# Module 1: Cells
# Cell structure

## Microscopy

### Key concepts you must understand

**Size matters**

It is very difficult to imagine the range of sizes that biologists deal with. A blue whale can be as long as 30 m. The largest viruses are about 0.0004 mm. Many plant and animal cells are between 0.02 mm and 0.04 mm.

We use microscopes in biology because much of what we want to see is so small. Many cells, for example, are about 0.02 mm across. At best, our eyes can only make out things that are about 0.1 mm in size, so using our eyes alone we would never see structures inside cells. The light microscope (LM) uses a beam of light that is focused by means of glass lenses. The electron microscope (EM) uses a beam of electrons focused by magnetic lenses.

**Units**

The units to use for measuring microscopic structures are the micrometre (μm) and the nanometre (nm). Remember:

- to convert millimetres to micrometres, multiply by 1000
- to convert micrometres to nanometres, multiply by 1000

Also remember:

- 1 μm (micrometre) = 0.001 mm; 1000 μm = 1 mm
- 1 nm (nanometre) = 0.001μm; 1000 nm = 1 μm

### Key facts you must know

**Resolution** is the ability to see detail. The LM has a resolution of 0.0002 mm. This means that two points this distance apart are viewed as separate objects. Visible light has a wavelength of between 400 nm and 700 nm. Objects about half the size of the wavelength interrupt the rays of light and are resolved in the LM. However, anything smaller than 0.0002 mm is not visible because it is too small to interrupt the light. No matter how much a photograph taken through the LM is enlarged, small cellular structures are never visible.

**Magnification** is the ratio between the actual size of an object and the size of an image, such as a photograph or a drawing.

Examiners may ask you to calculate magnifications or actual sizes. You should use these formulae:

magnification = size of image/actual size

actual size = size of image/magnification

With the LM, some structures, such as mitochondria, are just visible.

### Electron microscopes

The wavelength of an electron beam is about 1 nm, so objects half this size are visible. As the resolution is so good, the magnification can be very high (×250 000 or more). In the EM, magnets focus beams of electrons and an image is formed when the electrons strike a fluorescent screen or photographic film. The **transmission electron microscope (TEM)** is used to view thin sections of tissues. The **scanning electron microscope (SEM)** is used to view surfaces of three-dimensional objects, such as the bodies of insects and surfaces of cells.

Inside electron microscopes is a vacuum. This allows electrons to travel towards the specimen and afterwards strike a fluorescent screen or photographic film. It means, however, that living cells cannot be observed, since they would explode. In the light microscope, it is possible to watch living processes, such as cell division.

| Characteristic | Light microscope | Electron microscope |
|---|---|---|
| Wavelength | 400–700 nm | 1.0 nm |
| Resolution | 200 nm | 0.5 nm |
| Useful magnification | up to ×1000<br>(at best ×1500) | up to ×100 000 in SEM<br>up to ×250 000 in TEM |

***Table 1 The main characteristics of light and electron microscopes***

### Staining

Most biological material is colourless or transparent, and is composed of elements with low atomic mass. This means that visible light travels through tissues in the LM without being absorbed or reflected, so there is very little, if any, contrast. This problem is solved by adding stains, such as iodine, methylene blue and toluidine blue, all of which you may use during your course. Stains used in electron microscopy are salts of heavy metals, such as lead and uranium. These combine with proteins, for example in membranes, and absorb or scatter electrons as they pass through the specimen. This makes these areas show dark on photographs taken using the EM.

**Links** You may be asked to find the actual size of a cell or organelle in an electron micrograph or in a drawing made from an electron micrograph. Measure in millimetres, multiply by 1000 and divide by the given magnification to give an answer in micrometres (μm). You may also be asked to calculate the magnification of a cell or an organelle in an electron micrograph. You will be told the actual size in micrometres. Measure the size of the cell in millimetres, convert into micrometres by multiplying by 1000 and divide by the actual size. If you calculate a size, check it looks right. Here are some examples of things you may be asked: cells, 10–100 μm; chloroplasts, 3–10 μm; mitochondria, 1–3 μm; bacteria, 0.5–30 μm; membranes, 7–10 nm. If your answers are very different from these values, then you must have made a mistake. Sometimes you will be asked to give your answer to the nearest whole number, which means you may have to round your answer down or up.

