Unit
1A

Chapter 3
Cells

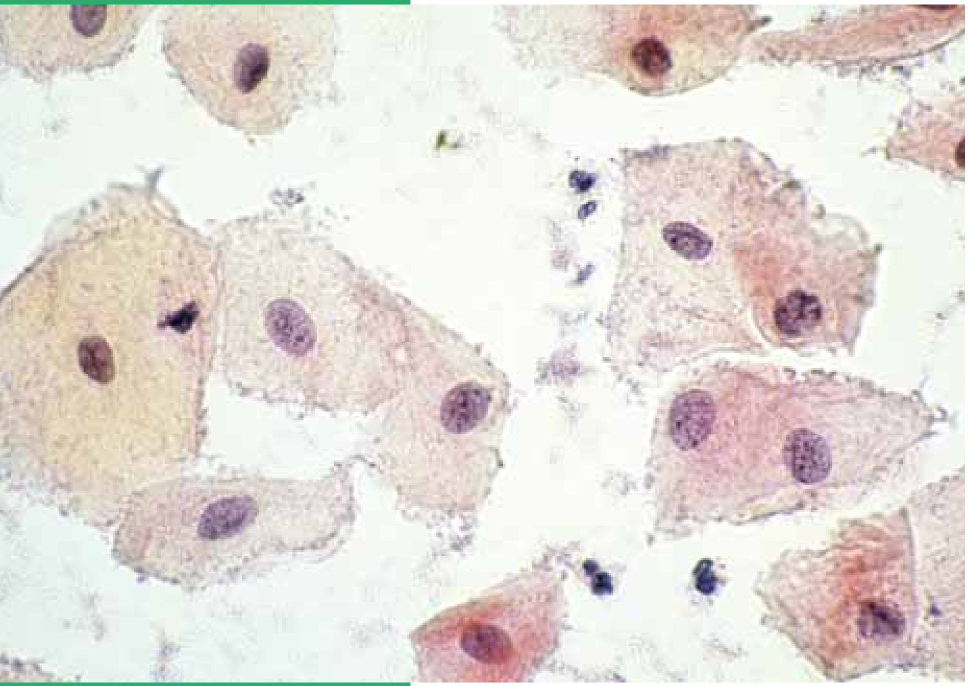


Figure 3.1 The human body is made up of cells

Unit content

Cells, metabolism and regulation

Cells carry out life processes to survive. Cells possess similar features including membranes, nuclei and cytoplasm that perform life processes.

Life processes:

- the cell theory
- basic cell structure/components and their functions (nucleus, nucleolus, cell membrane, cytoplasm, endoplasmic reticulum, mitochondria, Golgi body, lysosomes, vesicles).

All organisms are made of cells or substances produced by cells. Cells are the basic structural and functional units of plants and animals—the building blocks that make up all living organisms. The human body contains countless millions of cells. In just 1 mL of human blood there are about 5 million red blood cells—there are up to 6000 mL of blood in an adult human—and blood is just one of the many tissues that make up the human body!

All cells are very small: so small that you need a microscope to see most of them. They do vary in size and shape. Despite these variations, all human cells have a similar basic structure.

Cell structure

Cells are made up of the following parts:

- a **cell membrane**, which surrounds the cell and forms the outer boundary of the cell
- **cytoplasm**, a thick fluid that fills the inside of the cell
- **organelles**, structures suspended in the cytoplasm that carry out particular functions
- a **cytoskeleton**, or internal scaffolding of protein fibres within the cytoplasm
- **inclusions**, chemical substances occurring as granules or liquid droplets in the cytoplasm.

Cell membranes

The cell membrane, or **plasma membrane**, separates the cell from neighbouring cells and separates the cell contents from the environment outside the cell. It is very thin—too thin to be seen clearly with a light microscope.

