Ch. 15 Solutes, "Solutions", Solubility

skip (for test): 15. ~~2 ...~~ 5, 6, 9, 10

— homogeneous (uniform) mixture, usually liquid (also gas)

Q: Why does alcohol, salt, & sugar dissolve in water, but oil doesn't?

Facts: ① all gases mix fully
② Only some liquids & solids dissolve in a given "solvent"

- "solvent" ↑ major ~~component~~ liquid
- liquids → miscible or immiscible
- solids → soluble or insoluble

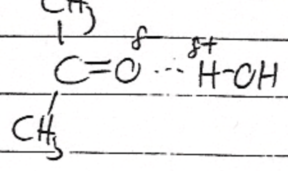
"Solute": minor component

15.1 Solubility and Noncovalent Forces

① Water is Strongly Polar

Dissolves	Solute-Solvent Interaction
"hydrophilic" a) many ionics	$Na^{\oplus} \cdots {}^{\delta-}OH_2$, $Cl^{\ominus} \cdots {}^{\delta+}H\text{-}OH$ ion-dipole
b) H-bonders	H-bond
c) molecules with N or O	H-bond

— H bond water, even if can't H-bond self



Won't Dissolve

hydrophobic {
a) nonpolar
b) hydrocarbon, halocarbon C_6H_{14}, C_2H_5Cl
c) weakly polar without N, O, F
- so can't H-bond (PCl_3, $SiHCl_3$ ...)

② Hydrocarbons/halocarbons are nonpolar/weakly polar
- oils, grease, fat, gasoline
- don't mix with water
- do dissolve related nonpolar/weakly polar things (other hydrophobics)

③ adding C's to molecule reduces H_2O-solubility

④ "Like Dissolves Like"
Hydrophilic - hydrophilic Yes
Hydrophobic - hydrophobic Yes
Hydrophilic - hydrophobic NO!!
- more alike, more soluble!
↳ in IMF

Why? IMF between solute-solvent results.
If comparable, ⇒ good (CH_3OH in H_2O) Fig 15.
improved ⇒ good ($H_2C{=}O$ in H_2O)
inferior ⇒ "bad!!" (CH_4 in H_2O)