# Cell structure and function

## Key facts you must know

### Cell ultrastructure

The fine structure of cells that is visible with an electron microscope is often called **cell ultrastructure**. Many of the structures (**organelles**) in plant and animal cells, such as chloroplasts and mitochondria, are made of membranes. Within the cytoplasm of plant and animal cells are fibrous structures composed of protein, which form the **cytoskeleton**. These fibrous structures include microfilaments, made from the protein actin, and microtubules, made from tubulin. Cilia, undulipodia and centrioles are composed of microtubules. Ribosomes are made of protein and ribonucleic acid (RNA).

Animal and plant cells are **eukaryotic** because they have a nucleus and organelles.

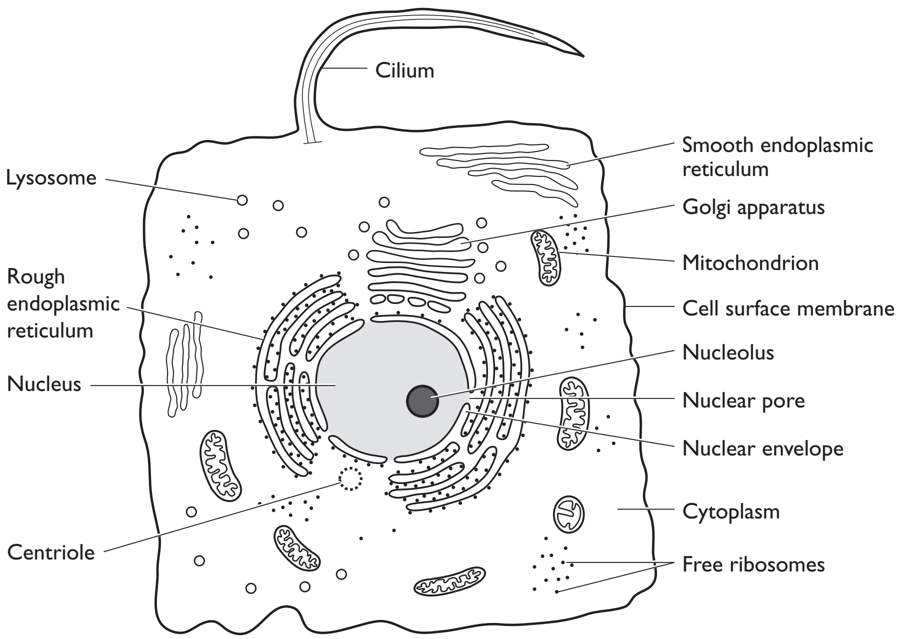


***Figure 1 A generalised animal cell viewed with the electron microscope***

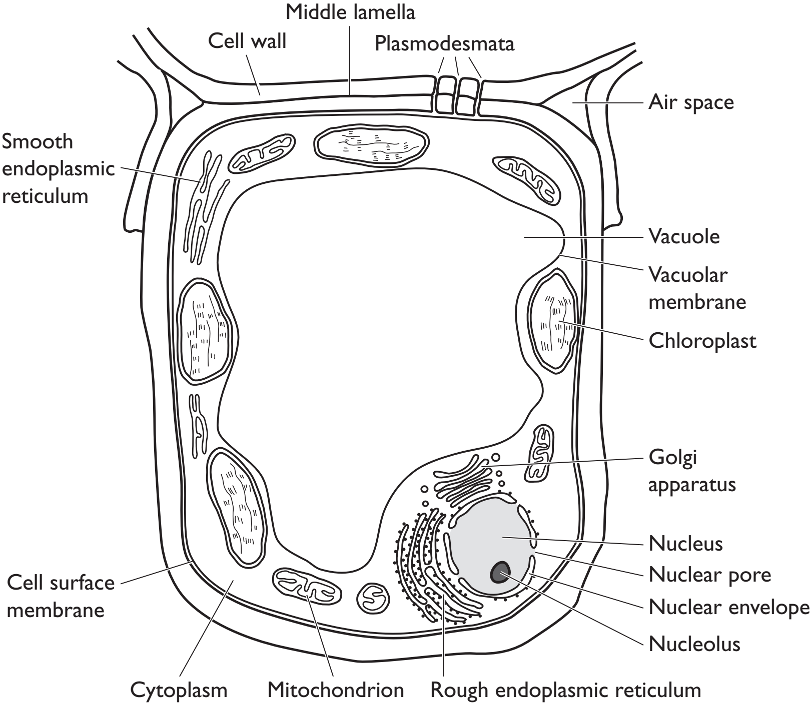


***Figure 2 A generalised plant cell viewed with the electron microscope***

### Functions of cellular structures

Table 2 summarises the features and functions of the main cellular structures in animal and plant cells.

| **Cellular structures** | **Features** | **Function(s)** |
|---|---|---|
| Rough endoplasmic reticulum (RER) | Flat sacs of membrane enclosing fluid-filled space; outer surface is covered in ribosomes | Ribosomes carry out protein synthesis; RER transports proteins to Golgi apparatus |
| Smooth endoplasmic reticulum (SER) | Like RER but with no ribosomes on outer surface | Makes triglycerides (fats), phospholipids, cholesterol |
| Golgi apparatus | Pile of flat sacs with vesicles forming around the edge | Modifies proteins by adding carbohydrates; packages proteins; makes lysosomes |
| Mitochondria (singular: mitochondrion) | Formed of two membranes surrounding a fluid-filled matrix; inner membrane is highly folded to give large surface area for enzymes of respiration | Site of aerobic respiration |
| Ribosomes | Attached to RER or free in cytoplasm — made of protein and RNA | Assemble amino acids to make proteins |

| Cellular structures | Features | Function(s) |
|---|---|---|
| Lysosomes | Single membrane surrounds fluid filled with enzymes | Contain enzymes for destroying worn out parts of cell and for digesting food particles |
| Chloroplasts | Many internal membranes, giving large surface area for chlorophyll, other pigments and enzymes of photosynthesis | Site of all the reactions of photosynthesis |
