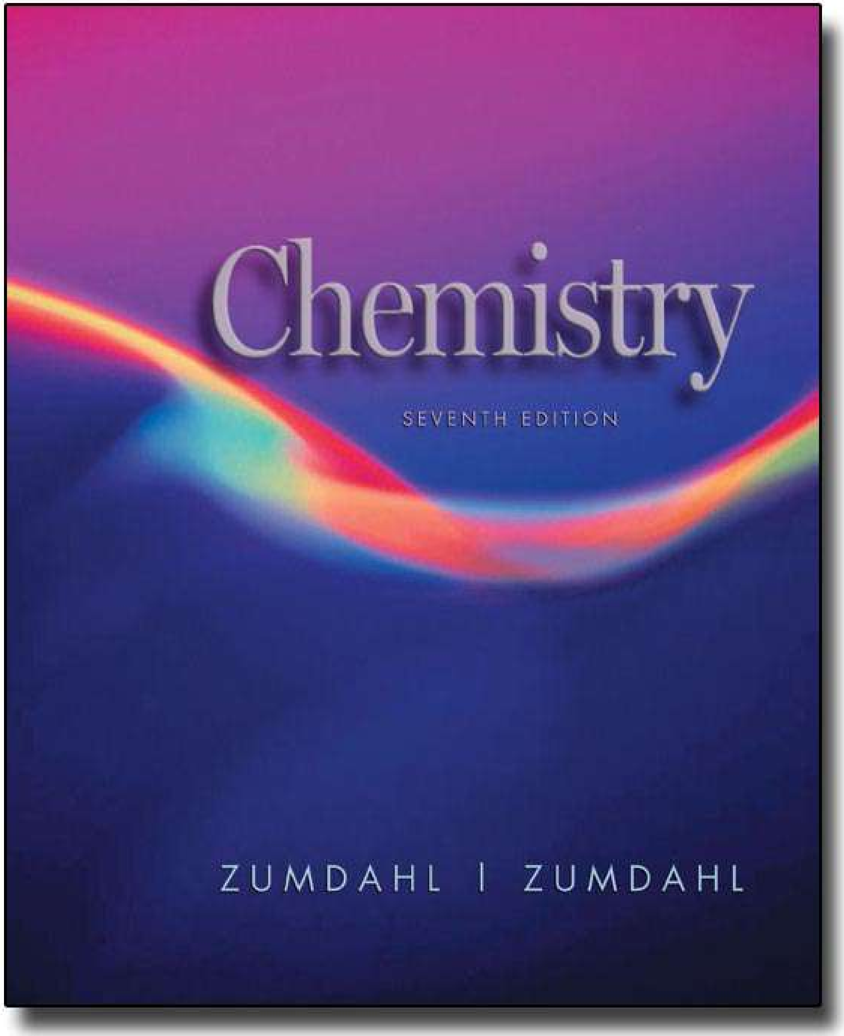
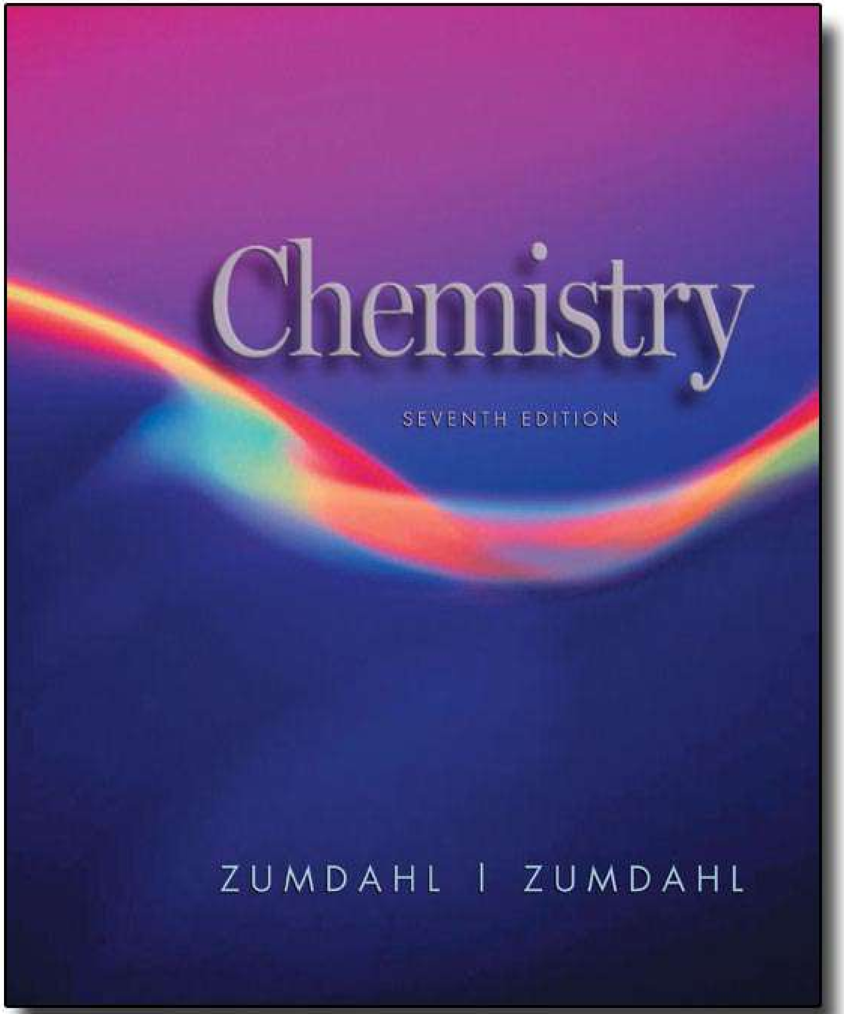


Chapter Eleven:

PROPERTIES OF SOLUTIONS



Solution Composition

Sign Using Electronic Ink

Table 11.1 Various Types of Solutions

TABLE 11.1 Various Types of Solutions

Example	State of Solution	State of Solute	State of Solvent
Air, natural gas	Gas	Gas	Gas
Vodka in water, antifreeze	Liquid	Liquid	Liquid
Brass	Solid	Solid	Solid
Carbonated water (soda)	Liquid	Gas	Liquid
Seawater, sugar solution	Liquid	Solid	Liquid
Hydrogen in platinum	Solid	Gas	Solid

Solution Composition

1. Molarity (M) = $\dfrac{\text{moles of solute}}{\text{liters of solution}}$

2. Mass (weight) percent = $\dfrac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$

3. Mole fraction (χ_A) = $\dfrac{\text{moles}_A}{\text{total moles in solution}}$

4. Molality (m) = $\dfrac{\text{moles of solute}}{\text{kilograms of solvent}}$

Table 11.2 The Molar Mass, Equivalent Mass, and Relationship of Molarity and Normality for Several Acids and Bases

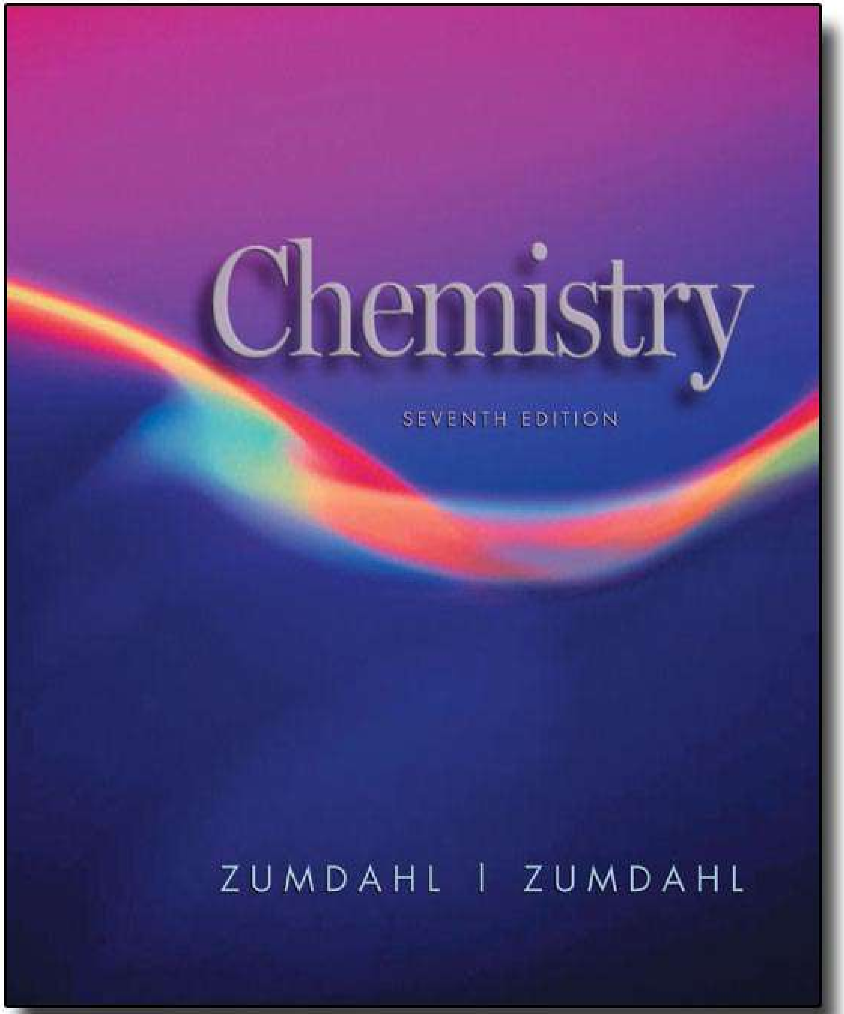
TABLE 11.2 The Molar Mass, Equivalent Mass, and Relationship of Molarity and Normality for Several Acids and Bases

Acid or Base	Molar Mass	Equivalent Mass	Relationship of Molarity and Normality
HCl	36.5	36.5	$1\ M = 1\ N$
H_2SO_4	98	$\frac{98}{2} = 49$	$1\ M = 2\ N$
NaOH	40	40	$1\ M = 1\ N$
$Ca(OH)_2$	74	$\frac{74}{2} = 37$	$1\ M = 2\ N$

A Modern 12-volt Lead Storage Battery of the Type Used in Automobiles

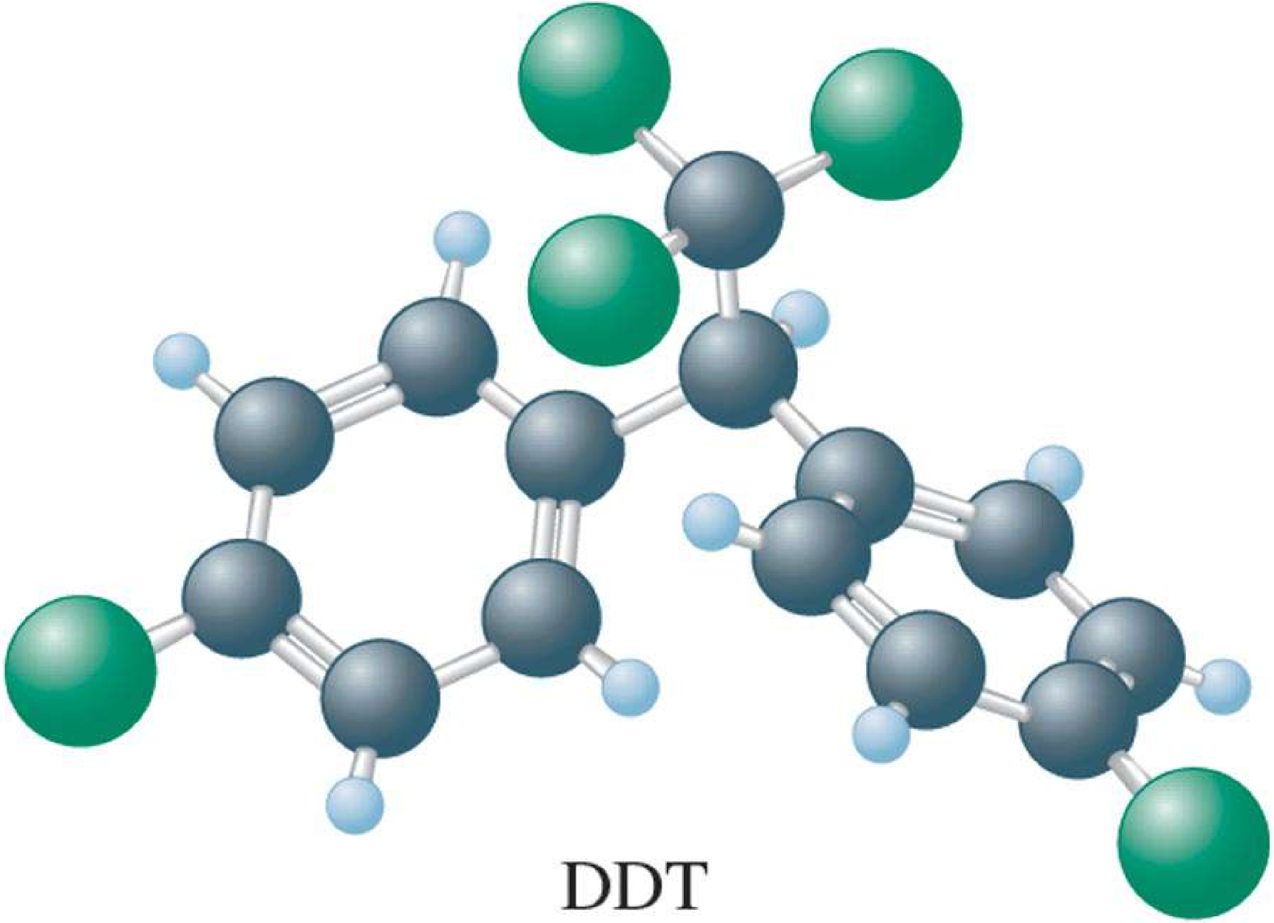
React 1

Consider two aqueous solutions, A and B (which contain different solutes). Is it possible for solution A to have a greater concentration than solution B in terms of mass percent, but a smaller concentration in terms of molarity? If no, explain why not. If yes, provide an example. What if the solutions contained the same solute?



