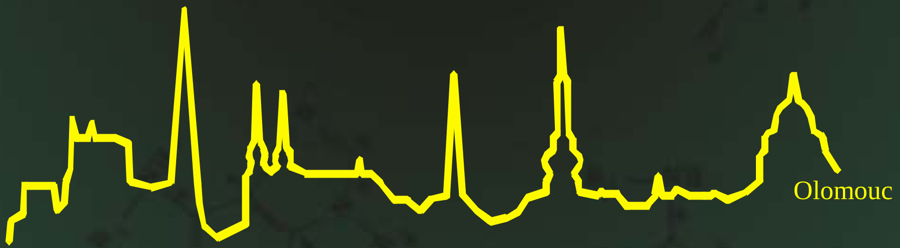
Laboratoř růstových regulátorů

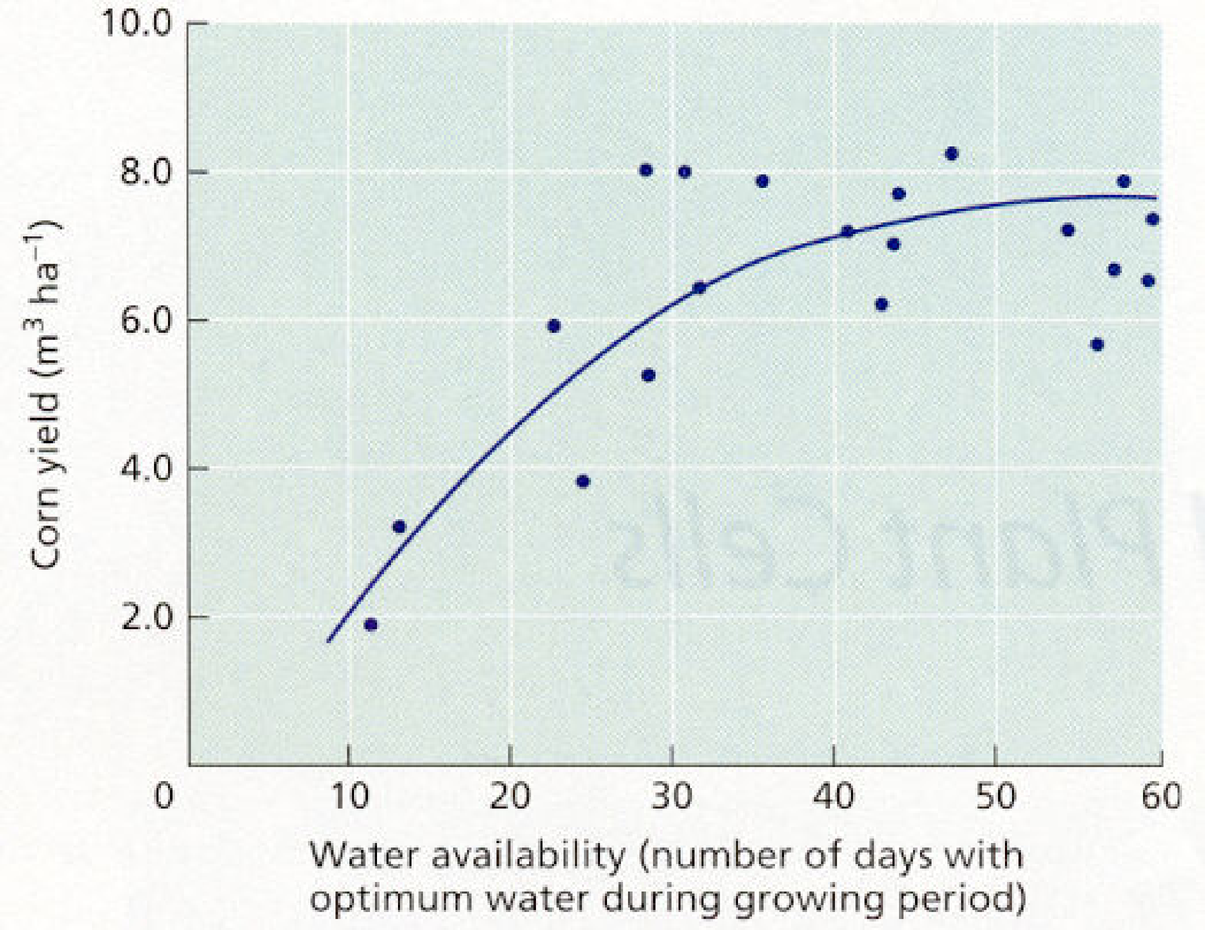
Miroslav Strnad

Voda v půdě a transport vody v rostlinách [kap 3]



- Univerzita Palackého & Ústav experimentální botaniky AV CR

Corn yield as a function of water availability [3.1]



Rostlina a voda

Rostliny se liší od ostatních organismů:

- Fotoautotrofie – voda jako komponent spolu se světlem a CO_2
- Schopnost získávat vodu a minerální látky
- Vnitrobuněčný hydrostatický tlak (turgor)

Rostlina a voda

Rostliny jsou homoiohydrické organismy – vysoký obsah vody v orgánech – 60-90%, kořeny 80-90%, dřevo 50%.

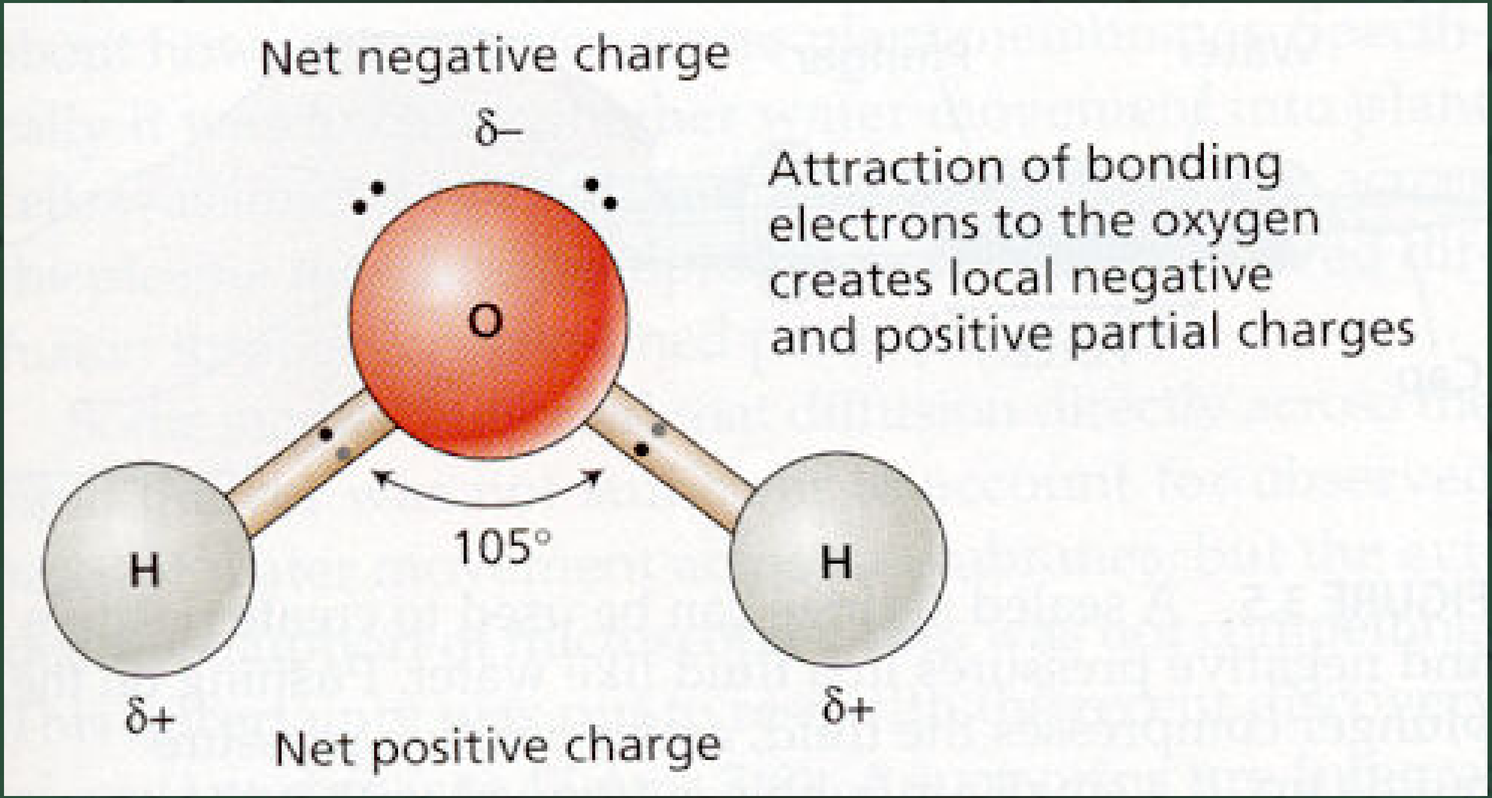
Orgánově závislé: semena , zrna – nízký obsah vody, Sleziník routička (Asplenium) jsou poikilohydrické – mohou vyschnout, nemají vakuolu

Obsah vody v rostlině velmi jemně regulován – transpirace a gutace *versus* fotosyntéza

Úloha vody v rostlinách

- Rozpouštědlo anorganických a organických látek, prostředí pro pohyb molekul a iontů
- Metabolická surovina: ve fotosyntéze, hydrolýza, hydratace
- Stavební materiál buňky – vakuola
- Transportní prostředek – hromadný tok látek
- Snižování teploty

Diagram of the water molecule [3.3]



Attraction of bonding electrons to the oxygen creates local negative and positive partial charges

The structure and properties of water

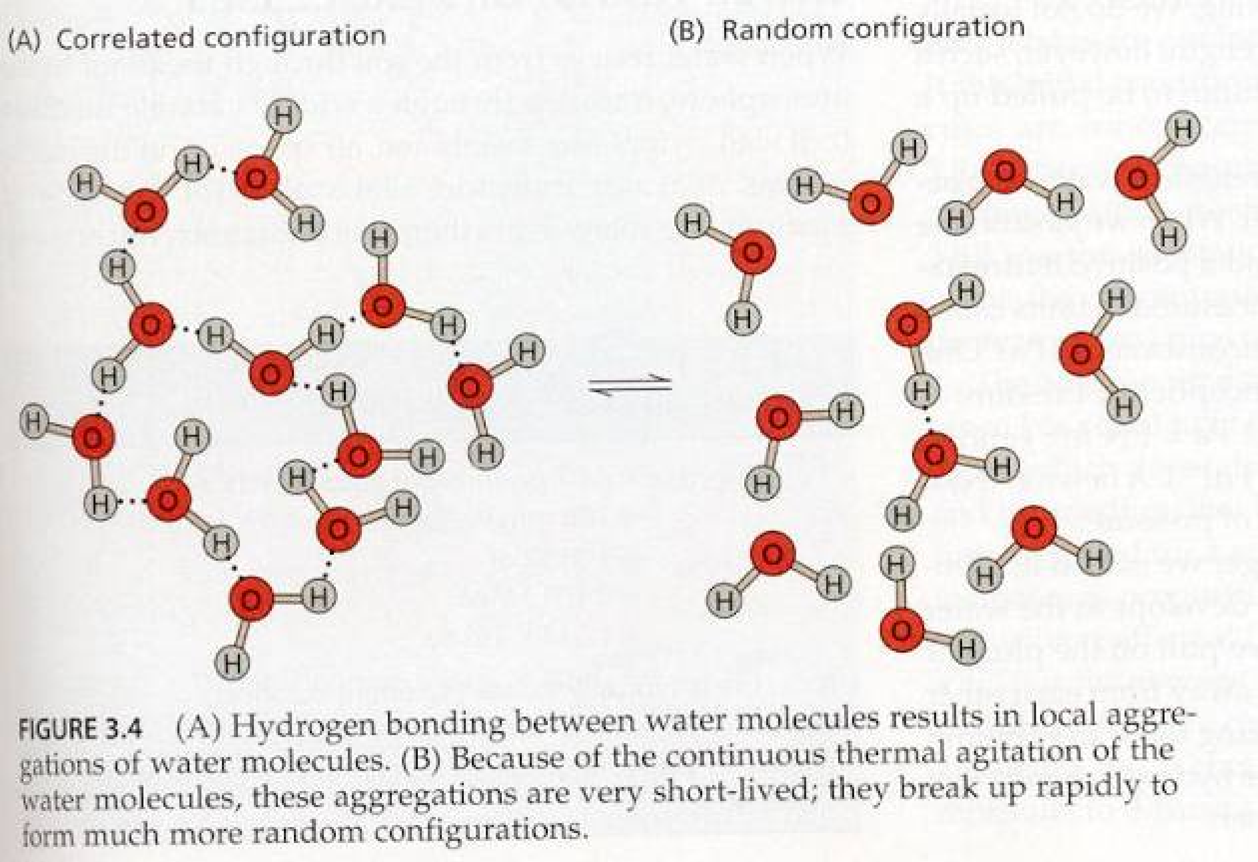
The Polarity of Water Molecules Give Rise to Hydrogen Bonds

- angle of 105°
- oxygen more electronegative - attracts electrons of the covalent bond
- the separation of partial charges + shape of water makes water a polar structure
- the polarity of water molecules give rise to hydrogen bonds

The Polarity of Water Makes it an Excellent Solvent

- shells of hydratation in the case of macromolecules

Hydrogen bonding between water molecules [3.4]