| Plasma (cell surface) membrane | Several (see pp. 19–20 for details) | Controls entry and exit of materials; retains cell contents |
| Nuclear envelope | Structure like that of ER, with ribosomes on outer surface; pores to allow substances to pass between cytoplasm and nucleus | Separates nucleus from cytoplasm |
| Nucleus | Clearly visible in LM and EM when stained | Contains genetic information as DNA in chromosomes |
| Nucleolus | Darkly staining area in nucleus | Produces ribosomes |
| Microfilaments | Made of actin — a type of protein | Provide mechanical support for cells; part of the cytoskeleton |
| Microtubules | Made of tubulin — a type of protein formed into hollow tubes | Part of the cytoskeleton; provide pathways within cells to enable vesicles and organelles to move about within the cytoplasm; form cilia, undulipodia and centrioles; form the spindle to move chromosomes during anaphase of nuclear division |
| Cilia (singular: cilium) | Extend from cell surface; made of microtubules arranged into a '9+2' arrangement in the shaft (9 peripheral microtubules and 2 central ones); no central microtubules in the base; extend from cell surface; surrounded by plasma membrane | Found in large groups; move fluid or mucus past cells (e.g. in the trachea); move eggs along the fallopian tube |
| Undulipodia (singular: undulipodium) | As for cilia | Found singly to move individual cells, e.g. sperm in animals and in some plants, such as ferns and mosses |
| Centrioles | Made of microtubules in same arrangement as in base of a cilium; not found in flowering plants | Assemble the spindle to move chromosomes when nuclei divide in animal cells (see pp. 28–29) |

***Table 2 Sub-cellular structures found in animal and plant cells***

## Key concepts you must understand

The cells depicted in Figures 1 and 2 are 'generalised' cells. They do not exist! They are drawn to show all the structures in plant and animal cells. You should look carefully at photographs taken through the light microscope (these are known as photomicrographs, or PMs) to see the differences between plant and animal cells. Sometimes you will be expected to identify organelles from electron micrographs (EMs) or from drawings made from electron micrographs. You should become proficient at recognising the organelles and using this information to explain how the structure of a cell, such as a sperm cell or a guard cell, is related to its function. There are many examples of how to do this throughout this Unit Guide and in the one for Unit F212.

