2 Movement of Substances

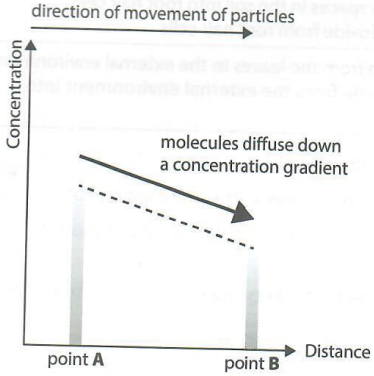
Study Station ▸▸

A Diffusion

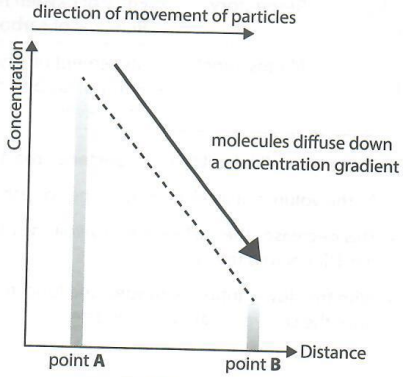
Learning Outcomes

- Define diffusion and discuss its role in nutrient uptake and gas exchange in plants and humans.
- Explain how an increase in surface area-to-volume ratio of a cell results in an increase in the rate of diffusion or absorption of substances.

1. All matter is made up of particles (atoms, molecules and ions).
2. Fluids (liquids and gases) are made up of particles that are constantly moving in a random manner.
3. Concentration is the amount of substance in a fixed volume. A **concentration gradient** is the difference in concentration between two regions.
   - The slope shown in each graph below is the concentration gradient.
   - The steeper the concentration gradient, the faster the rate of diffusion.



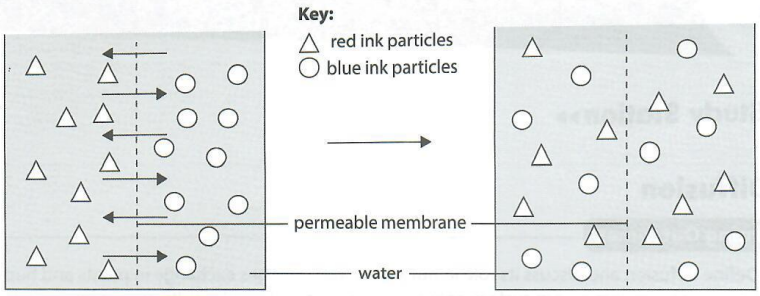
Less steep concentration gradient



Steeper concentration gradient

4. All particles have a natural tendency to move down their concentration gradient and become evenly spaced out after some time.
5. **Diffusion** is the net movement of particles from a region of higher concentration to a region of lower concentration down a concentration gradient.

6. A **permeable membrane** allows particles of all sizes to pass through freely. The diagrams below show the diffusion of red and blue ink particles across a permeable membrane.



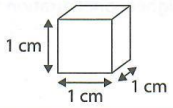
Both red and blue ink particles can pass through the permeable membrane

Concentration of red and blue ink particles on either side is equal

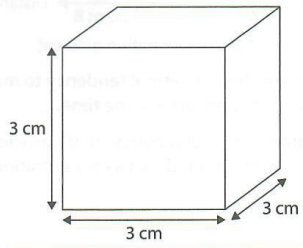
7. The table below describes examples of diffusion in biological systems.

System		Description
Human	Respiratory	• Diffusion of oxygen from the alveoli to red blood cells • Diffusion of carbon dioxide from the blood to the alveoli
	Digestive	• Absorption of digested food from the small intestine to blood capillaries
Plant	Respiratory	• Entry of oxygen from spaces in the soil into root hair cells • Removal of carbon dioxide from root hair cells
	Photosynthetic	• Movement of oxygen from the leaves to the external environment • Entry of carbon dioxide from the external environment into the leaves

8. The size of a cell is limited by its **surface area-to-volume ratio**.
   - As the volume of a cell increases, the corresponding increase in its surface area is not the same.
   - This decreases the surface area-to-volume ratio, which decreases the rate of diffusion of particles across the cell.
   - With the slower intake of oxygen and food, the growth of cells typically slows down and stops once the cells reach an optimum size.