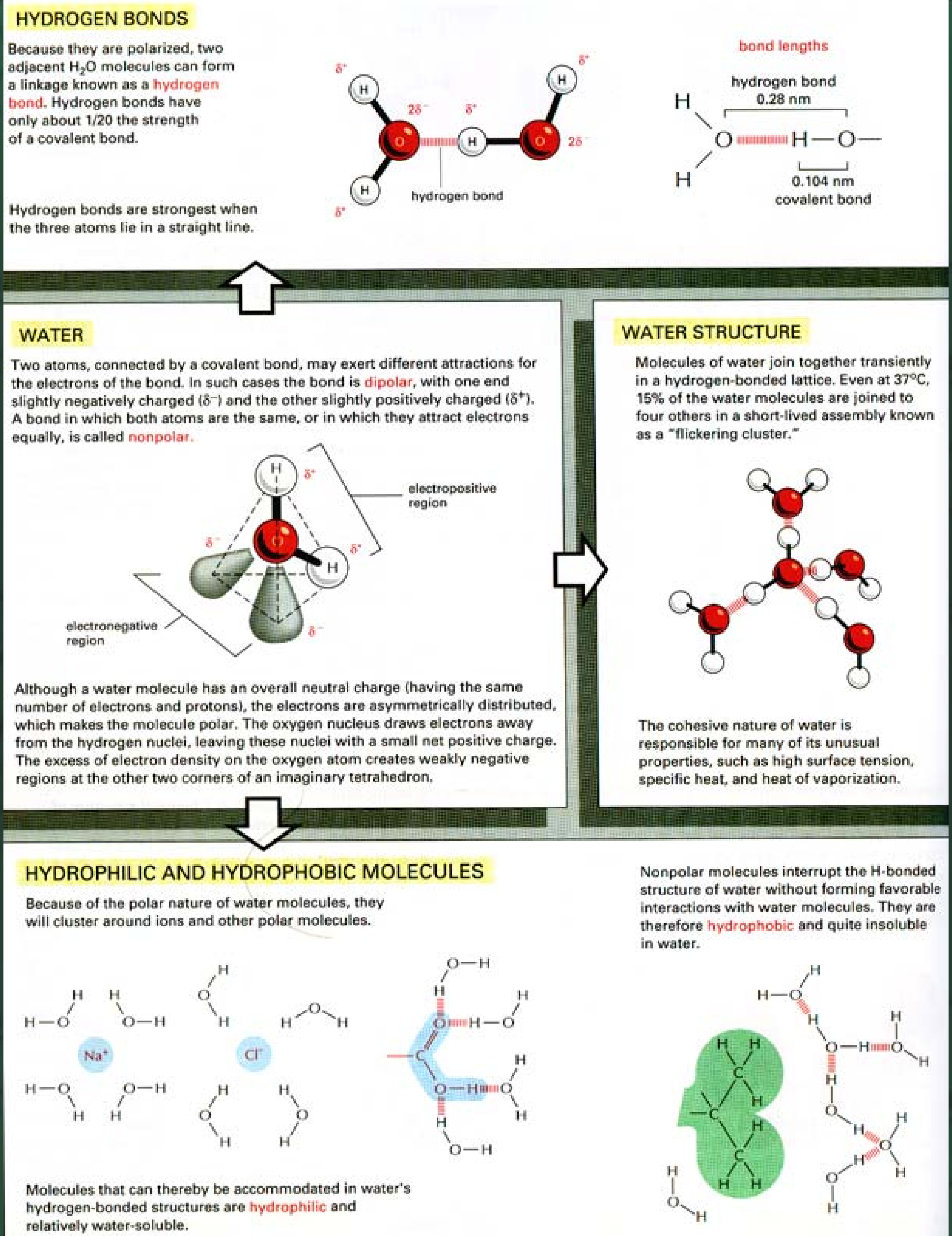


(A) Correlated configuration

(B) Random configuration

FIGURE 3.4 (A) Hydrogen bonding between water molecules results in local aggregations of water molecules. (B) Because of the continuous thermal agitation of the water molecules, these aggregations are very short-lived; they break up rapidly to form much more random configurations.

[3.1]



HYDROGEN BONDS

Because they are polarized, two adjacent H_2O molecules can form a linkage known as a **hydrogen bond**. Hydrogen bonds have only about 1/20 the strength of a covalent bond.

Hydrogen bonds are strongest when the three atoms lie in a straight line.

WATER

Two atoms, connected by a covalent bond, may exert different attractions for the electrons of the bond. In such cases the bond is **dipolar**, with one end slightly negatively charged (δ−) and the other slightly positively charged (δ+). A bond in which both atoms are the same, or in which they attract electrons equally, is called **nonpolar**.

Although a water molecule has an overall neutral charge (having the same number of electrons and protons), the electrons are asymmetrically distributed, which makes the molecule polar. The oxygen nucleus draws electrons away from the hydrogen nuclei, leaving these nuclei with a small net positive charge. The excess of electron density on the oxygen atom creates weakly negative regions at the other two corners of an imaginary tetrahedron.

WATER STRUCTURE

Molecules of water join together transiently in a hydrogen-bonded lattice. Even at 37°C, 15% of the water molecules are joined to four others in a short-lived assembly known as a "flickering cluster."

The cohesive nature of water is responsible for many of its unusual properties, such as high surface tension, specific heat, and heat of vaporization.

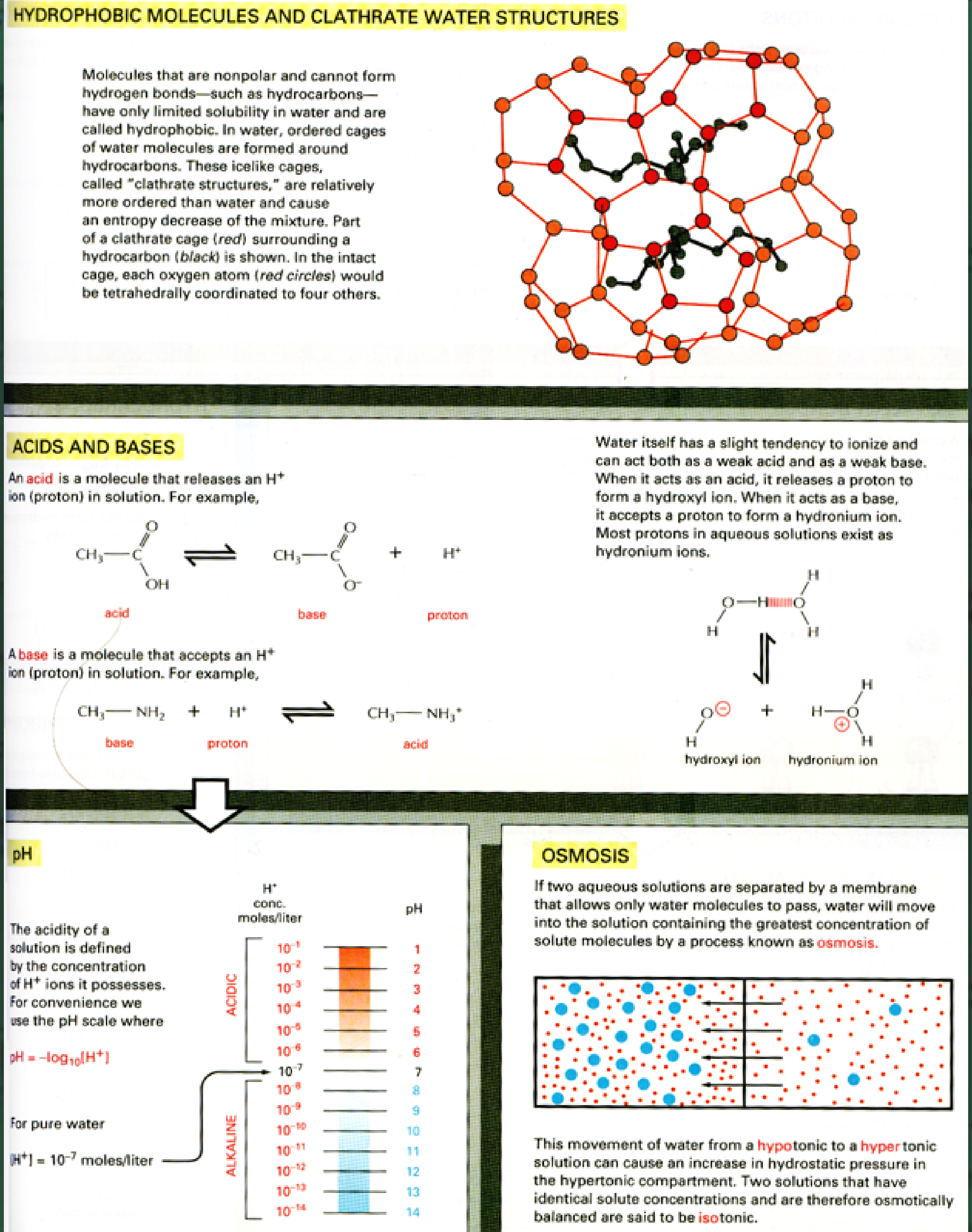
HYDROPHILIC AND HYDROPHOBIC MOLECULES

Because of the polar nature of water molecules, they will cluster around ions and other polar molecules.

Molecules that can thereby be accommodated in water's hydrogen-bonded structures are **hydrophilic** and relatively water-soluble.

Nonpolar molecules interrupt the H-bonded structure of water without forming favorable interactions with water molecules. They are therefore **hydrophobic** and quite insoluble in water.

[3.1]



HYDROPHOBIC MOLECULES AND CLATHRATE WATER STRUCTURES

Molecules that are nonpolar and cannot form hydrogen bonds—such as hydrocarbons—have only limited solubility in water and are called hydrophobic. In water, ordered cages of water molecules are formed around hydrocarbons. These icelike cages, called "clathrate structures," are relatively more ordered than water and cause an entropy decrease of the mixture. Part of a clathrate cage (*red*) surrounding a hydrocarbon (*black*) is shown. In the intact cage, each oxygen atom (*red circles*) would be tetrahedrally coordinated to four others.

ACIDS AND BASES

An acid is a molecule that releases an H^+ ion (proton) in solution. For example,

$$\underset{\text{acid}}{CH_3-COOH} \rightleftharpoons \underset{\text{base}}{CH_3-COO^-} + \underset{\text{proton}}{H^+}$$

A base is a molecule that accepts an H^+ ion (proton) in solution. For example,

$$\underset{\text{base}}{CH_3-NH_2} + \underset{\text{proton}}{H^+} \rightleftharpoons \underset{\text{acid}}{CH_3-NH_3^+}$$

Water itself has a slight tendency to ionize and can act both as a weak acid and as a weak base. When it acts as an acid, it releases a proton to form a hydroxyl ion. When it acts as a base, it accepts a proton to form a hydronium ion. Most protons in aqueous solutions exist as hydronium ions.

$$H-O-H \cdots OH_2 \rightleftharpoons \underset{\text{hydroxyl ion}}{HO^-} + \underset{\text{hydronium ion}}{H_3O^+}$$

pH

The acidity of a solution is defined by the concentration of H^+ ions it possesses. For convenience we use the pH scale where

$pH = -\log_{10}[H^+]$

For pure water

$[H^+] = 10^{-7}$ moles/liter

	H^+ conc. moles/liter	pH
ACIDIC	10^{-1}	1
	10^{-2}	2
	10^{-3}	3
	10^{-4}	4
	10^{-5}	5
	10^{-6}	6
	10^{-7}	7
ALKALINE	10^{-8}	8
	10^{-9}	9
	10^{-10}	10
	10^{-11}	11
	10^{-12}	12
	10^{-13}	13
	10^{-14}	14

OSMOSIS

If two aqueous solutions are separated by a membrane that allows only water molecules to pass, water will move into the solution containing the greatest concentration of solute molecules by a process known as osmosis.

This movement of water from a hypotonic to a hyper tonic solution can cause an increase in hydrostatic pressure in the hypertonic compartment. Two solutions that have identical solute concentrations and are therefore osmotically balanced are said to be isotonic.

Struktura a vlastnosti vody

- Kohezní a adhezní vlastnosti vody jsou závislé na existenci vodíkových můstků:
- koheze drží molekuly vody pohromadě při transportu
- adhezí lnou k povrchu
- Molekuly vody na rozhraní voda-vzduch jsou více atrahovány k sobě, povrch voda vzduch má tendenci minimalizovat povrch → koule
- E. potřebná ke zvětšení povrchu – **povrchové napětí**, vytváří rovněž napětí v kapalině
- koheze + adheze + povrchové napětí = kapilarita (vzlínavost)

Termální vlastnosti vody

Termální vlastnosti vody jsou rovněž způsobeny vodíkovými můstky

- Neobvyklé termální vlastnosti – vysoká měrná tepelná kapacita a vysoké skupenské teplo výparu – molekuly se musí napřed rozpojit a poté teprve zrychlení pohybu molekul a jejich zahřátí
- Vysoká měrná tepelná kapacita vody – velký přísun energie pro zvýšení teploty – 1 cal/g/°C
- Vysoké skupenské teplo výparu – energie potřebná k separaci molekul z kapalné fáze (transpirace) - 25°C = 44 kJ/mol – nejvyšší známe množství u kapalin
- Vysoké latentní teplo výparu – ochlazování rostlin, odběr E z okolí

Vlastnosti vody

Voda má vysokou pevnost v tahu

- pevnost v tahu (stříkačka jako příklad)
- positivní a negativní hydrostatický tlak (MPa) 1MPa = 9.9 Atm
- voda vydrží až -30 MPa
- kavitace

[3.1]

