D2.3 Water potential

Continuity and change—Cells

Standard level and higher level: 2 hours

Additional higher level: 2 hours

Guiding questions

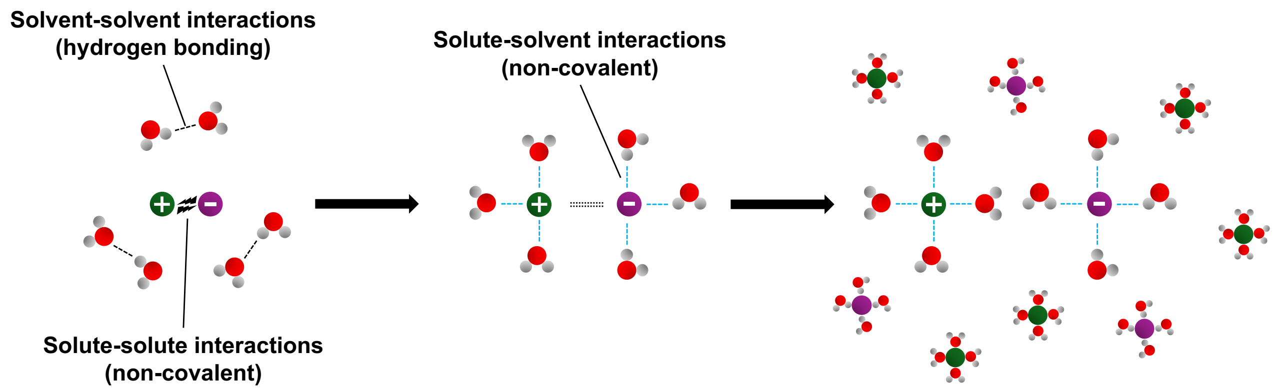
• What factors affect the movement of water into or out of cells?

• How do plant and animal cells differ in their regulation of water movement?

SL and HL

D2.3.1—Solvation with water as the solvent
Include hydrogen bond formation between solute and water molecules, and attractions between both positively and negatively charged ions and polar water molecules.

- **Solvation** is the interaction of a solvent particle with a solute particle
  - A **solvent** is the particle present in **larger** amounts within a solution
  - A **solute** is the particle present in **smaller** amounts within a solution
- Solvation depends on disrupting **solute-solute interactions** & forming **solute-solvent interactions**
  - These interactions are **non-covalent attractive forces** (hydrogen bonds & polar interactions)
  - If the attractive forces between the solvent & solute particles are greater than the attractive forces holding the solute particles together, solvent particles pull the solute particles apart & surround them
    - Surrounding solute particles with solvent particles ensures that solutes do not re-attract each other, which helps maintain a stable solution
  - A **hydration shell** is a layer of water molecules that surrounds solute particles
    - The **partially negative oxygen** atom in water faces **positively** charged atoms or ions
    - The **partially positive hydrogen** atoms in water face **negatively** charged atoms or ions
    - In a solution, water molecules that are not part of hydration shells are called **free water molecules**



D2.3.2—Water movement from less concentrated to more concentrated solutions

Students should express the direction of movement in terms of solute concentration, not water concentration. Students should use the terms "hypertonic", "hypotonic" and "isotonic" to compare concentration of solutions.

- Water moves from less concentrated to more concentrated solutions when they are separated by a **semi-permeable membrane** (e.g. cell membrane)
  - This is because solutions with high solute concentration have less free water molecules than solutions with lower solute concentration (which have more free water molecules)
  - Free water molecules move randomly in all directions, so on average, the solution with more free water molecules will have **more** random collisions with the membrane per unit time, which increases the probability of passage through the membrane
  - Thus, statistically, more water will exit the dilute side than will exit the concentrated side until both solutions reach the same solute concentration (i.e. reach **dynamic equilibrium**)
    - Free water molecules will continue to pass through the membrane even after both solutions reach dynamic equilibrium, but since the same amount of water will leave both solutions, there is **no net change in concentration or volume**
- **Tonicity** of a solution refers to its solute concentration **relative** to that of another solution on the opposite side of a semi-permeable membrane
  - A **hypertonic solution** has a **greater** solute concentration than another solution
  - A **hypotonic solution** has a **lower** solute concentration than another solution
  - An **isotonic solution** has the **same** solute concentration as another solution

D2.3.3—Water movement by osmosis into or out of cells

Students should be able to predict the direction of net movement of water if the environment of a cell is hypotonic or hypertonic. They should understand that in an isotonic environment there is dynamic equilibrium rather than no movement of water.

