3 Movement into and out of cells

Focus

In the last chapter you were introduced to the main features of animal, plant and bacterial cells and their functions. You studied examples of a range of specialised cells and how they are adapted to carry out their roles. You learned about the levels of organisation within the organism and how to calculate the magnification of microscopic structures. In this chapter, you will find out about how materials move into and out of cells. These materials include gases like oxygen and carbon dioxide, water, mineral ions, waste products and nutrients. How does the cell protect itself from gaining substances that could be toxic, or from losing vital resources? How can a plant keep its shape if it has no clear means of support? By studying the chapter carefully and following the practical suggestions, you should be able to answer these questions.

Cells need food materials, which they can respire for energy or use to build up their cell structures. They also need mineral ions and water, which play a part in chemical reactions in the cell. Finally, they need to get rid of substances like carbon dioxide, which would upset some of the chemical reactions or even poison the cell if they built up.

Substances may pass through the cell membrane either passively by **diffusion** or actively by some form of **active transport**.

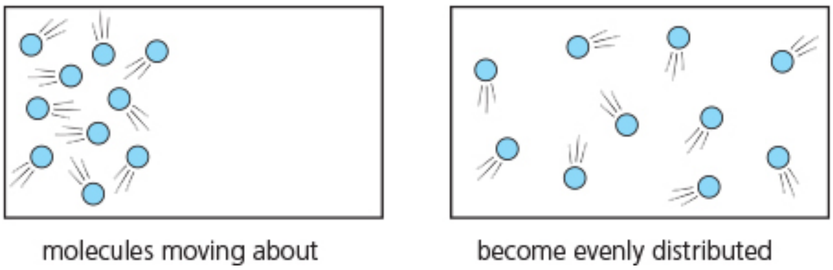
Diffusion

FOCUS POINT

- What is diffusion?
- Where does the energy for diffusion come from?
- How do substances move into and out of the cell by diffusion?

- How important is diffusion to living organisms?
- What effects do surface area, temperature, concentration gradient and distance have on diffusion?

The molecules of a gas like oxygen are moving about all the time. So are the molecules of a liquid or a substance like sugar dissolved in water. As a result of this movement, the molecules spread themselves out evenly to fill all the available space (Figure 3.1).

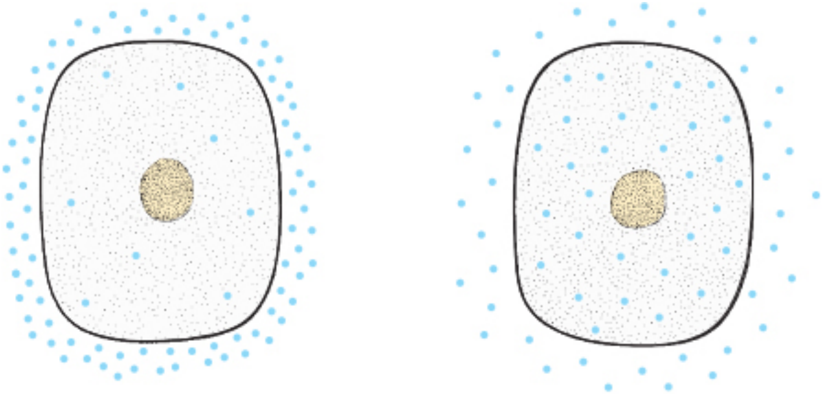


▲ **Figure 3.1** Diffusion

Key definitions

Diffusion is the net movement of particles from a region of their higher concentration to a region of their lower concentration (i.e. down a **concentration gradient**), as a result of their random movement.

This process is called diffusion. One effect of diffusion is that the molecules of a gas, a liquid or a dissolved substance will move from a region where there are a lot of them (i.e. concentrated) to regions where there are few of them (i.e. less concentrated), until the concentration everywhere is the same. In most organisms substances have to move through cell membranes. Some substances move by diffusion. Figure 3.2(a) is a diagram of a cell with a high concentration of molecules (e.g. oxygen) outside and a low concentration inside. The effect of this difference in concentration is to make the molecules diffuse into the cell until the concentration inside and outside is the same, as shown in Figure 3.2(b).



▲ **Figure 3.2** Molecules entering a cell by diffusion

Whether this will happen or not depends on if the cell membrane will let the molecules through. Small molecules like water (H_2O), carbon dioxide (CO_2) and oxygen (O_2) can pass through the cell membrane quite easily. So, diffusion tends to balance the concentration of these molecules inside and outside the cell all the time.

When a cell uses oxygen for its aerobic respiration, the concentration of oxygen inside the cell falls and so oxygen molecules diffuse into the cell until the concentration is raised again. During tissue respiration, carbon dioxide is produced and so its concentration inside the cell increases. Once again diffusion takes place, but this time the molecules move out of the cell. In this way, diffusion can explain how a cell takes in its oxygen and gets rid of its carbon dioxide.

The importance of diffusion of gases and solutes

Gases

Most living things need a reliable source of oxygen for respiration. This moves into the organism by diffusion down a concentration gradient. Small animals with a large surface area to volume ratio may get oxygen through their body surface. Larger animals need **gas exchange** organs like lungs or gills, which provide a large surface area for gas exchange. They also need a circulatory system to move the oxygen to all their cells. Carbon dioxide, produced during aerobic respiration, can be toxic if it builds up. It is removed in the same way, by diffusion.

Photosynthetic plants need carbon dioxide for making their food. This diffuses through the **stomata**in the leaves (see Chapter 8) into the air spaces in the mesophyll, before reaching the palisade cells. Oxygen produced during photosynthesis, as well as water vapour from the **transpiration stream**, diffuses out of the leaf through the stomata. The rate of diffusion of water vapour depends on the temperature, humidity and wind speed (see 'Water uptake' in Chapter 8). Any oxygen needed for respiration (some is produced by photosynthesis) and carbon dioxide produced (some is used up by photosynthesis) also diffuses through the stomata of the leaves.

Going further

Nitrogen is the most common gas in the **atmosphere** (78% of the air is nitrogen). Nitrogen gas also enters the bloodstream by diffusion, but it is not used by the body. It is an inert (unreactive) gas so normally it causes no problems. However, divers are at risk. As a diver swims deeper, the surrounding water pressure increases. This raises the pressure in the diver's air tank. An increase in nitrogen pressure in the air tank results in more nitrogen diffusing into the diver's tissues, the amount increasing the longer the diver stays at depth. Nitrogen is not used by the body tissues, so it builds up. When the diver begins to return to the surface of the water, the pressure decreases and the nitrogen can come out of solution, forming bubbles in the blood if the diver goes back to the surface too quickly. These bubbles can block blood flow and become stuck in joints, resulting in a condition called decompression sickness, or ‘the bends’. Unless the diver goes up slowly in planned stages, the effect of the nitrogen bubbles can be lethal and can only be stopped by rapid recompression.

Solutes

Scientists think that some mineral ions in solution, like **nitrates** and magnesium, diffuse across the tissues of plant roots, but that most are absorbed into the roots by active transport.

In the **ileum**, water-soluble vitamins like vitamin C are absorbed into the bloodstream by diffusion.

In the kidneys, some solutes, like **urea** and mineral ions, pass back into the bloodstream by diffusion. At first, **glucose** is reabsorbed by diffusion, but active transport is also involved.

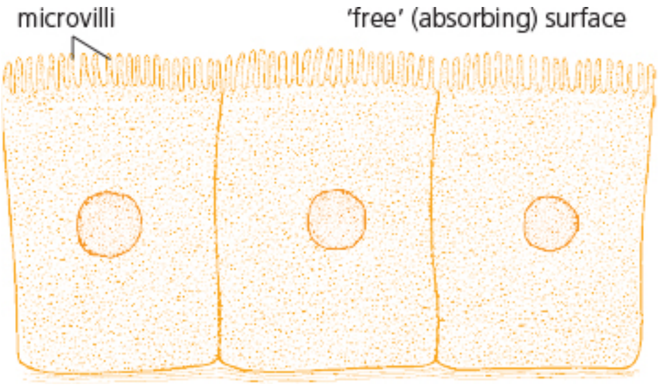
Rates of diffusion

Molecules and ions in liquids and gases move around randomly using **kinetic energy** (energy from movement). The speed with which a substance diffuses through a cell wall or cell membrane will depend on many conditions, including:

- the surface area across which the diffusion is happening
- the temperature
- the difference between its concentration inside and outside the cell
- the distance it diffuses.

Surface area

If 100 molecules diffuse through 1 mm^2 of a membrane in one minute, then an area of 2 mm^2 should allow twice as many molecules through in the same time. So, the rate of diffusion into a cell will depend on the cell’s surface area. A larger surface area will result in faster diffusion. Cells which are involved in rapid **absorption**, like those in the kidney or the intestine, often have their exposed surface membrane formed into hundreds of tiny projections called **microvilli** (see Figure 3.3). These increase the absorbing surface to make diffusion faster.



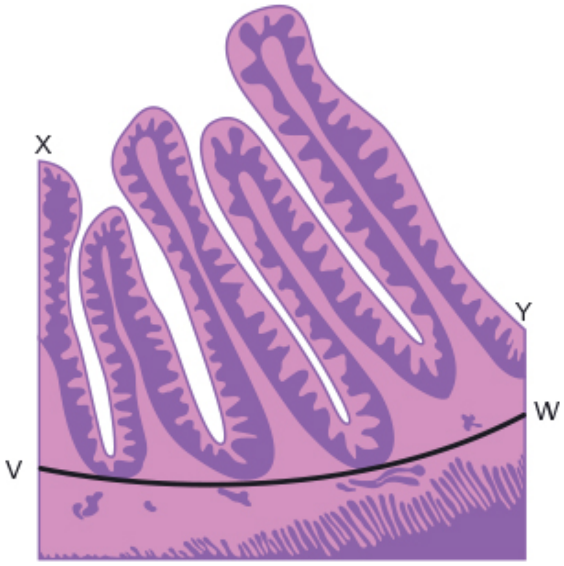
▲ **Figure 3.3** Microvilli

The shape of a cell will also affect the surface area. For example, the cell in Figure 3.4(a) has a greater surface area than the cell in Figure 3.4(b), eventhough they both have the same volume.