The Energies of Solution Formation

DDT



DDT

The Steps in the Dissolving Process

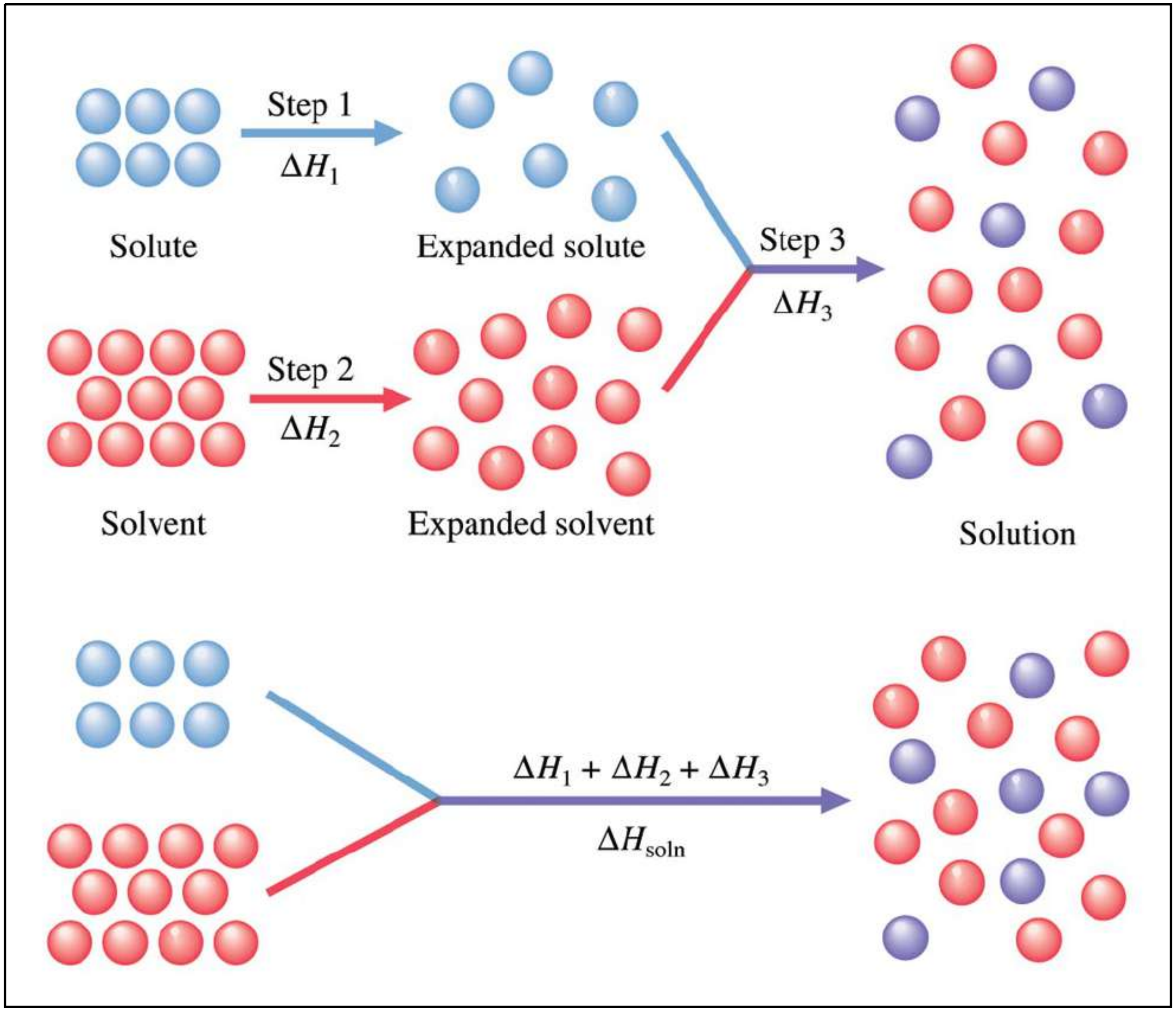
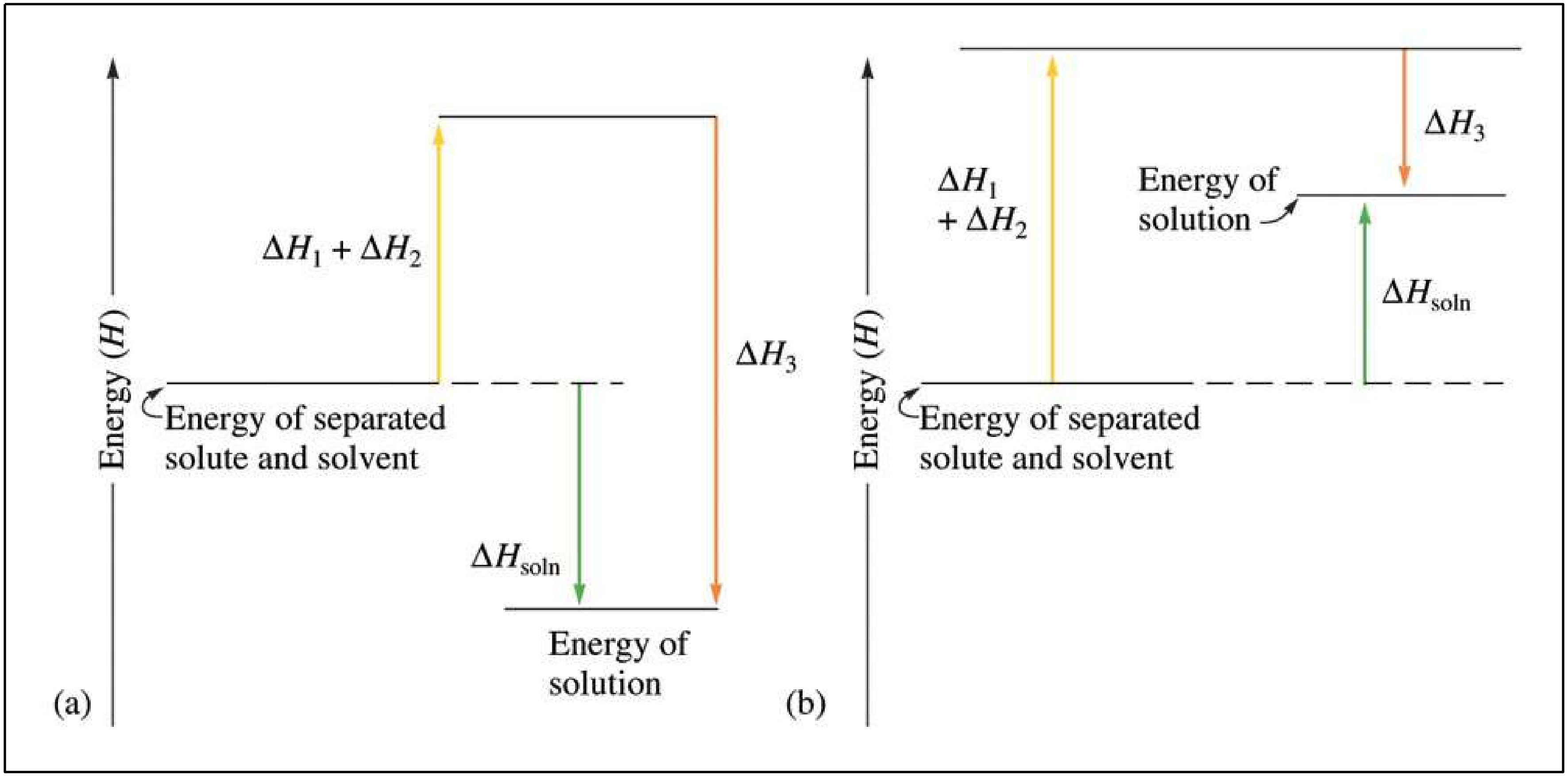


Figure 11.2 a&b (a) Exothermic and (b) Endothermic



Gasoline Floating on Water

Think About It

- What does the term “hydrophobic” mean?
- Oil is sometimes termed “hydrophobic”. Why? Also, why is the term “hydrophobic” not really correct?

React 2

Refer to Figure 11.1 in your text when answering the following. In your explanations, estimate the ΔH values of the various processes for solution formation (large or small, positive or negative), order these according to magnitude (absolute values), and explain.

a) Explain why water and oil (a long chain hydrocarbon) do not mix.

b) Explain why two different oils (oils are long chain hydrocarbons) will mix.

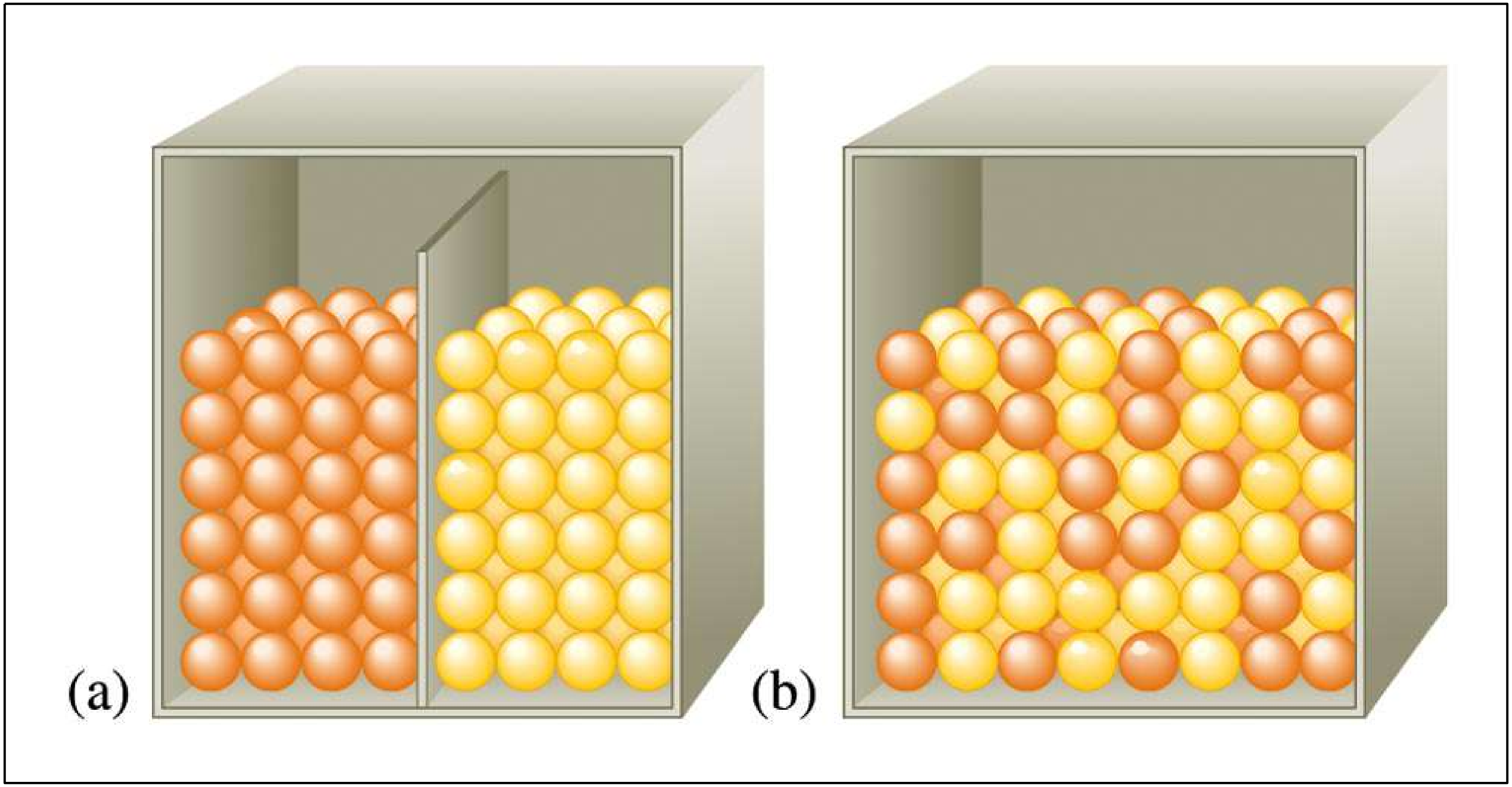
c) Explain why water and another polar liquid will mix.