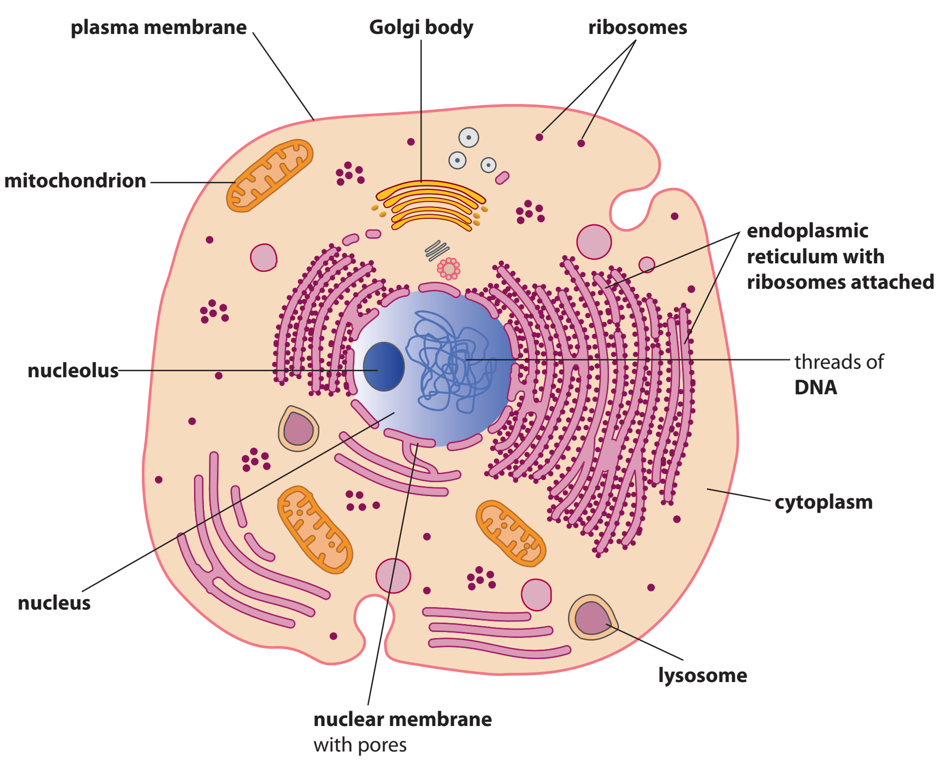


Figure 3.2 An animal cell showing the structures found in most cells

Substances that enter or leave the cell must pass through the cell membrane. The membrane is very important in selecting which substances will get into or out of the cell.

Cells of most organisms have complex systems of internal membranes in addition to the plasma membrane. These internal membranes form structures inside the cell called organelles.

Cytoplasm

Cytoplasm is the material in which the contents of the cell are suspended. It fills all the space between the nucleus and the cell membrane. Cytoplasm is 75% to 90% water. Substances like salts and carbohydrates are dissolved in the cytoplasm. Other compounds, such as proteins and fats, do not dissolve but are suspended in the watery fluid.

Organelles

The structures within a cell are called organelles. There are a number of different types of organelle, and each is specialised for a particular function. Many of the organelles are formed by the cell's internal membranes.

Nucleus

Almost all cells contain a single nucleus, although some, such as liver cells, have two or more nuclei, and mature red blood cells have no nucleus at all. The nucleus is the largest organelle in the cell and is usually oval or spherical in shape. A **nuclear membrane** separates the nucleus from the cytoplasm. The nuclear membrane is actually a double membrane—two membranes separated by a space (see Fig. 3.3). There are numerous gaps, or **nuclear pores**, in the nuclear membrane. Large molecules are able to enter and leave the nucleus through the pores.

Inside the nucleus is the **DNA** (deoxyribonucleic acid), which contains inherited information. When the cell is not dividing, the DNA is in the form of long threads. In a dividing cell, the threads thicken and coil to form **chromosomes**. DNA contains the information that determines the type of proteins a cell can make. In this way the nucleus, with its DNA, controls the structure of the cell and the way it functions.

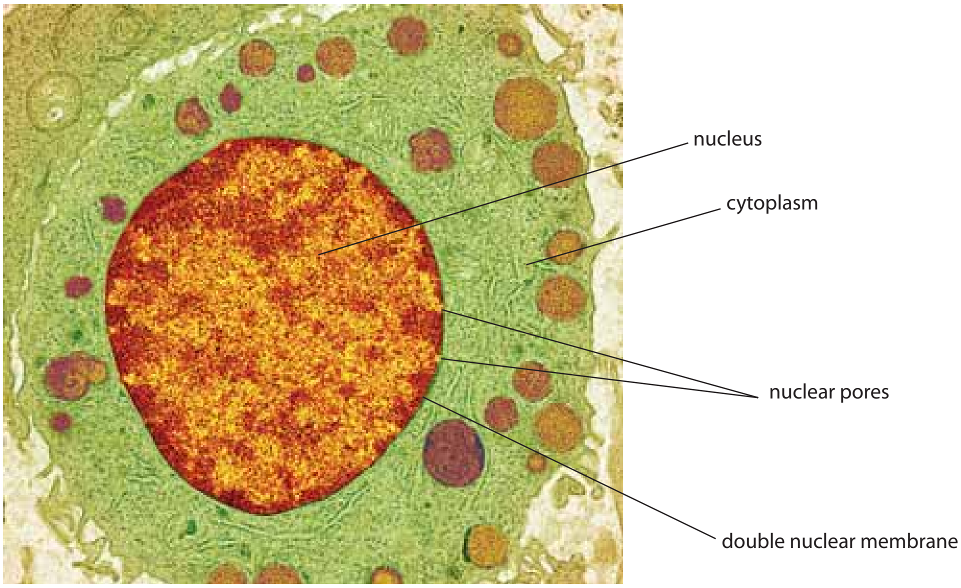


Figure 3.3 Electron micrograph of cell nucleus, showing the double membrane and nuclear pores

Also inside the nucleus is an area called the **nucleolus** (see Fig. 3.2). The nucleolus plays a part in the manufacture of proteins.

Ribosomes

Ribosomes are very small, spherical organelles (see Fig. 3.4). At the ribosomes, amino acids are joined together to make proteins. Ribosomes may be free in the cytoplasm or may be attached to membranes within the cells.

Endoplasmic reticulum

Pairs of parallel membranes extend through the cytoplasm of the cell from the cell membrane to the nuclear membrane. The network of channels formed by the parallel membranes is called the **endoplasmic reticulum**, or ER (see Fig. 3.4). It is thought that the membranes of the endoplasmic reticulum provide a surface for chemical reactions, while the channels are for storing or transporting molecules. Ribosomes are attached to the outside of some membranes of the endoplasmic reticulum (see Fig. 3.4).

Golgi body

The **Golgi body** (sometimes called the Golgi apparatus) is a series of flattened membranes stacked one upon the other. Usually the Golgi body is positioned near the nucleus. Its function is to modify proteins and to package them for secretion from the cell. Proteins produced at the ribosomes pass through the channels of the endoplasmic reticulum to the Golgi body. At the edges of the membranes of the Golgi body small bubbles of liquid containing proteins are formed. These bubbles are surrounded by a membrane and are called **vesicles** (see Fig. 3.5).

