3 Transport in cells

What does smelling your best friend's deodorant have in common with making a cup of tea? One thing is that they both involve the movement of particles. Particles spread out naturally from areas of high concentration to areas of low concentration. This movement is called diffusion and it is a key biological process. Without it your cells would not receive oxygen or glucose, and would quickly die.

Specification coverage

This chapter covers specification points 4.1.3.1 to 4.1.3.3 and is called Transport in cells.

It covers diffusion, osmosis and active transport.

Prior knowledge

Previously you could have learnt:

- **Diffusion can be explained in terms of the particle model.**
- **Breathing is the movement of air in and out of the lungs.**
- **Plants gain mineral nutrients and water from the soil via their roots.**

Test yourself on prior knowledge

1 Name the specialised cell that helps plants absorb water.
2 Describe the process of diffusion.
3 Explain why breathing and respiration are not the same thing.

Diffusion

KEY TERMS

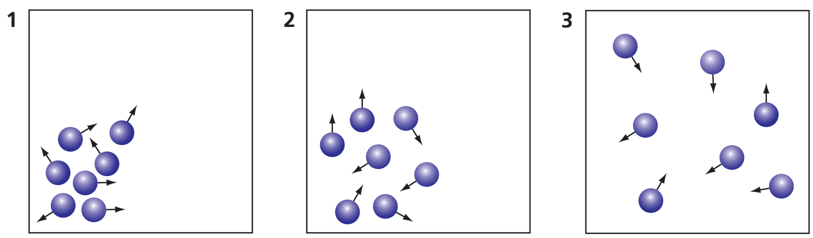
Net Overall.

Concentration gradient A measurement of how a concentration of a substance changes from one place to another.

Diffusion is the process by which particles of gases or liquids spread out from an area where there are lots of them to areas where there are fewer of them. We say that areas with lots of particles have a high concentration and areas with fewer particles have a low concentration. This process happens naturally, and no additional energy is needed for it to occur. It is a **passive process**. Diffusion is defined as the **net** movement of particles from an area of high concentration to an area of lower concentration. Because the movement is from high to low concentration, we say it is down a **concentration gradient**.

TIP

We say 'net' movement, which means overall movement, because some of the particles may naturally diffuse back to the area of high concentration they have just come from. Far fewer will ever do this than diffuse away, however.



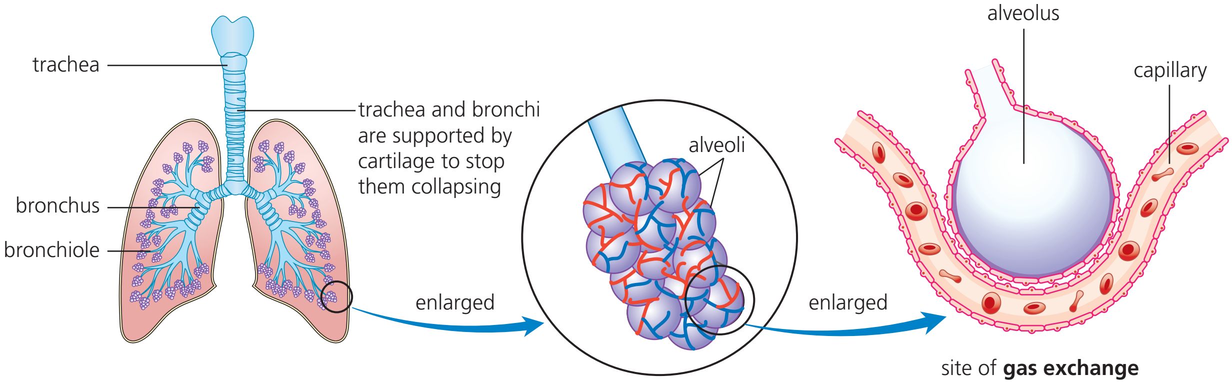
▲ **Figure 3.1** Molecules in a gas spread out by diffusion.

▲ **Figure 3.2** An everyday example of diffusion. The particles move from a high concentration in a scented candle to a low concentration in the air.

Examples of diffusion

When you put your deodorant on in the morning the highest concentration is under your arm. But not all of the deodorant particles remain under your arm, or nobody would be able to smell them. They slowly move by diffusion (we say they diffuse) from a high concentration under your arm to the lower concentration found in the air. The same is true of tea particles when you add hot water to your teabag. The particles of tea don't remain in the high concentration within the bag – they spread out to the lower concentration found in the boiling water.

In the body, **diffusion occurs across cell membranes**. A good place to study diffusion is in the lungs.