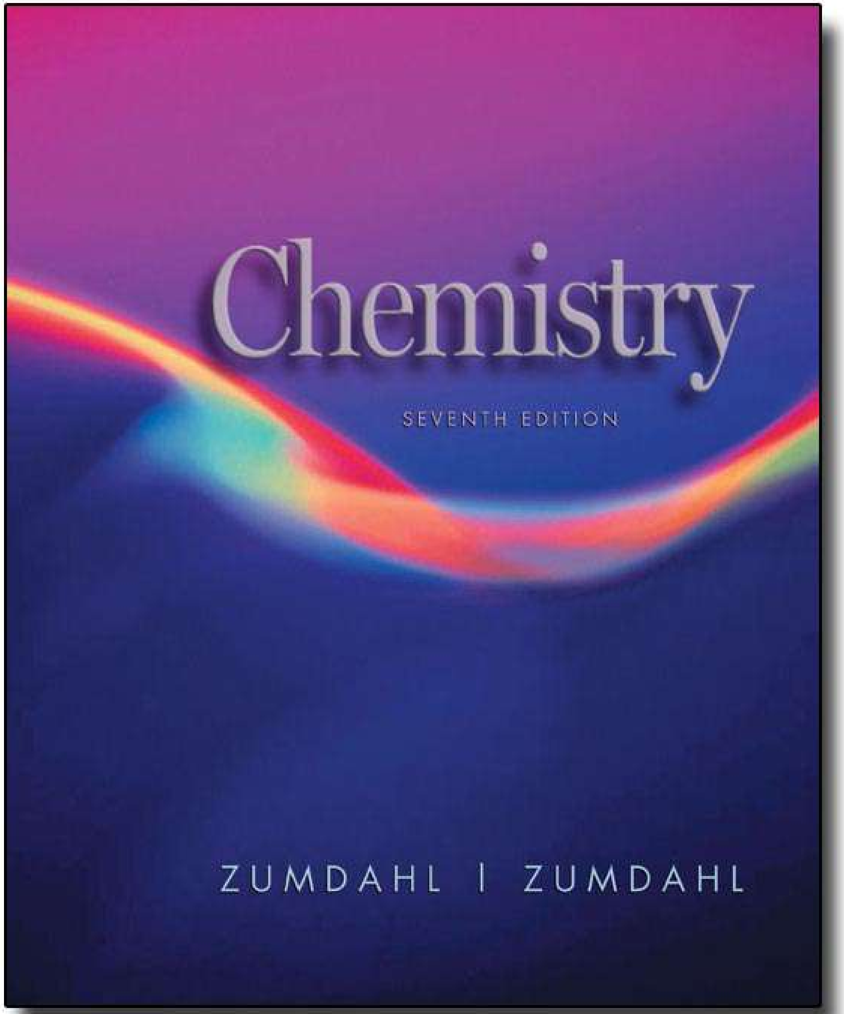
Table 11.3 The Energy Terms for Various Types of Solutes and Solvents

TABLE 11.3 The Energy Terms for Various Types of Solutes and Solvents

	ΔH_1	ΔH_2	ΔH_3	ΔH_{soln}	Outcome
Polar solute, polar solvent	Large	Large	Large, negative	Small	Solution forms
Nonpolar solute, polar solvent	Small	Large	Small	Large, positive	No solution forms
Nonpolar solute, nonpolar solvent	Small	Small	Small	Small	Solution forms
Polar solute, nonpolar solvent	Large	Small	Small	Large, positive	No solution forms