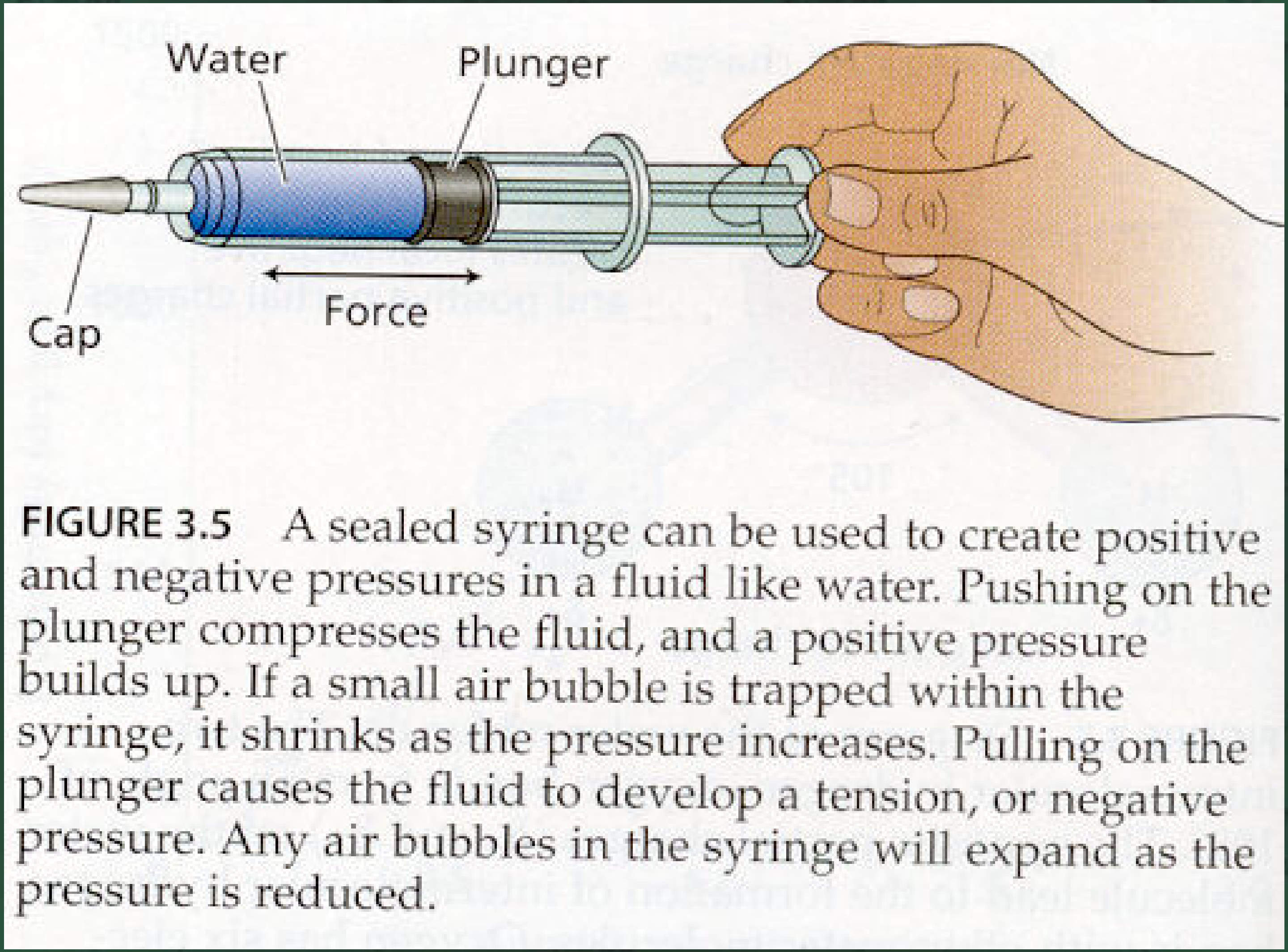


FIGURE 3.5 A sealed syringe can be used to create positive and negative pressures in a fluid like water. Pushing on the plunger compresses the fluid, and a positive pressure builds up. If a small air bubble is trapped within the syringe, it shrinks as the pressure increases. Pulling on the plunger causes the fluid to develop a tension, or negative pressure. Any air bubbles in the syringe will expand as the pressure is reduced.

Voda v půdě

Půdní vodní potenciál= koncentrace, tlak a gravidita

- $\Psi w = \Psi s + \Psi p + \Psi g + \Psi m$
- Ψs - osmotický potenciál – vliv rozpuštěných látek, látky redukují volnou energii, roste neuspořádanost, $\Psi_s = - RTc_\sigma$ (R- plynová konstanta, T-teplota, c_σ osmolalita) v půdě malý, max. 0.2 MPa
- Ψ_p - hydrostatický tlak (v půdě záporný), normální voda $\Psi_p = 0$ MPa
- $\Psi g = \rho_w gh$, $\rho_w g$ má hodnotu 0.01 MPa/m, 10 m = 0.1 MPa změna u Ψ_w
- Ψm = matricový potenciál – zmenšení Gibbsovy volné energie vody po adsorbci na povrch struktur

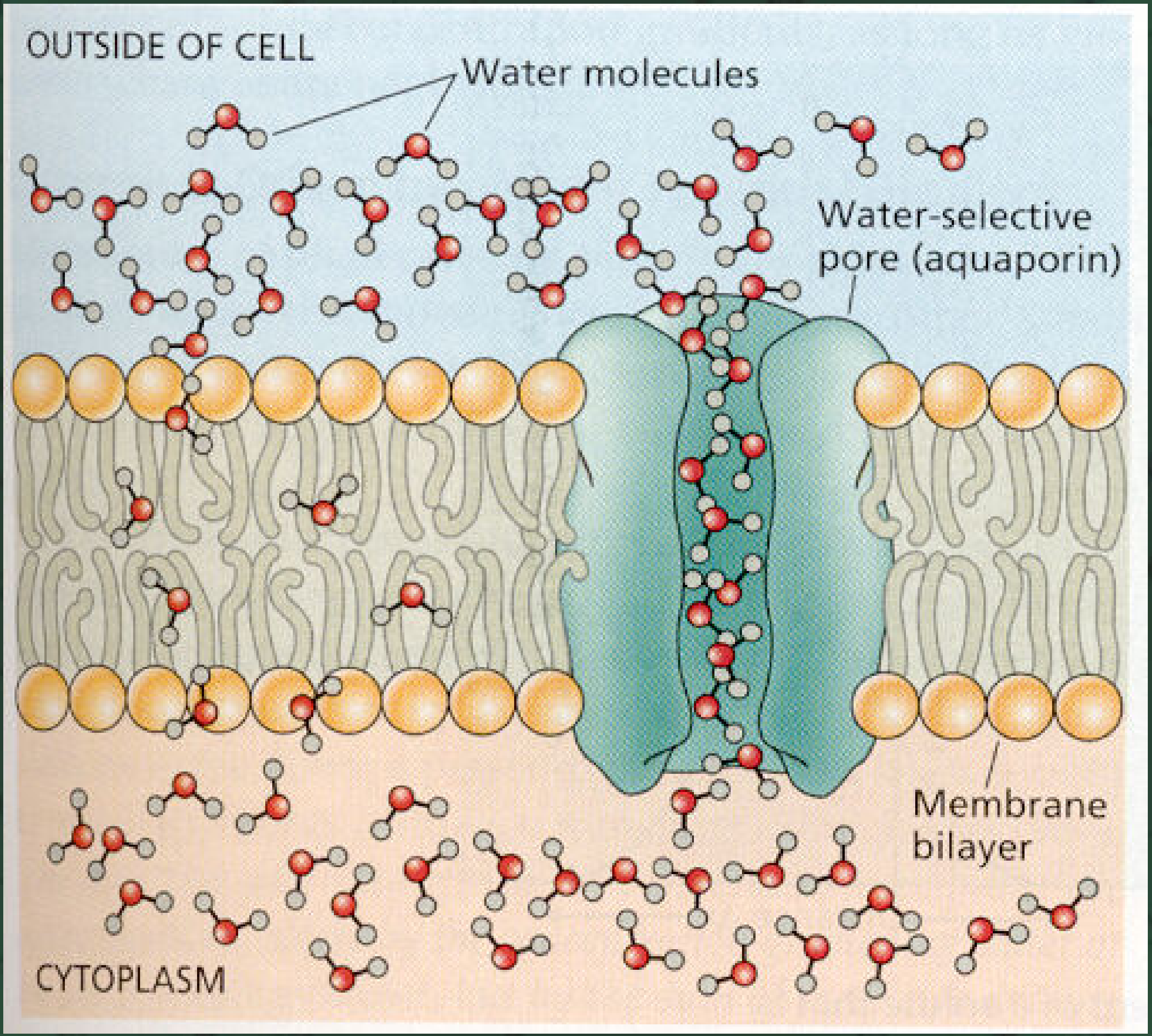
Pohyb vody v půdě

- Půdní hydraulická konduktivita – závisí na množství vody v půdě a její kvalitě
- Difuze a objemové proudění

Difuze je spontánní pohyb částic

- Spontánní pohyb molekul z oblasti vyšší koncentrace (vyššího chemického potenciálu) do oblasti nižší koncentrace. Je projevem jejich translační kinetické energie.
- 1880 Německý vědec Adolf Fick – rychlost difuzního pohybu je přímo úměrná koncentračnímu gradient ($\Delta c_s/\Delta x$), Δc_s – rozdíly v koncentraci látek, Δx - vzdálenost
- Rychlost transportu, nebo hustota toku: $J_s=-D_s (\Delta c_s/\Delta x)$, D_s je difuzní koeficient
- 2. Fickův zákon – lze odvodit závoslost doby difuze látky na vzdálenosti $t_{c=1/2} = x^2/D_s$. K – čas potřebný pro difuzi látky na určitou vzdálenost vzrůstá se čtvercem vzdálenosti.
- Difuze na malé vzdálenosti – buňka 50 μm, glukosa 10^{-9} m^2 s^{-1} → $t_{c=1/2} = 2,5$ s
- 1 m keř → $t_{c=1/2} = 10^9 = 32$ let
- Velmi pomalý na dlouhé vzdálenosti - glukosa - 1 m = 32 let,
- 50 μm = 2.5 s
- Difuzní koeficient – jaké množství látky difunduje jednotkou plochy za 1 s při koncentračním spádu 1 mol.m^{-2}. Závisí na prostředí, velikosti molekul

Difuze molekul vody [3.6]



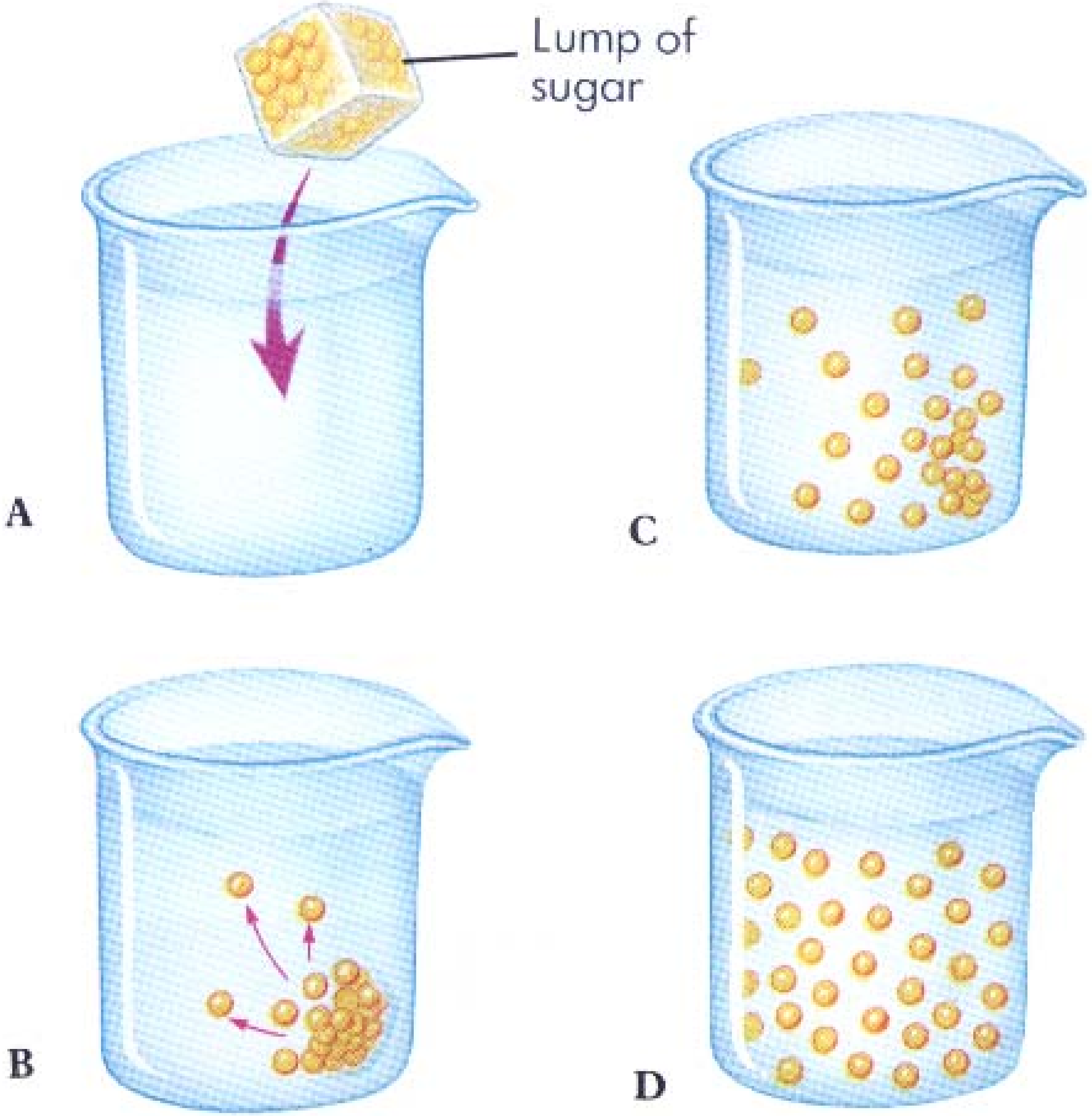
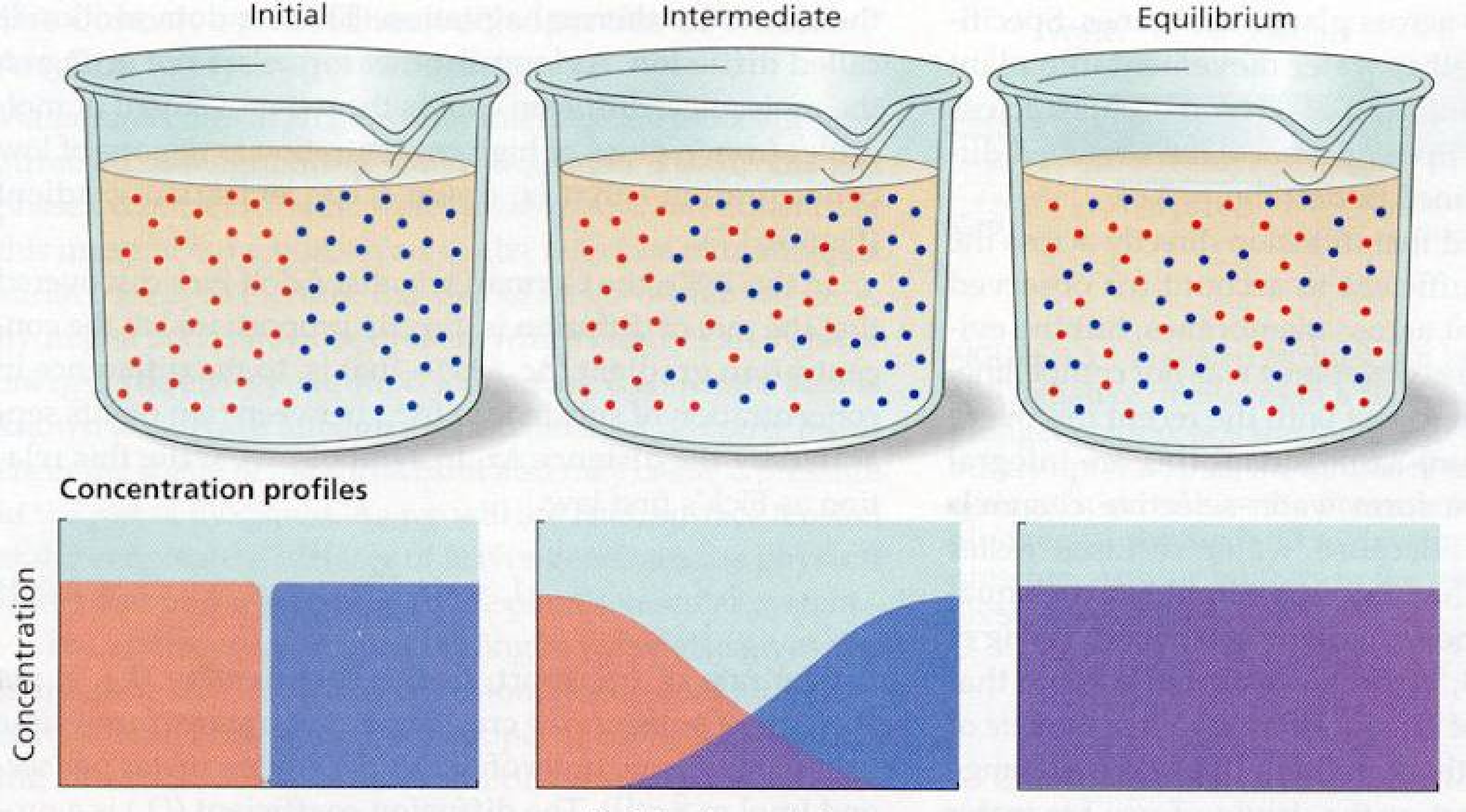


