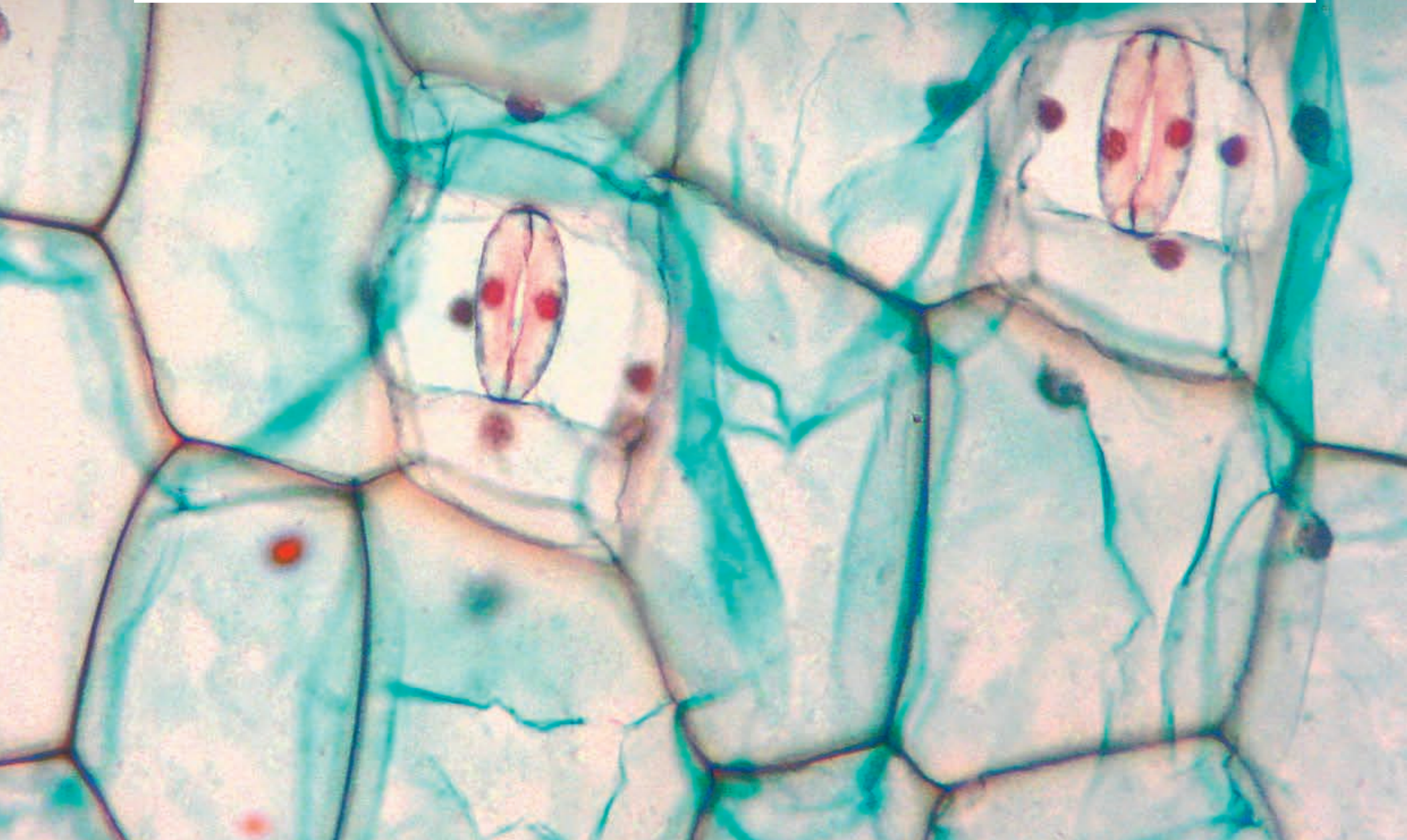
CHAPTER 8
CELLS IN THEIR ENVIRONMENTS



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By the end of this chapter you will have covered the following material.

Science Understanding

- The cell membrane separates the cell from its surroundings and controls the exchange of materials, including gases, nutrients and wastes, between the cell and its environment (ACSBL045)
- Movement of materials across membranes occurs via diffusion, osmosis, active transport and/or endocytosis (ACSBL046)
- Factors that affect exchange of materials across membranes include the surface-area-to-volume ratio of the cell, concentration gradients, and the physical and chemical nature of the materials being exchanged (ACSBL047)

Figure 8.1 ▶ Sardines preserved in salt

Dreamstime.com/Marcomayer

For more than 4000 years, salt has been an essential substance used in ancient and modern civilisations. The expression 'not worth his salt' comes from the days of Ancient Greece when salt was such a valuable commodity it could be traded for slaves. Used to help preserve mummies in Egypt, salt has also been used to preserve meats and fish throughout medieval times and even today. Without refrigeration, long voyages by past explorers and whalers were in need of a way to keep food from spoiling. The method of kegging meat or fish in alternate layers of dry salt could preserve them for years. The water would be drawn out of the **tissues** and bacteria would be killed. But what was actually happening? Why did water leave the cells of animal tissue and why couldn't bacteria survive in all that salt?

The plasma membrane: the boundary of cells

How do cells obtain their requirements, rid themselves of wastes and communicate? In this chapter we will see that the **plasma membrane** plays a vital role in the life of cells. Both the physical and chemical properties of the plasma membrane enable it to control the exchange of materials and messages. Many factors both within the cells and in their environment affect this sensitive balance.

In both **multicellular** and **unicellular** organisms, each cell is an independent unit enclosed by a plasma membrane. The plasma membrane forms the boundary between the **internal environment** of the cell, the **cytoplasm** and its **external environment**.

Figure 8.2 ▼ An *Amoeba* engulfing food demonstrates the flexibility of the plasma membrane.

Getty Images/Science Photo Library

Cells of plants, bacteria, fungi and most algae have a plasma membrane as well as a cell wall, whereas animal cells only have a plasma membrane. The cell wall surrounds the plasma membrane and adds strength and support. It is **permeable**, allowing the passage of almost all materials. It is the **selectively permeable** plasma membrane that controls the movement of substances into and out of cells.

An *Amoeba* is a unicellular freshwater organism, meaning the whole organism consists of a single cell. It is continuously interacting with its pond environment via its plasma membrane. When feeding, an *Amoeba* can sense food particles, ignoring silt and other indigestible material. As a protective boundary, the membrane allows the entrance of some molecules such as oxygen, but excludes others, some of which could damage the cell's contents. The plasma membrane is a very flexible structure, flowing like a liquid when the *Amoeba* moves or engulfs food (Figure 8.2).

Multicellular organisms, whether they are plants or animals, are made up of many cells, each surrounded by a plasma membrane. These cells also exchange substances with their external environment, which for most cells is the **extracellular fluid**. Extracellular fluid bathes the outside of the plasma membrane, providing the liquid medium through which nutrients are supplied and wastes are removed. Each of the cells in tissues communicates via the plasma membrane with many other types of cells. This communication can cause cells to grow or differentiate into a specialised cell or die.

The internal and external environment of cells

The internal environments of cells are distinct and very different from their external environments. For example, almost 99% of the mass of an average human body is made up of only six elements: oxygen, carbon, hydrogen, nitrogen, calcium and phosphorus. Table 8.1 shows that the proportions of these elements are very different in the human body compared with the external environment in the earth, seawater and atmosphere.

Table 8.1 Comparison of the proportion of different elements in the human body, earth, seawater and atmosphere

Element	Symbol	Percentage in human body	Percentage in earth	Percentage in seawater	Percentage in atmosphere
Carbon	C	18	0.03	0.0028	0.039455
Oxygen	O	65	47	86	21
Hydrogen	H	10	0.14	11	0.000055
Nitrogen	N	3	trace	negligible	78
Calcium	Ca	1.5	3.6	0.04	negligible
Phosphorus	P	1.1	0.07	negligible	negligible

Unicellular organisms often live in dynamic environments, such as freshwater ponds, where conditions may change quickly. An *Amoeba* living in a freshwater pond could experience a significant increase in salinity if run-off from the land carries minerals into its pond environment. An organism living in brackish (slightly salty) water could have the opposite problem after heavy rain. Unicellular organisms must control the movement of substances across their plasma membrane to cope with rapid changes like these.

The cells in multicellular organisms are more protected from the swings of environmental change because they are surrounded by extracellular fluid. In humans, the contents of this liquid are kept fairly constant by the workings of various organs such as the lungs, kidneys and liver. Nevertheless, the internal cellular environment has very different concentrations of some substances compared with the extracellular environment (Table 8.2).

Table 8.2 Comparison of the concentration of various ions inside and outside the cell

Type of ion	Extracellular concentration (mmol/L)	Intracellular concentration (mmol/L)
Sodium	145	15
Potassium	4.5	120
Chloride	116	20
Calcium	1.2	10

Table 8.2 shows that the level of potassium ions is more than 26 times greater inside a cell compared with extracellular fluid. Other ions are significantly more concentrated outside the cell. The plasma membrane is responsible for maintaining this concentration difference. It can do this because it is selectively permeable, allowing some substances through the membrane, but not others.

Scientific literacy: Development of the cell membrane model

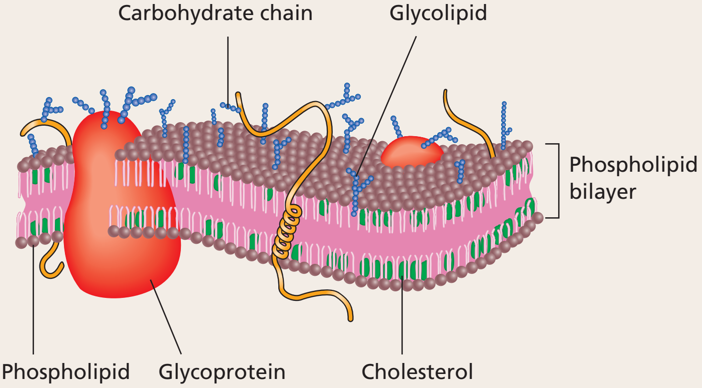
Although cells were named and described by Robert Hooke and Anton van Leeuwenhoek in the 1860s, it was another 30 years before scientists began to understand the nature of the plasma membrane. An important reason for this delay was that the membrane is so thin that it cannot be visualised in the light microscope. This means if a typical cell of 30 micrometres (μm) was enlarged 10000 times to the size of a watermelon (30 cm), the cell membrane would still only be equal to the thickness of a piece of paper.

Scientists had to take an indirect approach to model the structure of the plasma membrane, making predictions from its physical and chemical properties decades before it could be seen. In the mid 1890s, Charles Ernest Overton demonstrated that lipid-soluble substances such as ether and chloroform readily enter cells. This showed that the cell membrane was composed of lipid.

A series of pioneering experiments in 1925 indicated that the membrane consisted of a double layer of lipids, referred to as a lipid bilayer. A decade later, to account for the observation that up to half of the mass of plasma membranes was protein, Davson and Danielli proposed a model in which the lipid bilayer was coated on either side with a layer of proteins, rather like a lipid sandwich. In the 1950s, direct observation of the membrane with the newly invented electron microscope appeared to confirm this model, which became widely accepted and was extended to all cell and organelle membranes.

Not all experimental observations made over the next decade fitted neatly with predictions made from the Davson–Danielli model. It did not explain the fluidity of the membranes observed in living cells and why different membranes differ in composition and function.

In 1972, Singer and Nicolson proposed a new model that was able to explain all the physical and chemical properties of membranes known at that time. This fluid mosaic model, as they called it, hypothesised that discrete, globular protein molecules were embedded in the lipid bilayer, not overlying it. Furthermore, they proposed that these proteins moved around within the flexible lipid bilayer and many penetrated from one side to the other. With some modifications, this model is still used today. It colourfully describes membrane proteins as icebergs floating in a sea of lipids.



▲ **Figure 8.3** Three-dimensional view of a plasma membrane based on the fluid mosaic model

The determination of the structure of the plasma membrane gives a fascinating insight into the nature of scientific models and the way scientific concepts progress. Scientists develop models based on the available evidence, communicating their ideas by publishing their work for scrutiny by other scientists. As more evidence becomes available, often through technological advances such as the invention of the electron microscope, the model may be modified, revised or even replaced.