Figure 11.3 a-b The Probability of a Mixed State



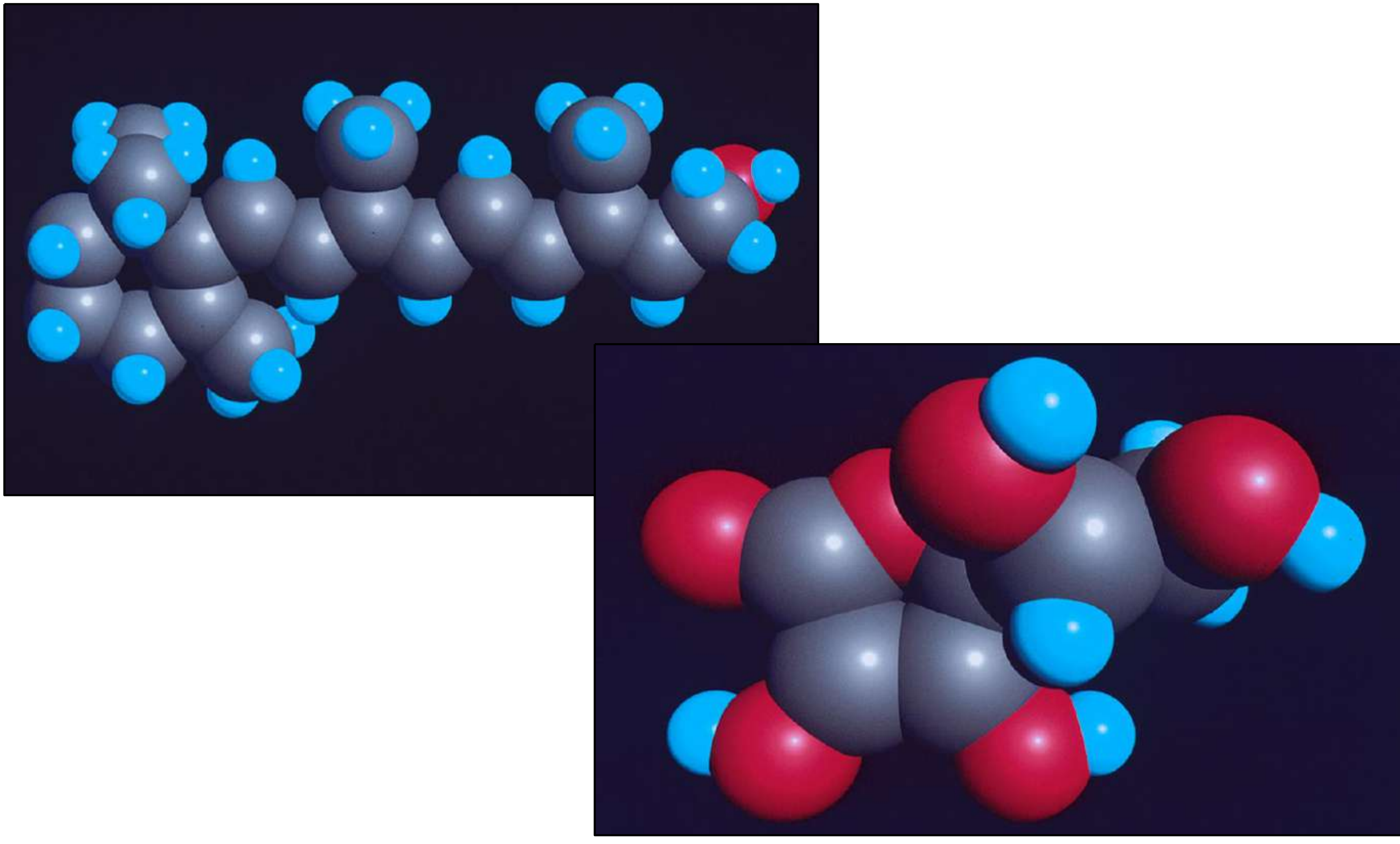


Factors Affecting Solubility

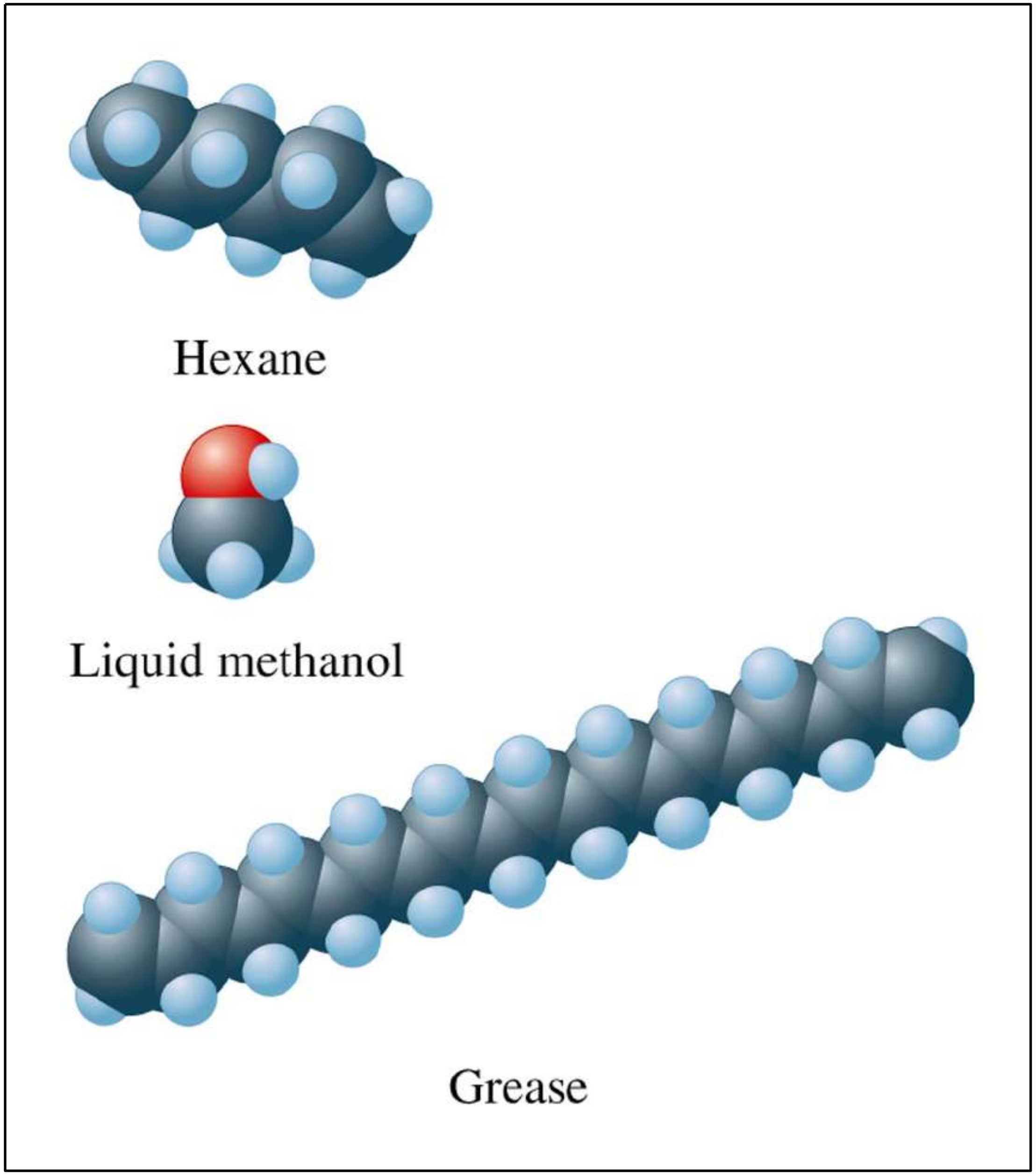
Factors Affecting Solubility

- Structural Effects
- Pressure Effects
- Temperature Effects

Figure 11.4 The Molecular Structures of (a) Vitamin A and (b) Vitamin C



Hexan,
Liquid
Methanol,
Grease



The Solubilities of Several Solids as a Function of Temperature

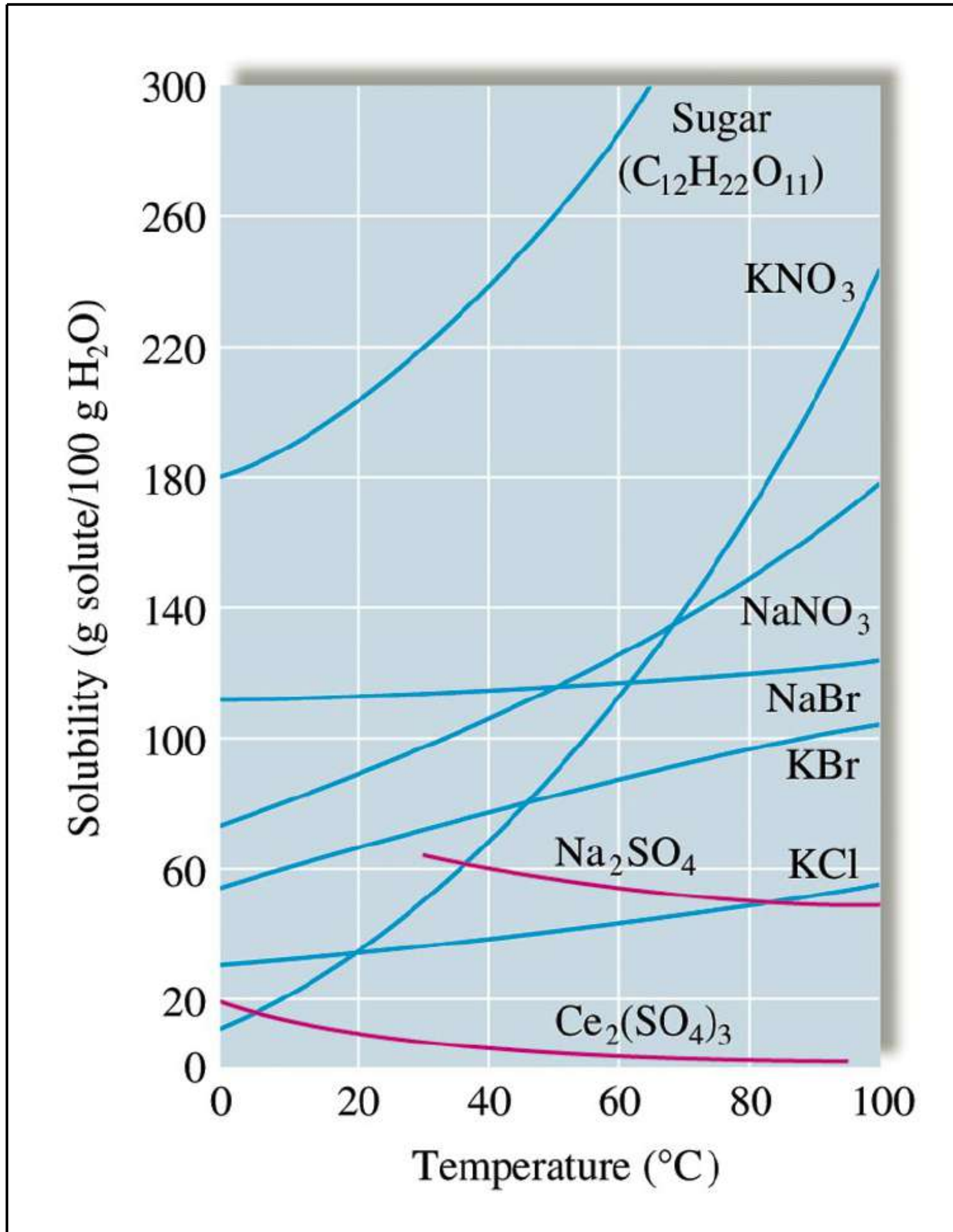
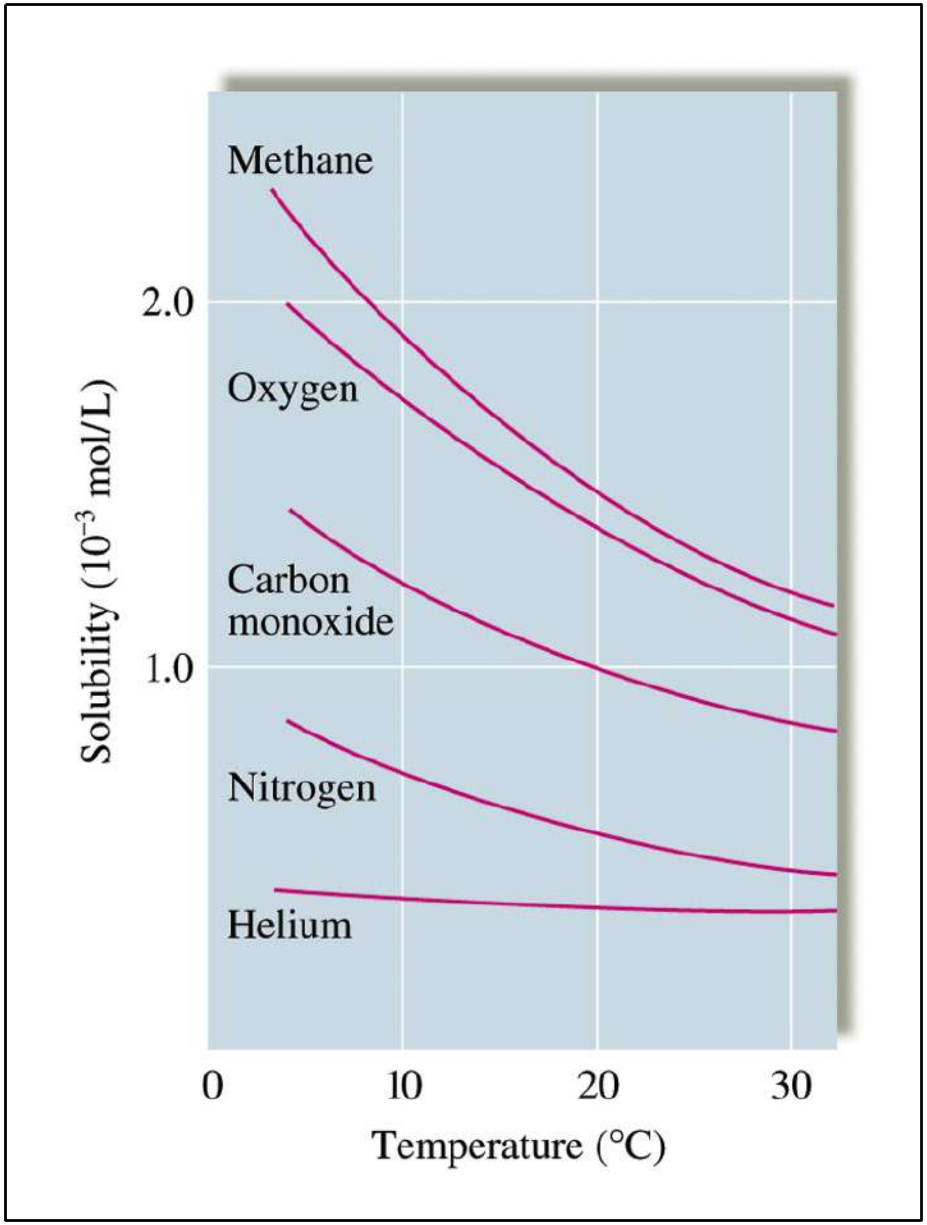
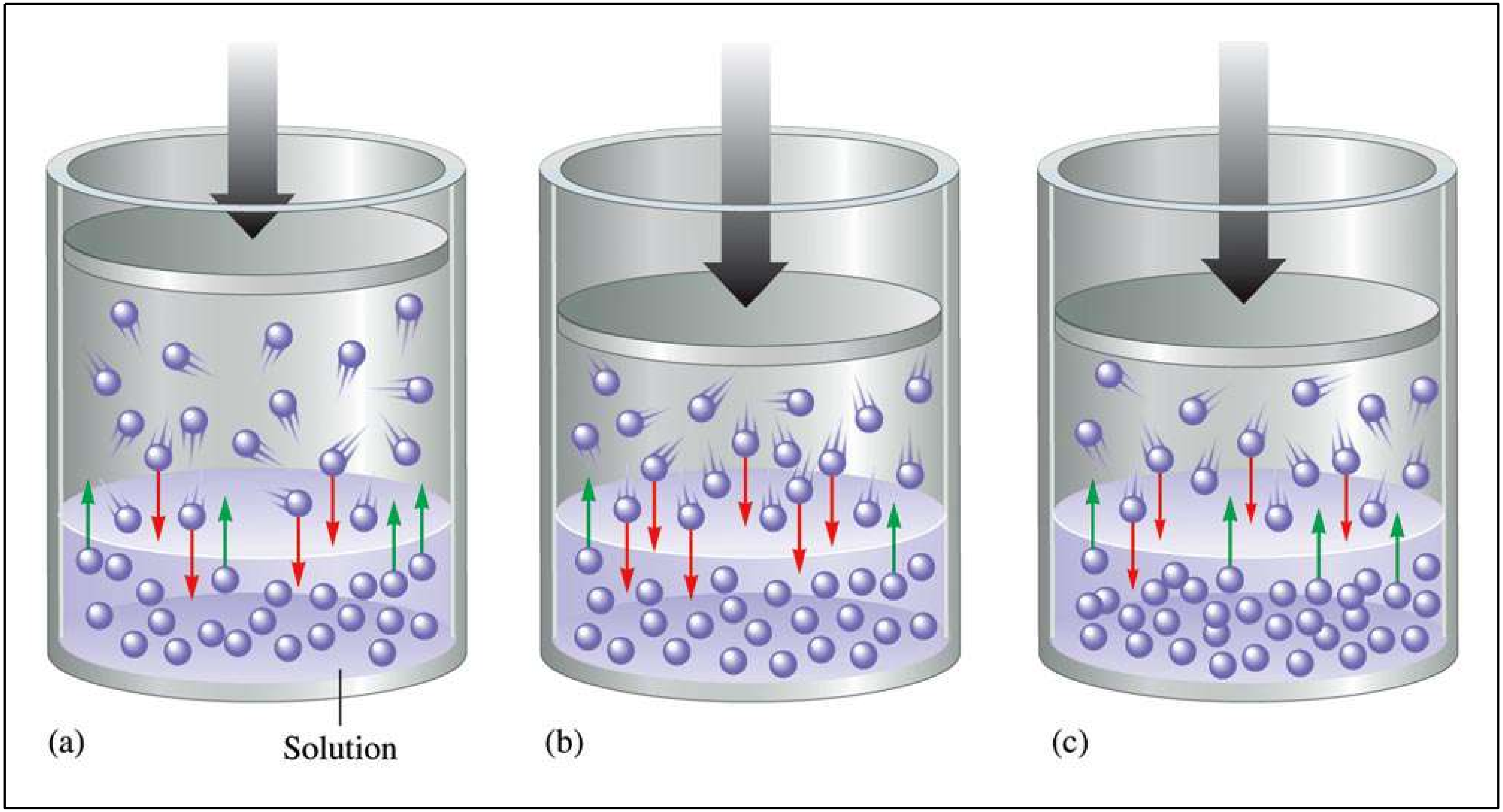