▲ **Figure 3.3** Lungs and alveoli.

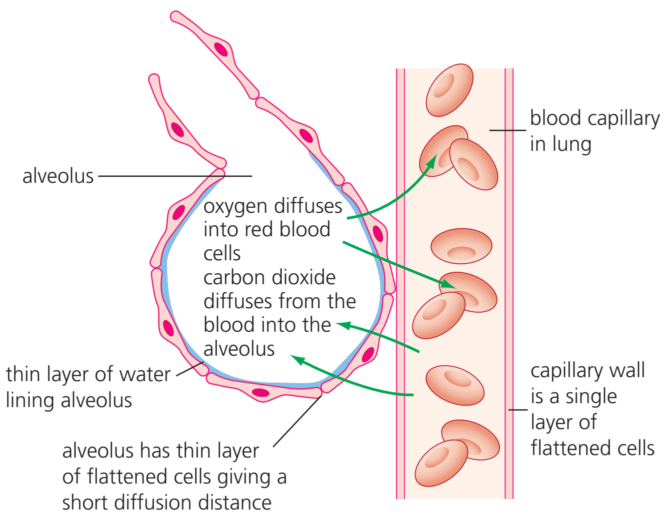
KEY TERMS

Alveoli Tiny air sacs found in the lungs through which gases exchange between blood and air.

Capillaries Tiny blood vessels that link arteries and veins that carry blood into tissues and organs.

Diffusion in the lungs

When we breathe in we take air that is relatively high in oxygen into our lungs. In the individual **alveoli** in our lungs the **oxygen** is in a higher concentration than in the blood, so the oxygen naturally diffuses from inside the alveoli into the blood. Because the blood in our body is always moving, the blood that now has a high concentration of oxygen is immediately moved away to the tissues and organs and is replaced by 'new' blood with lower levels of oxygen. This means more oxygen will always diffuse from the alveoli into the 'new' blood, keeping the blood rich in oxygen.



▲ **Figure 3.4** Diffusion of gases between an alveolus and a blood capillary in the lung.

The reverse is also true when the blood that is now high in oxygen reaches our tissues and organs. Here it travels through the tiny **capillaries** that supply the tissues and cells. These cells have a low concentration of oxygen because they have just used their oxygen in aerobic respiration to release energy from glucose. So the oxygen moves from a high concentration in the blood to a lower concentration in these cells.

Carbon dioxide diffuses in the reverse direction. It is produced during respiration in the tissues and organs and so is in a higher concentration within them. The blood moving towards the tissues and organs has a low concentration of carbon dioxide because it has just come from the lungs, where it unloaded carbon dioxide and picked up oxygen. So in body cells carbon dioxide diffuses from a high concentration to a low concentration in the blood. The blood now has a high concentration of carbon dioxide. It is transported to the lungs, where the carbon dioxide diffuses from an area of high concentration in the blood to an area of lower concentration in the alveoli. You then breathe it out.

TIP
As a model for a group of alveoli, imagine a red mesh bag (the type that fruit comes in) full of balloons. What are the positives and negatives of this model?

Activity

Diffusion

Place some vapour rub or strong-smelling oil onto some cotton wool and place this inside a balloon. Blow the balloon up and time how long it takes for the smell to pass through the balloon so that you can smell it.

Questions

1 Explain how the scent got from inside the balloon to the outside.
2 Describe how you could speed up the process.
3 Explain how this is similar to the movement of oxygen in the lungs.

Adaptations of the lungs

TIP
It is important that you can explain how the lungs in mammals are adapted to exchange materials.

KEY TERM
Ventilation Breathing in (inhaling) and out (exhaling).

TIP
Some people confuse the process of breathing, called ventilation, with the release of energy from glucose in the chemical reaction called respiration.

The combined surface area of your lungs is the total area that is open to air inside your lungs and to blood on the other side. Your lungs have a surface area of about half the size of a tennis court. This means they have a huge area to allow oxygen to diffuse from the alveoli into the blood and carbon dioxide to diffuse from the blood into the alveoli.

In addition to having a **large surface area**, your lungs are adapted for effective gas exchange by:

- having **moist membranes** that allow substances to diffuse faster across them
- alveoli and capillaries having **thin linings** (usually one cell layer thick)
- having a **rich blood supply**
- **breathing** (**ventilation**), providing the lungs with a regular supply of fresh air and removing air low in oxygen and high in carbon dioxide.