The Davson–Danielli model of membrane structure survived for decades before major revision. This makes it an important contribution to our understanding of the plasma membrane, even though it was ultimately shown to be an in accurate representation. It is important to understand that models are proposed as a hypothesis. They are used to organise and explain existing knowledge, as well as to generate predictions that can be tested with further research. Ongoing research, such as investigating the structure of channel proteins, continues to refine the fluid mosaic model. Therefore, it is possible that substantial modifications or even a new model could be seen in the future.

Questions

1 Explain why Singer and Nicolson used the words 'fluid', 'mosaic' and 'model' to describe their ideas.

2 In a table, describe the similarities and differences between the Davson–Danielli and Singer–Nicolson models.

3 A technique called freeze-fracture electron microscopy has been used to investigate the structure of membranes. Research the technique and briefly summarise:

   a the way images are obtained.

   b what those images show.

4 Using an example, construct an argument to support the statement: 'Advances in science understanding in one field can influence other areas of science, technology and engineering.'

5 It has been said that the development of complex models often requires a wide range of evidence from multiple individuals and across disciplines. Use the example of modelling the structure of membranes to either support or refute this statement.

The internal environment of cells is kept stable

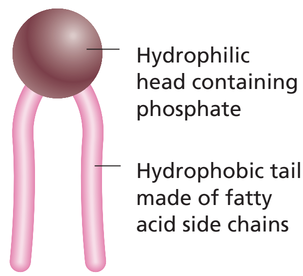
Depending on its activities, a cell will need to take in certain useful molecules and ions from the external environment and excrete others. For example, a cell producing protein will need to take in a variety of amino acids. When substances such as calcium ions are used as signals for cell communication, their levels inside cells will need to be controlled.

Many cellular reactions need specific conditions in order to occur efficiently and effectively. Cellular processes such as photosynthesis and respiration use **enzymes** to speed up chemical reactions to a point where each step proceeds smoothly to the next. Enzymes can only perform their tasks within narrow temperature and pH ranges. Hydrogen ion concentrations must be kept within strict limits to maintain suitable cytoplasmic pH levels. Toxic waste products need to be removed to ensure they do not interfere with chemical reactions in the cytoplasm. For all these reasons, the plasma membrane must regulate the internal environment of the cell.

Most chemical reactions in cells are controlled by enzymes. Their structure and function is discussed in Chapter 9.

Structure of membranes: the fluid mosaic model

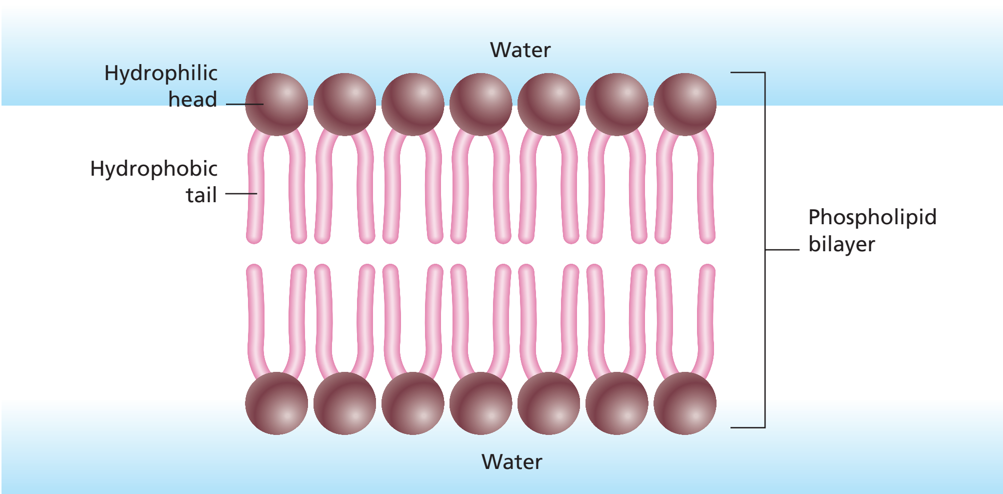
The ability of the plasma membrane to keep the concentration of substances inside cells fairly constant and very different from the external environment depends on its structure. The fluid mosaic model describes membranes as a double layer of lipids, a lipid **bilayer**, with the ability to flow and change shape, like a two-dimensional fluid. Specialised protein molecules are embedded in the lipid in various patterns like a mosaic. Some of these proteins can move laterally, and others are fixed in position. Both proteins and phospholipids help to control the exchange of materials between the external and internal environments.



▲ **Figure 8.4**
A phospholipid molecule. The hydrophilic head is attracted to water whereas the hydrophobic tails repel water.

Phospholipid bilayer

The lipid bilayer is composed of subunits called phospholipids. Each phospholipid can be represented by a head and two tails (Figure 8.4). A phosphate group on the head makes this end **hydrophilic** (able to absorb water or dissolve in water) and the fatty acid tails are **hydrophobic** (water avoiding or unable to dissolve in water). This means that while the heads are attracted to water, the tails are repelled. When these molecules spontaneously form a bilayer, the fatty acid tails turn inwards, away from the watery environment and cytoplasm, and towards each other (Figure 8.5), rather like salad oil forming a film on the surface of water.



◀ **Figure 8.5**
Representation of the way phospholipids form a bilayer in membranes

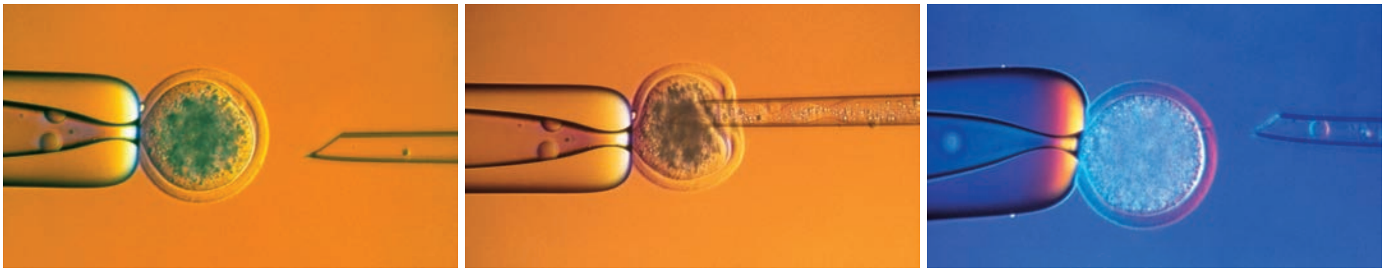
The plasma membrane controls the exchange of material between the internal and external environments of the cell.

ACTIVE PLASMA MEMBRANES

Watch the video, noting the fluid and flexible plasma membranes.

In animal cells, another type of lipid called **cholesterol** is interspersed among the phospholipid molecules. Cholesterol interferes with interactions between the lipid tails, making the membrane more flexible. In plants and bacteria, it is phytosterol (not cholesterol) that increases membrane flexibility.

The lipid components of all membranes, whether from plants, animals or bacteria, provide membranes with the unique properties of being flexible and able to repair themselves. This allows cells to change shape and grow. During cell division and vesicle formation, membranes can break and reassemble themselves. Additionally, if the plasma membrane is punctured, some of the cytoplasm will leak out but the hole will quickly seal. Biotechnological procedures make use of this property when the inside of a cell needs to be accessed (Figure 8.6).



Getty Images/SPL/W. A. Ritchie/Roslin Institute/Eurelios

Figure 8.6 ▲ Puncturing and resealing the membrane of a cell. Microscopic sequence of removal of the nucleus of an egg.

Membrane proteins

A range of different proteins are embedded in the phospholipid bilayer, with many penetrating from one side to the other (Figure 8.7). These proteins have evolved to enable cell–cell interaction and communication, and the exchange of substances with the external environment. For example, in multicellular organisms, **adhesion proteins** link cells together to maintain both the three-dimensional structure and the normal functioning of tissues.

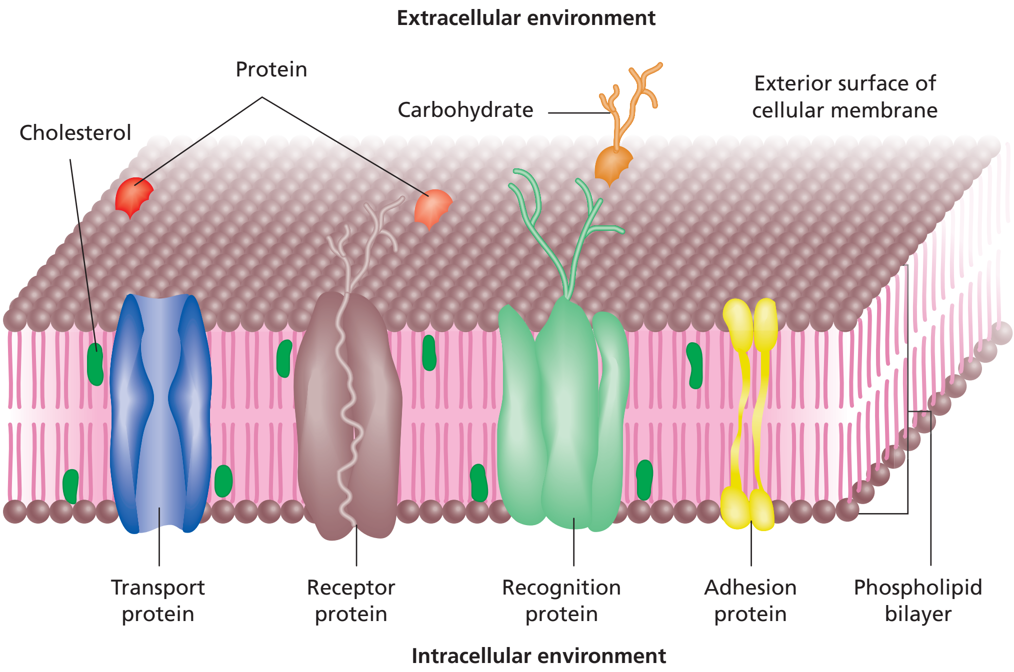


Figure 8.7 ▶ A view of part of the plasma membrane showing embedded proteins

VISUALISING THE PLASMA MEMBRANE

Work through the animation and complete the quiz.

Transport proteins act as passageways that allow specific substances to move across the membrane. An example is the rapid movement of **ions** across the membrane when a nerve is stimulated. This causes a dramatic change in the electric potential difference (the difference in positive and negative charges) across the membrane and explains how the electrical charge of a nerve impulse is transmitted along nerve cells.

Membrane proteins are also involved in cellular communication. **Receptor proteins** bind hormones and other substances that cause changes to the cell's activities. Different types of cells have different receptor proteins, enabling them to respond to only certain signals and so carry out specific functions.

Membrane **recognition proteins**, which are called **glycoproteins** because they combine with a sugar molecule, are unique to each individual. They act as markers, called **antigens**, which allow the immune system to distinguish between the body's own 'self' cells, and foreign invaders ('non-self' cells). If 'non-self' cells are discovered, the immune system will destroy them. This explains why the bodies of organ recipients often reject transplanted organs. Similarly, a blood transfusion with the wrong blood type can be fatal, as glycoproteins in the plasma membranes of red blood cells stimulate massive immune rejection.

More detail on the immune system is discussed in Unit 4 Biology.

The plasma membrane forms the boundary between a cell and its external environment. Its phospholipid bilayer and embedded proteins control the movement of substances into and out of the cell.

QUESTION SET 8.1

Remembering

1 Identify where the cytoplasm is found in cells.

2 State the chemicals responsible for each of the following features of the plasma membrane.

  a Ability to bind hormones

  b Flexibility

  c Movement of ions into cells

3 Describe the role of receptor proteins in plasma membranes.

Understanding

4 a Which part of the plasma membrane is described as fluid? Which part is described as mosaic?

  b Explain why these terms are used.

5 Explain why unicellular organisms are more likely to experience bigger changes in their external environment compared with cells in multicellular organisms.