Figure 11.8 A Pipe with Accumulated Mineral Deposits

The Solubilities of Several Gases in Water

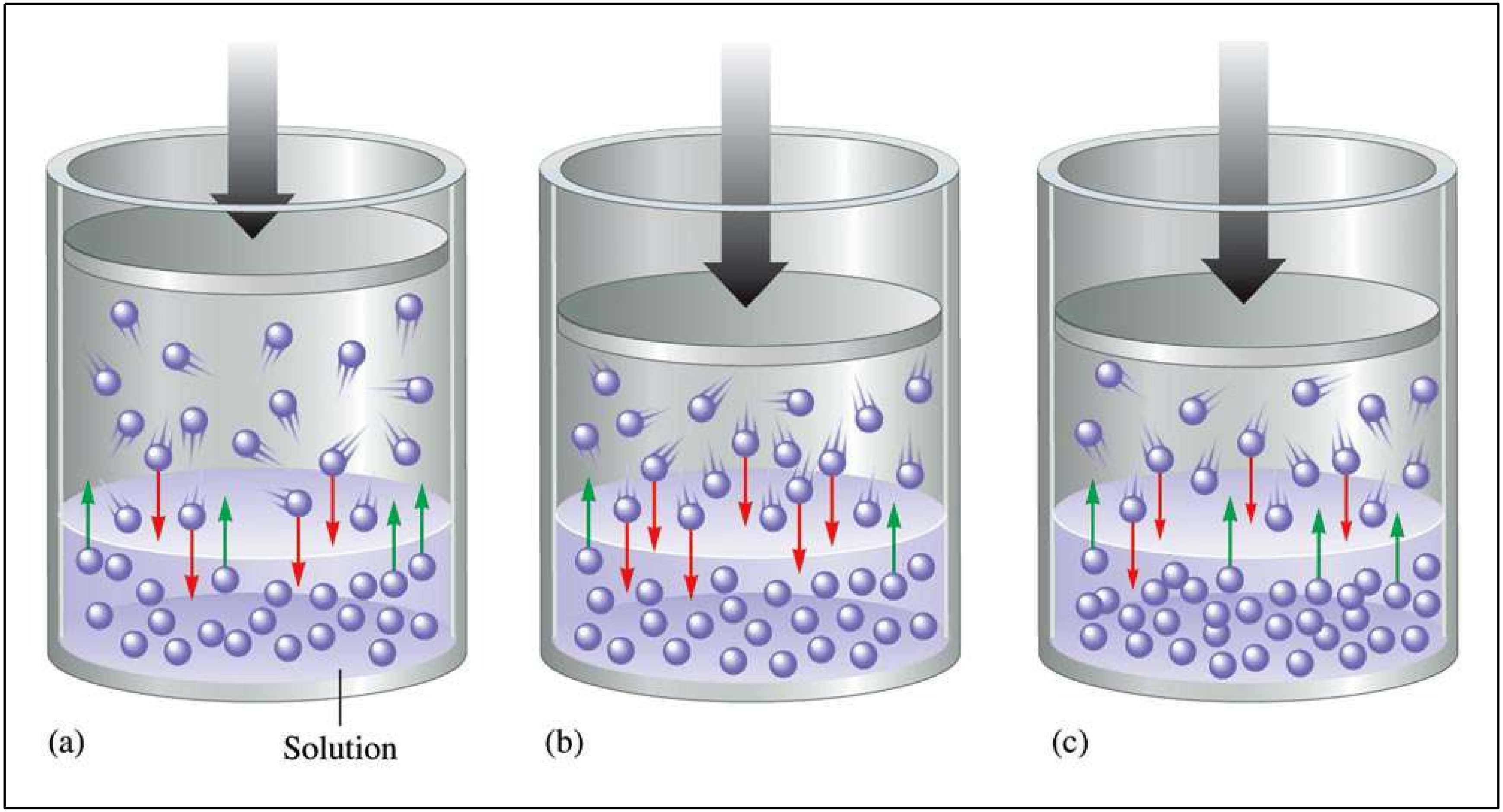


A Gaseous Solute

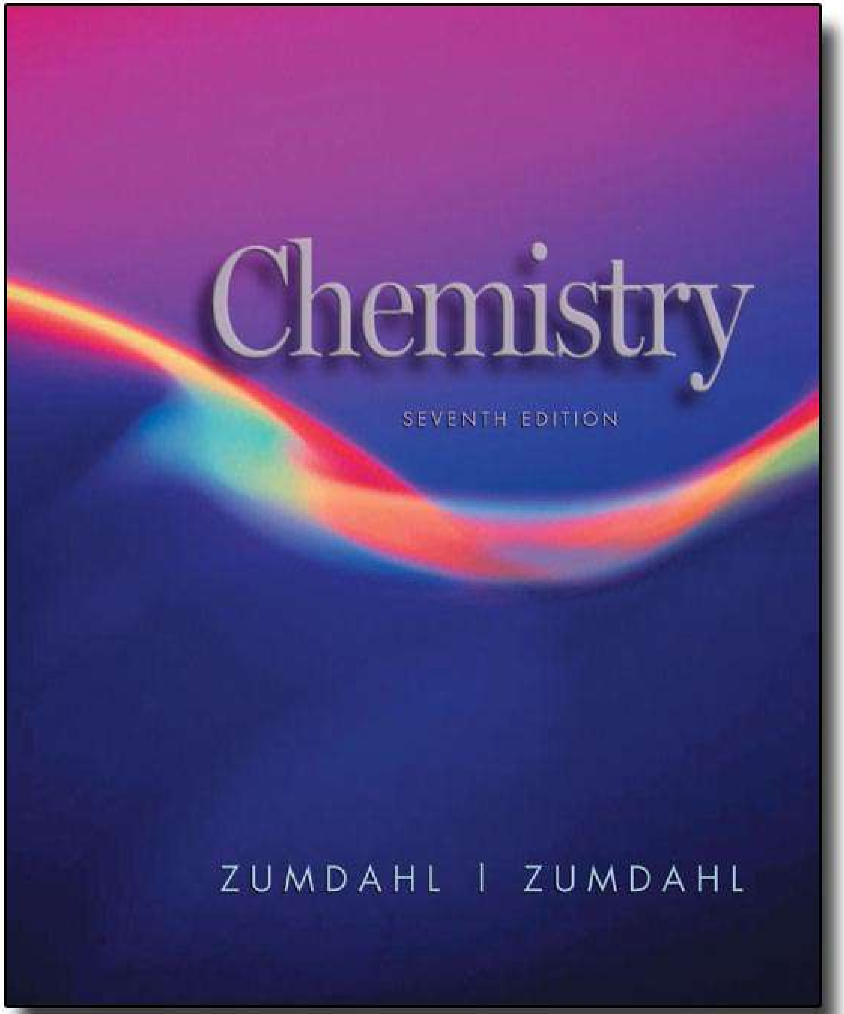


Carbonation

Figure 11.5 a-c Henry's Law



Lake Nyos in Cameroon



The Vapor Pressure of Solutions

An Aqueous Solution and Pure Water in a Closed Environment

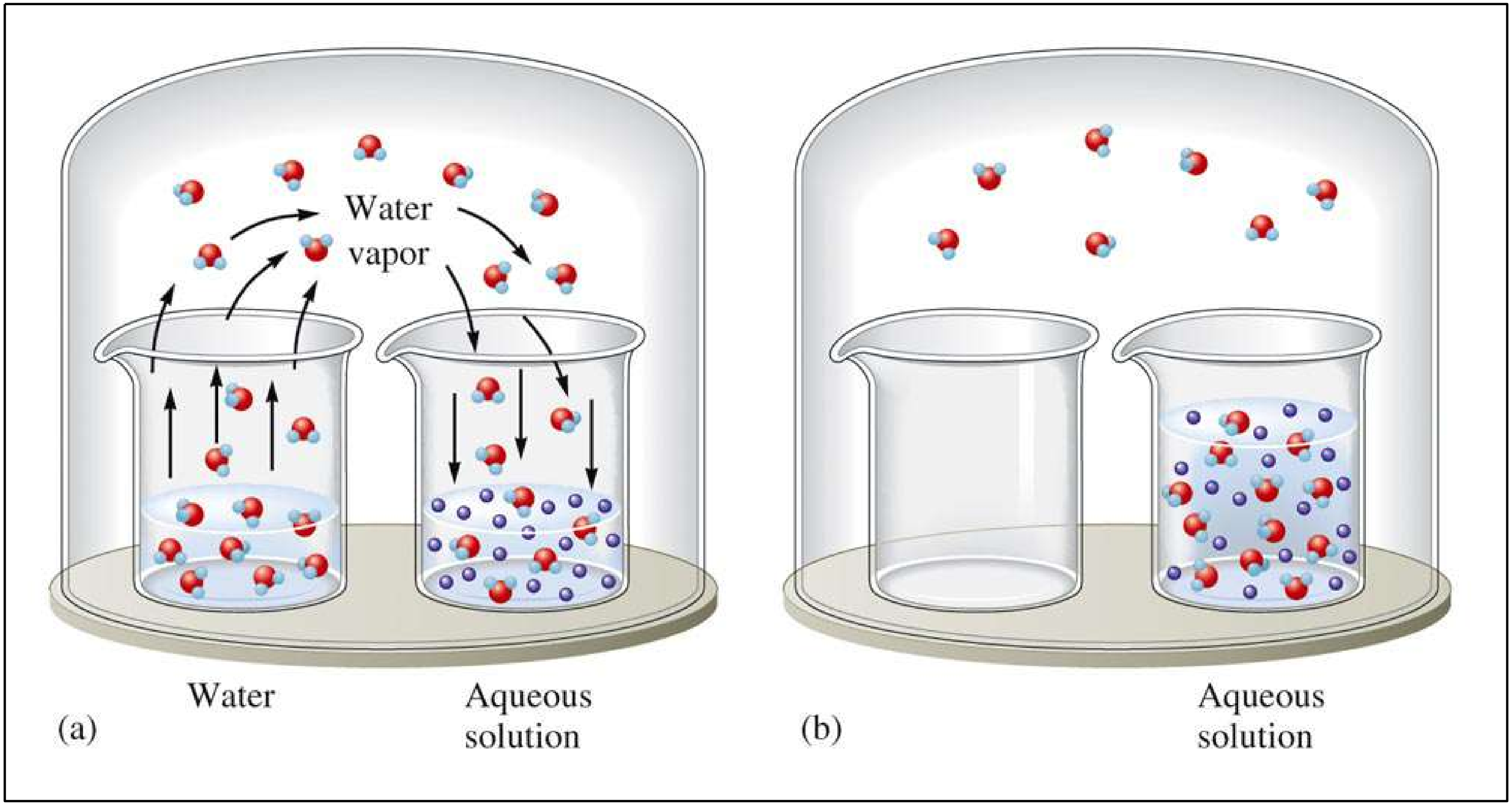
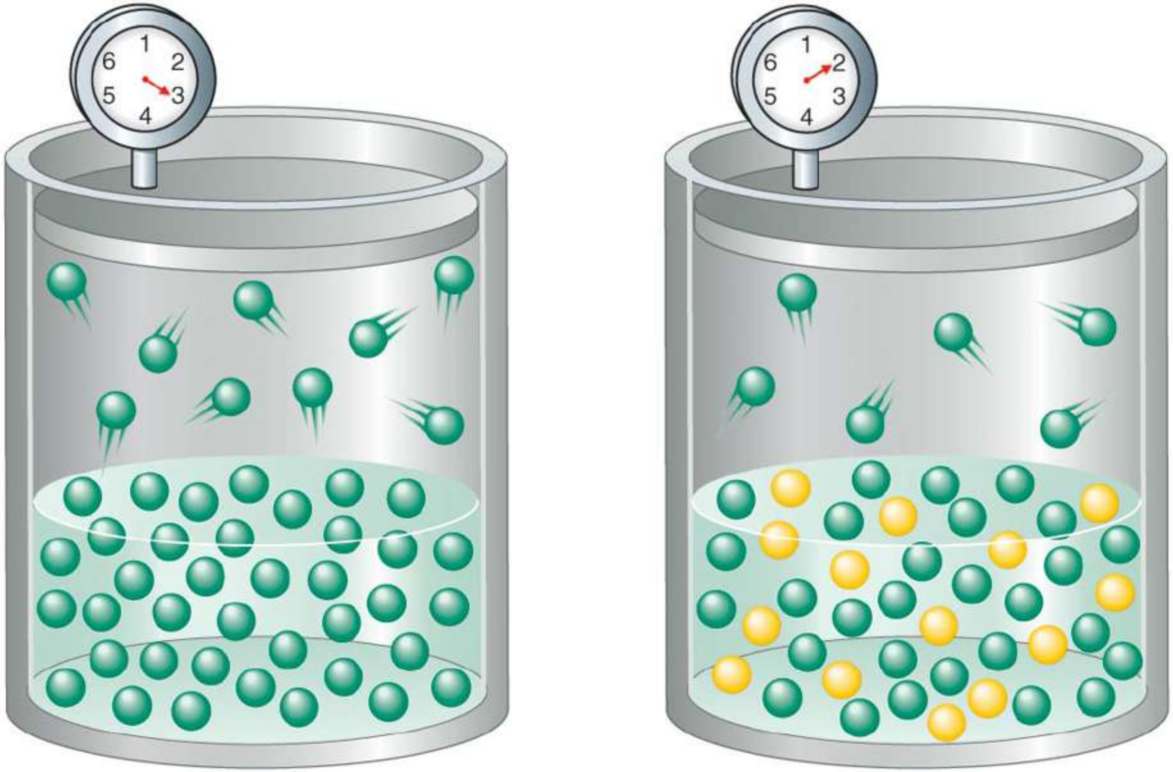


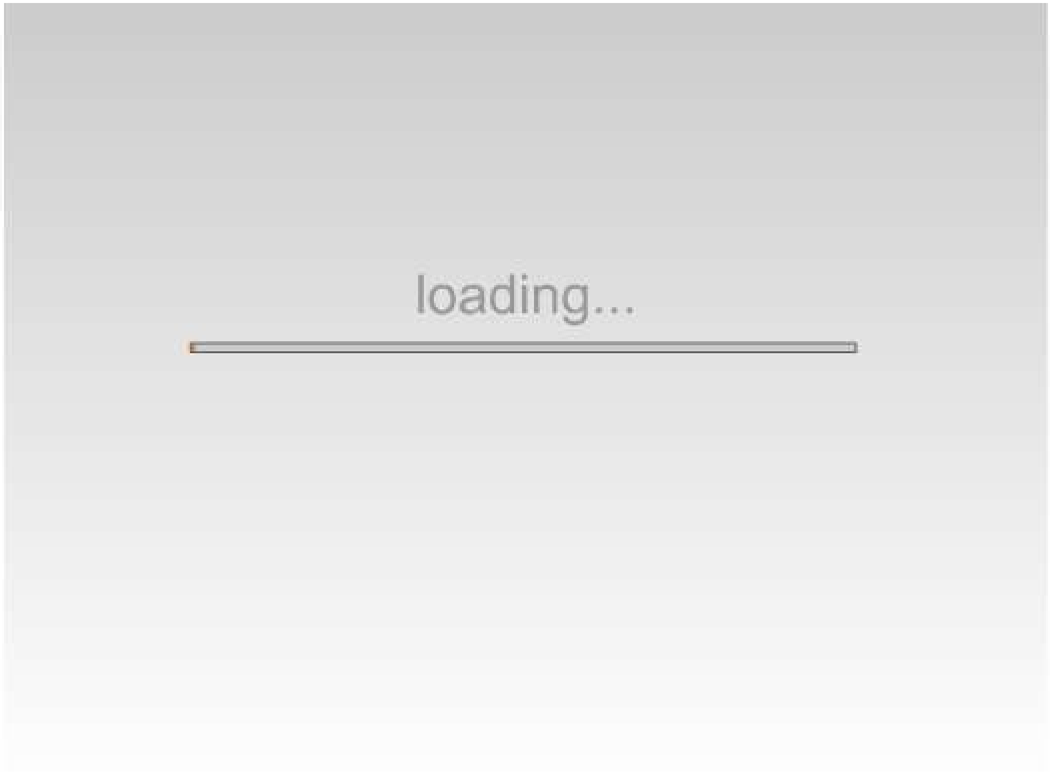
Figure 11.10 The Presence of a Nonvolatile Solute Lowers the Vapor Pressure of the Solvent



