Cell biology

Unit 4

Contents

4.1 Cell theory

By the end of this section you should be able to:

- Tell the history of cell biology.
- Describe cell theory and investigate the size, structure and shape of cells.
- State the basic functions of cells.
- Appreciate that all life on Earth originates from cells.

How did the modern cell theory develop?

Today we take it for granted that living things are made of cells. Billions of cells in the case of human beings, just one cell in the case of organisms like amoeba. Figure 4.1 shows some of the different types of cells that make up our bodies.

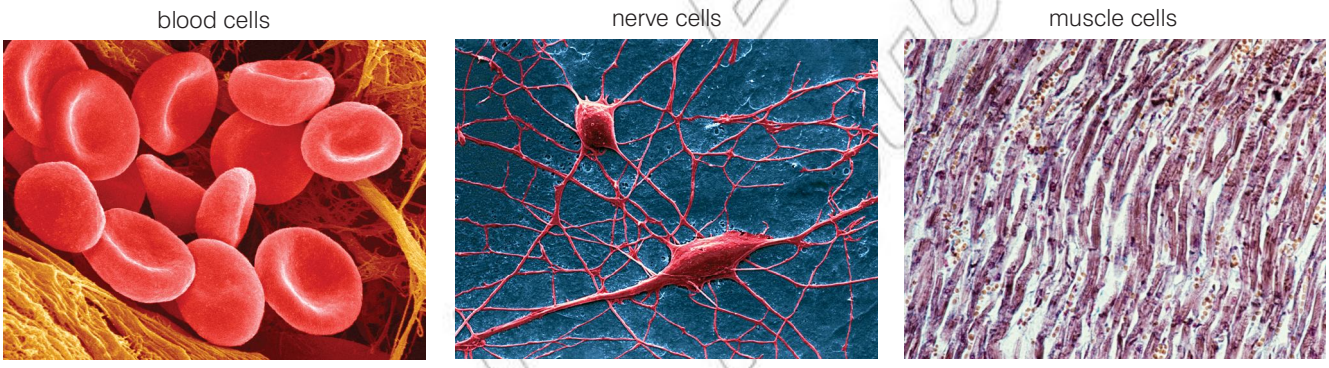


Figure 4.1 *Some of the different cells in our bodies*

There is only one cell in *Amoeba* and in *Vorticella*.

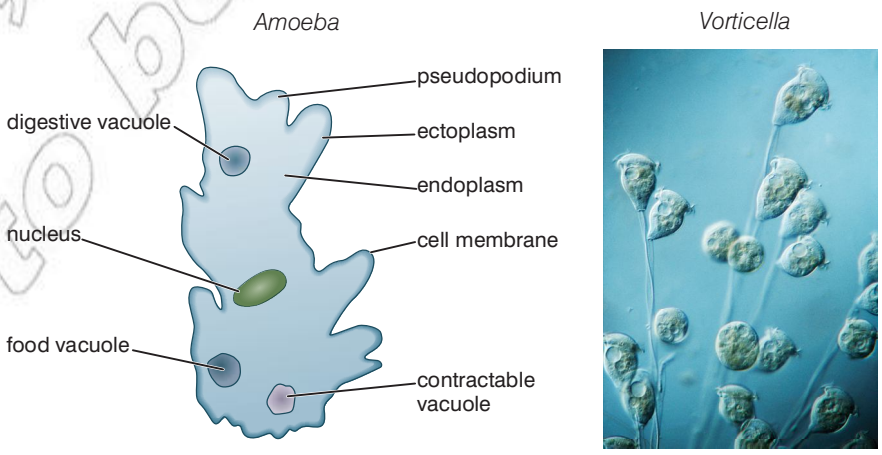


Figure 4.2 *The unicellular organisms* Amoeba *and* Vorticella

It seems strange that the idea of organisms being made from cells is a relatively recent idea. Only a few hundred years ago, cells had not been discovered. Their discovery had to wait for the development of reliable microscopes that could magnify sufficiently to show the cellular structure of living organisms. Many biologists and other scientists contributed to the discovery of cells and the statement of the very first cell theory. The timeline below shows some of the major contributors.

A timeline for the development of the cell theory

1665 Robert Hooke, with one of the earliest compound microscopes, makes drawings of cork and sees tiny structures that he calls 'cells'. However, although his microscope is a compound microscope, the lenses are not very good and magnifications of more than 30× are very blurred and do not show much detail. Also, Hooke saw only dead cells.

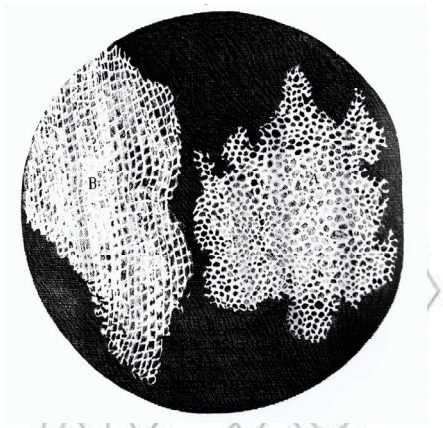


Figure 4.3 *Robert Hooke's drawing of cells in cork*

Figure 4.4 *Robert Hooke's microscope*

1674 Anton van Leeuwenhoek sees living, moving unicellular organisms (protoctistans) in a drop of water. He is using a simple microscope with only one lens. It is really little more than a magnifying glass with a mount for the specimens.

However, van Leeuwenhoek is very skilled at grinding lenses and so his microscope can achieve magnifications of 300×. He calls the moving organisms 'animalcules'. He also sees bacteria (from his teeth), which he also calls 'tiny animalcules'.

Figure 4.5 *Anton van Leeuwenhoek's microscope*

Figure 4.6 *Anton van Leeuwenhoek*

About compound microscopes

A compound microscope is the sort of microscope we use in biology today. It has two lenses – the eyepiece and the objective lens (check back to unit 1 for more details) – that combine to produce the final image. Because two lenses are used, compound microscopes are capable of higher magnifications than simple microscopes, which use only one lens. The second lens (the eyepiece) magnifies the already magnified image produced by the objective lens. However, it also magnifies any 'aberrations' or faults in the image. So if the lenses are not well made, the final image, at high magnifications, will be blurred. The first compound microscope was made in 1595 by the Dutch scientist, Zaccharias Jansen.

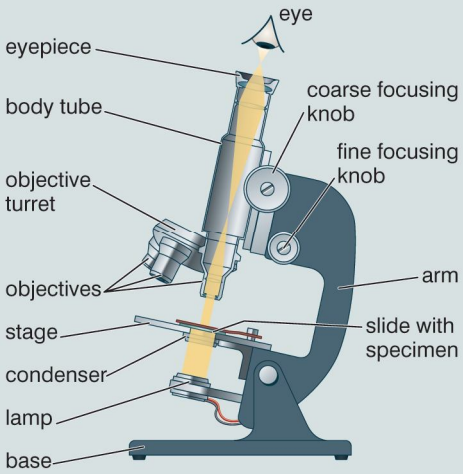


Figure 4.7 *A modern compound microscope*

Check back to unit 1 to look at the work of Francesco Redi and Louis Pasteur in disproving spontaneous generation.

DID YOU KNOW?

About Schwann cells

Schwann cells are special cells that contain a lot of a fatty substance called myelin. They wrap themselves around the axons of nerve cells as the nerve cells are growing and insulate the axons. They are named in honour of Theodor Schwann.

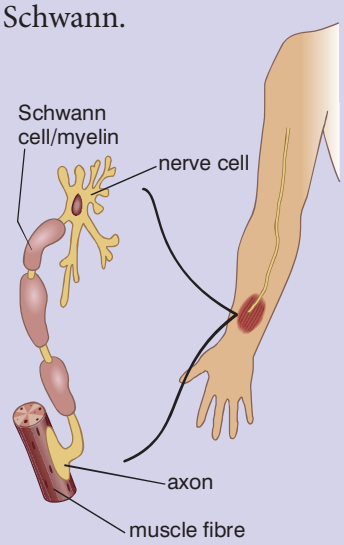


Figure 4.8 *Schwann cells around the axon of a nerve cell*

1824 The French biologist Rene Dutrochet concludes that all organisms are composed of cells. This follows many years work in which he also discovers:

- the stomata in the epidermis of leaves
- the process of osmosis
- chlorophyll is needed for photosynthesis to occur
- respiration occurs in both animals and plants

In many ways, Dutrochet is the man who first states the cell theory by recognising that all organisms are made of cells and that 'all growth occurs because of the increase in volume of cells or by the addition of more little cells'.

1839 Matthias Schleiden and Theodor Schwann put forward the first clearly stated cell theory. It states that:

- the cell is the unit of structure, physiology and organisation in living things
- the cell retains a dual existence as:
  - a distinct entity, and
  - a 'building block' in the formation of organisms
- cells form by free-cell formation (spontaneous generation)

Although we still accept the first two ideas, the final idea of spontaneous generation has now been proved false.

1858 Rudolf Virchow, a German doctor who develops many surgical techniques and promotes several fields of modern medicine, declares that: '*Omnis cellula e cellula*', which means that a cell can only arise from another cell like it. With this he completes the first accepted version of the cell theory:

- all organisms are made up of one or more cells
- all cells come from pre-existing cells
- the cell is the unit of structure, physiology and organisation in living things
- the cell retains a dual existence as a distinct entity and a building block in the construction of organisms

Today, this has been modified and extended in the light of our increased knowledge of genetics and cell biology and now reads:

- all known living things are made up of cells
- the cell is a structural and functional unit of all living things

- all cells come from pre-existing cells by division (there is no spontaneous generation of cells)
- cells contain hereditary information which is passed from cell to cell during cell division
- all cells have basically the same chemical composition
- all energy flow (the metabolism and biochemistry of life) occurs within cells

Besides these major steps in the development of a cell theory, there have been other developments in the study of cell biology. Some of these are listed below.

Key events in the study of cell biology

Table 4.1 *Key events in cell biology*

	Event
1595	Jansen builds the first compound microscope.
1626	Redi postulates that living things do not arise from spontaneous generation.
1665	Hooke describes 'cells' in cork.
1674	Leeuwenhoek discovers protozoa.
1833	Brown describes the cell nucleus in cells of an orchid.
1839	Schleiden and Schwann propose a cell theory.
1857	Kolliker describes mitochondria.
1858	Virchow states *omnis cellula e cellula*.
1869	Miescher isolates DNA.
1879	Fleming describes chromosome behaviour during mitosis.
1898	Golgi describes the Golgi apparatus in cells.
1939	The first transmission electron microscope.
1953	Watson and Crick propose the double-helix structure of DNA.
1965	The first scanning electron microscope.
2000	Human genome DNA sequence draft.

How big are cells?

It all depends on what kind of cell you are talking about. The contents of a chicken's egg are just one huge cell packed with food – it's a pretty big cell, up to 5 cm (0.05 m) in length. On the other hand, the smallest bacterial cells are only just over 100 nm in length. This is approximately one hundred-thousandth of the size of the chicken's egg. That's quite a range of sizes!

Activity 4.1

Work in groups for this activity. Each group is going to make a presentation to the class about one of the following scientists who all made a major contribution to our modern understanding of cells: Robert Hooke, Anton van Leeuwenhoek, Rene Dutrochet, Matthias Schleiden, Theodor Schwann and Rudolf Virchow. Use this textbook as a resource and use other books and the internet for your research if it is available. Make your presentations as interesting and lively as possible.

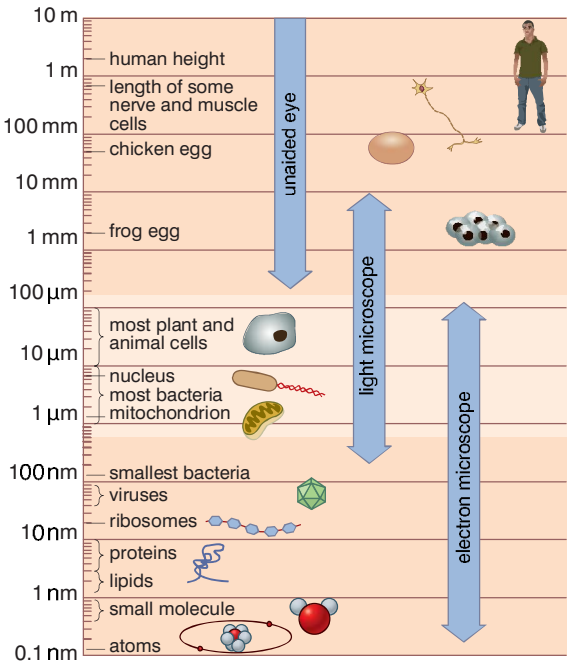


Figure 4.9 *Size and scale in living things*

What units shall we measure cells in?

Again, it all depends on which cells, but first we should understand which units are available and which ones would be convenient to use. We could measure cells in metres, but the size of a red blood cell in metres would be approximately 0.000007 m.

All those 0's are very confusing and we don't easily work with such small numbers. So we use other, smaller units to measure the size of cells and molecules. These smaller units give us numbers that are more convenient to work with. There are three smaller units commonly used:

- millimetres (mm) – 1/1000 of a metre
- micrometres (µm) – 1/1000 of a millimetre, and 1/1 000 000 of a metre
- nanometres (nm) – 1/1000 of a micrometre, 1/1 000 000 of a millimetre, and 1/1000 000 000 of a metre

We can convert the units from one to another as shown below:

$$\text{m} \underset{\div 1000}{\overset{\times 1000}{\rightleftharpoons}} \text{mm} \underset{\div 1000}{\overset{\times 1000}{\rightleftharpoons}} \text{µm} \underset{\div 1000}{\overset{\times 1000}{\rightleftharpoons}} \text{nm}$$

To convert a larger unit to the next smaller unit, multiply by 1000:

For example, convert 3.5 mm to µm.
3.5 mm = 3.5 × 1000 = 3500 µm

To convert a smaller unit to the next larger unit, divide by 1000:

For example, convert 87 nm to µm.
87 ÷ 1000 = 0.087 µm

So, our red blood cell that was 0.000007 m in diameter is 0.007 mm or 7 µm in diameter. This is a much more comprehensible number.