Passive movement across membranes

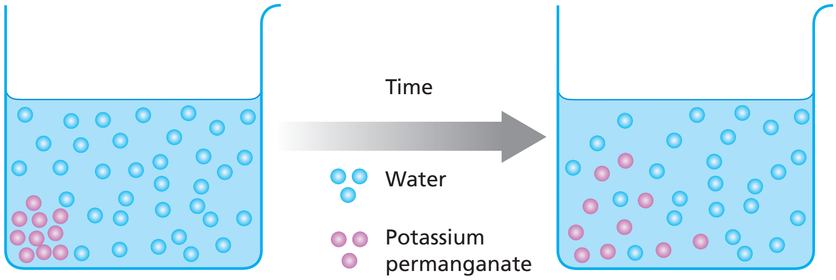
Materials can move across membranes either with or without the expenditure of energy. Movement that does not require energy is called **passive transport**. A simple analogy to explain this involves riding a bicycle. Riding uphill requires you to use energy in your leg muscles to pedal hard. You are actively peddling. Once you are at the top, you can move passively down the hill, without using any energy to move the pedals. Many molecules move across the plasma membrane passively, without using energy. This type of movement relies on a process called **diffusion**.

Diffusion

Why does a spoonful of sugar dissolve rapidly in a cup of tea? Why can you smell gas escaping from a gas stovetop? Part of the reason is that the particles of sugar and gas are constantly moving.

If you were to drop a crystal of potassium permanganate ($KMnO_4$) into a beaker of water, and you did not stir or move the beaker, what would happen? You will find that, over time, the purple colour of the permanganate spreads through the water until eventually it is evenly distributed. As the crystal dissolves, the potassium and the permanganate particles separate from the crystal and move through the water (Figure 8.8).

Figure 8.8 ▶ Diffusion of potassium permanganate in water over a period of time



DIFFUSION

View the animation. What is the end result of diffusion?

What causes the particles in the potassium permanganate crystal to behave in this way? The particles dissolving from the crystal are in a state of continual random motion. They can move in any direction. To start with, there are far more of them near the crystal, increasing the probability that they will move away from the crystal. This causes a net (overall) movement of potassium permanganate particles away from the crystal. This is the process of diffusion.

Diffusion is the net movement of particles from a region of high particle concentration to a region of lower particle concentration. The difference in particle concentration between the two regions is called the **concentration gradient**. Diffusion always takes place wherever such a gradient exists and continues until the particles are distributed evenly throughout the system. When that happens, **equilibrium** is said to be reached. Particles will continue to move randomly, but at equilibrium they move at equal rates in all directions.

Diffusion is a passive process as it does not require additional energy to make it happen. It takes place in gases and liquids, in both living and non-living systems. Increasing the concentration gradient or heating the particles to make them move faster will increase the rate of diffusion. The particle theory (also referred to as the kinetic theory of matter) says that the particles that make up matter are in constant motion and the higher the temperature, the faster the speed of the particles.

- Movement of particles down a concentration gradient, from where they are in high concentration to where they are in low concentration, is passive and does not require energy.
- Movement of particles up a concentration gradient, from where they are in low concentration to where they are in high concentration, is active and requires energy.

ACTIVITY 8.1

OBSERVING DIFFUSION

Aim

To explore the movement of particles within a liquid

You will need

- a glass jar or tall beaker
- warm water
- tea bag
- stirring rod

What to do

1. Fill the beaker with warm water.
2. Tie a tea bag to the stirring rod and place the rod across the top of the beaker, so that the tea bag enters the water with minimal disturbance.
3. Record the changes you observe over the next 10 minutes.

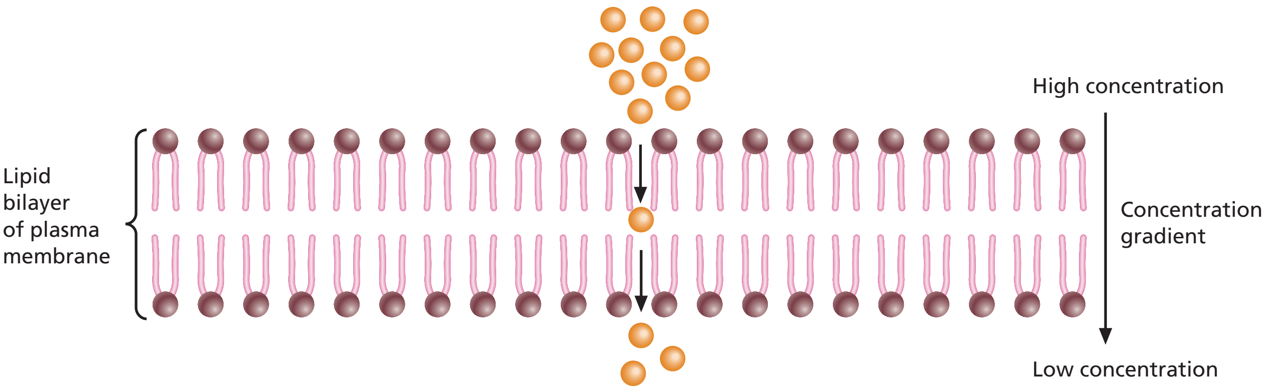
What did you discover?

1. Describe the change in colour over the 10 minutes.
2. Explain your observations ensuring you use the term 'concentration gradient'.
3. Predict what difference you would observe with hot water rather than warm water. If you have time, test this prediction.

Diffusion across membranes

Substances such as oxygen, water, carbon dioxide and other small, uncharged particles move easily through the plasma membrane of a cell by simple diffusion. Figure 8.9 shows these particles passing between the phospholipid molecules from a high to a low concentration. Oxygen always tends to diffuse into cells because their use of oxygen in cellular respiration maintains a low concentration in the cytoplasm.

▼ **Figure 8.9** Simple diffusion of small molecules through the plasma membrane is dependent on the concentration gradient.



EXPERIMENT 8.1

SELECTIVE PERMEABILITY AND TEMPERATURE

Aim

To investigate the effect of temperature on the plasma membrane

Materials

- beetroot
- mounted needle
- hot plate
- thermometer
- six small test tubes
- 10 mL measuring cylinder
- two 250 mL beakers
- fruit knife
- cork borer
- stopwatch

What are the risks in doing this experiment?	How can you manage these risks to stay safe?
Hot plates can burn.	Take care around hot plates. Place hot plates back from the edge of benches when not in use.

Procedure

1 Use a cork borer to cut cylinders of tissue from the beetroot.
2 Using a knife, cut the beetroot cylinders into discs 3 mm thick. You will need 36 discs.
3 Wash the discs in a beaker of water for 5 minutes, changing the water every minute or so.
4 Label the six test tubes as 30, 40, 50, 60, 70 and 80, and using a measuring cylinder place 6 mL of cold tap water in each.
5 Prepare a water bath by half filling a 250 mL beaker and heating it on a hot plate to 30°C, using a thermometer to test the temperature.
6 When the beetroot discs have been washed, thread six onto a mounted needle, leaving a 1 mm space between the discs. Plunge the discs into the hot water for exactly 1 minute.
7 Push discs off the needle and drop them into the tube labelled 30.
8 Increase the heat of the beaker to 40°C, repeating the procedure with another six discs of beetroot.
9 Keep repeating the procedure, raising the temperature by 10°C each time, until all of the discs have been used.
10 After leaving discs in the test tubes for at least 20 minutes, shake the tubes and record the colours of the liquid, using a scale from 1–5, with 1 being a very pale shade of pink.

Results

Copy and complete the table to display your results.

Temperature (°C)	30	40	50	60	70	80
Colour						

Analysis of results

1 Describe the pattern of your results.

Discussion

1 What evidence do you have that the living membrane is selectively permeable?
2 Explain why it was necessary to wash the discs thoroughly before heating.
3 Suggest how high temperatures affect membranes.

Facilitated diffusion

FACILITATED DIFFUSION

Explain how facilitated diffusion differs from simple diffusion.

Charged particles (such as sodium and chloride ions) and relatively large molecules (such as glucose and amino acids) do not readily pass through the phospholipid bilayer. There must be some way to help them enter the cell. In the plasma membrane, certain proteins assist such particles to diffuse into the cell. This process is called **facilitated diffusion**.

Two types of protein are involved in facilitated diffusion: **carrier proteins** and **channel proteins**. Carrier proteins bind to specific molecules on one side of the membrane, change shape and release the substance on the other side (Figure 8.10). An example is the glucose transporter protein, which is located in the plasma membrane of all mammalian cell types and carries glucose in either direction, depending on the direction of the concentration gradient.

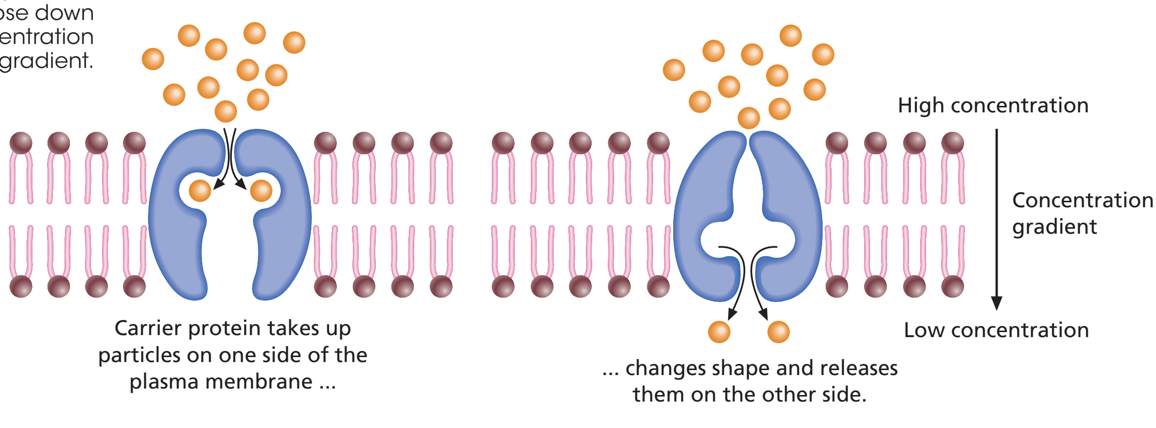
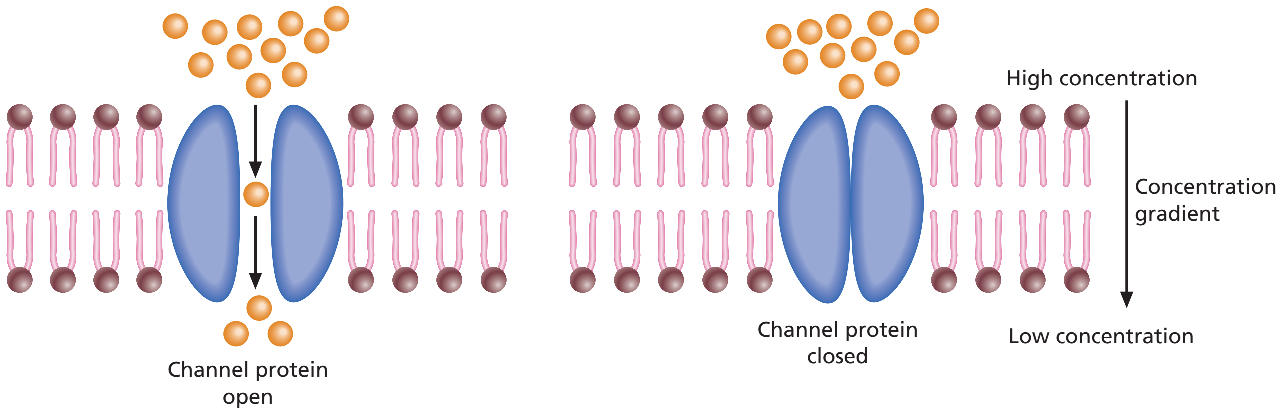


Figure 8.10 ▼ Facilitated diffusion using a carrier protein in the plasma membrane of a cell moves particles such as glucose down the concentration gradient.

Channel proteins form narrow passageways through which small ions can diffuse rapidly from a high ion concentration to a lower ion concentration (Figure 8.11). Only ions of a specific size and shape can pass through a particular channel protein.