Total surface area = $1 \times 1 \times 6 = 6\ cm^2$
Volume = $1 \times 1 \times 1 = 1\ cm^3$
Surface area-to-volume ratio = 6 : 1

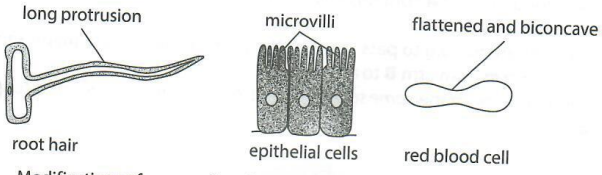


Total surface area = $3 \times 3 \times 6 = 54\ cm^2$
Volume = $3 \times 3 \times 3 = 27\ cm^3$
Surface area-to-volume ratio = 2 : 1

9. The table below summarises the factors that affect the rate of diffusion.

Factor	How It Affects the Rate of Diffusion
Concentration gradient	The steeper the concentration gradient, the faster the rate of diffusion.
Surface area-to-volume ratio	The larger the surface area-to-volume ratio, the greater the area for substances to pass through and hence, the faster the rate of diffusion.
Diffusion distance	The shorter the diffusion distance, the less time needed for the substance to travel and hence, the faster the rate of diffusion.

10. Cells involved in transport have modified shapes with a high surface area-to-volume ratio to ensure efficient rates of diffusion.



Modifications of some cells to increase their surface area-to-volume ratio

Common Error

✗ In diffusion, particles only move towards the region of lower concentration.

✓ In diffusion, particles move constantly and randomly in all directions.

Explanation
Particles move at random with an overall net direction down the concentration gradient.

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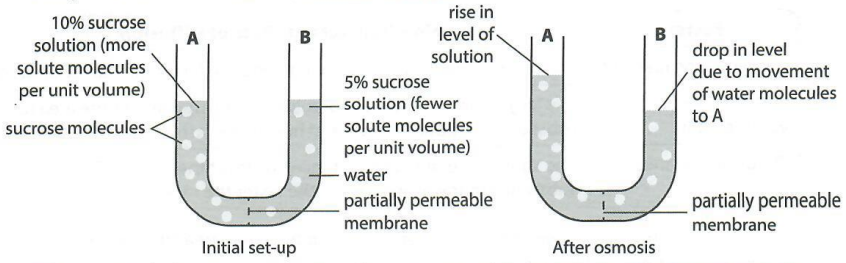
B Osmosis

Learning Outcome

- Define osmosis and describe its effect on plant and animal tissues.

1. **Osmosis** is 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**.
2. **Water potential** is the tendency for water molecules to move from one region to another.
3. Water molecules move from a dilute solution to a concentrated solution.
   - A dilute solution has a greater number of water molecules than a concentrated solution. Thus, it has a higher water potential than a concentrated solution.
   - A concentrated solution has a smaller number of water molecules than a dilute solution. Thus, it has a lower water potential than a dilute solution.
4. A **water potential gradient** is the difference in water potential between two bodies of liquids. Distilled water has the highest water potential of any solution as it is made up of 100% water molecules.
5. A **partially permeable membrane** allows smaller particles to pass through it but prevents larger particles from passing through.

6. The diagram below illustrates the process of osmosis.



- 10% sucrose solution in arm **A** contains fewer water molecules per unit volume compared to 5% sucrose solution in arm **B**.
- Sucrose molecules are too big to pass through the partially permeable membrane.
- Water molecules move from arm **B** to arm **A**.
- In the end, both arms have the *same solute concentration* (same number of solute molecules per unit volume).

Tip

Some differences between diffusion and osmosis

	Diffusion	Osmosis
Involves the Net Movement of	Particles (atoms, molecules, ions)	Water molecules
Direction of Movement	From a region of higher concentration to a region of lower concentration, down a concentration gradient	From a solution of higher water potential to a solution of lower water potential, down a water potential gradient
Partially Permeable Membrane	Not required	Required

Common Error

✗ Water vapour moves down a concentration gradient by osmosis.