FIGURE 6-9
Diffusion. If a lump of sugar is dropped into a beaker of water, its molecules dissolve (**A**) and diffuse (**B** and **C**). Eventually, diffusion results in an even distribution of sugar molecules throughout the water (**D**).

Thermal motion of molecules leads to diffusion [3.7]



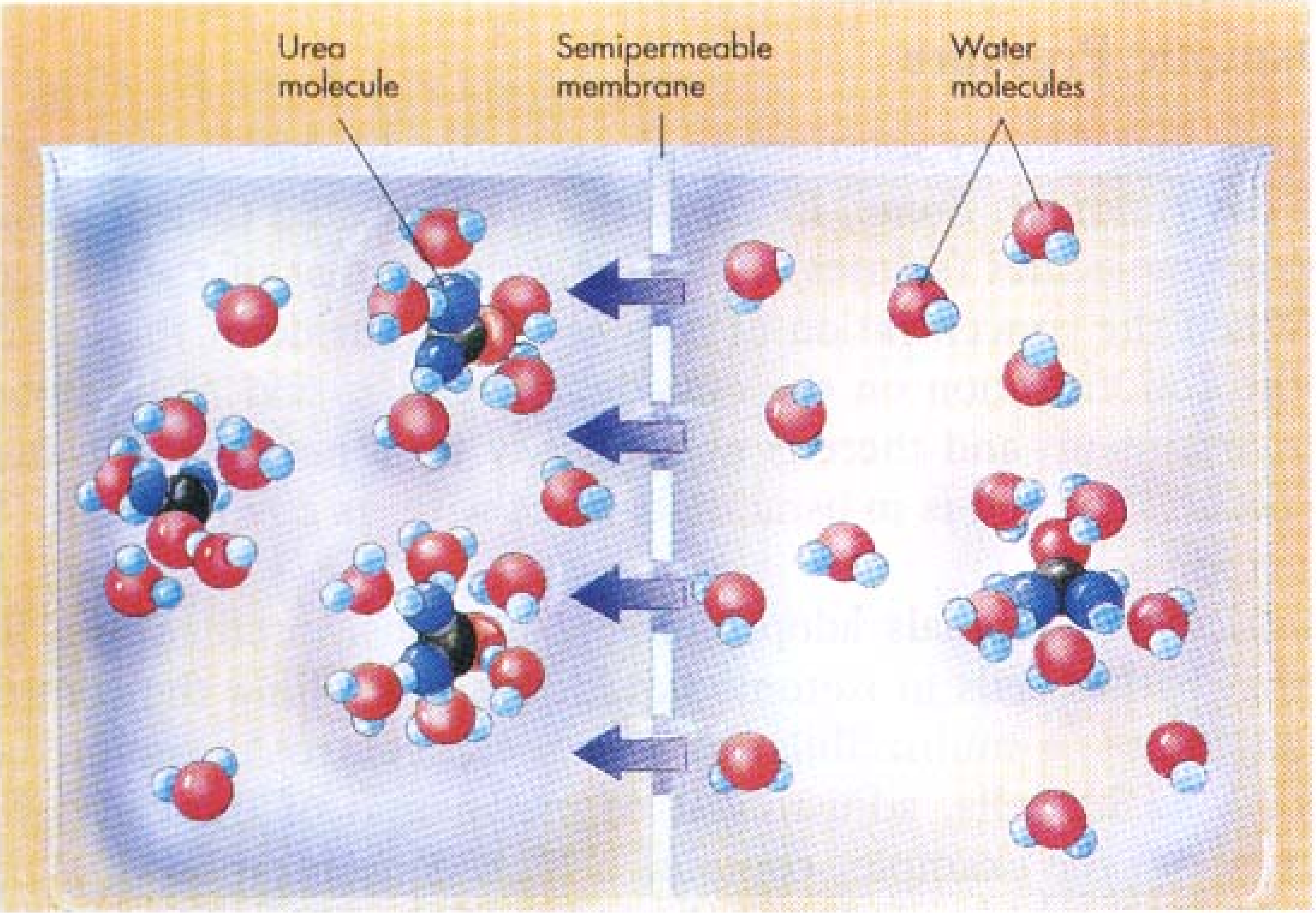


FIGURE 6-12

How solutes create osmotic pressure. Charged or polar molecules are soluble in water because they form hydrogen bonds with water molecules clustered around them. When such a polar solute (illustrated here with urea) is added to one side of a membrane, the water molecules that gather around each urea molecule are no longer free to diffuse across the membrane—in effect, the polar solute has reduced the number of free water molecules on that side of the membrane. Because the hypotonic side of the membrane (on right, with less solute) has more unbound water molecules than the hypertonic side with more solute, water moves by diffusion from the right to the left.

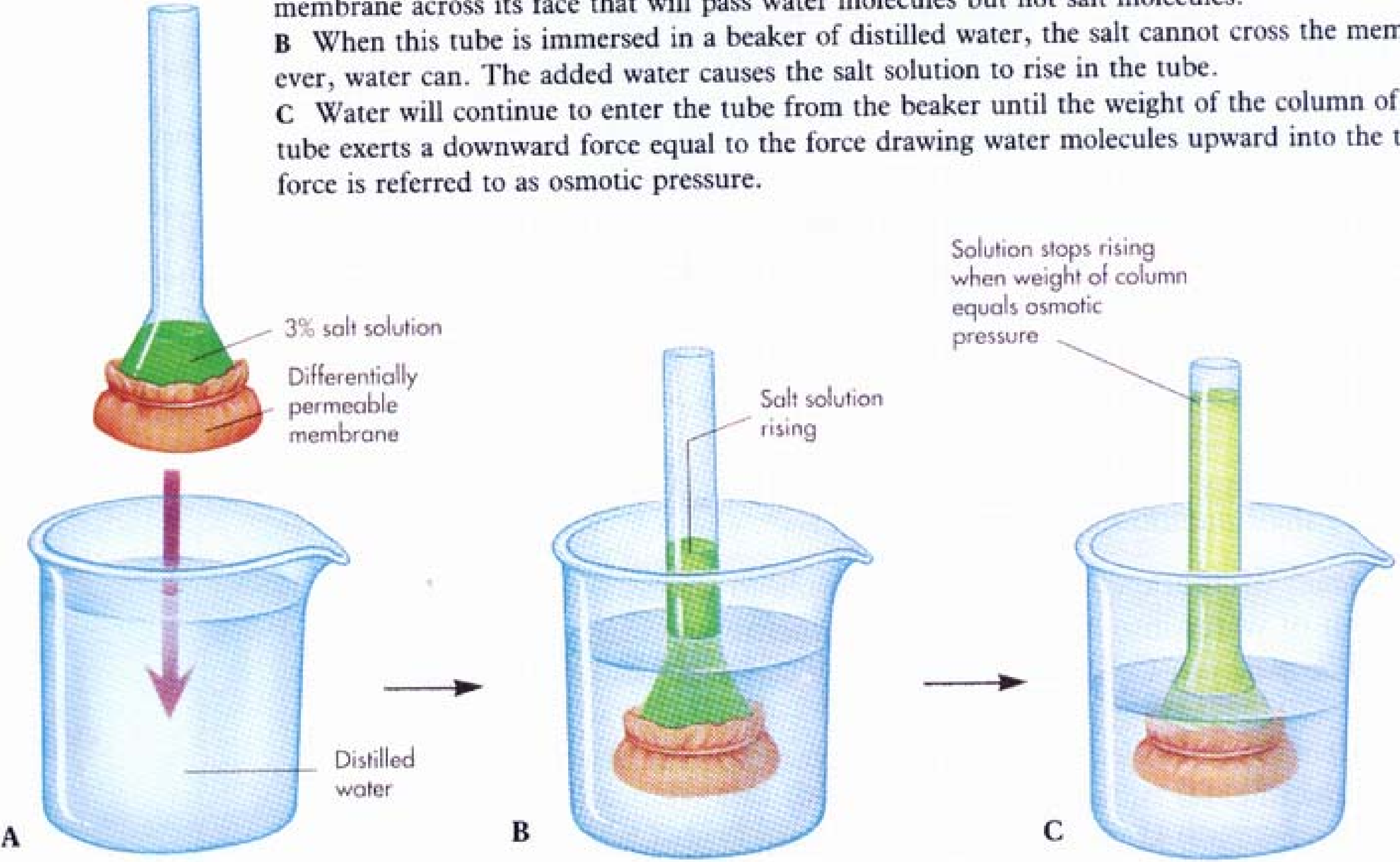
FIGURE 6-10

An experiment demonstrating osmosis.

A The end of a tube containing a 3% salt solution is closed by stretching a differentially permeable membrane across its face that will pass water molecules but not salt molecules.

B When this tube is immersed in a beaker of distilled water, the salt cannot cross the membrane; however, water can. The added water causes the salt solution to rise in the tube.

C Water will continue to enter the tube from the beaker until the weight of the column of water in the tube exerts a downward force equal to the force drawing water molecules upward into the tube. This force is referred to as osmotic pressure.

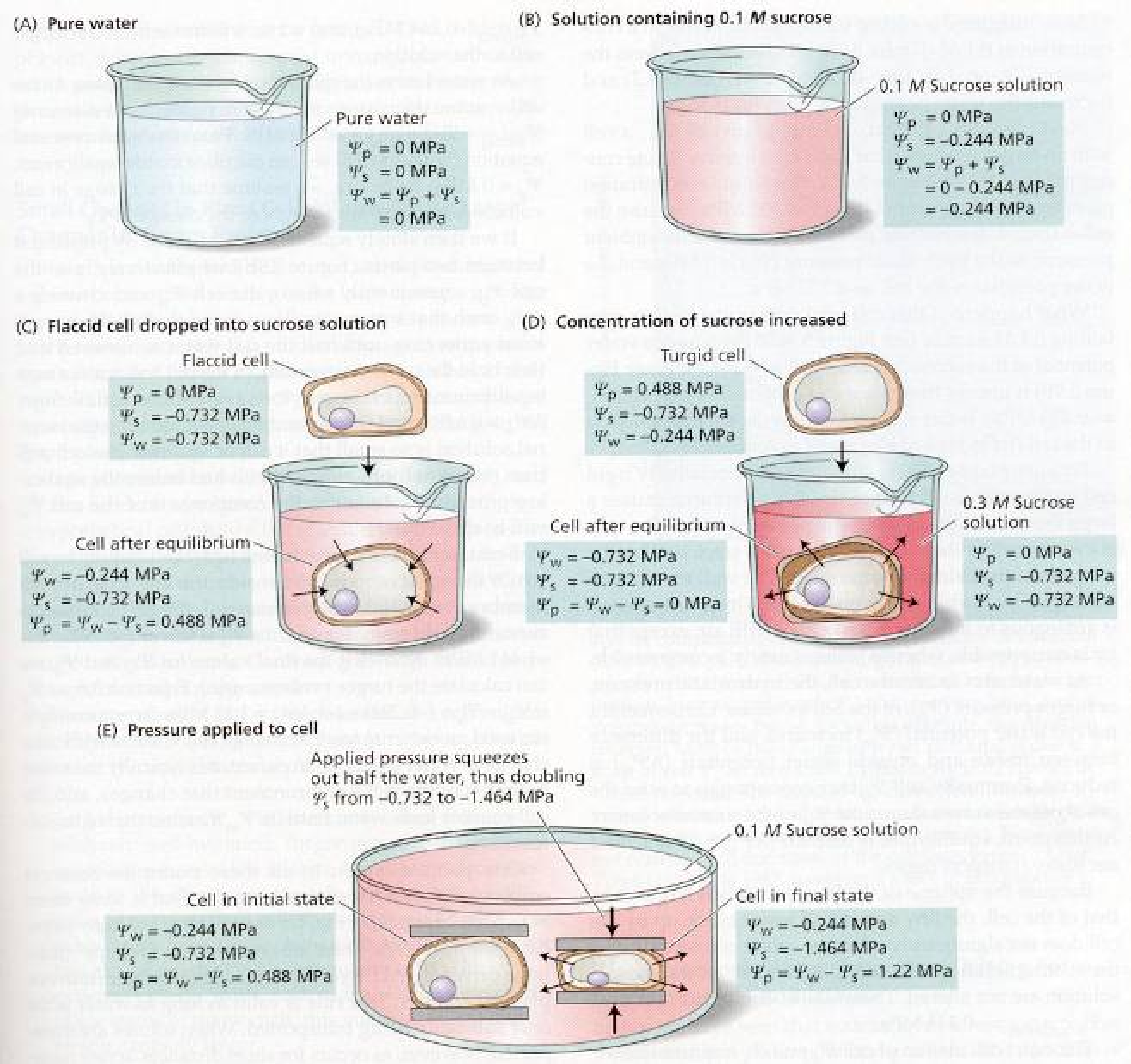


Tři hlavní faktory ovlivňující vodní potenciál buňky

Vodní potenciál= koncentrace, tlak a gravidita

- $\Psi w = \Psi s + \Psi p + \Psi g$
- Ψs - osmotický potenciál – vliv rozpuštěných látek, látky redukují volnou energii, roste neuspořádanost, $\Psi_s = - RTc_\sigma$ (R-plynová konstanta, T-teplota, c_σ osmolalita)
- Ψ_p - hydrostatic tlak (v buňce = turgorový tlak) (+/-), normální voda Ψ_p = O MPa
- $\Psi g = \rho_w gh$, $\rho_w g$ má hodnotu 0.01 MPa/m, 10 m = 0.1 MPa změna u Ψ_w