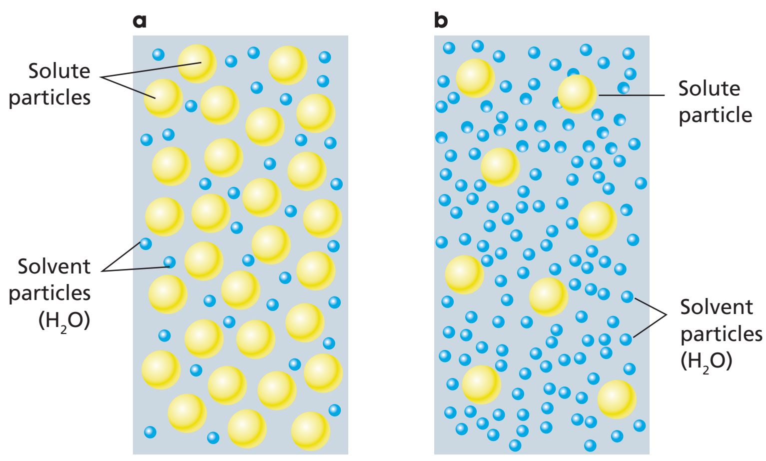


▲ **Figure 8.11** Facilitated diffusion through a channel protein in the plasma membrane of a cell. Movement is down the concentration gradient.

Osmosis: a special type of diffusion

When injured wildlife are received by wildlife recovery staff, they check to see if the animal is dehydrated by pinching the skin and seeing how quickly it returns to its usual position. The skin will stay bunched for longer in a dehydrated animal. A lack of water in cells and extracellular fluid means that the tissues are slack and do not keep their firmness. The equivalent in plants is **wilting** but it is usually more obvious. If the weather is extremely hot or we fail to water pot plants, they may droop because of lack of water in their cells.

Without water, no life can survive, although some organisms can survive with less water for longer than others. Water is the medium in which biochemical processes take place. Water also transports materials in **solution**, helps keep cells in shape and forms the fluid that bathes tissues. Water is described as the universal **solvent**. If you add sugar or salt to water, you are adding **solute** to solvent and making a solution. A dilute solution has a relatively high concentration of water molecules compared to solute particles dissolved in it, whereas a concentrated solution has a low concentration of solvent molecules and a high concentration of solute particles (Figure 8.12).

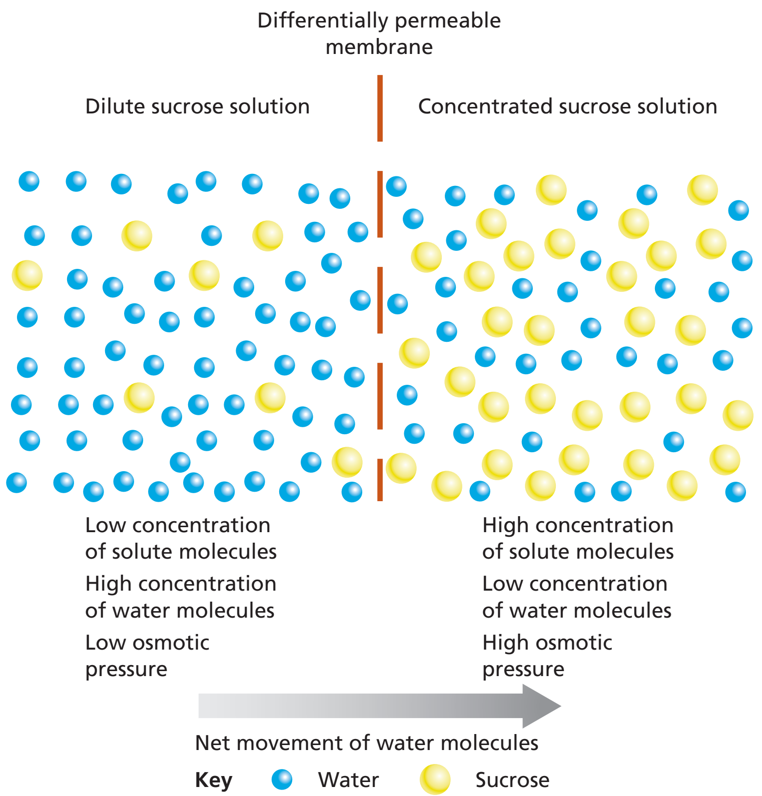


◀ **Figure 8.12** Making solutions: a) a concentrated solution; b) a dilute solution

Solution (mixture of particles) = solvent particles + solute particles
High-concentration solution = low concentration of solvent + high concentration of solute
Low-concentration solution = high concentration of solvent + low concentration of solute

Plasma membranes are selectively (differentially) permeable, meaning that water molecules pass through them easily but solutes do not. If the concentration of water molecules inside a cell is lower than the concentration outside, water will diffuse into the cell until a balance or equilibrium is reached. This process is called **osmosis**. By definition, osmosis is the diffusion of water across a selectively permeable membrane from an area of high water concentration (low solute) to an area of low water concentration (high solute). Osmosis is a special type of diffusion. Similar to diffusion, osmosis requires no input of energy as water is moving down its concentration gradient (Figure 8.13).

Figure 8.13 ▶ Summary of the conditions on the two sides of a differentially permeable membrane

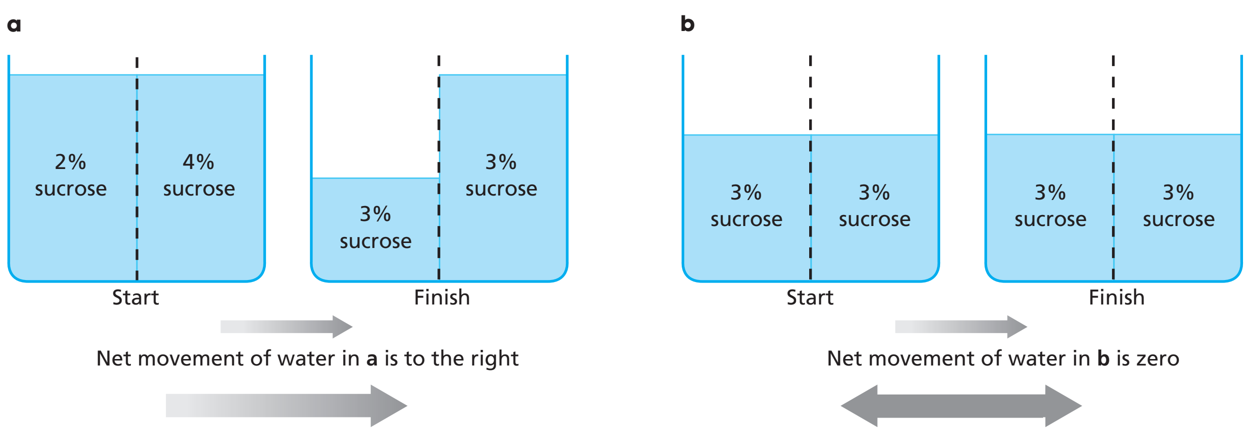


OSMOSIS

Watch the animation and explain why osmosis is a special case of diffusion.

If the fluids inside and outside a cell are of equal solute concentration, the external solution is said to be **isotonic** ('iso' = same) to the cells; water molecules jostle on both sides of the membrane, moving in both directions equally. When cells are surrounded by a solution that contains a lower solute concentration than their cytoplasm, the external solution is said to be **hypotonic** ('hypo' = lower) to the cells. Water molecules will diffuse through the membrane into the cells. The reverse applies if the cells are surrounded by a solution of higher solute concentration; the external solution is **hypertonic** ('hyper' = higher) to the cells and water molecules will diffuse out.

Figure 8.14 ▼ These diagrams show the net movement of water molecules between solutions separated by a differentially permeable membrane that is impermeable to sucrose.



EXPERIMENT 8.2

OSMOSIS IN POTATOES

Aim

To demonstrate the process of osmosis in plant tissue

Materials

- a large potato
- fruit knife
- pie dish
- honey
- teaspoon
- hot plate
- 250 mL beaker

What are the risks in doing this experiment?	How can you manage these risks to stay safe?
Knives are sharp.	Be careful when using the fruit knife and do not walk around the room carrying the knife.
Hot plates can burn.	Take care around hot plates. Place hot plates back from the edge of benches when not in use.

Procedure

1 Cut three cubes of potato, each 3 cm × 3 cm.
2 Cut a well in each cube, taking care not to cut all the way through.
3 Place one cube in a beaker of water and boil for 3 minutes.
4 Place all three cubes in the dish and add water until it is roughly level with the bottom of the wells.
5 Place a teaspoon of honey into the well of one unboiled cube and the boiled cube. Leave the third empty.
6 Leave for several hours then observe any changes.

Results

1 Describe any changes in the wells of your three potato cubes.

Discussion

1 Identify the independent variable in this experiment. What was the control?
2 Explain what happened to produce the results you obtained.

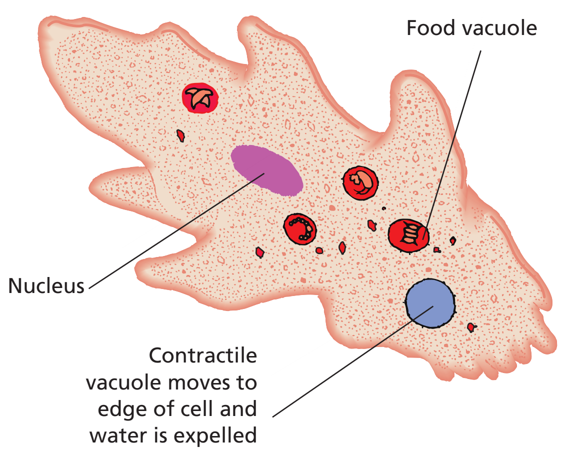
Taking it further

1 Try other types of vegetables to see if they respond in the same way.

Osmosis in animals

The cells of unicellular eukaryotes and multicellular organisms, such as animals, are surrounded only by a plasma membrane, unlike the cells of plants, fungi and bacteria, where a cell wall surrounds the plasma membrane. Hypertonic solutions, such as fresh water, pose a special problem for these organisms. Water moving into their cells by osmosis can cause the fluid plasma membrane to swell and eventually burst, killing the organism. Unicellular organisms such as *Amoeba* that live in fresh water have important regulatory mechanisms to combat these problems. They are able to remove excess water by forming little pools of water in cytoplasmic organelles called **contractile vacuoles** (Figure 8.15). When these vacuoles stretch to a certain point, they contract and expel the water.

In multicellular animals, cells are bathed in isotonic extracellular fluid. This means that cells can function efficiently because water diffuses equally in both directions, resulting in no net movement of water into or out of cells. To keep the internal environment of your body in isotonic balance, the solute concentration in the extracellular fluid is controlled by the concentration of solutes in blood plasma, which in turn is controlled by the kidneys.