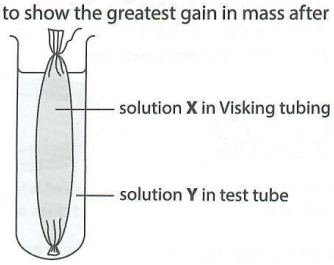
✓ Water vapour moves down a concentration gradient by diffusion.

Explanation

Osmosis is used to describe the movement of water molecules in the liquid state across a partially permeable membrane.

Worked Example 2.1

The diagram shows a set-up for investigating osmosis. Which combination of solutions **X** and **Y** will cause the Visking tubing to show the greatest gain in mass after 1 hour?



	Solution X	Solution Y
A	10% starch solution	20% starch solution
B	15% starch solution	Distilled water
C	20% starch solution	10% starch solution
D	Distilled water	10% starch solution

Solution

Option **B** is the correct answer.

Explanation

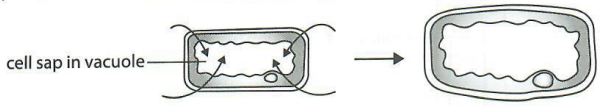
- Starch molecules are too big to move through the partially permeable Visking tubing.
- For the greatest increase in mass, there must be the greatest movement of water via osmosis into the Visking tubing. This requires the maximum water potential gradient.
- The maximum gradient is generated when the outside of the tubing has the highest water potential and the inside of the tubing has the lowest water potential.
- Distilled water has the highest water potential.

7. The table below describes some examples of osmosis in biological systems.

System		Description
Human	Transport	Movement of water molecules into cells from the tissue fluid
	Excretory	Reabsorption of water in the kidneys
Plant	Transport	Transport of water from cell to cell and up to the leaves for photosynthesis

8. In biological systems, the cell membrane acts as the partially permeable membrane for osmosis.
9. Plant and animal cells behave differently in solutions of varying water potential due to the presence or absence of a cell wall respectively.

10. In a solution with a higher water potential (more dilute) than the cytoplasm, water molecules move into the cell via osmosis. This causes the cell to swell.
    - In a plant cell, the vacuole expands and pushes the cytoplasm against the cell wall. The plant cell becomes turgid but does not burst as it is protected by the cell wall. The pressure exerted by the water in the vacuole is called **turgor pressure**.



Water molecules enter the cell by osmosis. | The cell becomes turgid and does not burst.

    - In an animal cell, the cell membrane bursts when water pressure builds up due to the absence of a cell wall.

Water molecules enter the cell by osmosis. | The cell expands and bursts.

11. In a solution with a lower water potential (more concentrated) than the cytoplasm, water molecules move out of the cell via osmosis. This causes the cell to shrink.
    - In a plant cell, the vacuole shrinks and the cell membrane pulls away from the cell wall when water molecules leave. This process is called **plasmolysis**. The plant cell becomes **limp** (flaccid) and is said to be plasmolysed. The cell will die if it stays plasmolysed for too long.

Water molecules leave the cell by osmosis. | The cell becomes plasmolysed and flaccid.

    - In an animal cell, spikes appear on the cell membrane when water molecules leave. This is due to the process called **crenation** and the cell will eventually die.

Water molecules leave the cell by osmosis. | The cell becomes crenated and eventually dies.

12. In a solution with the same water potential, the cell will not change its size or shape. The movement of water is the same in both directions and there is no net movement of water in or out of the cell.

13. The table below describes the factors that affect the rate of osmosis.

Factor	How It Affects the Rate of Osmosis
Water potential gradient	The steeper the water potential gradient, the faster the rate of osmosis.
Surface area-to-volume ratio	The larger the surface area-to-volume ratio, the greater the area for water molecules to pass through and hence, the faster the rate of osmosis.
Distance which water molecules need to move	The shorter the distance, the less time needed for the water molecules to travel and hence, the faster the rate of osmosis.

14. Turgor is important in plant cells.
    - The turgor pressure within plant cells allows the stems and leaves of non-woody plants to stay firm and erect. When the plant cells lose their turgor, the plant wilts.
    - Changes in turgor cause the movement of certain plant parts, e.g., the opening and closing of stomata is due to changes in the turgor of the guard cells.