▲ **Figure 3.4** Surface area. The cells both have the same volume but the cell in (a) has a much larger surface area

Worked example

The diagram in Figure 3.5 shows a section of the small intestine, with **villi**. These increase the surface area to make the diffusion of digested food molecules more efficient.



▲ **Figure 3.5** Section through the small intestine to show villi

Tasks

1. Use a piece of cotton or string. Hold one end of the cotton against point X. Now spread the cotton along the surface of the villi, weaving downwards and upwards until you reach point Y. Use a pen to mark this point on the cotton. Now hold the cotton against a ruler and measure its length. Record this length as the length between X and Y. It may take two or more attempts to follow the surface of the villi from X to Y. It works best to trap the end of the cotton at point X, then lie the cotton a short distance, for example, until the first bend and trap it with a finger from your other hand. Then lie the cotton along the next section and keep repeating the procedure until you get to point Y.
2. Repeat the process, measuring V to W, which is the length the surface would be without the presence of villi. Record this length.
3. Calculate the percentage increase in length by comparing X to Y (the surface with villi) with V to W (the surface without villi).

To calculate the percentage increase in length

$$\% \text{ increase} = \frac{\text{new length (X to Y)}}{\text{original length (V to W)}} \times 100$$

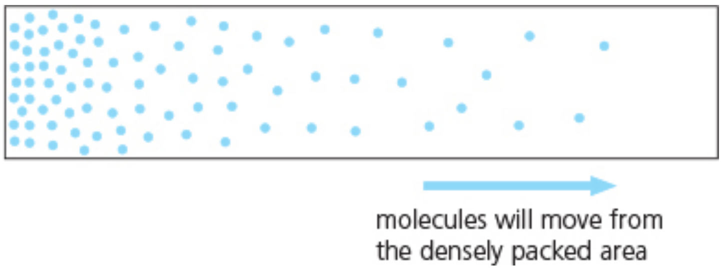
The percentage increase shows how important the villi are in the small intestine for increasing the surface area for absorption of digested food molecules. Bear in mind that this increase does not take into account the presence of microvilli!

Temperature

An increase in temperature gives molecules and ions more kinetic energy. This allows them to move faster, so the process of diffusion speeds up.

Concentration gradient

The greater the difference in the concentration of a substance on either side of a membrane, the faster it will diffuse. The difference is called a concentration gradient (Figure 3.6). If a substance on one side of a membrane is steadily removed, the concentration gradient stays the same. When oxygen molecules enter a red blood cell they combine with a chemical (**haemoglobin**), which takes them out of solution. So, the concentration of free oxygen molecules inside the cell is kept very low and the concentration gradient for oxygen stays the same.



▲ **Figure 3.6** Concentration gradient

Distance

Cell membranes are all about the same thickness (approximately 0.007 µm), but plant cell walls vary in their thickness and **permeability** (how easily materials pass through them). Usually, the thicker the wall, the slower the rate of diffusion. When oxygen diffuses from the **alveoli** of the lungs into red blood cells, it travels through the cell membranes of the alveoli, the blood capillaries and the red blood cells, as well as the cytoplasm of each cell. This increased distance slows down the diffusion rate.

Practical work

For safe experiments/demonstrations which are related to this chapter, please refer to the *Biology Practical Skills Workbook* that is also part of this series.

Safety

- Eye protection must be worn.
- Note your teacher's advice for using a knife.
- Take care using methylene blue or potassium permanganate solution – they will stain skin and clothing.
- Take care with hot water handling.

Experiments on diffusion

1 Diffusion and surface area

- Use a block of starch agar or gelatine at least 3 cm thick. Using a ruler and a sharp knife, measure and cut four cubes from the jelly with sides of 3.0 cm, 2.0 cm, 1.0 cm and 0.5 cm.
- Place the cubes into a beaker of methylene blue dye or potassium permanganate solution.
- After 15 minutes, remove the cubes with forceps and place them on to a white tile.
- Cut each of the cubes in half and measure the depth to which the dye has diffused.

2 Diffusion and temperature

- Set up two beakers with equal volumes of hot water and iced water.
- Add a few grains of potassium permanganate to each beaker and observe how quickly the dissolved dye spreads through the water in each beaker. An alternative is to use tea bags.

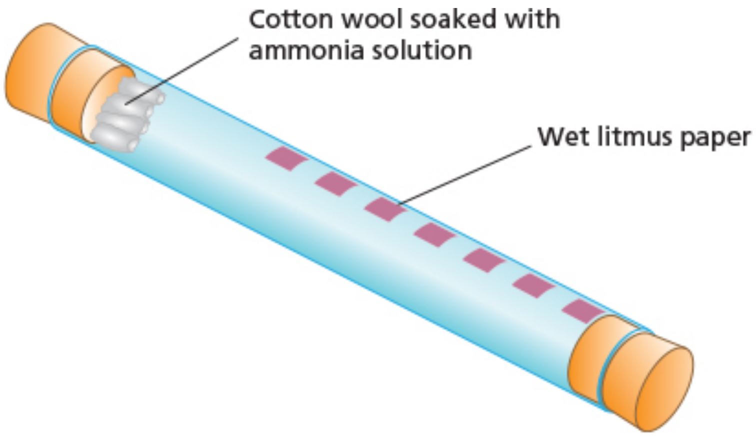
Safety

- Eye protection must be worn.
- Take care, concentrated ammonia solution is corrosive and irritant and should only be used in a fume cupboard. Wear

disposable gloves.

3 Diffusion and concentration gradients and distance (teacher demonstration only)

- Use a wide glass tube that is at least 30 cm long and corked at one end. Using a glass rod or wire, push squares of moist red litmus paper into the tube, so that they stick to the side and are evenly spaced out, as shown in Figure 3.7. (It is a good idea to mark 2 cm intervals along the outside of the tube, starting at 10 cm from one end, with a permanent marker or white correction fluid before inserting the litmus paper.)
- Close the open end of the tube with a cork carrying a plug of cotton wool saturated with a strong solution of ammonia. Start a stopwatch.
- Observe and record the time when each square of litmus starts to turn blue. Use this information to calculate the rate at which the alkaline ammonia vapour diffuses along the tube.
- Repeat the experiment using a dilute solution of ammonia.
- Plot both sets of results on a graph, labelling each plot line.



▲ **Figure 3.7** Experiment to measure the rate of diffusion of ammonia in air

Practical work questions

1 Calculate the surface area and volume of each cube used in experiment 1 and construct a table of your data. Remember to state the units in the heading for

each column.

2 Imagine that the cubes in experiment 1 are animals, with the jelly representing living cells and the dye representing oxygen. Which of the 'animals' would be able to get enough oxygen by diffusion through their surface to keep them alive? Explain your answer.

3 Try cutting different shapes, for example, cutting a block 3.0 cm long, 1.0 cm wide and 0.5 cm deep. Research what type of animal this would represent and how this type of animal obtains its oxygen.

4 Explain the results you observed in experiment 2.

5 A 10% solution of copper sulfate is separated by a partially permeable membrane from a 5% solution of copper sulfate. Will water diffuse from the 10% solution to the 5% solution or from the 5% solution to the 10% solution? Explain your answer.

6 If a fresh beetroot is cut up, the pieces washed in water and then left for an hour in a beaker of water, little or no red pigment escapes from the cells into the water. If the beetroot is boiled first, the pigment does escape into the water.

Using your knowledge of the properties of a living cell membrane, explain the difference in results.

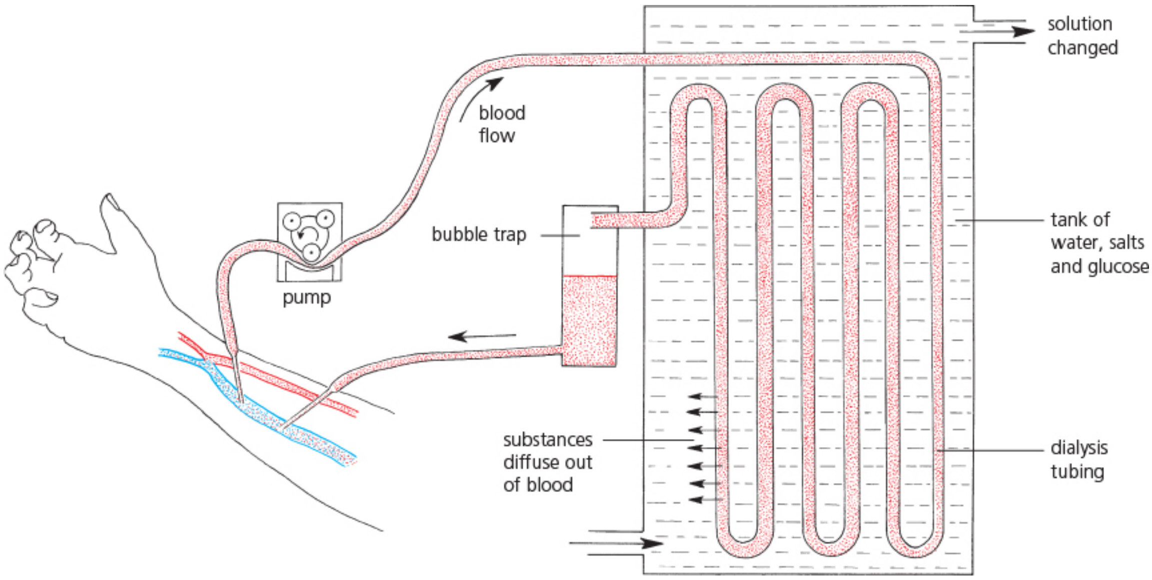
7 In experiment 3, which ammonia solution diffused faster? Can you explain why?

8 Study the graph you produced for this experiment. What happened to the rate of diffusion as the ammonia travelled further along the tube? Can you explain why?

Going further Artificial partially permeable membranes are made from cellulose acetate in sheets or tubes. These are used for a process called dialysis for patients suffering from kidney failure. The pore size can be altered during manufacture so that large molecules cannot get through at all.