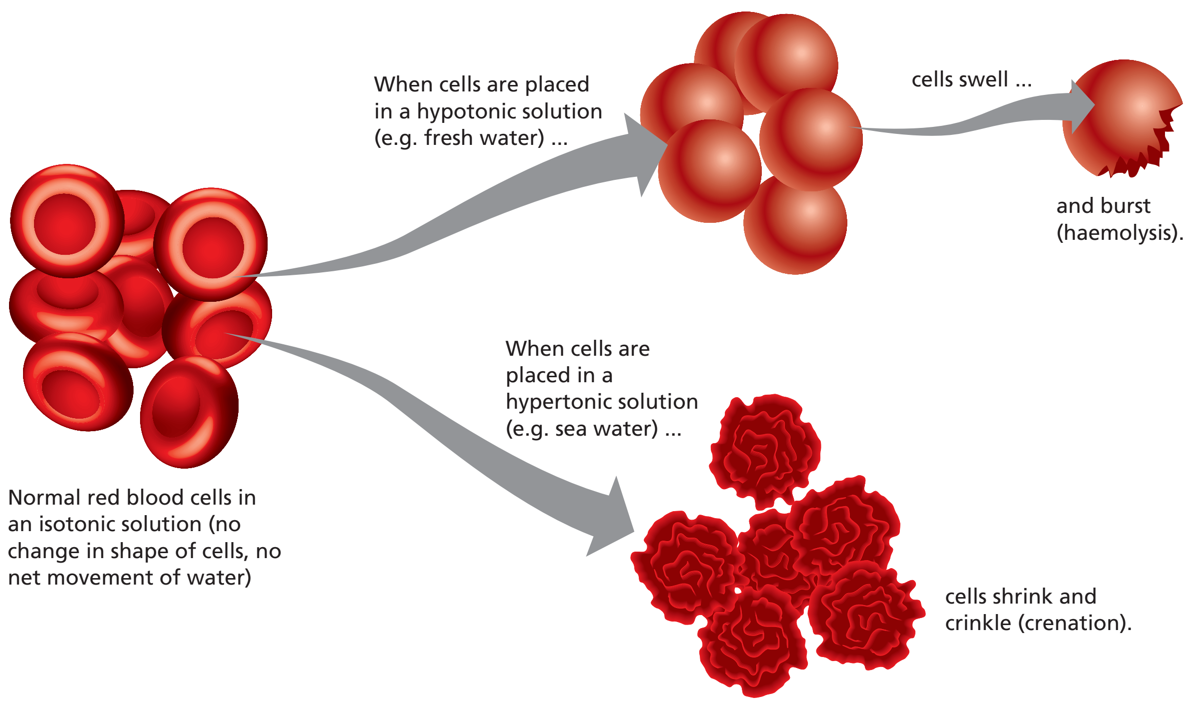
▲ **Figure 8.15** Amoebas are able to remove fresh water by organelles called contractile vacuoles.

You may have been in hospital and seen patients hooked up to an intravenous drip. This drip is connected directly to their circulatory system, adding fluid to their blood plasma. It is important that fluid in the drip has a solute concentration equal to blood plasma (isotonic). In this situation, water will enter and leave blood cells at the same rate, maintaining their ideal water concentration.

What will happen if the intravenous drip contains salty water? If the plasma surrounding blood cells becomes hypertonic, water will move out of the cells by osmosis and, in a process called **crenation**, they will shrink and become crinkled (Figure 8.16). The resulting small, shrunken blood cells tend to stick together, clogging small veins and arteries, and preventing oxygen reaching body tissues. If enough blockages occur, the results may be fatal.

It is equally dangerous for an intravenous solution to be hypotonic. If the blood plasma is diluted by water, the blood cells will swell and burst. This condition is called **haemolysis** and it can seriously reduce the amount of oxygen being transported to body tissues. Because of these effects of osmosis on animal cells, it is important that the solute concentration of blood plasma is regulated by the kidneys.

Figure 8.16 ▼ Damaged blood cells. Human red blood cells swell or shrink in solutions of varying solute concentrations.



WOW

Osmosis in the laundry

Consider the case of a blood-stained piece of clothing. If a cut spills blood onto some clothing, you will probably soak the blood-stained material in cold water to remove the stain. In this case, the concentration of water in the solution around the clothing is higher than that in the red blood cell's interior and there is a net movement of water into the cell. This causes the blood cells to swell and become so full of water that they eventually burst. This releases the red pigment and cleans your clothing. By taking this action, you are using the process of osmosis.

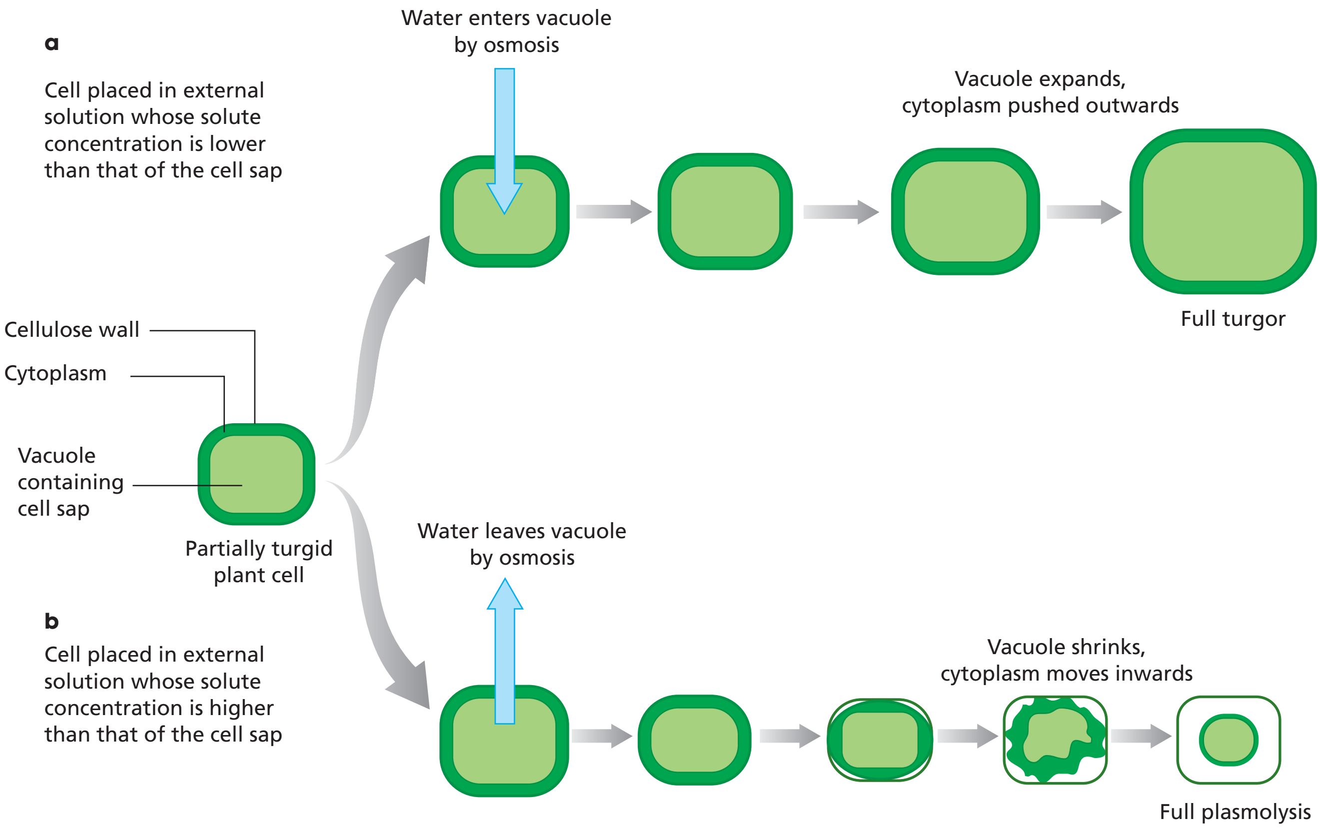
OSMOSIS IN RED BLOOD CELLS

View the animation and draw diagrams to show the direction of water movement in haemolysis and crenation.

Osmosis in plants

Did you know that soaking limp vegetables like celery in water restores their crispness? Unlike animal cells, the celery cells will not burst when soaked in fresh water (hypotonic solution), even though water moves into the plant by osmosis. How can you explain this difference?

Think about the differences in plant and animal cell structure. Animal cells lack cell walls and rarely contain large vacuoles. Plants commonly have large, fluid-filled vacuoles and firm but permeable cell walls that surround the plasma membrane. Like the plasma membrane, the vacuole membrane (**tonoplast**) is differentially permeable. Plant cell vacuoles contain cell sap that is rich in solutes: a solution of high concentration. When a hypotonic solution surrounds a plant cell, water molecules diffuse by osmosis, firstly into cytoplasm and then into the vacuole. The vacuole swells, pushing the cytoplasm and plasma membrane against the cell wall. The tough cell wall prevents the cell from bursting. When the cell wall stretches as much as possible, no more water can enter and the cell is said to be **turgid** (Figure 8.17).



▼ Figure 8.17
The effect of immersing a partially turgid plant cell in a) pure water and b) a high solute concentration.

Turgor is very important for plants. It supports them and maintains their shape and form. The stems of non-woody plants are kept erect by the turgid, tightly packed cells that fill them. Turgor is also responsible for holding leaves in a flat, opened-out position. Certain plant cells are able to undergo quite rapid changes in their solute concentration with consequent changes in turgor. This allows such cells to change their shape. Stomatal guard cells behave this way, as do cells responsible for the leaf movements of insectivorous plants (the Venus flytrap).

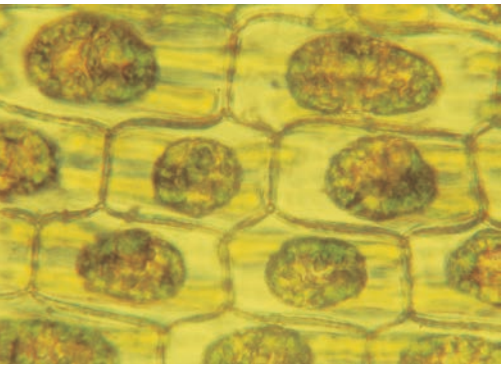
WOW

When turgid cells are a problem

Oil cells in the rind of citrus fruit become turgid after rainfall and during cold weather. These cells rupture more easily during harvesting and transport, and the oil released is toxic to surrounding epithelial cells. The resultant blemish on the skin provides a site for the invasion of fungus. It is common to see the dark blemishes as an outline of the finger positions of the picker who, when plucking the fruit from the tree, ruptured the turgid oil cells. This 'oil spotting' condition, known as oleocellosis, takes up to three days to appear.

To minimise the risk of oil cells rupturing, some citrus growers use a penetrometer to determine the pressure required to rupture oil cells. If cells rupture at a pressure lower than normally required to remove fruit from the tree, growers will delay harvesting until the cells are less turgid, when the weather is a little warmer or the fruit has dried.

On a hot, dry day, you may see some plants wilting. When significant quantities of water evaporate from the plant, the external concentration of water molecules becomes less than in the vacuole. Water molecules diffuse out, reducing the volume of the vacuole and causing the cells to become limp or **flaccid** and the plant to wilt. If enough water is lost, the plasma membrane pulls away from the cell wall in a process called **plasmolysis** (Figure 8.18).



Corbis/Visuals Unlimited

Figure 8.18
Plasmolysis in *Elodea* cells. Water has diffused out of the cells, causing the volume of cytoplasm to shrink. Gaps between the cytoplasm and cell wall are filled with external solution.

EXPERIMENT 8.3

INVESTIGATING THE RATE OF OSMOSIS

Potato tissue provides a simple model of a cell to test the factors that affect the rate of osmosis across a semi-permeable membrane.

Aim

To design an experiment to test how one of the following factors affects the rate of osmosis:
- 'cell' size
- 'cell' shape
- salt concentration of solution

Materials

- stopwatch
- two potatoes, raw, peeled
- table salt
- a 30-cm ruler
- any extra materials you will need for your chosen investigation

Procedure

1 Select the factor that your team will test.
2 List your materials. Include a risk assessment box and add a procedure.
3 Perform your investigation.
4 Record and analyse your results. Discuss and draw a conclusion.

QUESTION SET 8.2

Remembering

1 A salt solution is a mixture of salt and water. Which of these is the solvent and which is the solute?
2 List the factors that increase the rate of diffusion.
3 What is facilitated diffusion? What substances enter the cell by this process?
4 Give one reason why plant cells do not burst when placed in a hypotonic solution.

Understanding

5 Explain why red blood cells are stored in saline (salt) solution rather than pure water.
6 If salad greens such as lettuce are left for a period of time, they become limp. To restore their crispness they can be soaked in cold water. Explain the reason for this.

Applying

7 Explain why the juice comes out of strawberries if you sprinkle sugar on them.

8 Animal cells are placed in three different solutions. After a period of time, cells in solution X burst. Cells in solution Y remain the same and cells in solution Z became shrivelled.

a Which solution was hypertonic compared with the animal cell?

b Which cell was isotonic compared with the surroundings?

c How would plant cells look in these solutions?

Movement across membranes using energy

The processes of diffusion and osmosis do not require the input of energy. However, there are occasions when energy is needed to move substances across membranes. **Active transport** and bulk transport are some examples where movement of substances requires energy.