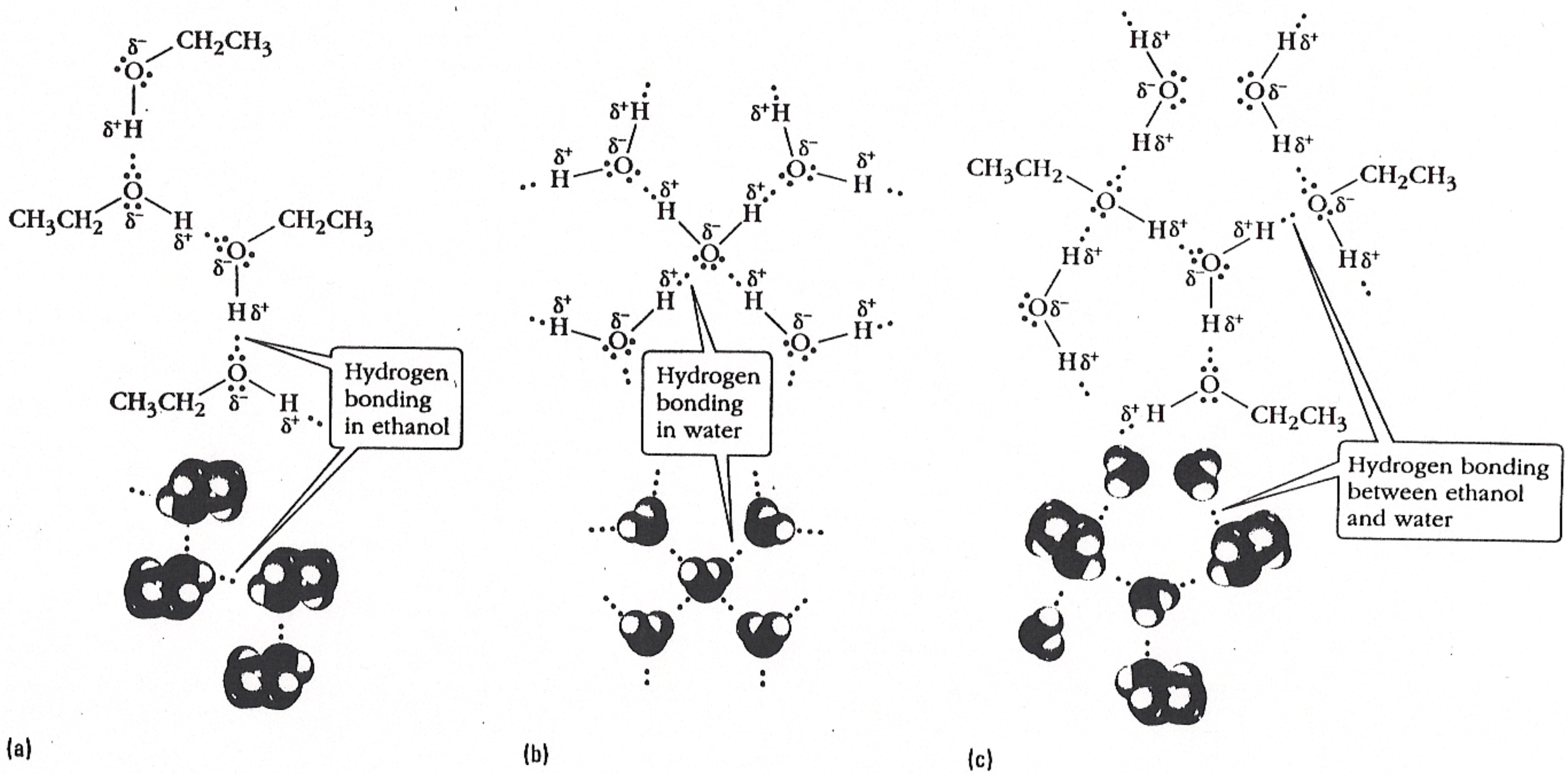


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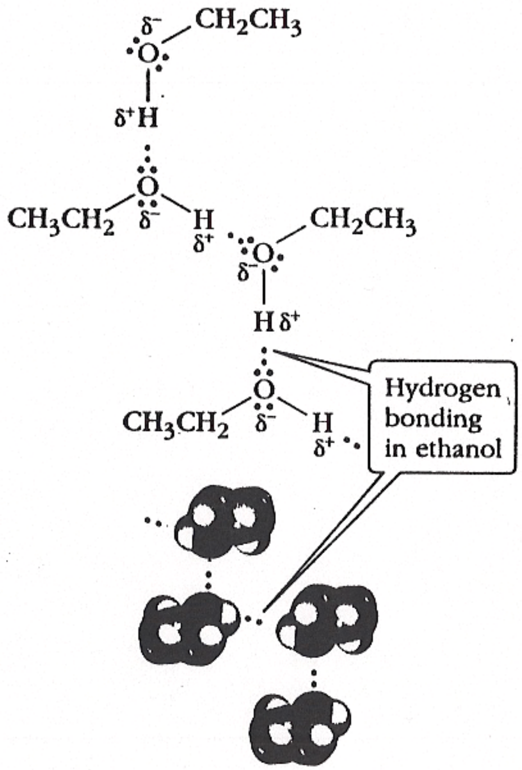
Figure 15.2



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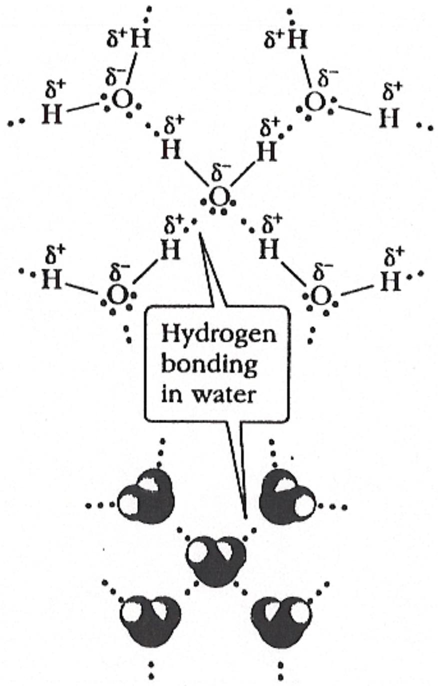

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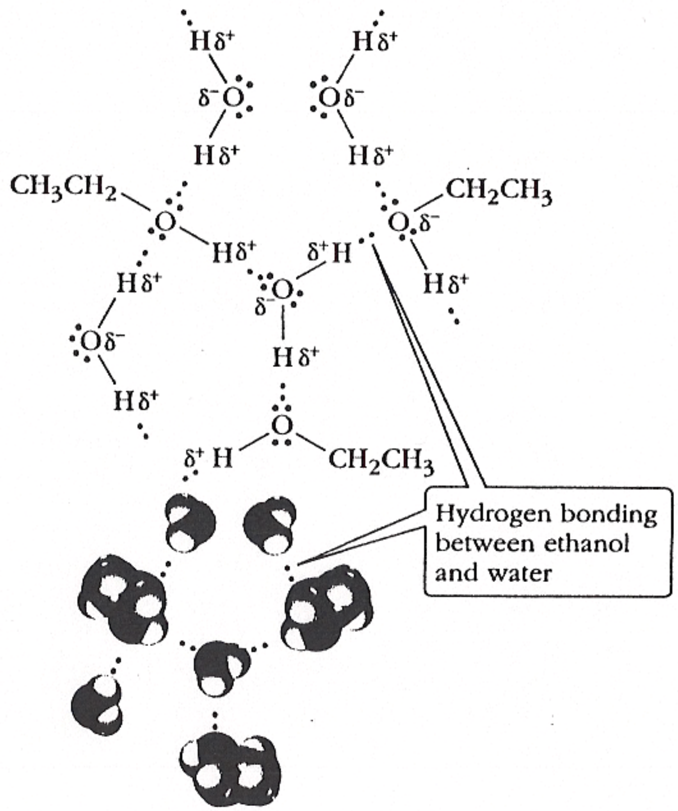

(c)

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Figure 15.2

1. More Soluble in H_2O or C_6H_{14}

a. NH_3

b. Br_2

c. $C_{12}H_{26}$

d. $CHCl_3$

e. CH_3OCH_3

2. Which is more soluble in water?

a. CH_3NH_2 or CH_3Cl

b. $MgCl_2$ C_6H_5Cl

c. $C_4H_{11}OH$ C_2H_5OH

3. Which is more soluble in CCl_4?

a. C_6H_{10} C_3H_7OH

b. $C_4H_{11}OH$ CH_3OH

Chem 160

① More Soluble in H_2O (polar) or C_6H_{14} (nonpolar)

a. NH_3 — H_2O ✓

b. Br_2 — C_6H_{14} X

c. $C_{12}H_{26}$ — C_6H_{14} X

d. $CHCl_3$ — C_6H_{14} X

(b–d: weakly polar or nonpolar)

e. CH_3OCH_3 — H_2O X

↳ can H-bond water: CH_3OCH_3 ⋯ H–OH

② Which is more soluble in water?

a. (CH_3NH_2) or CH_3Cl

b. ($MgCl_2$) C_6H_5Cl

c. $C_4H_{11}OH$ (C_2H_5OH)

↖ more C's less like water

③ Which is more soluble in CCl_4? (↳ nonpolar)

a. (C_6H_{10}) C_3H_7OH

b. ($C_4H_{11}OH$) CH_3OH

more C's, more hydrophobic

15.2, 15.1 Enthalpy, Entropy + Dissolving Solutes

A. 2 Factors Influence the Spontaneity of Any Process

① Energy/enthalpy: Exo (good) or endo (back

② "Entropy": the order/disorder

— increasing disorder is natural ≡ "good (desk, office, brain, etc.)