Lysosomes

Lysosomes are small spheres, bounded by a membrane, that are formed from the Golgi body (see Fig. 3.6). They contain digestive enzymes that are able to break down large molecules. When particles, or liquids, are taken into a cell they form vesicles in the cytoplasm. Lysosomes can join with these vesicles, and the digestive enzymes they contain break down the material inside the vesicle. Lysosomes also digest worn-out organelles in a similar way.

Mitochondria

Mitochondria (singular: mitochondrion) are spherical or sausage-shaped structures that are spread throughout the cytoplasm. Each has a double membrane. The smooth outer membrane surrounds the mitochondrion. The inner membrane is arranged into a series of folds that extend into the interior of the organelle (see Fig. 3.7).

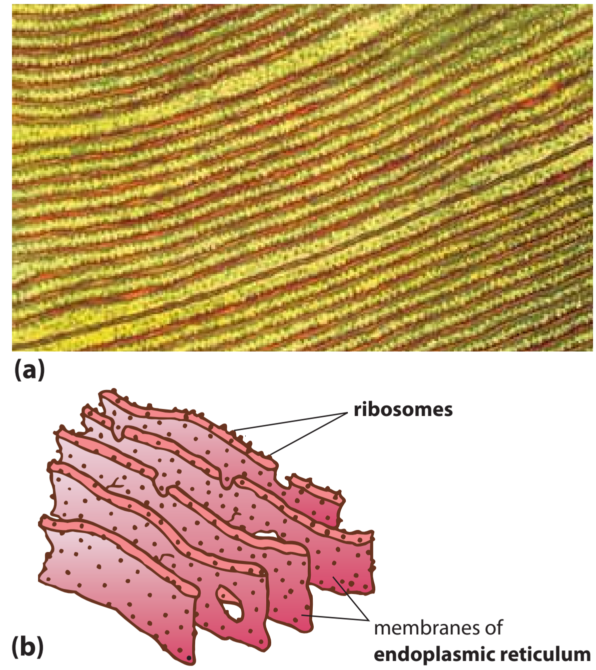


Figure 3.4 **(a)** Electron micrograph showing endoplasmic reticulum with ribosomes attached; **(b)** diagram showing the three-dimensional arrangement of the membranes

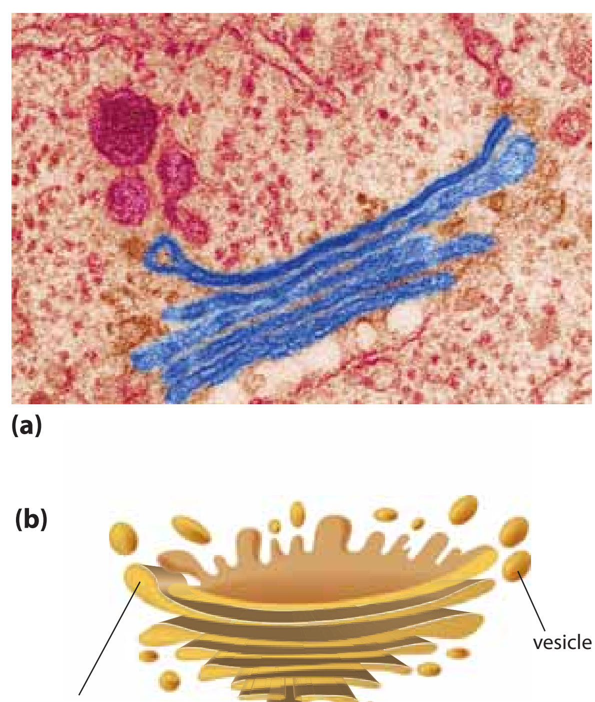


Figure 3.5 **(a)** Electron micrograph showing section through a Golgi body; **(b)** diagram indicating the three-dimensional shape of the Golgi body

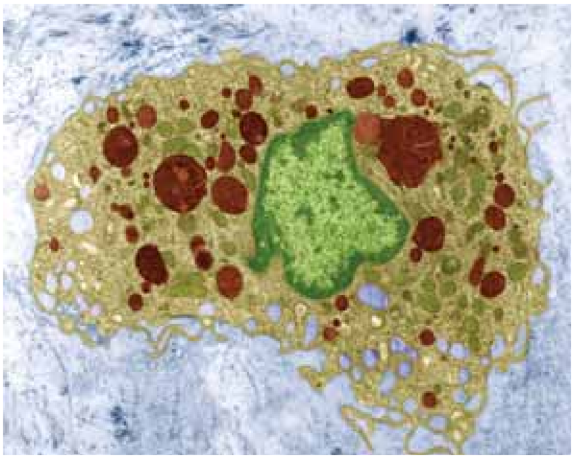


Figure 3.6 Electron micrograph showing a large number of lysosomes within the cytoplasm of a cell. The lysosomes are red and the cell nucleus green

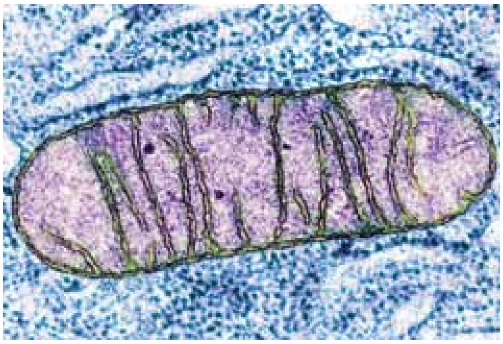
Some of the chemical reactions of cellular respiration occur in the mitochondria. Folding of the inner membrane produces a large surface area on which these chemical reactions can take place. Because the reactions of the mitochondria make energy available for the cell's activities, these organelles are often called the 'powerhouses' of the cell.