The dialysis machine ('artificial kidney') Kidney failure can be the result of an accident involving a drop in blood pressure or of a disease of the kidneys. In the first example, recovery is usually natural and quick, but if it takes longer than 2 weeks, the patient can die because of a potassium imbalance in the blood. This causes heart failure. In the case of kidney disease, the patient can stay alive with only one kidney, but if both fail, the patient's blood composition has to be controlled by a dialysis machine. In the same way, the accident victim can be kept alive on a dialysis machine until their blood pressure is returned to normal.

Simply, a dialysis machine consists of a long cellulose tube coiled up in a water-bath. The patient's blood is led from a vein in the arm and pumped through the cellulose (dialysis) tubing (Figures 3.8 and 3.9). The tiny pores in the **dialysis tubing** allow small molecules, like those of salts, glucose and urea, to leak out into the water-bath. Blood cells and protein molecules are too large to get through the pores (see experiment 5 on page 50). This stage is like the filtration process in the **glomerulus** (see Chapter 13).



▲ **Figure 3.8** The principle of the kidney dialysis machine

To prevent a loss of glucose and important mineral ions from the blood, the water-bath contains a solution of mineral ions and sugar of the correct composition, so that only the substances above this concentration can diffuse out of the blood into the bathing solution. In this way, urea, **uric acid** and excess mineral ions are removed.

The bathing solution is also kept at body temperature and is regularly changed as the unwanted blood solutes build up in it. The blood is then returned to the patient's arm vein.

A patient with total kidney failure spends 2 or 3 nights each week connected to the machine (Figure 3.9). With this treatment and a carefully controlled diet, the patient can lead quite a normal life. A kidney transplant is a better solution though, because then the patient does not need to use a dialysis machine.

▲ **Figure 3.9** Kidney dialysis machine. The patient's blood is pumped to the dialyser, which removes urea and excess mineral ions

Test yourself

1 Look at Figure 9.21 on page 161. The symbol O_2 is an oxygen molecule.

Explain why oxygen is entering the cells drawn on the left but leaving the cells on the right.

2 Look at Figure 11.5 on page 185. It shows one of the small air pockets (an alveolus) that form the lung.

a Suggest a reason why the oxygen and carbon dioxide are diffusing in opposite directions.

b What might happen to the rate of diffusion if the blood flow were to speed up?

Osmosis

FOCUS POINTS

- What is osmosis?
- What is the role of water in living organisms?
- How does water move into and out of cells by osmosis?
- What role does water have in supporting plants?
- How would you investigate osmosis?
- What is the effect of immersing plant cells in solutions of different concentrations?

- What do the terms turgid, turgor pressure, plasmolysis, flaccid and water potential mean?

Roles of water

Most cells contain about 75% water and will die if their water content falls much below this. Water is a good solvent and many substances move about the cells in a watery solution.

Water molecules take part in many vital chemical reactions. For example, in green plants, water combines with carbon dioxide to form sugar (see Chapter 6). In animals, water helps to break down and dissolve food molecules (see ‘Chemical digestion’ in Chapter 7). Blood is made up of cells and a liquid called **plasma**. This plasma is 92% water and is a way of transporting many dissolved substances, like carbon dioxide, urea, digested food and **hormones**. Blood cells are carried around the body in the plasma.

Water is also a way of transporting materials in plants. Water passes up the plant from the roots to the leaves in xylem vessels and carries dissolved mineral ions. Phloem vessels transport dissolved sugars and amino acids from the leaves to where they are used or stored (see Chapter 8).

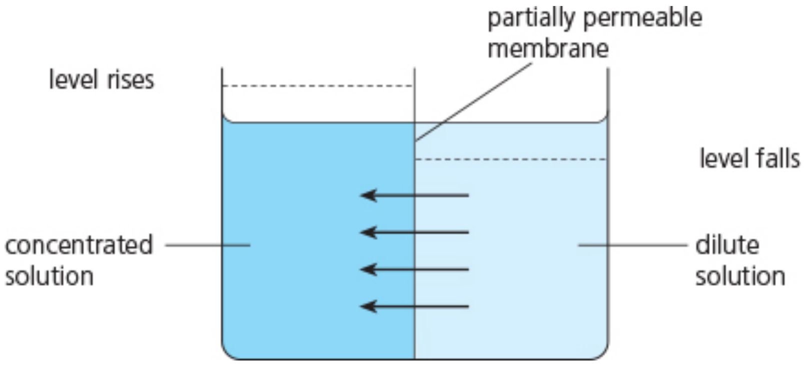
Water is important in the process of excretion in animals. It is a powerful solvent for excretory materials, like nitrogenous molecules (e.g. urea), as well as mineral ions, used hormones and **drugs**. The water has a diluting effect, so excretory materials are less toxic (poisonous).

Going further

The physical and chemical properties of water are different from those of most other liquids. These make it uniquely effective in helping living activities. For example, water has a high capacity for heat (high thermal capacity). This means that it can absorb a lot of heat without its temperature rising to levels that damage the proteins in the cytoplasm. However, because water freezes at 0 °C most cells are damaged if their temperature falls below this and ice crystals form in the cytoplasm. (Despite this, rapid freezing of cells in liquid nitrogen at below –196 °C does not harm them.)

Diffusion of water

If a dilute solution is separated from a concentrated solution by a partially permeable membrane, water diffuses across the membrane from the dilute to the concentrated solution. This is called **osmosis** and is shown in Figure 3.10.



▲ **Figure 3.10** Osmosis. Water will diffuse from the dilute solution to the concentrated solution through the partially permeable membrane. As a result, the liquid level will rise on the left and fall on the right

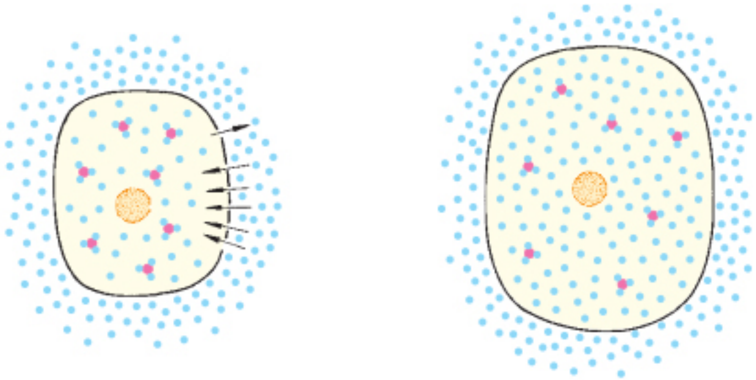
A partially permeable membrane is permeable but allows water to pass through more rapidly than dissolved substances.

Since a dilute solution effectively contains more water molecules than a concentrated solution, there is a concentration gradient, which encourages the passage of water from the dilute solution to the concentrated solution.

In living cells, the cell membrane is partially permeable and the cytoplasm and vacuole (in plant cells) contain dissolved substances. As a result, water tends to diffuse into cells by osmosis if they are surrounded by a weak solution (e.g. fresh water). If the cells are surrounded by a stronger solution (e.g. sea water), the cells may lose water by osmosis. These effects are described more fully later.

Animal cells

The cell in Figure 3.11 is shown surrounded by pure water. Nothing is dissolved in the water; it has 100% concentration of water molecules. So, the concentration of free water molecules outside the cell is greater than the concentration of water molecules inside. As a result, water will diffuse into the cell by osmosis. The membrane allows water to go in or out. So, in our example, water can move into or out of the cell. The cell membrane is partially permeable to most of the substances dissolved in the cytoplasm. So, although the concentration of these substances inside may be high, they cannot diffuse freely out of the cell. The water molecules move into and out of the cell, but because there are more of them on the outside, they will move in faster than they move out. The liquid outside the cell does not have to be 100% pure water. If the concentration of water outside is higher than that inside, water will diffuse in by osmosis.



(a) There is a higher concentration of free water molecules outside the cell than inside, so water diffuses into the cell.

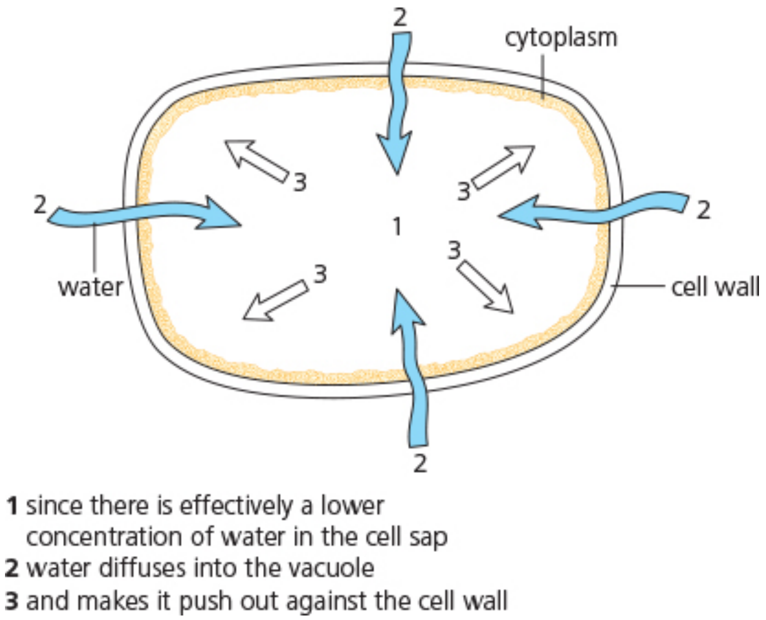
(b) The extra water makes the cell swell up.

▲ **Figure 3.11** Osmosis in an animal cell

Water entering the cell will make it swell up and, unless the extra water is removed in some way, the cell will burst. In the opposite situation, if the cells are surrounded by a solution which is more concentrated than the cytoplasm, water will pass out of the cell by osmosis and the cell will shrink. Too much uptake or loss of water by osmosis may damage cells. For this reason, it is very important that the cells in an animal's body are surrounded by a liquid which has the same concentration as the liquid inside the cells. In vertebrates, the brain monitors the concentration of the blood and the kidneys adjust it, as described in Chapter 13. By keeping the blood concentration within narrow limits, the concentration of the tissue fluid remains more or less constant (see 'Homeostasis' in Chapter 14). So, cells are not swollen by taking in too much water or dehydrated by losing too much.