— easy to decide if both agree (exo, disorder) but not if they disagree

B. Disorder increases for dissolving

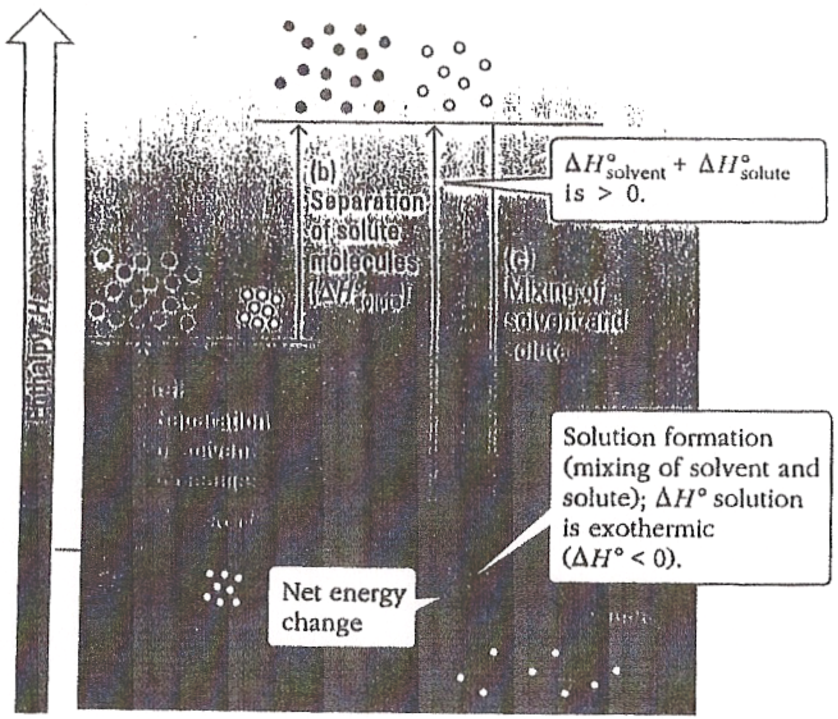
Solubility is primarily entropy-driven

+ Entropy always favors solubility (almost

When will something not dissolve: If enthalpy is so bad (endo) that it overrides entropy.

Enthalpy	Entropy	Overall
good ($\Delta H < 0$)	good	Yes!
indifferent ($\Delta H \approx 0$)	good	Yes!
slightly bad $\Delta H > 0$, but small	good	Yes (entropy wins) controls
very bad $\Delta H \gg 0$	good	No (enthalpy controls)

An exothermic solution-making process



An endothermic solution-making process

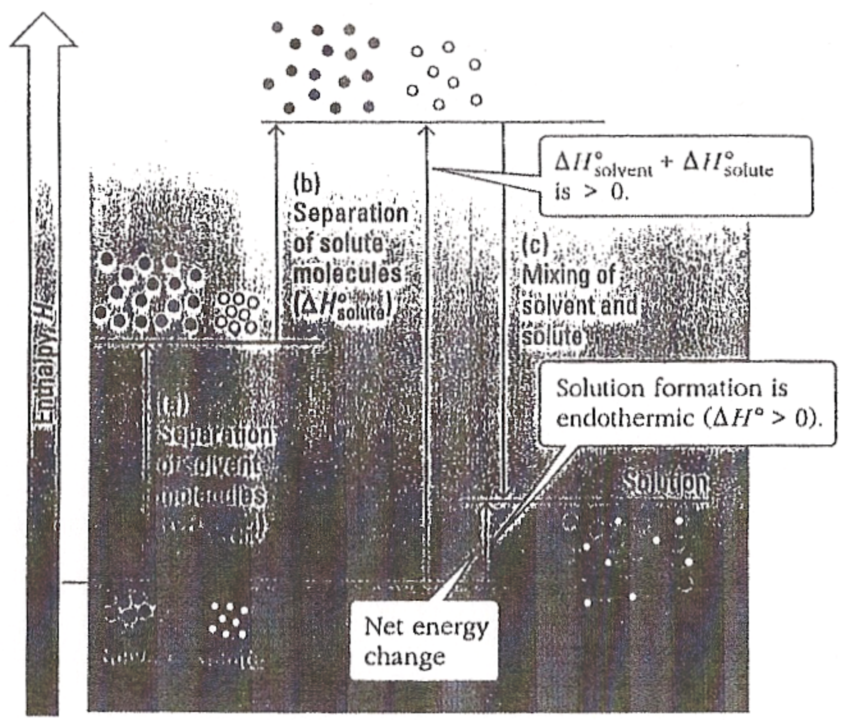


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Figure 15.3

Point: solubility fails only if strongly endothermic!
- if exo, neutral, or only weakly endo, solubility succeeds