Cilia and flagella

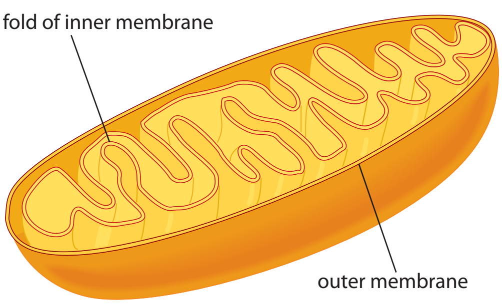
Some cells have fine projections that, by beating back and forth, can move the whole cell or can move substances over the surface of the cell. If the projections are short and numerous, resembling tiny hairs, they are called **cilia** (see Fig. 3.8). If they are longer, and there is only one or two of them, they are called **flagella** (see Fig. 3.9). One place in which cilia occur is in the cells lining the windpipe, where they move mucus and trapped particles towards the throat. In humans, only one type of cell—the sperm cell—has a flagellum; this enables the sperm to swim to the egg.

Figure 3.7 **(a)** Electron micrograph showing a mitochondrion in section; **(b)** diagram showing a three-dimensional view of a mitochondrion

(a)



(b)



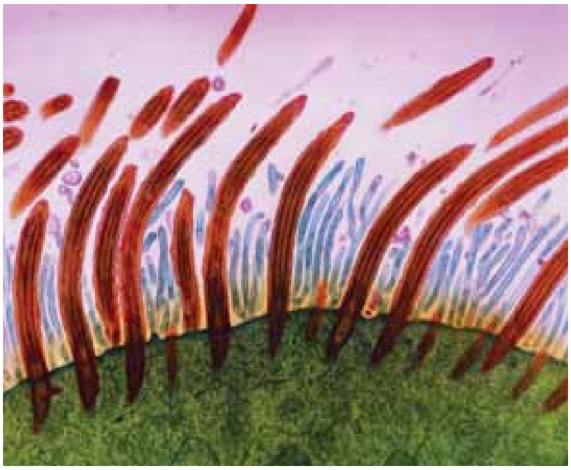


Figure 3.8 Cells from the lining of the trachea showing cilia

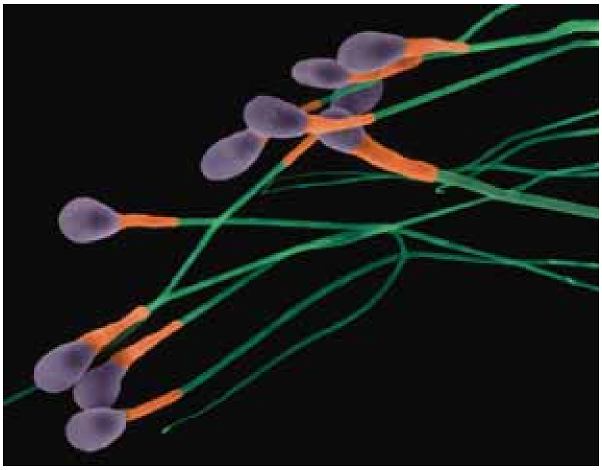


Figure 3.9 Scanning electron micrograph showing sperm cells with flagella

Cytoskeleton

The cytoskeleton is a framework of protein fibres that gives the cell its shape and assists cell movement. It consists of **microtubules**, hollow rods that keep organelles in place or move them around the cell, and **microfilaments**, which move materials around the cytoplasm or move the whole cell.

Inclusions

Inclusions are chemical substances that are not part of the cell structure but are found in the cytoplasm of the cell. The red pigment, haemoglobin, in red blood cells is an inclusion. In cells of the skin, hair and iris of the eye, particles of the pigment melanin are inclusions.

Table 3.1 The parts of a cell and their functions

Part	Location	Function
Cell membrane	Surrounding the cell	Forms the boundary of the cell; controls movement of materials into and out of the cell
Cytoplasm	Between the cell membrane and the nucleus	A medium in which the organelles are suspended and in which chemical reactions can occur
Organelles		
Nucleus	Often near the centre of the cell	Contains the inherited material that controls the cell's activities
Ribosomes	In the cytoplasm, often attached to the endoplasmic reticulum	Sites for protein manufacture
Endoplasmic reticulum	Penetrating the whole of the cytoplasm	A surface for chemical reactions; transport of materials within the cell; storage of materials
Golgi body	In the cytoplasm, often near the nucleus	Concentrates, stores and packages materials for secretion from the cell
Lysosomes	In the cytoplasm	Digest material within the cell
Mitochondria	In the cytoplasm	Make energy available for cell activities
Cilia and flagella	Projecting from the main body of the cell	Move particles along the cell surface or move the whole cell
Cytoskeleton	Throughout the cytoplasm	Maintains cell shape; allows the cell and its organelles to move
Inclusions	Within the cytoplasm	Chemical substances used by, or stored in, the cell

For an interactive look at cell structure visit:

- http://www.tvdsb.on.ca/WESTMIN/science/sbi3a1/Cells/cells.htm
- http://www.johnkyrk.com/CellIndex.html

or

- http://www.cellsalive.com/cells/cell_model.htm

But remember that most websites discuss plant cells as well as animal cells.