Plant cells

The cytoplasm of a plant cell and the cell sap in its vacuole contain mineral ions, sugars and proteins. This reduces the concentration of free water molecules inside the cell. The cell wall is freely permeable to water and dissolved substances, but the cell membrane of the cytoplasm is partially permeable. If a plant cell is surrounded by water or a solution more dilute than its contents, water will pass into the vacuole by osmosis. The vacuole will expand and press outwards on the cytoplasm and cell wall. The cell wall of a mature plant cell does not stretch, so the inflow of water is limited by the inelastic cell wall, as shown in Figure 3.12.



▲ **Figure 3.12** Osmosis in a plant cell

This has a similar effect to blowing up a soft bicycle tyre. The tyre is like the firm cell wall, the floppy inner tube is like the cytoplasm and the air inside is like the vacuole. If enough air is pumped in, it pushes the inner tube against the tyre and makes the tyre hard.

When plant cells have absorbed a maximum amount of water by osmosis they become very rigid, due to the pressure of water pressing outwards on the cell wall. As a result, the stems and leaves are supported. If the cells lose water, there is no longer any water pressure pressing outwards against the cell walls. So, the stems and leaves are not supported any more. At this point, the plant becomes limp and **wilts** (droops) (see Figure 3.13).

(a) plant wilting **(b)** plant recovered after watering

▲ **Figure 3.13** Wilting

Practical work

For safe experiments/demonstrations which are related to this chapter, please refer to the *Biology Practical Skills Workbook* that is also part of this series.

Safety

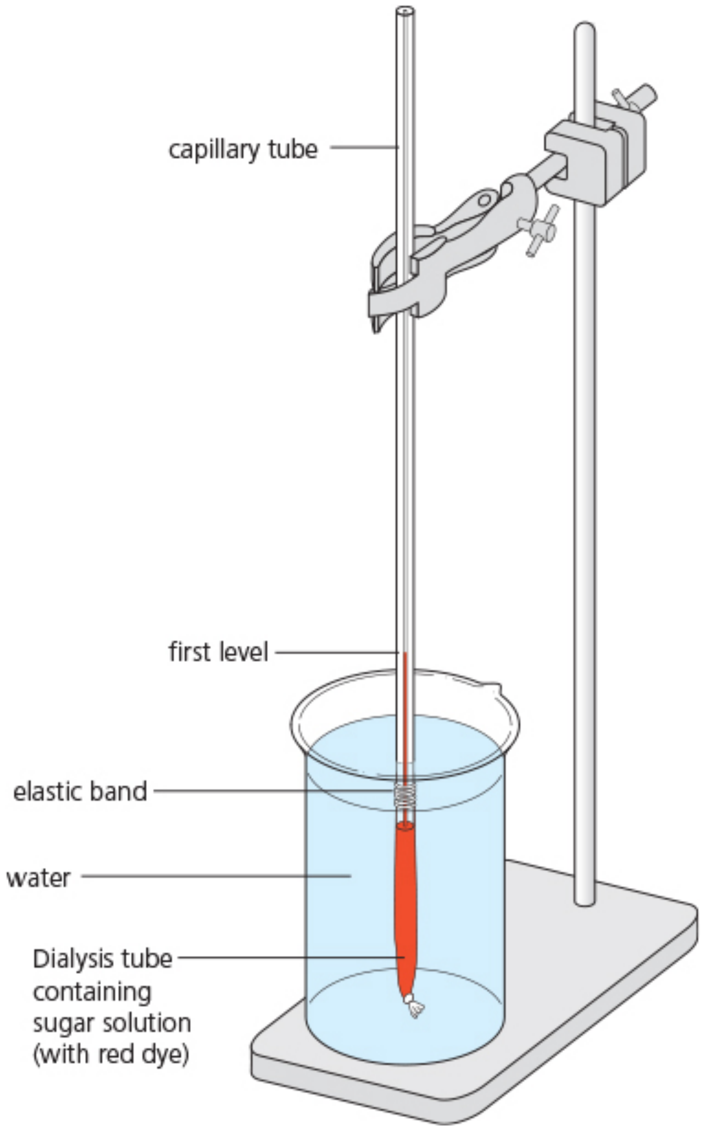
- Eye protection must be worn.
- Take care handling glass capillary tube, follow your teacher's guidance to avoid breakage.

Experiments on osmosis

Some of the experiments use 'Visking' dialysis tubing. It is made from cellulose and is partially permeable, allowing water molecules to diffuse through freely, but limiting the passage of some dissolved substances.

4 Osmosis and water flow

- Take a 20 cm length of dialysis tubing that has been soaked in water and tie a knot tightly at one end.
- Place 3 cm^3 of a strong sugar solution in the tubing using a plastic syringe and add a small amount of coloured dye.
- Fit the tubing over the end of a length of capillary tubing and hold it in place with an elastic band. Push the capillary tubing into the dialysis tubing until the sugar solution enters the capillary.
- Now clamp the capillary tubing so that the dialysis tubing is totally covered by the water in the beaker, as shown in Figure 3.14.
- Watch the level of liquid in the capillary tubing over the next 10–15 minutes.



▲ **Figure 3.14** Demonstration of osmosis

Result

The level of liquid in the capillary tube rises.

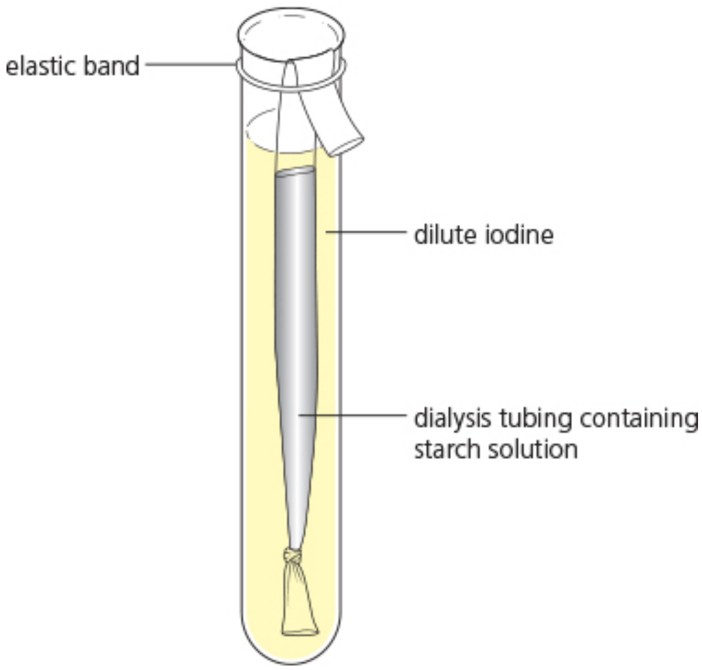
Interpretation

Water must be passing into the sugar solution from the beaker. This is what you would expect when a concentrated solution is separated from water by a partially permeable membrane.

A process like this may be involved in moving water from the roots to the stem of a plant.

5 Partial permeability

- Take a 15 cm length of dialysis tubing that has been soaked in water. Tie a knot tightly at one end.
- Use a dropping pipette to partly fill the tubing with 1% starch solution.
- Put the tubing in a test tube and hold it in place with an elastic band, as shown in Figure 3.15.
- Rinse the tubing and test tube under the tap to remove all traces of starch solution from the outside of the dialysis tube.
- Fill the test tube with water and add a few drops of iodine solution to colour the water yellow.
- Leave for 10–15 minutes.
- After this time, observe any changes in the solution in the test tube.



▲ **Figure 3.15** Experiment to demonstrate the effect of a partially permeable membrane

Result

The starch inside the dialysis tubing goes blue but the iodine outside stays yellow or brown.

Interpretation

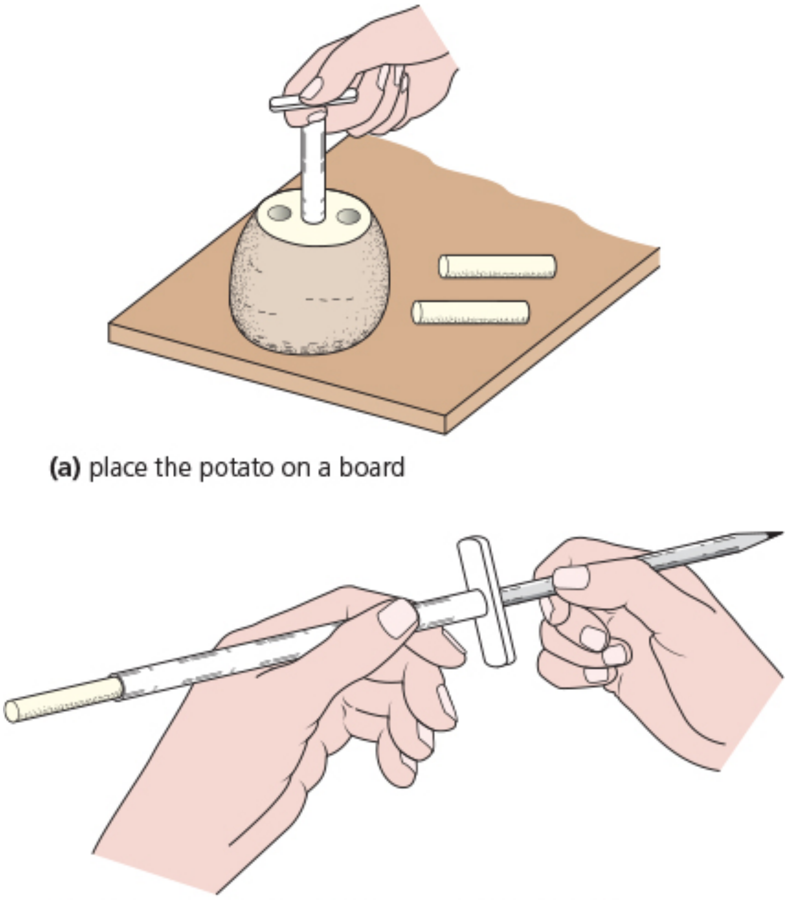
The blue colour is normal for the reaction that takes place between starch and iodine. This is used as a test for starch (see Chapter 4). The results show that iodine molecules have passed through the dialysis tubing into the starch, but the starch molecules have not moved out of the tubing into the iodine. The dialysis tubing is partially permeable because of its pore size. Starch molecules are very large and probably cannot get through the pores. Iodine molecules are much smaller and can get through.

