The big picture

? Guiding question(s)

- What factors affect the movement of water into or out of cells?
- How do plant and animal cells differ in their regulation of water movement?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

When leafy green vegetables such as lettuce, kale and spinach are exposed to the air, their leaves can lose moisture through evaporation, causing them to wilt and develop an undesirable texture.

A simple and effective technique to revive these vegetables is to immerse them in cold water for a few minutes (**Figure 1**). This process allows water to move into the leaf, replacing the moisture lost to the air and restoring freshness and crispness to the leaf. As well as extending the shelf life of the vegetable, this method contributes to reducing food waste.

Figure 1. Wilting leafy green vegetables can be revived by immersing them in cold water.

Credit: Penpak Ngamsathein, Getty Images

Overview (/study/app/bio/sid-422-cid-755105/o

If left in cold water for too long, the leaves may become soggy and mushy in texture, so it is important that they are only immersed for a few minutes.

Why and how does water move into the leaf? Why does over immersing a leaf cause an undesirable texture?

Creativity, activity, service

Strand: Service
Learning objective: Demonstrate engagement with issues of global significance

Food waste is a pressing global issue that has significant social, economic and environmental consequences. According to the Food and Agriculture Organization of the United Nations, 1.3 billion tonnes of edible food is wasted every year (https://www.fao.org/news/story/en/item/196402/icode/). This waste not only contributes to hunger and food insecurity, but it also squanders valuable resources and exacerbates environmental problems.

Host a panel discussion on practical ways to reduce food waste and promote a more sustainable future, both locally and globally.

Prior learning

Before you study this subtopic make sure that you understand the properties of water (see subtopic A1.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43193/)).

Practical skills

Once you have completed this subtopic, you can gain application of skills for measuring changes in tissues by going to Practical 2: Investigating the osmolarity of plant tissues (/study/app/bio/sid-422-cid-755105/book/investigating-the-osmolarity-of-plant-tissues-id-46693/).

D2. Continuity and change: Cells / D2.3 Water potential

Solvent properties of water

D2.3.1: Solvation with water as the solvent D2.3.2: Water movement from less to more concentrated solutions D2.3.3: Water movement by osmosis into or out of cells

Learning outcomes

By the end of this section you should be able to:

- Explain how water is able to dissolve many substances.
- Explain the movement of water from less concentrated to more concentrated solutions.
- Predict the net movement of water based on the environment of a cell.

Student view

Overview (/study/app/422-cid-755105/o

Water is often termed the 'universal solvent' because of its ability to dissolve so many other molecules. But how does water dissolve solutes? And how does the presence of dissolved solutes affect the movement of water?

Water as a solvent

As explained in section A1.1.1–3 (/study/app/bio/sid-422-cid-755105/book/structure-of-water-id-43194/), a water molecule contains two hydrogen atoms covalently bonded to one oxygen atom. Oxygen is more electronegative than hydrogen, which causes the shared pair of electrons to be pulled slightly closer to the oxygen atom. This results in a slight negative charge on the oxygen, and a slight positive charge on the hydrogen atoms. For this reason water is a dipolar molecule.

Hydrogen bonds form between water molecules due to the weak electrostatic attraction between the slightly positively charged hydrogen atom of one water molecule, and the slightly negatively charged oxygen atom of another. Large networks of hydrogen bonds result in the unique properties of water, such as its high specific heat capacity (see section A1.1.4–5 (/study/app/bio/sid-422-cid-755105/book/interactions-with-water-id-43195/)).

Nature of Science

Aspect: Theories

Hydrogen bonds are relatively weak in comparison to ionic and covalent bonds, and they are constantly forming and breaking. This makes them difficult to detect and measure.

Scientists have developed various indirect experimental techniques and theoretical models that strongly support the existence of hydrogen bonds in water based on their ability to explain the properties of water and its behaviour at a molecular level.

It was not until 2017 that scientists directly detected hydrogen bonds for the first time. Read more here (https://www.sciencealert.com/hydrogen-bonds-have-been-directly-detected-for-the-first-time).

Ions are atoms that have either lost or gained electrons, and as a result they have either a positive or negative charge. If the force of attraction between ions and water molecules is greater than the force of attraction between oppositely charged ions, water has the ability to dissolve the substance. When an ionic compound is introduced into water, the slightly positively charged hydrogen atoms of water will be attracted to the negative ions and the slightly negatively charged oxygen atoms will be attracted to the positively charged ions. As a consequence, water molecules surround the ions, creating hydration shells (**Figure 1**). The presence of these hydration shells leads to the separation of solute particles and their uniform distribution throughout the solution, a process called dissolution.

Student view

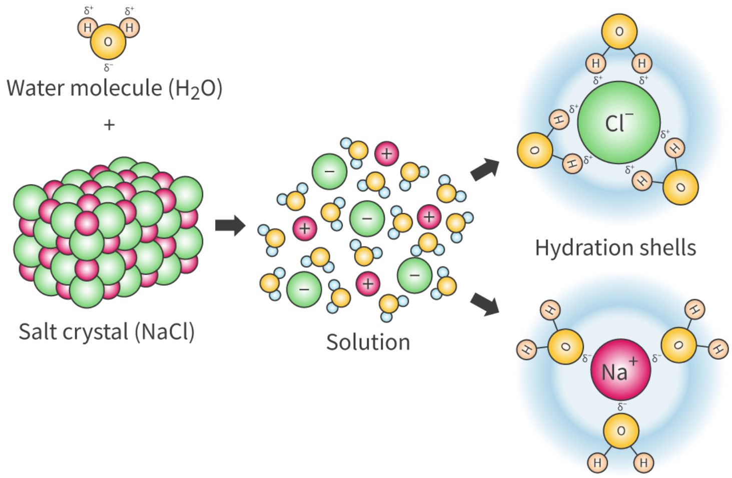


Figure 1. The attraction of multiple water molecules to ions of sodium and chlorine allows the water to overcome the attraction between sodium and chlorine, forming hydration shells around these ions, leading to their dispersal and dissolution.

More information for figure 1

The image is a diagram illustrating the process of water dissolving a salt crystal and forming hydration shells around ions. It is divided into several sections:

1. **Top Left:** Depicts a single water molecule (H_2O). The oxygen is shown with a slight negative charge (δ-) and the hydrogens with slight positive charges (δ+).
2. **Middle Left:** Displays a salt crystal (NaCl) as a cluster of red and green spheres representing sodium and chlorine ions, respectively.
3. **Center:** Shows the process where salt dissolves into a solution, with sodium (Na^+) and chloride (Cl^-) ions separating. Small water molecules, represented by two hydrogen atoms linked to an oxygen, surround these ions.
4. **Top Right:** Displays a hydration shell around a chloride ion (Cl^-). Water molecules orient with hydrogen atoms facing the Cl^- ion due to the attraction of opposite charges.
5. **Bottom Right:** Illustrates a hydration shell around a sodium ion (Na^+). Here, water molecules orient with oxygen atoms facing the Na^+ ion to neutralize the ionic charge.

Arrows between sections indicate the flow of the process, moving from a solid salt state, through dissolution, to the formation of hydration shells.

[Generated by AI]

Covalent compounds such as glucose, oxygen and alcohol can also dissolve in water by forming intermolecular interactions with the dipolar water molecules, even though they may not dissociate into ions like ionic compounds.

Substances that are soluble (able to dissolve) in water are called solutes. A substance that is able to dissolve a solute is called a solvent, and the homogenous mixture formed when a solute is dissolved in a solvent is called a solution.

Theory of Knowledge

The memory of water theory states that water can retain a 'memory' of substances it has been in contact with even after it has been diluted to a point of no longer containing any of the previously diluted substances. This theory is based on work carried out in the late 1980s by an immunologist named Jacques Benveniste.

Overview (/study/app/bio/sid-422-cid-755105/o

Numerous studies have attempted to replicate this investigation, but have failed to provide evidence to support Benveniste's findings. For this reason, the memory of water is widely regarded to be pseudoscience because the theory is presented as scientific, but lacks empirical evidence, scientific rigour and adherence to established scientific principles.