**Links** Aspects of cell structure and function occur throughout the AS course. For example, in Module 2 of this unit you will study red blood cells and how they carry oxygen and carbon dioxide. In Module 2 of Unit F212 you will study the action of phagocytes and lymphocytes in defence against disease-causing organisms. You should look at PMs and EMs of these cells and relate structure to function.

You should also look at the function of organelles. Some of the organelles in Table 2 on pp. 15–16 are involved in the production of protein. Figure 1 in Question 1 on p. 73 shows you how the nucleus, RER, Golgi apparatus and secretory vesicles work together to make and secrete a protein.

# Prokaryotes

## Key facts you must know

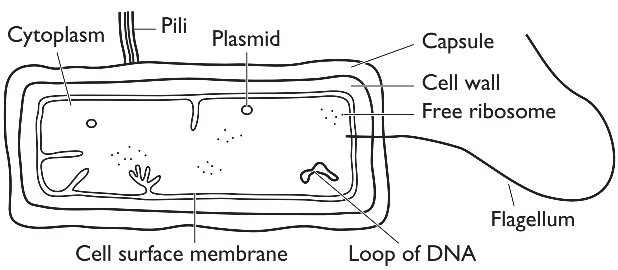


***Figure 3 A generalised prokaryotic cell***

Prokaryotic cells do not have a nucleus and have no organelles made of membranes. Most are smaller than eukaryotic cells.

| | |
|---|---|
| **Structures shared with eukaryotic cells** | Cytoplasm; ribosomes; cell surface membrane |
| **Structures from eukaryotic cells never found in prokaryotic cells** | Nucleus; nucleolus; nuclear envelope; mitochondria; Golgi apparatus; chloroplasts; cilia; vacuoles |
| **Structures only found in prokaryotic cells** | Ring of DNA (sometimes called bacterial chromosome) |
| **Structures found in some prokaryotic cells** | Small rings of DNA known as plasmids; pili (small projections from the surface); slimy outer capsule; flagellum (not built of microtubules) |

***Table 3 A summary of the differences and similarities between eukaryotic and prokaryotic cells***

**Links** Every time you come across cells of different types, check to see if they are eukaryotic or prokaryotic. When you study infectious diseases in Module 2 of Unit F212, you will find that the parasitic organism that causes malaria is eukaryotic; the organism that causes tuberculosis is a bacterium and therefore prokaryotic. You could identify the differences between prokaryotic and eukaryotic cells, as well as those between animal and plant cells, and summarise them in a table such as the one below:

| | | **Eukaryotic cell** | |
|---|---|---|---|
| **Feature** | **Prokaryotic cell** | **Plant cell** | **Animal cell** |
| | | | |
| | | | |
| | | | |
| | | | |

# Cell membranes

## Fluid mosaic structure of membranes

### Key concepts you must understand

Membranes form boundaries and divide cells into compartments. The cell membrane (also known as the plasma membrane or cell surface membrane) forms the outermost boundary of the cell. This allows cells to be different from their external environment. Membranes keep in large molecules such as enzymes, RNA and DNA. They keep out many others. They are barriers between the cytoplasm and the outside world. But cells need to exchange substances with their surroundings, so membranes are permeable — not freely permeable to anything and everything, but **partially permeable** to some substances.

Organelles, for example mitochondria, chloroplasts, endoplasmic reticulum and Golgi apparatus, are made of membranes and are separate compartments within cells. For example, the lysosome membrane encloses enzymes and stops them breaking down molecules, such as proteins, in the cytoplasm.

