Water potential

D2.3 · SL and HL

Why does a potato strip become firm in one solution?

Connect dissolved particles, a membrane and a resisting wall

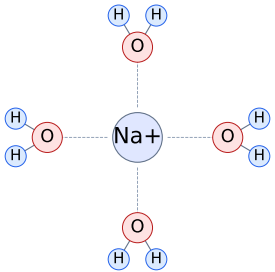
Shared D2.3 covers solvation, osmosis, cell responses, tissue investigations and isotonic applications.

AHL: develop energy per volume, signed solute/pressure components and changing plant cells.

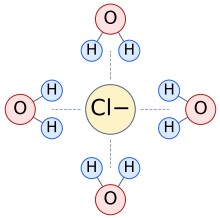
All diagrams, measurements and numerical examples are invented teaching models. Compare net movement with continuing molecular exchange.

Orient the polar water molecule around each ion

Water: O is partially negative; H is partially positive



O side toward Na+



H sides toward Cl−

O faces positive ions; H faces negative ions.

Solvation does not always mean dissociation into ions

Solute	Interaction with water
Sodium chloride	Dissolved sodium and chloride ions attract different sides of polar water
Glucose	Polar hydroxyl groups can hydrogen-bond with water
Distinction	Glucose need not split into sodium-like ions to dissolve
Solvation	Solvent molecules surround solute particles; hydration arrangements are dynamic

State the membrane and pressure assumptions before the direction

1. **Model.** Equal pressure; water-permeable membrane; solute particles do not freely cross.
2. **Direction.** Net water movement is from less concentrated toward more concentrated effective solute solution.
3. **Limit.** Both-way exchange continues. Mixing without a separating membrane also allows solute diffusion and is a different experiment.

Tonicity is a comparison relative to a cell

External medium	Expected effect under the stated model
Hypotonic	Net water entry; lower effective external solute concentration
Hypertonic	Net water loss; higher effective external solute concentration
Isotonic	No sustained net change in cell volume; balanced water exchange continues
Permeant solute	Total concentration alone may not predict tonicity
Energy	Osmosis is passive; regulating solutes or removing excess water can use energy

Connect an animal-cell volume change with its cause

1. **Hypotonic outside.** Net water entry causes swelling and can produce membrane rupture: lysis.
2. **Hypertonic outside.** Net water loss causes shrinkage; red-cell irregular shrinkage is crenation.
3. **Isotonic outside.** Volume can remain stable while exchange continues. Isotonic does not require identical chemical composition.

Freshwater organisms can balance continued entry with removal

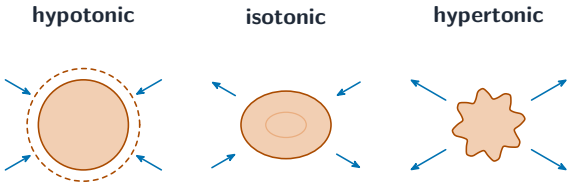
A contractile vacuole does not switch off osmosis

Freshwater can be hypotonic relative to a unicellular organism such as Paramecium.

Contractile vacuoles collect excess water and periodically expel it; energy-dependent cellular processes support removal.

The initial water entry follows an osmotic gradient. Removal allows persistence without proving that the membrane became impermeable to water.

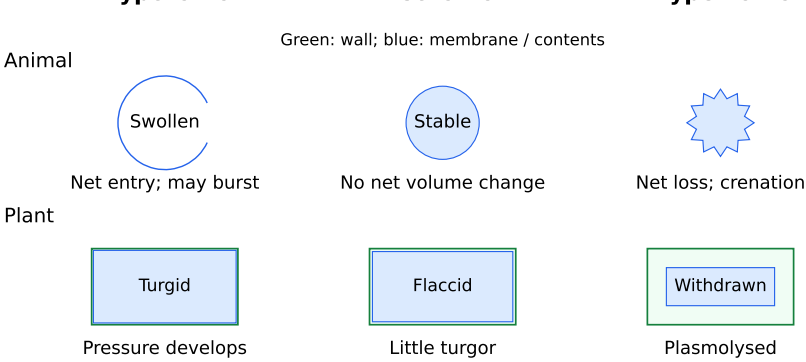
Red blood cells in different solutions



no cell wall, so no turgor and no plasmolysis; blue arrows show water movement

Hypertonic: water leaves; the cell shrinks

Compare the membrane with and without a resisting wall



Wall-supported pressure changes the result of water entry.

Name the structure before naming the osmotic condition

Plant-cell state	**Structural explanation**
Turgid	Water uptake expands contents against a resisting wall
Flaccid	Little wall-supported **turgor**; wall is still present
Plasmolysed	Membrane and shrunken contents withdraw from wall after sufficient loss
Boundary	Wall is relatively permeable; plasma membrane restricts particular solutes
Recovery	Suitable cells can regain water and turgor; damage can prevent full recovery

Independent pieces and consistent handling support a fair comparison

Control biological variation and measurement error separately

Use comparable tissue source, diameter and initial dimensions; randomly allocate independent pieces across solutions.