Most cells fall within a much narrower range of sizes than the chicken's egg and the smallest bacterium. As you can see from figure 4.9, the length of most animal and plant cells fall within a range of 10 µm to 100 µm. Most bacteria are about one-tenth of this length.

Figure 4.10 shows the relative sizes of an animal cell, a bacterium and a virus in a slightly different way. This diagram makes it clear just how much bigger an animal cell is than a bacterium.

The animal cell may be just ten times as long – but it is also ten times as wide and ten times as deep. This makes it 1000 times bigger than the bacterium!

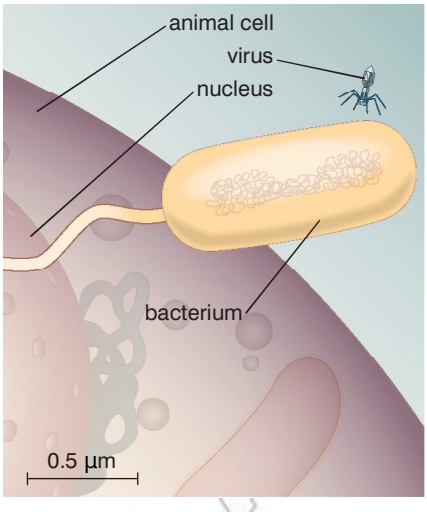


Figure 4.10 *The relative size of an animal cell, a bacterial cell and a virus*

KEY WORDS

calibrating *correlate the readings of an instrument with a standard*

Activity 4.2: How can we find out how big cells are?

To do this properly, you need to use two measuring devices with your microscope:

- a stage micrometer – this is really a microscope slide with a very precise scale etched onto it, and
- an eyepiece graticule – this is a piece of plastic with a less accurate scale than the graticule that fits inside the eyepiece of the microscope.

When you put the micrometer onto the slide and look at it through the eyepiece containing the graticule, you see something like figure 4.11.

The smallest divisions on the stage micrometer slide are 100 µm. So each large division on the stage micrometer is 10 times that – 1 mm.

If we look at the two scales, we can see that the range 50–60 on the stage micrometer corresponds with the range 35–72 on the graticule. Ten divisions on the micrometer scale correspond to 37 divisions on the graticule scale and 1 micrometer division therefore corresponds to 3.7 graticule divisions. But we know that 1 micrometer division = 100 µm (or 0.1 mm).

So 1 division of the eyepiece graticule = 100 µm ÷ 3.7 = 27 µm (or 0.027 mm).

This is called **calibrating** the eyepiece graticule. If we now put an object on an ordinary slide (having removed the stage micrometer) and view it at the same magnification, we can calculate its size. If it takes up 26 graticule divisions, then this length is: 26 × 27 = 702 µm (or 0.702 mm).

However, the graticule will need recalibrating if it is to be used at a different magnification.

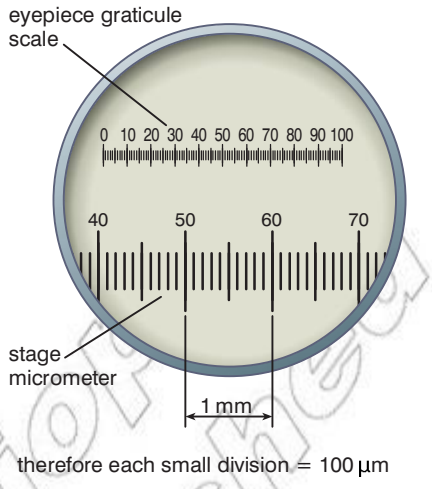


Figure 4.11 *An eyepiece graticule and stage micrometer*

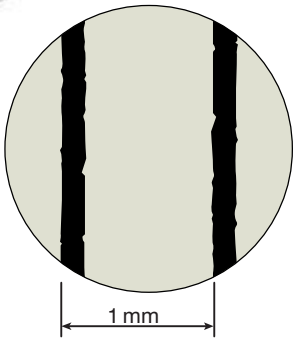


Figure 4.12 *Estimating the field of view*

How you can make a rough estimate of cell size

It's a way of using the same principle as the micrometer. It isn't as accurate, but it's a lot cheaper and easier.

- Place your slide of cells (for example, onion epidermis cells) under the microscope and get the cells in focus at about magnification ×100.
- Now take the slide away and replace it with a transparent plastic ruler. (Keep the magnification the same.)
- Focus on the millimetre scale on the ruler. You will see something like figure 4.12.
- Use this to estimate the width of 'field of view'. You would probably estimate the field of view as shown in figure 4.12 at about 2 mm.
- Now replace your slide of the onion cells and refocus.
- Count how many cells fit lengthways and widthways into the field of view.
- If 8 cells fit across the field of view the width of each cell is 2 mm ÷ 8 = 0.25 mm (or 250 µm). However, this is only one estimate and you should repeat the procedure in several areas of the slide and find the average.

KEY WORD

arbitrary units *are units we use when we don't know actual dimensions but we know the mathematical relationship between different conditions*

What are the consequences of the different sizes of cells?

When a cell gets bigger, all its dimensions change. It is easy to be tricked into thinking that when a cell doubles all its dimensions it is twice as big. But, in fact, there is now eight times more cell as a result! This is most easily explained if we pretend that our cell is a cube, but the same principles hold true for other shapes also.

Look at figure 4.13. It shows three cubic 'cells' of different sizes. The linear dimensions double from the first cell to the second and double again from the second cell to the third. But the surface area and volume of the cell doesn't double.

There are six sides to a cube. We calculate the area of each side by multiplying length by breadth. In the case of the first cell, this is 1 **arbitrary unit** (a.u.) × 1 a.u., so the area of one side is 1 a.u.^{2}. The volume of a cube is length × breadth × height. In this case 1 a.u. × 1 a.u. × 1 a.u. So the volume of the first cell is 1 a.u.^{3}. The ratio of the surface area to the volume is 6:1.

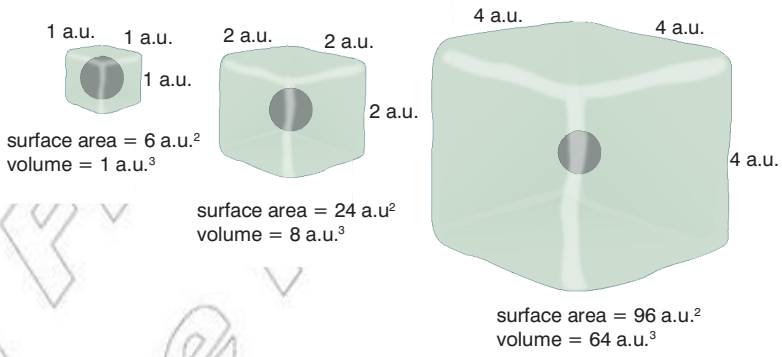


Figure 4.13 *How increasing size affects surface area and volume. The measurements are in arbitrary units (a.u.).*

So what about the second cell? The linear dimensions have doubled, but the surface area is 24 a.u.^{2} and the volume is 8 a.u.^{3}. The ratio of the surface area to volume is now 24 ÷ 8 = 3:1. It is half that of the smaller 'cell'.

The ratio of the surface area to volume of the third cell is in fact 1.5:1. Smaller again and half the value of the ratio of the cell with linear dimensions that are half of this one.

Activity 4.3: Can you spot a trend?

Calculate the surface area, volume and surface-area-to-volume ratio for cubes with linear dimensions ranging from 1 to 10. You could use a table like the one below.

Now plot a graph of your results. Plot linear dimensions on the x (horizontal) axis and surface-area-to-volume ratio on the y (vertical) axis. Describe the trend carefully.

Linear dimensions	Area of one side (l × b)	Total surface area (6 × l × b)	Volume (l × b × h)	Surface-area-to-volume ratio
1				6
2				3
3				
etc.				
10				

So, does it matter if the surface-area-to-volume ratio changes?

To answer this question, we must think about the functions of the surface area of the cell and of the volume of the cell. It is best understood if we think of just one function – that of respiration. A cell respires to release energy to drive all the other cellular processes that take place. If it can't release enough energy, these other processes will slow down and the cell may die. In order to respire, the cell needs oxygen, which enters through the surface of the cell.

- The volume determines how much activity there is in a cell. A large cell will have more processes happening, or at least the same processes happening faster, than a smaller cell. The amount of energy that must be released in respiration is therefore decided largely by the volume.
- The amount of oxygen that can be delivered into the cell is decided largely by how much 'surface' there is, since it is through the surface of the cell that the oxygen enters.

A large surface-area-to-volume ratio means that it is likely that the surface will be able to supply the oxygen demands of the cell. But as cells increase in size, *the volume increases faster than the surface area* and the surface-area-to-volume ratio decreases. How will this affect the ability of the cell to release the energy it needs?

KEY IDEA

Think of this surface-area-to-volume ratio in terms of 'supply' and 'demand'. The volume of the cell creates the 'demand' for oxygen, which is 'supplied' through the surface (area) of the cell.

Review questions

Choose the correct answer from A to D.

1. A compound microscope differs from a simple microscope in that it always has:
   - A more than one objective lens
   - B more than one ocular lens
   - C both ocular and objective lenses
   - D a condenser
2. The word 'cell' was first coined by Robert Hooke when he examined:
   - A living cells in cork tissue
   - B dead cells in cork tissue

Activity 4.4: Debate

Most biologists believe that a high surface area to volume ratio is advantageous to a cell.

Your teacher will divide the class into three groups:

- Group 1 – this group will present arguments to support the idea that a high surface area to volume ratio is advantageous to a cell
- Group 2 – this group will present arguments to support the idea that a low surface area to volume ratio is advantageous to a cell
- Group 3 – this group will form the 'audience' who will:
- question the members of each of the other groups after their presentation
- vote to decide the outcome of the debate

The debate will follow the following procedure:

- Group 1 will present their case (2 minutes)
- Group 2 will present their case (2 minutes)
- Groups 1 and 2 can question the other group and try to disprove their ideas (2 minutes)
- Group 3 (the audience) can question any members of any group (4 minutes)
- Group 3 votes on the issue

C dead cells in skin

D living cells in skin

3. Anton van Leeuwenhoek saw what he called 'animalcules' and 'tiny animalcules'. These were, respectively:

   A bacteria and viruses

   B bacteria and protoctistans

   C protoctistans and viruses

   D protoctistans and bacteria

4. In 1824, Rene Dutrochet stated that:

   A all living cells come from other cells

   B all living things are made of cells

   C cells can be spontaneously generated

   D cells cannot be spontaneously generated

5. The first cell theory stated by Schleiden and Schwann was not completely accurate because it held that:

   A all living things are made of cells

   B the cell is the basic unit of living things

   C the cell retains a dual existence

   D cells form by cell-free formation

6. The first correct cell theory was proposed by:

   A Koliker

   B Virchow

   C Fleming

   D Golgi

7. To convert mm to µm we:

   A multiply by 100

   B divide by 100

   C divide by 1000

   D multiply by 1000

8. 40 divisions on the scale of an eyepiece graticule correspond to 16 small divisions on the stage micrometer.
   Each small division on the stage micrometer = 10 µm.
   4 cells fit across 40 divisions of the eyepiece graticule.
   The length of each cell is:

   A 10 µm

   B 40 µm

   C 40 mm

   D 10 mm

9. Cube A has a side measuring 3 mm. Cube B has a side measuring 12 mm. The surface-area-to-volume ratio of cube A when compared to cube B is:
   A two times bigger
   B two times smaller
   C four times smaller
   D four times bigger
10. The surface-area-to-volume ratio of a cell is important because it is a measure of:
   A how efficiently the cell releases energy in respiration
   B how efficient the cell is in conserving energy
   C how efficient the cell is in obtaining the oxygen it needs for respiration
   C how efficiently the cell uses the energy it releases in respiration

KEY WORD

division of labour *the specialisation of different parts to carry out certain functions*

4.2 Types of cells

By the end of this section you should be able to:

- Appreciate that there are just two basic types of cells: prokaryotic and eukaryotic cells.
- Give examples and describe the basic structure of each type.
- Explain the difference between prokaryotic and eukaryotic cells.

DID YOU KNOW?

The structure of the cell wall and capsule vary between different bacteria. You will learn more about this in grade 12.

What are prokaryotic and eukaryotic cells?

Many biologists believe that **prokaryotic cells** were the first type of cells to be formed when life first evolved. Prokaryotic cells are much smaller and simpler than **eukaryotic cells**; even so these cells must carry out all the same functions that a eukaryotic cell carries out in order to survive. There is therefore some **division of labour** within the cell. There are specialised regions for certain functions. You can see this in figure 4.14.

However, there is much more division of labour in a eukaryotic cell. There are different types of eukaryotic cell, but all of them have a number of features in common. Figure 4.15 shows a generalised animal cell. Most of the structures shown are found in all eukaryotic cells. Plant cells have a number of other structures in addition to these, as figure 4.16 shows.