Water potential and its components [3.9]



Water flow [4.1]

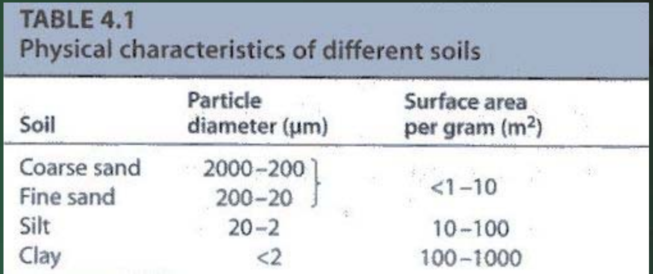
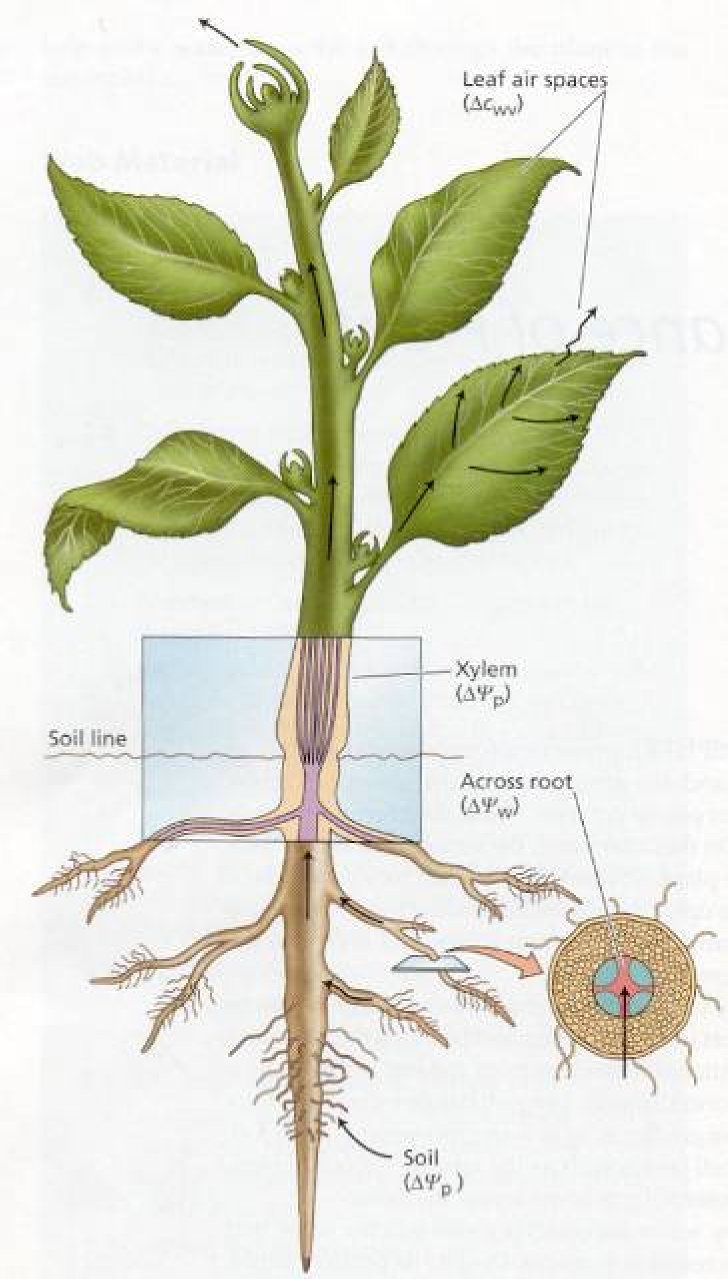
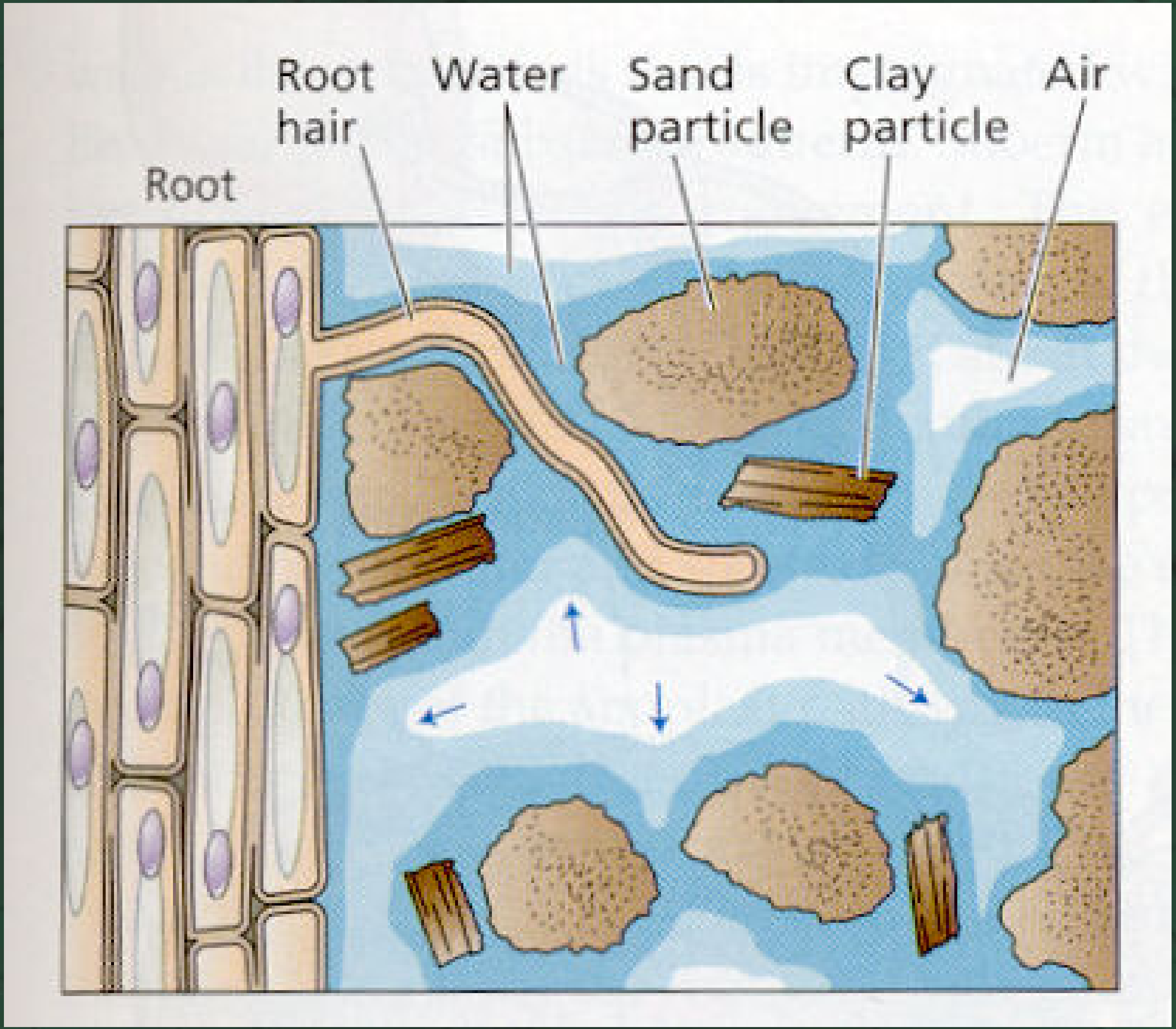


TABLE 4.1
Physical characteristics of different soils

Soil	Particle diameter (μm)	Surface area per gram (m^2)
Coarse sand	2000–200	<1–10
Fine sand	200–20	
Silt	20–2	10–100
Clay	<2	100–1000



Složení půdy [4.2]



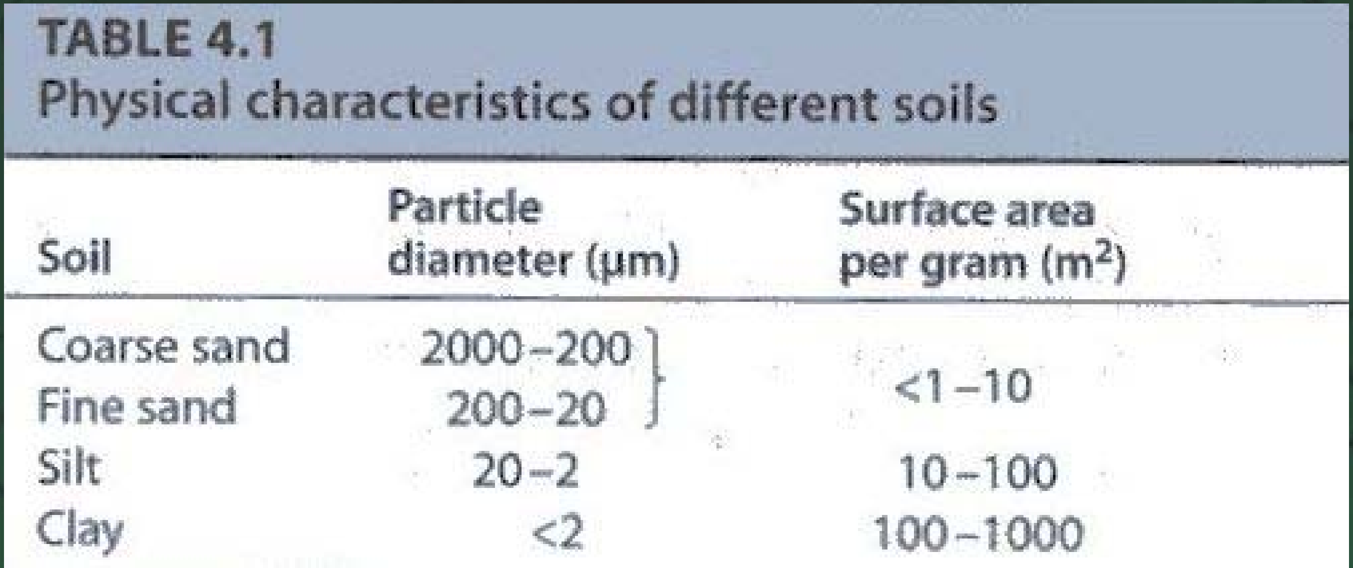
Složení půdy

-bio-organo-minerální systém

Prvná fáze – minerální látky, humus, biomasa; humus soli huminových kyselin a fulvokyselin, jílovité až písčité částice

Kapalná fáze –vodný roztok min. solí

Plynná fáze – půdní vzduch, půdní O_2



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Pathways for water uptake by the root [4.3]

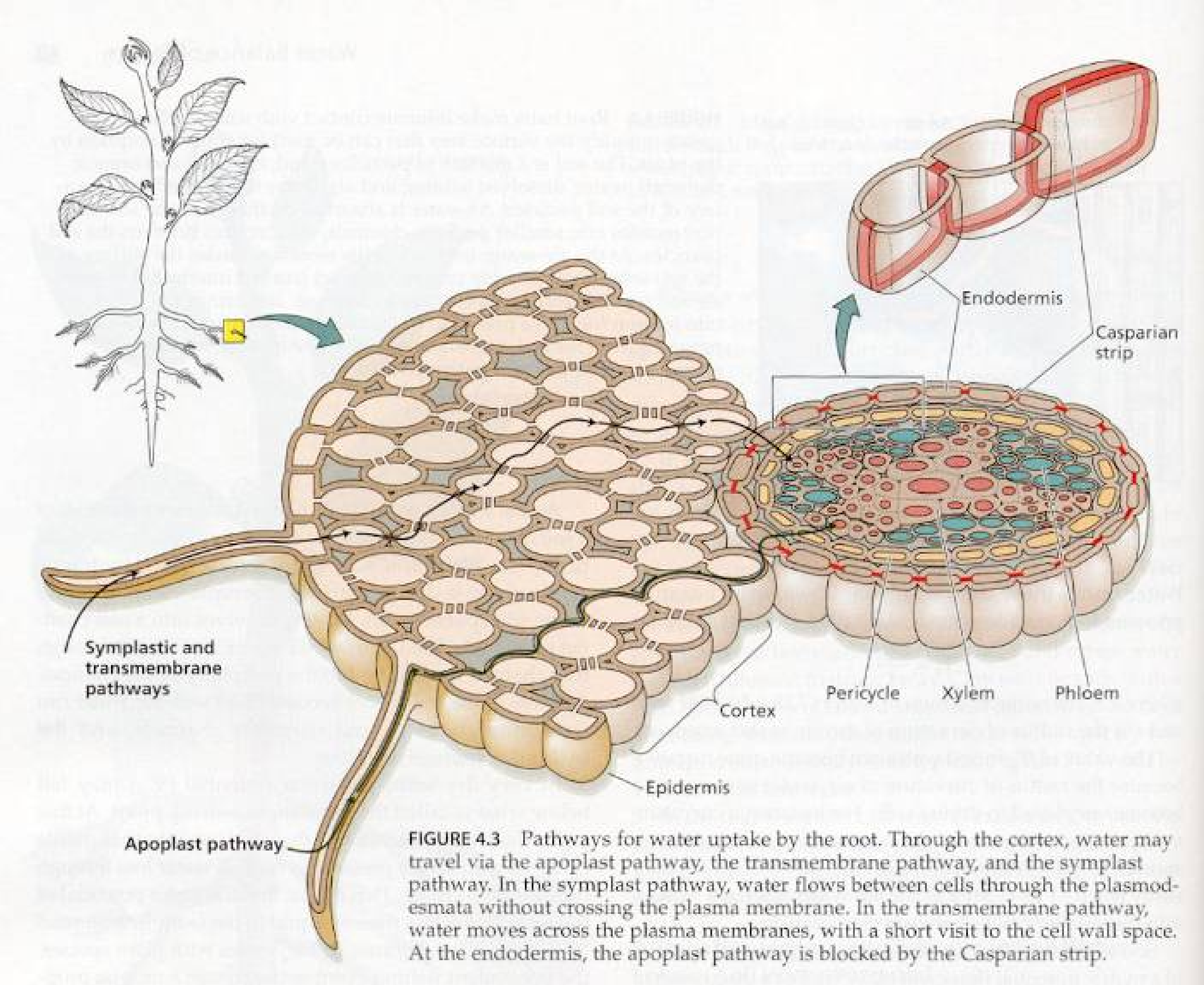


FIGURE 4.3 Pathways for water uptake by the root. Through the cortex, water may travel via the apoplast pathway, the transmembrane pathway, and the symplast pathway. In the symplast pathway, water flows between cells through the plasmodesmata without crossing the plasma membrane. In the transmembrane pathway, water moves across the plasma membranes, with a short visit to the cell wall space. At the endodermis, the apoplast pathway is blocked by the Casparian strip.