- **Osmosis** is **passive water movement** through membranes from **hypotonic** to **hypertonic** solutions
- Cell membranes create separate solutions (e.g. extracellular space & cytoplasm) with different concentrations whose solute levels control the direction of osmosis
  - If the extracellular environment of a cell is hypotonic, water moves into the cell
  - If the extracellular environment of a cell is hypertonic, water moves out of the cell

D2.3.4—Changes due to water movement in plant tissue bathed in hypotonic and those bathed in hypertonic solutions

Application of skills: Students should be able to measure changes in tissue length and mass, and analyse data to deduce isotonic solute concentration. Students should also be able to use standard deviation and standard error to help in the analysis of data. Students are not required to memorize formulae for calculating these statistics. Standard deviation and standard error could be determined for the results of this experiment if there are repeats for each concentration. This would allow the reliability of length and mass measurements to be compared. Standard error could be shown graphically as error bars.

- Plant tissue can change in mass & length depending on the concentration of the solution it is bathed in
  - **Hypertonic** solutions **decrease** mass & length of plant tissue due to water movement **out** of cells
  - **Hypotonic** solutions **increase** mass & length of plant tissue due to water movement **into** cells
  - **Isotonic** solutions cause **no change** in mass & length due to net zero water loss/gain
- Experiments involving bathing plant tissue in different solute concentrations should involve multiple trials (repetitions) to determine the reliability of the results by calculating standard deviation & error
  - **Standard deviation (SD)** measures how far the trials are from the mean
    - A **small SD** indicates that the plant tissue measurements are consistent
  - **Standard Error (SE)** measures how far the mean is from the true mean
    - A **small SE** indicates that the calculated mean is likely to be a precise estimate of the true mean response of the tissue at that concentration

D2.3.5—Effects of water movement on cells that lack a cell wall

Include swelling and bursting in a hypotonic medium, and shrinkage and crenation in a hypertonic medium. Also include the need for removal of water by contractile vacuoles in freshwater unicellular organisms and the need to maintain isotonic tissue fluid in multicellular organisms to prevent harmful changes.

- Cells that lack a cell wall (e.g. animal cells) only have their plasma membrane resisting changes in volume
- In a hypotonic medium, animal cells **gain water** & **swelling** occurs, which may eventually lead to **bursting** (**lysis**)
- In a hypertonic medium, animal cells **lose water** & **shrinkage** occurs, which produces a characteristic wrinkled appearance (**crenation**)
- Organisms that lack a cell wall have evolved mechanisms to regulate water movement
  - Unicellular organisms have **contractile vacuoles** that collect excess water and periodically expel it to prevent cell lysis
    - This is important for freshwater unicellular organisms that are always surrounded by water
  - Multicellular organisms have specialized organs (i.e. kidneys) for **osmoregulation**

D2.3.6—Effects of water movement on cells with a cell wall
Include the development of turgor pressure in a hypotonic medium and plasmolysis in a hypertonic medium.

- Cells with a cell wall can resist more changes in volume than those without one
- In a hypotonic medium, plant cells **gain water** & **store it in vacuoles**
  - Water storage leads to expansion of vacuoles, which presses cell contents against the cell wall
  - **Turgor pressure** is the force exerted by plant cell contents against the cell wall
  - Plant cells do not burst at high turgor pressure due to their rigid cell wall
  - Cells become **turgid** (**firm**) at high turgor pressures, which helps them maintain their shape to support plant tissue
- In a hypertonic medium, plant cells **lose water** from their vacuoles
  - This causes lower turgor pressure, which may eventually lead to **plasmolysis** (detachment of the plasma membrane from the cell wall)
  - Plasmolysis is usually fatal for the cell & leads to plant wilting if it occurs in many cells

D2.3.7—Medical applications of isotonic solutions
Include intravenous fluids given as part of medical treatment and bathing of organs ready for transplantation as examples.