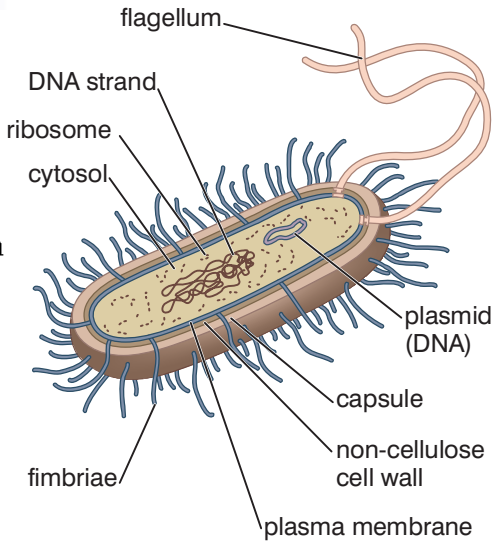


Figure 4.14 *A generalised prokaryotic cell*

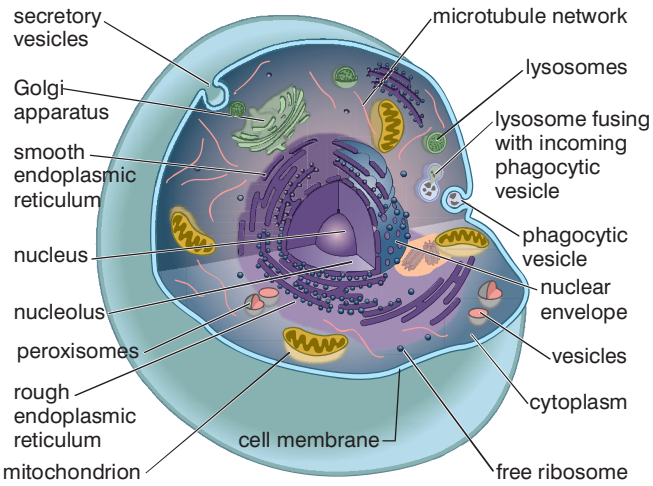


Figure 4.15 *A generalised animal cell*

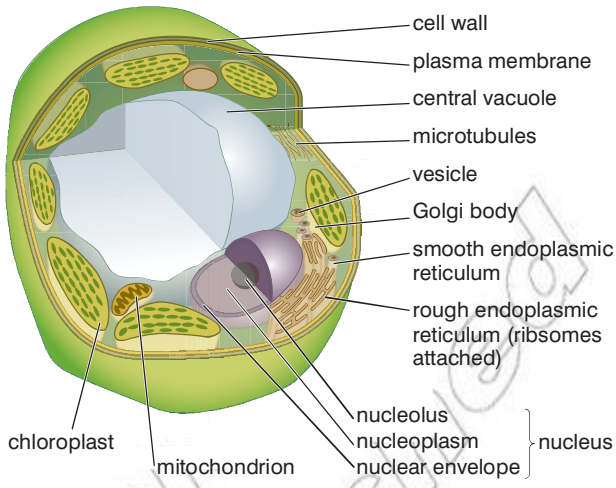


Figure 4.16 *A generalised plant cell*

KEY WORDS

prokaryotic cell *a type of cell that does not have a nucleus. The word prokaryotic is derived from Greek* pro *(before) and* karyos *(nuclear)*

eukaryotic cell *a type of cell that has a nucleus. The word eukaryotic is derived from Greek* eu *(true) and* karyos *(nuclear)*

organelles *individual structures in a cell with a specific function*

endoplasmic reticulum *the network of membranes in a cell*

membrane-bound organelles *organelles surrounded by membranes*

These are clearly much more complex cells than the prokaryotic cell. What is really different about them is that there are many more different individual structures, called **organelles**, in the cell. Also, there are many more membranes in the cell. Some of these form the complex membrane system that is found throughout the cell – the **endoplasmic reticulum**. In addition to these, several of the organelles are surrounded by membranes. These are the:

- nucleus
- mitochondria
- chloroplasts (if present)
- lysosomes
- Golgi apparatus

These are called **membrane-bound organelles**.

These membranes make the cell able to function more efficiently. Because each mitochondrion is enclosed by a membrane (actually by two membranes!), the reactions that take place here are not affected by other cellular reactions. The same applies to the other membrane-bound organelles. Also, membranes of the endoplasmic reticulum separate areas of the cytoplasm and allow them to function independently.

How did eukaryotic cells originate?

One theory is that the 'modern' eukaryotic cell was formed when several of the more primitive prokaryotic cells 'got together'. Over millions of years ancestral prokaryotic cells became more membranous. The plasma membrane around the cell became more and more 'infolded' until there was an extensive membrane system in the cell. This would eventually evolve into the endoplasmic reticulum (EPR) of eukaryotic cells. The next stage in the theory suggests that this membranous cell engulfed other smaller cells that were better at respiring organic molecules to release energy.

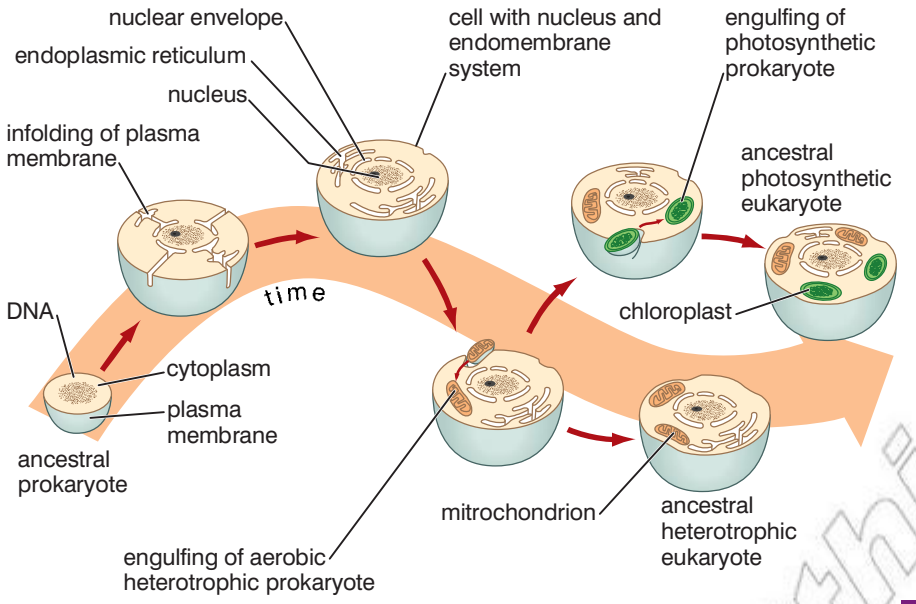


Figure 4.17 The origin of eukaryotic cells

These 'engulfed' prokaryotes would evolve into the mitochondria of eukaryotic cells. The cells that contained them were **heterotrophic** and the forerunners of animal, fungal and protoctistan cells. One further stage suggests that some of these cells with their 'primitive mitochondria' also engulfed other, smaller, prokaryotic cells. These were prokaryotic cells that could photosynthesise and would, in time, evolve into chloroplasts. The cells that contained these would be **autotrophic** and the forerunners of plant cells. This theory of the origin of eukaryotic cells is called the **endosymbiont theory** and was first proposed by the biologist Lynn Margulis.

KEY WORDS

heterotrophic *these cells must absorb organic molecules 'ready-made'*

autotrophic *autotrophic cells are capable of making their own organic molecules from inorganic ones, usually by photosynthesis*

endosymbiont theory *theory of the origin of eukaryotic cells*

DID YOU KNOW?

Which organisms have eukaryotic cells and which have prokaryotic cells?

Figure 4.18 shows the main groups of living things and which of these have prokaryotic and which have eukaryotic cells. The **archaebacteria** are thought to be the oldest organisms on Earth. They evolved when conditions on Earth were very harsh and are still only found where it is very hot, or where there are large concentrations of gases like methane or sulphur dioxide. The **eubacteria** are what you and I really mean when we talk about bacteria. These are the bacteria that inhabit our intestines, decay organisms, convert milk to yoghurt and so on.

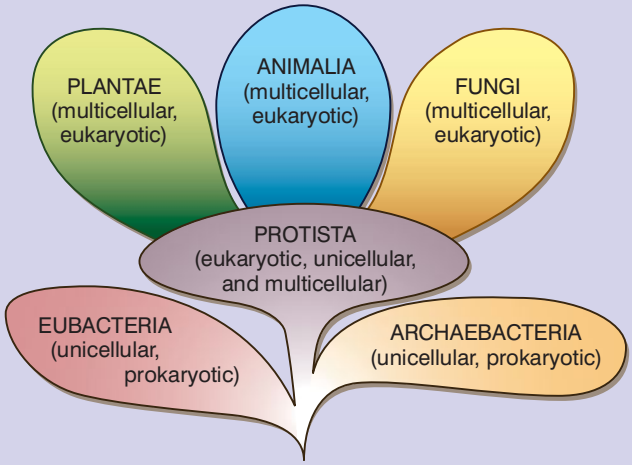


Figure 4.18 The main groups of living things

Activity 4.5

Make a table to compare and contrast the main features of eukaryotic and prokaryotic cells.

What are the differences between prokaryotic and eukaryotic cells?

Table 4.2 *A summary of the main differences between prokaryotic and eukaryotic cells*

Feature	Prokaryotic cells	Eukaryotic cells
Size	1–10 µm	10–100 µm
Nucleus	No membrane-bound nucleus	Nucleus surrounded by nuclear envelope
DNA	• In a continuous loop • Not associated with protein to form chromosomes	• Linear DNA • Associated with histone proteins in chromosomes
Mitochondria	Absent	Present
Chloroplasts	Absent (but some prokaryotic cells contain a kind of chlorophyll and can photosynthesise)	Present in some cells (some plant cells and some algal cells)
Ribosomes	Present, but smaller than in eukaryotic cells (**70S**)	Present, but larger than in prokaryotic cells (**80S**)
Cell wall	• Always present • Not made from cellulose (often made from peptidoglycan)	• Present in plant cells, algal cells and fungal cells • Cellulose in plant cells, various materials in other cells

KEY WORDS

70S *and* **80S ribosomes** *the 'S' stands for 'sedimentation coefficient' and is a measure of their mass*

Review questions

Choose the correct answer from A to D.

1. Differences between prokaryotic and eukaryotic cells are:
   - A prokaryotic cells are smaller but contain more organelles
   - B prokaryotic cells are larger and contain more organelles
   - C prokaryotic cells are larger and contain fewer organelles
   - D prokaryotic cells are smaller and contain fewer organelles
2. The DNA in prokaryotic cells is:
   - A linear and bound with proteins
   - B linear and not bound with proteins
   - C circular and not bound with proteins
   - D circular and bound with proteins

3. Membrane-bound organelles include:
   A ribosomes and mitochondria
   B mitochondria and chloroplasts
   C chloroplasts and peroxisomes
   D peroxisomes and nuclei
4. The cell wall of prokaryotic cells is made from:
   A protein
   B cellulose
   C peptidoglycan
   D another substance
5. It is thought that eukaryotic cells originated by several prokaryotic cells becoming associated. This theory is the:
   A endosymbiont theory
   B membrane association theory
   C both of the above
   D neither of the above

4.3 Parts of the cell and their functions

By the end of this section you should be able to:

- Discuss the importance of a cell membrane.
- Describe the composition and arrangement of lipids and proteins in the membrane.
- Compare the Davson–Danielli and fluid mosaic models.
- Construct and show the arrangement of the phospholipids and proteins in the fluid mosaic model.
- Explain the role of glycoprotein and other components in the cell membrane.
- Name the different parts of the cell and explain their functions.
- State and explain the mechanisms of substance transport across a cell membrane.
- Conduct an experiment to show movement of solvent through a semi-permeable membrane.
- Demonstrate osmosis at a semi-permeable membrane.
- Explain that the size of a cell changes by osmosis because of the inflow and outflow of water.
- Appreciate that osmosis is responsible for everyday life phenomena.

KEY IDEA

The cell's environment could be fluids inside the body of an animal, plant, fungus or alga, or it could be the ocean, a river, a pond, soil or just about anything you care to think of! The plasma membrane of a cell must isolate the cell from that environment, but, at the same time, allow exchange with the environment.

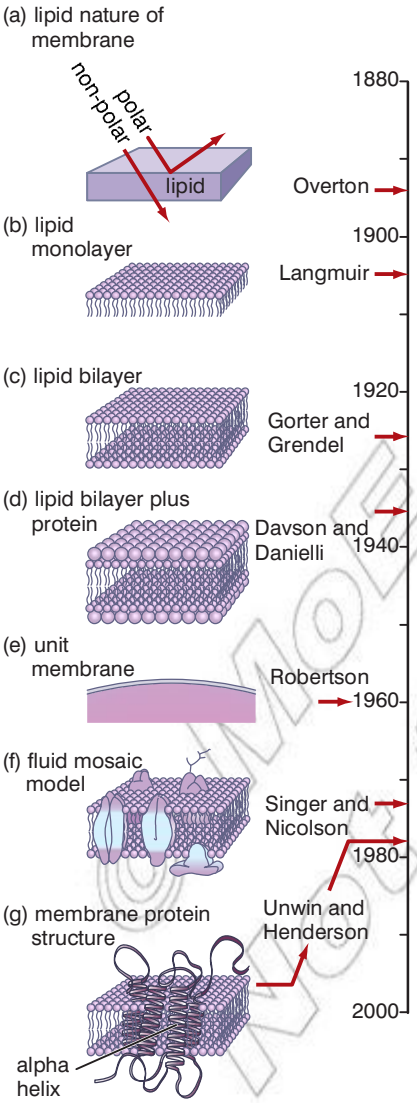


Figure 4.19 *A timeline of the development of our understanding of the structure of the plasma membrane*

What is the importance of the cell membrane?

The membrane that surrounds and encloses a cell is sometimes called the **cell surface membrane**, but most biologists now refer to it as the **plasma membrane**. Although this membrane has little mechanical strength to support the cell, it plays a crucial role in:

- controlling what enters and leaves the cell; the plasma membrane moves substances in and out of the cell by:
  - simple diffusion
  - facilitated diffusion
  - osmosis
  - active transport
  - endocytosis
  - exocytosis
- cell signalling; various molecules in the membrane allow the cell to be recognised by hormones and the immune system (in animals) and (in plants) growth regulator substances, such as auxins.

The plasma membrane clearly has a vital role in isolating the cell from its environment, whilst allowing necessary exchanges with that environment.

What is the plasma membrane like?

We already found out in unit 2 that the basis of plasma membranes is a phospholipid bilayer. But a plasma membrane is much more complex than a simple bilayer. There have been several models of the structure of the plasma membrane. Table 4.3 shows some key events in developing the current model of membrane structure. Figure 4.19 illustrates this history.