C. Solubility Enthalpy

Trade Old Forces for New Forces

solute-solute solute-solvent
solvent-solvent

Fig 15.3

If new are comparable or better than old, then $\Delta H \leq 0$ (exo or neutral)

If new are weaker, then $\Delta H > 0$ (endo)

Only if new interactions are weaker than old will ΔH be sufficiently endo to veto solubility

D. Why Like Dissolves Like
- in like/like, new forces resemble old!!

hilic + philic → strong → strong so $\Delta H \approx 0$ [Entropy ⇒ soluble]

hobic + phobic
weak → weak

in like/unlike, new forces much worse so $\Delta H > 0$ [Enthalpy ⇒ insoluble]

philic + phobic
strong + weak → weak

Point: solubility fails only if strongly endothermic!
- if exo, neutral, or only weakly endo, solubility succeeds

C. Solubility Enthalpy

Trade Old Forces	for	New Forces
solute-solute		solute-solvent
solvent-solvent		

Fig 15.3

If new are comparable or better than old, then $\Delta H \le 0$ (exo or neutral)
If new are weaker, then $\Delta H > 0$ (endo)

Only if new interactions are weaker than old will ΔH be sufficiently endo to veto solubility

D. Why Like Dissolves Like
- in like/like, new forces resemble old!!
philic + philic → strong → strong so $\Delta H \approx 0$ (Entropy ⇒ soluble)
phobic + phobic
weak → weak
- in like/unlike, new forces much worse so $\Delta H > 0$ (Enthalpy ⇒ insoluble)
philic + phobic
strong + weak → weak