Common Error

✗ The size of solute particles affects osmosis.

✓ Osmosis is not dependent on the size or type of solute particles in a solution.

Explanation

The water potential of the solution affects osmosis. The movement of water molecules is not affected by other particles in the solution.

Worked Example 2.2

To make fries crispy, many recipes suggest soaking cut potato strips in concentrated salt solution for an hour before frying. However, the strips are observed to be shorter and thinner than their original sizes. Which of the following statements about this observation is **true**?

A Salt diffuses into the potato strips from the concentrated salt solution.

B Water molecules diffuse out of the potato strips into the concentrated salt solution.

C Changes in the dimensions of the potato strips are due to their decreased water potential.

D Water molecules move out of the potato strips and into the concentrated salt solution which causes an increase in the potatoes water potential.

Solution

Option **C** is the correct answer.

Explanation

- The Na^+ and $C\ell^-$ ions in the salt solution cannot diffuse through the cell membrane due to their charges.
- The movement of water molecules only involves osmosis and not diffusion.
- The movement of water out of the potato strips decreased the water potential of the potato cells and caused them to shrink, changing their dimensions.
- The water potential of the potato cells would decrease when water moves out of the potato strip.

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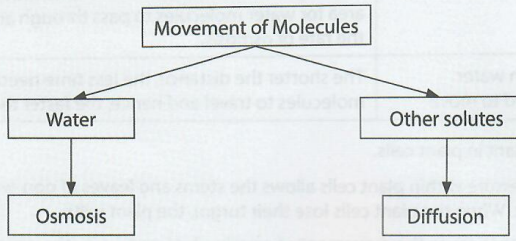
Tip

In answering questions on the movement of molecules, your thought process should be as follows:



Checkpoint 2.1

1. Which of the following statements about diffusion is **true**?
   - **A** It can only take place in living tissues.
   - **B** It can occur across the cell membrane of cells.
   - **C** It can transport solid, liquid, and gaseous substances.
   - **D** It requires energy when moving substances against their concentration gradient.
2. Which of the following regulates the passage of materials between a cell and its surroundings?
   - **A** Cytoplasm
   - **B** Plasma membrane
   - **C** Cell wall
   - **D** Ribosome
3. Plant cells have a _____ to prevent them from bursting in a solution with a _____ water potential than their cytoplasm.
   - **A** cell membrane; lower
   - **B** cell membrane; higher
   - **C** cell wall; lower
   - **D** cell wall; higher

4. Crenation is most likely observed when red blood cells are placed in _____.

   A a dilute salt solution

   B a concentrated salt solution

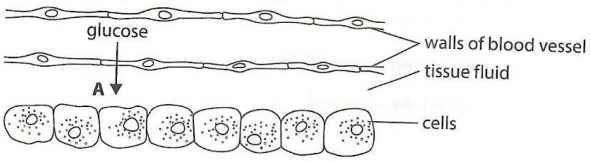
   C a dilute sugar solution

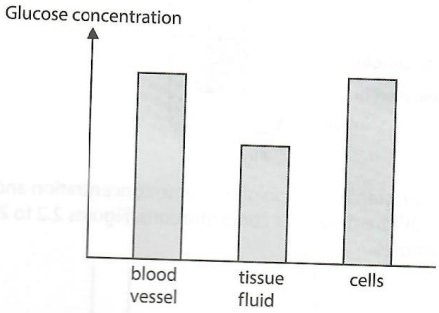
   D distilled water

Tip

The effect on plants and animal cells when placed in solutions of various water potentials has been asked in examination questions. One example can be found in O GCE 'O' Level Science (Biology) Oct/Nov 2017 Paper 4 Q2 or N GCE N(A) Level Science (Biology) Sep/Oct 2014 Paper 6 Q3.

5. The diagram shows a blood vessel and some body cells. The concentration of glucose in the different parts is shown in the bar graph.





(a) Describe the movement of glucose molecules at **A**.

(b) Albumins are large water-soluble proteins that are present in the blood. Explain why albumins are not able to move out of the capillaries.