Table 4.3 *Key events*

Year	Event
1665	Robert Hooke discovers cells, but only sees dead cells and has no idea of a cell membrane.
1895	Charles Overton shows that the cell membrane is composed of some kind of lipids.
1905	Langmuir proposes a lipid monolayer as the basic membrane structure.
1910–1920	Evidence accumulates to show that the lipid in the membrane must be a phospholipid.
1925	E Gorter and G Grendel suggest that the plasma membrane is a phospholipid bilayer.
1935	Davson and Danielli know that proteins are also found in plasma membranes and suggest a 'sandwich' model.
1959	Based on electron microscope evidence that appears to support the Davson–Danielli model, J D Robertson proposes the unit membrane model – he suggests that all membranes are essentially the same.

Year	Event
1972	S J Singer and G L Nicholson propose the fluid mosaic model of membrane structure. As more and more supporting evidence accumulates, this is essentially the model we accept today.

The Davson–Danielli model

In 1935, Davson and Danielli knew that both proteins and phospholipids were involved in the structure of plasma membranes. Without any direct observational evidence to assist them (the very first electron microscopes were only just being built and they could not reveal membrane structure) Davson and Danielli suggested a kind of 'sandwich' of protein and phospholipid.

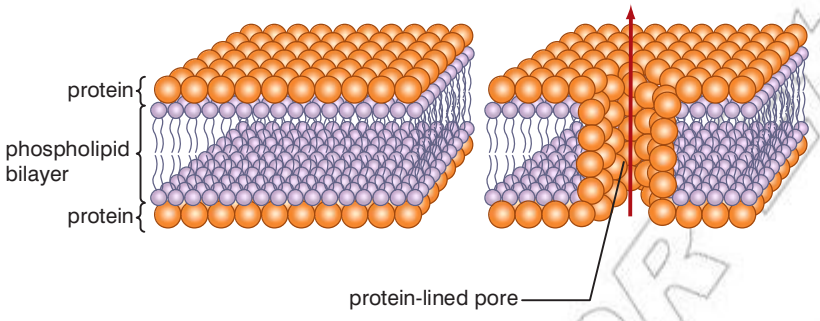


Figure 4.20 *The Davson–Danielli models of 1935 and 1954*

This was based on what they knew of the proportions of the two substances in the membrane. The protein was to form the 'bread' of the sandwich with the phospholipid forming the 'filling'. In 1954 they proposed a revised model in which they included protein-lined pores. Figure 4.20 shows the Davson–Danielli models of 1935 and 1954.

As more and more evidence accumulated about how molecules moved across membranes, it became clear that the Davson–Danielli model could not adequately explain all the new evidence. The model therefore had to be rejected.

In 1972, Singer and Nicholson proposed a totally different arrangement of the phospholipids and proteins in the plasma membrane. They retained the idea of a phospholipid bilayer, but rejected the sandwich arrangement. Instead, they suggested that proteins were 'studded' into the bilayer at different points. They also suggested that the arrangement was not static, but was fluid and constantly changing. Figure 4.21 shows the difference between the Davson–Danielli model and the original fluid mosaic model.

KEY IDEA

Scientific models

Models such as the Davson–Danielli membrane model and the fluid mosaic model are very important in science. But why do we call it a model, and what are scientific models?

- *Models are conceptual plans of some system that try to explain experimental observations and relate the various observations to each other.*
- *A good model incorporates what is known about some concept and adds in the best guesses about missing parts.*
- *A good model will allow you to make predictions about some aspect of the way in which a system works that can be tested experimentally.*
- *Models may, therefore, turn out to be wrong, if the evidence from experiments does not match the predictions. Even so, the model will have served a valuable purpose in eliminating one possible idea and, perhaps, hinting at how to change the model to explain the system we are interested in.*
- *As more evidence accumulates to support a model, it becomes accepted by scientists as the best explanation for the system they are investigating.*

KEY WORDS

plasma membrane/cell surface membrane *the membrane at the surface of all cells that isolates the cell from the environment and controls the exchange of substances between cell and environment*

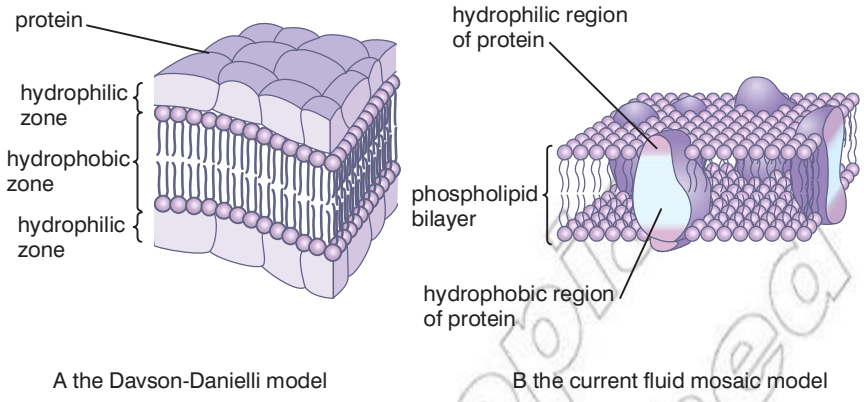


Figure 4.21 *The Davson–Danielli model and the fluid mosaic model*

As our understanding of processes that occur at the plasma membrane has increased and we have learned more of cell structure and function, the fluid mosaic model has become more sophisticated. Our current idea of membrane structure still assumes this fluid-mosaic nature, but there is now much more detail to the model, as figure 4.22 shows.

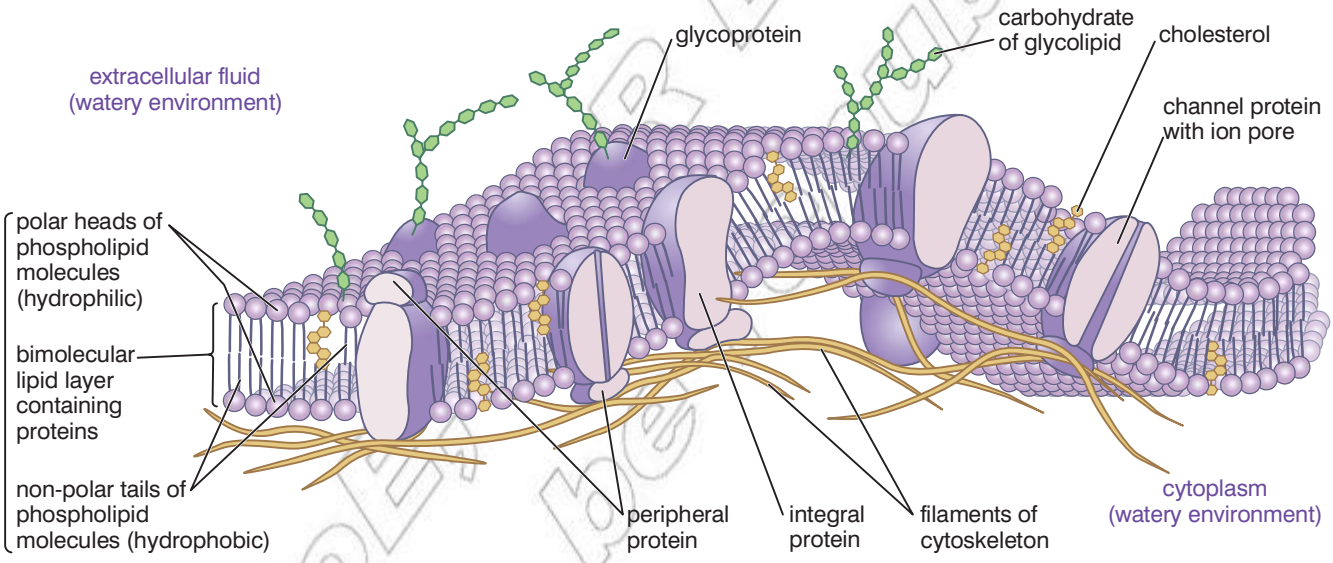


Figure 4.22 *The current fluid mosaic model of membrane structure*

The key features of the model as we currently understand it are:

- The phospholipid bilayer as the basis for the membrane
- **Integral proteins** (also known as intrinsic proteins and trans-membrane proteins) that span the membrane. Some of these proteins play an important role in moving substances across the membrane. There are three main types of these transport proteins:
  - **channel proteins** – these proteins have a channel through them along which a specific ion can pass; there are different channel proteins for different ions
  - **carrier proteins** – these proteins act in a more sophisticated way to move larger molecules through the membrane by facilitated diffusion or active transport; the ones involved in active transport are often referred to as pumps

KEY WORDS

integral proteins *proteins that span both phospholipid layers in a plasma membrane*

channel proteins *integral proteins with pores that allow ions to pass through the membrane*

carrier proteins *integral proteins that move medium-sized particles across the membrane*

– **peripheral proteins** (also known as extrinsic proteins) that span only one layer (or sometimes less) of the membrane. They have a range of functions; some are enzymes, others anchor integral proteins to the cytoskeleton

- **Glycoproteins** and glycolipids – protein and lipid molecules that have carbohydrate chains attached to them and often serve as signals to other cells. They also act as receptor sites for hormones and drugs. The carbohydrate component of each can be cell-specific and so allow identification of the cell by the immune system.
- **Cholesterol** – reduces the fluidity of the membrane.

DID YOU KNOW?

Receptors are the 'way in' for unwanted substances

Some viruses are able to bind with some of the receptors on the plasma membrane and gain entry to the cell as a consequence. Some bacterial toxins enter in the same way.

DID YOU KNOW?

Why is the fluid mosaic model called the fluid mosaic model?

It is fluid mainly because the phospholipids in the membrane can move and change position. Figure 4.23 shows some ways in which they do this.

The nature of the fatty acids (saturated or unsaturated) and the amount of cholesterol in the membrane both influence the fluidity of the membrane.

The 'mosaic' part of the name comes from the way the proteins in the membrane give a patchwork appearance when viewed from the inside or outside. This is rather like a mosaic.

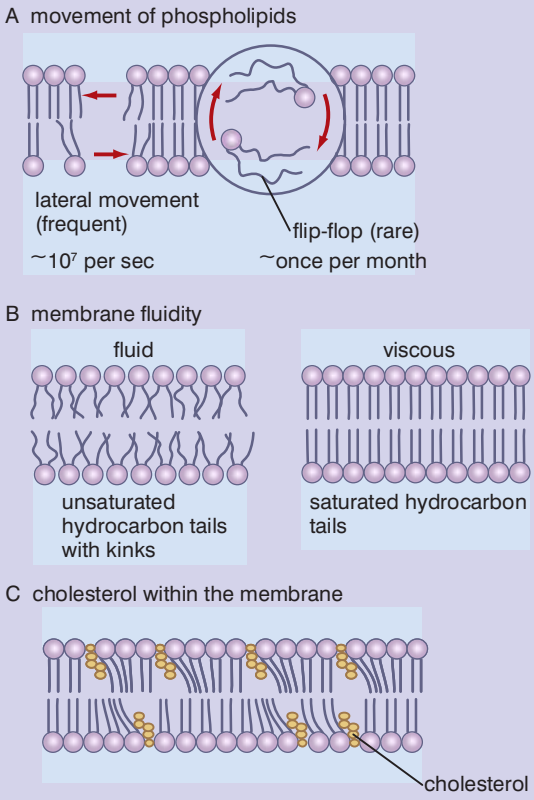


Figure 4.23 *Fluidity of the plasma membrane*

How do substances cross the plasma membrane?

Not all particles can actually pass through a plasma membrane unaided. This is because of the largely lipid nature of the membrane. To pass through the plasma membrane by simple diffusion particles must be:

- small
- lipid soluble
- non-charged

This excludes particles such as ions (they are charged), sugars and amino acids (they are not lipid soluble and are not small particles) and any of the really large particles, such as proteins.

KEY WORDS

peripheral proteins *proteins that span only one of the two phospholipid layers*

glycoproteins *proteins with chains of sugars attached*

cholesterol *a sterol lipid*

We can group the processes by which substances cross plasma membranes into two main types:

- **passive processes** – these processes rely only on the kinetic energy of the particles of the substances and on concentration gradients; they need no extra energy from the cell's metabolism
- **active processes** – these require energy from the cell's metabolism in the form of ATP to drive the transport.

Table 4.4 summarises the transport processes.

Table 4.4 The transport process

Passive processes		Active processes	
Process	**Brief description**	**Process**	**Brief description**
Simple diffusion	Particles move from a high concentration to a low concentration.	Active transport	Particles move from a low concentration to a higher concentration using a carrier protein (pump).
Facilitated diffusion	Particles move from a high concentration to a low concentration through an ion pore or carrier protein.	Endocytosis	Large particles are engulfed by the plasma membrane invaginating and forming a vesicle.
Osmosis	Water molecules move from a high water potential to a lower one.	Exocytosis	Large particles are secreted by a vesicle in the cell merging with the plasma membrane to release the substance.

Activity 4.6

Work in groups. EITHER make a big poster to show the fluid mosaic model of the structure of the membrane of a eukaryotic cell OR make a 3-D model of the fluid mosaic model of the structure of the membrane of a eukaryotic cell.

Passive processes

Simple diffusion

In fluids – liquids and gases – the particles that make up the fluid are free to move around. This kinetic energy is what drives diffusion. If particles are, for some reason, concentrated in a small area, they will move in such a way that the particles 'spread out' and occupy all the space that is available to them. This is a result of random particular motion. Diffusion need not involve a membrane.

When particles diffuse across a plasma membrane, there must be a concentration difference between the two sides of the membrane (a concentration gradient) to drive the process. As diffusion proceeds, the high concentration will decrease and the low concentration will increase until the two concentrations are the same. At this point there will be no further net diffusion.