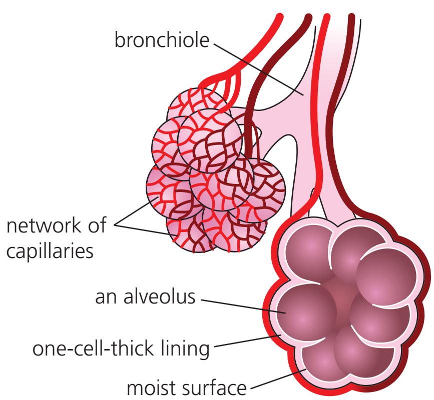
Diffusion also occurs in other places in the body.

KEY TERM
Excretion The removal of substances produced by chemical reactions inside cells.

Activity

Surface area

Make a fist with one hand and use a piece of string and a ruler to measure around the outside of it from the base of your thumb to the base of your little finger. Now open your hand and measure from the base of your thumb around all your fingers, to end in the same place. What is this a model for?



▲ **Figure 3.5** A cluster of alveoli showing their specialised features for gas exchange.

Some of your cells make **urea** as a waste product. This is at high concentration in your cells and a lower concentration in your blood, so it diffuses from your cells to your blood. It is transported in the blood to your kidneys for **excretion**.

Diffusion in other organisms

The size of many organisms is determined by the maximum distance that substances can diffuse quickly. Insects, for example, do not have lungs and therefore do not breathe. They simply have a number of small tubes that run into their bodies. Oxygen diffuses from these tubes into the cells of the insect because the cells are using it for aerobic respiration. So it moves from an area of higher concentration in the tubes to an area of lower concentration in the cells. The maximum size of insects is in part determined by the distance that oxygen can quickly diffuse into their cells.

These smaller organisms do have an advantage over larger ones, however. **The smaller they are the greater the relative size of their surface area compared to their volume**. That is, they have a greater surface area to volume ratio. Large surface area to volume ratios in smaller organisms make it easier for them to get the oxygen they need (and get rid of carbon dioxide).

> **TIP**
> It is important that you can calculate and compare surface area to volume ratios.

Large organisms like us need specialised exchange surfaces for exchange – such as alveoli in our lungs and villi in our intestines (see Chapter 4) – and a transport system such as the blood to transport substances around our bodies. This is because larger organisms have a smaller surface area to volume ratio.

Fish absorb dissolved oxygen into their blood by diffusion in their gills. These structures have a large surface area to maximise this.

Factors that affect diffusion

Concentration gradient

The steeper the **concentration gradient** (the bigger the difference in the number of particles between an area of high concentration and an area of lower concentration), the more likely the particles are to diffuse down the concentration gradient. For example, the more deodorant you put on, the more the particles of deodorant are likely to diffuse into the air, and so the more likely other people are to smell them.

Temperature

At **higher temperatures** all particles have more kinetic energy. They move faster as a consequence. This means that they are more likely to spread out from their high concentration to areas of lower concentration.

Surface area of the membrane

The **larger the surface area** of the membrane the more particles can diffuse at once. Many people who have smoked for long periods of time have a reduced surface area in their lungs. This is called emphysema. Because their lung surface area is reduced, they are less able to get oxygen into their blood. They therefore often find it harder to exercise.

Test yourself

1 Define the term 'diffusion'.
2 Describe four ways in which alveoli are adapted to their function.
3 Suggest why diffusion cannot happen in solids.

Show you can...

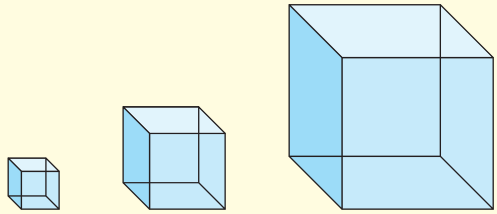
Explain where diffusion occurs to get oxygen to your cells.

Activity

Investigating surface area to volume ratio and diffusion

A class carried out an investigation to examine the effect of surface area on the diffusion of dye. They were provided with three cubes of clear agar jelly that had been cut to different sizes (Figure 3.6).

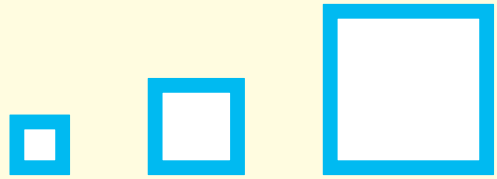
Cube A was 1 × 1 × 1 cm.
Cube B was 2 × 2 × 2 cm.
Cube C was 4 × 4 × 4 cm.



▲ Figure 3.6

Each cube was placed in a 200 cm^3 beaker and the beaker was filled with 150 cm^3 of blue dye. The cubes were left in the dye for 5 minutes. After this time the cubes were removed and any excess dye washed off before drying with a paper towel.

