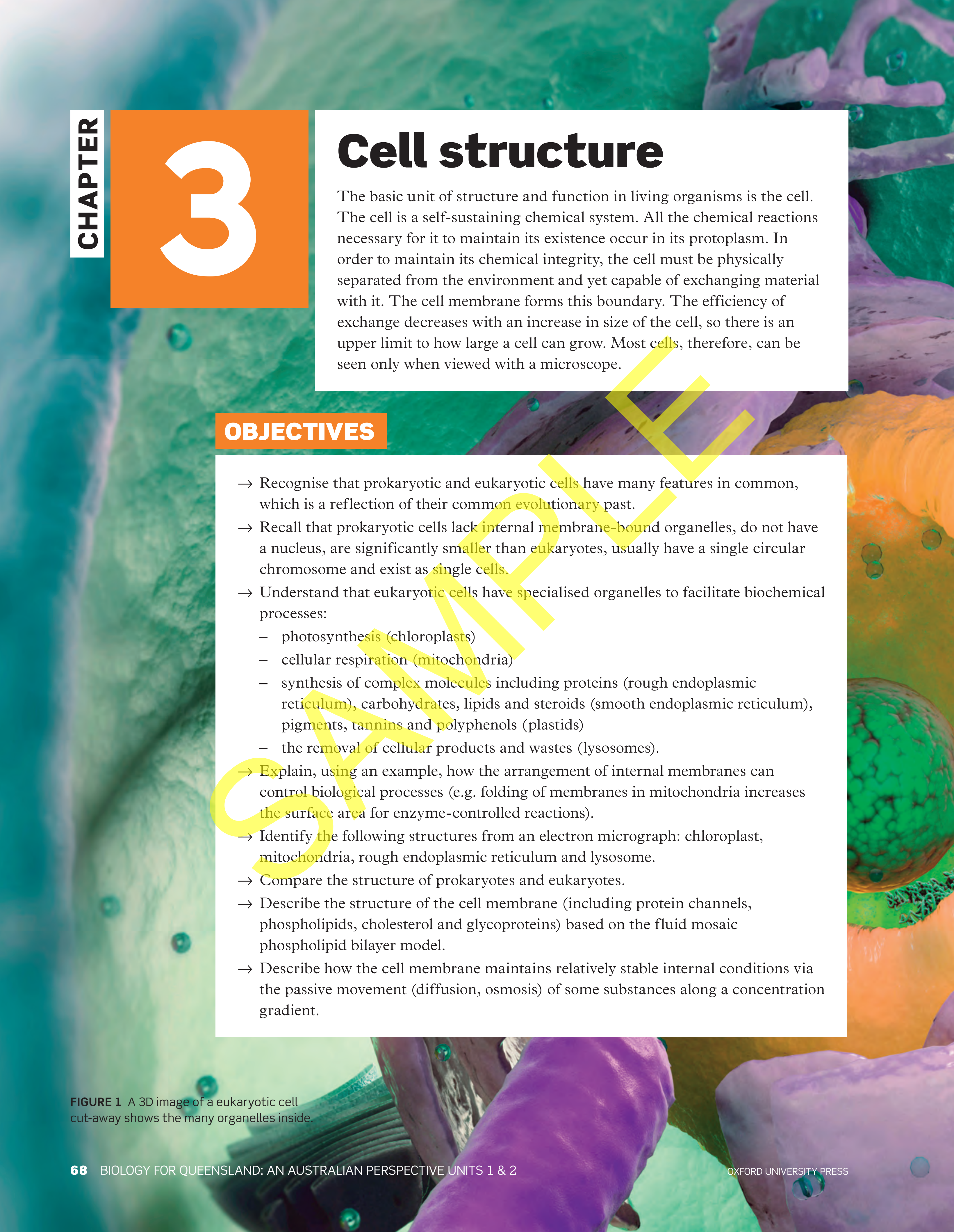

FIGURE 1 A 3D image of a eukaryotic cell cut-away shows the many organelles inside.

→ Explain how the cell membrane maintains relatively stable internal conditions via the process of active transport of a named substance against a concentration gradient.

→ Understand that endocytosis is a form of active transport that usually moves large polar molecules that cannot pass through the hydrophobic cell membrane into the cell.

→ Recognise that phagocytosis is a form of endocytosis.

→ Predict the direction of movement of materials across cell membranes based on factors such as concentration, and the physical and chemical nature of the materials.

→ Explain how the size of a cell is limited by the relationship between surface area to volume ratio and the rate of diffusion.

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PRACTICALS

MANDATORY PRACTICAL	**3.2** The effect of surface area to volume ratio on the rate of diffusion
MANIPULATIVE SKILL	**3.3A** Use of the light microscope
MANDATORY PRACTICAL	**3.3B** Preparation and examination of wet mount specimens
SUGGESTED PRACTICAL	**3.3C** Identifying organelles from electron micrographs
SUGGESTED PRACTICAL	**3.5** Modelling the selectively permeable cell membrane

SAMPLE

SCIENCE AS A HUMAN ENDEAVOUR

3.1 The development of the microscope

KEY IDEAS

- The development of the microscope paved the way to an understanding of cells
- Understanding of cells comes from the development of cell theory
- Cells are the smallest structural and functional unit of living organisms

Biology is the study of living things. To be considered as living, an organism needs to be able to control and regulate its internal environment, to grow, respond to stimuli and reproduce. The smallest unit of life that can perform these functions is a cell. As cells are extremely small, they could not be seen until the development of the microscope. This invention paved the way to a greater understanding of the structure and function of living matter.

The road to the development of the microscope began when the Romans first made glass in the first century BCE. At this early time, it was observed that objects viewed through a droplet of glass were magnified, even though the image was fuzzy. It was not until the late sixteenth century that the quality of glass and the technology to finely grind it was developed. These developments allowed the production of spectacles.

Work done in the 1590s by the spectacle maker Zacharias Janssen produced lenses that could magnify nine times. In 1595, he and his father built the first compound microscope. This consisted of two lenses separated in a hollow tube. The image produced, however, was not very clear and tended to split the light like a prism. This affected the microscope's resolution limits – the limit at which tiny objects that are close together stop being visibly separate.

These first microscopes were thought of as toys rather than scientific instruments. Part of the problem was that the lenses were not particularly smooth or of even thickness. Second, the smaller an object is, the less light reflects from it. Seeing anything really tiny requires a very good light source, something that was not available at the time.

Nevertheless, using such a microscope, in 1660, the Italian Marcello Malpighi was able to see blood capillaries in the tail of live fish. This showed that blood circulates in the body. Prior to this it was thought that blood was produced in the intestines and moved to other parts of the body where it was consumed.

In 1665 the Englishman Robert Hooke observed the bark of a cork tree under a microscope using reflected light. He found it was composed of minute chambers, which he called cells because they looked like the 'cells' in which monks lived. Although it is now known that there are no cells in dead cork, the modern term 'cell' comes from this label.

Hooke used a simple microscope (single lens) for examining specimens using transmitted light (light passing through the specimen) in order to get clearer images.

Dutchman Antonie van Leeuwenhoek further developed the microscope and improved the way it was used. He developed his interest in microscopes during his apprenticeship as a draper in Amsterdam in 1648 where he was able to observe the fibres that comprised different quality materials.

SAMPLE

He learned to grind and polish small glass spheres (a biconvex lens) of such quality that they had a magnification of 270. Leeuwenhoek mounted this lens on a flat copper plate and held it very close to his eye. The object being studied was placed on the head of a movable pin attached to the plate on the other side of the lens.

Using this simple microscope, Leeuwenhoek was the first to shine a light through living single-celled animals (protozoans) in pond water. He called them animalcules.

For about 150 years microscopic work was limited to these two 'primitive' types of microscope. By the late 1800s many of the distortions of the lenses were corrected due to the work by German engineer Carl Zeiss and his employees, Schott and Abbe. They developed optical systems that could focus on objects smaller than a wavelength (approximately 0.2 μm (micrometres)). Because they used light as an imaging system, they were called light microscopes. Although a powerful and useful tool, light microscopes still could not provide a detailed observation of the internal structure of the cell. While some recent techniques have been employed in improving light microscopes, they are still limited.

FIGURE 1 Hooke's microscope

FIGURE 2 Leeuwenhoek's microscope

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As an understanding of the physical nature of matter, particularly the structure of the atom, developed, new technologies arose. The application of these advances led to the development of microscopes with higher magnification and resolution.

In the 1930s, the electron microscope was developed by Ernst Ruska and Max Knoll. Like its predecessors, this changed the possibilities for science. This microscope uses a narrow beam of electrons. The beam width is adjustable, but at its smallest is below the size of a hydrogen atom. The beam is focused with magnets and the final image is converted to light in a way similar to that on a television screen. A photograph called an **electron micrograph** is taken of the image. This is necessary because the electron beam prevents the magnified image from being viewed directly. For the same reason, the electron microscope is difficult to use on living material.

electron micrograph
a photographic image of a sample magnified by an electron microscope

In summary, technological advancements in physics allowed magnification and resolution to be massively improved because the electron microscope uses a very narrow beam of electrons as opposed to the broader beam of light used previously.

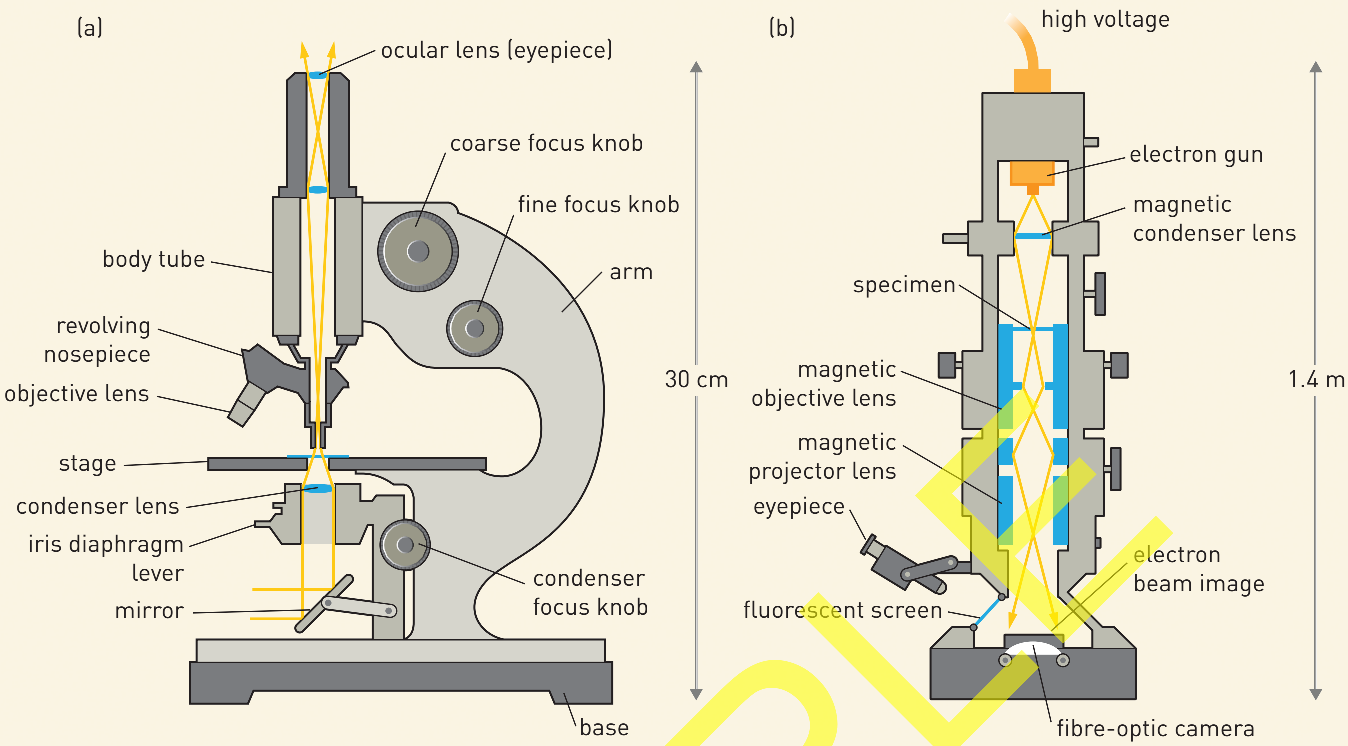

FIGURE 3 (a) A modern light microscope with inbuilt transmitted light source; (b) an electron microscope

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Most microscopes can be divided into another two groups depending on how the imaging beam (light or electrons) interacts with the specimen. In scanning microscopes, the beam reflects off the surface of the specimen to produce a three-dimensional image. Transmission microscopes send the beam through the specimen and a two-dimensional image is formed.

For a specimen to be useful in the transmission microscope, the beam has to be able to pass through it and reveal its internal detail. Specimens need to be stained with special chemicals to produce clear detail. Coloured dyes are used in light microscopy while heavy metals are used for electron microscopy. The stain produces variations in absorption by different parts of the specimen.

Large or thick specimens will not allow the beam through them. They must be sectioned or sliced, then stained. The object is embedded in a material (commonly, wax in light microscopy and plastic for electron microscopy) that will hold it together while being thinly sliced. Sequences of these sections can then be used to translate the two-dimensional information into a three-dimensional model.

Cell theory

cell theory
the theory that all organisms are made up of cells and their products, and that growth and reproduction are fundamentally due to division of cells

The relationship between science and technology is clearly demonstrated in the development of the **cell theory**. Three hundred and fifty years ago there was no knowledge of cells since they were too small to be seen. It was only with the invention of the microscope that scientists like Leeuwenhoek were able to discover the previously unseen world of cells. Just as the telescope was a critical device for astronomers, the microscope was central to the progress of biology.

While the discovery of cells was first made with the advent of the microscope in the seventeenth century, further progress was slow. In the nineteenth century two scientists

(Schleiden and Schwann) were credited with the development of the cell theory, which outlined the following:

- All known living things are made up of one or more cells.
- All living cells arise from pre-existing cells by division.

With the increase in knowledge since that time, this theory has been expanded and it is generally accepted that:

- The cell is the fundamental unit of structure and function in all living organisms.
- The activity of an organism depends on the total activity of independent cells.
- Energy flow (metabolism) occurs within cells.
- Hereditary information (DNA) is passed on from cell to cell.
- All cells have the same basic chemical composition.

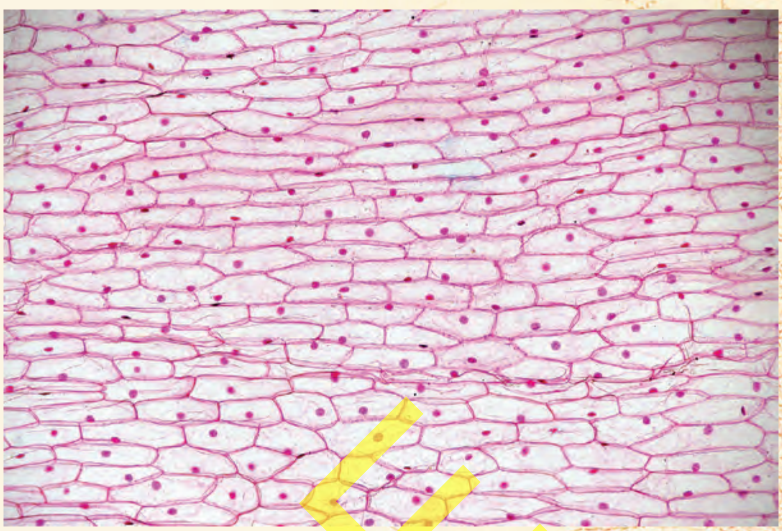

FIGURE 4 Cells are the building blocks of life. These are cells from the epidermis of an onion that have been treated with a stain.

CHECK YOUR LEARNING 3.1

Describe and explain

1 The development of the technology of the microscope represents a major advancement in science.

a **Identify** the main functions of a microscope.

b **Describe** the difference between images seen with a light microscope and those seen with an electron microscope.

c **Explain** the advantages and disadvantages of the light and electron microscopes.

2 **Explain** the cell theory. Explain why the current theory is more detailed than that proposed by Schleiden and Schwann.

Investigate, evaluate and communicate

3 **Justify** why the current cell theory is more detailed than that proposed by Schleiden and Schwan.

4 **Construct** a timeline that communicates the development of the microscope.

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3.2 The cell as the building block of life

KEY IDEAS

- The difference between prokaryotic and eukaryotic cells
- The endosymbiotic theory of the evolution of eukaryotic cells
- The size of cells including surface area to volume ratio

unicellular
composed of a single cell

multicellular
composed of many cells

colonial
an animal composed of the same unicellular organisms joined into a cluster where each individual can carry out all functions necessary for life

Cells tend to be very small (0.5–10 μ, or micrometres, in diameter, where 1 μ = 10^{-6} m = 1 millionth of a metre) although there are a few notable exceptions, for example an emu's egg which is 13 cm long. The smallest organisms have only one cell and are called **unicellular**. Although a size range exists in these organisms (the smaller cells are generally 'simpler'), they are all microscopic. Larger organisms are composed of several to trillions of cells working together and are **multicellular**. In these organisms, different groups of cells perform different jobs to keep the organism alive. Each cell in the group is dependent on each other to survive. Occasionally groups of cells are closely associated with each other but are not directly connected. These groups are called **colonial**. Each cell is technically able to live independently, but they band together and divide up their functions.