This means that although particles will still move across the membrane, they will move equally in both directions, so there will be no overall effect. We say that the concentrations are in equilibrium. Figures 4.24 and 4.25 show this.

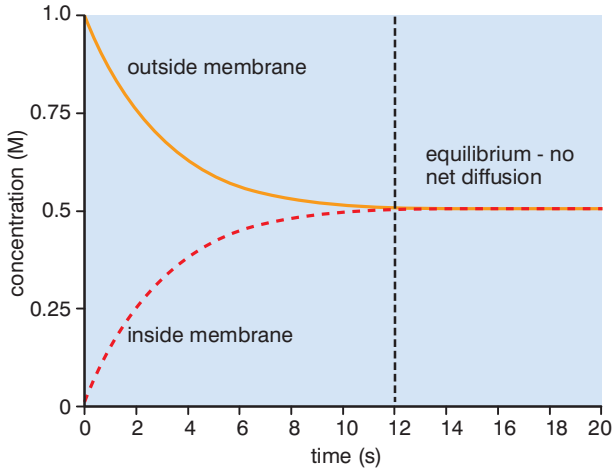


Figure 4.24 The change in concentrations as diffusion proceeds

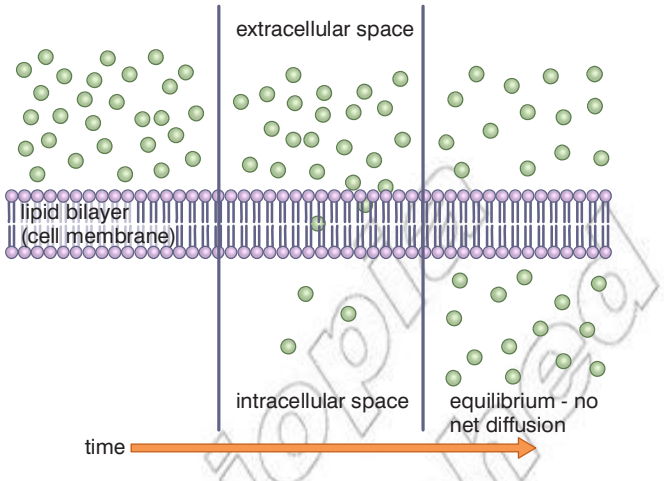


Figure 4.25 The change in concentrations across a membrane as diffusion proceeds

The rate at which diffusion across a membrane takes place is influenced by:

- the concentration gradient – a bigger difference in concentration results in faster diffusion than a smaller gradient
- the thickness of the membrane – as all plasma membranes are the same thickness, this is not really an issue when considering diffusion into and out of cells, but for other situations where particles must cross some kind of barrier, a shorter distance results in faster diffusion
- the surface area of the membrane – clearly if there is more membrane where diffusion can take place, diffusion will happen faster

These features are all related in an equation called Fick's law of diffusion:

$$\text{Rate of diffusion} \propto \frac{\text{Surface area of membrane} \times \text{Concentration difference}}{\text{Diffusion distance}}$$

The rate of diffusion is also influenced by temperature. Diffusion occurs faster at higher temperatures because the particles have more kinetic energy and so move faster.

Facilitated diffusion

Facilitated diffusion is essentially the same process as diffusion, in that it depends on a concentration gradient to allow particles to cross the membrane. However, it differs in that the particles must be helped to diffuse across the membrane (their diffusion must be 'facilitated') by a carrier protein or a channel protein with an ion pore. Figure 4.26A shows facilitated diffusion of an ion through an ion pore. Figure 4.26B shows a carrier protein moving particles across a membrane.

Note in both cases that the particles are moving from a high concentration to a low concentration (as with simple diffusion).

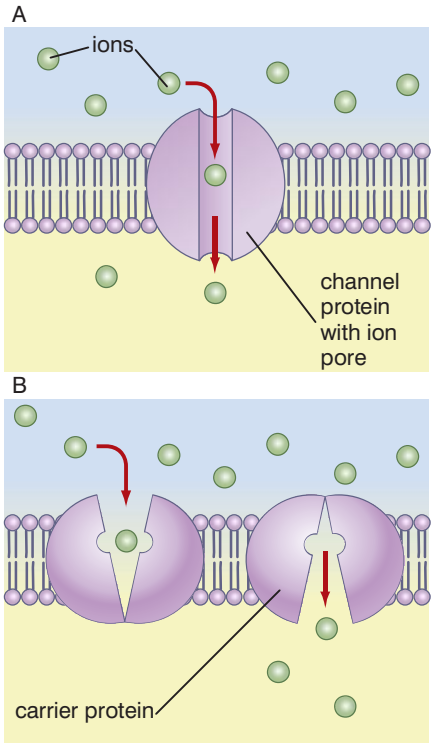


Figure 4.26 Facilitated diffusion through A an ion pore and B a carrier protein.

DID YOU KNOW?

Saturation of carrier proteins

Although increasing the concentration gradient will increase the rate of both simple diffusion and facilitated diffusion, a point will come with facilitated diffusion when all the carrier proteins are transferring particles as fast as they can. At this point we say that the carrier proteins are saturated and facilitated diffusion can go no faster.

KEY WORD

water potential *the concentration of water molecules*

However, also note that whilst the ions can simply move straight through the ion pore of a channel protein, the carrier protein must undergo a conformational change (change in shape) to move particles through the membrane.

The rate of facilitated diffusion is affected by the same factors that affect simple diffusion with the exception that it is not the actual surface area of the membrane that determines the rate, but the number of carrier proteins (or channel proteins) present.

Osmosis

Osmosis is the process by which water moves across a partially permeable membrane. It is, effectively, the diffusion of water. However, we do not refer to the concentration of water molecules, but to **water potential**. We can say that osmosis is the movement of water from a system with a high water potential to a system with a low water potential across a partially permeable membrane.

The symbol for water potential is the Greek letter Ψ (psi). Water potential is measured in units of pressure – pascals (Pa), kilopascals (kPa) or megapascals (MPa). Pure, liquid water has a higher water potential than any other system. It is defined as zero:

$$\Psi \text{ (pure water)} = 0 \text{ Pa}$$

All other systems (cells, solutions and suspensions) have a water potential that is lower than that of water. Therefore, their water potential values must be negative. So we can define osmosis more accurately as follows:

Osmosis is the movement of water from a system with a high (less negative) water potential to one with a lower (more negative) water potential, across a partially permeable membrane.

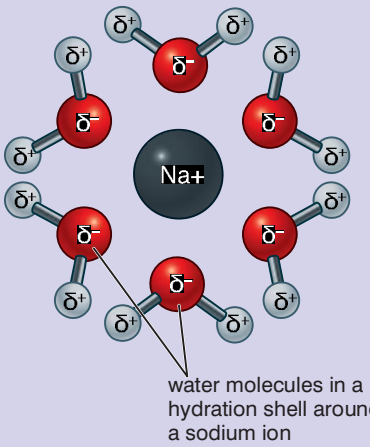


Figure 4.27 *Adding a solute reduces the water potential of a system*

DID YOU KNOW?

Why water potential values are negative

The water potential of a system is due to the concentration of free water molecules in that system. In pure water, there are only water molecules. When a solute is added, some of the water molecules form 'hydration shells' around the solute molecules. This reduces the number of (free) water molecules in the system and so the water potential is reduced. Since pure water is assigned a water potential of zero, the solution must have a negative water potential. A more concentrated solution will take more free water molecules out of the system and lower the water potential still further, making it more negative.

The rate at which osmosis proceeds is influenced by the same factors as simple diffusion:

- surface area of the membrane
- difference in water potential
- distance the molecules must travel

What happens to cells placed in solutions of different concentrations?

This depends on what type of cell. Animal cells have no cell wall, whereas plant cells do and this has a significant influence on the outcome. The difference in water potential between cell and solution will determine whether water enters or leaves by osmosis.

When comparing the water potential of a solution to that of a cell, we could describe it as:

isotonic – having the same water potential as the cell

hypertonic – having a lower (more negative) water potential than the cell

hypotonic – having a higher (less negative) water potential than the cell

KEY WORDS

isotonic *solution having the same water potential as the cell*

hypertonic *solution having lower water potential than the cell*

hypotonic *solution having a higher water potential than the cell*

Activity 4.7: Osmosis in an Egg

In this investigation, you will use a hen's egg which has had the shell removed by soaking in vinegar (the acid in the vinegar dissolves the calcium carbonate that makes up the shell)

You will need:

- 1-2 fresh hen eggs (shells fremoved)
- masking tape & marker
- distilled water,
- concentrated salt (sodium chloride) solution
- clear jar with lid,
- tongs,
- electronic balance,

Procedure:

- use tongs to *carefully* remove an egg to a paper towel & pat it dry.
- record the size & appearance of your egg in a table
- place the egg on an electronic balance & record
- *carefully* place the egg into the jar and cover the egg with distilled water
- loosely re-cap the jar & allow it to sit for 24 hours
- repeat the procedure with another egg, but cover this egg in concentrated sodium chloride solution (rather than distilled water)
- open the jars & discard the distilled water/sodium chloride solution
- use tongs to carefully remove the eggs to a paper towel and pat them dry
- record the size & appearance of the eggs in your data table.
- weigh the egg on an electronic balance & record the mass in your table

What happened to:
(a) the size of the egg
(b) the mass of the eggf

after soaking in:
(i) distilled water?
(ii) concentrated sodium chloride solution?

Explain these changes using your knowledge of osmosis.

Results table

Solution used	Original mass / g	Final mass / g	Size and appearance of egg
Distilled water			
Concentrated salt			

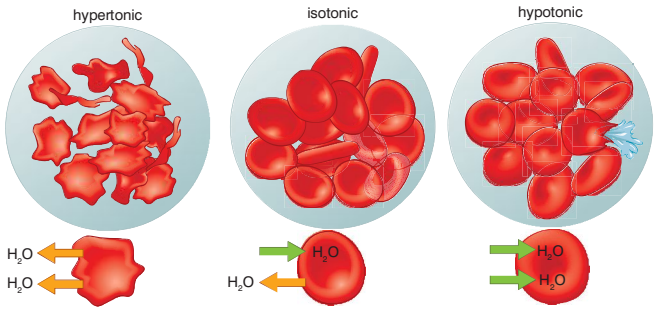


Figure 4.28 *The effect of different solutions on red blood cells*

Animal cells

Figure 4.28 shows what happens when red blood cells are placed in different solutions.

In the hypertonic solution, the cells lose water by osmosis and shrink.

In the hypotonic solution, the cells gain water by osmosis and swell. The pressure will eventually burst the weak plasma membrane: this is called haemolysis.

There is no change in the isotonic solution.

Plant cells

Figure 4.29 shows what happens when plant cells are placed in different solutions.

In the hypertonic solution, the cytoplasm of the cells loses water by osmosis and shrinks. Because of this, there is no pressure from the cytoplasm on the cell wall. The cell is said to be flaccid. If the cytoplasm shrinks too much, it loses contact with the cell wall and we say the cell has been plasmolysed.

In the hypotonic solution, the cells gain water by osmosis and swell. However, because of the cell wall, the cell cannot become much larger. Plant cells in this condition are turgid.

There is no change in the isotonic solution.

Turgidity is important in supporting young, non-woody plant stems. If the plant is kept well watered, the cells will remain turgid. The turgid cells will press against each other and this pressure will keep the plant upright. If the plant is not watered, the cells will be plasmolysed and become flaccid. They will no longer press against each other and the support will be lost. The plant will wilt.

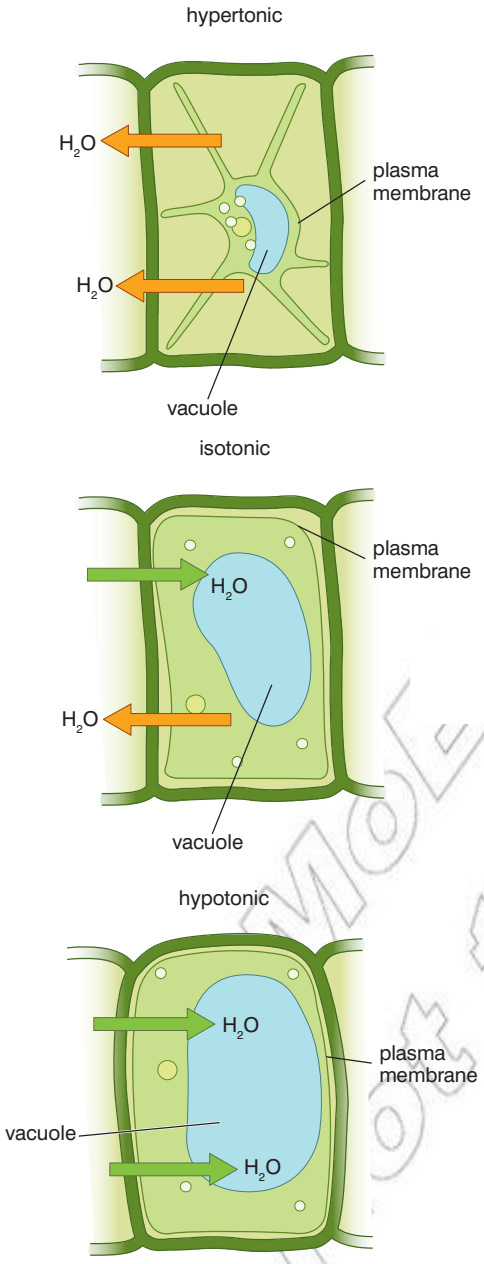


Figure 4.29 *The effect of different solutions on plant cells*

Activity 4.8: Investigation showing the pressure generated by different solutions

You will need:

- a thistle funnel
- clamp and stand
- cellophane to act as the membrane
- distilled water
- 0.2M, 0.4M, 0.6M, 0.8M and 1.0M solutions of sucrose
- a ruler

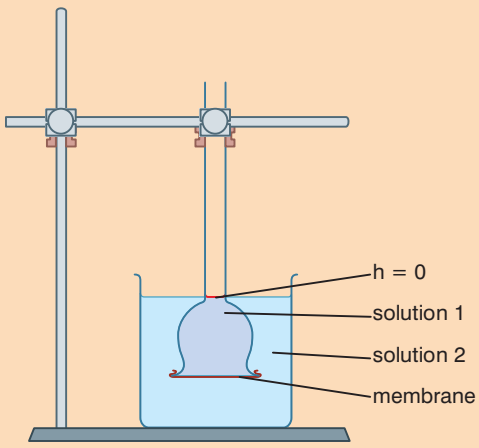


Figure 4.30 *Investigating the osmotic pressure generated by different solutions*

Method

1. Set up the apparatus as shown with distilled water on both sides of the membrane.
2. Leave for 30 minutes.
3. Measure the increase in height of the water inside the thistle funnel.
4. Repeat with 0.2M, 0.4M, 0.6M, 0.8M and 1.0M solutions of sucrose inside the membrane (solution 1) and distilled water outside the membrane (solution 2).
5. Plot a graph of your results.
6. What conclusion can you draw?