The cubes were then cut in half and observations were made on how far the dye had moved into the agar (Figure 3.7).



▲ Figure 3.7

Questions

1 Give two variables that were controlled in this investigation.

2 To work out the total surface area (SA) for cube A, first the surface area of one face needs to be calculated: this is 1 × 1. This then needs to be multiplied by the total number of faces (6), so the calculation is 1 × 1 × 6 = 6 cm^2. To work out the volume, all the dimensions should be multiplied: 1 × 1 × 1 = 1 cm^3. Copy and complete Table 3.1 by working out the surface area and volume for cubes B and C.

Table 3.1

Cube	Total surface area in cm^2	Total volume in cm^3	Surface area/volume	SA : V
A	6	1	6	6 : 1
B				
C				

3 Calculate the surface area divided by volume for cells B and C and add this to the table.

4 Use the values you worked out for Question 2 to complete the surface area to volume ratios (SA:V) for cubes B and C.

5 In which cube had the greatest proportion been dyed blue?

6 Explain how the dye entered each cube.

To make sure diffusion rates are fast enough, multicellular organisms have many adaptations to increase diffusion. Examples can be found in the lungs in humans, root hair cells and leaves in plants, and gills in fish. Gills contain many finely divided sections of tissue that are rich in blood capillaries. All the finely divided sections added together give a very large surface area.

Osmosis

KEY TERMS

Osmosis The net diffusion of water from an area of high concentration of water to an area of lower concentration across a partially permeable membrane.

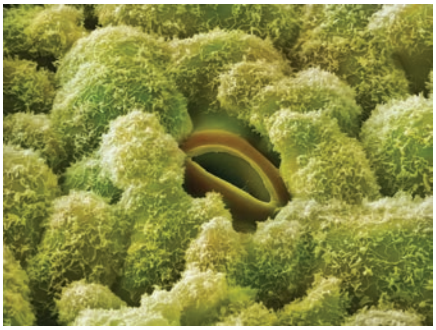
Partially permeable Allowing only substances of a certain size through.

We learnt in the previous section that particles of gases and liquids naturally move from areas of high concentration to areas of lower concentration by diffusion and that this can be across a membrane. **Osmosis** is the net diffusion of water from an area of high concentration of water (dilute solution) to an area of lower concentration of water (concentrated solution) across a **partially permeable** membrane. Water is the only substance that has a special name for diffusion. As in diffusion, no additional energy is used, and so this is a **passive process**. Because osmosis is from a high to a lower concentration of water, we say it is down a **concentration gradient**.

Example of osmosis

When it rains, water is present in a high concentration in the soil surrounding plant roots. The concentration of water inside the plant is lower, particularly if it hasn't rained for a while. So the water moves naturally from the soil into the plant cells across the membranes of the cells by diffusion. Because this is water and it moves across a membrane to get into the cells, we call this process **osmosis**.

The water will then be carried in the xylem up to the leaves, where most of it will evaporate into the air through stomata (tiny pores). This process is called transpiration. Because water is continuously evaporating, it will continuously be 'pulled up' from the roots, which means that the root cells almost always have a lower concentration of water than in the soil, therefore allowing water to continue to enter the plant by osmosis.

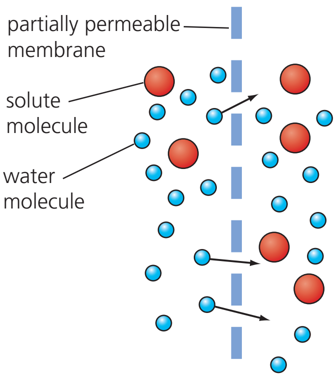


▲ **Figure 3.8** The stomata of this sycamore leaf open and close to let water vapour evaporate during transpiration.

Comparing water concentrations

If two solutions have the same concentrations of water and solutes (substances in the water), then there is no net overall movement of water. The same volume of water will move in both directions if they are separated by a partially permeable membrane. We say these solutions are **isotonic**.

If one solution has a higher concentration of solute than another we describe the first one as being **hypertonic** to the other one. Crucially, because this has a higher solute concentration it has a lower water concentration. So if we took a red blood cell and put it into a very salty hypertonic solution (brine), the water from inside the blood cell would pass into the solution by osmosis. It would move from an area of high water concentration (inside the cell) to an area of lower water concentration (in the brine). The red blood cell would **shrivel up** as a result.