Cell size

Cells vary in size (see Fig. 3.10). All the cells in Figure 3.10 are drawn to the same scale. The largest cell, an egg cell, would be just visible to the naked eye; all the other cells are microscopic.

> Cells are small because the smaller an object is, the greater its surface area in relation to its volume. This is known as the *surface area to volume ratio* (SA:V ratio).

Suppose you took a cube of plasticine that was 10 cm × 10 cm × 10 cm. Its volume would be 1000 cm^3 and its surface area 600 cm^2 (SA:V = 600:1000 or 6:10). If you cut the cube of plasticine in half, each half would have a volume of 500 cm^3—half of the volume of the large cube. The surface area of each half would be 400 cm^2—more than half the original surface area (SA:V is now 400:500 or 8:10). If you now cut the halves in half again—into quarters—each quarter would have a volume of 250 cm^3 and a surface area of 250 cm^2 (SA:V is now 250:250 or 10:10) (see Table 3.2). As the pieces become smaller and smaller, so the surface area in relation to the volume becomes larger and larger.

Why is surface area to volume ratio so important for cells? Anything that goes into or out of a cell must pass through the cell membrane that covers the whole surface. Cells need substances like oxygen and glucose. If the cell is to be effectively supplied with these substances it needs to have a large surface area. Cells must get rid of wastes like carbon dioxide, so the effective removal of waste also requires a large surface area.

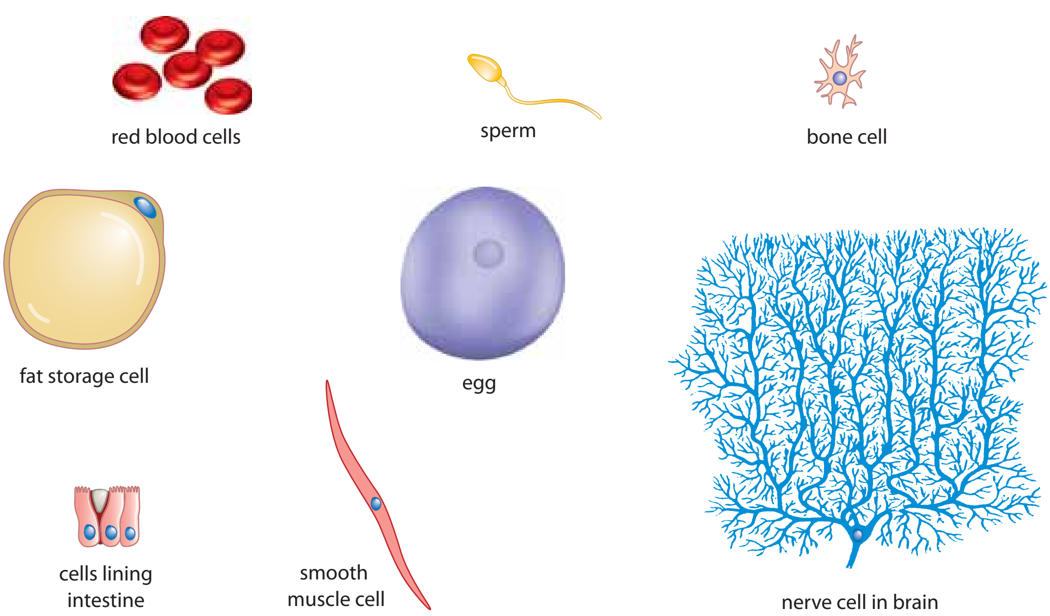
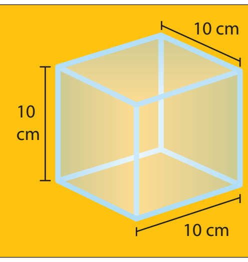
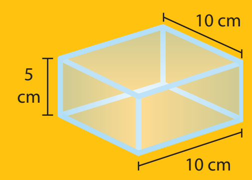
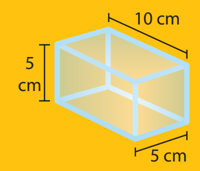


Figure 3.10 The diversity of size and shape of human cells

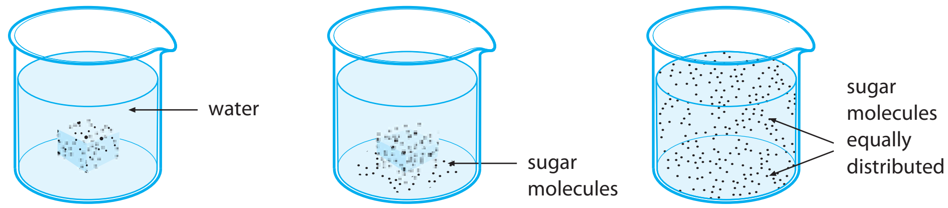
Table 3.2 Change in surface area to volume ratio

			
Volume	$10 \times 10 \times 10$ $= 1000\ cm^3$	$10 \times 10 \times 5$ $= 500\ cm^3$	$10 \times 5 \times 5$ $= 250\ cm^3$
Surface area	$6(10 \times 10)\ cm^2$ $= 600\ cm^2$	$2(10 \times 10)$ $+ 4(5 \times 10)$ $= 400\ cm^2$	$2(5 \times 5)$ $+ 4(10 \times 5)$ $= 250\ cm^2$
SA:V ratio	600:1000 = 6:10	400:500 = 8:10	250:250 = 10:10

Moving materials to and from the cell

Diffusion

Small molecules like oxygen and carbon dioxide move in or out of the cell by diffusion. **Diffusion** occurs in gases or liquids. It is the tendency for the molecules of a liquid or gas to spread evenly over the available space (see Fig. 3.11). The molecules move from areas where there are more of them—higher concentration—to areas where there are fewer of them—lower concentration.