Figure 4.31 The effect of watering a plant

Activity 4.9: Finding the water potential of potato cells

Method

1. Collect about 100 cm^3 1M sucrose and 100 cm^3 water in separate beakers.
2. Label six boiling tubes A–F.
3. Make up dilutions of the 1M sucrose solution supplied as below. Use a separate 10 cm^3 syringe for the water and for the sucrose.

Tube	Amount of sucrose/cm^3	Amount of water/cm^3	Final concentration/M
A	20	0	1.0
B	16	4	0.8
C	12	8	0.6
D	8	12	0.4
E	4	16	0.2
F	0	20	0.0

4. Prepare a table for your results; you will need columns for initial mass, final mass, change in mass and % change in mass.

Solution	Mass at the start/g	Mass at the end /g	Change in mass /g	% Change in mass
Distilled water				
0.2M sucrose				
0.4M sucrose				
0.6M sucrose				
0.8M sucrose				
1.0M sucrose				

5. Using a cork borer obtain six cylinders of potato tissue.
6. Trim each to a length of 5 cm. Cut off any 'skin' from the ends.
7. Roll each on absorbent paper to remove any surface water.
8. Weigh each and note the mass.
9. Place each cylinder in one of the solutions and leave for 30 minutes.
10. Remove each from the solution; roll each on absorbent paper to remove any surface water and reweigh.
11. Calculate the % change in mass for each.
12. Plot a graph of % change in mass against molarity and use the graph to estimate the molarity of the solution that has the same water potential as the potato cells.

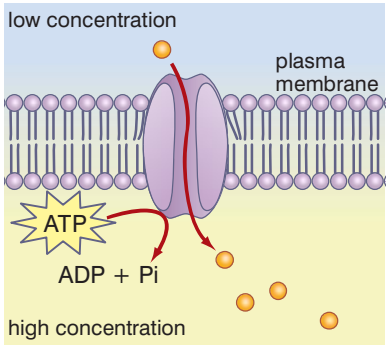


Figure 4.32 *Active transport*

Active processes

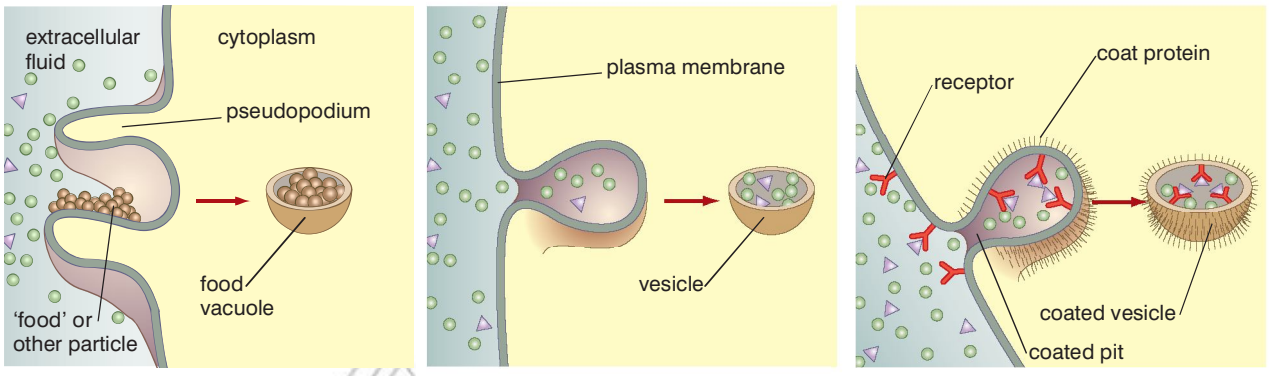
Active transport

Sometimes, substances must be moved against a concentration gradient – from a low concentration to a higher one. This cannot happen by diffusion, since it would tend to concentrate particles rather than spread them out. It can only happen if metabolic energy is used to drive the process. In living organisms, this energy is released from the ATP produced in respiration. When the energy is released from ATP, it is broken down into ADP and P_i (inorganic phosphate). The proteins used to actively transport substances across plasma membranes are called pumps.

Endocytosis

In this process, large particles are engulfed by a cell. There are several ways in which it can happen, but, essentially, part of the plasma membrane surrounds the particles to form a vesicle which is then processed by the cell. Figure 4.33 shows three different types of endocytosis. All of them require ATP to move the membrane around the particles to form the vesicle.

Figure 4.33 *Endocytosis can occur in a number of ways.*



A phagocytosis

B pinocytosis

C receptor-mediated endocytosis

Phagocytosis

This involves the creation of pseudopodia (extensions of the plasma membrane) to enclose large particles or even whole organisms outside the cell. Once enclosed by the pseudopodia, they form an internal vesicle which is then moved further inside the cell.

Pinocytosis

This differs from phagocytosis only in scale. It involves the ingestion of smaller particles (but particles that are still too large to cross the membrane by other methods) and does not require the formation of large pseudopodia to engulf the particles.

Receptor-mediated endocytosis

The membrane infolds to form vesicles only in regions where particles have bound to specific receptors. The binding stimulates the infolding.

Exocytosis

In this process, substances are moved from the inside to the outside of the cell in what is, effectively, the reverse of endocytosis. It is the process by which enzymes and hormones are secreted. Again, ATP is used to alter the configuration of the membrane.

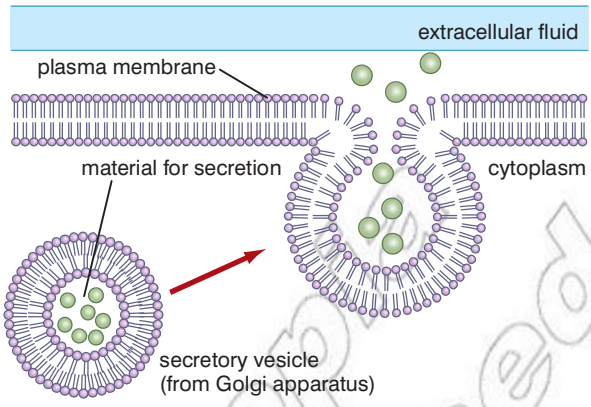


Figure 4.34 Exocytosis

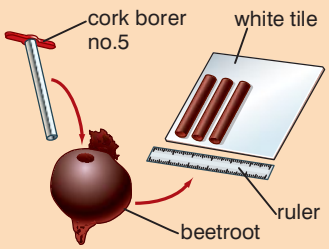
Table 4.5 The transport processes compared

Process	Influence of concentration	Requirement for ATP?	Type of particles moved	Transport proteins needed?
Simple diffusion	Occurs from high to low	No	Lipid-soluble, small, non-polar	No
Facilitated diffusion	Occurs from high to low	No	Ions and medium-sized particles	No
Osmosis	Occurs from high to low (water potential)	No	Water molecules	No
Active transport	Occurs from low to high	Yes	Ions and medium-sized, non-lipid-soluble particles	Yes
Endocytosis	Can occur either way	Yes	Very large particles	Yes
Exocytosis	Can occur either way	Yes	Very large particles	Yes

Activity 4.10: How does temperature affect the permeability of a plasma membrane?

Method

1. Set up water baths at 20 °C, 30 °C, 40 °C, 50 °C, 60 °C and 70 °C.
2. Using a cork borer, obtain 10 cylinders from beetroot (you may have to use more than one).



3. Cut off the 'skin' at the ends.
4. Cut each into 1 cm lengths – you will need 30.
5. Place them in a beaker and rinse under running water until the water no longer shows any colouration.

DO NOT PUT THE BEETROOT IN THE BOILING TUBES YET.

6. Place 10 cm^3 water into each of six boiling tubes; label them 20 °C, 30 °C, 40 °C, 50 °C, 60 °C and 70 °C.
7. Stand each in the appropriate water bath for five minutes to equilibrate to temperature.
8. Add five beetroot discs to each tube and leave for 15 minutes (**still in the water bath**). Start to clear away whilst you are waiting.
9. After 10 minutes, remove the tubes and shake them for 10 seconds to distribute any pigment.
10. Transfer a sample of the liquid to a cuvette.
11. Obtain a reading of absorbance for each sample. Remember to zero the colorimeter with a reference cuvette of distilled water each time.
12. Record your results in a table then use them to plot a line graph. Explain your results using your knowledge of membrane structure.

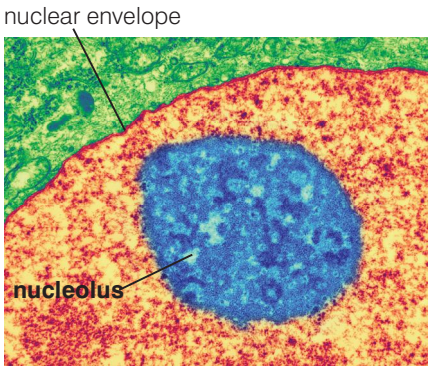


Figure 4.35 *An electron-micrograph of the nucleus*

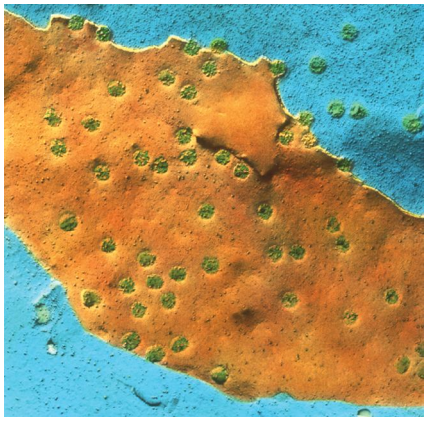


Figure 4.36 *An electron-micrograph showing pores in the nuclear membrane*

KEY WORDS

cristae *partial partitions in mitochondria*

fluid matrix *where some of the reactions of aerobic respiration take place in mitochondria*

DID YOU KNOW?

ATP is the 'energy storage molecule' of cells. Energy released in respiration is stored in ATP molecules, to be released and used when needed. Cells that are very active (such as muscle cells or epithelial cells that absorb molecules from the gut) use a great deal of ATP and, therefore, contain many mitochondria.

The other cell organelles – what are they like and what do they do?

In this section, we will discuss the other organelles in outline only. We shall discover their functions in more detail as we discuss the metabolic processes they carry out.

The nucleus

The nucleus typically occupies about 10% of the volume of a cell. It has several components:

- The nuclear envelope is a double membrane that surrounds the nucleus. There are many nuclear pores, which allow the passage of some molecules between the nucleus and the cytoplasm.
- The nucleolus is an organelle within the nucleus. It is not membrane-bound. Its function is to synthesise the components of ribosomes, which then pass through the nuclear pores into the cytoplasm.
- Chromatin consists of DNA molecules bound with proteins called histones. For most of the cell cycle, the chromatin fibres are loosely dispersed throughout the nucleus. Just before a cell is about to divide, the chromatin condenses into distinct, recognisable structures called chromosomes.

Mitochondria

Mitochondria are the sites of most of the reactions of aerobic respiration. They are surrounded by two membranes. The inner membrane is folded into **cristae** to increase the available surface area. Some of the reactions of aerobic respiration take place in the **fluid matrix**. The folded inner membrane provides a large surface area for the electron-transport system, which produces most of the ATP.

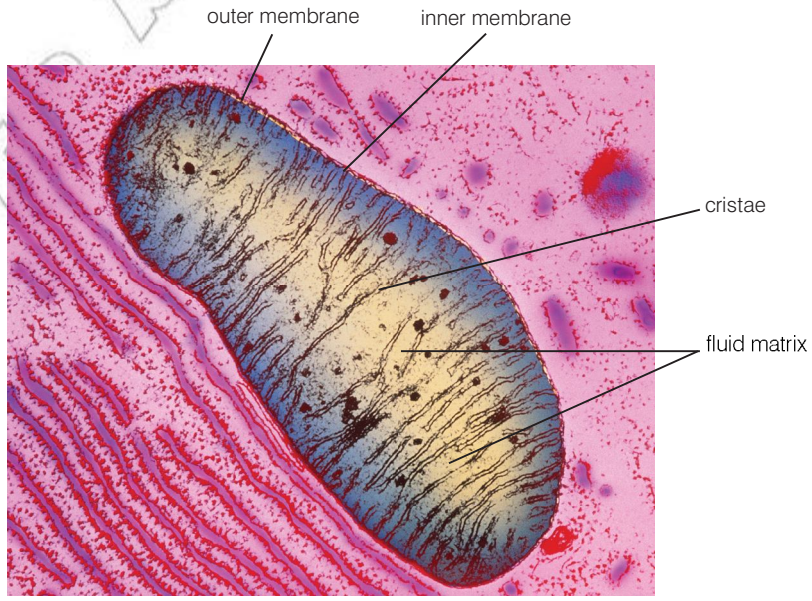


Figure 4.37 *An electron-micrograph of a mitochondrion*

Ribosomes

Ribosomes are the sites of protein synthesis. They can be found free in the cytoplasm, but are also bound to the membrane system of the endoplasmic reticulum, forming rough endoplasmic reticulum. Each ribosome comprises two subunits that are made from RNA and protein. The subunits are manufactured in the nucleolus. They leave the nucleus through nuclear pores and combine in the cytoplasm.