Water movement from less concentrated to more concentrated solutes

The attraction between water and dissolved solutes causes water to move from regions of lower solute concentration to regions of higher solute concentration.

If two regions are separated by a selectively permeable membrane, across which water can move but a solute cannot, for example due to its size or charge (see sections B2.1.4–5 (/study/app/bio/sid-422-cid-755105/book/membrane-proteins-and-their-functions-id-44638/) and B2.1.6–8 (/study/app/bio/sid-422-cid-755105/book/facilitated-diffusion-and-active-transport-in-id-44644/)), water will move across the membrane by osmosis (see sections B2.1.4–5 (/study/app/bio/sid-422-cid-755105/book/membrane-proteins-and-their-functions-id-44638/)), until both solutions have equal solute concentrations, resulting in a state of dynamic equilibrium.

A solution with a higher solute concentration (a higher osmotic concentration or osmolarity) is referred to as hypertonic, while a solution with a lower solute concentration (a lower osmolarity) is called hypotonic. Water always flows from a hypotonic solution to a hypertonic solution until they become isotonic, having the same solute concentration (**Figure 2**).

Note that the terms hypertonic and hypotonic are relative terms when comparing two solutions to allow us to understand the direction of water movement and the resulting effect on cells.

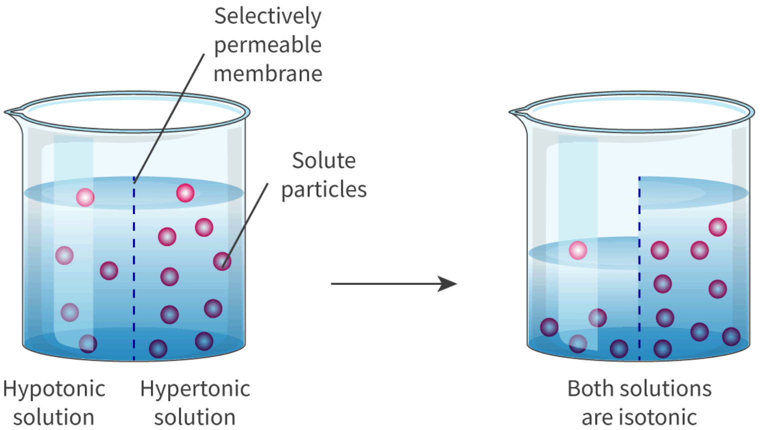


Figure 2. Water moves by osmosis from a hypotonic solution to a hypertonic solution.

More information for figure 2

The image is a diagram illustrating the process of osmosis between two beakers. The beaker on the left is divided by a selectively permeable membrane. The left side of the beaker contains a hypotonic solution with fewer solute particles, represented by fewer purple dots. The right side contains a hypertonic solution with more solute particles, shown by a higher concentration of purple dots. An arrow indicates the movement of water from the hypotonic to the hypertonic side. The beaker on the right demonstrates that both solutions become isotonic, with an equal distribution of solute particles across the membrane.

[Generated by AI]

Student view

Overview (/study/app/bio/sid-422-cid-755105/o

Water movement by osmosis into or out of cells

Water moves across cell membranes by osmosis (see sections B2.1.4–5 (/study/app/bio/sid-422-cid-755105/book/membrane-proteins-and-their-functions-id-44638/)). Osmosis is the movement of water molecules across a selectively permeable membrane from an area of lower solute concentration to an area of higher solute concentration. Osmosis is a specific type of diffusion. Diffusion is the general process of particle movement from an area of higher concentration to an area of lower concentration, not necessarily involving water or a membrane.

If a cell is placed in a hypertonic solution, where there is a higher solute concentration, there will be a net movement of water out of the cell and into the surrounding solution. This leads to the cell shrinking and becoming crenated if it is an animal cell, or undergoing plasmolysis if it is a plant cell.

If a cell is placed in a hypotonic solution, where there is a lower solute concentration, there will be a net movement of water from the solution into the cell, causing it to swell. If the cell is an animal cell it may burst if too much water moves into the cell, a process called lysis.

The effect of water movement on plant and animal cells will be covered later in this subtopic.

If a cell is placed in an isotonic solution, there will be equal movement of water into and out of the cell, resulting in a state called dynamic equilibrium (**Figure 3**). There will be no change in the shape or size of a cell in an isotonic solution.

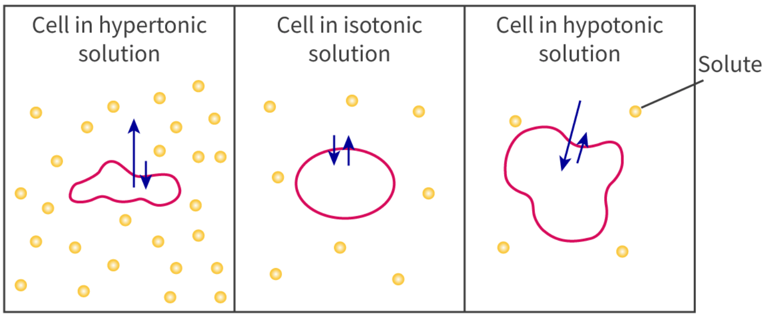


Figure 3. If a cell is placed in a hypertonic solution (higher solute concentration compared with the cell), there will be a net movement of water out of the cell. If placed in an isotonic solution (of equal solute concentration to the cell), there will be equal movement of water into and out of the cell. If a cell is placed into a hypotonic solution (lower solute concentration compared with the cell), there will be a net movement of water into the cell.

More information for figure 3

The diagram illustrates the behavior of cells when placed in different types of solutions. There are three sections labeled:

1. "Cell in hypertonic solution" - A pink outline of a cell is surrounded by numerous yellow circles representing solute molecules. Blue arrows indicate the net movement of water out of the cell due to the higher concentration of solutes outside. The cell appears shrunk.
2. "Cell in isotonic solution" - The cell is surrounded by an equal distribution of yellow solute molecules both inside and outside. Small blue double-headed arrows indicate that water moves equally in and out, maintaining the cell's shape.
3. "Cell in hypotonic solution" - The cell is depicted with a larger, expanded pink outline, with fewer yellow solute molecules outside than inside. A blue arrow indicates that water moves into the cell, causing it to swell.

The diagram provides a visual explanation of how cells interact with solutions of different solute concentrations, demonstrating concepts of osmotic movement across cellular membranes.

Student view

Overview (/study/ap 422- cid- 755105/o

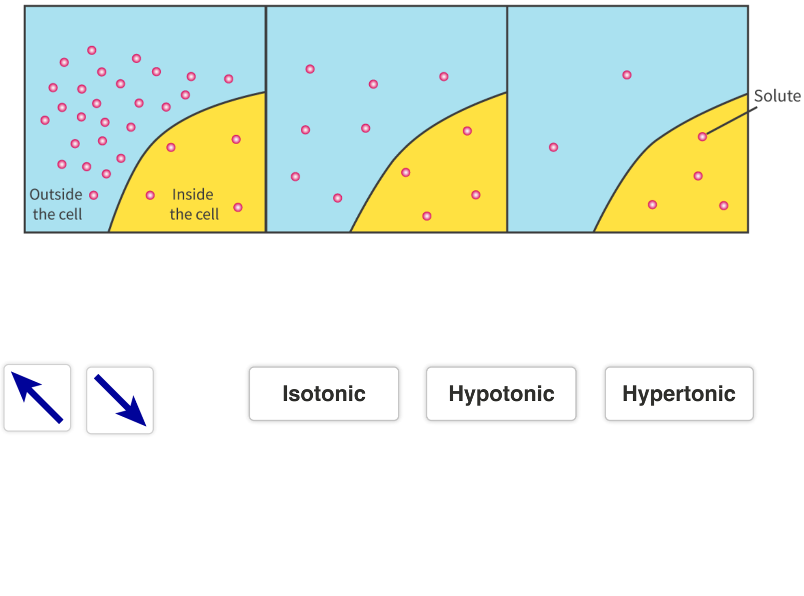
[Generated by AI]

Try this drag and drop activity to test your understanding of water movement between solutions of different concentrations of solute.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 10 minutes
- **Activity type:** Individual activity

Look at the images in **Interactive 1.**



Interactive 1. Water movement in solutions.