### Key facts you must know

All membranes have the same basic structure — the fluid mosaic structure.

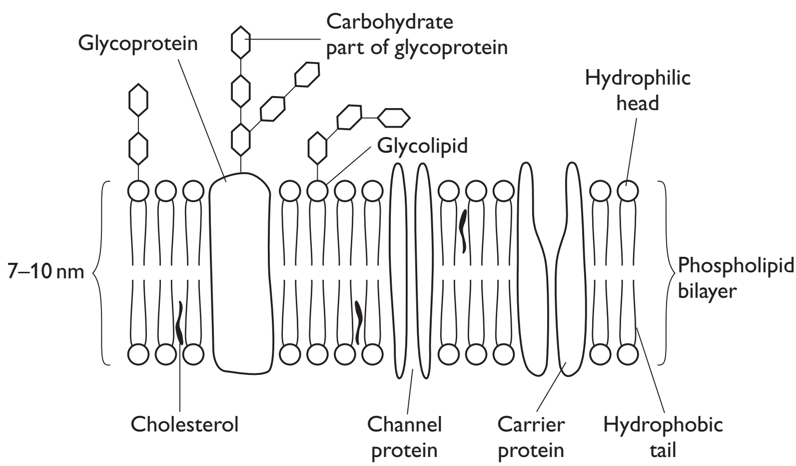


***Figure 4 The fluid mosaic model of membrane structure***

Figure 4 shows a cross-section of a tiny part of a membrane. It is composed of a double layer (bilayer) of phospholipids, together with proteins. Each phospholipid molecule has a 'head' and two 'tails'. The head end is polar and 'water-loving' (hydrophilic). The tails are non-polar and 'water-hating' (hydrophobic). Phospholipid heads are soluble in water; the tails provide a hydrophobic barrier that many water-soluble substances cannot cross easily. This hydrophobic barrier restricts the movement of substances in and out of cells, so helping to keep a constant environment inside the cytoplasm.

### How are the components arranged?

***Phospholipids***

- Membranes have two layers of phospholipid, forming a bilayer.
- The molecules in the two layers have opposite orientations, so that the non-polar ends associate with each other and the polar ends face the cytoplasm and the fluid outside the cell.

***Proteins***

- Membrane proteins are embedded in the phospholipid bilayer. Transmembrane proteins extend right through the bilayer with one end in the cytoplasm and the other end extending to the outside.
- Transmembrane proteins are held in the membrane because they have hydrophobic regions that span the hydrophobic interior of the membrane.

***Carbohydrates***

- These are short chains of sugar molecules that branch to give 'tree-like' attachments to proteins and lipids.
- Glycolipids are lipids with chains of sugar molecules attached.
- Glycoproteins are proteins with chains of sugar molecules attached.
- Carbohydrates are attached to lipids and proteins only on the external surfaces of cell membranes.

***Cholesterol***

- These molecules have polar and non-polar regions. Polar regions bind to polar heads of phospholipids; non-polar regions bind to phospholipid tails.
- It maintains the stability of membranes by preventing phospholipids solidifying at low temperatures and becoming too fluid at high temperatures.
- Cholesterol reduces the permeability of membranes to water, ions and polar molecules.
- It is not found in the membranes of prokaryotes.

### Why fluid mosaic?

***Fluid***

The membrane is held together mainly by hydrophobic interactions between the phospholipids and between proteins and phospholipids. These weak interactions allow the molecules to move so that the membrane is liquid. Phospholipid molecules move in the plane of the membrane. Proteins are much larger and move more slowly — imagine protein molecules moving about like icebergs in a 'sea' of lipid.

***Mosaic***

A membrane is like a collage of many different proteins in the lipid bilayer. Think of a Roman mosaic made of tiny pieces of tile. Now think of the pieces constantly moving about and you should have a picture in your mind of a fluid mosaic.