(a) sugar cube when placed in water **(b)** sugar cube slowly dissolves **(c)** sugar cube completely dissolved

Figure 3.11 Diffusion of sugar in a beaker of water

As oxygen is used up inside the cell, molecules of oxygen diffuse into the cell from the higher concentration of oxygen outside. As carbon dioxide is produced in the cell, the concentration of carbon dioxide becomes higher than outside and carbon dioxide diffuses out.

To see animations of molecules diffusing go to:
- http://www.wisc-online.com/objects/index_tj.asp?objID=AP1903,

or
- http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation__how_diffusion_works.html

Osmosis

The membrane around a living cell is **differentially permeable**. This means it will allow small molecules like water and oxygen to diffuse through but large molecules cannot easily pass through the membrane.

Animations of diffusion and osmosis can be seen at http://www.biologycorner.com/bio1/diffusion.html#

Osmosis is a special case of diffusion. It is the diffusion of water through a differentially permeable membrane from the 'more watery' to the 'less watery' side. The differentially permeable membrane allows water through but holds back large molecules like sugars and proteins. It acts as if it has tiny holes in it that are too small for the larger molecules to pass through (see Fig. 3.12).

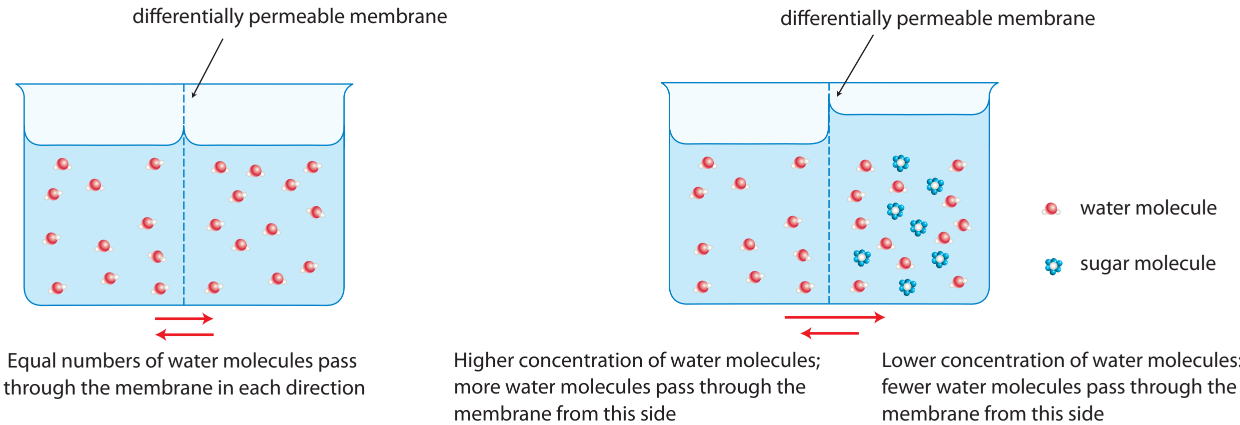


Figure 3.12 Osmosis

Animations of osmosis can be seen at:

- http://www.wisc-online.com/objects/index_tj.asp?objID=AP11003
- http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation__how_osmosis_works.html

Active transport

Active transport involves the movement of substances across a cell membrane from a lower to a higher concentration—that is, in the opposite direction from that in which diffusion would occur. Such transport is described as active because the cell must supply energy for the process to occur.

In active transport, the molecule or ion to be transported attaches itself to a carrier molecule that takes it across the membrane and releases it on the other side.

Endocytosis and exocytosis

You can see an animation of endocytosis and exocytosis at http://www.stolaf.edu/people/giannini/flashanimat/cellstructures/phagocitosis.swf

A cell may surround some outside material with a fold of the cell membrane. The enfolding membrane then breaks away, and the material is enclosed within the cell in the form of a small bubble of liquid surrounded by a membrane. Such a liquid-filled sac, within the cytoplasm, is called a vesicle. The process by which the vesicle is formed is called **endocytosis** (see Fig. 3.13).