For each image:

1. Label the solution as hypertonic, hypotonic or isotonic
2. Place an arrow to show the net direction of water movement.
3. Write a short paragraph (on paper) explaining the direction of movement of water.

5 section questions

Student view

Movement of water into and out of cells

Learning outcomes

By the end of this section you should be able to:

- Outline the changes that occur to plant tissues bathed in hypotonic and hypertonic solutions.
- Explain the effects of water movement into and out of cells on cells that lack a cell wall.
- Explain the effects of water movement into and out of cells on cells that have a cell wall.
- Outline medical applications of isotonic solutions.

The solute concentration of a solution can cause water to move towards or away from a cell. What happens to a cell bathed in a solution that is not isotonic to the cell?

Water movement in plant tissue bathed in hypotonic and hypertonic solutions

It is possible to determine the isotonic solute concentration of a plant tissue – the solute concentration at which there would be no net movement of water into or out of the tissue. To do this, we measure the percentage change in tissue mass and length of plant tissue placed in different concentrations of a solution (**Figure 1**).

When bathed in hypertonic solutions, plant tissue loses water due to osmosis (see section B2.1.4–5 (/study/app/bio/sid-422-cid-755105/book/membrane-proteins-and-their-functions-id-44638/)), resulting in a loss in length and mass. When bathed in hypotonic solutions, plant tissue gains water due to osmosis, resulting in an increase in length and mass.

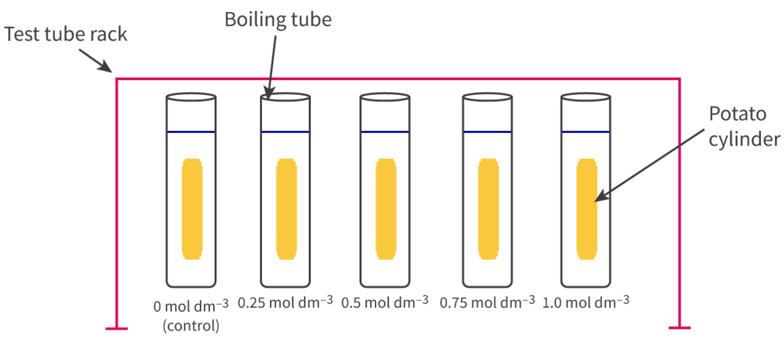


Figure 1. Plant tissue (potato cylinders) bathed in solutions of different concentrations. Changes in mass and length are then measured and used to determine the isotonic solute concentration of that plant tissue.

More information for figure 1

The image is a diagram showing a test tube rack holding five boiling tubes, each containing a potato cylinder immersed in a solution. The solutions are labeled with different molar concentrations: 0 mol dm⁻³ (control), 0.25 mol dm⁻³, 0.5 mol dm⁻³, 0.75 mol dm⁻³, and 1.0 mol dm⁻³. Each tube is marked with a horizontal line to indicate the solution level. Above each tube, labels point to the test tube rack and one of the boiling tubes, while another label indicates the potato cylinder's position within the tubes.

[Generated by AI]

The mass and/or length of pieces of plant tissue of the same size and shape are measured. The tissue will then be placed in different solute concentrations for a set period of time. They are then removed from the solution and patted dry. Their mass and/or length after immersion will be determined, and the percentage change in mass and/or size will be calculated to compare the data.

Once collected, the data can be plotted on a graph (**Figure 2**), and interpolation of the graph can be used to estimate the solute concentration where the plant tissue experiences no change in mass or length.

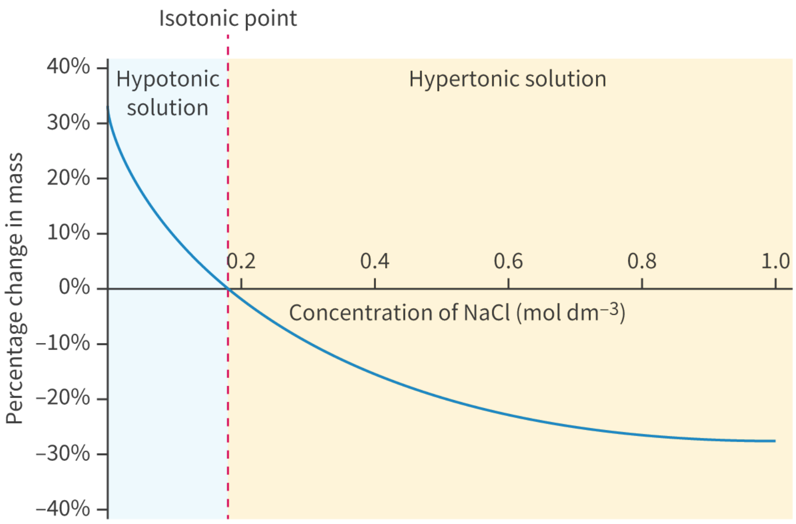


Figure 2. The percentage change in mass of plant tissue in different concentrations of NaCl.

More information for figure 2

The graph illustrates the percentage change in mass of plant tissue in relation to different concentrations of NaCl, ranging from 0 to 1.0 mol dm⁻³. The X-axis represents the concentration of NaCl in mol dm⁻³, with markers at 0.2, 0.4, 0.6, 0.8, and 1.0. The Y-axis shows the percentage change in mass, from -40% to 40%. A curve on the graph shows a declining trend in mass change as NaCl concentration increases. At lower concentrations, in the hypotonic solution, there is a higher increase in mass, decreasing towards the isotonic point. Past the isotonic point, where there's no change, mass begins to decrease in the hypertonic solution zone. Point 0.2 on the X-axis, near the hypotonic side, is highlighted by a dashed line labeled 'Isotonic point'.

[Generated by AI]

Video 1 explains this practical. (Note that the video uses the term ‘water potential’ which SL students do not need to know.)

Video 1. Determining the isotonic point of potato tissue.

Taking repeat measurements for each concentration will allow you to determine whether your data are reliable, and will provide you with the data to calculate standard deviation and standard error, which can be used in the analysis of your data (see section 1.5.4 (/study/app/bio/sid-422-cid-755105/book/data-analysis-id-46700/) for data processing).

Standard deviation is a measure of the variability (spread) of a data set relative to the mean within a data set. A high standard deviation indicates that there is higher variability in the data set, whereas a low standard deviation indicates that there is lower variability in the data set.

Standard error is a measure of the variability (spread) between multiple data sets. This can be used to determine how precise the data are, where a data set with a low standard error has a higher precision than a data set with a high standard error. Standard error is often shown graphically as error bars.

Watch **Video 2** for an explanation of the difference between standard deviation and standard error.

Video 2. Standard deviation and standard error.

Changes due to water movement in plant tissue bathed in hypotonic and hypertonic solutions will be covered in more detail in the Investigation (/study/app/bio/sid-422-cid-755105/book/investigation-id-46229/) at the end of this subtopic.

Overview (/study/ap 422- cid- 755105/o

Effects of water movement on cells without a cell wall

In a hypotonic medium, where the concentration of solutes outside the cell is lower than the concentration of solutes inside the cell, water will move into the cell by osmosis (**Figure 3**). The influx of water causes the cell to swell.

If the cell lacks a cell wall it can reach a point when it bursts, or undergo lysis due to increased internal pressure.

When placed in a hypertonic solution, where the solute concentration outside the cell is higher than the solute concentration inside the cell, water will leave the cell by osmosis. This leads to the cell shrinking and crenating due to the loss of water. This can affect the cell structure and function, potentially leading to cellular damage.