Note: This experiment shows that movement of water is not necessarily involved, and the pore size of the membrane makes it truly partially permeable with respect to iodine and starch.

6 The effects of water and sugar solution on potato tissue

- Push a No.4 or No.5 cork borer into a large potato.

  Caution: Do not hold the potato in your hand; use a board as in Figure 3.16(a).
- Push the potato tissue out of the cork borer using a pencil, as in Figure 3.16(b). Prepare a number of potato cylinders in this way and choose the two longest. (They should be at least 50 mm long.) Cut these two accurately to the same length, e.g. 50, 60 or 70 mm. Measure carefully.
- Label two test tubes A and B and place a potato cylinder in each. Cover the potato tissue in tube A with water; cover the tissue in B with a 20% sugar solution.
- Leave the tubes for 24 hours.
- After this time, remove the cylinder from tube A and measure its length. Notice also whether it is firm or flabby. Repeat this for the potato in tube B but rinse it in water before measuring it.



▲ **Figure 3.16** Obtaining cylinders of potato tissue

Result

The cylinder from tube A should have increased in length and feel firm. The cylinder from tube B should have decreased in length and feel flabby.

Interpretation

The cells of the potato in tube A have absorbed water by osmosis, causing an increase in the length of the potato cylinder.

In tube B, the sugar solution is more concentrated than the cell sap of the potato cells, so these cells have lost water by osmosis. As a result, the potato cylinder has become flabby and shorter.

An alternative to measuring the potato cores is to weigh them before and after the 24 hours' immersion in water or sugar solution. The core in tube A should gain mass and that in tube B should lose mass. It is important to blot the cores dry with a paper towel before weighing them.

Whichever method is used, the changes may be quite small. So it is a good idea to collect the results of the whole class. An increase in length of 1 or 2 mm might be due to an error in measurement, but if most of the class record an increase in length, then experimental error is unlikely to be the cause.

7 The effects of varying the concentration of sucrose solution on potato tissue

- Push a No.4 or No.5 cork borer into a large potato.

  Caution: Do not hold the potato in your hand; use a board as in Figure 3.16(a).
- Push the potato tissue out of the cork borer using a pencil, as in Figure 3.16(b). Prepare six potato cylinders in this way and cut them all to the same length. (They should be at least 50 mm long.) Measure them carefully.
- Label six test tubes with the concentration of **sucrose** solution in them (e.g. 0.0 mol dm^{-3}, 0.2 mol dm^{-3}, 0.4 mol dm^{-3}, 0.6 mol dm^{-3}, 0.8 mol dm^{-3} and 1.0 mol dm^{-3}) and place them in a test-tube rack.
- Add the same volume of the correct sucrose solution to each test tube.
- Weigh a cylinder of potato, record its mass and place it in the first test tube. Repeat until all the test tubes have been set up.
- Leave the tubes for at least 30 minutes.
- After this time, remove the potato cylinder from the first tube, surface dry the potato and re-weigh it. Notice also whether it is firm or flabby. Repeat this for the other potato cylinders.
- Calculate the change in mass and the percentage change in mass for each cylinder.

$$\text{Percentage change in mass} = \frac{(\text{change in mass})}{(\text{mass at start})} \times 100$$

- Plot the results on a graph with sucrose concentration on the horizontal axis and percentage change in mass on the vertical axis.

Note: there will be negative as well as positive percentage changes in mass, so your graph axes will have to allow for this.

Result

The cylinders in the weaker sucrose solutions will have gained mass and feel firm. One of the cylinders may have shown no change in mass. The cylinders in the more concentrated sucrose solutions will have lost mass and feel limp.

Interpretation

If the potato cells are in a solution that has a lower concentration than the solution in the cell vacuoles, water will move into the cells by osmosis. The potato will increase in mass because of the extra water it has gained. The cells swell up and this makes the potato feel firm.

If the potato cells are in a solution that has a higher concentration than the solution in the cell vacuoles, water will move out of the cells by osmosis. The potato will decrease in mass because it has lost water. The cell vacuoles are no longer full of fluid and this makes the potato feel limp.

Practical work questions

9 In experiment 4 (Figure 3.14), what do you think would happen in these cases?

- **a** much stronger sugar solution was placed in the cellulose tube.
- **b** The beaker contained a weak sugar solution instead of water.
- **c** The sugar solution was in the beaker and the water was in the cellulose tube?

10 In experiment 4, the column of liquid accumulating in the capillary tube applies a steadily increasing pressure on the solution in the dialysis tubing. If a very long capillary is used, when would you expect the net flow of water from the beaker into the dialysis tubing to stop?

11 For experiment 5, explain how the iodine got into the dialysis tubing.

12 For experiment 5, suggest what would happen if you did not rinse the dialysis tubing thoroughly before placing it in the test tube.

13 For experiment 6, explain why the potato cylinder in test tube A increased in length.

14 For experiment 6, suggest two safety precautions you need to take when carrying out this experiment.

15 Use data from your graph in experiment 7 to describe and explain the effect of changing concentration of sucrose on potato tissue. If you do not have your own data, use the information in the table below to plot a graph first.

concentration of sucrose solution/mol dm -3	percentage change in mass
0.0	+3.3
0.2	–2.5
0.4	–8.3
0.6	–10.0
0.8	–10.8
1.0	–12.5

Key definitions

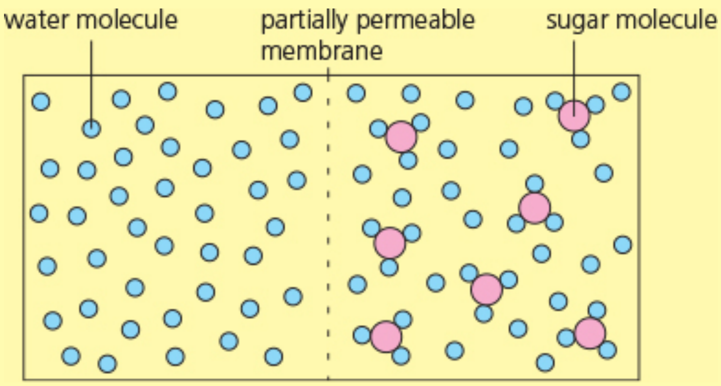
Osmosis is the net movement of water molecules from a region of higher **water potential** (dilute solution) to a region of lower water potential (concentrated solution) through a partially permeable membrane.

How osmosis works

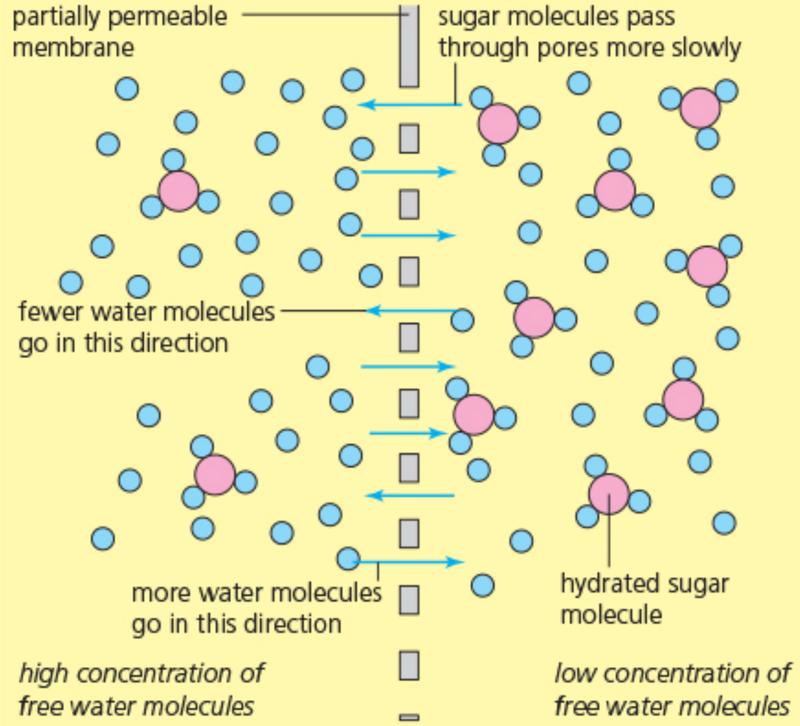
When a substance like sugar dissolves in water, the sugar molecules attract some of the water molecules and stop them moving freely. This effectively reduces the concentration of water molecules. In Figure 3.17 the sugar molecules on the right have held on to half the water molecules. There are more free water molecules on the left of the membrane than on the right, so water will diffuse more rapidly from left to right across the membrane than from right to left.

The partially permeable membrane does not act like a sieve here. The sugar molecules can diffuse from right to left. However, they are bigger and surrounded by a cloud of water molecules. So they diffuse more slowly than the water, as shown in Figure 3.18.

The **cell membrane** behaves like a partially permeable membrane. The partial permeability may depend on pores in the cell membrane. However, the processes involved are much more complicated than in an artificial membrane. They depend on the structure of the membrane and on living processes in the cytoplasm. The cell membrane contains fats and proteins. Anything that **denatures** proteins, for example, heat, also destroys the structure and the partially permeable properties of a cell membrane. If this happens, the cell will die because essential substances will diffuse out of the cell and harmful chemicals will diffuse in.