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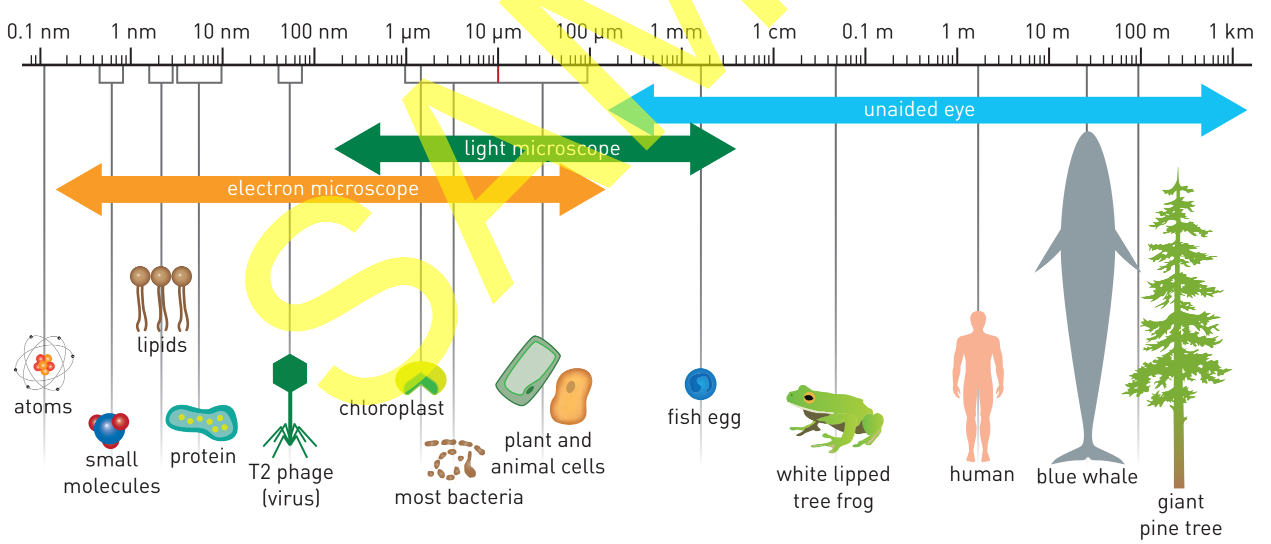
(a)



(b) Units of measurement

Ångstrom units (Å)	nanometres (nm)	micrometres (μm)	millimetres (mm)	centimetres (cm)	metres (m)
10 × 1000 × 1000 × 1000 Å = 1 m	1000 × 1000 × 1000 nm = 1 m	1000 × 1000 μm = 1 m	1000 mm = 1 m	100 cm = 1 m	
1 Å = 10^{-10} m	1 nm = 10^{-9} m	1 μm = 10^{-6} m	1 mm = 10^{-3} m	1 cm = 10^{-2} m	

range of sizes for atoms, molecules and viruses | range of sizes for cells | range of sizes for organs and tissues | range of sizes for organisms

FIGURE 1 The size of a range of objects

Common features

All the chemical reactions necessary for a cell to stay alive occur in its protoplasm (the colourless insides of the cell). To maintain its internal environment, the cell must be physically separated from the environment and still able to take in nutrients and remove waste. The **cell membrane** surrounds the outside of the cell and forms a boundary between the chemical reactions occurring inside the cell and the ever-changing outside of the cell. To be able to reproduce, all cells need a set of instructions that contain all the information that enable the cell to survive. These instructions are contained in genetic material called nucleic acids. The most important of the nucleic acids is deoxyribonucleic acid (DNA).

Prokaryotic cells

It is believed that the first life forms arose, under unique environmental conditions, about four billion years ago in a process termed **abiogenesis**. These first organisms were composed of a single cell – a cell membrane containing a watery mixture of organic chemicals, including a strand of nucleic acid. This type of cell is called a **prokaryotic cell**. All of the chemical processes required to sustain life occurred in this single cell. It is highly likely that there were many different types of nucleic acid, each coding for slightly different proteins, and so the original cells would have been slightly different to each other right from the beginning. It is thought that the early life forms arose from two different groups that are now called the Archaea and the Bacteria.

Over billions of years these cells have mutated and changed into diverse types with different physical and chemical characteristics. All of these prokaryotic organisms, known as **prokaryotes**, are composed of an extremely small, single cell contained within a semi-rigid cell wall. There is no compartmentalisation of the cell contents for specific functions. Some have a flagellum to help them move about in their aquatic environment (which may be the body fluids of **multicellular organisms**). Some die in the presence of oxygen while others cannot survive without it. Some are heterotrophs (feed on other organisms), some use inorganic molecules to provide for their energy needs (chemosynthesis) and others rely on photosynthesis.

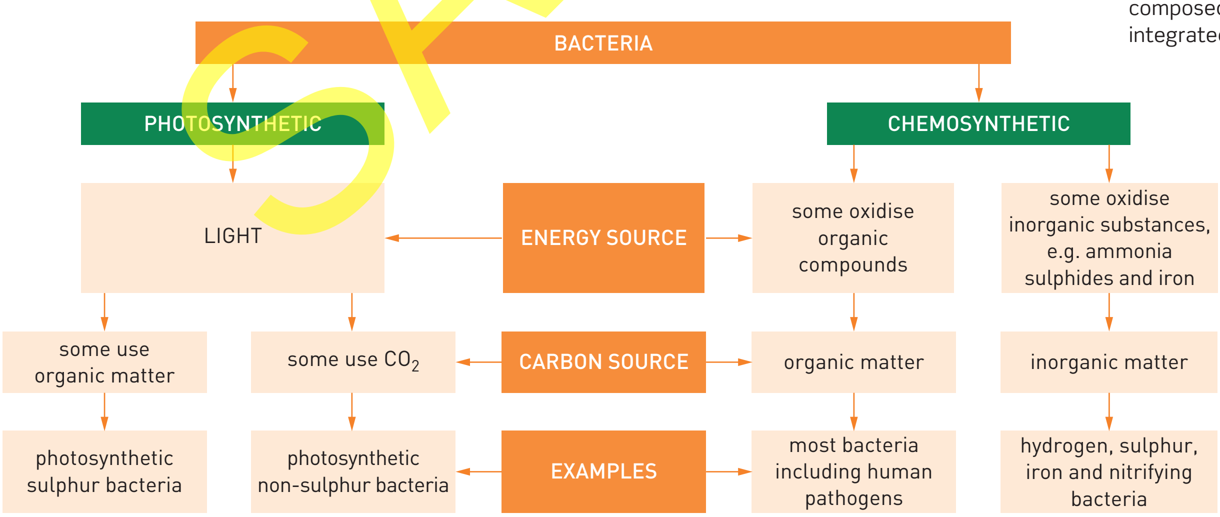


FIGURE 2 Energy and substrate requirements of bacteria

Prokaryotic cells are very small. Their DNA or genetic material is usually found in an area of the cell called the nucleoid in the form of a single circular **chromosome** (see Figure 3).

cell membrane
a selectively permeable barrier that controls the movement of substances into and out of the cell

abiogenesis
the formation of a living organism from non-living matter

prokaryotic cell
a cell which does not contain a membrane-bound nucleus or organelles

prokaryote
an organism without a membrane-bound nucleus or organelles

chromosome
a thread- shaped body consisting of nucleic acid (usually DNA) and (except in bacteria) protein

multicellular organism
an organism composed of many integrated cells

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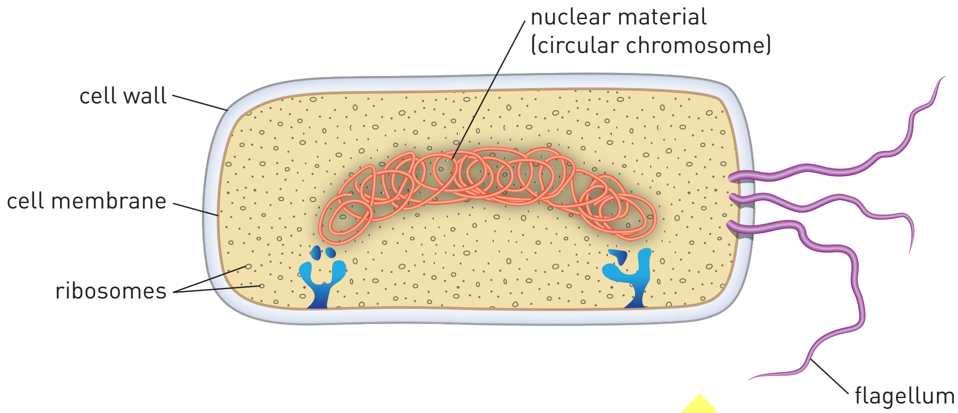

FIGURE 3 Structure of a prokaryotic cell

Eukaryotic cells

As cells become larger, it becomes more difficult for nutrients to get to all parts of the cell, and for the waste to leave. **Eukaryotic cells** are larger than prokaryotes and their protoplasm contains a series of structures called organelles. Eukaryotic cells differ from prokaryotic cells in that their DNA is enclosed by a double-layered membrane to form a nucleus. This means the protoplasm is divided into **nucleoplasm** contained within the nucleus, and **cytoplasm**. The cytoplasm is compartmentalised into membrane-bound organelles, and so there is division of labour of the cytoplasmic contents, with different organelles performing different functions. The inclusion of these organelles has resulted in a cell size larger than that of the typical prokaryotic cell.

eukaryotic cell
a cell which contains membrane-bound organelles

nucleoplasm
a protoplasm within the nuclear membrane; contains DNA, RNA and proteins; involved in control of cell activities through protein production and cell division

cytoplasm
cell contents not including the nucleus

endosymbiotic hypothesis
the theory that eukaryotic cells evolved when a single-celled organism was engulfed and survived within the cell of another single-cell organism

Evolution of eukaryotic cells

One view of the evolution of the eukaryotic cell is the **endosymbiotic hypothesis**. According to this hypothesis, there was such a strong symbiotic relationship between a small group of prokaryotic cells that they became permanently integrated, with smaller cells living inside a larger cell. These smaller cells became the organelles of the eukaryotic cell. (There is more information about this hypothesis on the obook.) Most scientists today accept the idea that photosynthetic and other cells were engulfed (swallowed up) by larger prokaryotes. These were not destroyed but remained within the larger cells as separate structures that performed specific functions. So chloroplasts (which convert solar energy into chemical bond energy during photosynthesis), mitochondria (which release chemical bond energy using oxygen) and other cell organelles are believed to have originated by the symbiosis (living together) of different organisms within a single structure. (More information about these processes will be covered in Chapter 4.) These organelles are described in more detail in the next section.

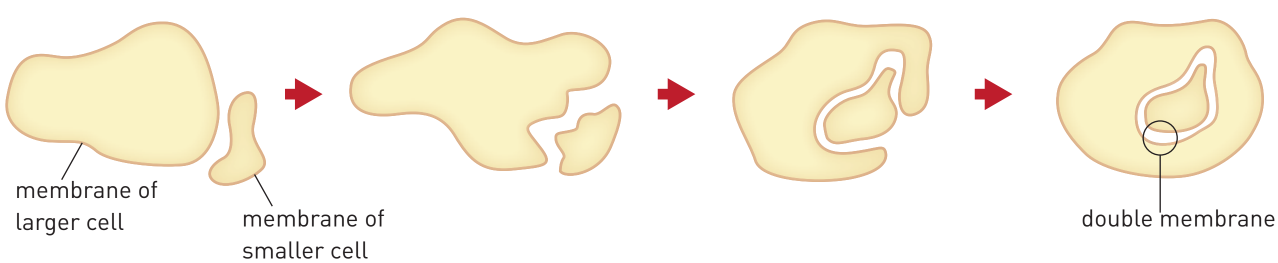

FIGURE 4 Endosymbiosis is thought to be responsible for the evolution of cells with organelles

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One view of nucleus formation is that the cell membrane began to infold. Not only did the membrane enclose the DNA to form a nucleus, but it also formed other membranous structures and channels within the cell.

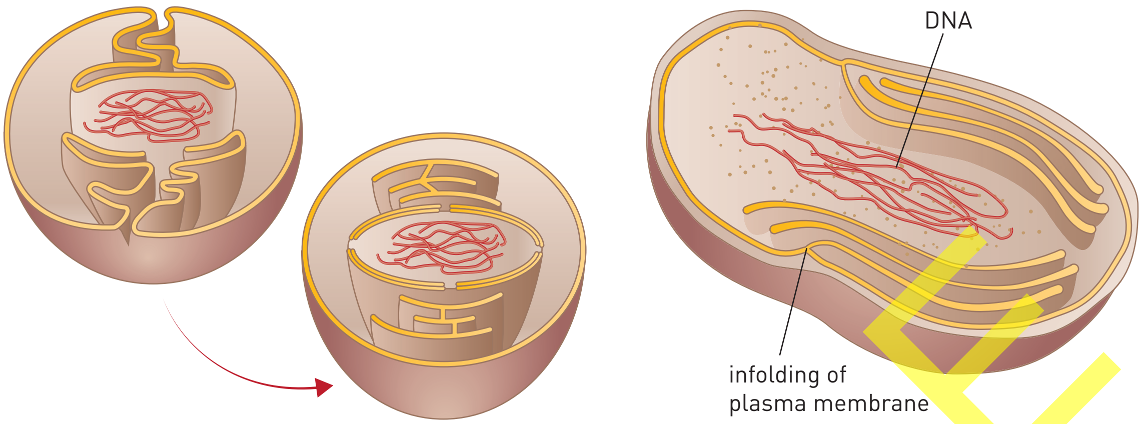

FIGURE 5 Possible formation of the nucleus and membranous structures of the eukaryotic cell

Further mutations in these cells resulted in different types of single-celled eukaryotic organisms. As different organisms evolved, they changed the environment in which they lived and this led to further evolution. The development of the eukaryotic cell paved the way for the evolution of the multicellular organism. Different cells could become specialised for specific functions as a result of the numbers and types of organelles they possessed.

Organisms made up of eukaryotic cells are known as **eukaryotes**. Examples are animals, plants, protists and fungi.

eukaryote
an organism whose cells contain membrane-bound organelles

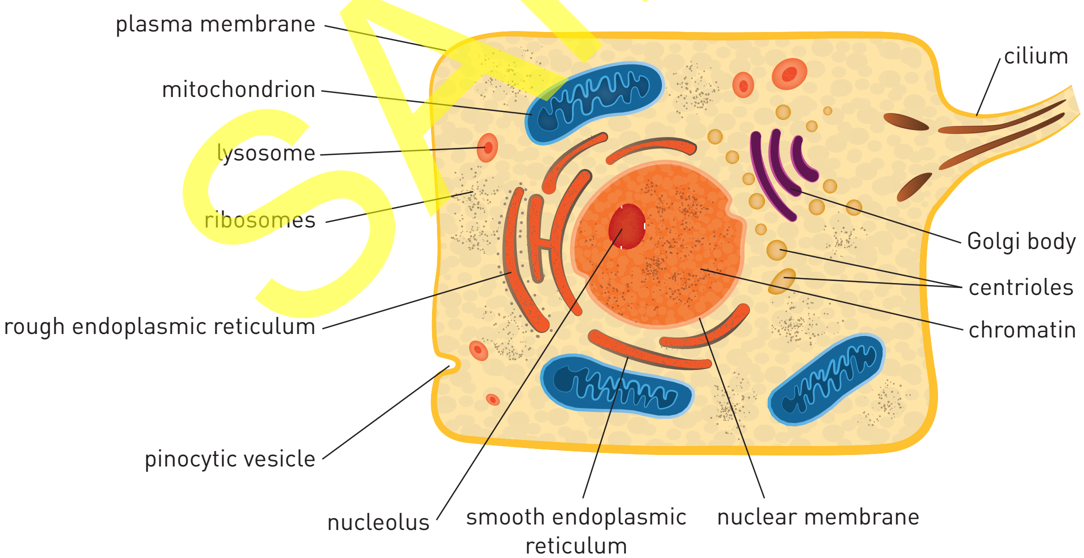

FIGURE 6 A eukaryotic animal cell

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TABLE 1 Characteristics of prokaryotic and eukaryotic cells

	Prokaryotic		Eukaryotic		
Characteristic	Bacteria	Protists	Fungi	Plants	Animals
Nuclear membrane	Absent	Present	Present	Present	Present
Mitochondria	Absent	Present	Present	Present	Present
Chloroplasts	Absent	Present in some forms	Absent	Present	Absent
Mode of nutrition	Heterotrophic or autotrophic (chemosynthesis or photosynthesis)	Photosynthesis or heterotrophic or combination of both	Heterotrophic by absorption	Photosynthesis	Heterotrophic by ingestion
Multicellularity	Absent	Absent in many groups	Present except in yeasts	Present	Present

Surface area to volume ratio

Cells can be different shapes, making it difficult to compare their sizes. As a cell becomes larger, both the surface area and the volume of the cell increases; however, the volume increases at a faster rate than the surface area. For this reason, biologists compare the surface area to volume ratio of cells to compare the size of cells. Large cells have small surface area : volume ratios, while small cells have large surface area : volume ratios.

All the chemical reactions (metabolism) required for cell survival occur within its volume. Cells need to be small to allow nutrients to move easily into the centre of a cell's volume and for wastes to move out. Larger cells (with a large surface area and even larger volume) have more needs and wastes than can be coped with by their limited surfaces. Therefore, when a cell becomes too large, it struggles to survive.