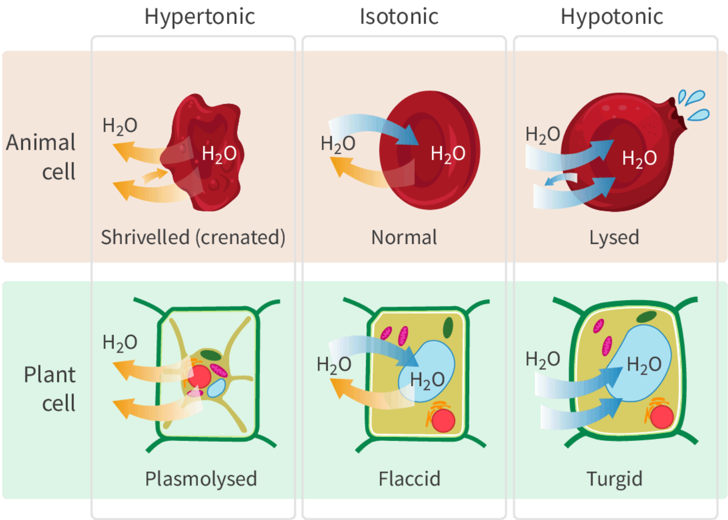


Figure 3. Animal and plant cells in hyper-, iso- and hypotonic solutions.

More information for figure 3

The diagram illustrates the effects of hypertonic, isotonic, and hypotonic solutions on animal and plant cells. It is divided into three sections based on the type of solution: hypertonic, isotonic, and hypotonic.

For animal cells: - In a hypertonic solution, the animal cell is shriveled (crenated) due to water leaving the cell. Water molecules are depicted flowing outwards. - In an isotonic solution, the animal cell remains normal with no net movement of water. - In a hypotonic solution, the animal cell is lysed as it bursts due to excessive water intake.

For plant cells: - In a hypertonic solution, the plant cell is plasmolyzed as water leaves the cell. The cell membrane pulls away from the cell wall. - In an isotonic solution, the plant cell is flaccid with balanced water movement in and out. - In a hypotonic solution, the plant cell becomes turgid as it fills with water, pressing against the cell wall.

[Generated by AI]

To prevent excessive water intake, certain freshwater unicellular organisms such as *Paramecium* and *Amoeba* have evolved specialised structures called contractile vacuoles to survive their hypotonic environments. These vacuoles actively expel water from the cell to maintain a correct intracellular solute concentration and prevent cellular bursting. This is shown in **Figure 4** and **Video 3**.

Student view

Overview
(/study/app/bio/sid-422-cid-755105/o

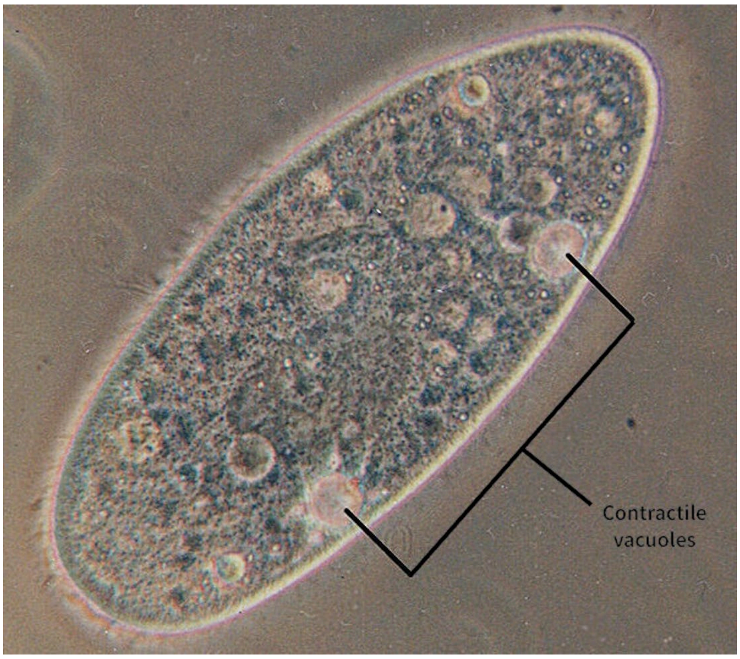
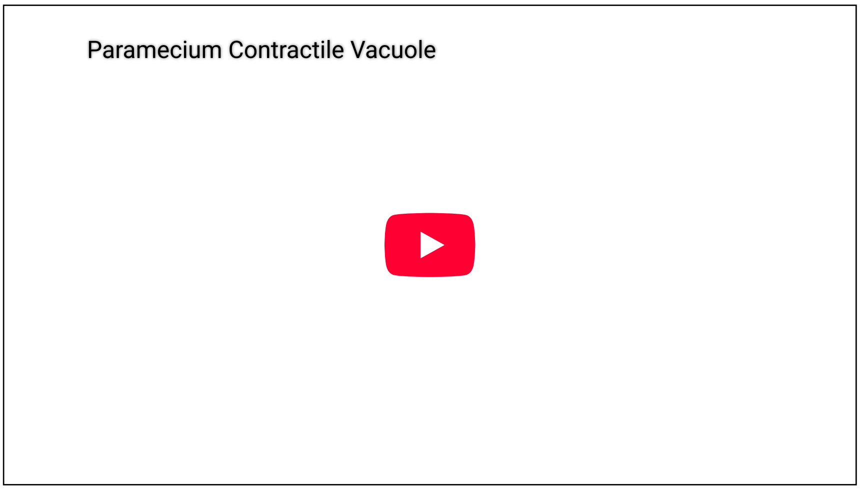


Figure 4. *Paramecium* are single-celled organisms that use contractile vacuoles to survive in hypotonic freshwater conditions.



Video 3. *Paramecium* contractile vacuole.

More information for video 3

Imagine a tiny, single-celled organism called a Paramecium living in freshwater. Because the water outside is different from inside, the Paramecium has a special part called a contractile vacuole to help it stay balanced.

This video uses close-up views to show you how this works. First, you'll see star-like channels, called radiating canals, reaching out like tiny arms. These canals collect extra water that has seeped into the Paramecium. As they gather water, they get bigger and the water flows into a central, round sac — the contractile vacuole itself. It fills up and looks like a clear, circular bubble.

This bubble suddenly squeezes down and disappears! This action pushes the extra water out of the Paramecium and into the surrounding water.

This whole process of the canals filling, the round vacuole swelling, and then quickly shrinking repeats over and over again at a steady pace. It's like a tiny pump that constantly removes extra water.

This amazing system helps the Paramecium stay the right size and prevents it from taking in too much water and bursting. By visualizing this process up close, you can understand how even tiny living things have incredible ways to survive in their environment.

Student view

Overview (/study/app/bio/sid-422-cid-755105/o

For multicellular organisms, maintaining isotonic tissue fluids is crucial to prevent harmful changes. Each cell within the organism needs to be in an environment with an equal concentration of solutes to maintain proper functioning. Any deviation from isotonicity can lead to adverse effects on cellular processes and overall health. The kidney is an example of an organ that plays a vital role in maintaining isotonic tissue fluids (see section D3.3.7–8 (/study/app/bio/sid-422-cid-755105/book/excretion-hl-id-46231/)).

Effects of water movement on cells with a cell wall

Animals and plants are eukaryotic (see section A2.2.4–6 (/study/app/bio/sid-422-cid-755105/book/prokaryotic-and-eukaryotic-cells-id-43583/)). Unlike animal cells, plant cells contain a cell wall (see section A2.2.8–11 (/study/app/bio/sid-422-cid-755105/book/animal-plant-and-fungal-cells-id-44719/)). When a plant cell is placed in a hypotonic solution, water will move into the cell by osmosis. As water enters, it accumulates within the cell leading to an increase in internal pressure. This internal pressure, known as turgor pressure in plant cells, is exerted by the cytoplasm against the rigid cell wall. The presence of the cell wall prevents the cell from bursting and ensures the cell maintains its shape. The cell is referred to as turgid (**Interactive 1**).

In a hypertonic solution, water will exit the plant by osmosis. As water leaves, the cell membrane will shrink away from the cell wall in a process called plasmolysis. The loss of water causes the cell to shrink and lose turgor pressure. In extreme cases, plasmolysis can lead to irreversible damage of plant cells. These two states can be compared using the slider in **Interactive 1**.

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/solvent-properties-of-water-id-46196/print/) Assign

Interactive 1. Effects of Water Movement on Onion Epidermis Cells.

More information for interactive 1

Student view

Overview
(/study/ap
422-
cid-
755105/o

The interactive illustrates how plant cells (specifically onion epidermis cells) respond to hypotonic and hypertonic solutions through osmosis, highlighting the crucial role of the cell wall in maintaining structure and preventing rupture. It features a comparative microscopic image showing onion epidermis cells in two states: turgid (left), and plasmolysed (right). The left and right images can be viewed using a slider. The comparison reinforces the cause-and-effect relationship between solute concentration and cell structure.