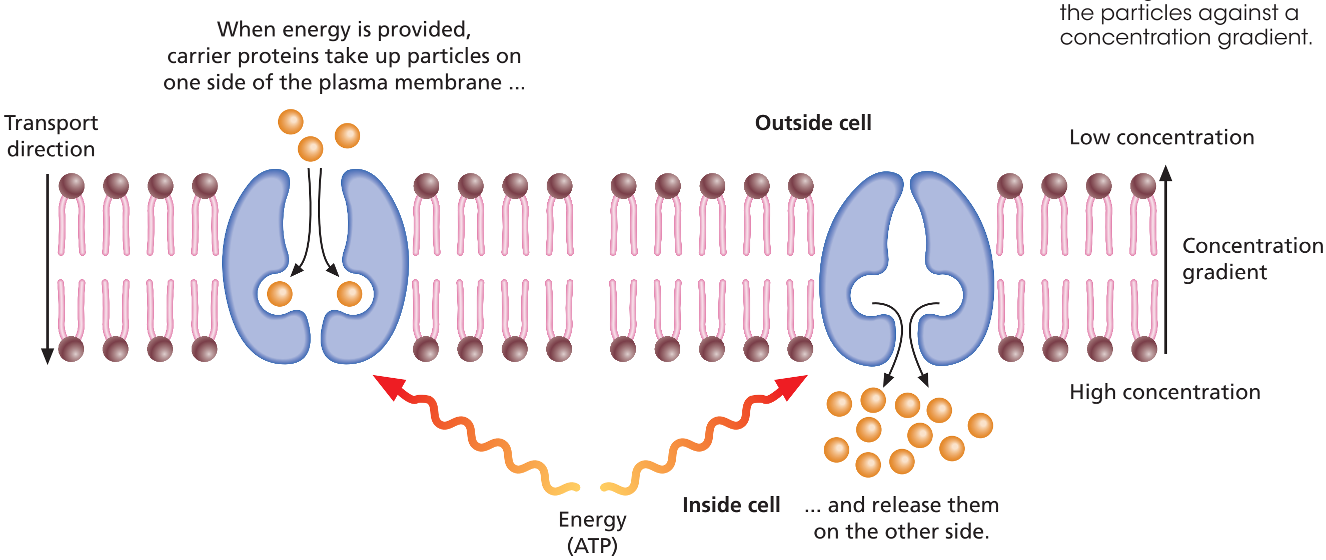
Active transport

After you eat a meal, nutrients such as glucose are absorbed into the cells lining the inside of the small intestine. If diffusion alone were to be involved, once the concentration of glucose inside and outside the cell became equal, there would be no net movement. Some of the glucose available from digestion would be excreted along with wastes and undigested food. This is not the case. Glucose continues to move into cells lining the small intestine even when its concentration is lower outside the cell. Cells appear to pump glucose in through their plasma membranes.

In this and other similar situations, molecules or ions move up their concentration gradient, from a region where they are in a low concentration to a region of higher concentration. As this movement of molecules or ions through a membrane against a concentration gradient requires the input of energy, it is called active transport.

How does active transport take place? Membrane transport proteins, similar to those responsible for facilitated diffusion, use energy from **adenosine triphosphate (ATP)** to move molecules or ions up their concentration gradient (Figure 8.19). As these carrier proteins work in only one direction, they effectively act as one-way valves. The importance of these pumps becomes apparent when individuals, such as those suffering the disease cystic fibrosis, cannot produce them in adequate amounts.

▼ Figure 8.19
Active transport via a carrier protein in the plasma membrane of a cell. Energy is transferred to the carrier protein, enabling it to move the particles against a concentration gradient.



Mitochondria and ATP production is studied in more detail in Chapter 9.

Without active transport the kidneys could not reabsorb useful materials, muscles would not contract and impulses would not be able to travel along nerves. As we saw in Table 8.2, animal cells contain high concentrations of potassium ions but low concentrations of sodium ions. The mechanism responsible for this is the **sodium–potassium pump**, which moves these two ions in opposite directions across the plasma membrane. The sodium–potassium pump has a particular significance for excitable cells, such as nerve cells, which respond to stimuli. Other substances such as amino acids and hydrogen ions are also pumped across membranes by active transport.

The energy demands of these processes are significant. It has been estimated that while a person sleeps, as much as 40% of the total energy budget is used for active transport. Cells engaged in active transport have huge numbers of mitochondria. These organelles build up the ATP that is used as the energy source in these cells.

WOW

Criminals beware!

Medical examiners using high-performance liquid chromatography, coupled with mass spectrometry, have found traces of plant toxins in homicide cases that might otherwise have gone unnoticed. Digoxin, a potent heart toxin found in the foxglove plant, works by blocking calcium ion channels in heart muscles. This disrupts the heartbeat and kills the victim. Foxglove poisoning is well known to Western toxicologists. A similar toxin, cerberin, has been found in the kernels of *Cerbera odollam*, a widespread plant in India. The poison has a bitter taste that is easily obscured by spices. Murderers beware! New autopsy tests will show if the victim consumed cerberin.

Corbis/Visuals Unlimited

Figure 8.20 ▲ A scanning electron micrograph of an *Amoeba* surrounding its prey (*Tetrahymena*) for ingestion

Endocytosis

At times, very large particles or even whole cells have to be moved into a cell across its plasma membrane. In other circumstances, relatively large molecules have to be exported from a cell. The large size of these particles makes their movement through the membrane by diffusion or active transport impossible. In these cases of bulk transport, membranes and cytoplasmic vesicles have an important role to play in **endocytosis** and **exocytosis**. These are active processes, requiring energy to move vesicles around the cytoplasm and to change the shape of the cell.

Figure 8.20 shows a unicellular *Amoeba* feeding on a smaller organism, illustrating the process of endocytosis. The *Amoeba* changes shape by sending out projections that surround the prey. When the plasma membrane of the projections meet, membrane fusion occurs. This results in the formation of a vesicle, which then stores or transports the material within the cytoplasm (Figure 8.21). The two types of endocytosis discussed in this chapter are named according to the type of material consumed. The process that engulfs solids, like an *Amoeba* eating, is called **phagocytosis**, and the other process that takes in droplets of liquid is **pinocytosis**.

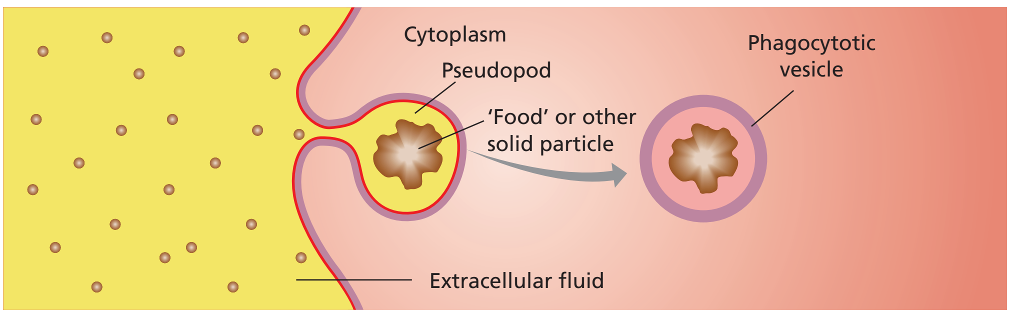
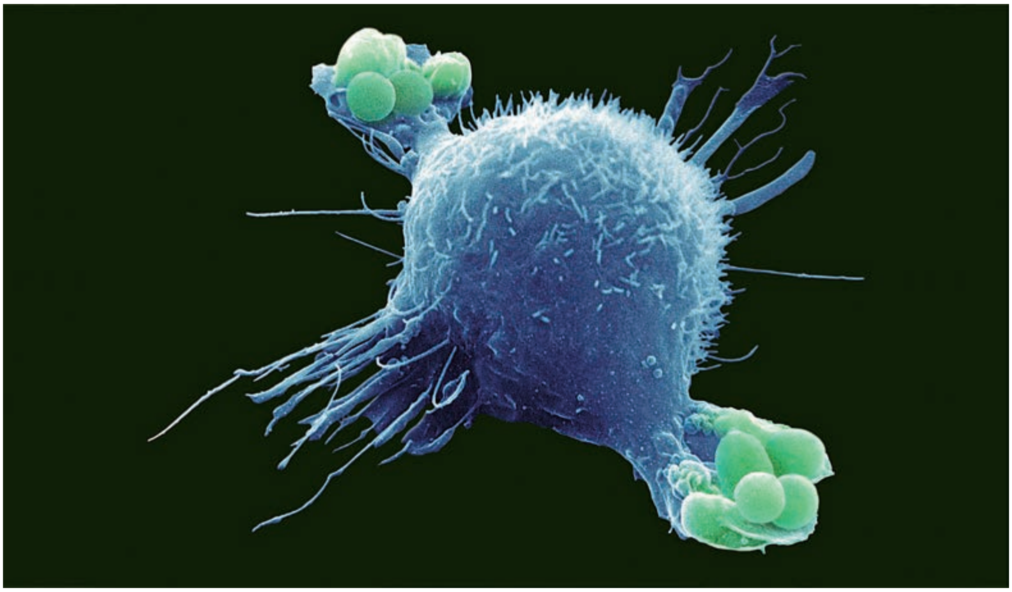


Figure 8.21 ▶ The process of phagocytosis



Corbis/Visuals Unlimited/Dr David Phillips

◀ Figure 8.22
A macrophage engulfing cells by phagocytosis

Human macrophages (a type of white blood cell) are called phagocytes because, in defending the body against disease, they engulf bacteria by phagocytosis (Figure 8.22). Macrophages use recognition proteins in the plasma membrane of the cells they encounter to discriminate between invading bacteria and body cells, demonstrating that phagocytosis is a selective process.

Pinocytosis occurs when the plasma membrane engulfs a drop of extracellular fluid in much the same way as phagocytosis (Figure 8.23). Fat droplets found in the small intestine after a meal move into cells by means of pinocytosis.

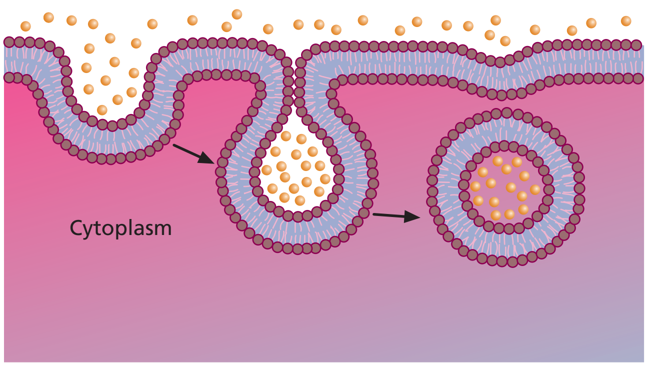
ATP energy is required to move substances across membranes by active transport and bulk transport.

Exocytosis

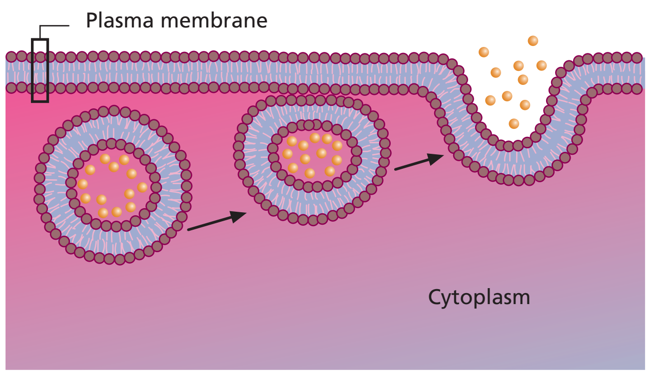
Specialised animal cells produce a variety of substances, such as hormones, mucus, milk proteins and digestive enzymes, which have important functions elsewhere in the organism. This is also true for plants, where particular cells are specialised to produce products that need to be relocated. These include growth regulators, toxins to ward off predators and macromolecules for use elsewhere. In all these cases, exocytosis is involved.