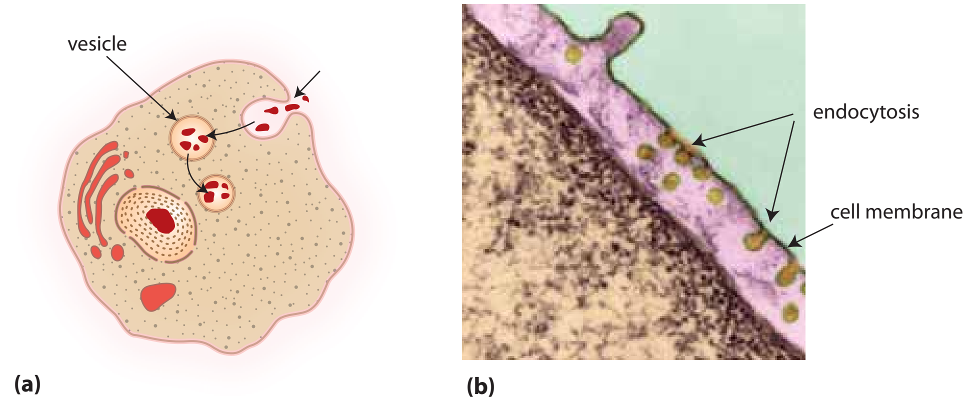


Figure 3.13 Endocytosis: **(a)** diagram showing the process; **(b)** electron micrograph showing endocytosis

If the contents of a vesicle are pushed out through the cell membrane, the process is called **exocytosis**. The membrane around the vesicle fuses with the cell membrane and the vesicle contents are passed to the exterior (see Fig. 3.14).

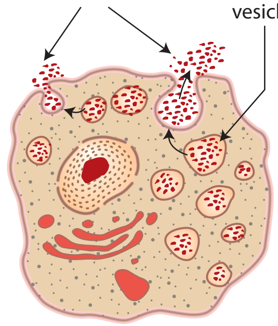


Figure 3.14 Exocytosis

Working scientifically

Activity 3.1 Observing cells

This activity will familiarise you with the use of a microscope to observe cells. You may have to work with a partner.

You will need

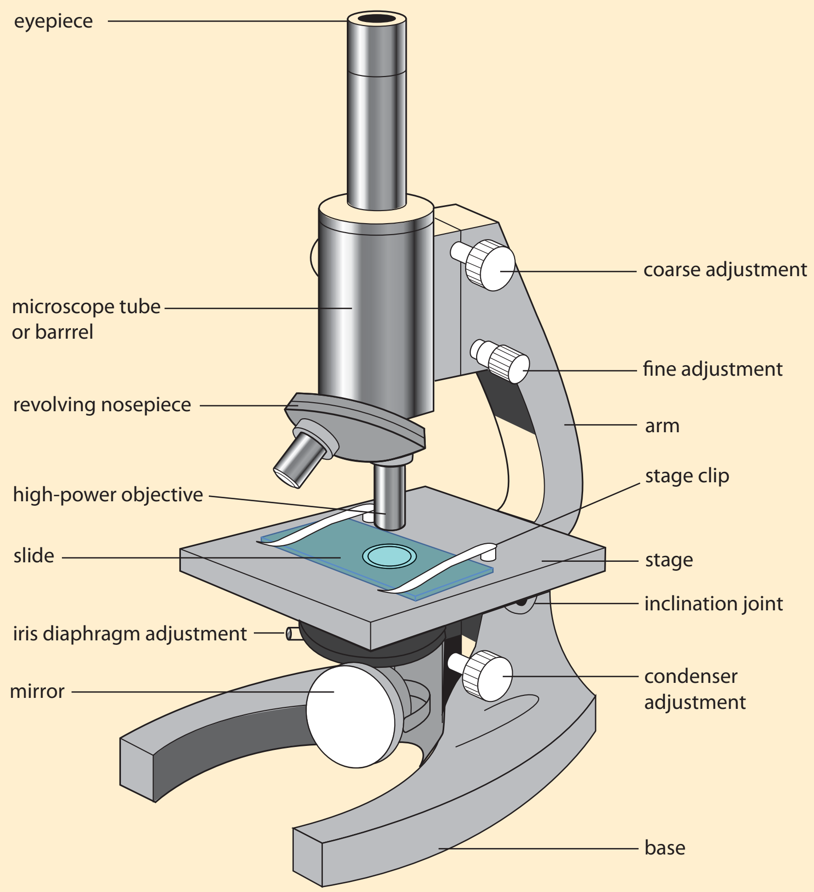
Microscope and microscope lamp, prepared microscope slides of cheek cells, minigrid or piece of millimetre graph paper

What to do

1. Use Figure 3.15 to identify the parts of your microscope. Check:
   - **(a)** the number of objective lenses on your microscope and their magnification
   - **(b)** whether your microscope has a condenser with a condenser focus knob
   - **(c)** whether your microscope has a mirror or a built-in light source
   - **(d)** whether your microscope has an iris diaphragm or a wheel diaphragm
2. Rotate the nosepiece of the microscope so that the low-power objective (the shortest one) is in line with the body tube. It should click into position. If the microscope has a mirror, look through the eyepiece and move the mirror so that it reflects light up through the opening in the stage. If you are using a microscope lamp, use the concave side of the mirror.
3. While looking through the eyepiece, open and close the iris diaphragm or rotate the wheel diaphragm. If your microscope has a condenser, focus it up and down and observe any changes in light intensity.
4. Place a minigrid, or a slide with a piece of millimetre graph paper, on the stage. Lower the body tube until the objective almost touches the slide. While looking through the eyepiece, use the coarse adjustment to slowly raise the body tube until the specimen comes into view. With the fine adjustment, focus as sharply as possible. (**Never** focus down while you are looking through the eyepiece. The objective lens may hit the slide and break it or the lens may be scratched.)
5. Move the slide so that one of the grid lines is on the very left of the field of view (see Fig. 3.16). As the grid lines are 1 mm apart you can estimate the field of view using low power.