▲ **Figure 3.9** Osmosis: water moves from the left side of the partially permeable membrane to the right side because more water molecules are on the left. Note that the solute molecules are too big to pass through the partially permeable membrane.

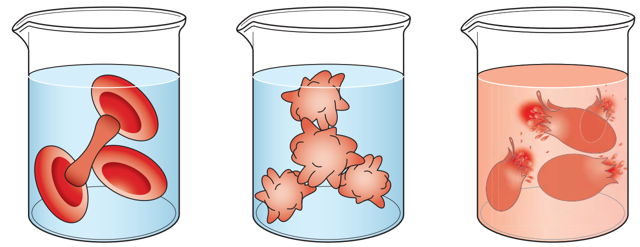
The reverse is also true. If one solution has a lower concentration of solute than another, we describe it as being **hypotonic** to the other solution. Crucially, because this has a lower solute concentration it has a higher water concentration. So if we took a red blood cell and put it into pure water (a hypotonic solution) the water from outside the blood cell would move into it. It would move from an area of high water concentration (outside the cell) to an area of lower water concentration (inside the cell). The red blood cell would **swell up** as a result.

TIP
It is not important to be able to recall the terms 'isotonic', 'hypotonic' and 'hypertonic'. They are included here to help you understand how water moves between different concentrations.

TIP
It is important to know that water will move by osmosis from a dilute solution to a more concentrated one.

Show you can...

Explain how osmosis leads to the uptake of water into a plant.



▲ **Figure 3.10** This is what happens to red blood cells in solutions with different concentrations of water (not to scale).

Test yourself

4 Define the term 'osmosis'.
5 Name the plant cell that is adapted to allow plants to absorb water.
6 Describe one key difference between osmosis and diffusion.

Required practical 2

Investigate the effect of a range of concentrations of salt or sugar solutions on the mass of plant tissue

Here is one way to investigate osmosis in potatoes, but your teacher may suggest you use another method or investigate different types of vegetables.

Method

1 Label six boiling tubes 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0.
2 Using the volumes given in Table 3.2 and the 1.0 M solution of salt or sugar you have been provided with, make up the following concentrations in each boiling tube.

Table 3.2 Volumes used to make a range of concentrations.

Concentration in M	Volume of 1 M salt or sugar solution in cm^3	Volume of distilled water in cm^3	Total volume in cm^3
0.0	0	25	25
0.2	5	20	25
0.4	10	15	25
0.6	15	10	25
0.8	20	5	25
1.0	25	0	25

3 Using a chipper or corer, remove tissue from the middle of a potato and cut it into six equal 1 cm-long pieces.
4 Pat the first tissue sample dry with a paper towel, then measure and record its starting mass in a table like the one shown on the right.
5 Place a 1 cm-long piece of potato in the tube labelled 0.0 M and start the stopwatch.
6 Repeat this for the other five concentrations.
7 After 30 minutes (or the time specified by your teacher), remove the potato piece from the tube and dry it gently using a paper towel.
8 Record the end mass for the potato piece.
9 Repeat for the other concentrations after each sample has been in the solution for 30 minutes.

Table 3.3 The results of an investigation into the effects of solute concentration on plant tissue.

Concentration in M	Starting mass in g	End mass in g	Change in mass in g	Change in mass in %
0.0				
0.2				
0.4				
0.6				
0.8				
1.0				

Questions

1 Work out the change in mass for each potato piece and record it in your table. The mass changes will be positive if the potato piece got heavier and negative if it became lighter. Ensure you have clearly indicated this.
2 Calculate the percentage mass change for each piece of potato using the equation:

$$\%\text{ change in mass} = \frac{\text{change in mass}}{\text{starting mass}} \times 100$$

3 Now plot a graph of your data with the sugar or salt concentration on the *x*-axis and the percentage change in mass on the *y*-axis. Think carefully about how you will set up your axes to show both positive and negative values on the same graph.
4 Why did you have to pat dry the potato piece before and after each experiment?

5 Why did working out percentage change in mass give more appropriate results than simply recording the change in mass?

6 Write a conclusion for this investigation. You will need to describe the trend shown by your graph and consider how the rate of osmosis is affected by the concentration of solution.

7 Use your graph to predict what concentration of salt or sugar would have led to no change in mass in a piece of potato.

Active transport

KEY TERMS

Active transport The net movement of particles from an area of low concentration to an area of higher concentration using energy.

Mineral ions Substances that are essential for healthy plant growth, e.g. nitrates and magnesium.