The first image (left) is titled "Turgid onion epidermis cell". The cells are in a hypotonic solution (lower solute concentration outside than inside) and are turgid due to water uptake. Cells appear plump, with clear rectangular shapes. The central vacuole is swollen, pushing cytoplasm against the cell wall and the nuclei are visible at the edges. Cell walls maintain a rigid structure and prevent bursting. Turgidity provides mechanical support to plant tissues.

The second image (right) is titled "Plasmolysed onion epidermis cell." The cells are in a hypertonic solution (higher solute concentration outside than inside). Cells appear wrinkled, the cell membrane detaches from the cell wall and the vacuole is shrunk. Gaps between the cell wall and the membrane are visible. Loss of turgor pressure leads to wilting. Extreme plasmolysis can cause irreversible damage (cell death).

This interactive effectively contrasts how plant cells respond to osmotic challenges, emphasizing the protective role of the cell wall.

Medical applications of isotonic solutions

Organs and tissues intended for transplantation are typically bathed or preserved in a specialised solution. These solutions have been carefully formulated to provide optimal conditions to protect the organ or tissue against damage, provide the organ with the necessary nutrients and oxygen, and prevent the loss or gain of water by osmosis. To prevent the loss or gain of water, it is essential that the solution is isotonic to the cytoplasm of the cells of the tissue or organ. This helps to protect against harm that may be caused by water loss or gain, reducing the risk of damage and increasing the likelihood of a successful transplantation.

Isotonic fluids may be given intravenously (administered directly into a vein) (**Figure 5**). This allows rapid and direct absorption of medications, fluids or nutrients into the circulatory system, bypassing the digestive system. Fluids may be given intravenously in medical settings to replace lost fluids, administer drugs, transfuse blood and to administer nutrients.

Figure 5. Saline solutions are isotonic to blood and tissue fluid, meaning they do not disrupt the osmotic balance of cells.
Credit: whitbalance.oatt, Getty Images

International Mindedness

According to the World Health Organization (https://www.who.int/news-room/fact-sheets/detail/drinking-water#:~:text=In%202020%2C%2074%25%20of%20the,needed%2C%20and%20free%20from%20contamination.), over 2 billion people worldwide use a drinking water source contaminated with faeces, pathogenic bacteria and

Student
view

Overview
(/study/ap
422-
cid-
755105/o

harmful chemicals. This situation poses a significant public health issue that can lead to the spread of diseases such as cholera and typhoid fever, along with many other health problems. These health risks disproportionately affect vulnerable populations including those in low-income and developing countries. Addressing water inequality requires implementation of water treatment processes, promoting hygiene practices and enhancing wastewater management.

Try the activity to help you understand the effects of placing red blood cells in solutions of differing concentrations.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Combining different ideas in order to create new understandings
- **Time required to complete activity:** 15 minutes
- **Activity type:** Individual activity

Red blood cells were placed in different concentrations of sodium chloride solution. **Figure 6** shows the percentage of cells that haemolysed (ruptured) at different concentrations. While the terms lysis and cytolysis are used generally to describe the rupture of animal cells that occurs when they are placed in hypotonic solutions, haemolysis refers more specifically to the rupture of red blood cells placed in hypotonic solutions, and the subsequent release of haemoglobin into the surrounding solution.

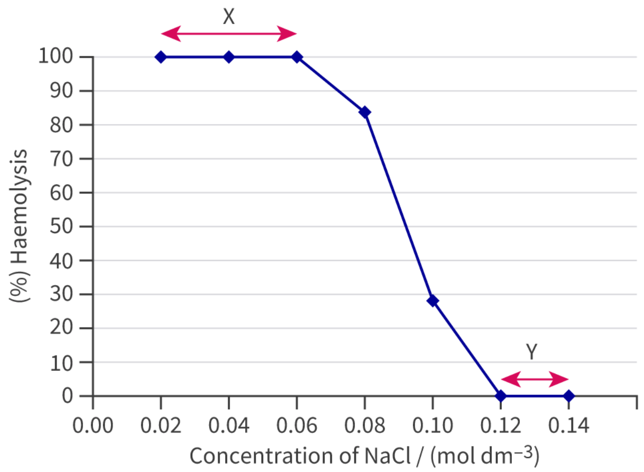


Figure 6. Percentage haemolysis of red blood cells at different concentrations of sodium chloride solution.

More information for figure 6

The image is a line graph depicting the percentage of haemolysis of red blood cells against varying concentrations of sodium chloride solution. The horizontal axis (X-axis) represents the concentration of NaCl in mol/dm³, ranging from 0.00 to 0.14. The vertical axis (Y-axis) indicates the percentage of haemolysis, ranging from 0% to 100%.

Data points plotted on the graph show that up to a concentration of approximately 0.08 mol/dm³, the percentage of haemolysis remains at 100%, indicating full haemolysis. As the concentration increases beyond 0.08 mol/dm³, the percentage of haemolysis sharply decreases, reaching 0% at 0.12 mol/dm³ and remaining there as the concentration increases to 0.14 mol/dm³.

This trend suggests that red blood cells are fully haemolysed in lower concentrations of NaCl, but as the solution becomes more concentrated, the cells become less likely to haemolyse.

[Generated by AI]

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Study **Figure 6** and answer the questions below:

1. Explain what has happened to cells at point X.
2. Explain why red blood cells rupture, but palisade mesophyll cells would not.
3. Suggest what would happen to a cell placed in a solution of 5 mol dm^{-3} NaCl. Explain your answer.
4. What measures could be taken to prevent or minimise haemolysis during medical procedures involving blood samples? Provide at least two strategies and explain their effectiveness.

5 section questions

D2. Continuity and change: Cells / D2.3 Water potential

Water potential (HL)

D2.3.8: Potential energy of water per unit volume (HL) D2.3.9: Movement of water from higher to lower water potential (HL) D2.3.10: Solute potential and pressure potential (HL) D2.3.11: Water potential and water movements in plant tissue (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Define the term water potential.
- Explain the direction that water moves in terms of water potential.
- Explain how solute potential and pressure potential affect the water potential within cells.
- Explain the changes that occur when a plant tissue is bathed in either a hypotonic or hypertonic solution in terms of solute and pressure potentials.

What is water potential? What determines water potential? How can we use water potential to explain the movement of water?

Water potential as the potential energy of water per unit volume

Water potential is a measure of the potential energy of water per unit of volume of water, relative to the potential energy of pure water at standard conditions (atmospheric pressure and 20 °C). Water potential is usually measured in kilopascals (kPa), and in some cases it may be expressed in bars, with one bar equal to 100 kPa. Pure water in standard conditions has a water potential of 0 kPa, which is the highest possible water potential. As water potential becomes more negative, it becomes harder for water to move (**Figure 1**).

Student
view

Overview
(/study/ap
422-
cid-
755105/o

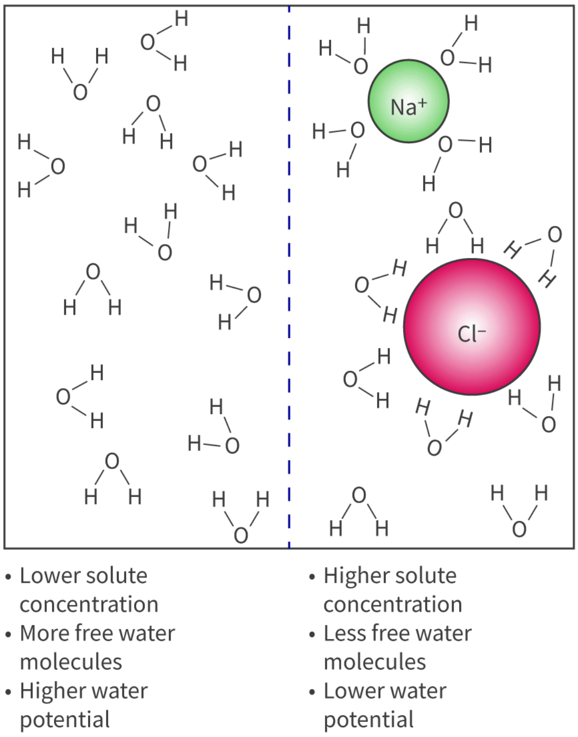


Figure 1. The presence of solute particles attracts water molecules, decreasing the number of free water molecules and decreasing water potential.