Ways around this dilemma involve a change in shape or the development of projections. Flattening or lengthening a cell or having numerous fine projections of the cell membrane (**microvilli**) can increase the cell's surface area : volume ratio.

microvillus (plural microvilli)
minute finger-like projection from a cell's surface; can form a brush border

The largest plant cell yet discovered is found in a green alga (*Valonia*) and is about 1 cm in diameter (the average diameter of plant cells is 30–50 μm). This alga lives in the warm waters of the Great Barrier Reef and tidal movement ensures the rapid supply of nutrients and removal of wastes. The longest animal cell is the 2 m nerve cell of the giant squid. An increase in the internal membranes of the eukaryotic cell can also improve exchanges with its environment. The fact remains, however, that cells tend to be small and large organisms tend to be multicellular.

Increasing the surface area for metabolic reactions within the cell

Eukaryotic cells contain membrane-bound organelles in which specific metabolic reactions occur. In some of these organelles the membrane is highly folded, e.g. the inner membrane of the mitochondria and the endoplasmic reticulum. This increases the surface area for attachment of enzymes involved in the enzyme-controlled reactions. The more enzymes available, the greater the reaction rate for the available substrate.

SAMPLE

MANDATORY PRACTICAL

3.2 The effect of surface area to volume ratio on the rate of diffusion

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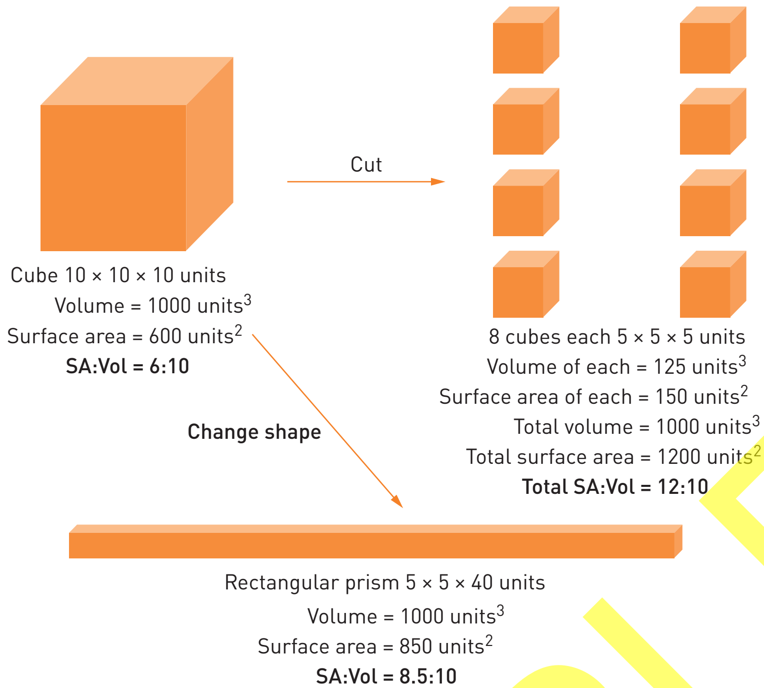

FIGURE 7 How surface area to volume ratio (SA:Vol) changes with size and shape. When the large cube is cut into eight equal-sized cubes its surface area to volume ratio is increased from 6:10 to 12:10; that is, its surface area doubles for the same volume. As the same cube is changed in shape to a rectangular prism the surface area to volume ratio increases from 6:10 to 8.5:10 – the flatter the 'cell', the greater the surface area to volume ratio for the same volume.

SAMPLE

CHECK YOUR LEARNING 3.2

Describe and explain

1 **Explain** the difference between a prokaryote and a eukaryote.

2 **Describe** the endosymbiotic theory of the evolution of eukaryotes.

3 **Describe** how the nucleus is thought to have formed.

4 **Explain**, in terms of the cell's metabolic activities, why cells generally need to have a large surface area to volume ratio.

Apply, analyse and interpret

5 **Classify** these cells as prokaryotic or eukaryotic based on the description.

a The cell appears to have no membrane-bound nucleus.

b The cell has numerous organelles.

c The sample is a specialised human skin cell.

Investigate and communicate

6 A student used Plasticine models to make 'cells' that were a sphere, a rectangular prism, a cylinder, and a flat sheet. All had the same volume.

Predict which shape(s) would have:

a the largest surface area to volume ratio

b the smallest surface area to volume ratio.

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3.2 The effect of surface area to volume ratio on the rate of diffusion

» Interactive
Cells

» Interactive
Plant cells

3.3 Eukaryotic cell organelles

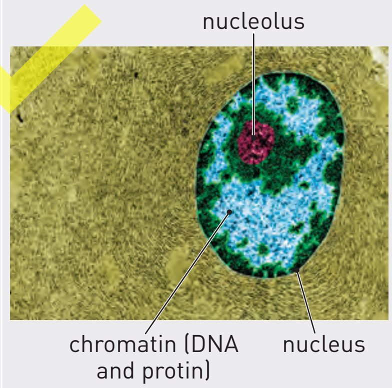
KEY IDEAS

- Organelles and their different structures and functions
- The difference in structure between prokaryotic and eukaryotic cells

The cells of eukaryotic organisms (all organisms apart from archaebacteria, bacteria and cyanobacteria, which are prokaryotic) contain membrane-bound organelles. Most of these structures are not normally visible under the light microscope but can be viewed with an electron microscope.

A number of organelles are found in both plant and animal cells – these are outlined in Table 1, along with an electron micrograph of each.

TABLE 1 Organelles found in plant and animal cells

Organelle	Structure and function	Electron micrograph
Nucleus	The total contents of the **nucleus** are called nucleoplasm. The nucleus controls cell activity through DNA, the genetic material that controls protein production and cell division. In the non-dividing cell, the DNA and protein form a diffuse network of threads called **chromatin**. These condense during cell division into chromosomes. The nucleus is surrounded by a double membrane, with pores that allow specific molecules into and out of the nucleus. The nucleus contains the nucleolus, which is composed of proteins, DNA and RNA, and which produces ribosomes.	
Endoplasmic reticulum	Endoplasmic reticulum is a network of flattened, membrane-bound sacs called cisternae. It is primarily involved in transporting molecules around the cell. There are two types of endoplasmic reticulum. **Smooth endoplasmic reticulum** is responsible for the synthesis and transport of lipids and steroids. **Rough endoplasmic reticulum** has **ribosomes** on the membrane surfaces that are involved in the synthesis of proteins. Transport of proteins occurs in their cisternae. The extensive network of the endoplasmic reticulum provides a large surface area for enzyme-mediated metabolic reactions to occur.	 Rough ER – ribosomes are seen as small dots on the surface

nucleus
control centre of the eukaryotic cell

chromatin
the nucleoprotein of chromosomes seen as fine, dispersed threads of genetic material and found in eukaryotic cells in the interphase stage

smooth endoplasmic reticulum (smooth ER)
a membranous structure with connections to both nuclear and cell membranes, involved in production, storage and transport of materials within the cells; lipids and steroids are produced here

rough endoplasmic reticulum (rough ER)
a membranous structure with connections to both nuclear and cell membranes, involved in production, storage and transport of materials within the cells; proteins are synthesised on ribosomes

ribosome
the site of protein synthesis in cells; composed of RNA, produced in nucleolus and found on rough ER (eukaryotes) or in cytoplasm (eukaryotes and prokaryotes)

SAMPLE

MANIPULATIVE SKILL
3.3A Use of the light microscope
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MANDATORY PRACTICAL
3.3B Preparation and examination of wet mount specimens
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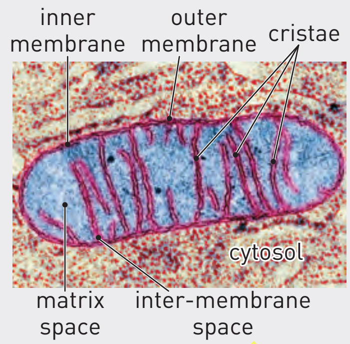
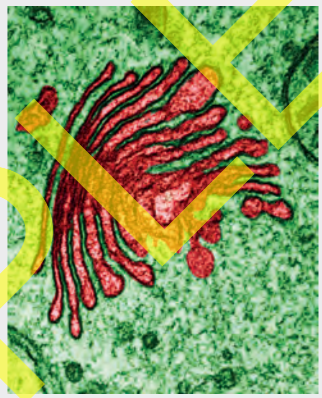
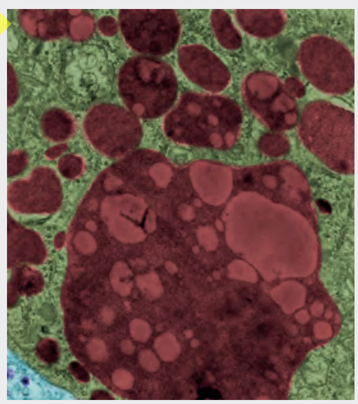
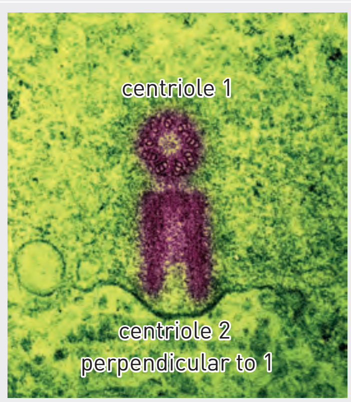
Organelle	Structure and function	Electron micrograph
Mitochondria	**Mitochondria** (singular *mitochondrion*) are cigar-shaped and bound by a double membrane. The inner membrane is folded into **cristae**, which increase the surface area for attachment of enzymes and their metabolic reactions. The membranes enclose the fluid matrix. Mitochondria are the site of chemical reactions that release energy in a useable form. Mitochondria contain special mitochondrial DNA and ribosomes that control their enzyme production, and allow them to replicate themselves. Mitochondria are crucial for the process of **cellular respiration**.	
Golgi body	The **Golgi body** is composed of a stack of flattened membranous sacs or cisternae, which are continually being formed at one end and budded off as vesicles at the other. They are closely associated with the endoplasmic reticulum, receiving the enzymes, proteins, lipids, glycoproteins and polysaccharides synthesised there, enclosing them in membranes and releasing them either into the cytoplasm or outside the cell. Consequently, they serve as collecting, sorting, processing and distribution centres.	
Vesicle	A vesicle is a membranous sac that transports molecules around a cell. There are different types of vesicles including lysosomes and **vacuoles**.	
Lysosome	A **lysosome** is a simple spherical sac containing digestive enzymes. Lysosomes can fuse with vesicles or food vacuoles to digest their contents. Unwanted cellular products and wastes are broken down (autophagy) by lysosomes. They can also cause complete breakdown of damaged cells (autolysis) and so are sometimes termed 'suicide sacs'.	
Centrioles	**Centrioles** consist of a set of two cylindrical bodies next to the nucleus. They organise the DNA when a cell divides, and can form the whip-like **flagella** or hair like **cilia** that help some cells move.	

mitochondrion (plural mitochondria)
a membrane-bound cellular organelle; has enzymes for aerobic respiration on inner folded membrane (cristae), and a fluid matrix

cristae
the folds of the inner membrane of mitochondria

cellular respiration
cellular process in which glucose is broken down to release energy in many small, enzyme-controlled reactions

Golgi body
a membranous stack of cisternae involved in the packaging and secretion of cell products

vacuole
a cellular inclusion, or space within the cell; small in animals (food storage or digestion); large in plants (storage and osmotic control)

lysosome
an organelle containing digestive enzymes concerned with intracellular digestion

centriole
a paired tubular structure found in animals and algae; involved in formation of cilia and flagella and in cell division

flagellum (plural flagella)
a whip-like extension of the cell, used in locomotion by some Bacteria, Protozoa and spermatozoa

cilium (plural cilia)
a hair-like projection of the cell membrane

SAMPLE

SUGGESTED PRACTICAL

3.3C Identifying organelles from electron micrographs
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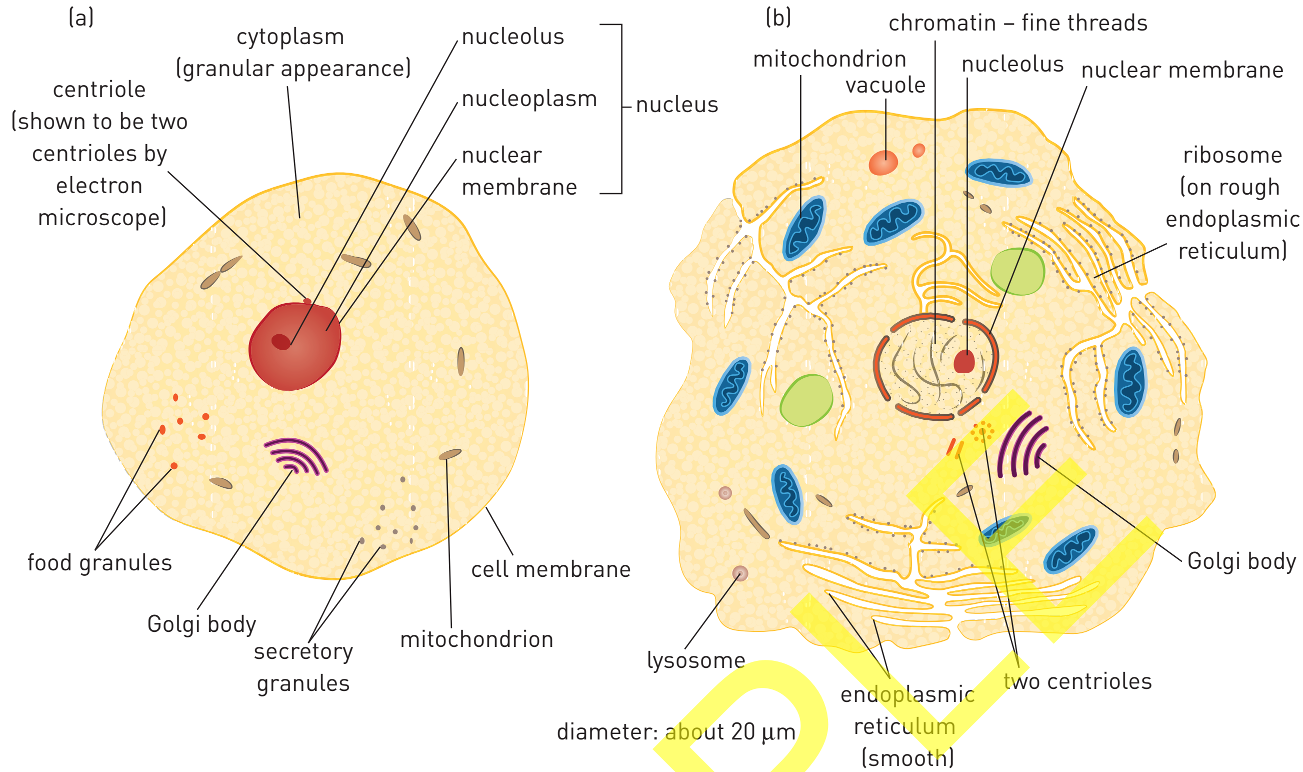


FIGURE 1 Features of an animal cell viewed with (a) a light microscope and (b) an electron microscope. The amount of detail seen in cells varies based on the equipment that is being used to view it.

SAMPLE

Plant cells have many features in common with animal cells, but there are some distinct differences (see Table 2). They have a number of different organelles whose structure and function work to maintain a plant's survival.

Organelles are not scattered randomly throughout the cytoplasm. The nucleus generally takes a central position in the cell, with the Golgi bodies and endoplasmic reticulum clustered around it. Not all plant cells have chloroplasts. Root cells do not see sunlight and therefore do not need to use sunlight to make glucose. The chloroplasts in a leaf cell are usually oriented with their grana facing the light source.

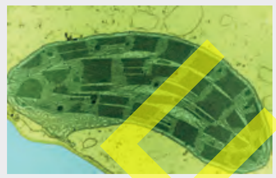
chromoplast
a plastid found in plants, containing red, yellow or orange pigments

leucoplast
a colourless plastid found in plant cells; concerned with starch or oil storage

chloroplast
a plastid found in green plants, containing chlorophyll on membranous grana, and enzymes in the liquid stroma; photosynthetic organelle

TABLE 2 Organelles found in plant cells

	Structure and function	Electron micrograph
Cell wall	This is a non-living wall, composed of cellulose, and enclosing the cell membrane. It may be secondarily thickened with the chemical lignin. The cell wall provides mechanical support and protection of the cell. It prevents the cell from rupturing when large amounts of water diffuse into the cell (turgor pressure). A middle lamella between the walls of adjacent cells cements neighbouring cells together. The gaps in the cell wall can allow two plant cells to connect to each other. These links are called plasmodesmata. These allow rapid movement of materials from cell to cell.	 Cell wall between two cells, showing plasmodesmata

	Structure and function	Electron micrograph
Plastids (chloroplasts, chromoplasts and leucoplasts)	These are double-membraned organelles of varying shape. Three types are common. **Chromoplasts** are non-photosynthetic, containing red, yellow and orange pigments that provide colour to flowers, fruit and leaves. **Leucoplasts** are colourless and involved in starch storage. **Chloroplasts** are large, consisting of a fluid matrix or stroma and stacks of flattened membranous discs called **grana** (singular stack = *granum*). Each disc is termed a thylakoid. They contain chlorophyll and function in photosynthesis. Like mitochondria, they also contain DNA and ribosomes and can replicate themselves. Chloroplasts are an important site for photosynthesis in plant cells.	Chromoplast  Chloroplast 
Vacuole	A large central vacuole contains cell sap and is responsible for storage of substances and control of water levels in the cell (osmotic balance).	

grana (singular granum)
stacked portions of membranes found in chloroplasts; sites of light-dependent reactions for photosynthesis

Study tip

Students must be able to identify a chloroplast, mitochondria, rough endoplasmic reticulum and lysosomes from an electron micrograph.