Control temperature, exposure time and solution volume; limit evaporation and use consistent blotting and measurement.

Repeated weighing of one piece is not another biological replicate. A tissue is not a single perfectly uniform compartment.

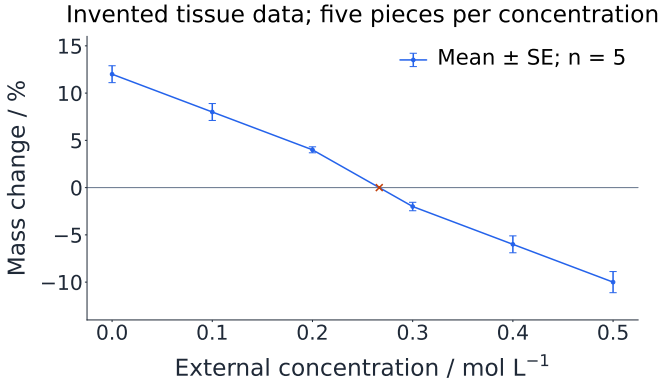
Use each sample's own initial mass as denominator

1. **Invented masses.** A: 5.00 $\rightarrow$ 5.40 g. B: 4.00 $\rightarrow$ 4.20 g.
2. **Percentage change.** $(m_{final} - m_{initial})/m_{initial} \times 100$: A $= 8\%$; B $= 5\%$.
3. **Compare.** A gained more proportionally. Surface solution left on a sample could inflate the apparent gain.

A reverse change has a different initial denominator

1. **Forward.** $3.00 \to 3.36$ g: gain $0.36/3.00 \times 100 = 12\%$.
2. **Reverse.** $3.36 \to 3.00$ g: decrease $0.36/3.36 \times 100 \approx 10.7\%$.
3. **Length.** $40.0 \to 42.0$ mm: gain $2.0/40.0 \times 100 = 5.0\%$. Mass and length percentages need not be equal.

Locate the zero crossing within the measured range



Interpolate locally; label the uncertainty bars.

Interpolate between opposite signs under a local linear model

1. **Neighbouring invented means.** $+4\%$ at 0.20 mol/L and -2% at 0.30 mol/L.
2. **Fraction across interval.** $4/(4+2) = 2/3$; crossing $= 0.20 + (2/3) \times 0.10 \approx 0.267$ mol/L.
3. **Limit.** The estimate assumes local linearity. Sample more independent pieces closer to the crossing; do not extrapolate far outside the data.

Spread and uncertainty of the mean are different

Quantity	Interpretation
SD	Spread among individual results
SE	Uncertainty in an estimated mean under the sampling model
More independent pieces	Can reduce SE without reducing biological SD
Error-bar label	State the statistic and sample size
Significance	Overlapping SE bars alone are not a complete test

Keep sample spread distinct from mean precision

1. **Invented pieces.** 3, 4, 5, 4 and 4%: mean 4%, sample SD about 0.71 percentage points.
2. **Mean uncertainty.** SE = SD / $\sqrt{n}$ ≈ 0.32 percentage points for these five independent pieces.
3. **Another sample.** SD 2.0 with n = 5 gives SE ≈ 0.89 percentage points. Repeated weighing of one piece does not make n = 5 independent pieces.

A zero mass change supports a bounded inference

The tissue method does not separately measure every cell component

No net change is consistent with a balanced overall transfer under the experimental conditions and interval.

It does not prove stopped molecular exchange, identical internal values in all cells, or separate solute and pressure measurements.

Leakage, tissue damage and inconsistent surface blotting can affect measured mass. Check the method before assigning a biological mechanism.

Apply the osmotic principle without replacing the other requirements

Application	Purpose and limit
Intravenous fluid	Appropriate effective osmotic properties help avoid damaging cell-volume shifts
Organ preservation	Controlled bathing/perfusion solutions limit osmotic damage
Composition	Isotonicity does not mean every chemical component matches cytoplasm
Other conditions	Clinical purpose, composition and preservation conditions still matter; isotonicity alone is insufficient

Solute concentration alone cannot explain every turgid cell

Use the overall tendency for water movement

Water potential compares the tendency of water to move relative to a reference; net movement is from higher toward lower potential.

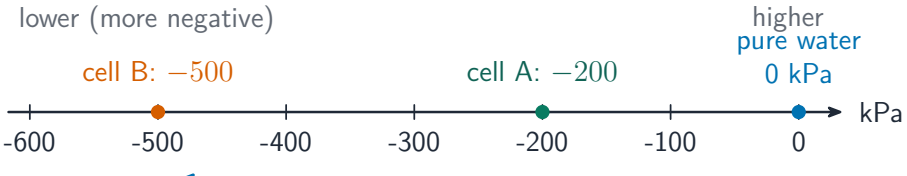
Dissolved solute lowers the tendency; pressure supported by a wall can oppose the solute effect.

A cell can stop gaining net water without identical inside/outside solute concentrations. Equilibrium still includes exchange in both directions.