Exocytosis is the process by which large molecules held in vesicles within the cell are transported to the external environment. It is essentially the reverse of endocytosis. During exocytosis, a membrane-bound vesicle moves to the plasma membrane, fuses with it and then releases its contents to the exterior of the cell (Figure 8.24).

ENDOCYTOSIS AND EXOCYTOSIS
View the simulation and complete the quiz.



▲ Figure 8.23
The process of pinocytosis



▲ Figure 8.24
The process of exocytosis

Case study

Curing cancer: cell death could save lives

After holding a number of research positions overseas, including a stint at the Harvard Medical School, Dr Barbara Sanderson returned to Flinders Medical Centre in Adelaide, South Australia. To follow her interest in genetic damage related to cancer, she took up a lectureship in Medical Biotechnology at Flinders University. Her research group's long-term goals are to understand and model the cell damage that leads to cancer and to develop new anti-cancer treatments. Cancer has such enormous economic and social cost to the community that the development of new cancer treatments will have a significant effect on the lives of those affected.

Dr Barbara Sanderson

Figure 8.25 ▲
Dr Barbara Sanderson, Senior Lecturer in Medical Biotechnology

In a major breakthrough, Dr Sanderson and her colleagues have shown that the milky venom from the sea anemone, *Heteractis magnifica*, kills human lung cancer cells. They intend to test the venom on other cancer cell lines and an animal model before approaching pharmaceutical companies. The venom induces **apoptosis**, a particular type of cell death that cancer cells override.

Plasma membrane receptors on cancer cells are thought to respond to the sea anemone venom by relaying messages to 'death receptors' inside the cell. This activates a group of 'protein-eating' enzymes that change the structure and composition of the plasma membrane. The plasma membrane then becomes more permeable to small molecules. Other venom enzymes disrupt the phospholipid asymmetry by moving specific molecules to the outer side of the lipid bilayer. This marks the cell for death. The molecules act like 'eat me' signals and the cells are engulfed by roaming white blood cells.

Questions

1 Name and describe the process used by macrophages to engulf cells undergoing apoptosis.
2 Describe how Dr Sanderson is using scientific knowledge to respond to the social and economic needs of society.
3 Use your knowledge of membrane structure to predict what changes might occur to the plasma membrane during apoptosis, to make it more permeable to small molecules.
4 Explain why modelling apoptosis has required a wide range of evidence from multiple individuals and across many science disciplines.
5 Any research that uses animals must be passed by an animal ethics committee. Evaluate this research and construct a clear reasoned argument to explain why you would or would not approve it if you were a member of this committee.

APOPTOSIS
View this video and draw a simple flow chart to illustrate the steps involved in apoptosis.

ACTIVITY 8.2

MODELLING ENDOCYTOSIS AND EXOCYTOSIS

Aim

To enhance your understanding of movements of plasma membranes during endocytosis and exocytosis

You will need

- small object like a coin or eraser
- two pieces of string, one 1 m long the other 30 cm

What to do

1. Form the outline of a cell using both pieces of string end to end: do not join the pieces of string.
2. Place the coin near the outer side of the short piece.
3. Use the shorter piece of string to form an endocytotic vesicle around the coin.
4. Move the vesicle into the cytoplasm, closing the plasma membrane behind it.
5. To simulate exocytosis, carry out these directions in reverse.

What did you discover?

1. What happened to the amount of plasma membrane when the model cell carried out endocytosis?
2. Predict what action the cell must take to regulate the amount of plasma membrane when it carries out endocytosis.

QUESTION SET 8.3

Remembering

1. Explain why certain white blood cells are known as phagocytes.
2. Identify two types of cells in which active transport would occur.
3. Distinguish between active transport and simple diffusion.
4. List four types of substances that are secreted from cells.

Understanding

5. Compare and contrast the passive and active cellular uptake of glucose molecules and ions.
6. Explain how the plasma membrane is involved in the processes of endocytosis and exocytosis.

Applying

7. Certain cells lining the intestine have densely packed mitochondria. What would you predict about the function of such cells? Explain your reasoning.

Factors affecting the exchange of materials

Whether or not a substance crosses a membrane, and the method it uses, is determined by characteristics of the selectively permeable membrane and the physical and chemical properties of the substance itself. The rate of movement is determined by the size and shape of a cell and the concentration gradient of the substance being exchanged.

Chemical factors

The chemical properties of a substance indicate how it will behave in the extracellular environment and affect its transport across cell membranes. Ethanol and chloroform are able to easily penetrate and cross membranes because they are uncharged molecules. This allows them to dissolve in the phospholipid bilayer. Charged ions such as sodium (Na^+), potassium (K^+) and calcium (Ca^{2+}), which are hydrophilic, cannot cross the hydrophobic interior of the membrane (Figure 8.26). They move across membranes through membrane transport proteins, called ion channels, which are specific for the substance they carry.

Physical factors

The physical properties of size and shape affect whether or not a substance moves across the plasma membrane, how it is transported and how quickly it moves. Small molecules like water, oxygen and carbon dioxide are able to slip between the phospholipids. They cross the membrane easily and quickly, diffusing passively from a high concentration to a low concentration.

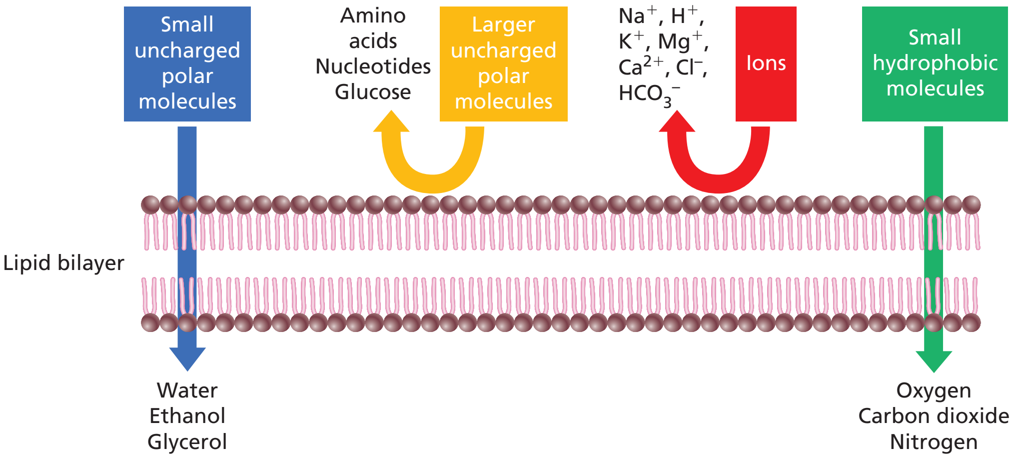


Figure 8.26 ▶ The relative permeability of a lipid bilayer to different classes of molecules

Earlier in this chapter, you learned that larger molecules that are physically too big to move in this way are transported by specific membrane proteins that span the plasma membrane. The specificity of transport proteins depends on the physical shape of the molecule fitting into the carrier protein, much like an enzyme fitting its substrate. Very large molecules, such as proteins that are too large to fit into membrane transport proteins, are taken up by cells in vesicles in the process of endocytosis. Similarly, very large molecules, such as the hormone insulin, are secreted out of the cell in vesicles by exocytosis.

Concentration gradient

The rate of diffusion of any substance is affected by the relative concentration of the substance on either side of the membrane. If the concentration gradient is high, then the substance will diffuse rapidly. As the concentrations become more similar, the rate of diffusion will be slower. There are various ways that cells can increase the concentration gradient across their membranes in order to maintain a rapid rate of diffusion.

Plant cells, from either unicellular or multicellular organisms, carry out **cytoplasmic streaming**, which is a process whereby organelles and **cytosol** flow through the cell in a circular movement. The effect is to maintain a steeper concentration gradient, as materials diffusing into the cell are rapidly removed, keeping them at a lower concentration than if the cytoplasm was stationary.

In multicellular animals, one way of maintaining a steep concentration gradient is for the circulatory system to remove the diffused substance, such as carbon dioxide, away from the tissues. Another is to convert the diffused substance into something else, thus lowering its concentration. For example, when glucose molecules diffuse into liver cells, some are used up and others are converted to glycogen, maintaining a steep concentration gradient.

CYTOPLASMIC STREAMING

After viewing the video, draw a diagram to show the position of chloroplasts, vacuole, plasma membrane and cell wall.

A concentration gradient exists when a substance is at a higher concentration on one side of a membrane compared with its concentration on the other side.

Size and shape of cells

There are many different cell types in your body, each carrying out a specialised function. Yet unicellular organisms survive successfully with only one type of cell. No matter where they are from, almost all cells are very small. Why are there no large unicellular organisms? Why is it that cells divide rather than continue to increase in size? There must be an advantage for multicellular organisms to consist of many, smaller, specialised cells. This advantage relates to the ability of a cell to obtain its nutrients and remove its waste products.

CELL SURFACE AREA VS VOLUME

Use the applet to explore the relationship between cell surface area and volume.

Surface-area-to-volume ratio

An important concept related to exchange across membranes is the **surface-area-to-volume (SA:volume) ratio**. This ratio may be expressed as a single number (e.g. 3) or a ratio (e.g. 3:1). It represents an important relationship between the area of the membrane surrounding a cell and the volume of its cytoplasm.

As we have seen, the uptake of materials from the external environment into a cell occurs via its plasma membrane. These materials are then used to fuel the chemical reactions that occur throughout the volume of the cytoplasm. For a cell to be able to supply the cytoplasm with its metabolic requirements and remove wastes, it needs a large surface area in relation to its volume. That is, it needs a large surface-area-to-volume ratio, where the surface area is the area of membrane around the cell and the volume is the amount of cytoplasm.

As a cell grows larger, both its surface area and volume increase, but its volume grows faster than its surface area. This is shown in Table 8.3. Cell A has a volume of 0.52 cm^3 and a surface area of 3.14 cm^2 to service it. This is a surface-area-to-volume ratio of 6:1. Cell C, however, has a volume of 14.14 cm^3 and a surface area of 28.28 cm^2 to service it, a surface-area-to-volume ratio of only 2:1.

Table 8.3 Surface-area-to-volume ratios of three hypothetical cells

	Cell A	Cell B	Cell C
Diameter (cm)	1.0	2.0	3.0
Surface area (cm^2)	3.14	12.57	28.28
Volume (cm^3)	0.52	4.19	14.14
SA:volume ratio	6:1	3:1	2:1

As the size of a cell increases, the surface-area-to-volume ratio decreases. This means the efficiency with which a cell obtains its nutrients and removes its wastes is reduced as its size increases. A cell increasing in size reaches a point where the inward movement of essential substances and the outward movement of wastes across the surface area by diffusion are not fast enough to service the increasing volume of the cell. For this reason, individual cells tend to be very small.

How big can cells grow?

Because of the restrictions of the surface-area-to-volume ratio, most cells are too small to see without the aid of a microscope. Red blood cells, for example, are about 8 millionths of a metre wide; approximately 2000 of them would fit across your thumbnail. However, some eukaryotic cells can be observed with the unaided human eye, such as the yolks of bird eggs, cells in some algae, and the eggs of fish and frogs (spawn).

Such cells have special ways to offset the low surface-area-to-volume ratio that comes from their large size. In giant algal cells, an inert vacuole fills the majority of the cell. This pushes the metabolically active cytoplasm to the outside of the cell, just beneath the plasma membrane. This has two benefits. It means that the distance materials need to diffuse when moving into or out of the cell is much less. It also has the effect of reducing the active volume of the cytoplasm and so reducing the amount of exchange that must occur across the membrane.

Cells with a larger surface-area-to-volume ratio can obtain nutrients and remove wastes more efficiently.

Shape of cells

Getty Images/Science Photo Library/Andrew Syred

▲ **Figure 8.27**
Scanning electron micrograph of root hairs in oregano, *Origanum vulgare*. They greatly increase the surface area for absorption of water.

In a multicellular organism, some cells need to be of a certain size in order to perform their specific function. For example, nerve cells that connect your spinal cord to your toes are more than 1 m long. To explain how they overcome issues associated with increased size, we need to look at the relationship between shape and surface-area-to-volume ratio.