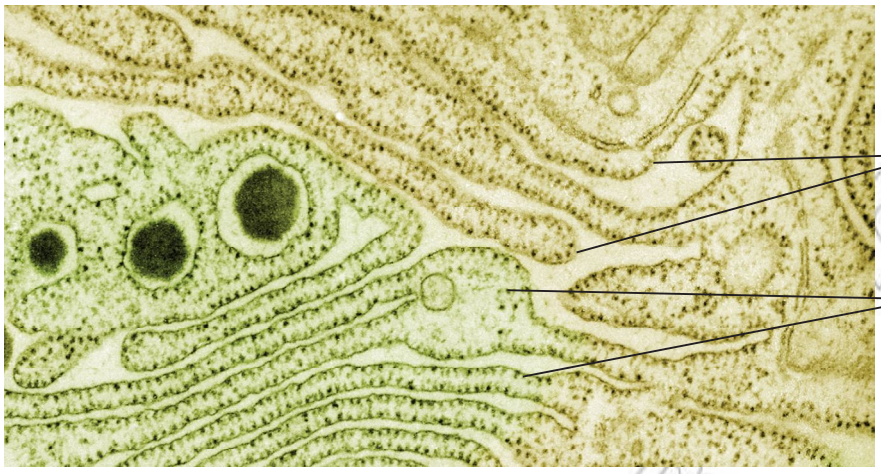


Figure 4.38 *Rough endoplasmic reticulum with ribosomes attached*

Endoplasmic reticulum

Endoplasmic reticulum (ER) is a membrane system found throughout the cytoplasm of eukaryotic cells. There are two types of endoplasmic reticulum:

- **Rough ER** has ribosomes on its surface and is responsible for the manufacture and transport of proteins. Protein molecules manufactured by the ribosomes pass through small pores into the lumen (inner space) of the ER. They are then moved in a vesicle to the Golgi body. Rough ER is extensive in cells that manufacture a lot of protein, such as cells that manufacture enzymes to be secreted into the lumen of the intestine.
- **Smooth ER** has no ribosomes on its surface. It is concerned with the synthesis of lipids. It is also associated with carbohydrate metabolism and detoxification.

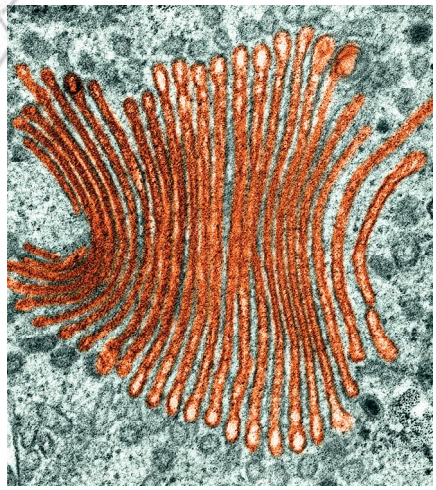


Figure 4.39 *An electron-micrograph of the Golgi apparatus*

Golgi apparatus (or Golgi body)

The Golgi apparatus consists of a number of flattened membrane-bound sacs in which proteins are modified. Proteins may be converted into glycoproteins, for example. Many of the modifications added in the Golgi apparatus act as a kind of 'tag', which determine the final destination of the molecule. Think of the Golgi apparatus as a cellular post office that labels and then distributes molecules!

Many of the modified molecules are released from the Golgi apparatus in vesicles to be carried to other parts of the cell or to the plasma membrane to pass out of the cell by exocytosis to be used elsewhere. Some vesicles form the lysosomes.

Figure 4.40 *An artist's impression of the Golgi apparatus*

KEY WORDS

grana *membranous regions in a chloroplast*

thylakoids *flattened sacs inside a chloroplast where photosynthesis takes place*

Lysosomes

Lysosomes have no specialised internal structure and are surrounded by a single membrane. They are formed in the Golgi apparatus and contain digestive enzymes that break down cellular waste and debris. Lysosomes are particularly abundant in phagocytic white blood cells. Here, enzymes from the lysosomes digest foreign cells that have been engulfed.

The organelles we have described so far are found in all eukaryotic cells. However, not all eukaryotic cells are the same. In particular, there are important differences between plant and animal cells.

Organelles found in plant cells

Cell wall

We have studied the molecular structure of the cell wall in unit 2. The criss-cross arrangement of cellulose fibres in the cell wall gives it both strength and elasticity. Because there are large 'gaps' (on a molecular scale) between the fibres, the cell wall is freely permeable.

Vacuole

The vacuole in a plant cell is a fluid-filled sac that stores a range of solutes. It is also important in maintaining the turgidity, or turgor, of a cell. When the vacuole is full of liquid (mainly water), it exerts pressure on the cytoplasm and, in turn, on the cell wall. If the vacuole loses water by osmosis, the pressure reduces and turgor is lost. The cell becomes flaccid (see the section on osmosis).

Chloroplast

Figure 4.41 is an electron-micrograph showing the structure of a chloroplast. Chloroplasts are surrounded by two membranes, like mitochondria, but, unlike mitochondria, the inner membrane is not folded. There are two main regions in chloroplasts that are linked to the stages of photosynthesis:

- membranous regions called **grana** (each of which is a stack of **thylakoids**) where the light-dependent reactions occur, and
- a fluid stroma – where the light-independent reactions occur.

Figure 4.41 *An electron-micrograph of a chloroplast*

How have biologists been able to study the different organelles?

This has been possible because of a technique called cell fractionation. The technique is based on the fact that the masses of organelles vary and depend on their size. When a mixture of organelles is spun in a centrifuge, the various types settle out at different speeds of spinning. The large nucleus requires a relatively low centrifuge speed to make it settle out; the much smaller ribosomes require a much higher speed. The technique is carried out as follows:

- The cell sample is stored in a suspension that is:
  - buffered – the neutral pH prevents damage to the structure of proteins, including enzymes
  - isotonic (of equal water potential) – this prevents osmotic water gain or loss by the organelles; gaining too much water could rupture the organelles
  - cool – this reduces the overall activity of enzymes released later in the procedure
- The cells are homogenised in a blender and filtered to remove debris.
- The homogenised sample is placed in an ultracentrifuge and spun at low speed. The nuclei settle out, forming a pellet.
- The supernatant (the suspension containing the remaining organelles) is spun at a higher speed – chloroplasts settle out (if plant tissue is used).
- The supernatant is spun at a higher speed still – mitochondria settle out.
- The process is repeated at ever higher speeds until all the organelles have been separated.
- The process is shown in figure 4.43.

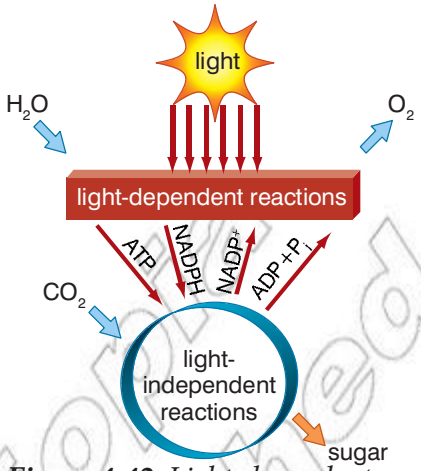


Figure 4.42 *Light-dependent and light-independent reactions of photosynthesis*

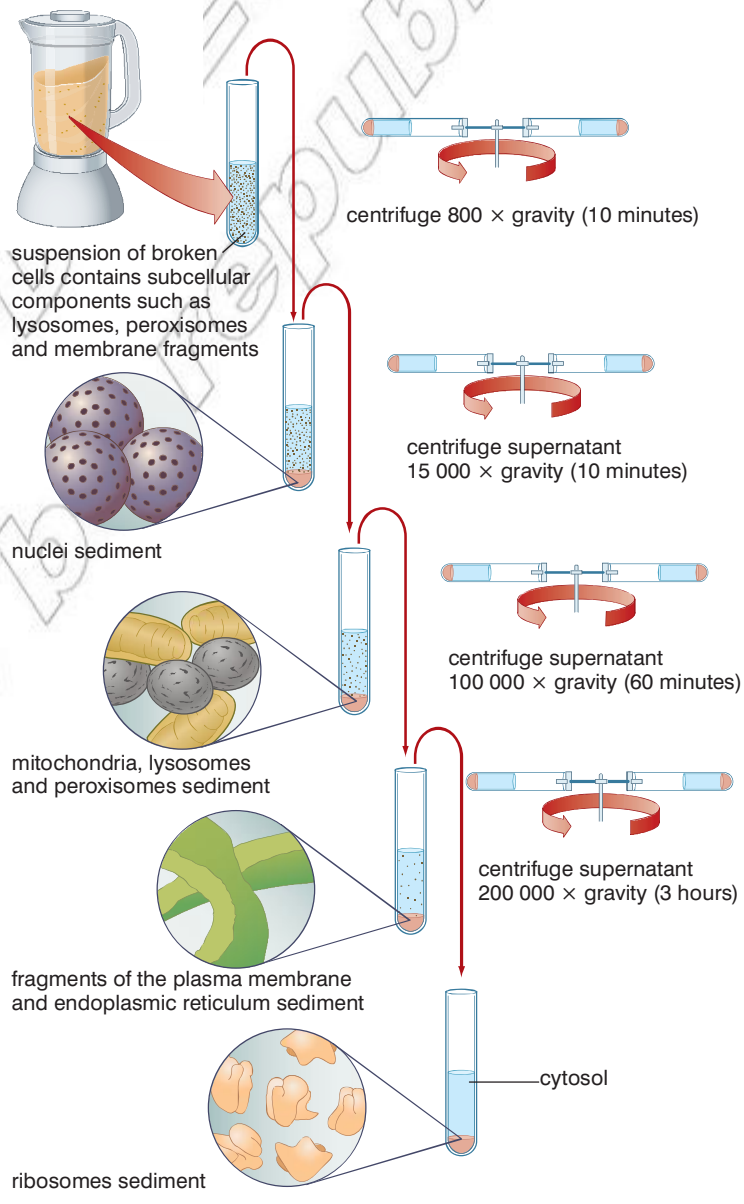


Figure 4.43 *Cell fractionation*

Review questions

Choose the correct answer from A to D.

1. To convert millimetres to micrometres:
   - A multiply by 1000
   - B divide by 100
   - C divide by 1000
   - D multiply by 100
2. The functions of the rough endoplasmic reticulum and the Golgi body are related because:
   - A proteins synthesised by the rough endoplasmic reticulum are modified by the Golgi body
   - B proteins synthesised by the Golgi body are modified by the rough endoplasmic reticulum
   - C lipids synthesised by the Golgi body are modified by the rough endoplasmic reticulum
   - D lipids synthesised by the rough endoplasmic reticulum are modified by the Golgi body
3. In cell fractionation, the purpose of keeping the tissue sample in an isotonic solution in a refrigerator prior to homogenisation is:
   - A to prevent osmotic damage to the cells and to reduce the metabolic activity of the cells
   - B to prevent osmotic damage to the cells and to increase the metabolic activity of the cells
   - C to prevent osmotic damage to the organelles and to reduce the metabolic activity of the cells
   - D to prevent osmotic damage to the organelles and to increase the metabolic activity of the cells
4. Which of the following is not part of the structure of mitochondria?
   - A a double membrane surrounding the organelle
   - B a fluid matrix inside the organelle
   - C stacks of membranes know as thylakoids
   - D folds of membranes known as cristae
5. The plasma membrane provides:
   - A structural support for the cell and regulates which substances enter and leave
   - B structural support for the cell but does not regulate which substances enter and leave

C no structural support for the cell and does not regulate which substances enter and leave

D no structural support for the cell but regulates which substances enter and leave

6. The principle behind separating cell organelles by ultracentrifugation is that:

A the various organelles have different masses

B the various organelles have different volumes

C the various organelles have different shapes

D the various organelles have different widths

7. Which of the following does not use energy in the form of ATP?

A active transport

B endocytosis

C facilitated diffusion

D phagocytosis

8. Which of the following statements concerning mitochondria and chloroplasts is correct?

A Only mitochondria are surrounded by two membranes.

B The inner membrane of chloroplasts is folded into cristae.

C Both organelles have a fluid interior.

D Mitochondria contain stacks of membranes called thylakoids.

9. If red blood cells are immersed in a hypotonic solution, they will:

A take in water by osmosis, swell and become turgid

B lose water by osmosis and shrink

C lose water by osmosis and burst

D take in water by osmosis, swell and burst

10. In the fluid mosaic model of membrane structure, intrinsic proteins can be:

A glycoproteins

B ion channel proteins

C carrier proteins

D all of the above

Summary

In this unit you have learnt that:

- A cell is the smallest unit of life capable of independent existence.
- The cell theory proposed by Schleiden and Schwann stated:
  - the cell is the unit of structure, physiology and organisation in living things
  - the cell retains a dual existence as:
    - a distinct entity, and
    - a 'building block' in the formation of organisms.
- Virchow added another important idea which was that all cells come from pre-existing cells.
- Modern cell theory also includes the ideas that:
  - cells contain hereditary information which is passed from cell to cell during cell division
  - all cells have basically the same chemical composition
  - all energy flow (the metabolism and biochemistry of life) occurs within cells
- Dimensions of cells are measured in units derived from the metre, including:
  - millimetre, mm = 0.001 m
  - micrometre, µm = 0.000,001 m (0.001 mm)
  - nanometre, nm = 0.000,000,001 m (0.001 µm)
- We can measure the size of cells using an eyepiece graticule calibrated by a stage micrometer.
- As cells increase in size, the surface-area-to-volume ratio decreases; this affects their ability to obtain the resources they need to carry out their metabolism.
- There are two main types of cells: prokaryotic cells and eukaryotic cells; the table shows the differences between them.