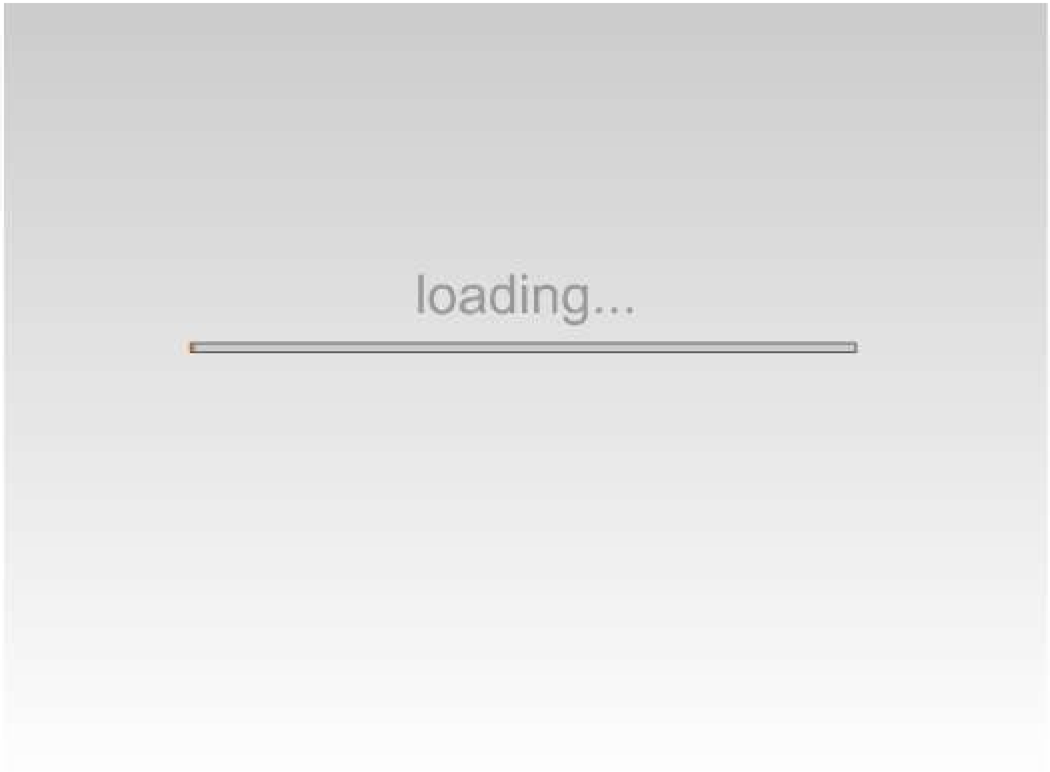
Pure solvent

Solution with a nonvolatile solute

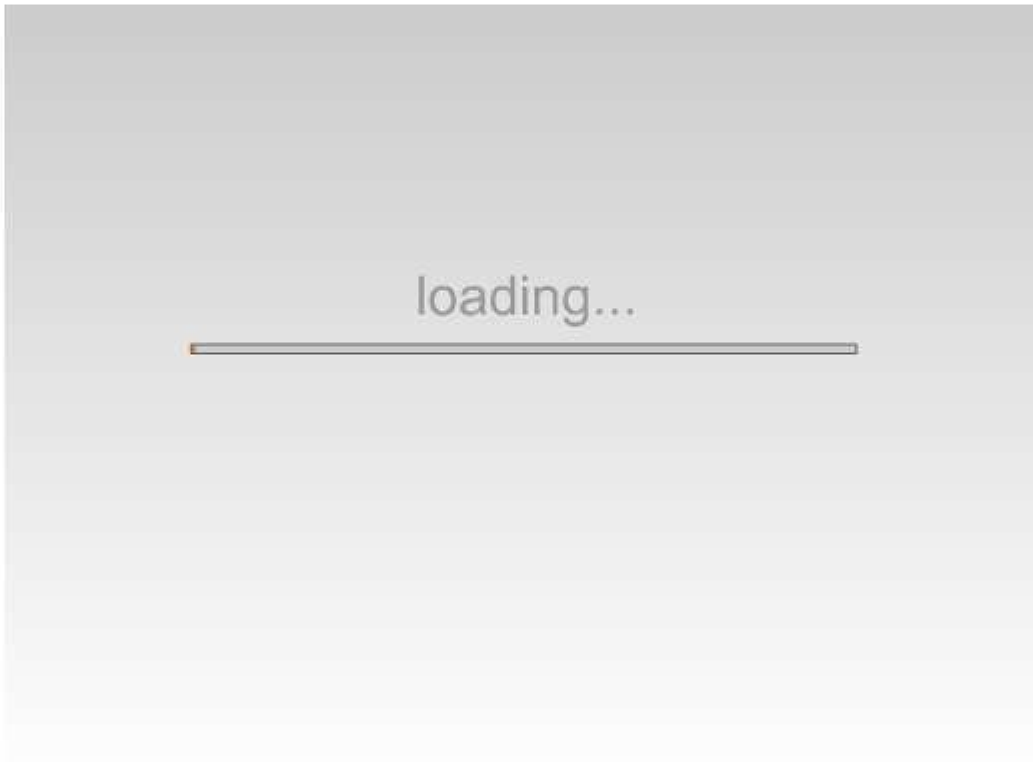
Vapor Pressure Lowering: Liquid/Vapor Equilibrium



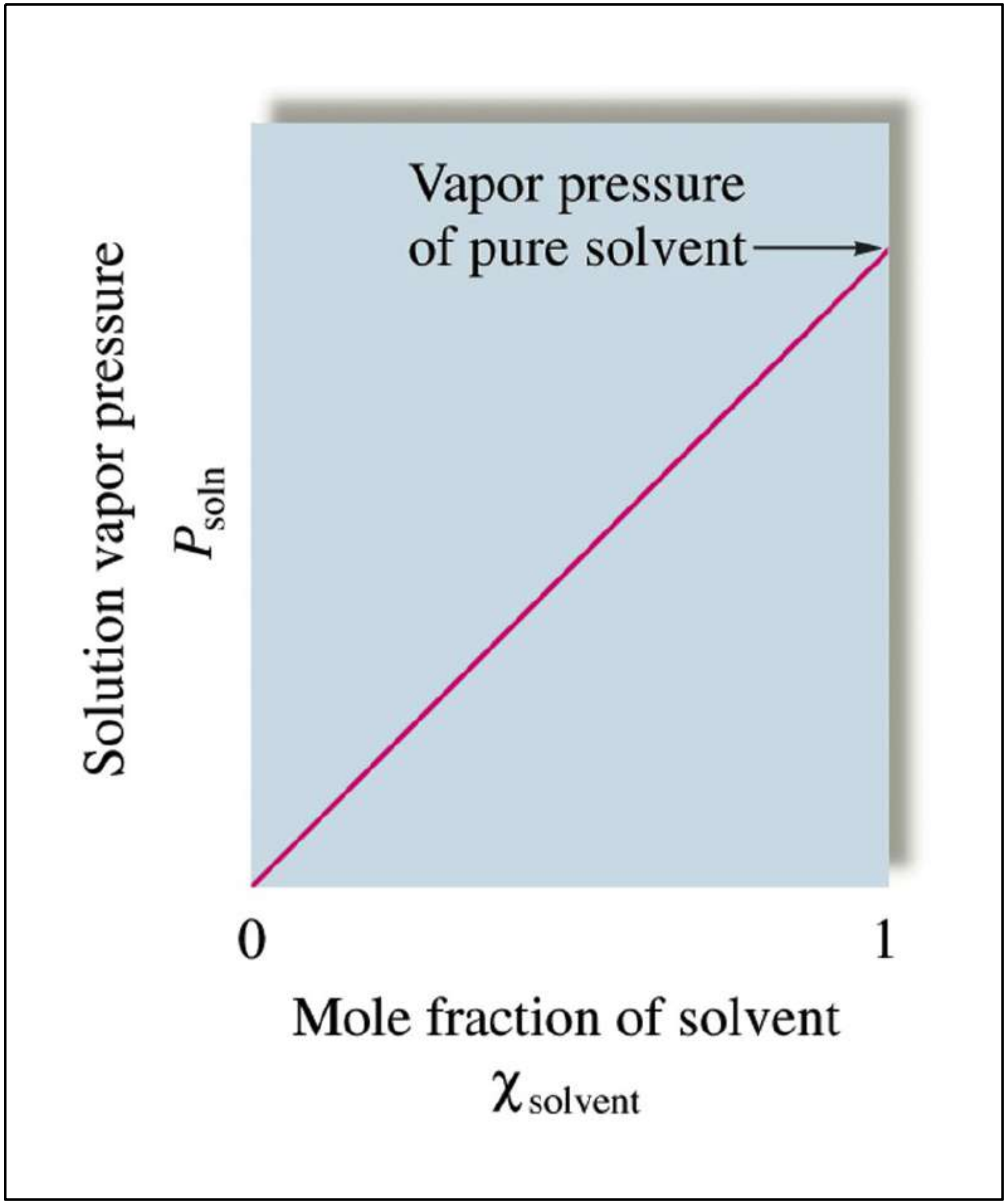
Vapor Pressure Lowering: Addition of a Solute



Vapor Pressure Lowering: Solution/Vapor Equilibrium



A Solution Obeying Raoult's Law



Insecticide is Sprayed from an Aerosol Can

An Aerosol Can for Delivery of an Active Ingredient Dissolved in an Aqueous Solution

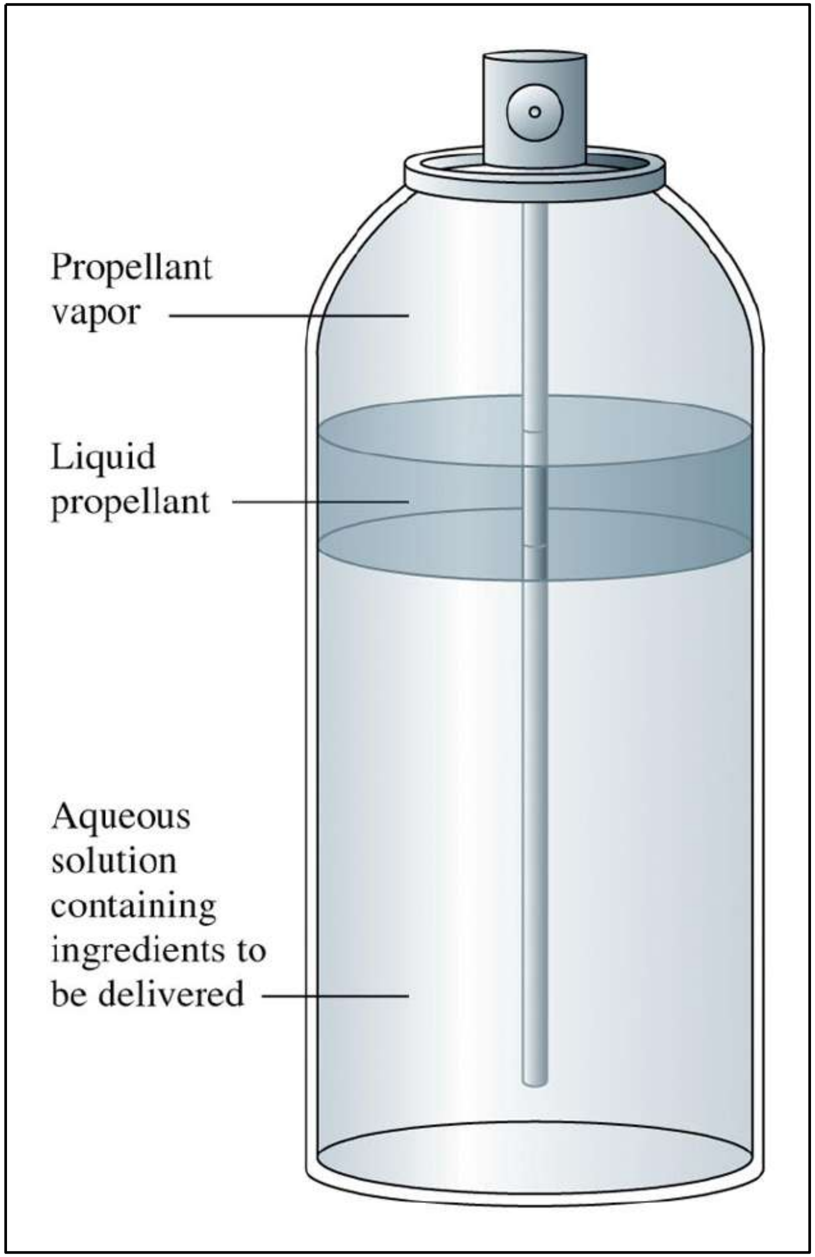
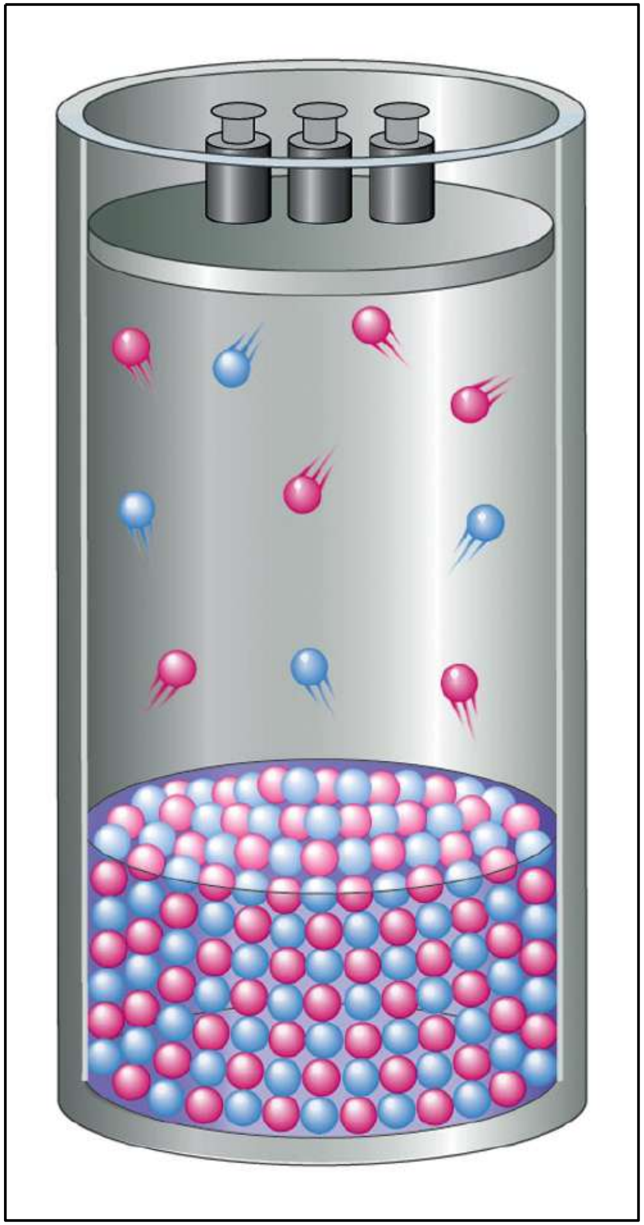


Figure 11.12 Solution Containing Two Volatile Components



React 3

Consider an ideal mixture of two volatile liquids, A and B. Answer the following questions. Use pictures in your explanations.

- Suppose you have an equimolar mixture of A and B, and the vapor pressure of pure liquid A is twice that of pure liquid B. Determine the mole fraction of A in the vapor above the mixture.
- Suppose you make a mixture with twice as much A as B (in moles), and the vapor pressure of pure liquid A is twice that of pure liquid B. Determine the mole fraction of A in the vapor above the mixture.

React 4

Benzene and toluene form ideal solutions. Imagine mixing benzene and toluene at a temperature where the vapor pressure of pure benzene is 750.0 torr and the vapor pressure of toluene is 300.0 torr. Consider the following:

- You make a solution in which the mole fraction of the benzene is 0.500. You then place this solution in a closed container, and wait for the vapor to come into equilibrium with the solution. Then, you condense the vapor. Determine the composition (mole percent) of the vapor. Explain why the relative numbers make sense.