The shape of an object can significantly change its surface-area-to-volume ratio. A sphere has the least surface area for the volume it encloses. This explains why soap bubbles are perfect spheres. The thin elastic membrane made by the soap mixture contracts to the smallest area that can enclose the volume of air blown into it when the bubble was made. Spherical cells have a relatively small surface-area-to-volume ratio compared with cells of other shapes.

Cells often have specific features that ensure they have the highest surface-area-to-volume ratio possible. Long, thin or flat cells have relatively more membrane for a certain volume compared with spherical cells. A good example is seen in the root hairs that cover the root tips of most plants. The long thin extensions of the single cells that form root hairs are able to significantly increase the surface area over which water and mineral salts can be absorbed (Figure 8.27).

WORKED EXAMPLE 8.1

Calculate the surface-area-to-volume ratio of a cube 1 cm × 1 cm × 1 cm. (3 marks)

Answer	Logic	
Surface area of a cube = 6 × length of side^2	Calculate surface area. Insert correct formula.	
Surface area = 6 × 1 × 1 = 6 cm^2	Insert numbers into formula. Calculate answer.	1 mark
Volume of a cube = length × width × height	Calculate volume. Insert correct formula.	
Volume = 1 × 1 × 1 = 1 cm^3	Insert numbers into formula. Calculate answer.	1 mark
Surface area : volume = 6 ÷ 1	Calculate SA:volume ratio. Insert numbers into formula.	
= 6	Calculate answer.	1 mark

Try these yourself

1 Calculate the surface-area-to-volume ratio of a cube 2 cm × 2 cm × 2 cm. (3 marks)

2 Calculate the surface-area-to-volume ratio of a cube 3 cm × 3 cm × 3 cm. (3 marks)

ACTIVITY 8.3

CAN YOU MAKE SQUARE SOAP BUBBLES?

Aim

To explore shape and surface area

You will need

- 250 mL beaker (or large glass)
- two 30 cm pipe cleaners
- liquid dishwashing detergent

What to do

1 Place approximately 200 mL of cold water into the beaker.
2 Add about 10 mL of detergent, being careful not to let it froth. If froth does appear, scrape it off.
3 Bend each pipe cleaner to form a square, one with sides 3×3 cm, the other 5×5 cm.
4 Dip the pipe cleaners into the soapy mixture and gently blow to form bubbles. Observe the shape changes that occur as the bubble forms and floats away.
5 If you can get bubbles to land on a surface, measure their diameter. Find their radius and then calculate their surface area, volume and surface-area-to-volume ratio.

What did you discover?

1 Were you able to blow square bubbles?
2 Explain your observations in terms of surface-area-to-volume ratio.

QUESTION SET 8.4

Remembering

1 List two examples of physical factors and two examples of chemical factors that affect the movement of substances across cell membranes.
2 Describe the effect of differing concentration gradients on the rate of diffusion of oxygen into a cell.
3 State two ways that cells can increase the concentration gradient of a substance.

Understanding

4 Explain how the shape of a cell affects its surface-area-to-volume ratio.
5 Explain how increasing the size of a cell affects the cell's ability to gain and lose substances by diffusion.

Applying

6 Using four different-sized cubes, construct a table to show how the surface-area-to-volume ratio changes.

Analysing

7 Analyse the data in Table 8.3 and discuss whether or not there is a linear relationship between size and surface-area-to-volume ratio.

CHAPTER SUMMARY

- The plasma membrane forms a barrier between the internal and external environments of cells.
- The plasma membrane is composed of a phospholipid bilayer into which proteins are embedded.
- The plasma membrane regulates the internal environment by allowing some molecules but not others to pass across it.
- Molecules on the surface of the plasma membrane allow cells to recognise each other and respond to chemical messengers like hormones.
- Simple diffusion, facilitated diffusion and osmosis are ways that molecules can cross membranes by passive transport (does not require energy).
- Energy is required to move substances across membranes by active transport, endocytosis and exocytosis.
- The physical and chemical nature of a substance determines the way in which it will be transported across membranes by cells.
- The size, shape and surface-area-to-volume ratio of a cell affects the adequate supply of nutrients and removal of wastes.
- The greater the concentration gradient of a substance across a membrane, the faster it will diffuse.

CHAPTER GLOSSARY

active transport the process whereby cells actively transport substances across a membrane from a low concentration to higher concentration of the substance; characterised by the fact that the process consumes energy

adhesion protein membrane proteins that help link cells together

antigen the marker on a cell surface that distinguishes one cell from another

apoptosis the programmed series of events that lead to cell death as a result of the dismantling of internal contents of the cell

adenosine triphosphate (ATP) a high-energy compound composed of adenine and ribose and three phosphate groups attached; it releases energy for cellular reactions when its last phosphate group is removed and it is converted to ADP

bilayer a double layer

carrier protein a protein within membranes that assists other molecules to cross the membrane in facilitated and active transport

channel protein a protein that forms channels within membranes to allow the passage of hydrophobic substances across the membrane

cholesterol a type of lipid found in cell membranes

concentration gradient the difference in concentration of a substance between two different regions

contractile vacuole the vacuole found in some freshwater unicellular organisms that maintains osmotic balance by collecting water and emptying it from the cell

crenation the crinkling of red blood cells when they lose water

cytoplasm all the fluid, dissolved materials and organelles between the plasma membrane and the nuclear membrane

cytoplasmic streaming the mixing and movement of the cytoplasm

cytosol the fluid part of the cytoplasm containing highly organised fluid material with dissolved substances; excluding the organelles

diffusion the passive movement of molecules from a high to a low concentration of that substance

endocytosis the movement of solids or liquids into a cell from the environment via vesicle formation

enzyme a specific protein catalyst that acts to increase the rate of a chemical reaction within the cell by lowering the amount of energy required for the reaction to proceed

equilibrium the point at which particles are distributed evenly throughout a system; they move at equal rates in all directions

exocytosis the movement of solids or liquids from a cell to the environment via vesicle formation

external environment the environment surrounding a cell outside the plasma membrane

extracellular fluid the fluid that bathes the outside of cells in multicellular organisms

facilitated diffusion a form of diffusion that requires a substance to be attached to a specific carrier molecule to move across a membrane

flaccid floppy; describes condition of a plant cell that has lost water

glycoprotein a protein molecule with an attached carbohydrate chain

haemolysis the bursting of red blood cells

hypertonic a solution with a higher solute concentration compared with another solution

hypotonic a solution with a lower solute concentration compared with another solution

hydrophilic a substance that tends to interact with and dissolve in water

hydrophobic avoiding association with water

internal environment all material contained within the plasma membrane

ion a charged particle

isotonic describes fluid with an equal solute concentration to another fluid

multicellular describes an organism consisting of more than one cell

osmosis the movement of water across a selectively permeable membrane from regions of low solute concentration to high solute concentration

passive transport the movement of molecules that does not require input of energy

permeable able to pass through

phagocytosis the bulk transport of solids into a cell inside a vesicle

pinocytosis the bulk transport of liquids into a cell inside a vesicle

plasma membrane the insoluble boundary of all living cells that maintains the contents of the cell and regulates movement of substances in and out of the cell

plasmolysis the cytoplasm pulling away from the cell wall because of water loss

receptor protein a protein that binds hormones and other signal molecules

recognition protein a protein that acts as a marker on membranes

selectively permeable describes a membrane that allows some substances but not others to pass across it

sodium–potassium pump a membrane protein that uses energy to transport sodium ions out of, and potassium ions into, cells against their concentration gradients

solute a substance that can be dissolved in another substance

solution a mixture of solute and solvent

solvent a substance in which another substance can be dissolved to create a solution

surface-area-to-volume (SA:volume) ratio the mathematical ratio of the size of the surface area (in two dimensions) compared to the volume of an object (in three dimensions)

tonoplast vacuole membrane

tissue a group of specialised cells working together to perform a specific function

transport protein a protein that carries molecules across membranes

turgid describes a cell that is tight and rigid from absorbing water

unicellular an organism made up of a single cell

wilt to become limp and floppy

CHAPTER REVIEW QUESTIONS

Remembering

1 List two natural conditions that might cause plant cells to become plasmolysed.

2 Outline ways in which simple diffusion and osmosis differ from active transport.

3 Explain what would happen, in terms of the diffusion of water molecules, if an animal cell was placed in a hypotonic solution.

4 Look at Figure 8.14 on page 194 and explain why sucrose molecules do not diffuse across the differentially permeable membrane.

5 Draw a diagram of a unicellular freshwater organism in seawater labelling the direction of the net movement of water.

6 When human cheek cells are studied under a microscope, they are mounted on a slide in a drop of 'normal' saline (salt) solution, rather than tap water. Explain why this is the best method of preparing these cells.

7 Describe the structure of the plasma membrane according to the fluid mosaic model.

8 Describe the difference between pinocytosis and phagocytosis.

Understanding

9 A student places a living cell into a drop of liquid containing a 5% sugar solution. After 30 minutes, the student notices the liquid contains less than 5% sugar. Explain what has happened.

10 Describe, by means of labelled diagrams, the processes of endocytosis and exocytosis.

11 Explain the importance of turgor to plants.

12 Write a few sentences to explain the process by which carbon dioxide might move from the external environment into a cell.

13 Explain why red blood cells become crenated in a hypertonic solution.

14 When plants do not have enough water, they wilt. Once watered, they will stand up straight again. Explain the role of vacuoles in this process.

Applying

15 Half fill a drinking cup with water and add 30 mL of raspberry cordial. Do not stir. After half an hour the cordial is evenly distributed in the cup. Explain this example in terms of diffusion. Use the terms 'net movement', 'concentration gradient' and 'equilibrium' in your explanation.

16 Explain one way in which a large unicellular organism could have a larger surface-area-to-volume ratio than a smaller unicellular organism.

17 Find out how the produce departments of supermarkets keep vegetables looking fresh and feeling firm. Use your understanding of osmosis to explain why this method is successful.

18 When a person's kidneys fail, the person can be connected to a dialysis machine. Arterial blood is pumped through dialysis tubing that is made of selectively permeable membranes. Surrounding the tubing is a solution similar to blood plasma. Waste materials diffuse from the tubing into the surrounding solution. Cleaner blood then travels back into the person's veins.

- a What must be done to the surrounding solution in order for the wastes to continue diffusing out of the dialysis tube?
- b Predict what would happen if the surrounding solution is not changed.
- c Find out more about how dialysis machines work.

Analysing

19 Two cells have the same internal concentration of sugar solution when they are placed in distilled water. Even though both cells expand over time, one expands faster than the other. Discuss some possible reasons for this observation.

20 Three duck eggs with their shells removed all weigh 50 g. They are placed in different concentrations of salt solutions: 1.0, 1.5 and 2.0 M (molar) concentration, respectively. After 2 hours, the eggs are reweighed. The egg placed in the 1.0 M salt solution weighed 54 g, the egg placed in the 1.5 M salt solution weighed 50 g and the egg in the 2.0 M salt solution weighed 46 g.

- a Construct a line graph showing probable change in egg mass over a 2-hour period.
- b Explain, for each concentration, why the eggs gained or lost mass or stayed the same.

Evaluating

21 There is a great deal of concern about rising levels of salt in many parts of Australia. Evaluate whether it would be better for a citrus farmer in Mildura to have a lack of available fresh water or to have saline soils. Discuss reasons for your answer.

22 Evaluate whether a round cell with a diameter of 5 mm will have a greater chance of survival than a round cell of 2 mm.

Creating

23 Your friend says that a particle taken into a cell by phagocytosis is not truly inside the cell. Analyse this statement and use an argument to agree or disagree with it.

24 Xenophyophores are giant unicellular organisms found more than 10 km below the sea surface. They are the largest individual cells known to exist; they can grow up to 10 cm across. Reflect on the issues facing these organisms and describe three adaptations that you would expect them to display.

25 A student made the comment that 'The formation of vesicles by endocytosis should reduce the size of the plasma membrane'. Apply your knowledge of both endocytosis and exocytosis to critically examine this comment.

26 A person marooned on a desert island surrounded by seawater must look for fresh water to drink. There are plants on the island. Suggest how they might find enough water to stay alive. Discuss would happen to the person if he or she used the seawater for drinking.