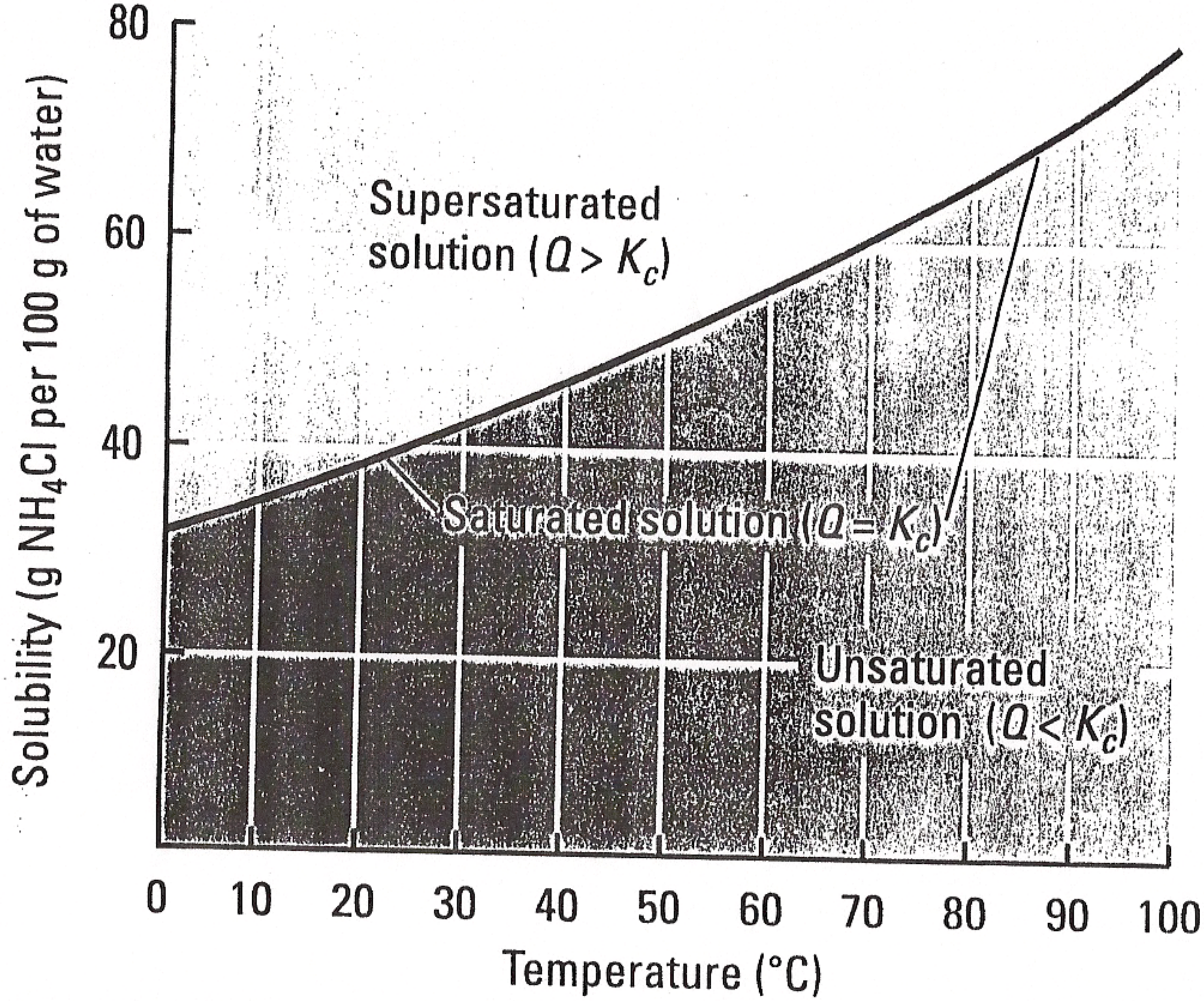

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Figure 15.4

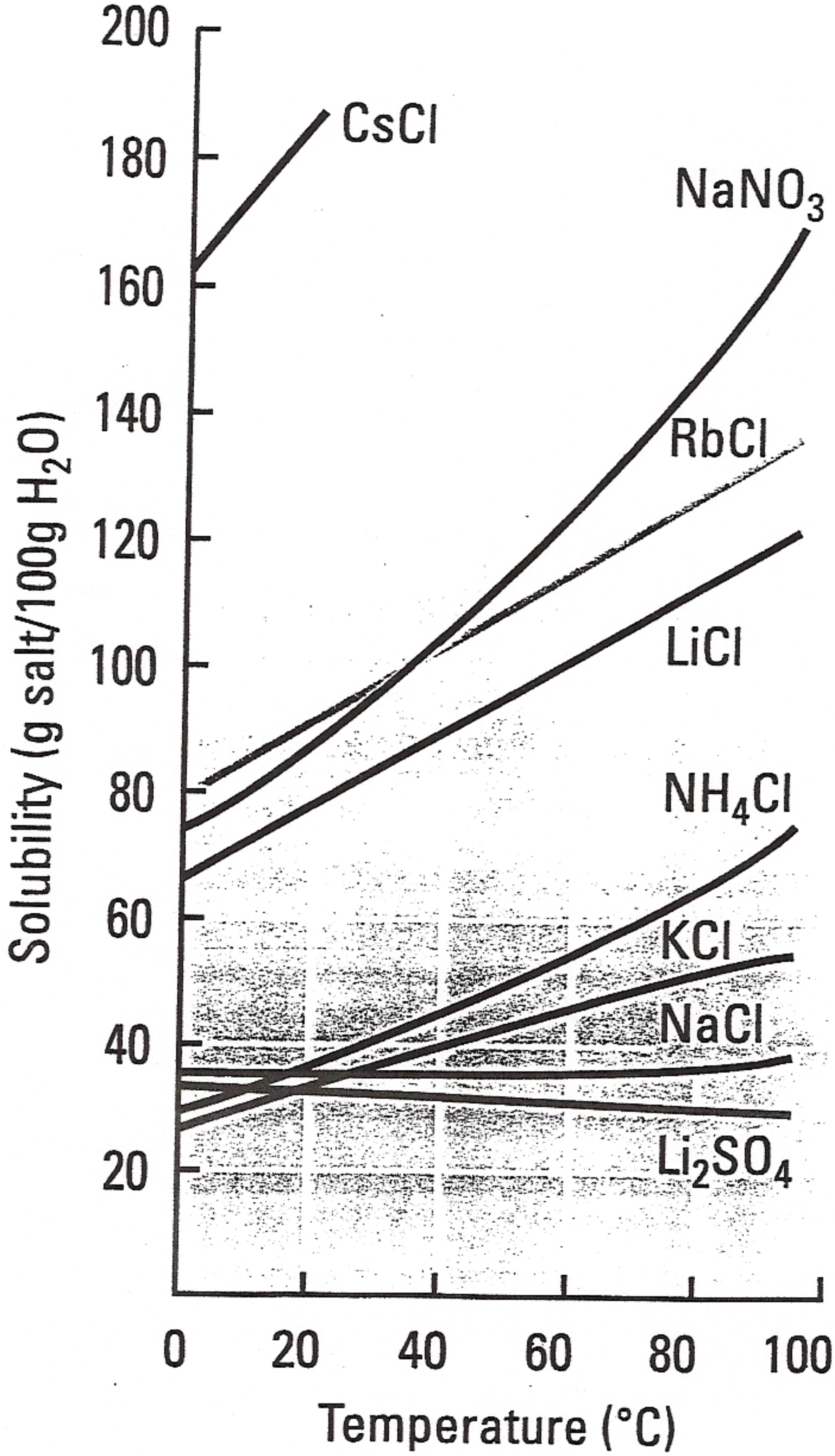

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Figure 15.10

15.3 Solubility + Equilibrium
"water can dissolve only so much solute!"

"unsaturated" – could hold more
"saturated" – holds as much as it can

– in a saturated solution, a dynamic equilibrium exists between dissolved & undissolved solute

$$\text{solid, undissolved} \underset{\text{crystallizes}}{\overset{\text{dissolves}}{\rightleftharpoons}} \text{dissolved solution}$$

– a steady state quantity of dissolved stuff

Practical

ex: $MgO_{(s)} + 2HCl \rightarrow H_2O + MgCl_2$

① solubility for ionic things varies
 – most things at least partly soluble
 – "soluble" means > 10g / 100 mL
② more volume of solvent can dissolve more stuff
③ for solids, solubility increases as temperature goes up (15.4) Fig 15.4
④ temp-based crystallization: if a hot saturated solution is cooled → solubility drops → crystal grows
⑤ "supersaturated" – more than max, because not at equilibrium – can't crystallize without a seed
 – add seed, get crystal growth

Ionic solids in water

old force: ionic bonds

new force: ion-dipole

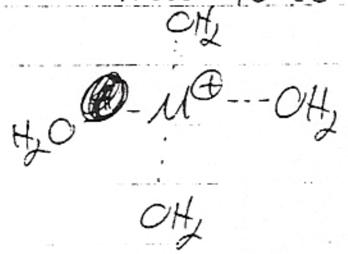
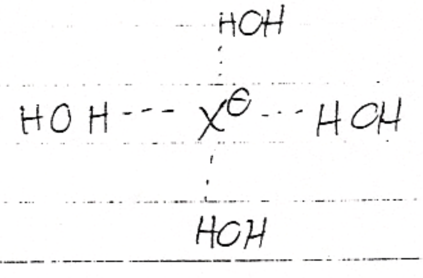


Fig 15.6

"hydration"