Test Station ▸▸

1. Four potato slices of the same mass, size and shape are put into four containers containing different liquids. Which combination of solutions can cause the greatest and least increase in mass of the potato slices respectively?

	Liquid that Causes the Greatest Increase in Mass	Liquid that Causes the Least Increase in Mass
A	Dilute salt solution	Concentrated salt solution
B	Concentrated salt solution	Dilute sugar solution
C	Dilute sugar solution	Distilled water
D	Distilled water	Concentrated salt solution

2. Figure 2.1 shows the apparatus used during an investigation.

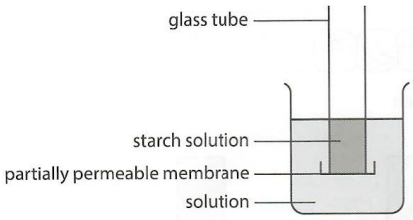


Figure 2.1

Glass tubes were filled with starch solution of the same concentration and placed in beakers with solutions 1, 2, 3 and 4 of different glucose concentrations. Figures 2.2 to 2.5 show the results of the investigation after 30 minutes.

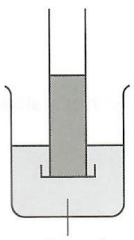


Figure 2.2

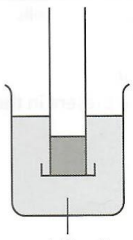


Figure 2.3

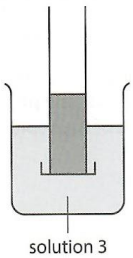


Figure 2.4

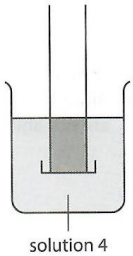


Figure 2.5

Which of the following statements is **correct**?

A The water potential of solution 1 is lower than that of solution 3.

B The concentration of solution 1 is higher than that of solution 3.

C The concentration of solution 3 is lower than that of solution 2.

D The concentration of solution 4 is equivalent to that of the starch solution.

3. Figure 2.6 shows four identical animal cells. The number of dots represents the concentration of a type of molecule both inside and outside of each cell. The molecules move into and out of the cells by diffusion.

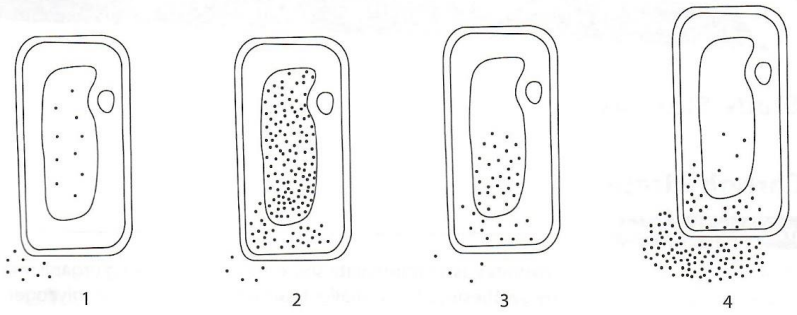


Figure 2.6

Which row gives the direction of movement of the molecules for each cell?

	Cell 1	Cell 2	Cell 3	Cell 4
A	into the cell	no net movement	out of the cell	no net movement
B	no net movement	out of the cell	out of cell	into the cell
C	out of the cell	into the cell	no net movement	into the cell
D	no net movement	out of cell	into the cell	out of cell

4. Figure 2.7 shows a root hair cell which is adapted for absorbing water.

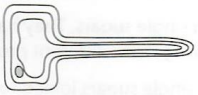


Figure 2.7

If the root hair cell is surrounded by a concentrated fertiliser solution, suggest what would happen to the plant to which the root hair cell belongs. [3]

5. Most of the water filtered out by the kidney will eventually be reabsorbed in a healthy person. Water filtered out of the kidney moves back into the blood down a concentration gradient. Water that is not reabsorbed will be passed out as urine.

(a) State the gradient that allows water to move. [1]

(b) Name the process that allows water to move down the gradient in (a). [1]

(c) Explain what happens to a person's urine production when he consumes a large amount of salty food while limiting water intake.
(Note: The salt ingested will be taken up by the blood.) [3]