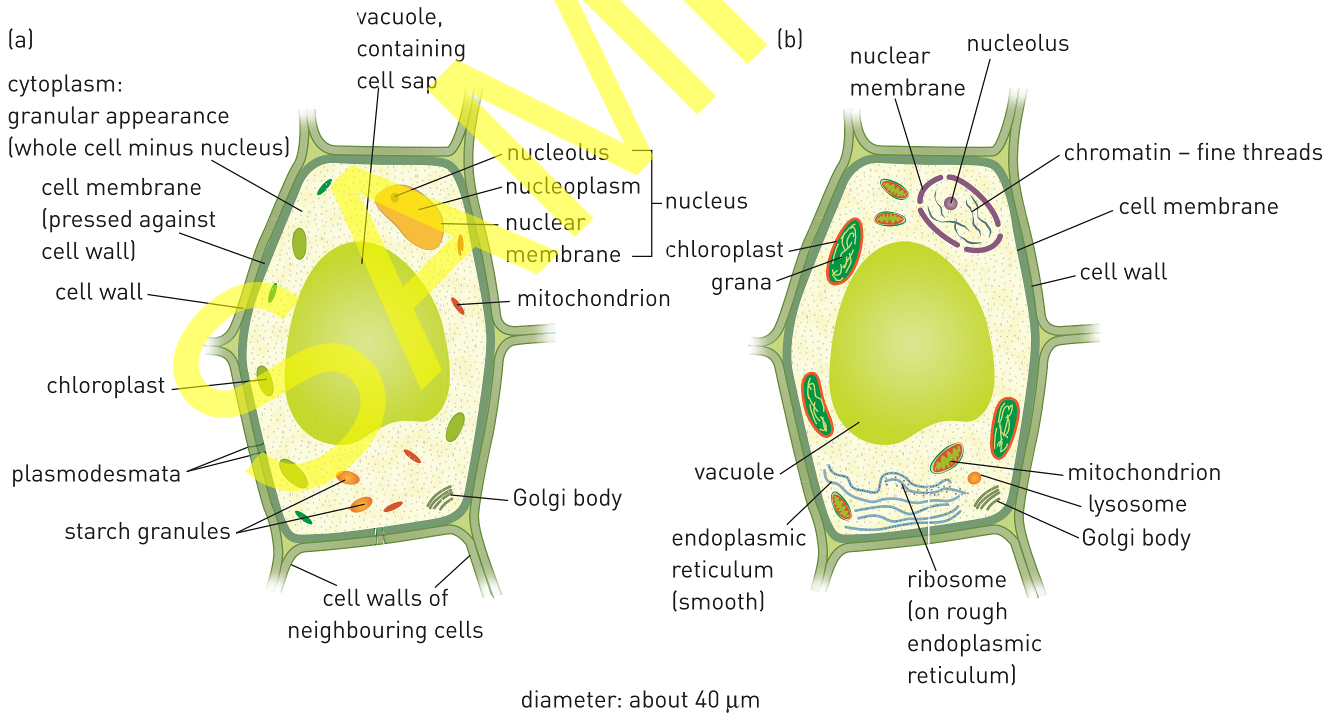


FIGURE 2 A plant cell viewed with (a) a light microscope and (b) an electron microscope. The amount of detail seen in cells varies based on the equipment that is being used to view it.

Many organelles move within the cytoplasm in an ordered fashion. They are held in place by a series of fine filaments inside the cell called the cytoskeleton. There are three main components of the cytoskeleton, outlined in Table 3.

SAMPLE

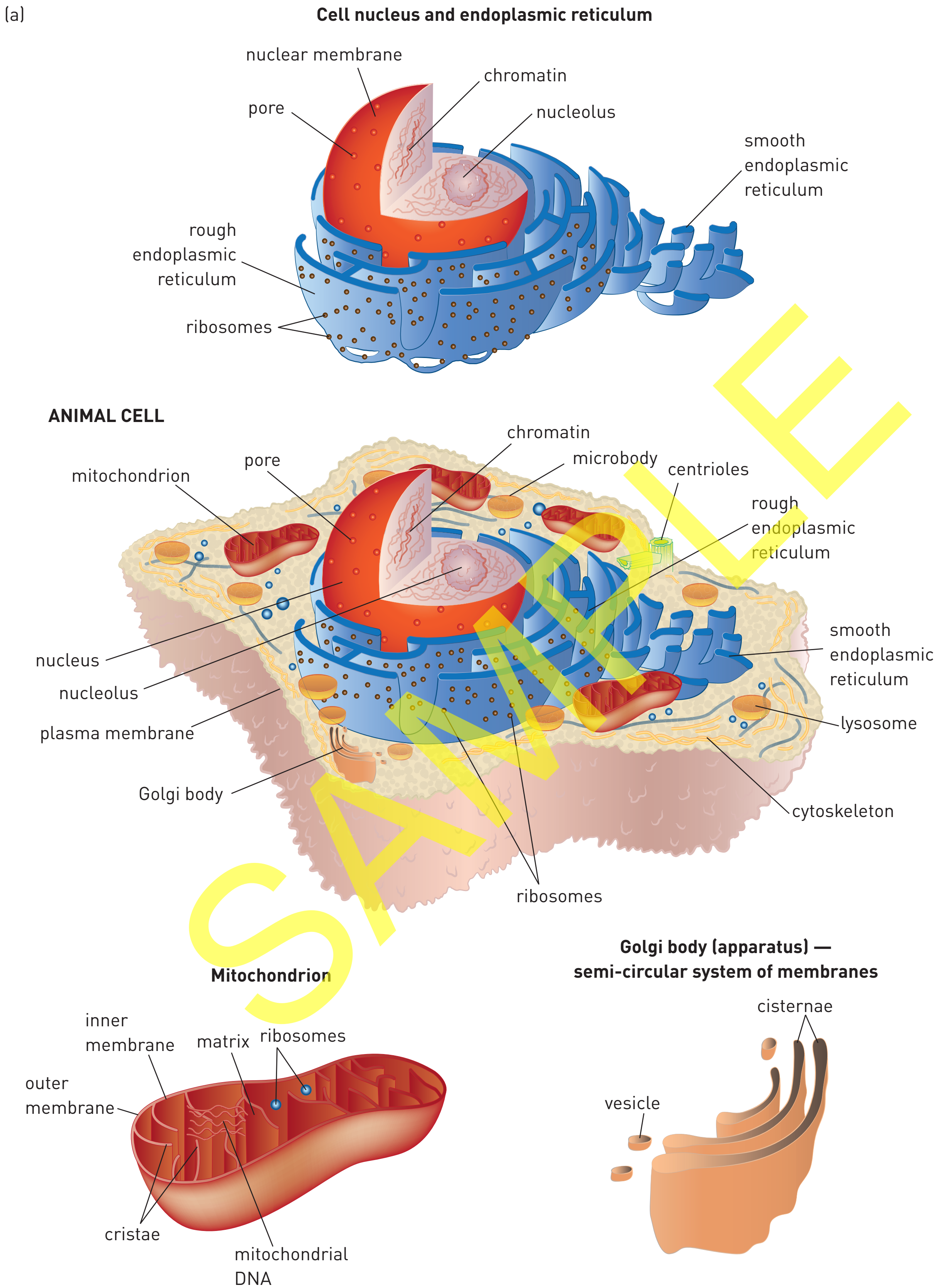


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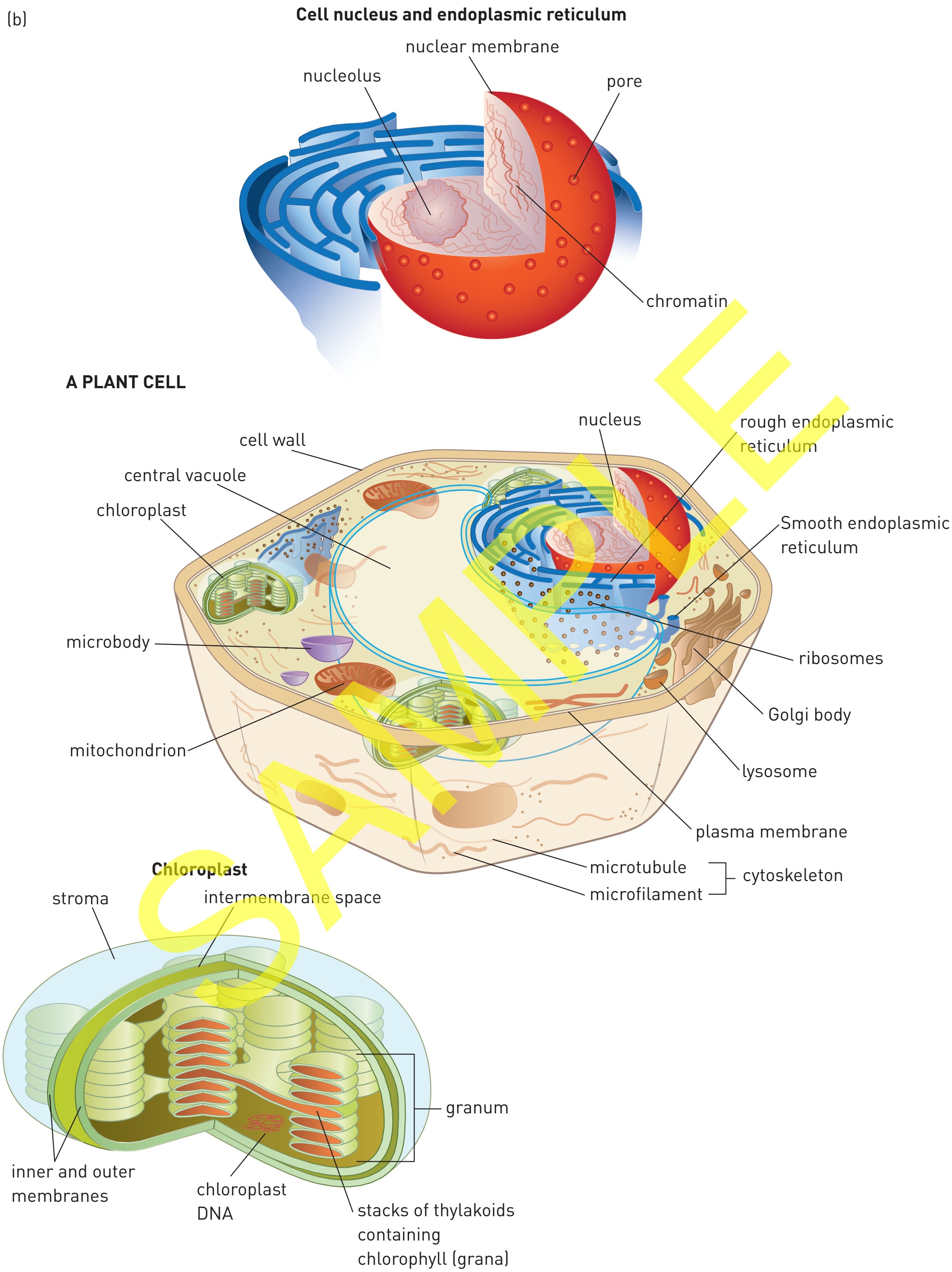
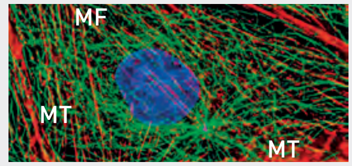
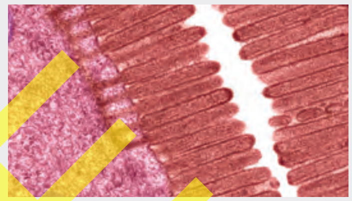
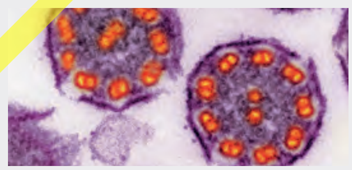
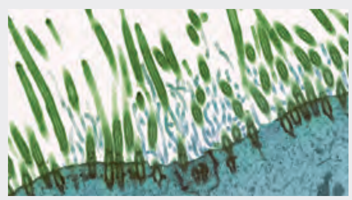
FIGURE 3 Animal cell (a) and plant cell (b)

(b)


Cell nucleus and endoplasmic reticulum
nuclear membrane
nucleolus
pore
chromatin
A PLANT CELL
cell wall
central vacuole
chloroplast
microbody
mitochondrion
nucleus
rough endoplasmic reticulum
Smooth endoplasmic reticulum
ribosomes
Golgi body
lysosome
plasma membrane
microtubule
microfilament
cytoskeleton
Chloroplast
stroma
intermembrane space
granum
inner and outer membranes
chloroplast DNA
stacks of thylakoids containing chlorophyll (grana)

SAMPLE

TABLE 3 Components of the cytoskeleton

Feature	Structure and function	Electron micrograph
Microfilaments	**Microfilaments** are fine strands of the globular protein actin. They are able to bind with other proteins, and in so doing are able to hold organelles in position within the cytoplasm. Interactions of actin microfilaments with another protein, myosin, bring about general movement of the cytoplasm, organelles and the cell as a whole. Muscle cells have a high content of both of these proteins. The sliding action of actin and myosin results in contraction and relaxation and therefore movement. Some cells in animals (e.g. lining the intestine and kidney tubules) have minute finger-like projections of the membrane. These microvilli increase the cell surface area greatly without increasing volume to any great extent. Since they usually occur in large numbers and appear like the bristles of a brush, cells bearing microvilli are said to have a brush border. Actin microfilaments allow them to contract. The combined actions of increased surface area and movement facilitate uptake of materials into the cell.	MF – microfilament MT – microtubule   A cell with a brush border – each projection is a microvillus
Microtubules	**Microtubules** are hollow cylinders of the protein tubulin. Being more rigid than microfilaments, they provide greater mechanical support for the cell. In plant cell walls microtubules provide the framework along which cellulose is laid down. Microtubules also provide routes along which materials in the cytoplasm can move, assisting transport within cells. During cell division microtubules form the spindle fibres that attach to chromosomes and draw them apart. Cilia (short) and flagella (long) are cellular projections covered by the cell membrane. They are composed of an exact array of microtubules. The sliding of adjacent pairs of these tubules causes the projections to move. In this way, cilia and flagella can bring about movement of a cell or of a liquid over the cell's surface.	 Transverse section of a cilium showing the arrangement of microtubules  Cilia  *Salmonella* bacteria with several flagella
Intermediate filaments	Intermediate filaments are composed of a variety of fibrous proteins, and range in size between that of the microfilaments and microtubules. These filaments are strong, stable and resistant to stretching, thereby providing mechanical support for the cell.	

SAMPLE

TABLE 4 Comparison of eukaryotic cells: plant, animal and fungal

Feature	Plant cell	Animal cell	Fungal cell
Cell wall	Rigid, cellulose, may be lignified	None	Chitin
Vacuoles	Large: up to 80% of cell volume	Small if present	Small if present
Centrioles	Absent in most	Present	Absent in most
Chloroplasts	Present in photosynthetic cells	Absent	Absent
Granules	Starch	Glycogen	Glycogen
Cilia	Absent	Present in certain cells or cell types	Absent
Mode of nutrition	Autotrophic	Heterotrophic	Heterotrophic

microfilament
a solid rod of actin protein found in the cytoplasm, cilia and flagella of eukaryotic cells

microtubule
a hollow protein strand in cytoplasm; involved in cell transport and structure

Comparing prokaryotic and eukaryotic organelles

The prokaryotes (bacteria and cyanobacteria) are the most ancient cells. They are smaller than eukaryotic cells and have a simpler structure (see Table 5). Like plant cells, bacteria have a semi-rigid cell wall surrounding the cell membrane, but it is made of **murein** (a protein–carbohydrate complex), and also they lack distinct membrane-bound organelles and a cytoskeleton. The genetic material is bound into a single circular DNA molecule floating within the cytoplasm. Smaller segments of DNA, called plasmids, are not part of the prokaryote's chromosome, but can carry **antibiotic resistance**. Although many ribosomes are present in prokaryotes, they are not attached to any other structure and differ chemically from those of eukaryotes.

Some bacteria have flagella. The flagellum, however, is outside the cell membrane and is different in structure to that found in animals.

murein
a glycoprotein forming the cell wall in bacteria

antibiotic resistance
the ability of bacteria to resist the effects of an antibiotic to which they were once sensitive

TABLE 5 Comparison of eukaryotic and prokaryotic cells

Structure	Eukaryotic cells	Prokaryotic cells
Cell wall	Absent in animal cells, present in plant cells (cellulose) and fungi (chitin)	Present (murein)
Cell membrane	Present	Present
Nucleus	Surrounded by membrane	Not surrounded by membrane
Chromosomes	Multiple, composed of nucleic acid (linear DNA) and proteins	Singular, composed only of nucleic acid (circular DNA)
Ribosomes	Present	Present but are different chemically
Chloroplasts Endoplasmic reticulum Golgi body Lysosomes Membrane-bound organelles Mitochondria Vacuoles	Present (chloroplasts present only in plants)	Absent
Flagella	Complex – microtubules	Simple, with no microtubules (extracellular, i.e. not enclosed by the cell membrane)

SAMPLE

xylem
a complex tissue composed of living and dead cells; the tracheids and vessels are the non- living components through which water and dissolved mineral nutrients pass from the roots to the leaves in the transpiration stream

CASE STUDY 3.3

Using cellulose

Cellulose and lignin are the major molecules found in plant cell walls. The lignin strengthens the cell walls, providing rigidity to the flexible cellulose. Wood comes from the central, dead part of tree trunks. The properties of these molecules in cell walls make wood ideal as a building material. The water-conducting (**xylem**) cells have died, as lignin has been embedded in their cellulose cell walls. Plant waste products can be deposited in the central cavities left behind when the cells die. Wood can support buildings for years and is more widely used in construction of buildings, bridges, furniture and tools than all other materials put together.