- normally +1, -1 ions hydrate well, dissolve well
- +2, +3 ions don't



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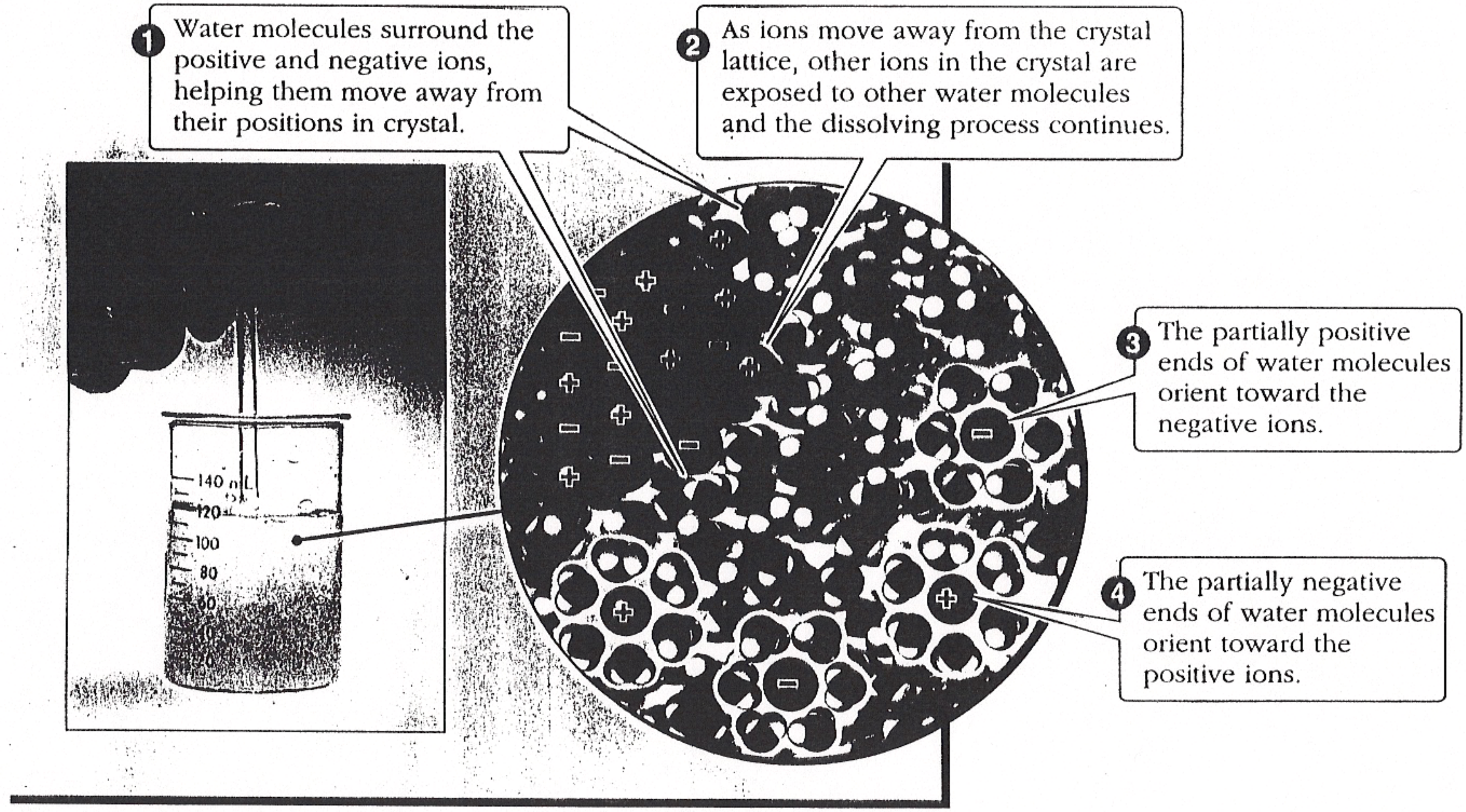

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Figure 15.6

bring Frosty Mug

15.7 Impact of Solutes on 3 Properties
- solutes alter properties that involve phase changes
- dissolved solute dilutes the solvent
- the molar quantity of dissolved particles is what matters
"molality" = moles solute particles/kg solvent

① Vapor Pressure is Reduced
- if solvent is diluted by solute, proportional reduction in vapor pressure
- fewer solvent molecules to escape, reduced escape rate
(ex 95% solvent ⇒ 95% of VP)
5% solute

☆ ② BP is Elevated
- "salt" raises bp of soup, etc.
- increased molality ⇒ reduced VP/escape rate
⇒ need to raise temp to make up for it for boiling
(since VP = external pressure at bp)

☆☆ ③ Freezing point (mp) is Depressed
- solutes lower mp
- salt on ice ($CaCl_2$)
- freezing range not only lowered but greatly broadened: ice freezes as pure water, so remaining solution gets more & more rich in solute!

why: as solvent is diluted, fewer able to crystallize, so freezing slows down, need to get colder to force it

Key: depends on moles (not g) of particles (proportional) (ionics can split into many)

① For the following, how many moles of solute particles are produced when 1 mole of "formula" is dissolved?

a. C_3H_8O

b. $NaCl$

c. Na_2SO_4

d. $Mg_3(PO_4)_2$

② Which would depress mp more, adding 1 mole of CH_3OH or 0.5 mol of $Al(NO_3)_3$?

③ If 1 mole of CH_3OH depressed a solvent mp by 12°C, how much would the mp be depressed by 0.5 mole of $Al(NO_3)_3$?

④ $C_6H_{12}O_6$ 180g/mol LiF 26g/mol
Which would inflate bp more, adding 45g $C_6H_{12}O_6$ or 6.5 g LiF??