On occasions organisms need to move particles from areas where they are in low concentration to areas of higher concentration across membranes. This is called **active transport**, and we say that the particles are moving **up (or against) a concentration gradient**. If this is the case, then **energy** must be used. This is not a passive process like diffusion and osmosis. The energy needed comes from respiration.

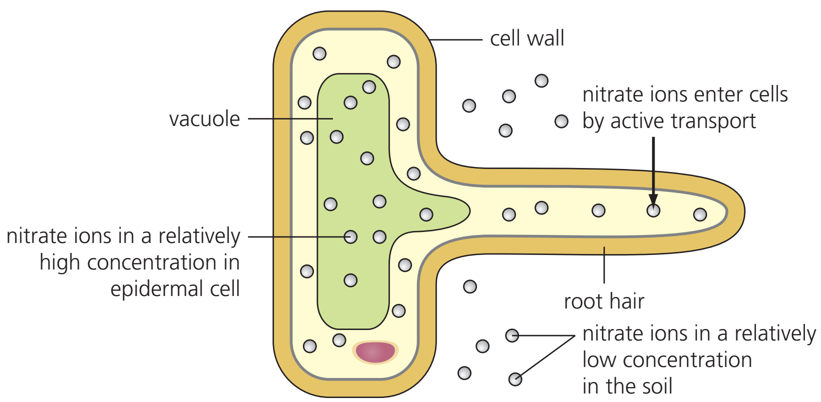
Examples of active transport

Mineral ions and plant roots

We learnt in the previous section that water moves from an area of high concentration in soil to a lower concentration in plant roots across a membrane and that this is called osmosis. But plants need to take up **mineral ions** from the soil as well. These exist in very low concentrations in the soil but in high concentrations in the plants. So we might expect the mineral ions to diffuse out from the plant roots into the soil. Because the plants need to move the mineral ions from low to high concentrations, against the concentration gradient, they need to use energy. This is an example of active transport.

TIPS

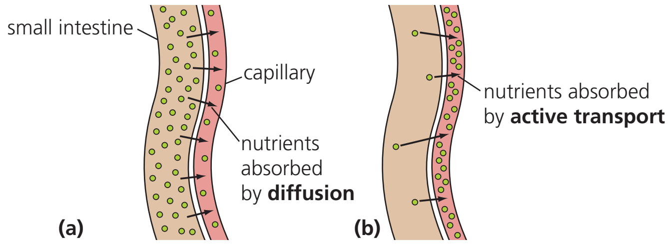
- It is important that you can explain the differences between diffusion, osmosis and active transport.
- It is important that you can explain how roots are adapted to absorb materials. You learnt about root hair cells in Chapter 1.



▲ **Figure 3.11** Active transport of nitrates in an epidermal cell (root hair cell).

Sugars and the digestive system

Following a sugary meal you will have high concentrations of sugars in your small intestine and lower concentrations in your blood. This means that sugars will naturally diffuse into your blood. But what happens if your last meal didn't have much sugar in it? The lining of the small intestine is able to use energy to move sugars from lower concentrations in your gut into your blood.



▲ **Figure 3.12** Look carefully at the nutrient concentrations in the intestine and the blood: (a) diffusion; (b) active transport.

Test yourself

7 Define the term 'active transport'.
8 Give one example of where active transport occurs in the human body.
9 Describe the key difference between diffusion and active transport in terms of the concentration gradient.

Show you can...

Explain where active transport occurs in a plant.

Chapter review questions

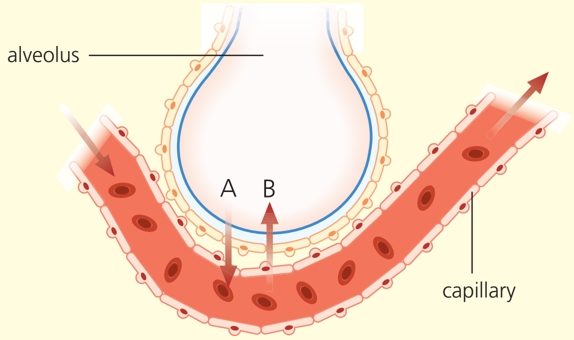
1 Define the term 'diffusion'.
2 Suggest an everyday example of diffusion of gases.
3 In which direction does oxygen diffuse in the lungs?
4 In which direction does carbon dioxide diffuse in the lungs?
5 Name the blood vessels from which oxygen diffuses into cells.
6 Give the scientific name for breathing.
7 Name the process by which oxygen moves into the blood from the lungs.
8 Define the term 'osmosis'.
9 Describe where and how osmosis occurs in a plant.
10 Name the tiny holes in leaves.
11 Define the term 'active transport'.