More information for figure 1

The diagram illustrates two sections separated by a dashed blue line. On the left side, labeled 'Lower solute concentration,' there are more free water molecules, represented by H_2O molecular structures, and it is indicated that this side has a higher water potential. On the right side, labeled 'Higher solute concentration,' there are fewer free water molecules as they are depicted interacting with solute particles, specifically a green Na+ ion and a larger pink Cl- ion. This side is associated with a lower water potential. The text below summarizes these conditions: Left section - Lower solute concentration, More free water molecules, Higher water potential. Right section - Higher solute concentration, Less free water molecules, Lower water potential.

[Generated by AI]

Water potential is influenced by solute potential and pressure potential and can be calculated using the equation:

$$\Psi_w = \Psi_s + \Psi_p$$

Where:

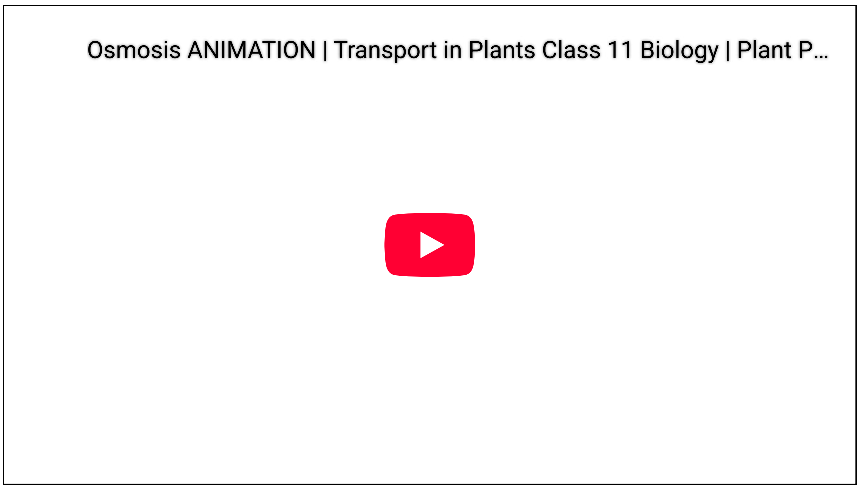
- Ψ_w is water potential
- Ψ_s is solute potential
- Ψ_p is pressure potential.

Solute potential refers to the attraction of water molecules to solute particles, which, when present, reduces the number of free water molecules and limits the movement of water.

Video 1 and this animation (https://contrib.pbslearningmedia.org/WGBH/arct15/SimBucket/Simulations/osmosis/content/index.html) show the attraction between solute particles and water molecules, decreasing the number of free water molecules and decreasing water potential.

Student
view

Overview
(/study/app/bio/sid-422-cid-755105/o



Video 1. Osmosis explained.

Pressure potential relates to the physical pressure exerted on a system. Pressure potential can be positive and is exerted outwards from a cell, such as the root pressure in plant root hair cells (see section B3.2.17–18 (/study/app/bio/sid-422-cid-755105/book/phloem-and-xylem-hl-id-44454/)). Pressure potential can also be negative, such as the suction exerted on water in the xylem as a result of transpiration (see section B3.2.7–10 (/study/app/bio/sid-422-cid-755105/book/transport-in-plants-id-44452/)).

Positive pressure potential increases water potential and negative pressure potential decreases water potential.

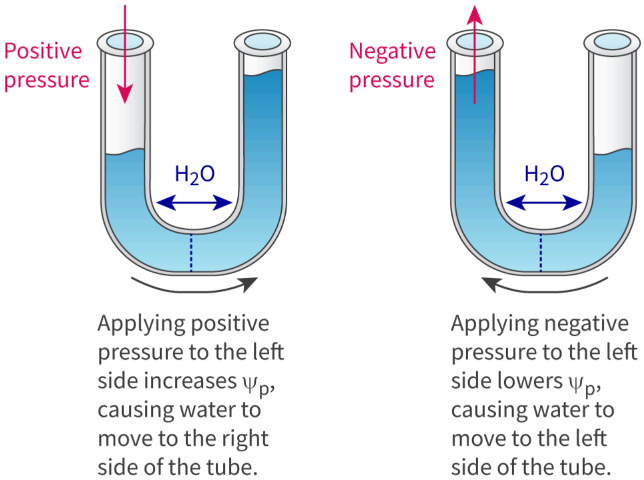


Figure 2. Positive and negative pressure potentials.

More information for figure 2

The image contains two U-shaped tubes that demonstrate the effects of positive and negative pressure on water movement. On the left, the tube shows positive pressure being applied downward from the top left, labeled as 'Positive pressure'. This increases the water potential (ψ_p), pushing water towards the right side of the tube, indicated by arrows and marked 'H_2O'. There is additional text that explains: 'Applying positive pressure to the left side increases ψ_p, causing water to move to the right side of the tube'.

On the right, the tube illustrates negative pressure being applied upwards from the top left, labeled as 'Negative pressure'. This decreases the water potential (ψ_p), causing water to shift to the left side of the tube, also shown with arrows and labeled 'H_2O'. The accompanying text reads: 'Applying negative pressure to the left side lowers ψ_p, causing water to move to the left side of the tube'.

[Generated by AI]

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Water moves by osmosis from areas of higher water potential to areas of lower water potential until equilibrium is achieved. A bigger difference between the water potential of two areas increases the speed with which water moves.

Water potential and water movements in plant tissue in hypotonic solutions

When a plant tissue is bathed in a hypotonic solution, the solute potential of the tissue is more negative than the solute potential of the solution (**Figure 3**).

As a result, water moves into the tissue, from an area of less negative solute potential to an area of more negative solute potential to equilibrate the solute potentials of the inside of the tissue and the solution.

The additional water inside the cells in the tissue causes them to apply an outward pressure called turgor pressure, which pushes the cell membrane against the cell wall. As a result the pressure potential is positive because the pressure inside the cell is higher than the pressure outside the cell.

The positive pressure potential can offset the negative solute potential, resulting in an equilibrium whereby the water potential of the tissue is equal to the water potential of the solution, maintaining the water balance of the tissue.

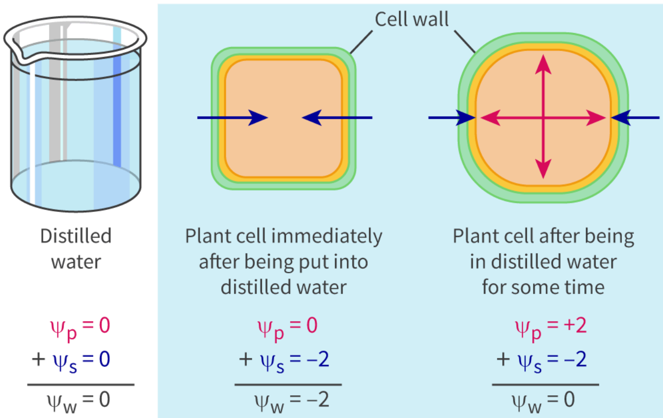


Figure 3. Plant tissue bathed in hypotonic solution will eventually reach an equilibrium where the negative solute potential is equal to the positive pressure potential.

More information for figure 3

The image is a diagram demonstrating the effect of a hypotonic solution on plant cells. On the left, there's a beaker labeled 'Distilled water' with a Ψp (pressure potential) of 0, Ψs (solute potential) of 0, and Ψw (water potential) of 0. Next to it, a plant cell is shown immediately after being placed in the distilled water. The cell, with arrows pointing inward, has a Ψp of 0, Ψs of -2, and Ψw of -2. On the right, the plant cell is depicted after being in distilled water for some time. The cell, now with arrows pointing outward, has a Ψp of +2, Ψs of -2, and Ψw of 0, indicating the equilibrium state where the positive pressure potential equals the negative solute potential.