The stems of the papyrus reed were used by the Egyptians to construct boats, sails, mats, cloth cords and paper as early as the fifth century BCE. Cutting the stem of the reed into long strips produced papyrus scrolls. These strips were laid side by side to the required width. Another layer of shorter strips was then laid on these at right angles. This sheet was then soaked in water before being hammered and dried in the sun. Papyrus was used as a writing material in Europe until the fifth century CE. Although the reed is very light when dried, the cellulose components are very strong.

In about 105 CE, the Chinese, using the broken up bark of trees, hemp waste, old rags and fishnets, developed true papermaking. Today the fibres are pulped either mechanically or chemically to release the cellulose fibres. In high-quality papers the lignin, which can cause discolouration, is chemically removed. The pulp is washed to remove soluble impurities and filtered to remove insoluble matter, such as knots, dirt and unpulped fibres. Bleaching removes any unwanted colours in the pulp, after which the pulp is beaten. This shortens the fibres and mashes them to create hair-like fibrils that absorb water and become slimy. The whole mass of pulp can then be spread on wire frames and rolled, to press out water and enmesh the fibrils to form paper. Different types of paper are produced according to the particular plant material used.

Cellulose is used in the manufacture of a variety of textiles. Linen, produced from the flax plant (*Linum usitatissimum*), is one of the oldest textile fibres known. The fibres are obtained from the bark of the stalks. This is removed by a process called retting, in which the stalks are subjected to partial decomposition by bacteria. The fibres, after mechanical separation from the wood, can then be spun and woven. Hemp fibres from the plant *Cannabis sativa* are prepared in a similar manner. These fibres are used to produce a range of textile materials from fine fabrics to coarse ropes.

The seed hairs of the cotton plant (*Gossypium*) are almost pure cellulose and therefore do not need the same preparation as the stalks of flax and hemp. Cotton, therefore, supplanted linen and hemp as a fabric material.

In recent years there has been added interest in the production of hemp. Genetically engineered crops of *Cannabis* species that do not produce the narcotic drug in its shoots are currently being grown in Tasmania. Unlike cotton plants, they are not subject to pest attack and can grow in less fertile soils with lower water content. Therefore, they are a more ‘environmentally friendly’ crop than cotton. Also, since the whole stalk produces usable fibre, it is a more productive crop than cotton, from which only the seed head is utilised.

SAMPLE

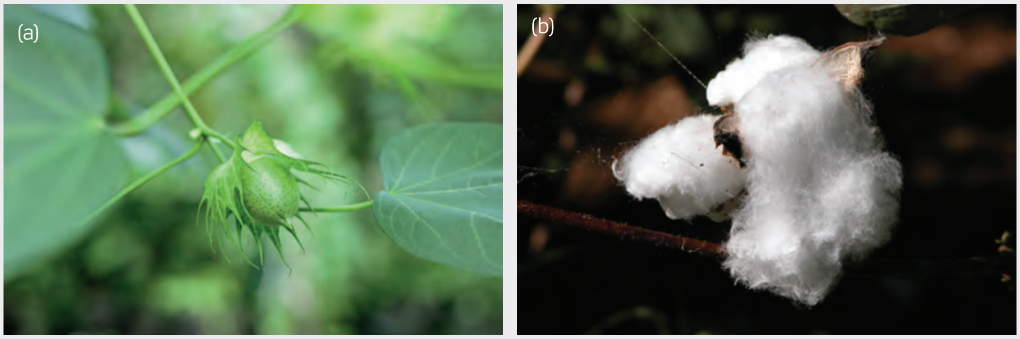


FIGURE 4 Cotton: (a) unripe and (b) ripe cotton boll

Cellulose can also be processed into a wide range of products such as thickeners for paint, stabilisers in foods and cosmetics, adhesive tapes and dialysis membranes.

SAMPLE

CHECK YOUR LEARNING 3.3

Describe and explain

1 **Describe** the main functions of the following cell parts. Indicate the kind(s) of cells in which they are usually found.

- a Cell wall
- b Centriole
- c Chloroplast
- d Endoplasmic reticulum
- e Golgi body
- f Lysosome
- g Mitochondrion
- h Nucleolus
- i Nucleus
- j Ribosome
- k Vacuole

2 **Explain** why enzymes are contained within a lysosome instead of being free in the cytoplasm.

3 **Describe** the difference between rough and smooth endoplasmic reticulum.

4 **Describe** two structural features that would help to identify the difference between prokaryotic and eukaryotic cells.

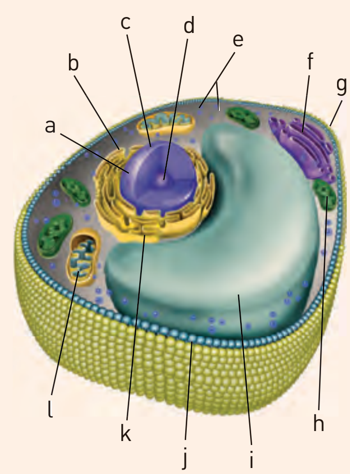
Apply, analyse and interpret

5 A protozoan is a single-celled eukaryotic organism. Many freshwater protozoans contain contractile vacuoles that can change their volume. Analysis shows that these vacuoles contain almost pure water, dissolved substances being in less concentrated solution than the same substances in the rest of the organism. **Determine** which inference is correct.

- A The vacuole fills by diffusion.
- B The vacuole fills by osmosis.
- C The protozoan must expend energy to fill the vacuole.
- D There is insufficient data to answer the question.

Provide a justified reason for your answer.

6 Using the letters given on the diagram below, correctly **differentiate** three organelles in this plant cell and give the main function for each.



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3.4 The cell membrane

KEY IDEAS
- The cell membrane as a selectively permeable barrier
- The chemical structure of the cell membrane based on the fluid mosaic phospholipid bilayer model
- The role of protein channels, cholesterol and glycoproteins in the cell membrane

The cell membrane is a selectively permeable barrier that controls the movement of substances into and out of the cell. It is described as selectively permeable because some small substances can diffuse through very easily (e.g. water), while larger molecules such as protein molecules are prevented from moving through the membrane.

A permeable membrane would allow the free movement of all molecules in both directions. A selectively permeable membrane allows particular molecules through that fit with the selective criteria.

The cell membrane and its structure has the following functions:
- To help in the active transport of materials in and out of the cell
- To provide a certain degree of mechanical support to the cell, so that it can maintain its shape
- To act as a receptor for chemical materials (e.g. hormones) and so maintaining the specificity of the particular cell type.

The chemical structure of the cell membrane

phospholipid bilayer
the main structure of the cell membrane consisting of two layers of phospholipids arranged so that the hydrophilic heads face the internal and external fluid environments

The cell membrane is very thin – about 7.5 nm (nanometres) in width (1 nm = 10^{-9} m). The basic structure of the membrane is a known as a **phospholipid bilayer**. This is because it consists of two thin sheets of polar phospholipids. A phospholipid is a molecule that has a negatively charged phosphate 'head' and two fatty acid 'tails'. The phosphate end of the molecule is able to mix well with water, and is therefore described as hydrophilic (water-loving). The tails do not mix with water (fatty acids do not mix with water) and are described as hydrophobic (water-hating).

The phospholipid layer has to be arranged as a double layer because it is surrounded on either side by a water-based mixture (the extracellular fluid and the cytoplasm). This

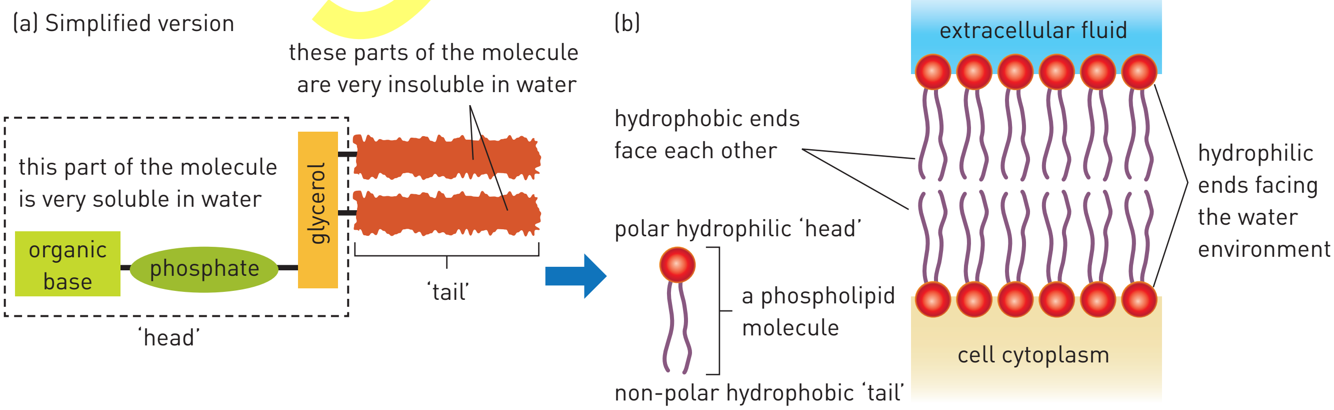


FIGURE 1 Phospholipid molecule. (a) Simplified version; (b) molecule and arrangement of the phospholipid bilayer.

SAMPLE

also dictates the orientation of the individual phospholipid molecules. The hydrophobic tails repulse water, so the phospholipid molecules automatically arrange themselves so that the hydrophobic tails are sandwiched between the hydrophilic phosphate heads. This arrangement of these molecules is termed a bilayer.

As with all molecules, the phospholipid molecules move about. However, their polarity restricts their movement mainly to the lateral plane.

A lot of energy is required to move the phospholipid molecules from one layer to the other, since the hydrophilic head must pass through the hydrophobic tail region. The tails must come into contact with water in this action. As a result, 'flip-flop' movement is very rare.

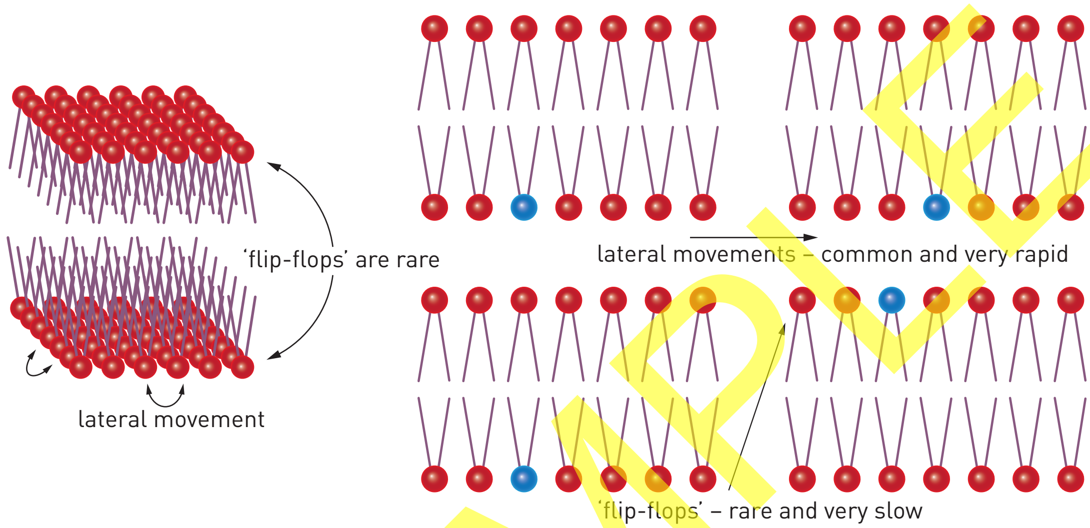


FIGURE 2 Movement of phospholipids within the membrane

SAMPLE

The phospholipid bilayer, according to the **fluid mosaic model**, is regarded as a dynamic structure in which proteins can float – some moving about freely while others are fixed in position by microfilaments running into the cytoplasm.

Some proteins, known as **integral proteins**, penetrate either part of the way into the membrane or all the way through it. The middle parts of these proteins are hydrophobic and therefore are able to mix freely with the hydrocarbon tails of the membrane lipids. They can only be released by detergents or organic solvents. The parts of the protein in contact with extracellular or intracellular fluid are hydrophilic. Other proteins are on the outside of the membrane or attached to the outer surfaces of integral proteins and are called **peripheral proteins**. These peripheral proteins are weakly bound to the membrane or other proteins. Adding salts or changing the pH easily disrupts these bonds.

Protein channels

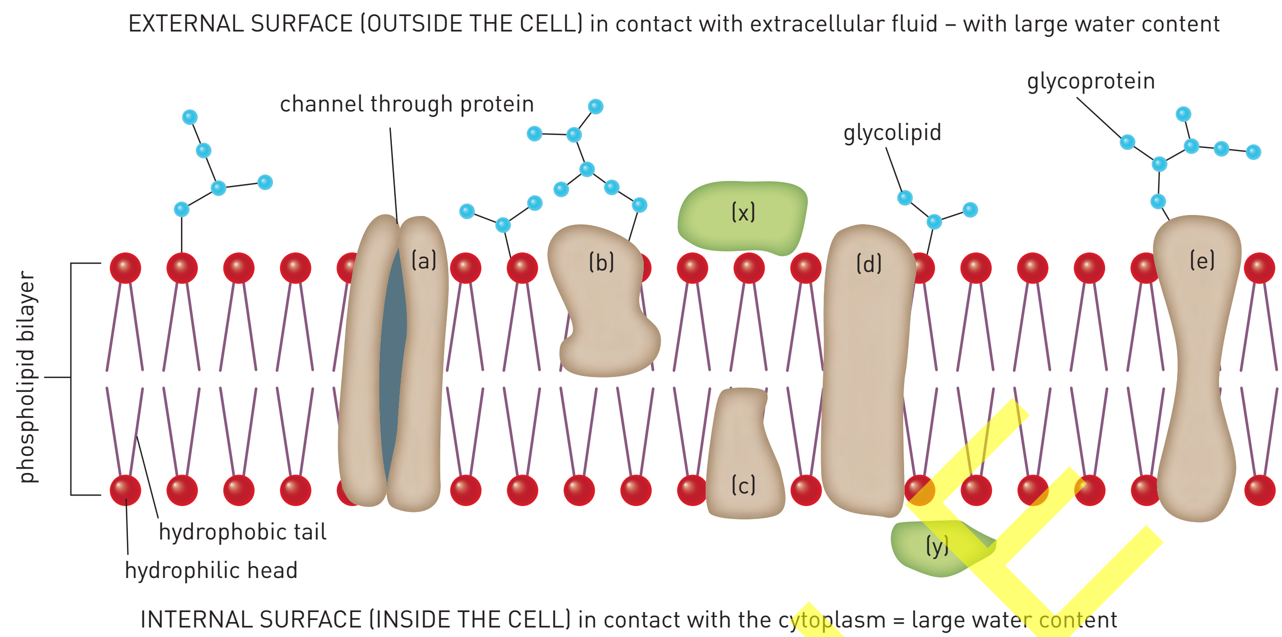
Usually the integral proteins have a hydrophobic portion that interacts with the phospholipids, and a hydrophilic portion facing the water-based surroundings. Some of the proteins (of which thousands may occur in membranes) may be purely structural in function. Others act as carrier molecules in transporting specific substances through the membrane. It is thought that hydrophilic channels (**protein channels**) occur within integral proteins or between adjacent protein molecules. The channels allow the passage of large or some water-soluble molecules that otherwise would be excluded by the phospholipid molecules.

fluid mosaic model
a description of how molecules are arranged in the cell membrane; 'mosaic' refers to the many different types of molecules (including phospholipids) that make up the structure of the membrane; 'fluid' refers to the constant movement of the phospholipids and other molecules that make up the membrane

integral protein
a protein found within the structure of the cell membrane

peripheral protein
a protein attached to or partially embedded in the cell membrane

protein channel
a channel passing through the centre of a protein, the lining of which is hydrophilic



(a), (b), (c), (d) and (e) are integral (globular) proteins. They have hydrophilic regions towards the surrounding watery medium and hydrophobic regions in the bilipid layer.The channels through certain integral proteins are hydrophilic. (x) and (y) are peripheral (globular) proteins.