12 Is moving up a concentration gradient going from high to lower or from low to higher concentration?
13 Give an example of diffusion in a liquid.
14 Describe two ways in which your lungs are adapted for gas exchange.
15 Define the term 'partially permeable membrane'.
16 Explain why mineral ions moving into a plant root is not an example of osmosis.
17 Describe what would happen to the size of a red blood cell if it were placed into a solution with the same concentration of solutes.
18 Describe what would happen to the size of a red blood cell if it were placed into a solution with a higher concentration of solutes.
19 Describe what would happen to the size of a red blood cell if it were placed into a solution with a lower concentration of solutes.
20 Describe one place where active transport occurs in plants.
21 Describe one place where active transport occurs in humans.

22 Explain why we say 'net movement' in our definition of diffusion.
23 Explain, in terms of diffusion, why insects are small.
24 Describe how you could use your hand and a length of string to model increasing surface area.
25 Explain how temperature affects diffusion.
26 Explain how the surface area of the membrane affects diffusion through it.
27 Describe an experiment in which you could investigate osmosis in plants using pieces of potato.

Practice questions

1 Figure 3.13 shows an alveolus and blood capillary in the lung.



▲ **Figure 3.13**

a) During gas exchange, oxygen and carbon dioxide are exchanged between the alveolus and capillary. Which arrow (A or B) shows the net direction in which oxygen moves? [1 mark]

b) Gases move across cell membranes by diffusion.

i) Define the term 'diffusion'. [2 marks]

ii) Copy and complete the sentence using words from the box below:

active	passive	energetic	kinetic
oxygen	energy	carbon dioxide	

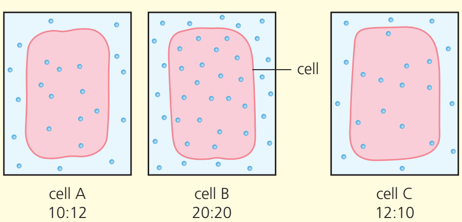
Diffusion is a ______________________________ processes. This means it does not require additional ______________________________. [2 marks]

2 Figure 3.14 shows three model cells (the pink areas) containing and surrounded by the same particles which can move freely into and out of the cell.

a) Which cell will have the greatest net movement of particles into it? [1 mark]

b) i) What effect would increasing the temperature have on the rate of movement of particles? [1 mark]

ii) Why would this occur? [1 mark]



▲ **Figure 3.14**

c) i) Choose a cell which will have no net movement. [1 mark]

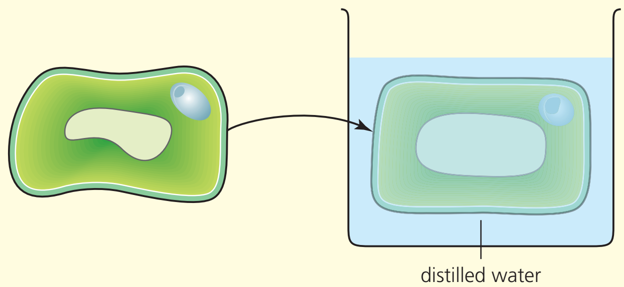
A Cell A **B** Cell B
C Cell C

ii) Give the reason why you have chosen this cell. [1 mark]

d) Which cell will have the greatest rate of movement of particles into the cell? [1 mark]

A Cell A **B** Cell B
C Cell C

3 Figure 3.15 shows a plant cell before and after it was placed in distilled water for 10 minutes.



▲ **Figure 3.15**

a) Describe one way in which the cell looks different after being left in distilled water. [1 mark]

b) i) Describe what would happen if an animal cell were placed in the distilled water. [1 mark]

ii) Give the reason why this is different to what happened to the plant cell. [1 mark]

c) i) Draw a diagram to show what the plant cell would look like if it had been placed in a concentrated salt solution. [3 marks]

ii) Explain why the cell would look this way. [3 marks]

4 A student investigated the effect of osmosis on potato pieces. This is the method used:

a) The student started out with three pieces of potato that each measured 2 cm in length.

b) They then placed one piece of potato into a concentrated salt solution and one piece of potato into a dilute salt solution.

c) They left the potato pieces for 10 minutes.

d) They then removed the potato pieces and re-measured their length.

Describe how this method could be improved to produce valid results. [6 marks]

Working scientifically: Dealing with data

Presenting data in tables

Tables are an important part of most scientific investigations and are used to record the data collected. A good scientific table should present the data in a simple, neat way that is easy to understand.