① For the following, how many moles of solute particles are produced when 1 mole of "formula" is dissolved?

a. C_3H_8O molecular 1

b. NaCl ionic 2 $1 Na^+ + 1 Cl^-$

c. Na_2SO_4 ionic 3 $2 Na^+ + 1 SO_4^{2-}$

d. $Mg_3(PO_4)_2$ ionic 5 $3 Mg^{2+} + 2 PO_4^{3-}$

② Which would depress mp more, adding 1 mole of CH_3OH or 0.5 mol of $Al(NO_3)_3$?

CH_3OH ↓ 1 mol particles

$Al(NO_3)_3$ ↓ 2 moles of particles $\equiv$ 0.5 Al^{3+} + 1.5 mol NO_3^-

③ If 1 mole of CH_3OH depressed a solvent mp by 12°C, how much would the mp be depressed by 0.5 mole of $Al(NO_3)_3$?

24°C Twice as many particles, twice as much depression

④ $C_6H_{12}O_6$ 180 g/mol LiF 26 g/mol
Which would inflate bp more, adding 45 g $C_6H_{12}O_6$ or 6.5 g LiF??

45 g $C_6H_{12}O_6$ ↓ 0.25 mol

6.5 g LiF ↓ 0.25 mol Li^+ + 0.25 mol F^-

15.8 Osmosis: selective movement of a solvent through a semipermeable membrane

① usually motivated by a desire to equalize concentrations

② normally solvent moves from "dilute" to concentrated side (in order to dilute the conc. side)

③ membrane is selective: only some things (usually solvent) can pass through (like a sieve, a filter)
- usually based on size (not always)

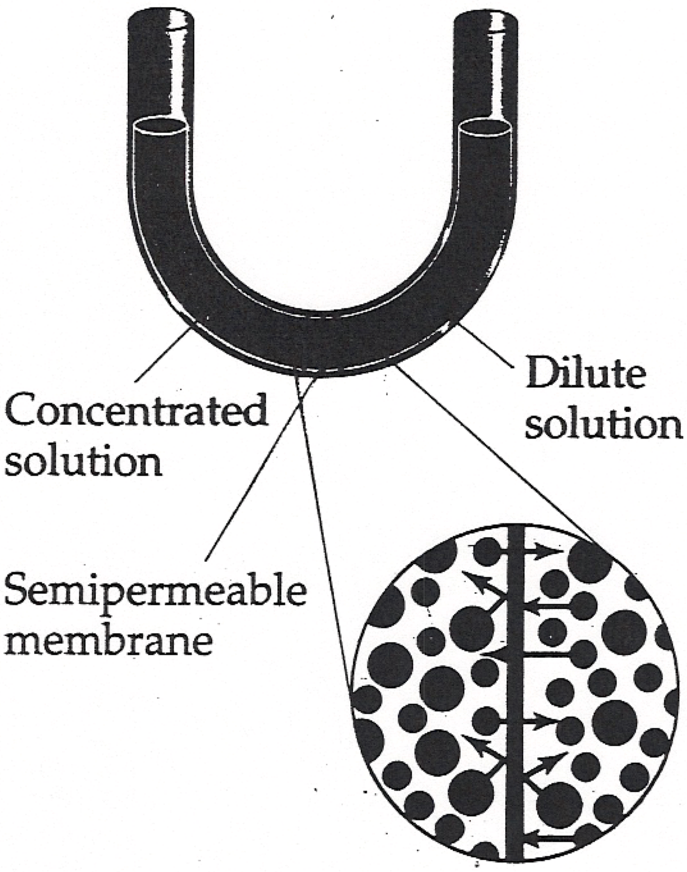
volume of "conc" side	⇒ grows
dilute	⇒ shrinks

④ osmotic "pressure" - can be quantified

"theory - equilibrium desired at membrane. Due to solutes, passage of solvent to conc. side is greater. For pressure case, extra gravity "pressure" needed to make up for it."

⑤ reverse osmosis: pressure pushes solvent through membrane, leaves salt behind ⇒ pure water (Saudi Arabia, etc.)

Fig. 13.20 Osmosis



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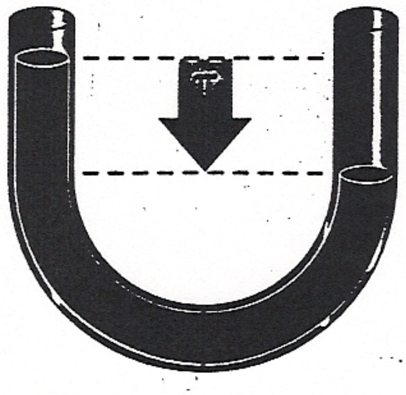

(b)