For comprehensive instructions on how to use a microscope go to http://www.cas.muohio.edu/mbi-ws/microscopes/usage.html

Figure 3.15 The parts of a monocular microscope



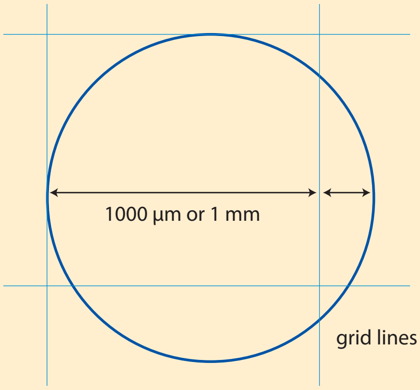


Figure 3.16 Estimating field diameter using a minigrid

6. Remove the minigrid and place a prepared microscope slide of cheek cells on the stage of the microscope so that the cells you wish to examine are over the hole in the stage.
7. Focus the microscope on low power. Adjust the diaphragm so that you can see the maximum amount of detail. Note that you can often see more detail with a reduced light intensity, especially if the cells are almost transparent.
8. Turn the revolving nosepiece so that the high-power objective is in line with the barrel. If you do this carefully the microscope should remain in focus or almost in focus.
9. Identify any structures that you can see in the cheek cells.

Studying your observations

1. What happens to the light intensity when you adjust the iris diaphragm or wheel diaphragm?
2. How does focusing the condenser affect the light intensity?
3. When you move the slide on the stage from right to left, which way does the image move?
4. When you move the slide towards you, which way does the image move?
5. Compare what you can see with high power and low power. On which magnification do you see more of the specimen?
6. On which magnification is the image brighter?
7. Multiply the magnification of each of the objective lenses by the magnification of each of the eye pieces. List the magnifications that are possible with your microscope.
8. What was the field diameter on low power?

9. Estimate the diameter of the cheek cells in millimetres on the prepared slide.
10. One millimetre equals 1000 micro metres (µm). What is your estimate of the diameter of an average cheek cell in micrometres?
11. Draw a large, labelled diagram showing one or two cheek cells.
12. The cheek cells that you observed had been stained. Why would biologists stain cells?

Activity 3.2 A model cell

Make a model of a cell showing all, or most, of the structures described in this chapter. Use any materials that you like to show the relative sizes and approximate shapes of the structures. Label each of the structures, or number them and provide a key to the numbers.

Activity 3.3 Surface area and volume

The surface area to volume ratio is very important to a cell. In this activity we will model cells of different sizes and see how well they can be supplied with materials.

You will need

Block of phenolphthalein agar (agar with small amount of phenolphthalein added); 200 mL of 4% sodium hydroxide; 250 mL beaker; razor blade; plastic spoon; rule with mm scale; paper towel

What to do

1. Use the razor blade to cut three cubes of phenolphthalein agar: a 3 cm cube, a 2 cm cube and a 1 cm cube. These are your models of three different-sized cells.
2. Calculate the volume, surface area and SA:V ratio of each 'cell' (volume = length × width × height; surface area = 6 × area of one side). Record these in a suitable table.
3. Place the three 'cells' in the 250 mL beaker. Pour in enough sodium hydroxide solution to cover them. Using the plastic spoon, turn the 'cells' every minute. Be careful not to damage the surface of the 'cell'. After four minutes remove the 'cells' and immediately blot them dry with paper towel.
4. Cut each 'cell' in half using the razor blade. Measure the distance from the edge of each 'cell' that the sodium hydroxide diffused in the four minutes. Estimate, or calculate, the percentage of the 'cell's' volume that was reached by the sodium hydroxide.

Studying your results

Write a paragraph explaining what this activity has demonstrated about the relationship between surface area to volume ratio and the supply of materials to the cell. Why are cells so small?

REVIEW QUESTIONS

1. Describe the four main parts of a cell.
2. **(a)** What is the cell membrane?
   (b) Describe the functions of the cell membrane.
3. Organelles are suspended in the cytoplasm.
   (a) What is the cytoplasm?
   (b) What are organelles?
4. The nuclear membrane has large gaps in it. What is the importance of these gaps?
5. Why are most cells microscopic?
6. Explain the difference between diffusion and osmosis.
7. Explain the difference between endocytosis and exocytosis.
8. Unlike plant cells, animal cells have no cell wall. How is the shape of a human cell maintained?
9. Describe the functions of the endoplasmic reticulum.
10. What is a vesicle? Describe two ways in which vesicles can be formed.

APPLY YOUR KNOWLEDGE

1. Cells of bacteria and some other simple organisms do not have internal membranes. The cells of plants and animals do possess internal membranes. Describe the internal membranes that occur in human cells.
2. What organelle would make the energy available for active transport? Explain your answer.
3. Imagine that you are the size of a large molecule and that you are taking a group of tiny human biology students on a guided tour through a typical cell. Describe what you would tell them about the structure and function of the various parts of the cell that they would see. Introduce them to the scientific terms that are used for the parts of the cell and their functions.
4. The word reticulum means a network. Explain why certain membranes within the cell are called the endoplasmic reticulum.
5. List the part/s of the body in which you would expect to find cells with:
   (a) particularly large numbers of mitochondria
   (b) a very well-developed Golgi body
   (c) very large numbers of ribosomes
   (d) a large number of cilia
   Give reasons for your answer in each case.
6. When an animal cell is placed in distilled water it gains water by osmosis, swells up and bursts. Why don't our cells swell and burst when we swim in fresh water?
7. Would you expect the cells of a large mammal like an elephant to be larger than those of a small mammal like a mouse? Explain your answer.