Questions

1 Look at Table 3.4 and note down as many mistakes as you can see.

Table 3.4

Time taken to smell the deodorant	Room temperature
1 minute and 45 seconds	10 °C
54.0 seconds	25 °C
1 minute and 30 seconds	15 °C
1 minute	20 °C
42.0 seconds	30 °C

When drawing tables there are some conventions (rules) to be followed:

- **The independent variable (variable that is changed) should always be recorded in the first column. The dependent variable (variable that is measured) can be recorded in the next columns, with additional columns added if repeats are taken.**
- **The independent variable should be organised with an increasing trend.**
- **If a mean is calculated, this should be in the column furthest to the right.**
- **Column headers must have a clear title. If quantitative data are recorded, correct SI units must be given.**
- **Units must be given in the headers and not rewritten in the table body.**
- **All data in a column must be recorded to the same unit as the header, and mixed units should not be used.**
- **Data should be recorded to the same number of decimal places or significant figures.**

Questions

2 Use this information to redraw Table 3.4 above so that it is correct.

3 Read the following instructions for an experiment examining osmosis in model cells. Draw a suitable table to record the volumes required in each beaker in order to prepare for the experiment.

Method for making up solutions

Collect five 100 cm^3 beakers and label them A, B, C, D and E. In each beaker add the following amounts of a concentrated fruit squash: A 100 cm^3, B 75 cm^3, C 50 cm^3, D 25 cm^3 and none in E. Then use distilled water to bring the volume of beakers B–E up to 100 cm^3. Stir the solutions to ensure they are mixed thoroughly.

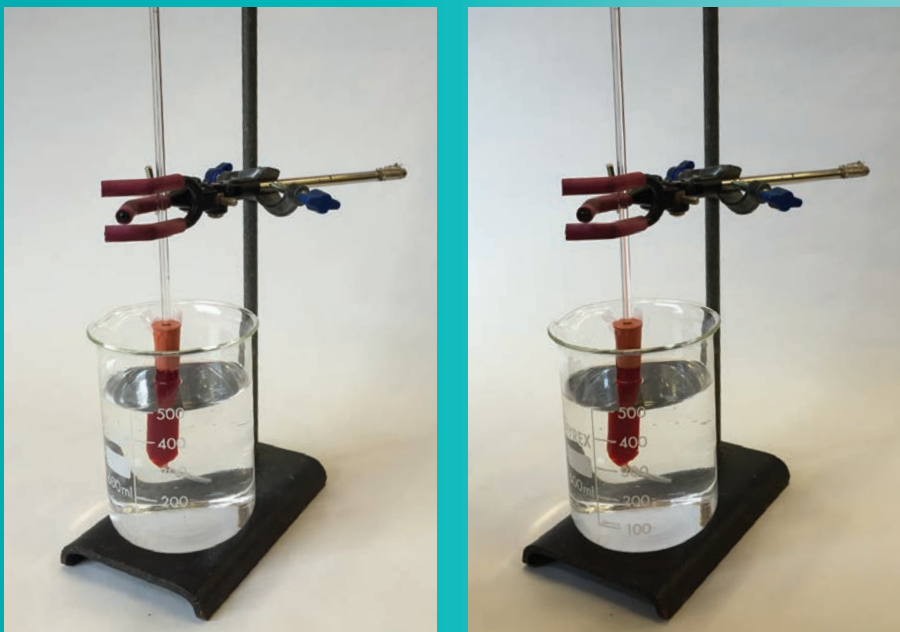
Questions

4 Read through the method of the experiment on the next page and design a suitable table to record the results of the experiment. Ensure you identify the independent and dependent variables.

Method

Take five equal-sized pieces of Visking tubing that have been soaked in water. Tie one end of each securely. Using a pipette add 10 cm^3 of the solution from beaker A into one piece of Visking tubing. Tie the other end of the tubing using string and ensure that no liquid can escape. Repeat this process for the other four solutions B–E. Use a balance to determine the starting mass of each tube.

Place each tube in a separate beaker containing 200 cm^3 of distilled water. After 5 minutes remove the tubes and pat dry with a paper towel. Record the mass of each tube. Return to the beakers they came from and repeat, recording the mass at 10, 15 and 20 minutes.



▲ Figure 3.16 The liquid in the beaker is pure water. The red liquid is a very concentrated sugar solution with some red food dye added and is placed inside Visking tubing. This special tubing allows molecules of water through it but not larger sugar molecules. Water moves by osmosis through the Visking tubing from an area of high water concentration in the beaker to an area of lower water concentration (because of the added sugar) in the Visking tubing. This makes the red solution rise up the glass tube.