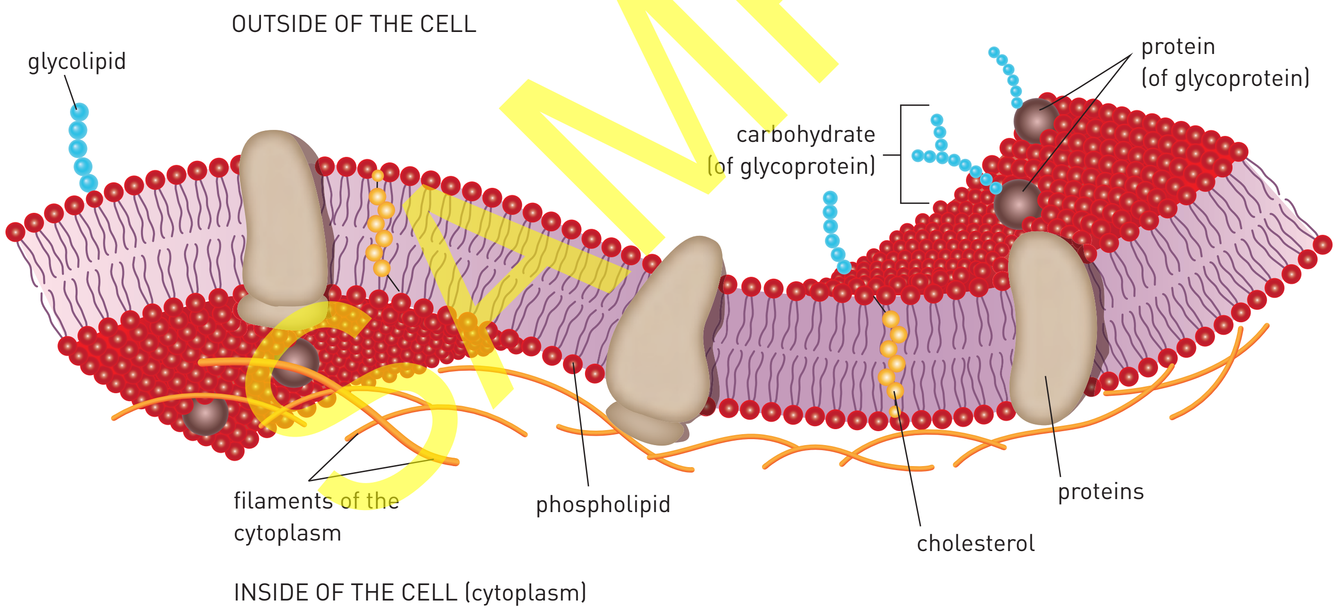


FIGURE 3 Two representations of the fluid mosaic model of the cell membrane

SAMPLE

Other membrane proteins may act as recognition markers or receptor molecules that bind to chemical messengers that may be in the fluid outside the cell.

Glycoproteins and glycolipids are also present in the membrane. They are proteins or lipids that have branching carbohydrate portions on their free surfaces. These 'antennae' are made up of a number of sugar molecules and have a range of precisely defined patterns. They are important as recognition features:

- Sugar recognition sites of two neighbouring cells may bind to each other, causing cell-to-cell adhesion. This results in a particular orientation of the cells and the formation of tissues.
- Glycoproteins act as specific markers when the body is trying to defend itself, for example **antigens** in the immune response.
- Various control systems rely on recognition sites. For example, hormones and other chemicals have recognition sites that enable them to be taken up specifically by cells that have the complementary sites.

glycoprotein
a protein with attached polysaccharides that reacts predominantly as a protein

antigen
a protein on the surface of matter foreign to the body

Cholesterol

Cholesterol is found between the phospholipid molecules in the bilipid layer. It also has hydrophobic and hydrophilic portions. Cholesterol regulates the fluidity of the membrane so that it is neither too rigid nor too fluid for the functioning of the cell.

cholesterol
a steroid found in animals; an important component of cell membranes and precursor molecule for other steroids

Variations in membrane properties

Differing types of phospholipids in the membrane affect such properties as its fluidity and permeability. In turn, these properties affect the ease with which membranes fuse with each other, and the activity of the protein channels, glycoproteins and glycolipids. The variations in membrane properties of different cells can be attributed to differences in:

- lipid composition and as a result fluidity
- integral proteins and as a result 'channel' sizes
- peripheral and integral proteins and as a result
  - recognition sites
  - carrier molecules
  - enzymes attached.

SAMPLE

CHECK YOUR LEARNING 3.4

Describe and explain

1 **Explain** why the cell membrane must consist of a bilayer of phospholipids.
2 **Summarise** the functions proteins perform in the cell membrane.
3 **Identify** two factors that determine whether a particle will pass through a cell membrane.
4 **Explain** the functions of the cell membrane.

Apply, analyse and interpret

5 **Consider** the structure of the cell membrane in terms of the fact that cells vary in their ability to allow different types of molecules to pass through them.
6 **Deduce** why recognition sites on the outside of cell membranes are significant to living things.

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3.5 Movement of chemicals in and out of cells

KEY IDEAS

- Passive transport of molecules across a membrane
- Simple diffusion, facilitated diffusion and osmosis
- Active transport of molecules across a membrane
- Protein carriers, exocytosis and endocytosis (including pinocytosis and phagocytosis) as forms of active transport

SAMPLE

The membrane phospholipid bilayer is a major barrier that is impermeable to the usual water-soluble substances such as ions, glucose and amino acids. Lipid-soluble substances such as oxygen, nitrogen and alcohols dissolve in the phospholipids and diffuse rapidly through the cell membrane as if it were not there. Even though water is highly insoluble in the membrane phospholipids, it is readily able to penetrate the phospholipid layer as well as pass through the protein channels. The reason for this is not certain, but it is believed that water molecules are sufficiently small, and their kinetic energy sufficiently great, for them to penetrate the lipid portion before the hydrophobic 'tails' can stop them.

The very fluid nature of the cell membrane ensures that it is in constant motion, so small molecules can pass between the lipid molecules. At any time there are 'pores' in the membrane that will allow small molecules, such as water, or water-soluble molecules, such as urea, to pass through.

The phospholipid bilayer is impermeable to ions because of their electrical charge, and to glucose and amino acids because of their larger size. These molecules must enter the cell through the channels in the integral proteins.

Various materials must move in and out of cells so that biological activities can take place in the cell. The cell membrane allows some solute molecules or ions, but not others, to move freely through it. It is selectively permeable. A permeable membrane allows the free movement of all molecules in both directions; often a selectively permeable membrane allows solvent molecules and excludes the solute molecules.

passive transport the movement of materials into and out of a cell without the expenditure of energy

active transport the movement of materials into and out of a cell, usually against a concentration or ionic gradient, requiring cellular energy

Materials move in and out of cells via **passive transport** or **active transport**. Passive transport can be further broken into categories of diffusion and osmosis, as shown in Figure 1.

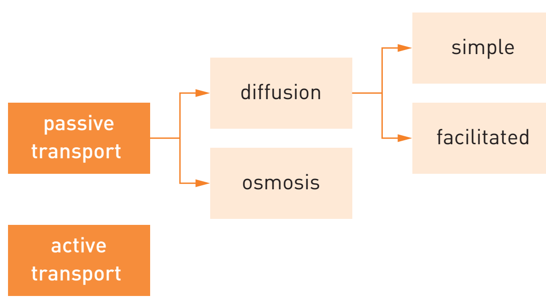

FIGURE 1 The basic mechanisms of transport across a membrane

Passive transport

Passive transport is a way of moving molecules that does not require energy. Many molecules do not need extra energy to move across a membrane.

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3.5 Modelling the selectively permeable cell membrane
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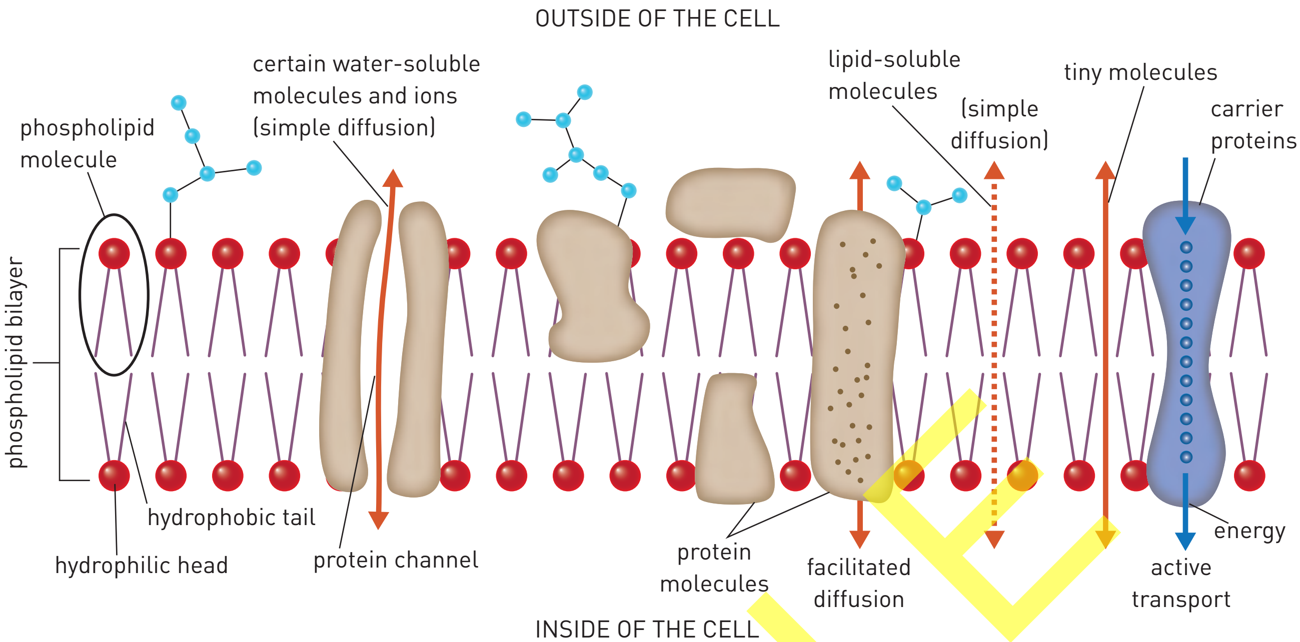

FIGURE 2 Transport pathways through the cell membrane

Diffusion is the process by which molecules or ions of liquids or gases tend to spread out from regions of their higher concentration to regions of their lower concentration. This results from their random movement (Brownian motion). Eventually, the molecules become more or less evenly distributed throughout the space they occupy. For example, a sugar cube (solute) placed in water (solvent) will dissolve and slowly spread throughout the solution.

There are three main factors that affect the rate of diffusion.

1 Temperature: molecules move faster at higher temperatures. This means diffusion will occur faster at high temperatures.
2 Particle size: small molecules require less energy to move. This means smaller particles will diffuse faster than larger particles.
3 Concentration: the greater the difference in concentration between the two locations (the **concentration gradient**) the faster diffusion will occur.

Diffusion through the cell membrane may be divided into two separate processes: **simple diffusion** and **facilitated diffusion**.

Simple diffusion

Simple diffusion is the free and unaided movement of molecules or ions through the cell membrane from an area of high solute concentration to an area of low solute concentration. For example, oxygen molecules (solute) dissolved in water (solvent) will be in constant random motion, causing an even dispersion of them through the solvent. If the concentration of oxygen molecules outside a cell is higher than that inside the cell, a concentration gradient will exist. Oxygen molecules are soluble in both water and lipids and can therefore pass freely through the cell membrane. The oxygen molecules do not stop moving once they are inside the cell, but the number of oxygen molecules passing into the cell will initially be greater than those moving out: there will be a net flow into the cell. As the concentrations on both sides of the membrane become equal, the number of molecules passing from each direction will become the same. At this

concentration gradient
a difference in the concentration of a solution at two different points, e.g. across a barrier such as a cell membrane

simple diffusion
the unaided movement of molecules or ions across a differentially permeable membrane from an area of high solute concentration to an area of low solute concentration

facilitated diffusion
the passive movement of molecules loosely bound to carrier molecules through the cell membrane from an area of high solute concentration to an area of low solute concentration

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dynamic equilibrium
a state of balance that exists when the amount of a particular substance entering a cell is exactly the same as the amount leaving it

point **dynamic equilibrium** has been reached. The number of molecules entering the system will equal the number of molecules leaving.

Facilitated diffusion

Sometimes, specific proteins in the cell membrane provide a pathway for particular molecules that cannot freely pass through the cell membrane. This passive movement through a membrane, with the help of a protein, from an area of high solute concentration to an area of low solute concentration is called facilitated diffusion. The molecules are carried across the cell membrane by (globular) proteins that collect them on one side of the membrane, diffuse across it and deposit them on the other side of the membrane. For example, glucose molecules are insoluble in the phospholipid bilayer of the cell membrane and are too large to pass through. However, the glucose plus its protein carrier is soluble in lipids and can diffuse across. It is thought that no overall energy is expended in this process.

Osmosis

osmosis
the movement of water from a region of low solute concentration to a region of high solute concentration through a selectively permeable membrane to counteract the differences in solute concentration

Osmosis occurs when there is a concentration gradient of solute (dissolvable molecules) across a membrane which is impermeable to the solute. Osmosis is the passive movement of water molecules across a selectively permeable membrane from an area of low solute concentration to an area of high solute concentration. Because the high solute concentration traps many of the water molecules around the hydrophilic solute, the water molecules are not free to move back across the membrane.

Osmotic/water potential is the capacity of a solution to lose water molecules through a selectively permeable membrane. It depends upon the concentration of the solute in the solution (e.g. the cytoplasm of a cell), compared with the concentration on the other side of the membrane (e.g. extracellular fluid). If the solute concentration in the extracellular fluid is higher than the solute concentration in the cytoplasm, the surrounding extracellular solution is said to be **hypertonic**, and its osmotic potential is low. Water will move out of the cell. If the solute concentration of the surrounding extracellular fluid is lower than the solute concentration of the cytoplasm in the

hypertonic
a solution having a higher solute concentration than that of the surroundings

(a) Simple diffusion
This results in the random but even distribution of solute molecules throughout the solvent.

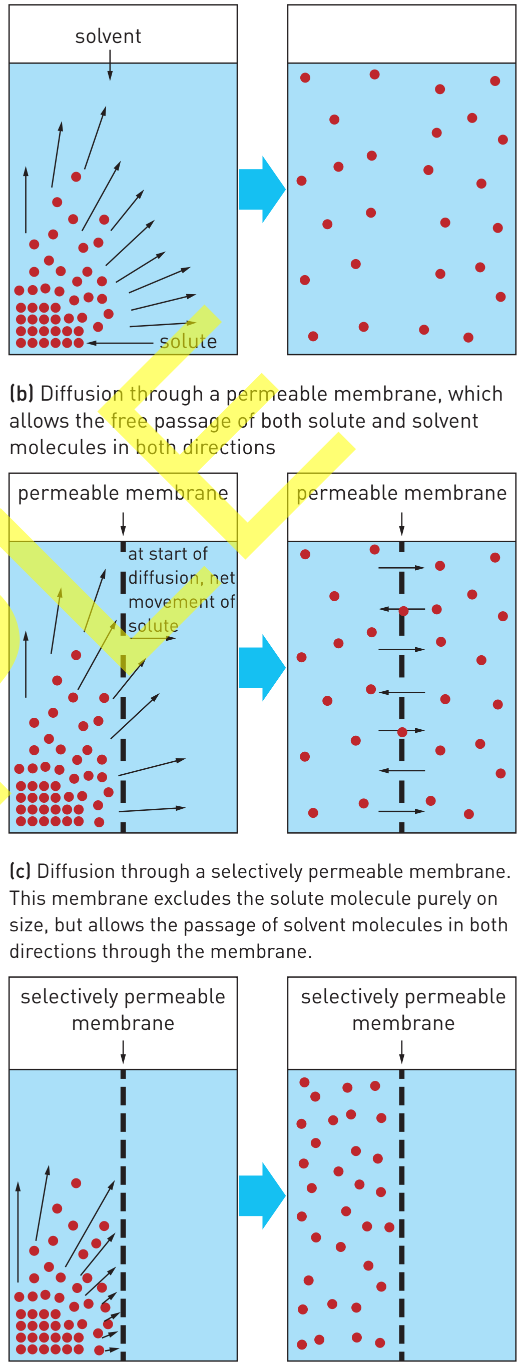

FIGURE 3 Diffusion, and the effect of different types of membranes

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cell, the solution of the extracellular fluid is **hypotonic**, and its osmotic potential is high. Water will move into the cell. When the solute concentration of the extracellular fluid is the same as that of inside of the cell, the solutions are said to be **isotonic** (see Table 1).

hypotonic
a solution having a lower solute concentration than that of the surroundings

isotonic
a solution having the same solute concentration as that of the surroundings

TABLE 1 Relationship between solute concentration and osmotic potential between the extracellular fluid and the cytoplasm in cells

Extracellular solute concentration	Cytoplasm solute concentration	Osmotic potential of extracellular fluid and direction of water movement
High (hypertonic)	Low (hypotonic)	Low – water moves out of the cell
Low (hypotonic)	High (hypertonic)	High – water moves into the cell
Same (isotonic)	Same (isotonic)	Nil – no net movement of water

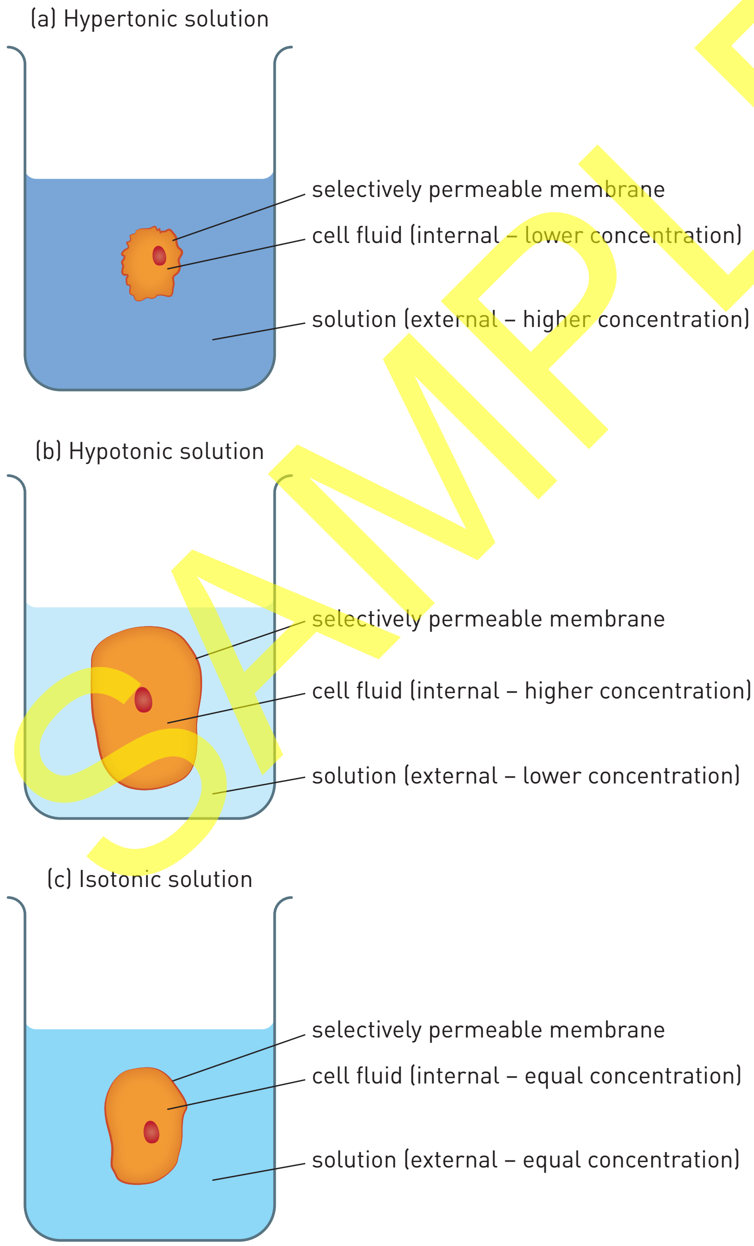

FIGURE 4 Types of extracellular solution

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If the osmotic or water potential of a cell is low, there will be a net flow of water *into* the cell by osmosis. If it is high, there will be a net flow of water *out of* the cell by osmosis. In an isotonic solution the same amount of water leaves the cell as enters.