React 4

Benzene and toluene form ideal solutions. Imagine mixing benzene and toluene at a temperature where the vapor pressure of pure benzene is 750.0 torr and the vapor pressure of toluene is 300.0 torr. Consider the following:

- You make a solution by pouring some toluene into some benzene. You then place this solution in a closed container, and wait for the vapor to come to equilibrium with the solution. Then, you condense the vapor and determine the mole fraction of the toluene to be 0.500. Determine the composition (mole percent) of the original solution. Explain why the relative numbers make sense.

Figure 11.13 a-c Vapor Pressure for a Solution of Two Volatile Liquids

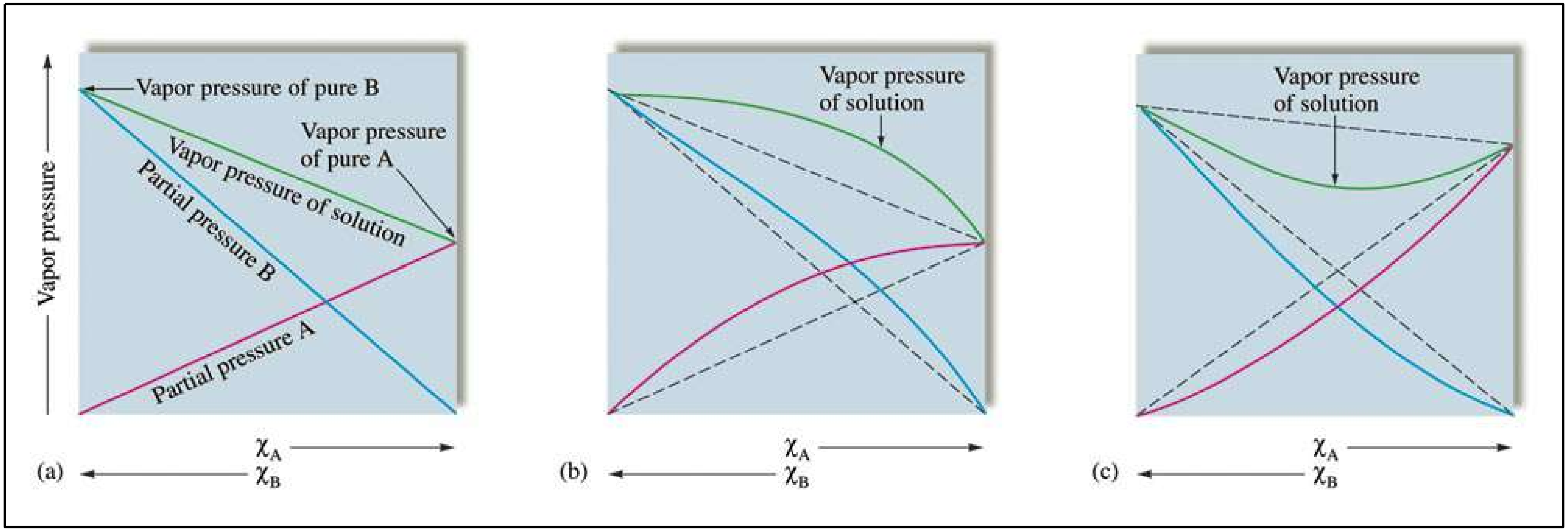
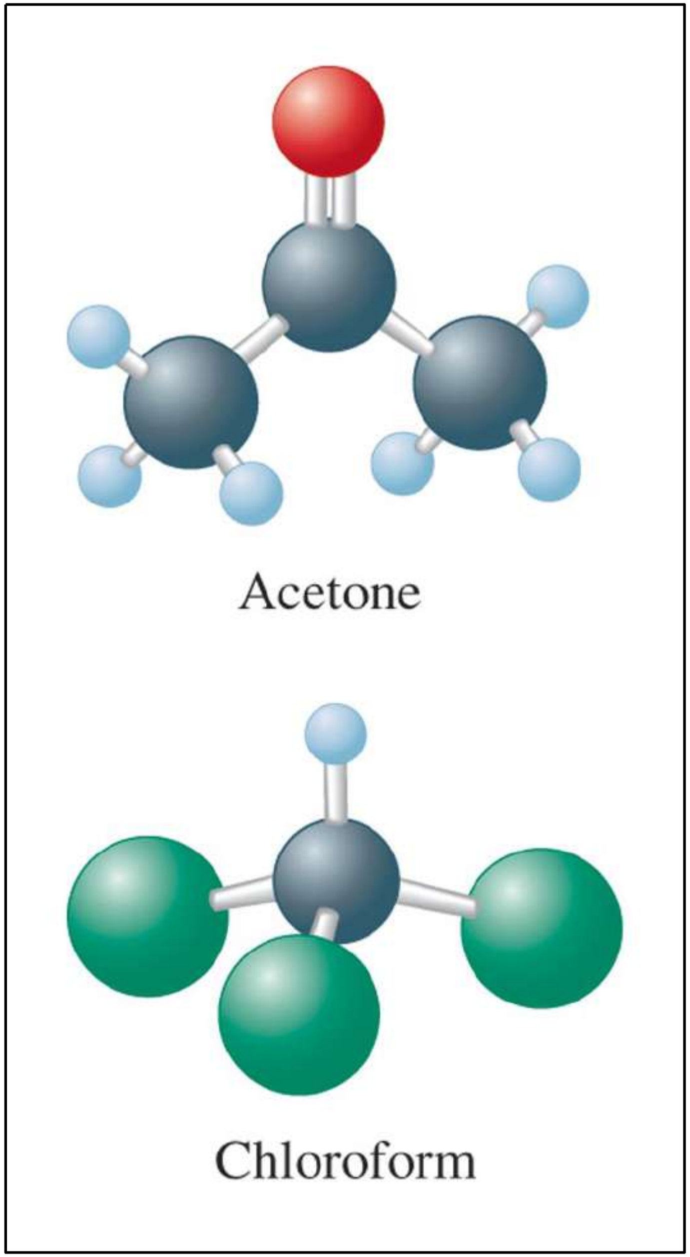


Table 11.4 Summary of the Behavior of Various Types of Solutions

TABLE 11.4 Summary of the Behavior of Various Types of Solutions

Interactive Forces Between Solute (A) and Solvent (B) Particles	ΔH_{soln}	ΔT for Solution Formation	Deviation from Raoult's Law	Example
$A \leftrightarrow A, B \leftrightarrow B \equiv A \leftrightarrow B$	Zero	Zero	None (ideal solution)	Benzene–toluene
$A \leftrightarrow A, B \leftrightarrow B < A \leftrightarrow B$	Negative (exothermic)	Positive	Negative	Acetone–water
$A \leftrightarrow A, B \leftrightarrow B > A \leftrightarrow B$	Positive (endothermic)	Negative	Positive	Ethanol–hexane

Acetone and Chloroform



React 5

For each of the following solutions, would you expect it to be relatively ideal (with respect to Raoult's Law), show a positive deviation, or show a negative deviation?

Hexane (C_6H_{14}) and chloroform ($CHCl_3$)

a) Ethyl alcohol (C_2H_5OH) and water

b) Hexane (C_6H_{14}) and octane (C_8H_{18})

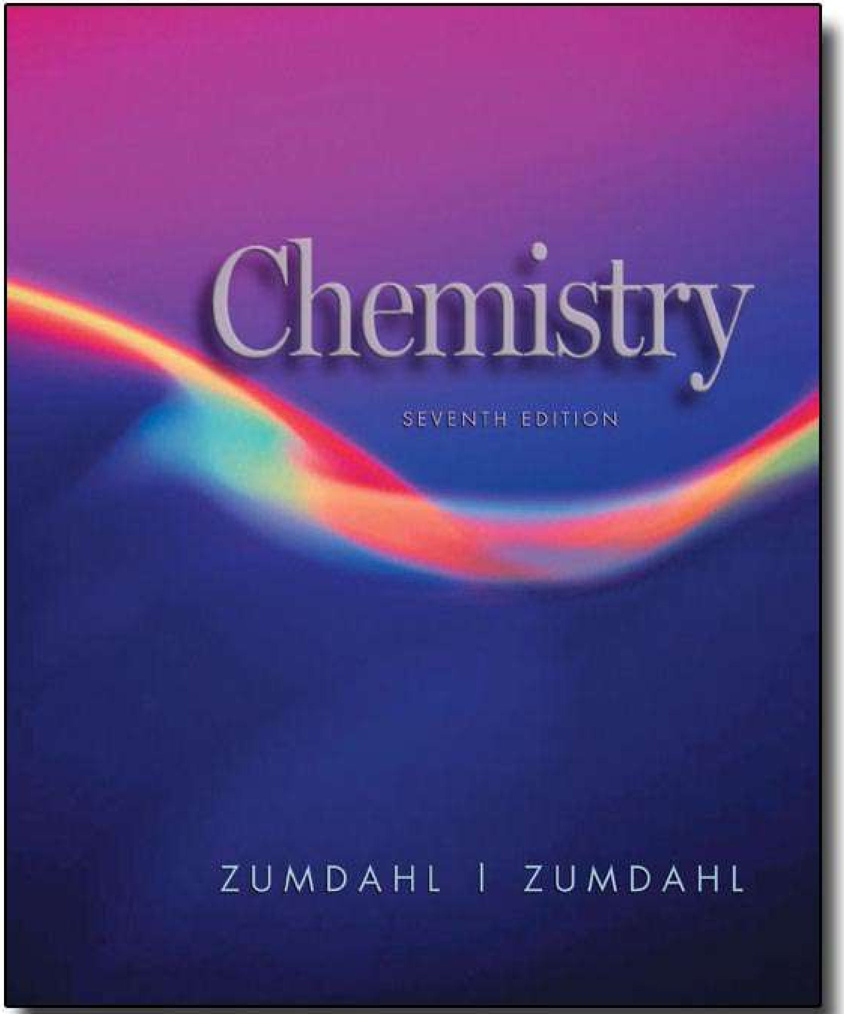
React 6

Would a solution with a positive deviation from Raoult's Law have a higher or lower boiling point than ideal? Explain.

Colligative Properties

Depend only on the number, not on the identity, of the solute particles in an ideal solution.

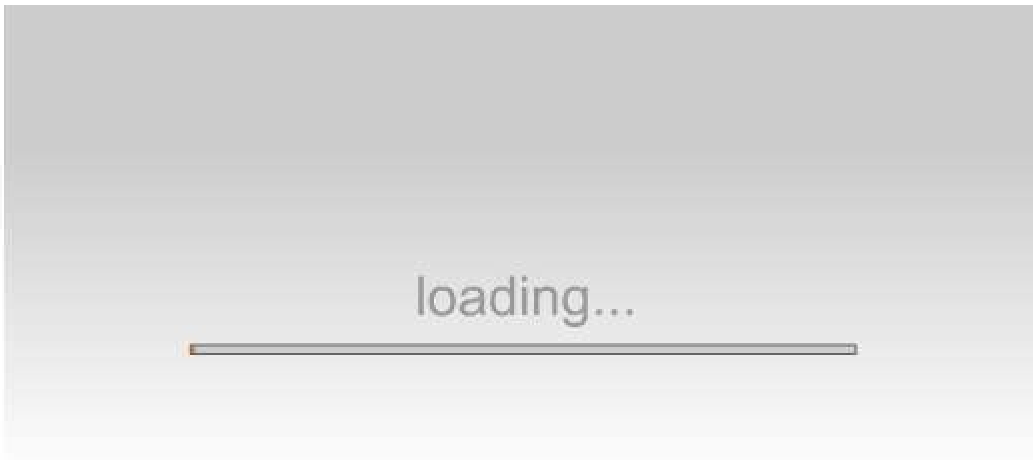
- Boiling point elevation
- Freezing point depression
- Osmotic pressure



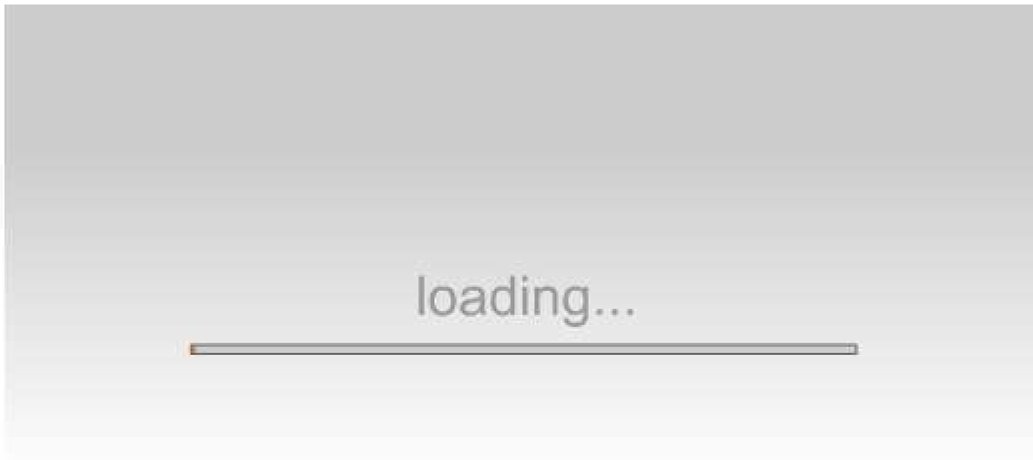
Boiling-Point Elevation and Freezing-Point Depression