Feature	Prokaryotic cells	Eukaryotic cells
Size	1–10 µm	10–100 µm
Nucleus	No membrane-bound nucleus	Nucleus surrounded by nuclear envelope
DNA	• In a continuous loop • Not associated with protein to form chromosomes	• Linear DNA • Associated with histone proteins in chromosomes
Mitochondria	Absent	Present
Chloroplasts	Absent	Present
Ribosomes	Smaller than in eukaryotic cells (70S)	Larger than in prokaryotic cells (80S)
Cell wall	• Always present • Not made from cellulose	• Present in some • Cellulose in plant cells

- Animal cells contain a nucleus, mitochondria, lysosomes, ribosomes, ER (rough and smooth) as well as Golgi apparatus, all enclosed within a plasma membrane.
- Plant cells contain all the same organelles but also contain chloroplasts, a cellulose cell wall and a permanent vacuole.
- The organelles of cells have specific functions:
  - the nucleus contains DNA which controls the metabolism of the cell
  - mitochondria carry out aerobic respiration to release energy from organic molecules and store it in the ATP molecule
  - ribosomes synthesise proteins from amino acids
  - lysosomes contain hydrolytic enzymes that digest worn-out or damaged organelles as well as engulfed bacteria
  - the Golgi body modifies proteins and distributes them to the appropriate part of the cell
  - chloroplasts in plant cells carry out the reactions of photosynthesis
  - the plant cell wall supports and protects the contents of the cell; it is freely permeable to all molecules
  - the vacuole in plant cells contains a solution of mineral ions and sugars; it is important in maintaining the turgor of the cell
- The current model of the structure of the plasma membrane is called the fluid mosaic model; most biologists now prefer this model to Davson and Danielli's 'sandwich' model.
- The fluid mosaic model suggests that:
  - the plasma membrane is based on a phospholipid bilayer
  - cholesterol molecules in this bilayer reduce the fluidity of the membrane
  - the plasma membrane has protein molecules 'studded' in the bilayer
  - some proteins are intrinsic (trans-membrane), whilst others are extrinsic (only span part of the membrane)
  - proteins can be:
    - channel proteins with ion pores
    - carrier proteins for facilitated diffusion or for active transport
    - glycoproteins for cell signalling and cell recognition
- Molecules pass through the plasma membrane in several ways, summarised in the table overleaf.

Activity 4.11

Work in groups. This is a revision exercise. Each group should draw or make a model of one cell organelle and research as much as possible about that organelle. Each group then presents the details of their organelle and its role in the cell to the rest of the class.

Process	Influence of concentration	Requirement for ATP?	Type of particles moved	Transport proteins needed?
Simple diffusion	Occurs from high to low	No	Lipid-soluble, small, non-polar	No
Facilitated diffusion	Occurs from high to low	No	Ions and medium-sized particles	No
Osmosis	Occurs from high to low (water potential)	No	Water molecules	No
Active transport	Occurs from low to high	Yes	Ions and medium-sized, non-lipid-soluble particles	Yes
Endocytosis	Can occur either way	Yes	Very large particles	Yes
Exocytosis	Can occur either way	Yes	Very large particles	Yes

- Cell fractionation separates the components of a cell by centrifugation, heavier organelles being isolated at lower centrifuge speeds.

End of unit questions

1. a) Schleiden and Schwann were the first biologists to put forward a tenable cell theory.

   (i) State two ideas of this theory that we still accept today.

   (ii) State one idea of this theory that we reject today.

   (iii) Name the biologist who modified Schleiden and Schwann's theory to make it acceptable to us.

   b) State the cell theory as we understand it today.

2. Describe the role of each of the following in the development of a cell theory:

   a) Robert Hooke

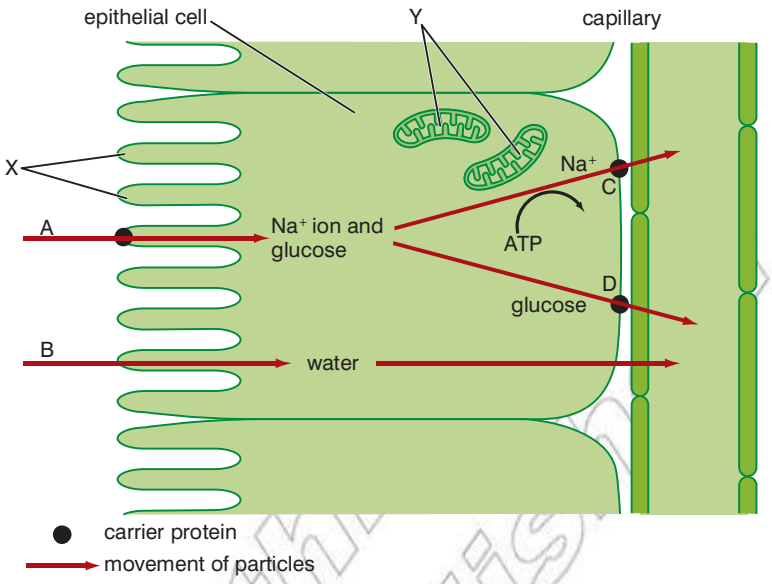
   b) Anton van Leeuwenhoek

   c) Rene Dutrochet

3. Copy and complete the table.

Feature	Prokaryotic cells	Eukaryotic cells
Size	1–10 µm	
Nucleus		
DNA	• in a continuous loop	• •
Mitochondria		
Ribosomes	70S ribosomes	

4. The diagram represents the uptake of glucose, sodium ions and water by an epithelial cell in a kidney tubule.



   a) Suggest how the structures labelled X help to maintain a high rate of absorption from the lumen of the kidney tubule.

   b) Explain how the presence of the organelles labelled Y is essential to the absorption of glucose.

   c) Name, with a reason, the transport process occurring at A, B, C and D.

5. The table below shows the percentage masses of protein, lipid and carbohydrate in four different plasma membranes.

Membrane	Percentage mass		
	Protein	Lipid	Carbohydrate
A	18	79	3
B	51	49	0
C	52	44	4
D	76	24	0

   (i) Calculate the mean ratio of protein to lipid for the four membranes.

   (ii) Describe two functions of proteins in plasma membranes.

   (iii) Describe one function of carbohydrates in plasma membranes.

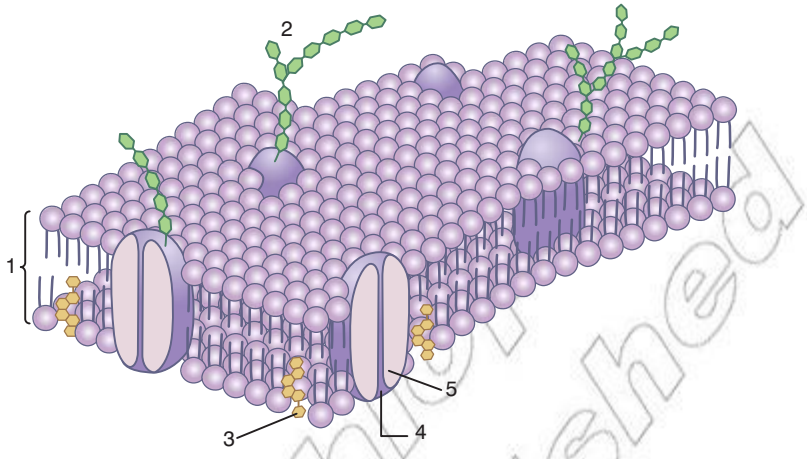
   (iv) Suggest why plasma membrane D has a much higher protein content than plasma membrane A.

6. a) Copy and complete the table showing the functions of cell organelles.

Organelle	Function
	Contains DNA, regulates cell metabolism
Ribosome	
	Site of aerobic respiration, produces most of the ATP in a cell
	Modifies structure of protein molecules
Lysosome	
Chloroplast	
	Controls entry and exit of substances from cell
	Gives cell support and rigidity

   b) Describe the main stages in the process of cell fractionation. Explain why each stage is necessary.

7. The diagram shows the structure of a plasma membrane.



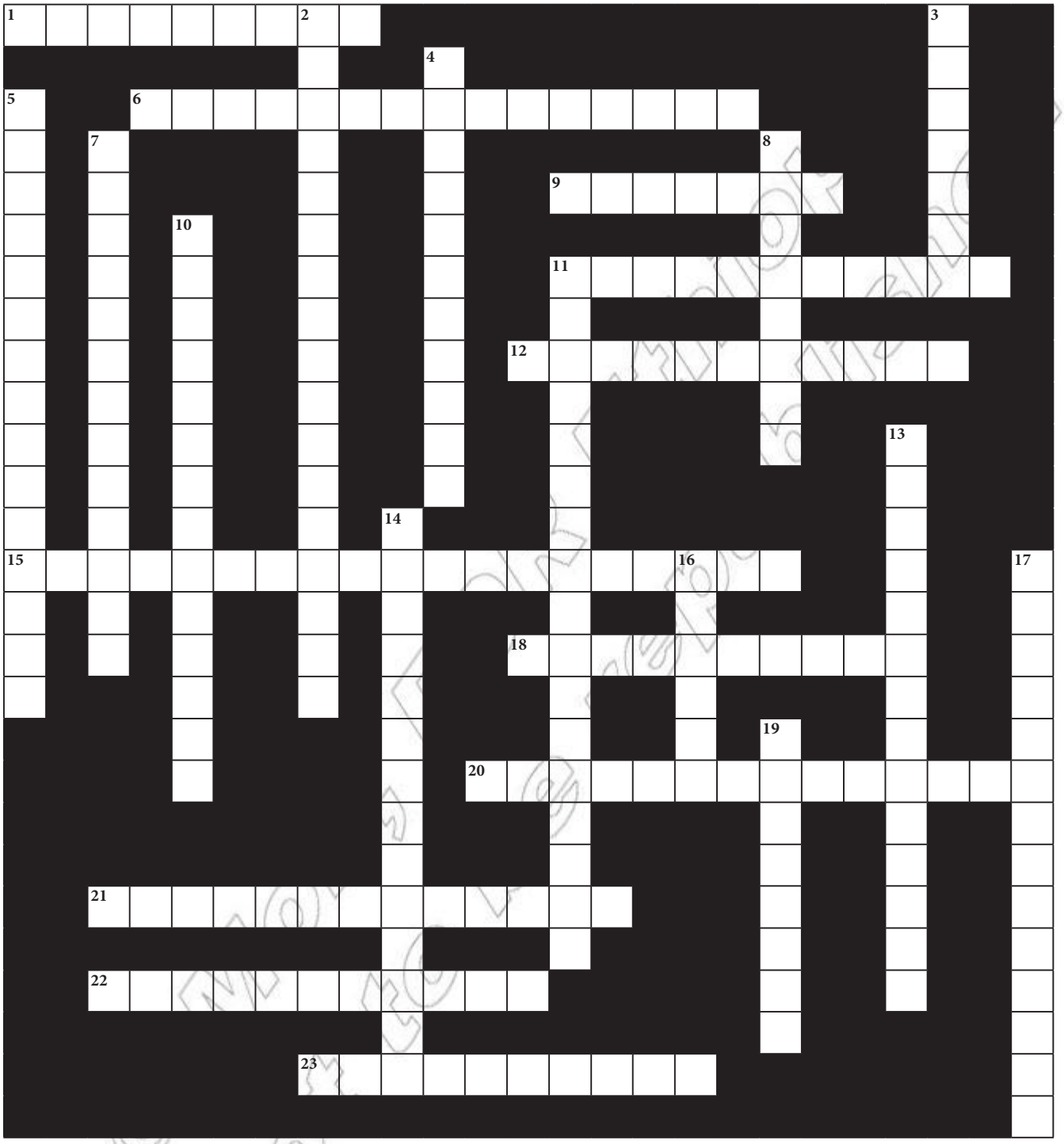
a) Name the structures numbered 1, 2, 3 and 4.

b) Describe the function of the structure labelled 5.

c) This model of the structure of a membrane is called the fluid mosaic model. Explain why.

8. Write a short essay to describe the history of the development of modern cell theory. In your essay, try to explain why events happened as and when they did. You will be given credit for logical presentation and breadth of coverage as well as for scientific accuracy.

Copy the crossword puzzle below into your exercise book (or your teacher may give you a photocopy) and solve the numbered clues to complete it.



Across

1. The organelle in which proteins are modified (5, 4)
6. Process that moves particles across the plasma membrane against the concentration gradient (6, 9)
9. The process by which water moves across the plasma membrane (7)
11. The site of photosynthesis in a plant cell (11)

12. The model of plasma membrane structure proposed by Sanger and Nicholson in 1972 (5, 6)
15. The Germans who proposed the first cell theory (9, 3, 7)
18. Unit in which the size of cells and cell organelles is measured (10)
20. The membrane at the surface of the cell (6, 8)
21. The site of aerobic respiration in a cell (13)
22. This Englishman drew dead cork cells that he saw through his microscope (6, 5)
23. Cells with chromosomes and membrane-bound organelles (10)

Down

2. These biologists suggested that the plasma membrane was a 'sandwich' of protein and lipid (6, 3, 8)
3. The organelle that controls all the cell's activities (7)
4. Cells with no true nucleus (11)
5. Process by which small, lipid-soluble and non-polar particles cross the plasma membrane (6, 9)
7. The German who stated that 'a cell can only arise from another cell like it' (6, 7)
8. The site of protein synthesis in a cell (8)
10. A measure of the free energy of water molecules in a solution (5, 9)
11. The procedure that allows biologists to separate different cellular organelles (4, 13)
13. A protein in the plasma membrane that moves medium-sized particles across the membrane (7, 7)
14. Anton … the Dutchman who saw 'animalcules' and bacteria through an early microscope (3, 11)
16. This famous organism has only one cell (6)
17. A protein in the plasma membrane that allows ions to cross (7, 7)
19. Organelles like the nucleus, mitochondrion and chloroplast are said to be … bound (8)