When a cell is placed in a strong sugar solution, the sugar cannot diffuse through the cell membrane. There is a net flow of water out of the cell to a region of high solute concentration, until the concentration on both sides of the cell is equal, or isotonic.

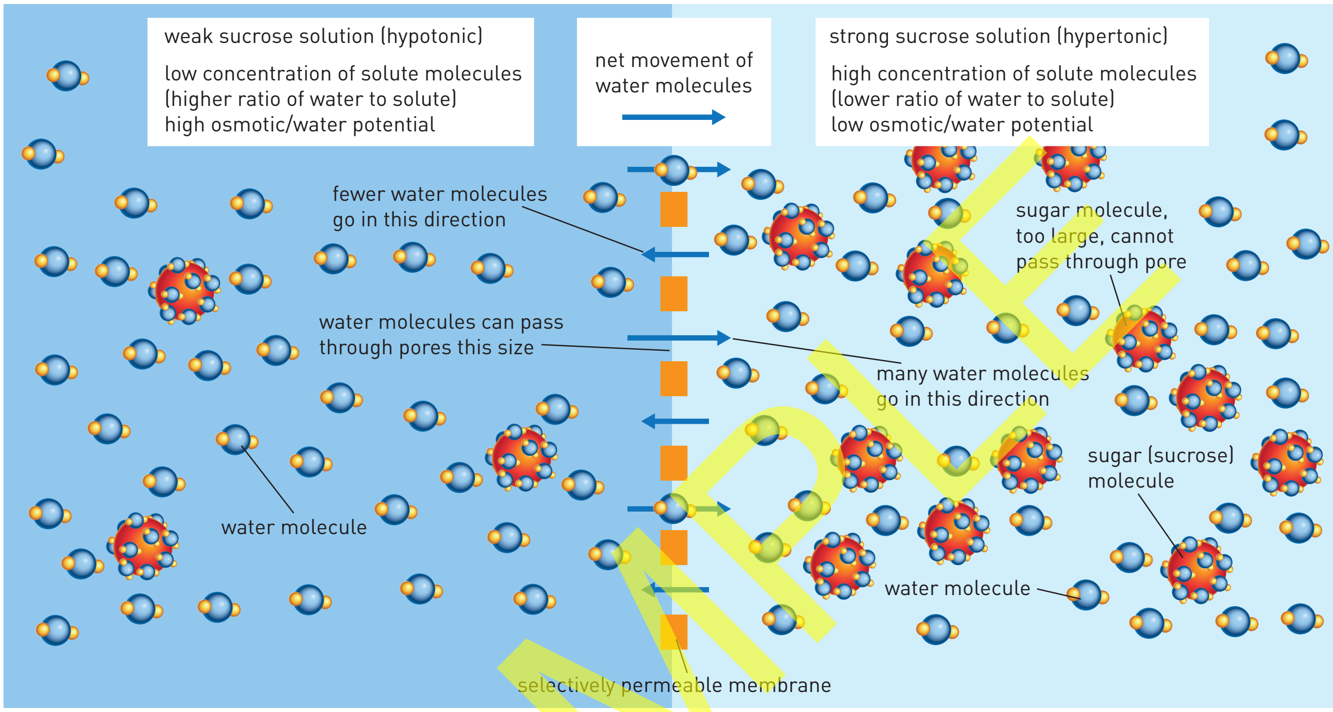

FIGURE 5 The process of osmosis

Study tip

'Where salt goes, water flows.' This suggests that there is a net water movement towards the higher solute concentration.

plasmolysis
the shrinkage of cytoplasm of a plant cell away from the cell wall as a result of loss of water by osmosis out of the cell

turgor pressure
the inward pressure exerted on plant cells due to the presence of the cell wall

Plant cells have large vacuoles that are involved in maintaining the water balance of the cell. In doing so, they are important in the support structure of non-woody plants. When plant cells are placed in a hypertonic solution, the cell wall remains rigid but the protoplasm loses water through osmosis and the membrane shrinks away from it, because the fluid of the vacuole is reduced in volume by osmosis. Shrinkage of the cytoplasmic membrane away from the cell wall is known as **plasmolysis**. If these cells are then placed in distilled water or a hypotonic solution, water will enter the cytoplasm and the vacuole, and restore the cell to its normal state. The cell is now deplasmolysed.

When water enters a plant cell by osmosis the volume of the total cell contents increases and exerts a **turgor pressure** against the rigid cell wall. When this is at a maximum, no net movement of water into the cell can occur. The cell is fully turgid. The cell wall prevents further uptake and so protects the cell membrane from rupturing.

A similar phenomenon takes place in animal cells (e.g. red blood cells or single-celled protists such as *Amoeba*). Because it lacks a cell wall, the entire cell shrinks and shrivels in a hypertonic solution (crenation), and in a hypotonic solution it expands, stretching the cell membrane, which may burst. Red blood cells that rupture due to osmosis are said to be haemolysed since the red pigment haemoglobin is released into the surrounding liquid.

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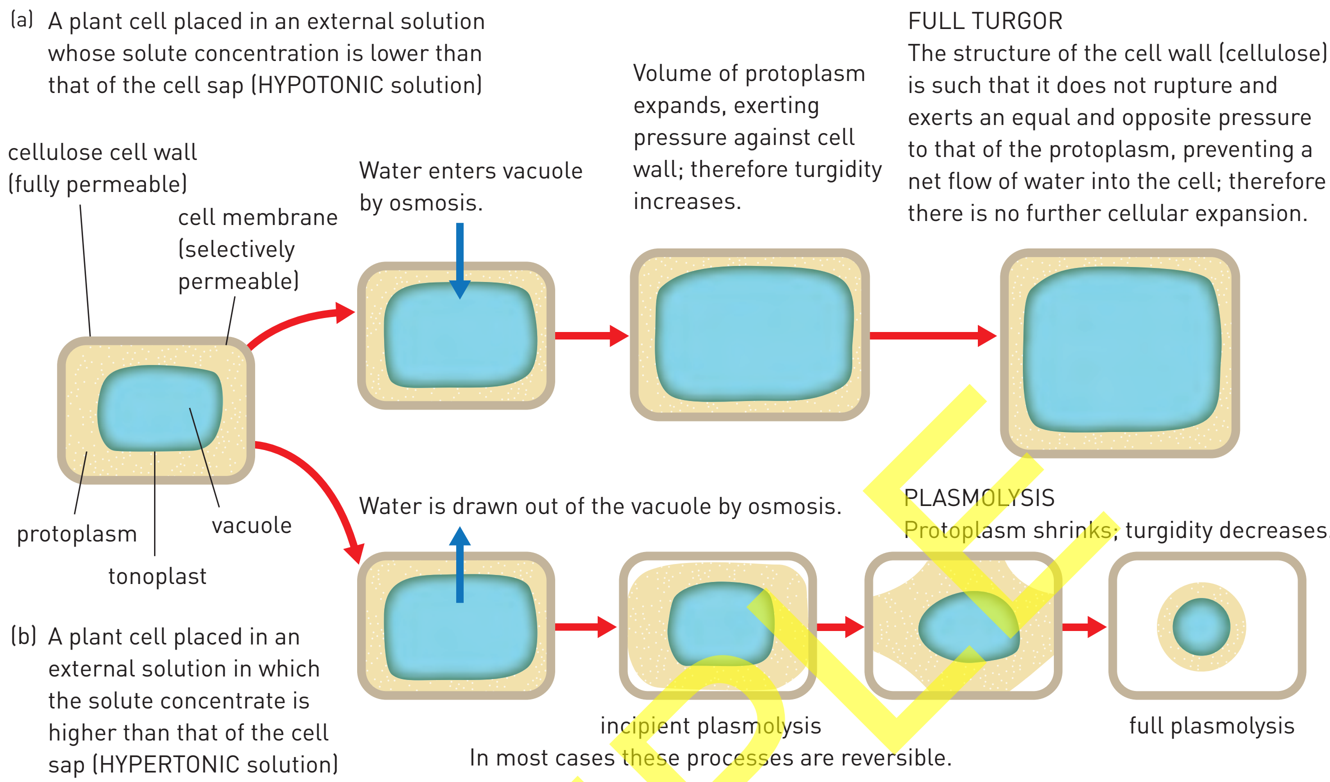

FIGURE 6 Plasmolysis and turgidity in plant cells

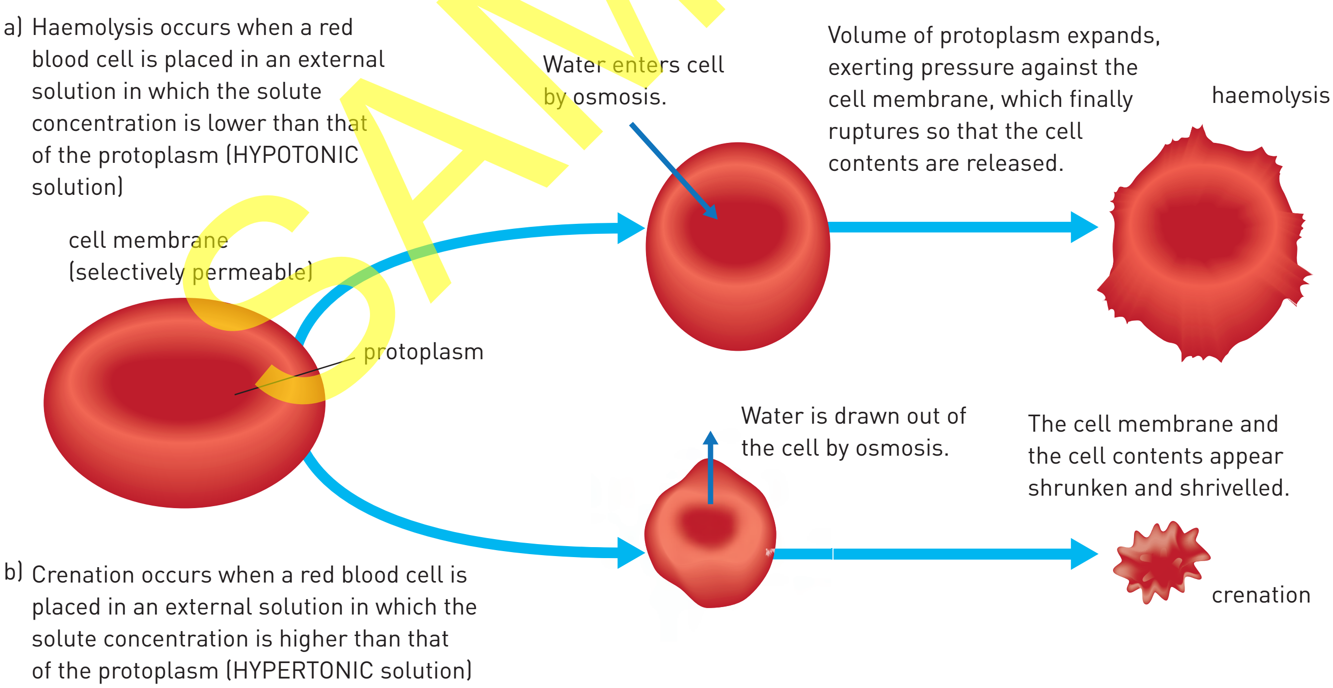

FIGURE 7 Haemolysis (a) and crenation (b) in red blood cells

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Active transport

Active transport is the energy-consuming transport of molecules or ions across a membrane against a concentration gradient or an ionic gradient. Energy is required because the substance must be moved against its natural tendency to diffuse in the opposite direction. Movement is unidirectional. In contrast, diffusion is reversible, depending on the direction of the concentration gradient. Active transport of materials out of cells is termed **exocytosis**; the active movement of materials into the cell is termed **endocytosis**. Active transport may involve:

- carrier molecules in the membrane, or
- formation or breakdown of membrane-bound 'packages' of matter. These packages are membrane-bound vacuoles formed by the processes of phagocytosis or pinocytosis.

In endocytosis, the membrane may actually engulf particulate matter (**phagocytosis**) or extracellular fluid and its contents (**pinocytosis**). Phagocytosis (cell eating) involves the extension part of the cell membrane extending out and surrounding a solid particle outside the cell. The membrane fuses around the particle and, in doing so, forms a vesicle which becomes incorporated into the cytoplasm. The term vacuole is used when large particles are taken up. Lysosomes fuse with this food vacuole, releasing enzymes. The resulting digested molecules diffuse into the cytoplasm. The vacuole with its undigested matter moves to the cell membrane where it fuses, releasing the waste (exocytosis).

Pinocytosis (cell drinking) occurs by infolding the cell membrane to form a channel. The liquid material enclosed in the channel is pinched off in a vesicle as the membrane fuses at the surface.

exocytosis
the movement of materials out of the cell

endocytosis
the movement of materials into the cell

phagocytosis
'cell eating': engulfing of a solid material by a cell through extension of the cell membrane over it, and formation of a food vacuole

pinocytosis
'cell drinking': formation by the cell membrane of channels that take in fluid at their base

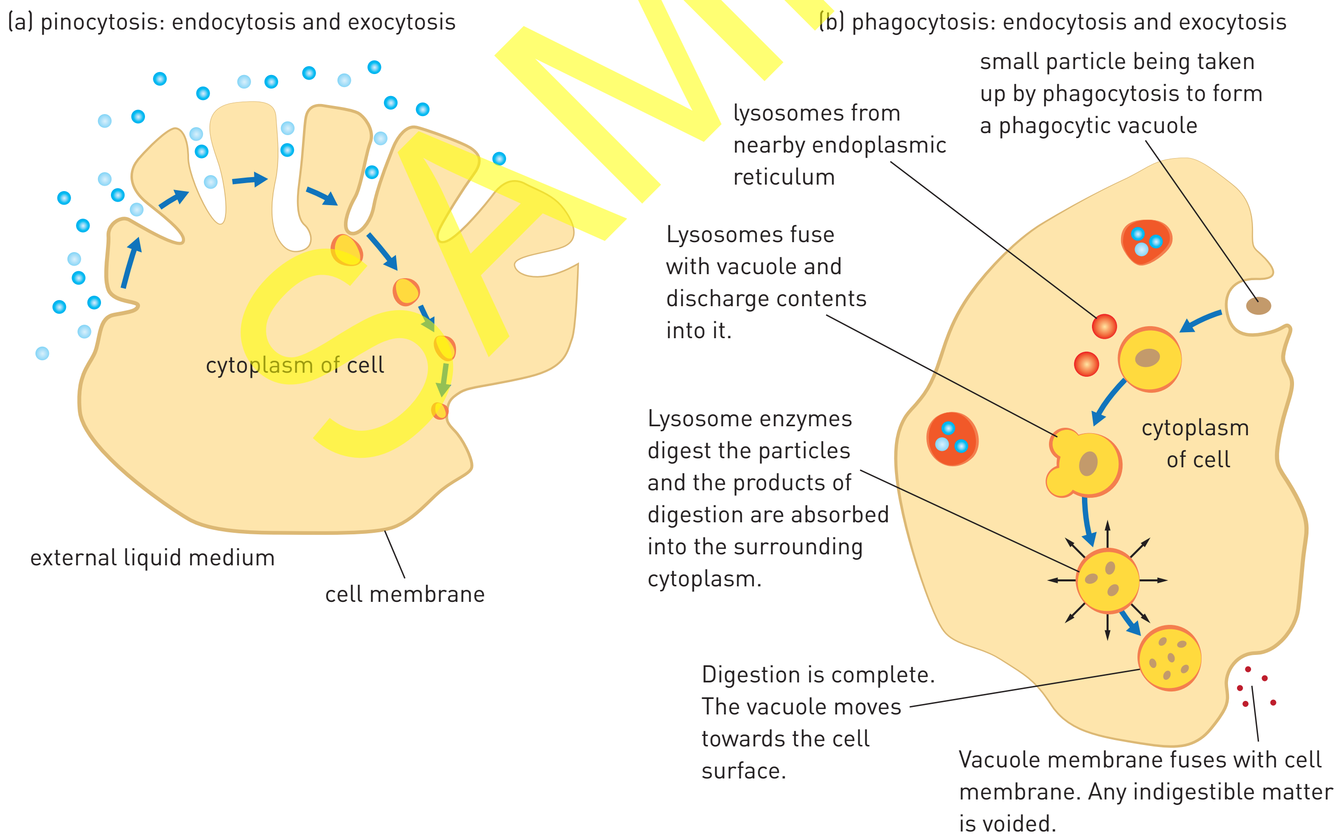

FIGURE 8 The sequence of events in pinocytosis (a) and phagocytosis (b)

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Phagocytosis and pinocytosis do not occur in plant cells due to the presence of the relatively inflexible cell wall. Phagocytosis is an important feeding mechanism in many single-celled animals (Protozoa) and is one of the means that multicellular animals use to destroy invading bacteria and viruses.