▲ **Figure 3.17** The concentration gradient for water. There are more free water molecules on the left, so more will diffuse from left to right than in the other direction. Sugar molecules will diffuse more slowly from right to left



▲ **Figure 3.18** The diffusion theory of osmosis

Water potential

The water potential of a solution is a measure of whether it is likely to lose or gain water molecules from another solution. A dilute solution has a high proportion of free water molecules. So, it has a higher water potential than a concentrated solution. Water will flow from the dilute to the concentrated solution (from a high potential to a low potential). Pure water has the highest possible water potential because water molecules will flow from it to any other aqueous solution, even if it is very dilute. When cells containing sap with different water potentials are in contact with each other, a water potential gradient is made. Water will move from a cell with a higher water potential (a more dilute solution) to a cell with a lower water potential (a more concentrated solution). This explains one way in which water moves from root hair cells through to the xylem of a plant root (see Figure 8.11 on page 134).

The importance of water potential and osmosis in plants

A plant cell with the vacuole pushing out on the cell wall is **turgid** (it is swollen because the cell has taken up water) and the vacuole is exerting **turgor pressure** on the inelastic cell wall. Turgor pressure is the force inside the cell which pushes outwards, pushing the cell membrane against the cell wall.

If all the cells in a leaf and stem are turgid, the stem will be firm and upright. The leaves are held out straight. If the vacuoles lose water for any reason, the cells will lose their turgor (a process called **plasmolysis**) and become **flaccid**. (See experiment 9 ‘Plasmolysis’ on page 56.) Plasmolysis is the process of losing water from the cell. When a cell loses water and is between the states of being turgid and plasmolysed it is flaccid. If a plant has flaccid cells, the leaves will be limp and the stem will droop. A plant that loses too much water is wilting (see Figure 3.13).

Root hair cells are touching water trapped between soil particles. When the water potential of the cell sap is lower than the water potential of the soil water, the water will enter the cells by osmosis. This gives the plant the water it needs. (This process is described in more detail in ‘Water uptake’ in Chapter 8.) When a farmer spreads chemical fertiliser on the soil, the fertiliser dissolves in the soil water. Too much fertiliser can lower the water potential of the soil water. This can draw water out of the plant root hair cells by osmosis. The plants can wilt and die.

Irrigation of crops (the supply of controlled amounts of water to plants as they need it) can have a similar effect. Irrigation which provides just enough water for the plant can lead to a build-up of salts in the soil. The salts will eventually cause the soil water to have a lower water potential than the plant root cells. Crops can then no longer be grown on the land, because they wilt and die through water loss by osmosis. Much agricultural land in hot countries has become unusable because of the side-effects of irrigation (Figure 3.19).

▲ **Figure 3.19** An irrigation furrow

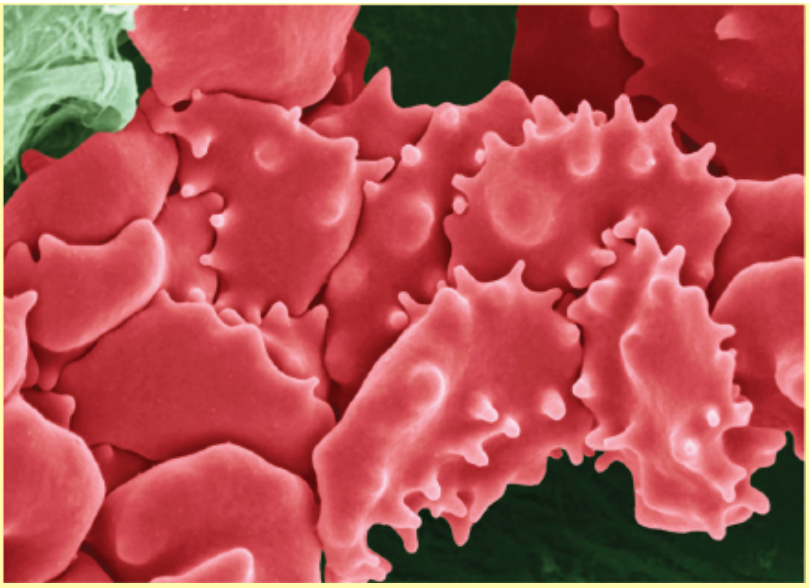
Some countries apply salt to roads in the winter to stop the formation of ice (Figure 3.20). However, vehicle wheels splash the salt on to plants at the side of the road. The build-up of salts in the roadside soil can kill plants living there, due to water loss from the roots by osmosis.

▲ **Figure 3.20** Salt gritter at work to prevent ice formation on a road

The importance of water potential and osmosis in animal cells and tissues

It is important that the fluid which bathes cells in animals, like tissue fluid or blood plasma, has the same water potential as the cell contents. This prevents any net flow of water into or out of the cells. If the bathing fluid has a higher water potential (a weaker concentration) than the cells, water will move into the cells by osmosis, causing them to swell up. As animal cells have no cell wall and the membrane has little strength, water would continue to enter. The cells will eventually burst. Single-celled animals like *Amoeba* (see Figure 1.35 on page 21) living in fresh water obviously have a problem. They avoid bursting by having a contractile vacuole. This collects the water as it enters the cell and regularly releases it through the cell membrane, keeping the water content of the cell under control. When surgeons carry out operations on a patient's internal organs, they sometimes need to rinse a wound. Pure water cannot be used as this would enter any cells it met and cause them to burst. A saline solution (salt solution), with the same water potential as tissue fluid, has to be used.

During physical activity, the body may sweat to keep a steady temperature. If liquids are not drunk to make up for water loss through **sweating**, the body can become dehydrated. Loss of water from the blood results in the plasma becoming more concentrated (its water potential decreases). Water is then drawn out of the red blood cells by osmosis. The cells become plasmolysed. Their surface area is reduced, so they are less effective in carrying oxygen (see Figure 3.21).



▲ **Figure 3.21** Plasmolysed red blood cells

People doing sport sometimes use sports drinks (Figure 3.22) which are isotonic (they have the same water potential as body fluids). The drinks contain water, salts and glucose. They are designed to replace lost water and salts, and provide energy, without creating osmotic problems to body cells. However, use of these drinks when not exercising vigorously can lead to weight gain in the same way as the prolonged use of any sugar-rich drink.

▲ **Figure 3.22** People may use isotonic sports drinks

Test yourself

3 Explain why the long-term use of irrigation in farming can result in making the soil unsuitable for growing crops.

4 Explain why it is more damaging for animal cells to be immersed in water than plant cells.

5 When soil becomes saturated with water, it fills up the air spaces between the soil particles. Suggest why root hair cells may die in water-logged soil.

Practical work

For safe experiments/demonstrations which are related to this chapter, please refer to the *Biology Practical Skills Workbook* that is also part of this series.

Safety

- Eye protection must be worn.

8 Osmosis and turgor

- Take a 20 cm length of dialysis tubing that has been soaked in water and tie a knot tightly at one end.

- Place 3 cm^3 of a strong sugar solution in the tubing using a plastic syringe (Figure 3.23(a)) and then knot the open end of the tube (Figure 3.23(b)). The partly filled tube should be quite floppy (Figure 3.23(c)).
- Place the tubing in a test tube of water for 30–45 minutes.
- After this time, remove the dialysis tubing from the water and note any changes in how it looks or feels.

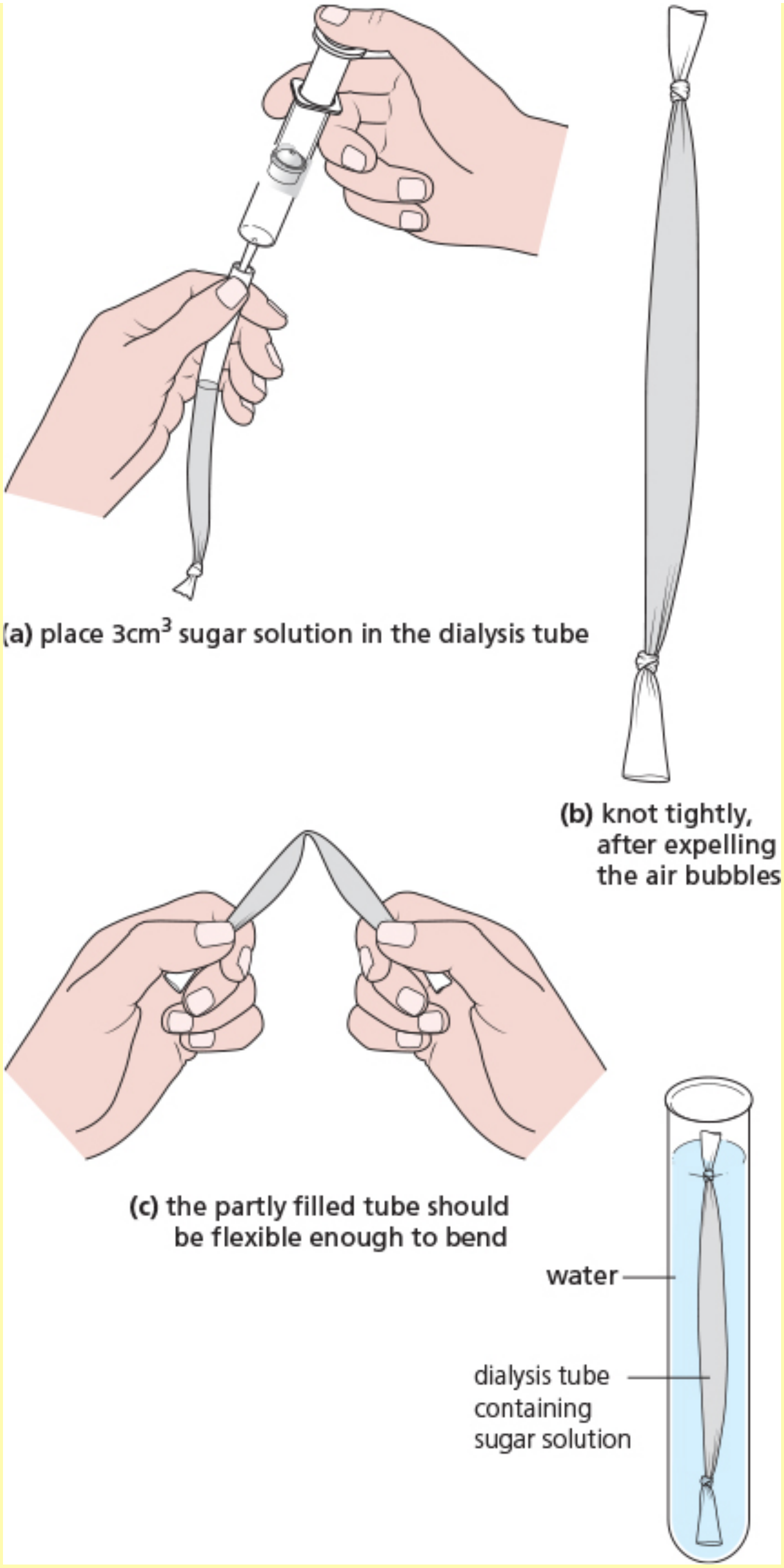
Result

The tubing will become firm, swollen by the solution inside.