[Generated by AI]

Because animal cells do not have cell walls (see section A2.2.8–11 (/study/app/bio/sid-422-cid-755105/book/animal-plant-and-fungal-cells-id-44719/)), they are unable to generate significant internal (turgor) pressure and therefore do not generate positive pressure potentials.

Water potential and water movements in plant tissue in hypertonic solutions

When a plant tissue is bathed in a hypertonic solution, the solute potential of the solution is more negative than the solute potential of the tissue (**Figure 4**).

Student
view

Overview
(/study/ap
422-
cid-
755105/o

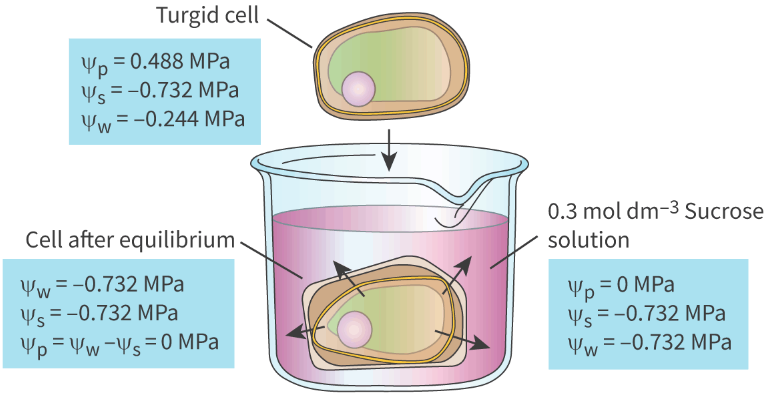


Figure 4. Plant tissue bathed in a hypertonic solution loses water due to a negative solute potential and a negative pressure potential.

More information for figure 4

The diagram illustrates the process of a plant cell placed in a hypertonic solution and the resulting changes in water potential. At the top, a turgid plant cell is shown with three key values for the cell: pressure potential (ψ_p = 0.488 MPa), solute potential (ψ_s = -0.732 MPa), and water potential (ψ_w = -0.244 MPa). Below this, the cell is depicted within a beaker containing 0.3 mol dm^{-3} sucrose solution. In equilibrium, the cell has solute (ψ_s) and water potential (ψ_w) both equal to -0.732 MPa, and pressure potential (ψ_p) at 0 MPa. Arrows indicate the movement of water out of the cell to the solution, due to the solute potential difference between the cell and the surrounding solution, leading to the cell losing turgidity.

[Generated by AI]

As a result, water moves out of the tissue, from an area of less negative solute potential to an area of more negative solute potential to try to equalise the solute potentials of the inside of the tissue and the solution.

When water leaves the cell, the volume of the cell decreases, causing a decrease in pressure in the cell relative to the solution which causes the cell membrane to detach from the cell wall. The pressure potential is negative, indicating that the pressure inside the cell is lower than the pressure outside the cell.

Because both the solute potential and the pressure potential are negative, the resulting water potential is also negative, reflecting the tendency of water to move out of plant tissues placed in hypertonic environments.

Try the activity to help with your understanding of water potential calculations.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity:** 15 minutes
- **Activity type:** Individual activity

Study the information below and then answer the questions.

A plant cell is placed in a solution. The initial pressure potential acting on the cell is 900 kPa and the solute potential is —250 kPa.

Note: The water potential of a typical plant cell ranges from 5.0000^{-7} to 0.000001 kPa.

Questions:

Student
view

Overview
(/study/ap
422-
cid-
755105/o

1. Calculate the water potential for the cell.
2. The water potential of the solution is —300 kPa. Explain whether the solution is hypertonic or hypotonic to the cell.
3. Will water move into or out of the cell? Explain your answer.
4. How will the resulting water movement affect the pressure potential in the cell?
5. After a certain time, the cell will reach a state of equilibrium. Explain equilibrium with reference to water potential.
6. How will the appearance of the cell change over time?

5 section questions

D2. Continuity and change: Cells / D2.3 Water potential

Summary and key terms

- Because of its dipolarity, water is able to dissolve many other substances. The attraction between water and dissolved solutes causes water to move by osmosis from hypotonic areas (areas of lower solute concentration) to hypertonic areas (areas of higher solute concentration), until both areas are isotonic (have equal solute concentrations).
- When a cell is placed in a hypertonic solution, there will be a net movement of water out of the cell into the surrounding solution. This can cause animal cells to decrease in size and crenate. In plant cells, this process can lead to plasmolysis, where the cell membrane shrinks away from the cell wall.
- When placed in a hypotonic solution, there will be a net movement of water into a cell, causing the cell to increase in size. The resulting increase in pressure in animal cells can lead to lysis (cell bursting). Because plant cells have a cell wall, they do not burst, and instead the build up of turgor pressure leads to the cells becoming turgid.
- When placed in an isotonic solution, there will be no net movement of water into or out of the cell. Maintaining isotonic tissue concentrations is important to ensure correct cell functioning, and for this reason, organs and tissues intended for transplantation are typically bathed or preserved in a specialised isotonic solution. It is also important that many intravenous fluids such as blood transfusions or nutritional supplementation are isotonic to the blood and body tissues.
- Changes in the mass or length of plant tissues placed in different concentrations of solutions can be used to estimate the isotonic solute concentration of plant cells.

Higher level (HL)

- Water potential is a measure of the potential energy of a solution relative to the potential energy of pure water at normal atmospheric conditions. Water moves from areas of higher water potential to areas of lower water potential until a state of equilibrium is reached where both areas have equal water potentials.
- Water potential is a sum of solute potential and pressure potential. Solute potential is a measure of the effect of solute concentration on water, where pure water has a solute potential of 0 kPa and the more concentrated a solution is, the more negative the solute potential. Pressure potential refers to the physical pressure applied on a system, and can be positive, where it is exerted outwards from a cell or system, or negative, where it is a pull or tension exerted on a cell or system.
- Plant cells placed in hypotonic solutions experience a larger negative solute potential than the solution, which will draw water into the cell. The build up of turgor pressure in the cell leads to a positive pressure potential which offsets the negative solute potential.

Student view

Overview (/study/ap 422- cid- 755105/o

- Plant cells placed in hypertonic solutions experience a smaller negative solute potential than the solution, which results in a loss of water from the cell, which reduces the pressure inside the cell, resulting in a negative pressure potential.

Key terms

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. Water moves by ______ from areas of lower solute concentration to areas of higher solute concentration until the solute concentrations on both sides of a partially permeable membrane are in ______.
2. Hypertonic solutions have ______ solute concentrations than the region they are being compared to. When a cell is placed in a hypertonic solution, water will move out of the cell into the solution. This loss of water can cause animal cells to shrink, shrivel and potentially crenate, while plant cells can undergo ______.
3. Hypotonic solutions have ______ solute concentrations than the region they are being compared to. When a cell is placed in a hypotonic solution, water will move into the cell from the solution. This influx of water can cause animal cells to swell, potentially leading to bursting or lysis. The increase in internal pressure causes plant cells to become ______.
4. [HL] Water ______ is a measure of the potential energy of water, relative to the potential energy of pure water under normal atmospheric conditions. It is calculated as a sum of the solute potential and the pressure potential.
5. [HL] Solute pressure, which determines the effect of solute ______ on the movement of water, is always a ______ value relative to pure water. The higher the solute concentration, the more negative the solute potential.
6. [HL] Pressure potential can be negative or positive. ______ pressure potentials act as a pulling force or tension, and ______ pressure potentials act as a pushing force.

turgid | concentration | plasmolysis | lower | equilibrium | negative | osmosis | positive | Negative | higher | potential

Check

Interactive 1. Key Terms in Osmosis and Water Potential.

D2. Continuity and change: Cells / D2.3 Water potential

Checklist

Student view

What you should know

After studying this subtopic you should be able to:

- Explain how water is able to dissolve many substances.
- Explain the movement of water from less concentrated to more concentrated solutions.
- Predict the net movement of water based on the environment of a cell.
- Outline the changes that occur to plant tissues bathed in hypotonic and hypertonic solutions.
- Explain the effects of water movement into and out of cells on cells that lack a cell wall.
- Explain the effects of water movement into and out of cells on cells that have a cell wall.
- Outline medical applications of isotonic solutions.