Use a reference and compare signed values in the same units

1. **Reference.** Pure water at atmospheric pressure and 20°C is assigned zero. Values are relative, not absolute total molecular energy.
2. **Units.** Energy per volume has pressure units; 1 MPa = 1000 kPa.
3. **Direction.** −200 kPa is higher than −500 kPa: net movement is toward −500 along a suitable pathway. Positive pressure can raise potential above zero.

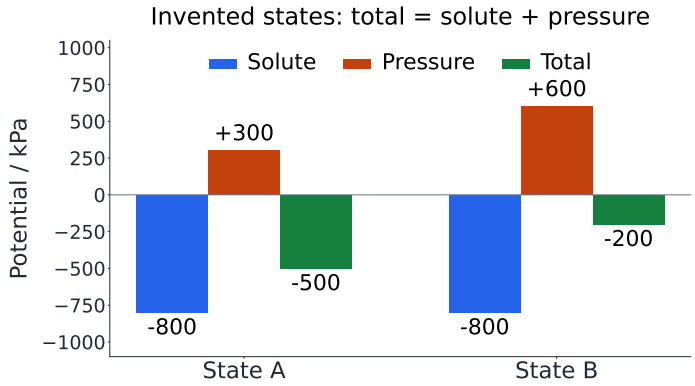
Water potential



$$1\ \mathrm{J\,m^{-3}} = 1\ \mathrm{Pa};\quad 1\ \mathrm{MPa} = 1000\ \mathrm{kPa}$$

Water moves from higher to lower: A to B

Add both signed contributions before comparing totals



Equal solute potentials need not give equal total potentials.

The pressure contribution can oppose an osmotic tendency

1. **Equation.** $\psi_w = \psi_s + \psi_p$: solute is zero or negative; pressure is generally positive in a turgid cell.
2. **Invented cell.** $-800 + 300 = -500$ kPa; outside -200 kPa gives initial net entry.
3. **Conditional balance.** At fixed solute -800 kPa, pressure $+600$ gives total -200. Actual entry can also dilute the solutes.

Rearrange while preserving the negative sign

1. **Known.** Total -350 kPa; solute -900 kPa.
2. **Pressure.** $\psi_p = \psi_w - \psi_s = -350 - (-900) = +550$ kPa.
3. **Context.** Negative pressure potentials can occur in xylem under tension. They do not represent a negative amount of water.

Water movement changes components, not only volume

Change	Typical component response in this model
Water enters	Solutes dilute; solute potential becomes less negative; pressure rises
Water leaves	Solutes concentrate; solute potential becomes more negative; pressure falls
Incipient plasmolysis	**Pressure potential** approximately zero
Equilibrium	Equal total potentials; components need not individually match
Model boundary	Use comparable height and the stated solute/pressure model

A lower internal solute potential does not guarantee entry

1. **Starting cell.** Solute -700, pressure $+400$: total -300 kPa.
2. **Outside.** -600 kPa: total cell potential is higher, so net water initially leaves.
3. **Evolution.** Pressure falls and concentration increases. Keeping both original components fixed during continued movement would contradict the changing cell.

Attempt the handout questions before checking

State the membrane, comparison and measurement

Explain solvation, tonicity, contractile vacuoles, animal and plant responses; identify medical applications.

Calculate mass/length changes and a zero crossing; distinguish SD from SE and independent pieces from repeated measurements.

AHL: convert units, add components and predict initial direction; then explain why the components can change.

Check the shared quantitative answers

1. **Mass and length.** 5.00 $\rightarrow$ 5.40 g: 8%; 4.00 $\rightarrow$ 4.20 g: 5%; reverse 3.36 $\rightarrow$ 3.00 g: 10.7% decrease. 50.0 $\rightarrow$ 47.5 mm: -5.0%.
2. **Interpolation.** $+3\%$ at 0.20 and -5% at 0.30 mol/L: $0.20 + (3/8) \times 0.10 = 0.2375$ mol/L, about 0.24.
3. **Uncertainty.** SD 2.0 percentage points with five independent pieces gives SE $\approx$ 0.89 percentage points. Label both statistic and sample size.

AHL practice: totals determine initial net movement

1. **Question 12.** -0.75 MPa $= -750$ kPa; plus 250 gives -500. Outside -300 gives entry; fixed-solute balance requires $+450$ kPa.
2. **Question 13.** A pressure $-200 - (-850) = +650$. B total $-900 + 500 = -400$ kPa; net A $\rightarrow$ B.
3. **Question 14.** Cell $-700 + 400 = -300$; outside -600 gives loss. Pressure falls and solutes concentrate; incipient-plasmolysis pressure is approximately zero.

Check yourself

Name the boundary, denominator and assumptions

Wall and membrane have different roles. Crenation and plasmolysis are different changes. Dynamic equilibrium still has exchange.

Use each initial measurement in its percentage calculation. State SD or SE, independent sample size and uncertainty in a zero crossing.

AHL: convert units and compare signed totals. A changing cell can change both pressure and solute potential.