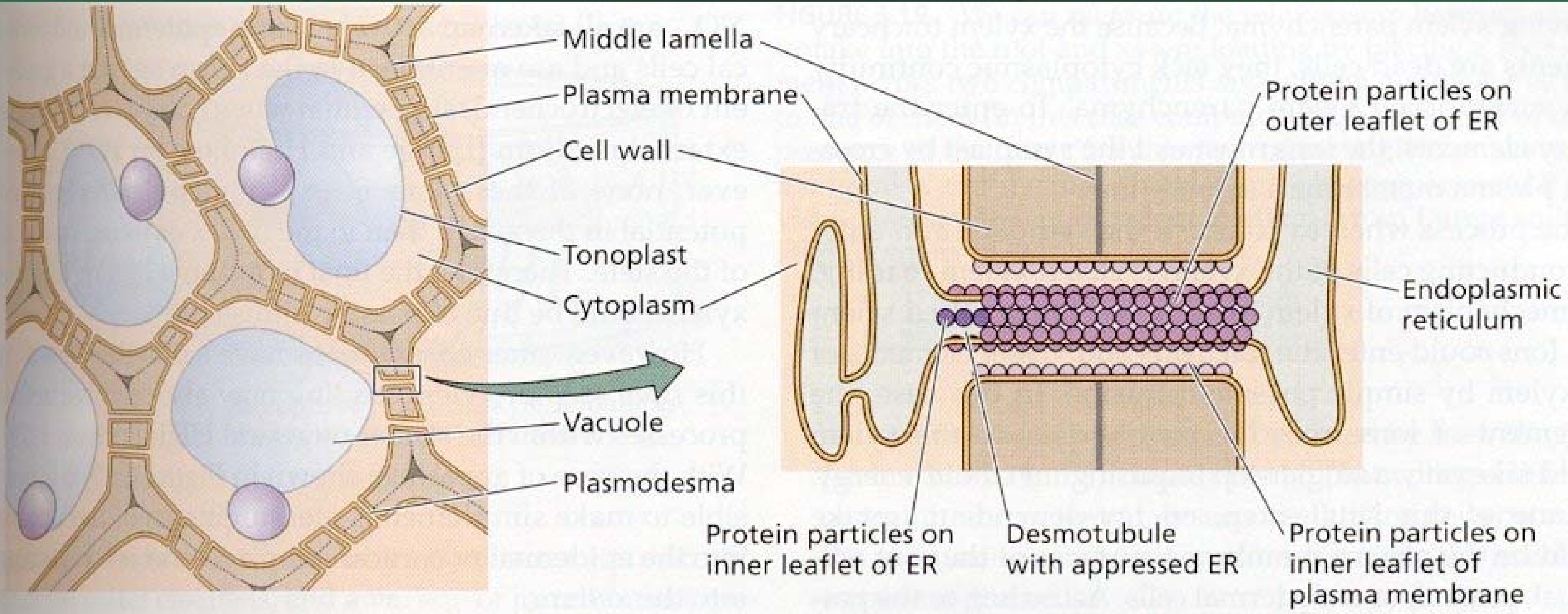


FIGURE 6.17 Diagram illustrating how plasmodesmata connect the cytoplasms of neighboring cells. Plasmodesmata are about 40 nm in diameter and allow diffusion of water and small molecules from one cell to the next. In addition, the size of the opening can be regulated by rearrangements of the internal proteins to allow the passage of larger molecules.

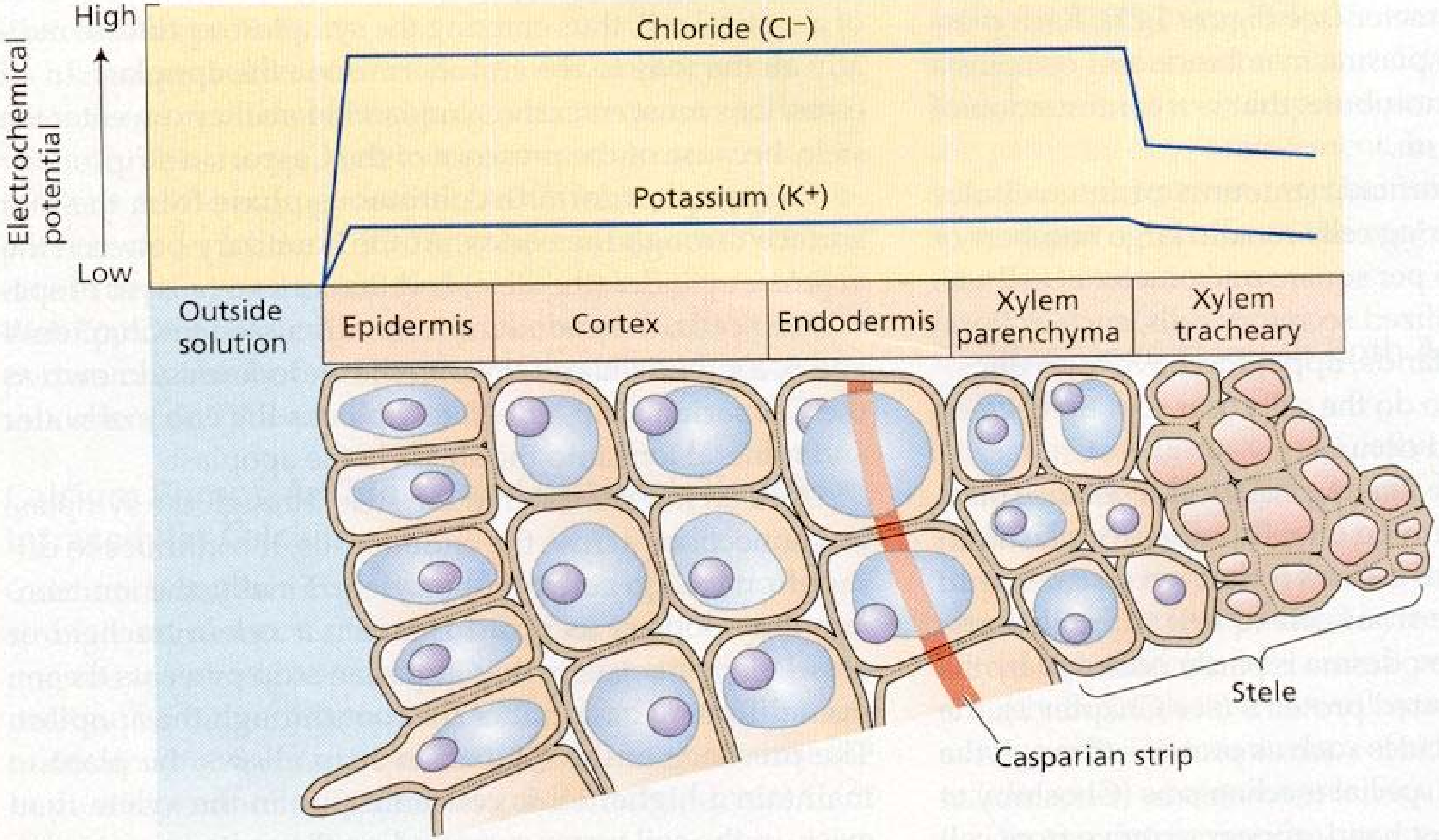


FIGURE 6.18 Diagram showing electrochemical potentials of K^+ and Cl^- across a maize root. To determine the electrochemical potentials, the root was bathed in a solution containing 1 m*M* KCl and 0.1 m*M* $CaCl_2$. A reference electrode was positioned in the bathing solution, and an ion-sensitive measuring electrode was inserted in different cells of the root. The horizontal axis shows the different tissues found in a root cross section. The substantial increase in electrochemical potential for both K^+ and Cl^- between the bathing medium and the epidermis indicates that ions are taken up into the root by an active transport process. In contrast, the potentials decrease at the xylem vessels, suggesting that ions are transported into the xylem by passive diffusion down the gradient of electrochemical potential. (After Dunlop and Bowling 1971.)

Gutace [4.5]

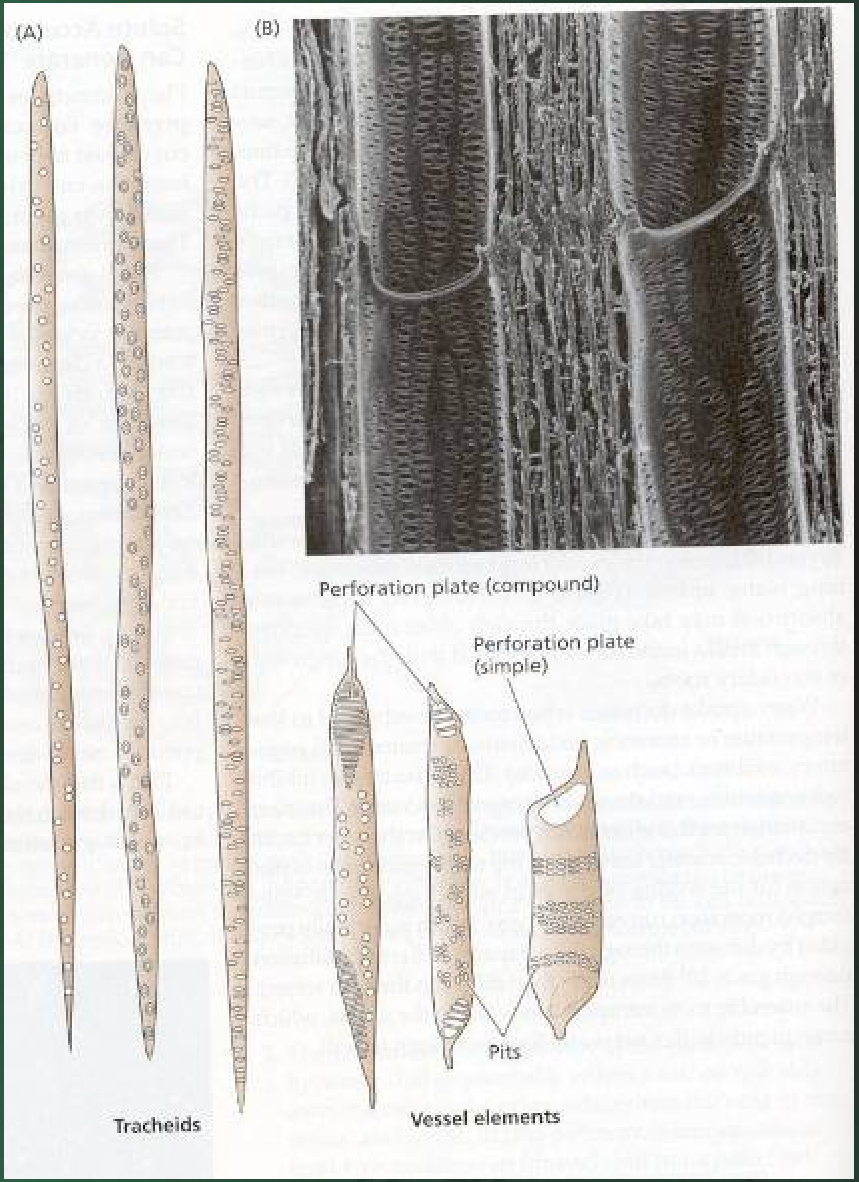
Transpirační proud

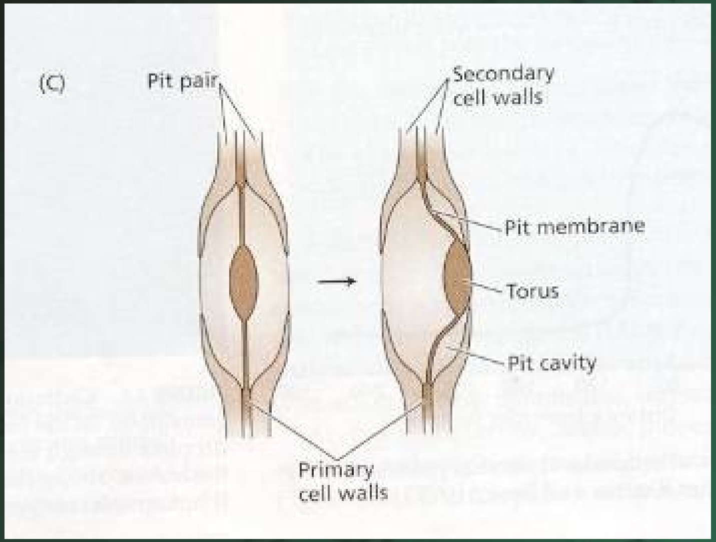
Je to proud vody směřující z kořenů do listů a dalších orgánů, kde přechází v proud vodní páry.