Interpretation

The dialysis tubing is partially permeable and the solution inside has fewer free water molecules than outside. So, water has diffused in and increased the volume and the pressure of the solution inside.

This is a simple model of what is thought to happen to a plant cell when it becomes turgid. The sugar solution is like the cell sap and the dialysis tubing is like the cell membrane and cell wall together.


(a) place 3cm3 sugar solution in the dialysis tube
(b) knot tightly, after expelling the air bubbles
(c) the partly filled tube should be flexible enough to bend
water
dialysis tube containing sugar solution

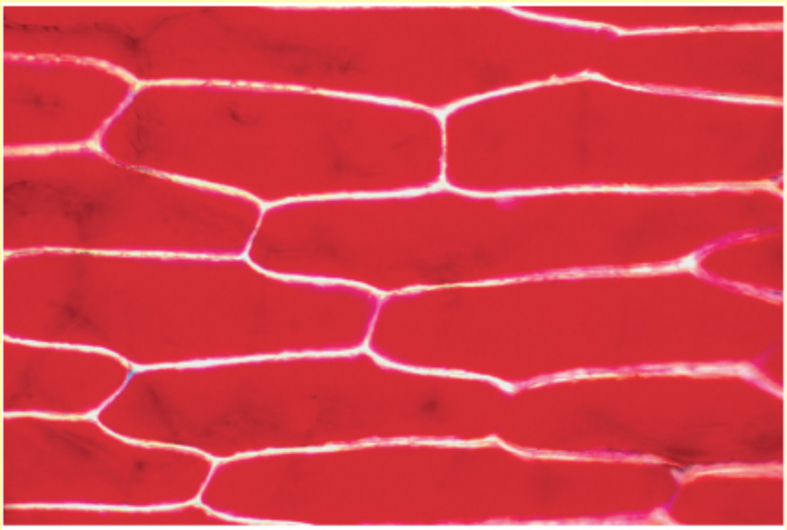
▲ **Figure 3.23** Experiment to model turgor in a plant cell

9 Plasmolysis

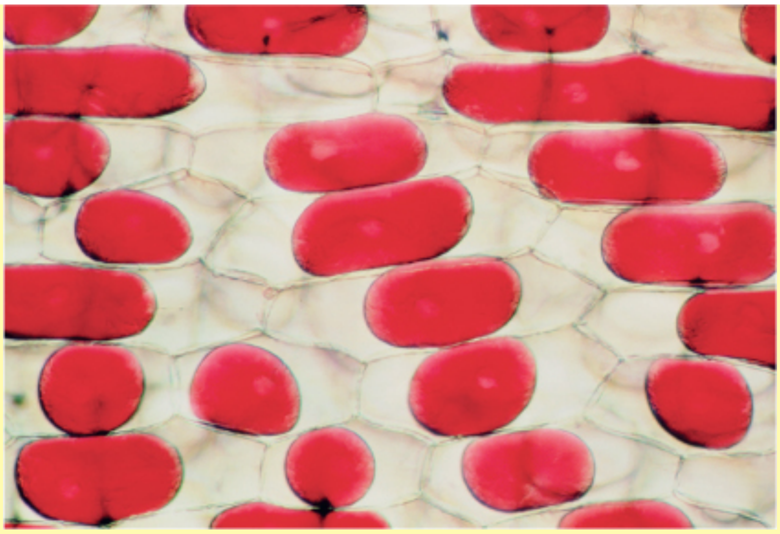
- Peel a small piece of epidermis (the outer layer of cells) from a red area of a rhubarb stalk (see Figure 2.12(c) on page 31).
- Place the epidermis on a slide with a drop of water and cover with a cover-slip (see Figure 2.12(b)).
- Put the slide on a microscope stage and find a small group of cells.
- Place a 30% solution of sugar at one edge of the cover-slip with a pipette. Move the solution under the cover-slip by placing a piece of blotting paper on the opposite side.
- Study the cells you identified under the microscope and watch for any changes in their appearance.

Result

The red cell sap will appear to get darker and shrink, pulling the cytoplasm away from the cell wall and leaving clear spaces. (It is not possible to see the cytoplasm, but its presence can be assumed because the red cell sap seems to have a distinct outer boundary where it has separated from the cell wall.) Figure 3.24 shows the turgid and plasmolysed cells.

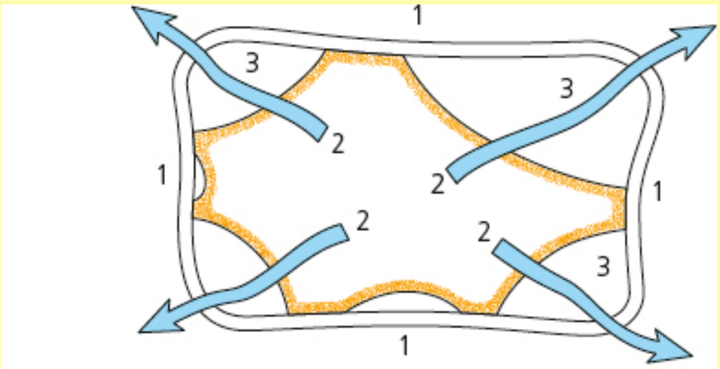


▲ **Figure 3.24** Demonstration of plasmolysis in rhubarb cells



Interpretation

The interpretation in terms of osmosis is given in Figure 3.25. The cells are plasmolysed.



▲ **Figure 3.25** Plasmolysis

The plasmolysis can be reversed by drawing water under the cover-slip in the same way that you drew the sugar solution under. It may need two or three lots of water to move out all the sugar. If you watch a group of cells, you should see their vacuoles expanding to fill the cells once again.

Rhubarb is used for this experiment because the coloured cell sap shows up. If rhubarb is not available, the epidermis from a red onion scale can be used.

10 The effects of varying the concentration of sucrose solution on potato tissue

Refer back to experiment 7.

Interpretation

If the cells of the potato have absorbed water by osmosis, there will be an increase in the mass of the potato cylinder. This happens when the external solution has a higher water potential than the water potential inside the potato cells. (The sucrose solution is less concentrated than the contents of the potato cells.) Water molecules move into each cell through the cell membrane. The water molecules move from a higher water potential to a lower water potential. The cells become turgid, so the cylinder feels firm.

If the cells of the potato have lost water by osmosis, there will be a decrease in mass of the potato cylinder. This happens when the external solution has a lower water potential than the water potential inside the potato cells. (The sucrose solution is more concentrated than the contents of the potato cells.) Water molecules move out of each cell through the cell membrane. The water molecules move from a higher water potential to a lower water potential. The cells become plasmolysed or flaccid, so the cylinder feels flabby.

Practical work questions

16 **a** Which part of a plant cell do the parts of the model represent?

i) dialysis tube

ii) the contents of the dialysis tube.

b Explain how the process you have observed would be useful in a plant.

17 **a** Explain how a cell becomes plasmolysed.

b How could a plasmolysed cell be returned to full turgor?

18 Study your graph from experiment 7. Can you predict the sucrose concentration which would be the equivalent to the concentration of the cell sap in the potato cells?

19 Would you expect to get the same results if the potato cylinders had been boiled before the investigation? Explain your answer.

Active transport

FOCUS POINT

- What is active transport?

- Why is active transport needed for moving molecules or ions across membranes?
- How are protein carriers involved in active transport?

Key definitions

Active transport is the movement of particles through a cell membrane from a region of lower concentration to a region of higher concentration (i.e. against a concentration gradient) using energy from respiration.

The importance of active transport

If diffusion was the only way a cell could take in substances, it would have no control over what went in or out. Anything that was more concentrated outside would diffuse into the cell even if it was harmful. Substances which the cell needed would diffuse out as soon as their concentration inside the cell increased above their concentration outside it. However, the cell membrane has a lot of control over the substances which enter and leave the cell.

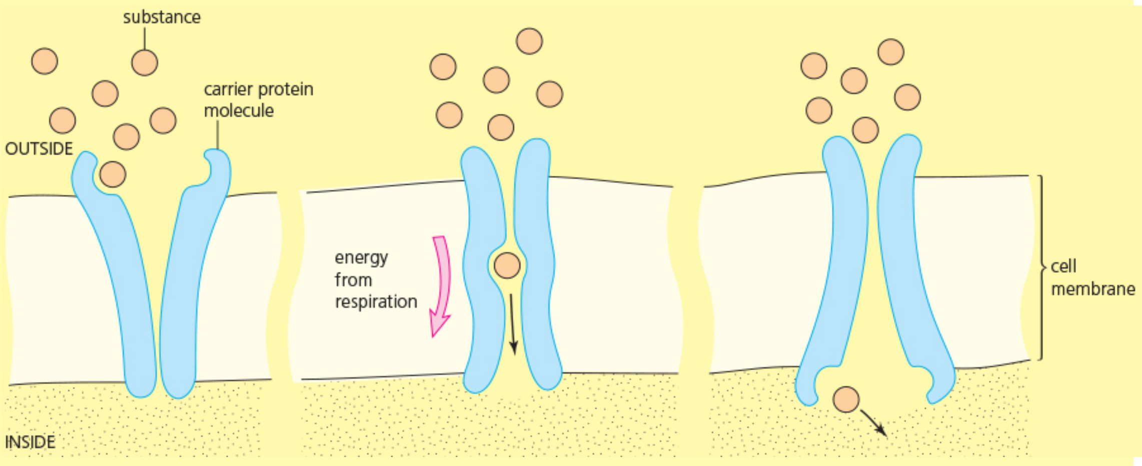
In some cases, substances are taken into or removed from the cell against the concentration gradient. For example, sodium ions may continue to pass out of a cell even though the concentration outside is greater than inside. The cells lining the small intestine take up glucose against a concentration gradient. The processes by which substances are moved against a concentration gradient are not fully understood. The processes may vary for different substances, but they are described as active transport.