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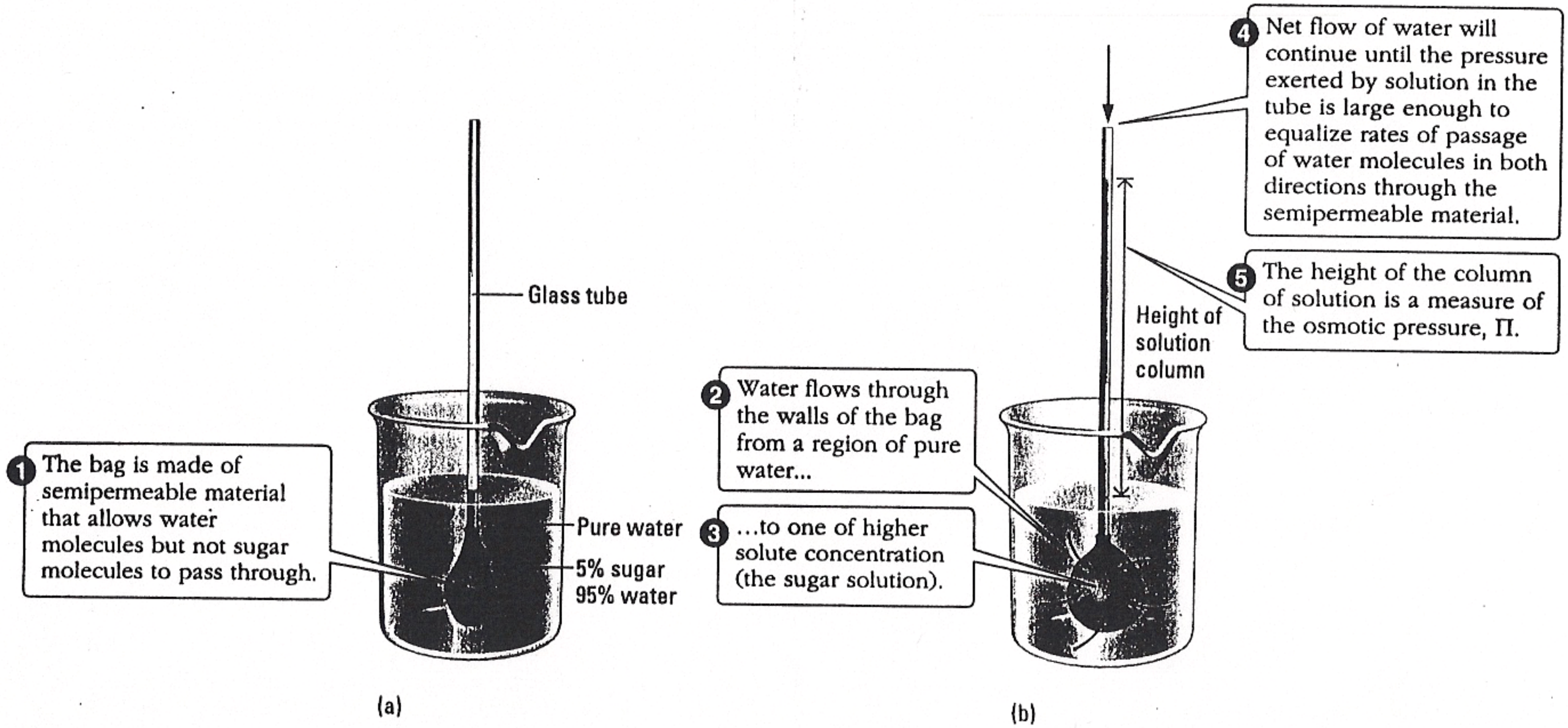

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Figure 15.18

Cells: modest salt concentration.

① Shrink/dehydrate in "hypertonic" soln. (sa

② Swell/burst in "hypotonic" soln. (pure water) ("lyse" cells for biology)

- impact on "hydrating" a dehydrated person: just water will burst the cells!

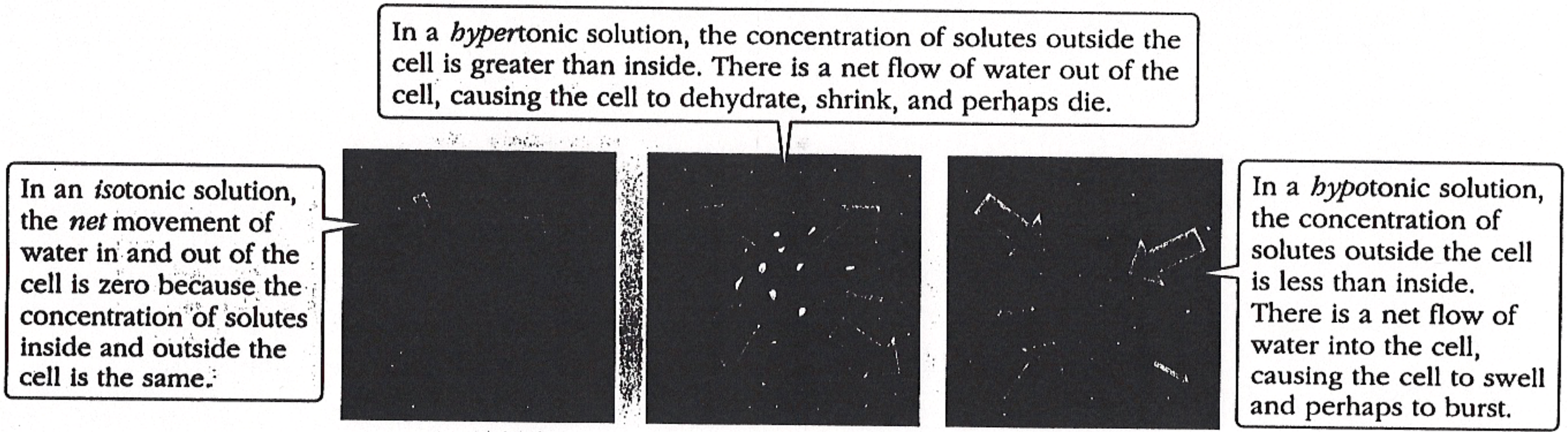
Pickles: shrink cucumber in high salt

Salt/sugar meat/fruit: bacteria get dehydrated, die ⇒ preserves "dried" meat

H_2O transport in plants: absorb water from soil

Diabetes: bad metabolism ⇒ high conc ⇒ need water in

edema: salty food ⇒ water retention ⇒ puffiness.



(a) Isotonic solution (b) Hypertonic solution (c) Hypotonic solution

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Figure 15.19