Exocytosis of materials in vacuoles and vesicles involves them again fusing with the cell membrane and then opening up to the external environment to expel the contents. White blood cells use exocytosis to expel the digested remains of bacteria cells. Nerve cells (neurones) use exocytosis to pass chemical messenger molecules to other cells.

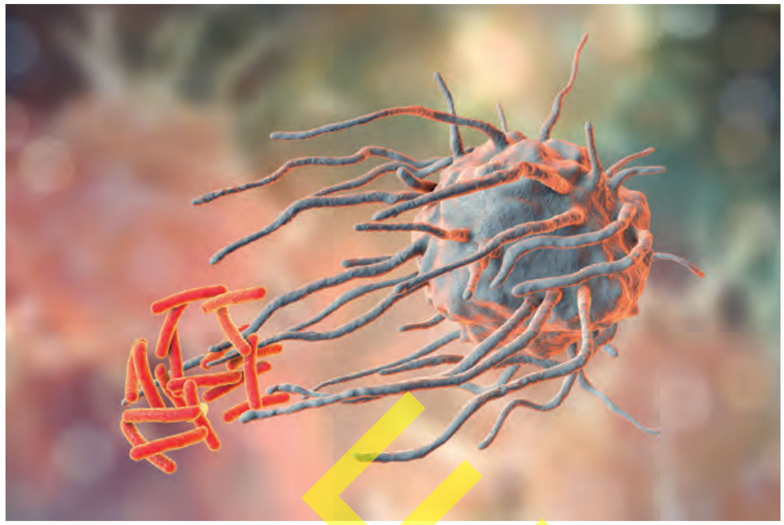

FIGURE 9 An artist's depiction of a macrophage engulfing tuberculosis bacteria

CHECK YOUR LEARNING 3.5

Describe and explain

1 **Explain** what is meant by the terms 'passive transport' and 'active transport'.

2 **Describe** the difference between a permeable and a selectively permeable membrane. Give an example of each.

3 **Explain** what is meant by dynamic equilibrium between two solutions separated by a selectively permeable membrane.

4 **Describe** simple diffusion. **Explain** how it differs from facilitated diffusion.

5 **Compare** diffusion and osmosis.

6 **Describe** the different methods of active transport used by cells.

7 **Compare** phagocytosis and pinocytosis.

Apply, analyse and interpret

8 Animal cells placed in a hypotonic solution swell and burst. Plant cells placed in a hypotonic solution swell only to a particular point and do not rupture.

a **Classify** the process involved in the swelling.

b **Consider** why animal cells rupture but plant cells do not.

c **Deduce** the name given to this action in plant cells.

Study tip

When explaining the method of transport through a cell membrane, always name the mode of transport, describe if it is active or passive, and provide the direction of motion (e.g. simple diffusion, passive movement from an area of low solute concentration to an area of high solute concentration).

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CHAPTER 3

Review

Chapter summary

3.1 As microscope technology became more advanced, many observations were made on cellular structure, which in the mid-1800s led to the cell theory that all living things are composed of one or more cells. With further knowledge, this theory has been expanded to encompass the processes of cell division (including DNA and inheritance), chemical composition and coordination of activities between different cell types.

3.2 The first cells to develop (prokaryotic cells) were very simple, consisting of a cell membrane (some enclosed by a cell wall) and protoplasm.

Eukaryotic cells are believed to have arisen by one cell engulfing and incorporating different prokaryotic organisms into it, and the engulfed cells evolving into membrane-bound organelles (via endosymbiosis).

3.3 Eukaryotic cells are distinct from prokaryotic cells in having a 'division of labour' of the cytoplasm into membrane-bound organelles.

Plant cells, unlike animal cells, are each surrounded by a rigid cell wall of cellulose, and those cells exposed to light contain chloroplasts, which are the sites of photosynthesis, and a large, central vacuole filled with cell sap.

3.4 The cell is bound by a membrane, which consists of a phospholipid bilayer through which integral proteins are inserted and on which peripheral proteins and other chemicals, such as sugars, are bound. Different cells have membranes with different chemical compositions, and this changes their properties.

The functions of the cell membrane are to maintain each cell as an integral structure, to control movement of substances into and out of the cell (through passive and active transport), to provide some mechanical support to the cell and help maintain shape, and to provide receptors to extracellular material for different cell types.

3.5 The cell membrane is a selectively permeable structure that allows the passage of only certain molecules.

Diffusion is the passage of solutes from a hypertonic solution (one of high concentration) to a hypotonic one (one of low concentration) through a selectively permeable membrane.

Facilitated diffusion is the transport of substrate molecules through the membrane by special enzyme-like carrier molecules.

Osmosis is the passage of the solvent (water) from a hypotonic to a hypertonic solution through a selectively permeable membrane that is impermeable to the solutes in this solution.

Diffusion, facilitated diffusion and osmosis are forms of passive transport of materials.

Key terms

- abiogenesis
- active transport
- antibiotic resistance
- antigen
- cell membrane
- cell theory
- cellular respiration
- centriole
- chloroplast
- cholesterol
- chromatin
- chromoplast
- chromosome
- cilium
- colonial
- concentration gradient
- cristae
- cytoplasm
- dynamic equilibrium
- electron micrograph
- endocytosis
- endosymbiotic hypothesis
- eukaryote
- eukaryotic cell
- exocytosis
- facilitated diffusion
- flagellum
- fluid mosaic model
- glycoprotein
- Golgi body
- grana
- hypertonic
- hypotonic
- integral protein
- isotonic
- leucoplast
- lysosome

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- microfilament
- microtubule
- microvillus
- mitochondrion
- multicellular organism
- murein
- nucleoplasm
- nucleus
- osmosis
- passive transport
- peripheral protein
- phagocytosis
- phospholipid bilayer
- pinocytosis
- plasmolysis
- prokaryote
- prokaryotic cell
- protein channel
- ribosome
- rough endoplasmic reticulum
- simple diffusion
- smooth endoplasmic reticulum
- turgor pressure
- unicellular
- vacuole
- xylem

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 Plant cells can usually be distinguished from animal cells because only plant cells possess:

A cell walls and mitochondria
B Golgi bodies and central vacuoles
C cell walls and central vacuoles
D chromosomes and mitochondria

2 In a multicellular organism the growth rate of a cell decreases as the cell gets larger. Of the following, the most probable reason for this is that:

A The materials needed for growth are in short supply in the surroundings.
B As the cell gets larger it approaches maturity and assumes a very specialised role, depending on its position in the organism.
C Most of the energy available for growth of the cell has already been used.
D Small cells can more readily obtain needed nutrients and release wastes than large cells in the same environment.

3 If living cells, similar to at least some of those found on Earth, were found on another planet on which there was no free oxygen, which organelle is *not* likely to be present?

A Cell membrane
B Mitochondria
C Nucleus
D Ribosomes

4 A plant cell is in a turgid condition when:

A it is put in an isotonic solution
B it is haemolysed
C water enters it and causes the vacuole to press the cytoplasm against the cell wall
D it is put in a hypertonic solution

Short answer

Describe and explain

★ **5** **Describe** cell theory.

★★ **6** **Contrast** a prokaryotic and a eukaryotic cell.

★ **7** **Explain** the meaning of the terms 'diffusion' and 'concentration gradient'.

★ **8** **Describe** a simple experiment to demonstrate diffusion in water.

★★ **9** **Explain** how diffusion and osmosis are necessary for cell existence.

Apply, analyse and interpret

★★★ **10** A summary of the various ways in which bacteria meet their energy needs is shown in Figure 1.

a A survey of certain hot springs that emitted strong sulphur dioxide fumes found that the only living matter in the springs was a single type of bacterium. Carbon dioxide levels in the water were measured and found to be stable over several weeks. **Classify** the bacteria sample to a major group of bacteria (photosynthetic or chemosynthetic). Give reasons for your answer.

b **Classify** bacteria that use light as an energy source.

c *Salmonella* is a bacterium that causes food poisoning in humans. **Determine** the characteristics (such as energy source, carbon source and so on) of this bacterium.

★★ **11** The surface area of a cube = 6 x l^2, where l is the length of one side.
The volume of a cube = l^3.
The surface area of a cylinder (both ends included) = $(2\pi r \times l) + 2r^2$, where r is the radius, $\pi = 3.14$ and l is the length.
The volume of a cylinder = $\pi r^2 \times l$.

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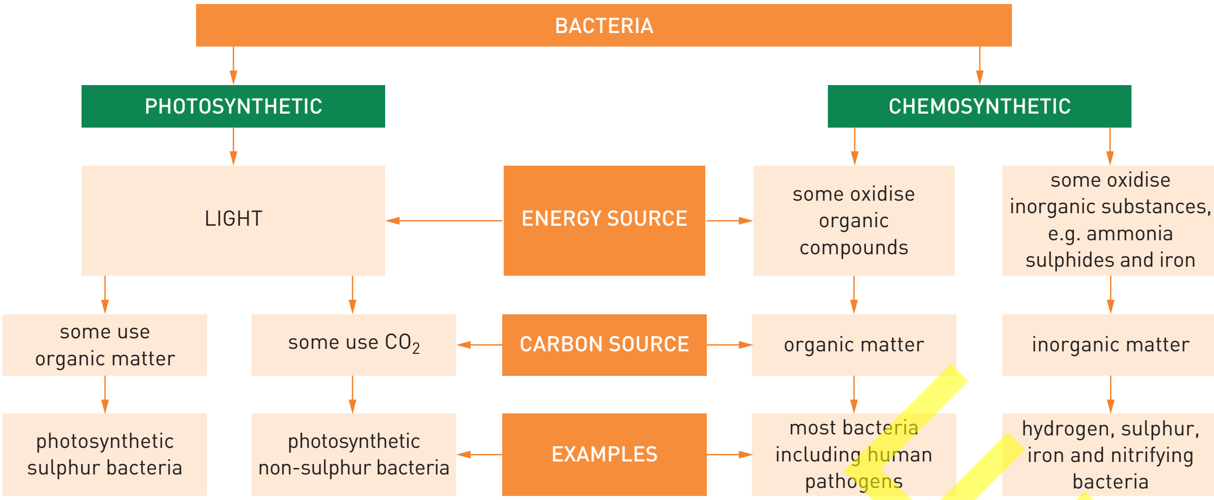


FIGURE 1 How various bacteria meet their energy needs

Showing the working for all calculations, **calculate** surface area, volume, and the ratio of surface area to volume:

a of a cube where *l* is:

i 1 μm long

ii 3 μm long

b of a cylinder where $r = 0.5$ μm and $l = 1$ μm.

Infer, referring to the calculations above, the most efficient size and shape for a cell.

★★ **12** The electron micrograph (photograph produced from an electron microscope) in Figure 2 shows a cell organelle, labelled A.

a **Identify** this organelle. Give reasons for your identification.

b **Judge** whether this organelle is found in a plant or animal cell, or both.

c **Identify** the function of this organelle.

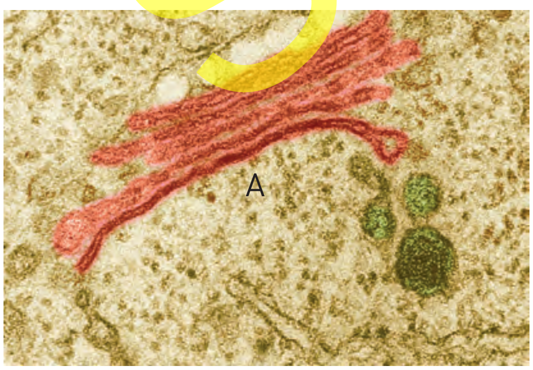


FIGURE 2 Electron micrograph of part of a cell

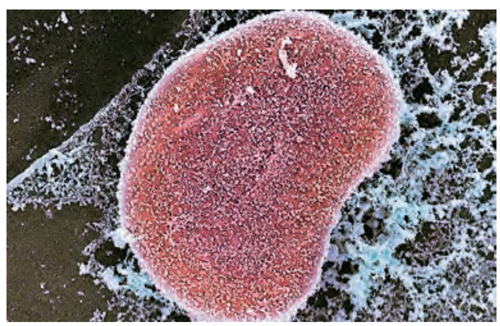
★★★ **13** Examine the three electron micrographs of cell organelles shown in i, ii and iii.

a **Identify** each organelle, giving reasons for your choice.

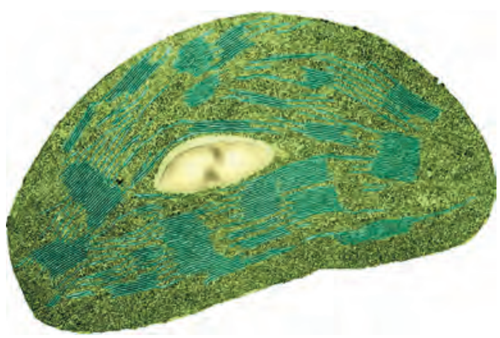
b **Judge** whether you would expect to find all three organelles in the same cell type.

c If these electron micrographs were taken from the same cell, **deduce** whether the same magnification scale is used in each. **Explain** your answer.

i



ii



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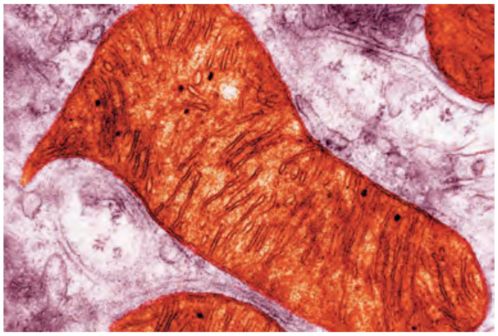
iii



★★ **14** The electron micrograph in Figure 3 shows part of a typical cell of a certain tissue.

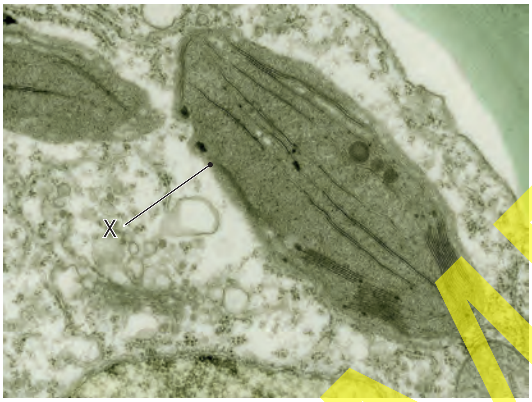


FIGURE 3 Cell tissue

a **Identify** the structure labelled X.

b **Identify** the structure as coming from a plant or animal cell. Give reasons for your answer.

c **Consider** where in the organism you would expect to find this structure.

Investigate, evaluate and communicate

★★★ **15** A group of students on an excursion to a beach collected 50 sandworms of approximately equal size. They organised the worms into five groups of 10. Each group was weighed.

Each group of worms was then placed in a separate jar. The students poured into each of the first four jars a different concentration of saline (salt) solution. The fifth jar was filled with normal sea water. The worms were left in the solutions for one hour and then reweighed. (Sandworms can tolerate extremes of salt concentration for several hours.) The weight change for each group of worms was recorded as shown in the table below.

Jar	Saline concentration (M)	Weight change (g)
1	0.1	+10.0
2	1.0	+5.0
3	1.5	0.0
4	2.0	–10.0
5	Normal seawater	0.0

Analyse the relationship between the weight of the worms and the solution in which they were placed, suggesting reasons for any variation in weight.

★★★ **16** A 5% glucose solution is frequently administered intravenously to persons who have undergone surgery. **Predict** whether the 5% glucose solution will be hypertonic, hypotonic or approximately isotonic. Justify your answer.

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