Anything which interferes with respiration, like a shortage of oxygen or glucose, stops active transport happening. This shows that active transport needs a supply of energy from respiration. Figure 3.26 shows a possible model to explain active transport.

The **protein carrier** molecules shown in Figure 3.26 are protein molecules. As the name suggests, their job is to transport substances across the membrane during active transport, as shown in (b).

Epithelial cells in the villi of the small intestine have the job of absorbing glucose against a concentration gradient. The cells contain large numbers of mitochondria in which respiration takes place. The chemical energy released is converted into kinetic energy for the movement of the glucose molecules. The same type of process happens in the cells of the kidney tubules for the reabsorption of glucose molecules into the bloodstream against their concentration gradient.

Plants need to absorb mineral salts from the soil, but these salts are in very dilute solution. Active transport allows the root hair cells of plant roots to take up salts from this dilute solution against the concentration gradient. Again, chemical energy from respiration is converted into kinetic energy for movement of the salts.



▲ **Figure 3.26** A theoretical model to explain active transport

Going further

Controlled diffusion

Although for any one substance the rate of diffusion through a cell membrane depends partly on the concentration gradient, the rate is often faster or slower than expected. Water diffuses more slowly and amino acids diffuse more rapidly through a membrane than expected. In some cases, scientists think this happens because the ions or molecules can pass through the membrane through special pores. There may not be many of these pores, or they may be open or closed in different conditions.

In other cases, the movement of a substance can be speeded up by an enzyme working in the cell membrane. So, 'simple passive' diffusion, even of water molecules, may not be so simple or so passive where cell membranes are involved.

When a molecule gets inside a cell, there are many structures and processes which may move it from where it enters to where it is needed. Simple diffusion is unlikely to be the only way that this movement happens.

Test yourself

6 Suggest why a cell stops taking in substances by active transport which has been exposed to

   6 high temperature
   7 respiratory poison.

- State which parts of a cell are responsible for

  1. making proteins to act as carrier molecules in the cell membrane
  2. releasing energy for active transport across the cell membrane
  3. controlling cell activities such as active transport
  4. storing mineral ions which have passed through the cell membrane.

Revision checklist After studying Chapter 3 you should know and understand the following:

- Diffusion is the random movement of molecules of liquid, gas or dissolved solid.
- The molecules of a substance diffuse from a region where they are very concentrated to a region where they are less concentrated.
- Kinetic energy of molecules and ions results in their diffusion.
- Substances may enter cells through the cell membrane by simple diffusion or active transport.
- The rate of diffusion is affected by surface area, temperature, concentration gradient and distance.
- Water has several roles as a solvent in organisms.
- Cell membranes are partially permeable, and cytoplasm and cell sap contain many substances in solution.
- Osmosis is the diffusion of water through a partially permeable membrane, from a dilute solution of salt or sugar to a concentrated solution, because the concentrated solution contains fewer free water molecules.
- Water enters cells bathed in dilute solutions but leaves cells bathed in concentrated solutions because of osmosis.
- Osmosis maintains the pressure of water in plant cells to support the plant.
- Active transport involves the movement of substances against their concentration gradient.
- Active transport requires energy.

✔ Osmosis involves the net movement of water molecules from a region of higher water potential to a region of lower water potential through a partially permeable membrane.

- ✔ The meanings of the terms *turgid*, *turgor pressure*, *plasmolysis* and *flaccid*.
- ✔ The importance of water potential and osmosis in the uptake and loss of water by organisms.
- ✔ Active transport is important as it allows movement of substances across membranes against a concentration gradient.
- ✔ The role of protein carriers in cell membranes.

Exam-style questions

1. Diffusion, osmosis and active transport are processes involved in the movement of substances in a plant.

   Complete the table by

   1. defining what each term means
   2. giving one example of a substance moved by the process in the plant. [9]

name of process	**definition**	**example of a substance moved by the process in the plant**
diffusion		
osmosis		
active transport		

2. When a plant leaf is in daylight, its cells make sugar from carbon dioxide and water. The sugar is turned into starch straight away and stored in plastids. Sugar is soluble in water; starch is insoluble. With reference to osmosis, suggest why it is an advantage for the plant to convert the sugar to starch. [3]

3 When doing experiments with animal tissues they are usually bathed in Ringer's solution, which has a concentration like the concentration of blood or the fluid that surrounds cells. With reference to osmosis, explain why this is necessary. [2]

4 Explain why a dissolved substance reduces the number of 'free' water molecules in a solution. [2]

5 Some plant cells were placed on a microscope slide and covered with sugar solution, which was more concentrated than the sugar inside the cells.

a Describe what changes would happen in each of the following cell parts:

a cell wall [1]

b cytoplasm [1]

c sap vacuole. [1]

6 With reference to water potential gradient, explain how these changes occur. [1] [2]

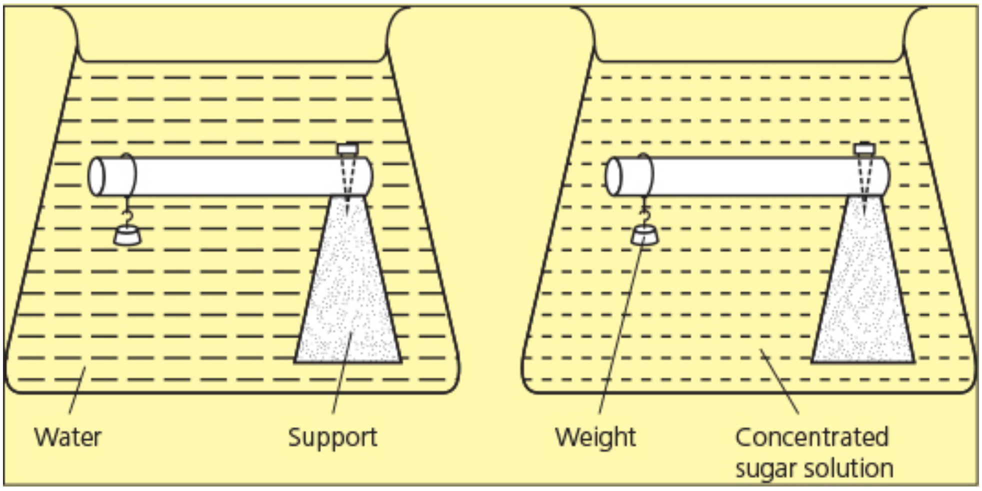
7 **3** State the differences between diffusion and active transport. [2]

4 Give one example of each process in living organisms. [2]

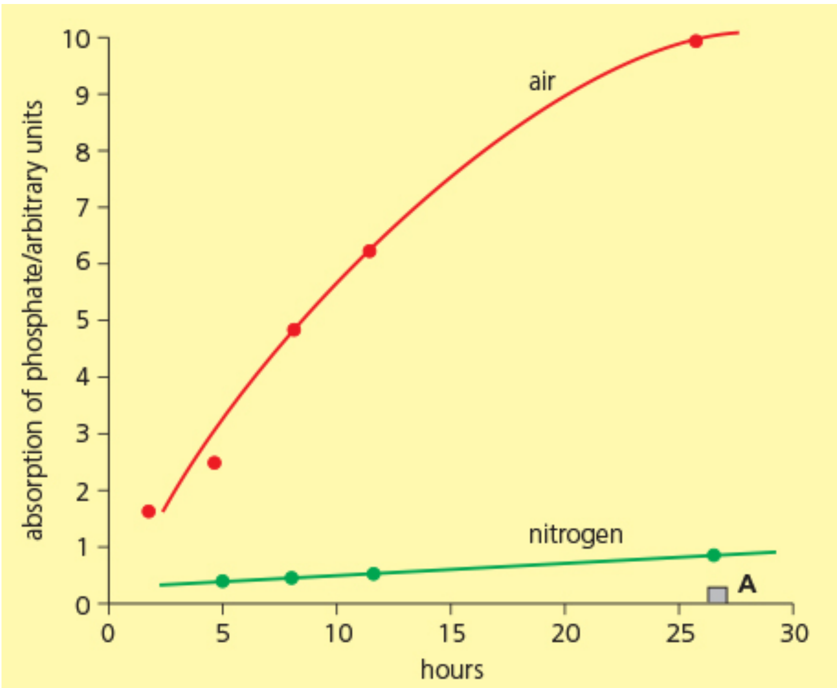
- The diagram shows a cylinder of potato tuber, with a weight attached, in a container of water. A second, identical cylinder of potato was set up in the same way but placed in a container of concentrated sugar solution. Both cylinders were left for 3 hours.

1. Describe and explain in terms of water potential what would happen to
   1. the potato in water [3]
   2. the potato in the concentrated sugar solution. [3]

- State the name of the process involved in causing any changes to the appearance of the cylinders. [1]
- Root hair cells are involved in taking up water and mineral ions from the surrounding soil. State how the processes of taking up these substances are different. [2]



- The graph shows the absorption of phosphate ions by the roots of a beech plant when kept in an atmosphere of air or nitrogen. **A** represents the concentration of phosphate in external solution.



1. State which plant cells absorb the phosphate ions. [1]
2. Describe the absorption of phosphate ions by the beech plant

i) in an atmosphere of air [2]

ii) in an atmosphere of nitrogen. [2]

3. Suggest what process is involved in the absorption of phosphate ions. Explain your answer. [3]