Závisí na:

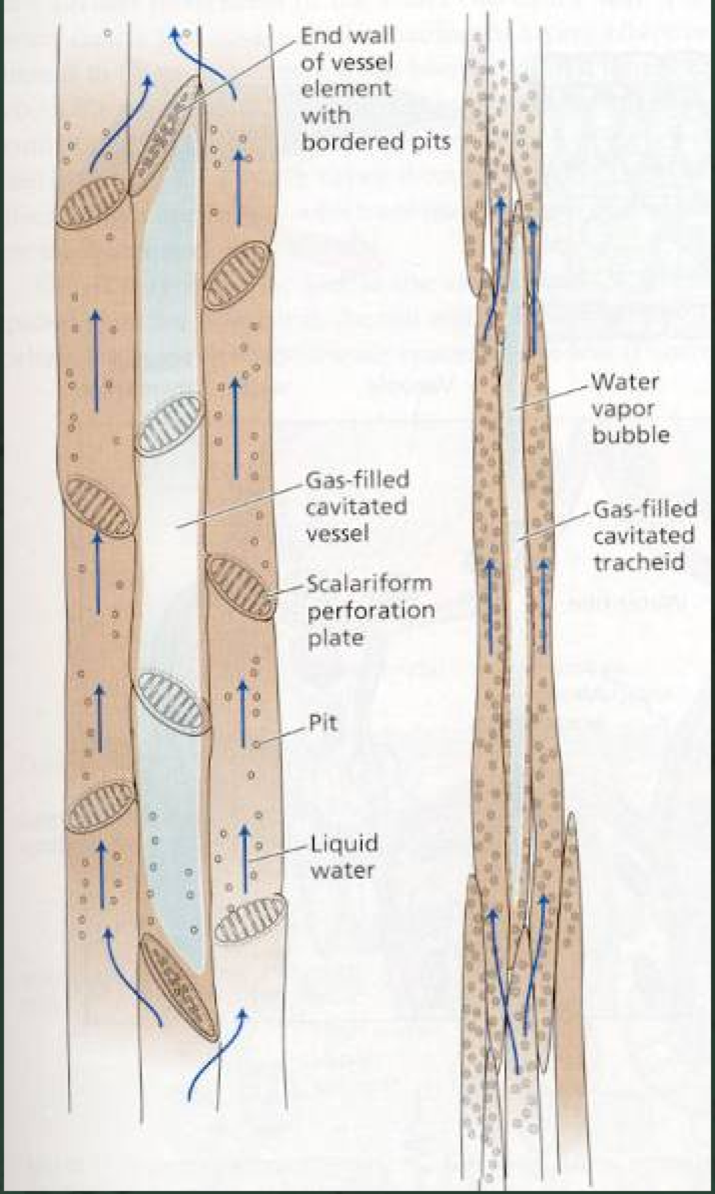
- Transpiraci – zdroj tažné síly
- Koheze vody – kontinuita vodního sloupce
- Adheze – přilnavost přispívá ke stabilitě
- Kapilární síly – v submikroskopických kapilárních prostorách – stabilizace vodního sloupce
- Hydraulická vodivost, resp. hydraulický odpor vodních drah a difuzní odpor proudu vodní páry.

Tracheary elements [4.6]



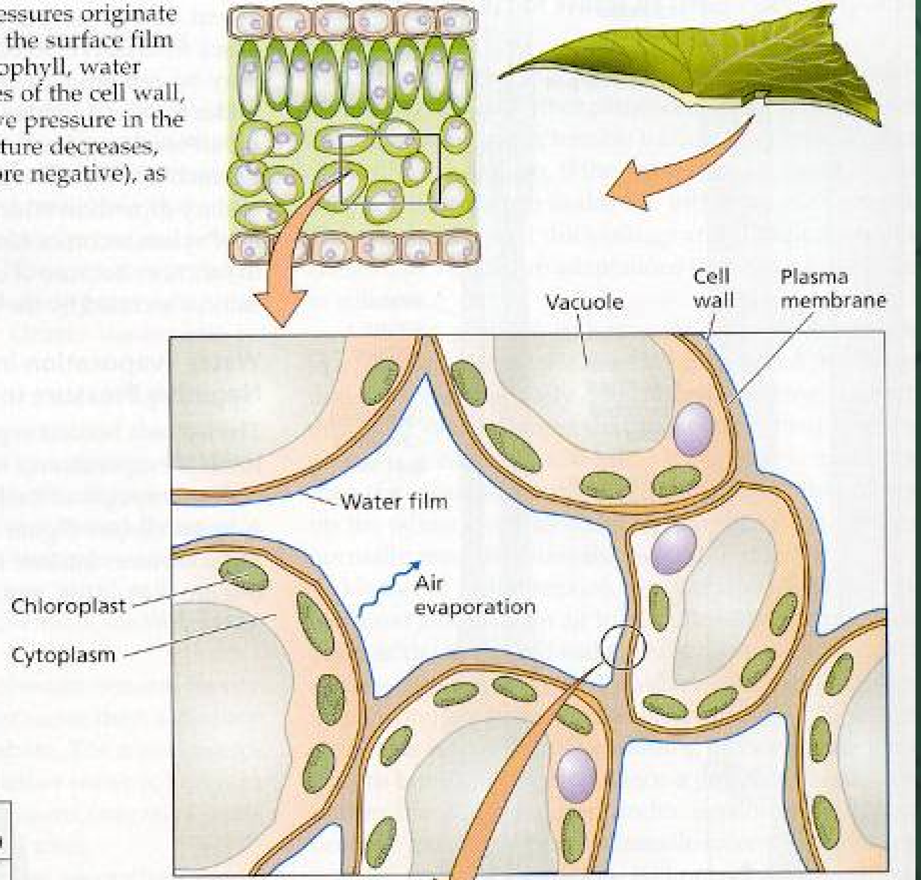


Vessels and tracheids [4.7]

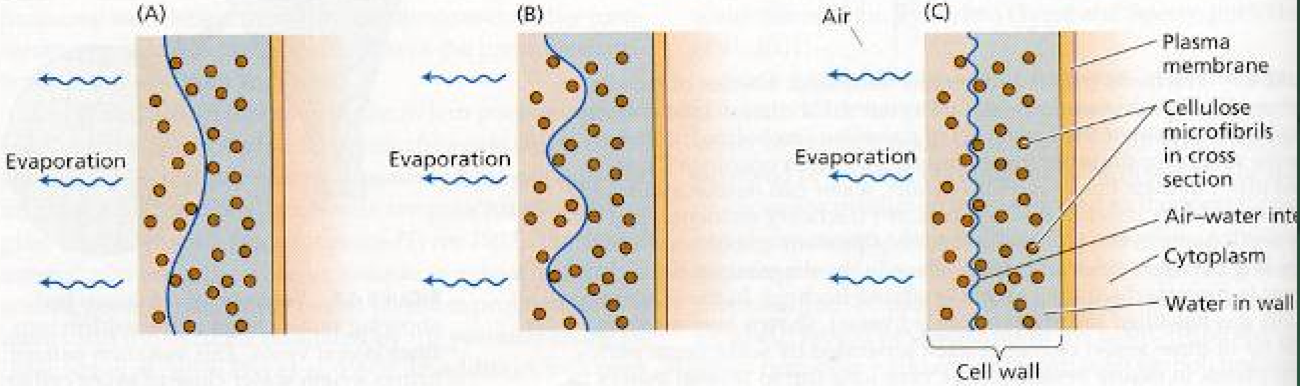


[4.9]

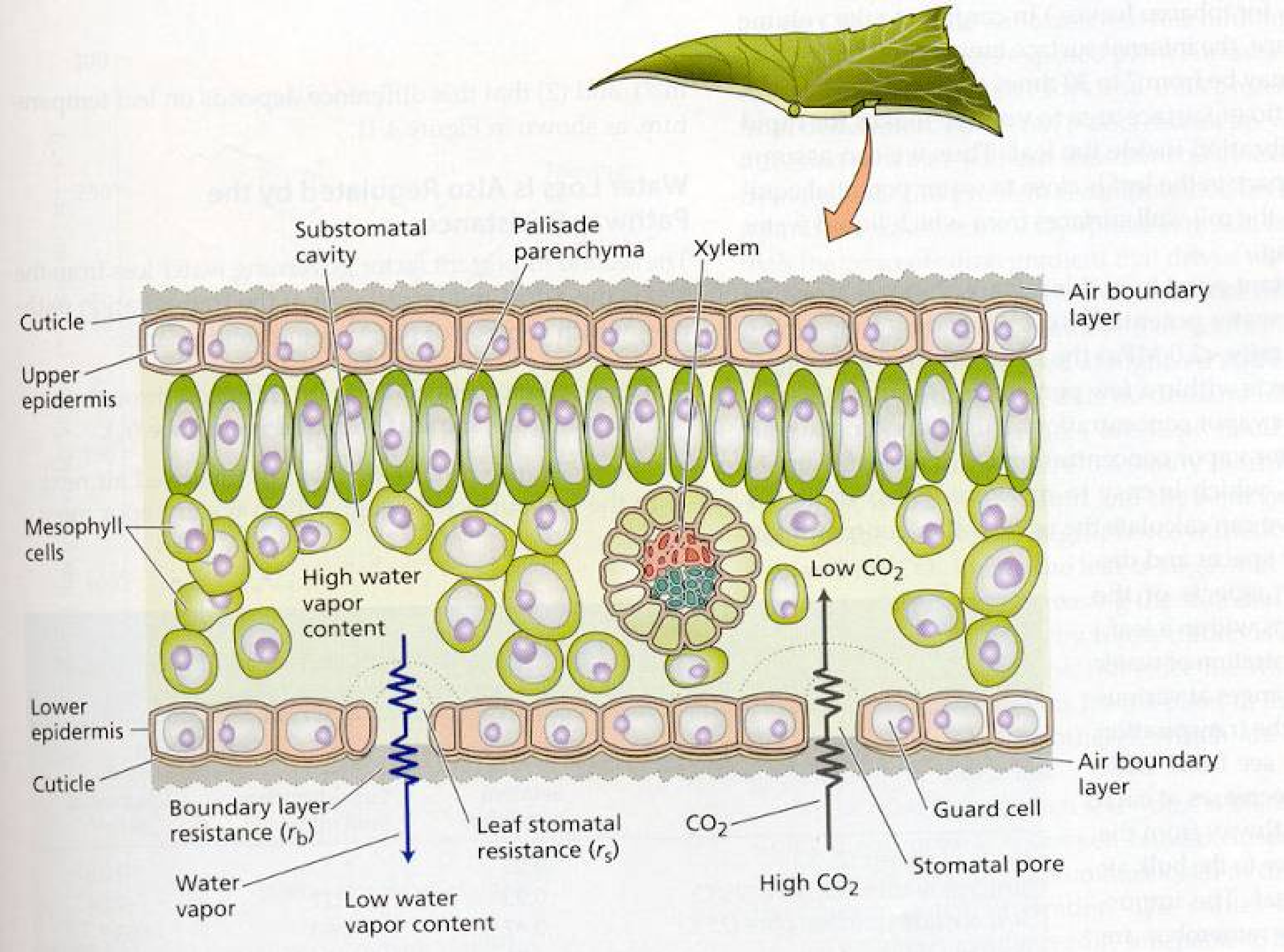
FIGURE 4.9 Tensions or negative pressures originate in leaves. As water evaporates from the surface film that covers the cell walls of the mesophyll, water withdraws farther into the interstices of the cell wall, and surface tension causes a negative pressure in the liquid phase. As the radius of curvature decreases, the pressure decreases (becomes more negative), as calculated from Equation 4.1.



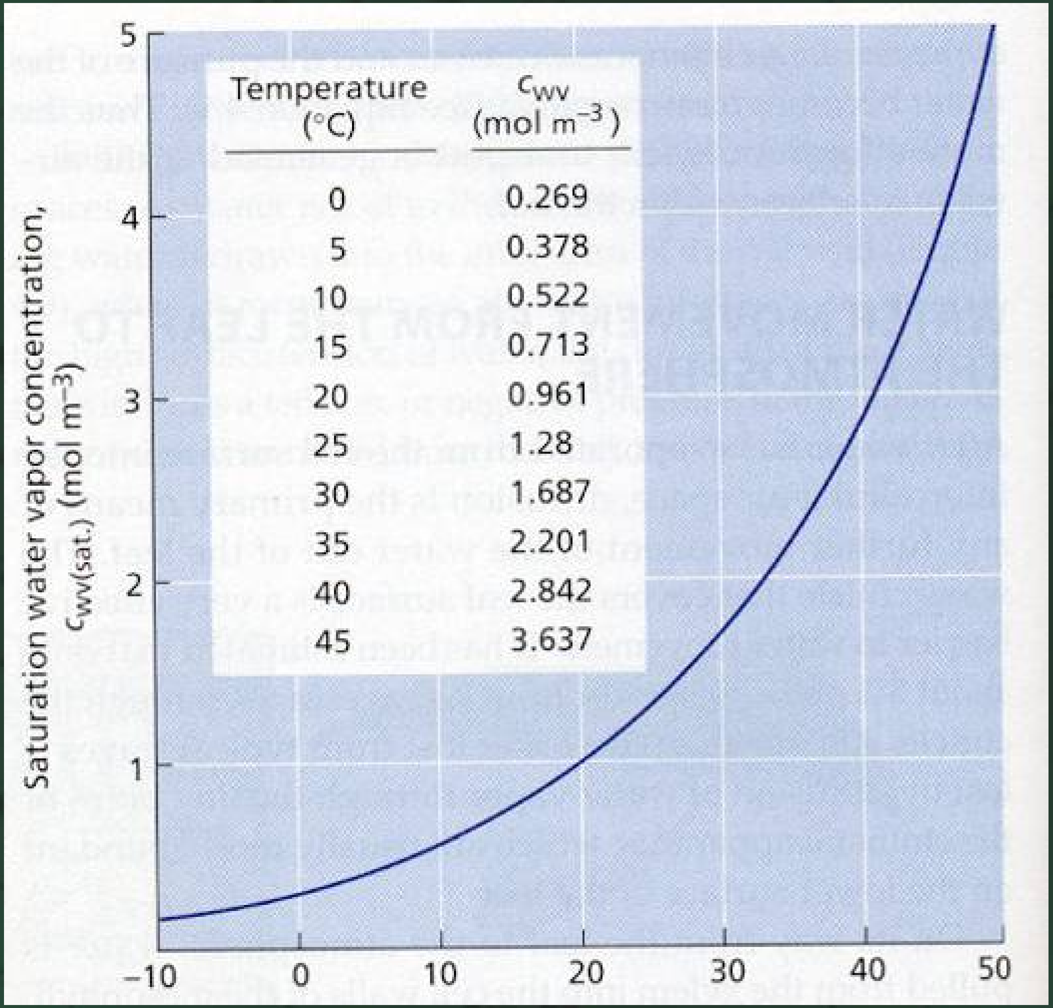
	Radius of curvature (μm)	Hydrostatic pressure (MPa)
(A)	0.5	−0.3
(B)	0.05	−3
(C)	0.01	−15



Water pathway through the leaf [4.10]



Conc. of water vapor in saturated air as a function of air temperature [4.11]



Temperature (°C)	c_{wv} (mol m^{-3})
0	0.269
5	0.378
10	0.522
15	0.713
20	0.961
25	1.28
30	1.687
35	2.201
40	2.842
45	3.637

Stomatární transpirace jako difuze vodní páry průduchy

-děje se průduchy a závisí na koncentračním gradientu vodní páry.