## Cell signalling

Many glycoproteins are receptors for chemical signals sent between cells. You will remember from GCSE that neurones (nerve cells) release chemicals into gaps known as synapses. These chemicals act as signals from one neurone to the next, so that information can be sent through the nervous system. As another way of signalling, some cells release hormones into the bloodstream.

When tissues are damaged, special cells called mast cells release histamine, which signals to cells lining blood capillaries to become leaky and allow more fluid to pass out from the blood.

The cells that receive such signals are called target cells, and they have receptors on the surface of their membranes that bind with the signalling molecule. The shape of the receptor matches the shape of the signalling molecule, so the two fit together. It is possible to design drugs to bind to these receptors. For example, some asthmatics use salbutamol (Ventolin™) in an inhaler. This drug binds to receptors for adrenaline on smooth muscle in the bronchioles, making these air passages widen, thereby making it easier to breathe.

**Links** Membranes are involved in all exchanges between living things and their environment, for example, across alveoli in the lungs (see p. 40) and across plant root hairs (see pp. 66–67). You will need to know the structure of membranes if you are asked to explain the effect of different temperatures on membrane permeability (see 'Focus on practical skills' below).

Cholesterol is a molecule that we need, but also one that can cause harm (see Module 2 of Unit F212 for more detail).

Cell signalling is a theme that recurs throughout the AS course and at A2. Note the importance of glycoprotein receptors as the 'receivers' on the target cells. Another theme that recurs throughout the course is that of protein shapes. Receptors and signalling molecules fit together because they have complementary shapes, in the same way that substrates and enzymes fit together.

### Focus on practical skills: investigating membranes

***The effect of temperature on membrane permeability***

Some plant cells have vacuoles that contain pigments. Beetroot is a good example — the vacuoles contain the red pigment betalain. If you cut up a beetroot into small slices, you will notice that a lot of the red pigment leaks out, because you have cut through many cells. If you wash the slices of beetroot in lots of water the leakage will eventually stop because cell surface membranes and membranes around vacuoles in undamaged cells are intact. To investigate the effect of temperature on membranes, place some of the beetroot slices into test tubes of water, and place these into water baths at different temperatures. Leave them for a while, before pouring off the water and examining its appearance.

This investigation could be the subject of the qualitative task in Unit F213, e.g. you could compare the intensity of the colours in the test tubes and rank them. It is unlikely that any pigment will leak from beetroot tissue kept at 20°C, but a lot will leak when the tissue is immersed in water at 80°C or above. You could investigate whether there is a relationship between temperature and the quantity of pigment that leaks from the beetroot tissue.

This investigation could also be used for the quantitative task, but you would need a device that measures the intensity of colour in the test tubes, e.g. a colorimeter (described in the Unit Guide for Unit F212).

Why does temperature have this effect? At temperatures above 40°C, the membrane proteins will lose their structure — they will become denatured — which is something you have learnt at GCSE. The phospholipids will also gain more kinetic energy and the membrane will become more fluid. This happens to such an extent that the membrane breaks down and the pigment molecules can leak out.

# Movement across membranes

## Key concepts you must understand

Membranes are barriers, but they allow considerable exchange of substances between the cytoplasm and the surroundings. Some substances are small enough to pass through membranes easily; others are larger and need special methods. Some molecules move through the membrane down a concentration gradient, e.g. oxygen moves into animal cells and carbon dioxide diffuses out of animal cells in this way. This is **passive transport**, because the cell does not use any of its energy from respiration to move the molecules. All cells have a *lower* concentration of sodium ions than their surroundings, because they use membrane proteins to pump sodium ions out of the cells, utilising some of their energy to do this. This type of movement is **active transport**. Some molecules, and even large particles, are moved into or out of cells surrounded by membrane. This type of movement is **bulk transport**, and also requires energy from the cell to move vacuoles or small vesicles away from or towards the cell surface membrane.

## Key facts you must know

There are five ways in which substances can cross membranes, divided into two categories:

**Passive transport — not requiring energy from cells**
- simple diffusion
- facilitated diffusion
- osmosis