- Isotonic solutions minimize water movement in or out of cells to maintain tissue integrity & health
- **Intravenous fluids** must be isotonic to maintain the integrity of blood cells & surrounding body tissue
- Organs stored for future **transplantation** must be bathed in isotonic solution to prevent damage while they are outside of the body

Additional higher level

D2.3.8—Water potential as the potential energy of water per unit volume
Students should understand that it is impossible to measure the absolute quantity of the potential energy of water, so values relative to pure water at atmospheric pressure and 20°C are used. The units are usually kilopascals (kPa).

- **Water potential (ψ)** is the potential energy of water per unit volume (units are usually **kilopascals** (**kPa**))
  - It predicts the direction of water movement between two solutions
- It is impossible to measure the absolute quantity of the potential energy of water because it is comparative (like tonicity); water potential values are relative to that of **<u>pure</u> water** at **atmospheric pressure** & **20°C**
  - The potential of pure water is, by convenience of definition, designated a value of zero (although pure water contains plenty of potential energy, that energy is ignored)
- **Solutes lower water potential** (make it more negative) because water molecules form hydration shells around solute particles, which lowers the overall energy of the solution (& thus water potential)

D2.3.9—Movement of water from higher to lower water potential
Students should appreciate the reasons for this movement in terms of potential energy.

- Water movement is from **higher** to **lower water potential**
  - This allows solutions to exist in stable (low potential) energy states at dynamic equilibrium

D2.3.10—Contributions of solute potential and pressure potential to the water potential of cells with walls
Use the equation $\psi_w = \psi_s + \psi_p$. Students should appreciate that solute potentials can range from zero downwards and that pressure potentials are generally positive inside cells, although negative pressure potentials occur in xylem vessels where sap is being transported under tension.

- Water potential in organisms is influenced mainly by 2 factors:
  - **Solute potential** (**ψ_s**): represents the effect of dissolved solutes on water potential
    - It is 0 in pure water & negative in any solution (more negative = higher solute concentration)
  - **Pressure potential** (**ψ_p**): represents the effect of turgor pressure on water potential
    - ψ_p increase when water enters the cell & decreases when it leaves
    - It is positive in plant cells because water is being compressed (i.e. exerting outward pressure)
    - It is negative in xylem vessels where sap is being transported under tension (water is being 'pulled' during transpiration)
- Thus, water potential (ψ_w) in living systems is the sum of solute (ψ_s) and pressure potentials (ψ_p):

$$\psi_w = \psi_s + \psi_p$$

D2.3.11—Water potential and water movements in plant tissue
Students should be able to explain in terms of solute and pressure potentials the changes that occur when plant tissue is bathed in either a hypotonic or hypertonic solution.

- Plant cells bathed in hypotonic solution **gain water** from the surrounding medium
  - Solute potential **increases** (becomes less negative) as water volume inside the cell increases
  - Pressure potential **increases** (becomes more positive) as turgor pressure increases from water entry
  - Water volume inside the cell continues to increase until the difference in water potential between the cell & the solution it is bathed in becomes zero
- Plant cells bathed in hypertonic solution **lose water** to the surrounding medium
  - Solute potential **decreases** (becomes more negative) as water volume inside the cell decreases
  - Pressure potential **decreases** (becomes less positive) as turgor pressure decreases due to water exit
  - Water volume inside the cell continues to decrease until the difference in water potential between the cell & the solution it is bathed in becomes zero

Linking questions

• What variables influence the direction of movement of materials in tissues?

• What are the implications of solubility differences between chemical substances for living organisms?

References

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