$T_{c=1/2} = x^2/\text{difuzní koeficient} \rightarrow (10^{-3}\ \text{m})^2/2{,}4 \times 10^{-5}\ \text{m}^2\ \text{s}^{-1} = 0{,}042\ \text{s}$ - velká rychlost

- Rychlost přímo závisí na gradientu vodních par a difuzním odporem cesty:
- $E = c_{wv(list)} - c_{wv(vzduch)} / r_s + r_b$

E = rychlost transpirace ($\text{mol m}^{-2}\ \text{s}^{-1}$)

[4.13]

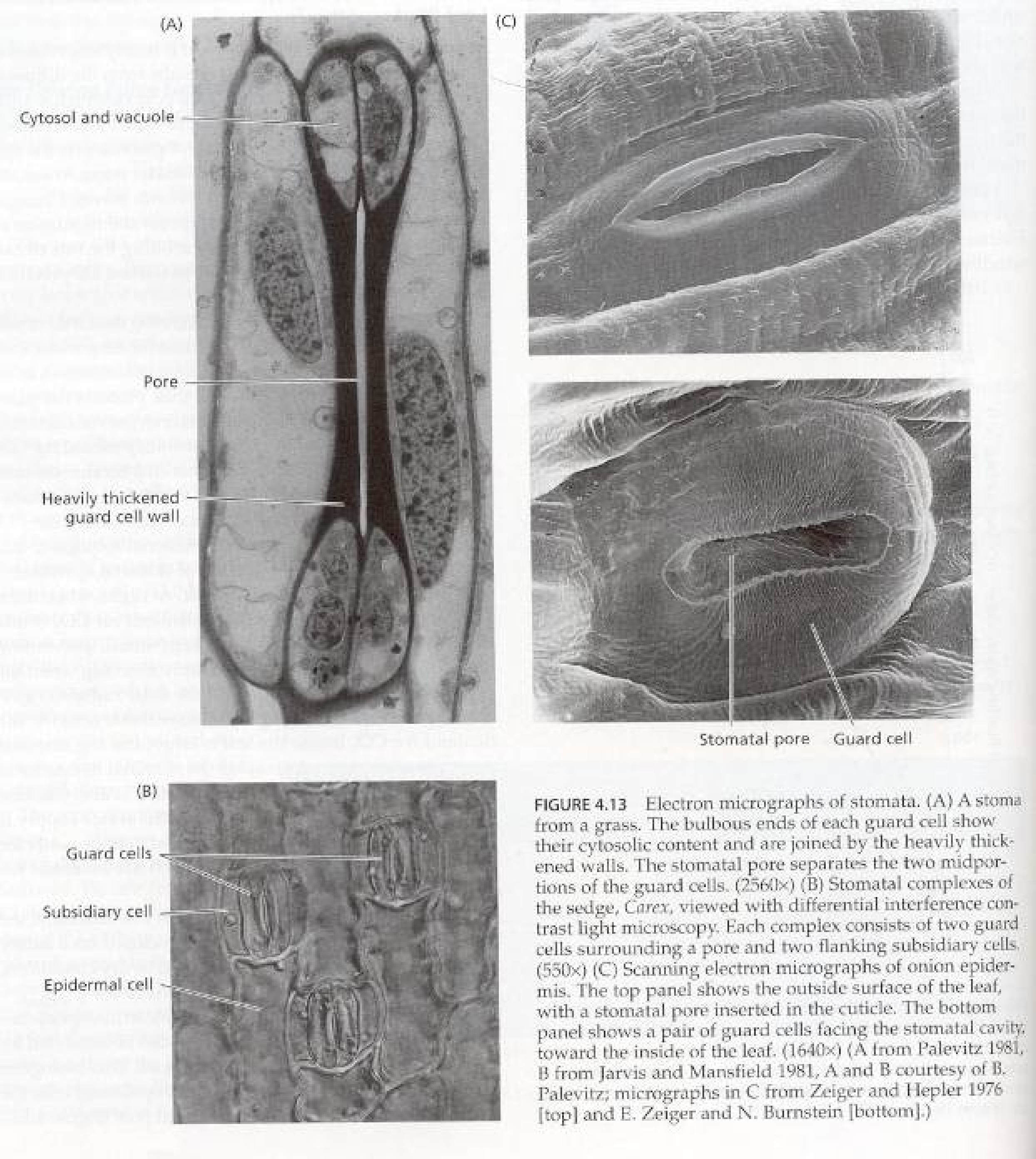


FIGURE 4.13 Electron micrographs of stomata. (A) A stoma from a grass. The bulbous ends of each guard cell show their cytosolic content and are joined by the heavily thickened walls. The stomatal pore separates the two midportions of the guard cells. (2560×) (B) Stomatal complexes of the sedge, *Carex*, viewed with differential interference contrast light microscopy. Each complex consists of two guard cells surrounding a pore and two flanking subsidiary cells. (550×) (C) Scanning electron micrographs of onion epidermis. The top panel shows the outside surface of the leaf, with a stomatal pore inserted in the cuticle. The bottom panel shows a pair of guard cells facing the stomatal cavity, toward the inside of the leaf. (1640×) (A from Palevitz 1981, B from Jarvis and Mansfield 1981, A and B courtesy of B. Palevitz; micrographs in C from Zeiger and Hepler 1976 [top] and E. Zeiger and N. Burnstein [bottom].)

CO_2 concentration and relative humidity was circulated. Photosynthesis and stomatal conductance increase in parallel with the amount of light reaching the leaf surface and decrease later in the day as the solar radiation declines. (From Schulze, 1970.)


(a) (b)

FIGURE 6.15. Stomata in detached epidermis of the broad bean *Vicia faba*, showing a wide-open stomatal pore (a) and a nearly closed pore (b). Stomatal apertures are measured under a microscope by recording aperture widths. Measurements of the change in aperture as a function of experimental conditions allow characterization of stomatal responses to different environmental stimuli. Bar = 20 μm. (Photos courtesy of G. Tallman and E. Zeiger.)

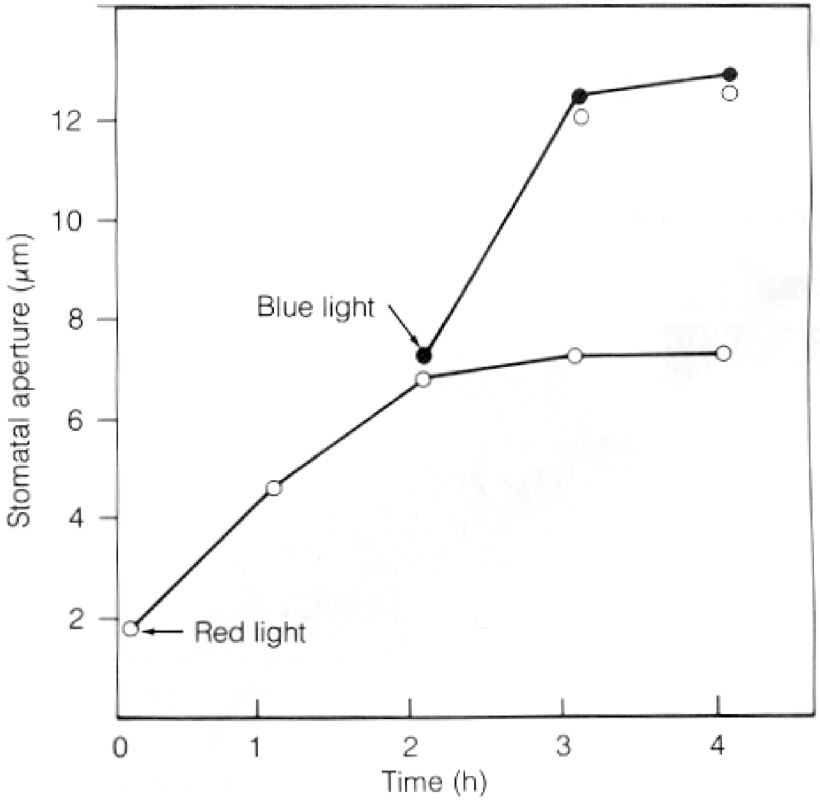


FIGURE 6.16. Changes in stomatal aperture as a function of time in stomata from detached epidermis of *Commelina communis* treated with red light at saturating fluence rates (open circles). In a parallel experiment, stomata exposed to red light also received blue light, added at the time indicated by the arrow. The increase in stomatal apertures above the level reached in the presence of saturating red light indicates that a second photosystem, responding to blue light, stimulates the aperture changes observed in the second phase of the experiment. (From Schwartz and Zeiger, 1984.)

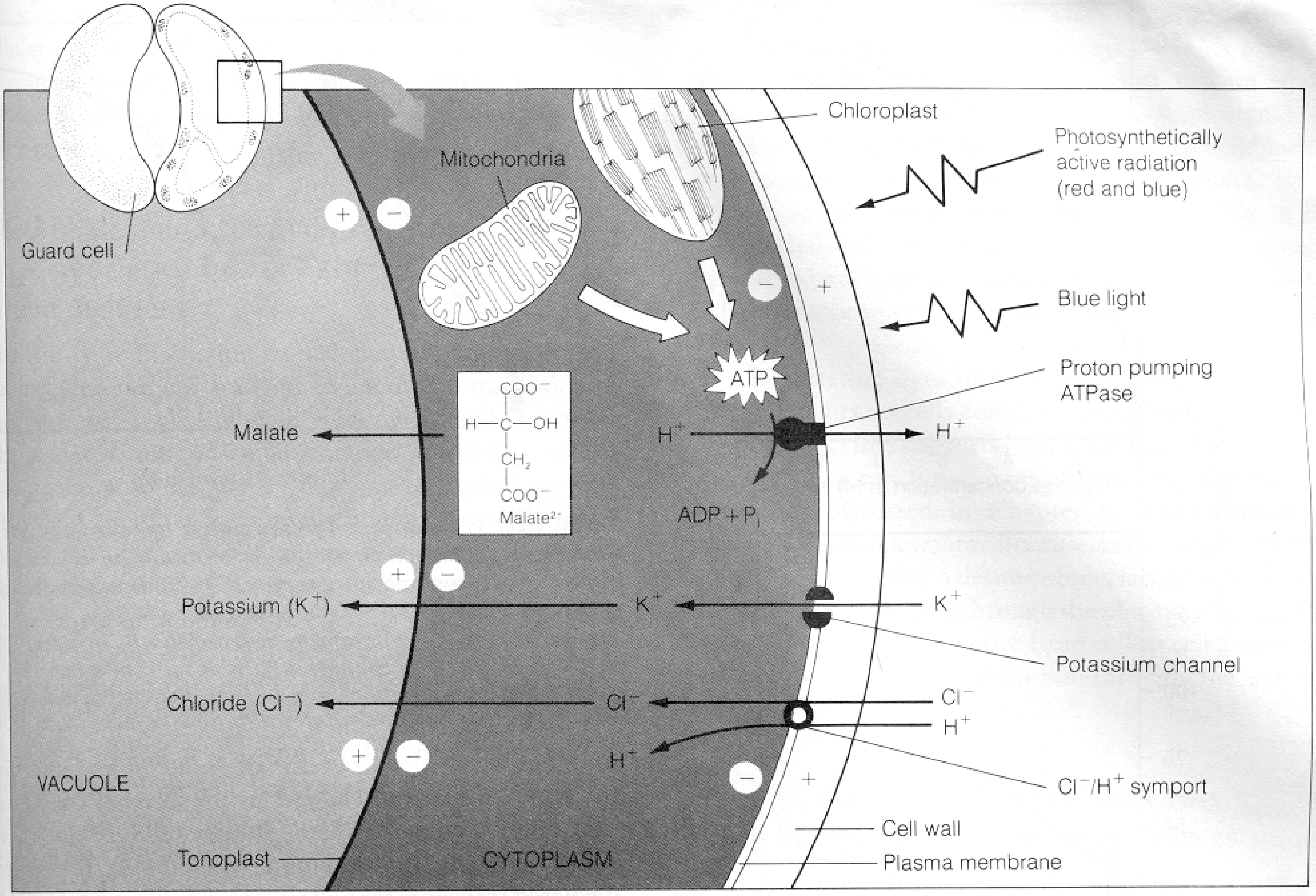


FIGURE 6.19. Stomatal guard cells have a light-activated H^+-pumping ATPase. Proton pumping is stimulated by photosynthetically active radiation via responses of the guard cell chloroplasts. The pump is also activated by a different photoreceptor system that is sensitive to blue light. The ATPase can be driven by ATP produced by the chloroplasts or by the mitochondria. The electrochemical proton gradient is used for uptake of potassium via K^+-specific channels. Chloride might be taken up via a Cl^-/H^+ symport. Malate is synthesized in the cytoplasm from carbon skeletons produced during starch hydrolysis in the chloroplast. Malate, K^+, and Cl^- are transported into the vacuole.