Higher level (HL)

- Define the term water potential.
- Explain the direction that water moves in terms of water potential.
- Explain how solute potential and pressure potential affect the water potential within cells.
- Explain the changes that occur when a plant tissue is bathed in either a hypotonic or hypertonic solution in terms of solute and pressure potentials.

Practical skills

Once you have completed this subtopic, go to Practical 2: Investigating the osmolarity of plant tissues (/study/app/bio/sid-422-cid-755105/book/investigating-the-osmolarity-of-plant-tissues-id-46693/) in which you will determine the effects of different solute concentrations on osmosis.

Investigation

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills – Applying key ideas and facts in new contexts
- **Time required to complete activity:** 60 minutes
- **Activity type:** Individual activity

Your task

In this investigation you will determine the isotonic solute concentration of carrot tissue. You will then determine the standard deviation and the standard error of the data collected to analyse the data. See section D2.3.4–7 (/study/app/bio/sid-422-cid-755105/book/movement-of-water-into-and-out-of-cells-id-46226/) for a reminder of how to investigate the isotonic solute concentration of plant tissue.

Overview
(/study/ap
422-
cid-
755105/o

A student follows the following method:

- Use a 1 cm diameter cork borer to make 25 cylinders of carrot tissue, ensuring that the cylinders are of approximately equal size and surface area.
- Take 25 boiling tubes, label 5 boiling tubes pure water (0 mol dm^{-3} NaCl), and 5 with each of the following pre-prepared concentrations: 0.2 mol dm^{-3} NaCl, 0.4 mol dm^{-3} NaCl, 0.6 mol dm^{-3} NaCl, 0.8 mol dm^{-3} NaCl.
- Measure and record the starting mass of each carrot piece, placing each in front of a labelled boiling tube.
- Place each carrot piece into its corresponding boiling tube. Each carrot piece is placed in its own boiling tube so that the percentage change of each, rather than an average for each concentration can be calculated. This means that anomalous results will be easier to identify and hence from the processed data.
- After 20 minutes, remove the carrot pieces and pat dry with a paper towel.
- Re-weigh each carrot piece and record the final mass.

Complete **Table 1** by calculating the missing values for percentage change in mass using the equation:

$$\frac{\text{Final value} - \text{Initial value}}{\text{Initial value}} \times 100$$

An example calculation is given below to calculate the percentage change for NaCl 0 mol dm^{-3} (Repeat 1):

$$\frac{(6.0 - 5.3)}{5.3 \times 100} = 13.2\%$$

Note that, as the starting mass and final mass are both given to one decimal place, your percentage change in mass should also be given to one decimal place.

Table 1. Raw and processed (three columns on the right-hand side columns) data table (note, 1 mol dm^{-3} = 1 M).

NaCl concentration (mol dm−3)	Repeat	Starting mass (g)	Final mass (g)	Percentage change in mass (%)	Mean percentage change in mass	Standard deviation of the mean percentage change in mass	Standard error of the mean percentage change in mass
0	1	5.3	6.0	13.2	11.3	2.0	0.89
	2	5.4	5.9	9.3			
	3	5.3	5.9	11.3			
	4	5.3	5.8	9.4			
	5	5.2	5.9	13.5			
0.2	1	5.2	5.4				
	2	5.5	5.8				
	3	5.4	5,7				
	4	5.4	5.8				
	5	5.5	5.8				

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/summary-and-key-terms-id-46227/print/) Assign

Student view

Overview
(/study/ap
422-
cid-
755105/o

NaCl concentration (mol dm−3)	Repeat	Starting mass (g)	Final mass (g)	Percentage change in mass (%)	Mean percentage change in mass	Standard deviation of the mean percentage change in mass	Standard error of the mean percentage change in mass
0.4	1	5.3	5.5				
	2	5.5	5.6				
	3	5.3	5.6				
	4	5.3	5.4				
	5	5.4	5.4				
0.6	1	5.4	5.3				
	2	5.4	5.2				
	3	5.3	5.3				
	4	5.3	5.2				
	5	5.3	5.2				
0.8	1	5.4	5.0				
	2	5.6	5.1				
	3	5.4	5.3				
	4	5.4	5.1				
	5	5.3	4.9				

Section Student… (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/movement-of-water-into-and-out-of-cells-id-46226/print/) Assign

Questions

Calculate the mean percentage change in mass for each solute concentration. The mean percentage mass for pure water (0 M NaCl) is given below:

$$\frac{(13.2 + 9.3 + 11.3 + 9.4 + 13.5)}{5} = 11.3$$

Explain why it is necessary to calculate the percentage change in mass.

Watch the **Video below** explaining standard deviation.

Student view

Overview (/study/ap 422- cid- 755105/o

Video 1. Standard deviation.

Calculate the standard deviation for each data set. You can use formulae on a spreadsheet or calculate standard deviation on your graphing calculator (https://www.wikihow.com/Find-Standard-Deviation-on-the-TI%E2%80%9384).

The standard deviation for pure water (0 mol dm^{-3} NaCl) is given below:

$$S = \sqrt{\frac{\Sigma(x - x)^2}{n - 1}}$$
$$= 2.0$$

Calculate the standard error for each data set. Refer back to **Video 2** in section D2.3.4–7 (/study/app/bio/sid-422-cid-755105/book/movement-of-water-into-and-out-of-cells-id-46226/) for a reminder of how to calculate standard error. The standard error for pure water (0M NaCl is given below:

$$\text{SE} = \frac{S}{n}$$

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/water-potential-hl-id-44813/print/) Assign

$$= \frac{2.0}{\sqrt{5}}$$
$$= 0.89$$

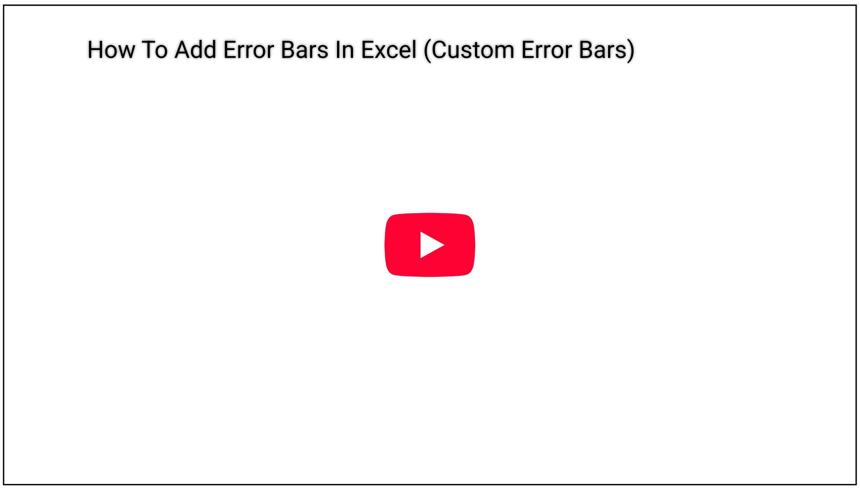
You are not required to memorise the formulas for standard deviation or standard error.

Plot a graph of NaCl concentration (mol dm^{-3}) against mean percentage change in mass (%).

Include error bars using the standard error that you have calculated in the processed data. You may find **Video 3** useful.

Student view

Overview
(/study/ap
422-
cid-
755105/o



Video 3. Adding error bars onto a graph.

Use your graph to estimate the isotonic concentration of carrot tissue.

Write a paragraph analysing your data. Consider the reliability and precision of your data.

D2. Continuity and change: Cells / D2.3 Water potential

Reflection

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/reflection-id-46895/print/) Assign

Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Reflection

Now that you've completed this subtopic, let's come back to the guiding question introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43550/).

- What factors affect the movement of water into or out of cells?
- How do plant and animal cells differ in their regulation of water movement?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?

Student
view

Overview
(/study/ap
422-
cid-
755105/o

- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

Once you submit your response, you won't be able to edit it.

0/2000

Submit

Rate subtopic D2.3 Water potential

Help us improve the content and user experience.

Student
view