Sugar Dissolved in Water to Make Candy Causes the Boiling Point to be Elevated

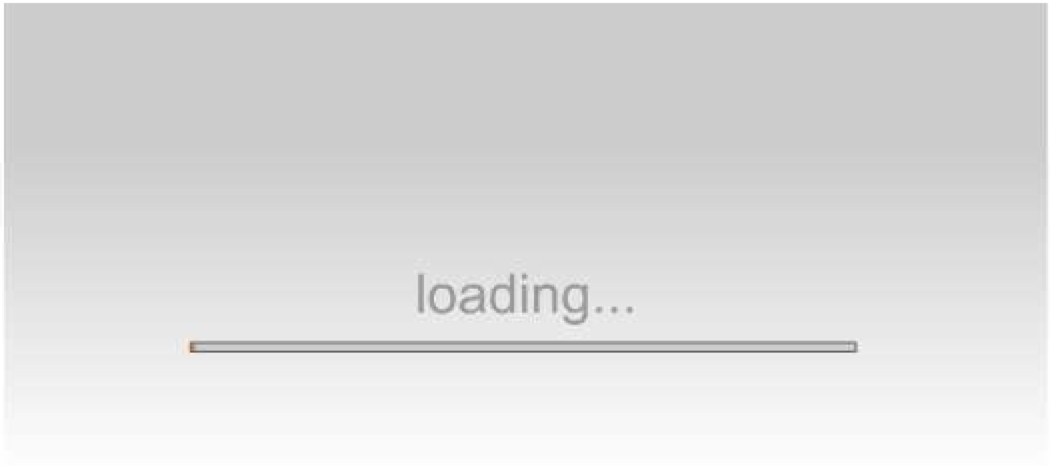
Boiling Point Elevation: Liquid/Vapor Equilibrium



Boiling Point Elevation: Addition of a Solute

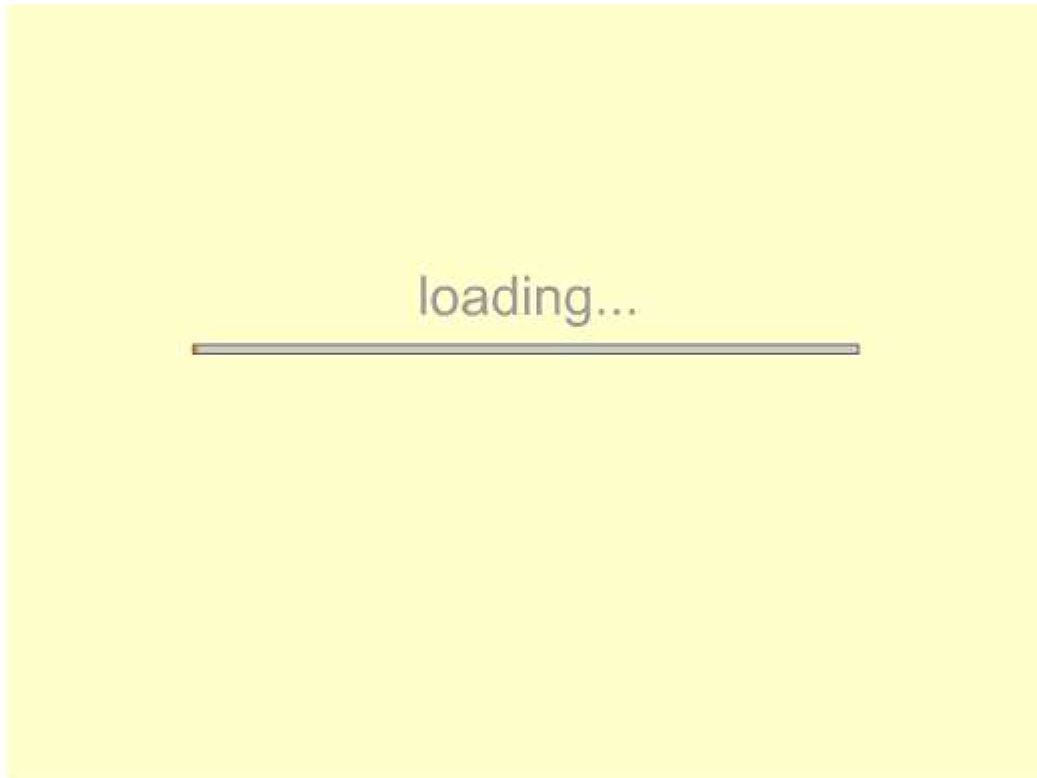


Boiling Point Elevation: Solution/Vapor Equilibrium

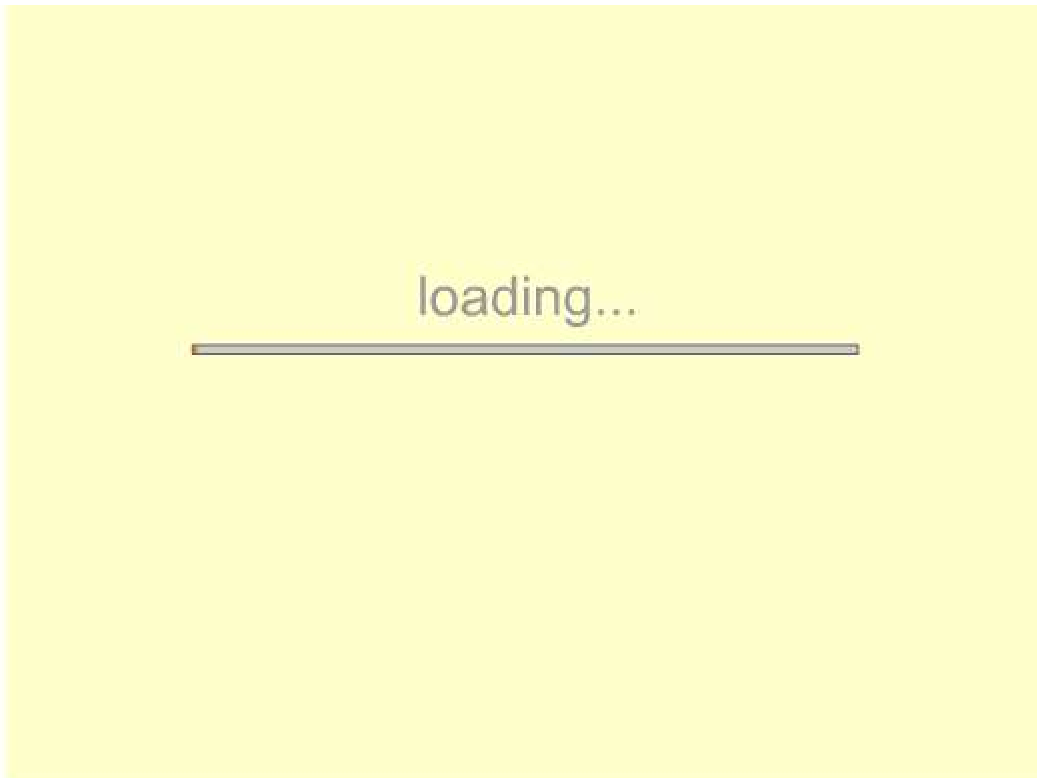


Spreading Salt on a Highway

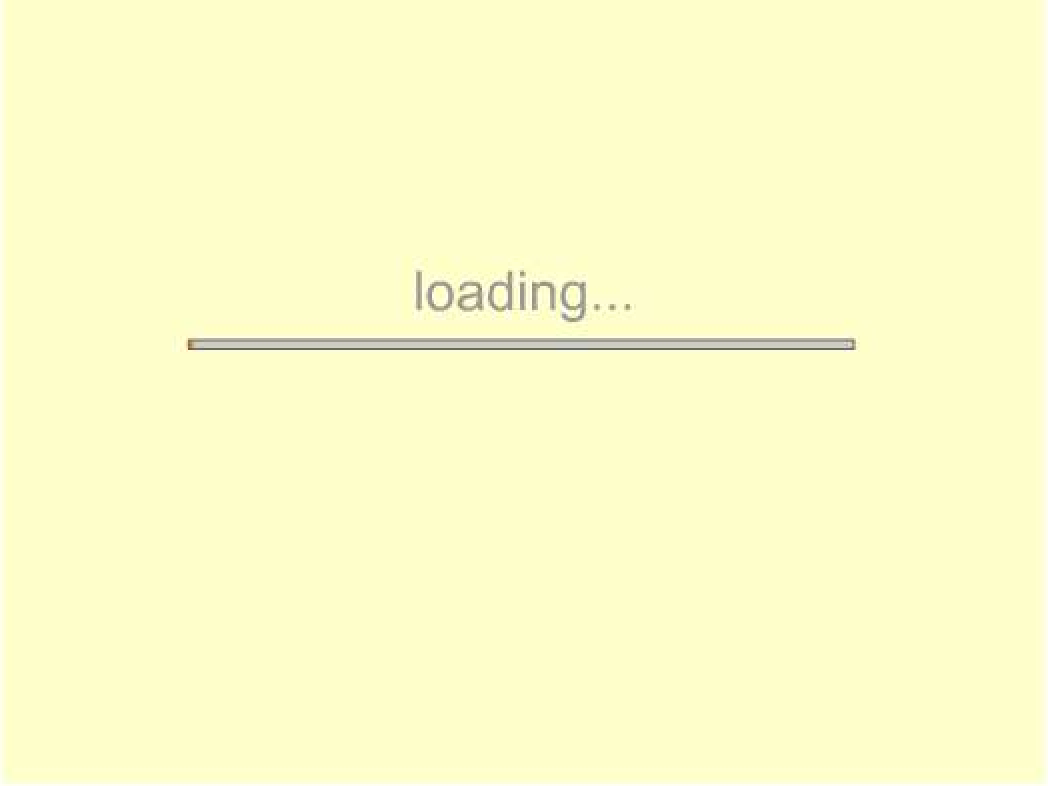
Freezing Point Depression: Solid/Liquid Equilibrium



Freezing Point Depression: Addition of a Solute



Freezing Point Depression: Solid/Solution Equilibrium



Changes in Boiling Point and Freezing Point of Water

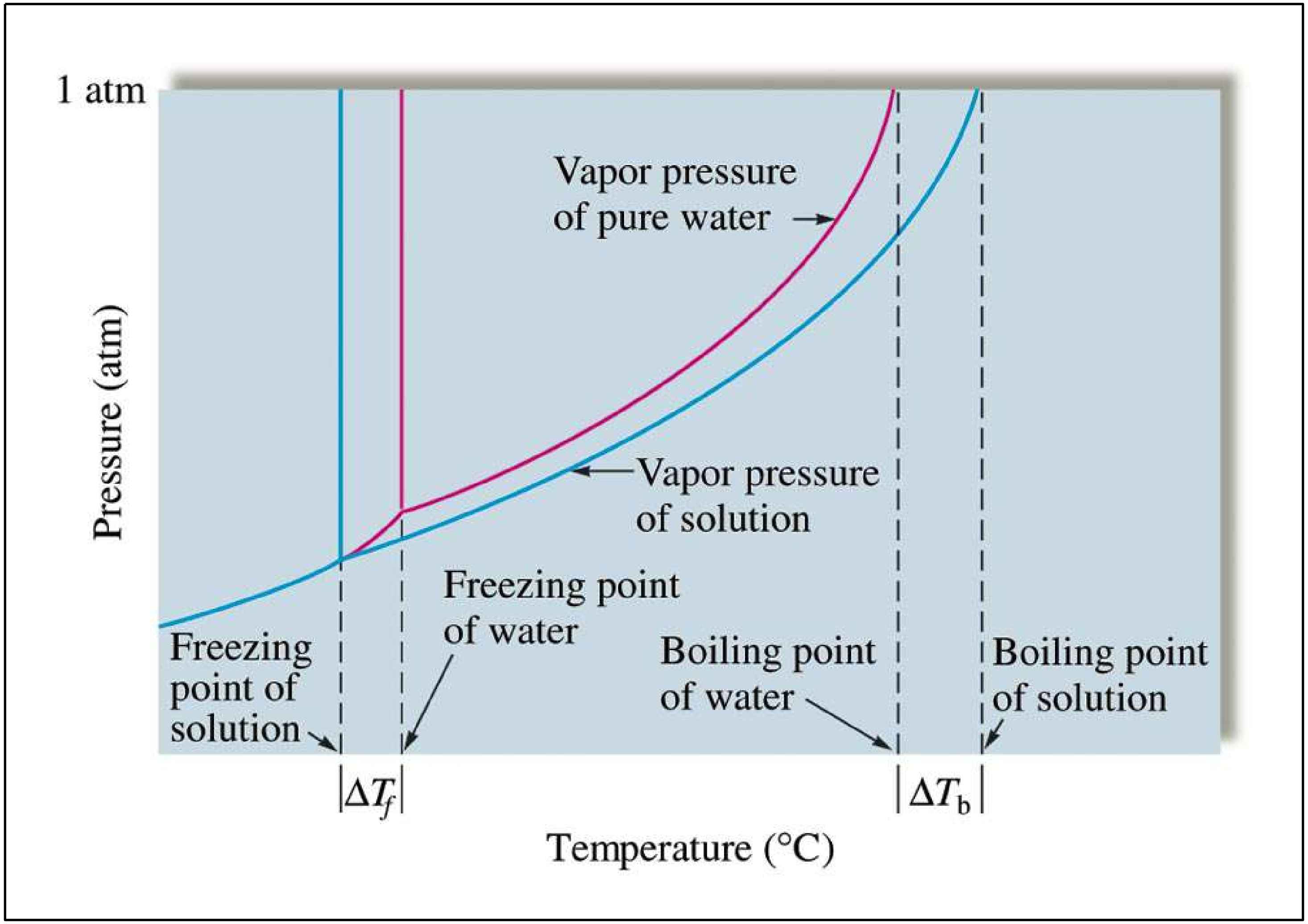
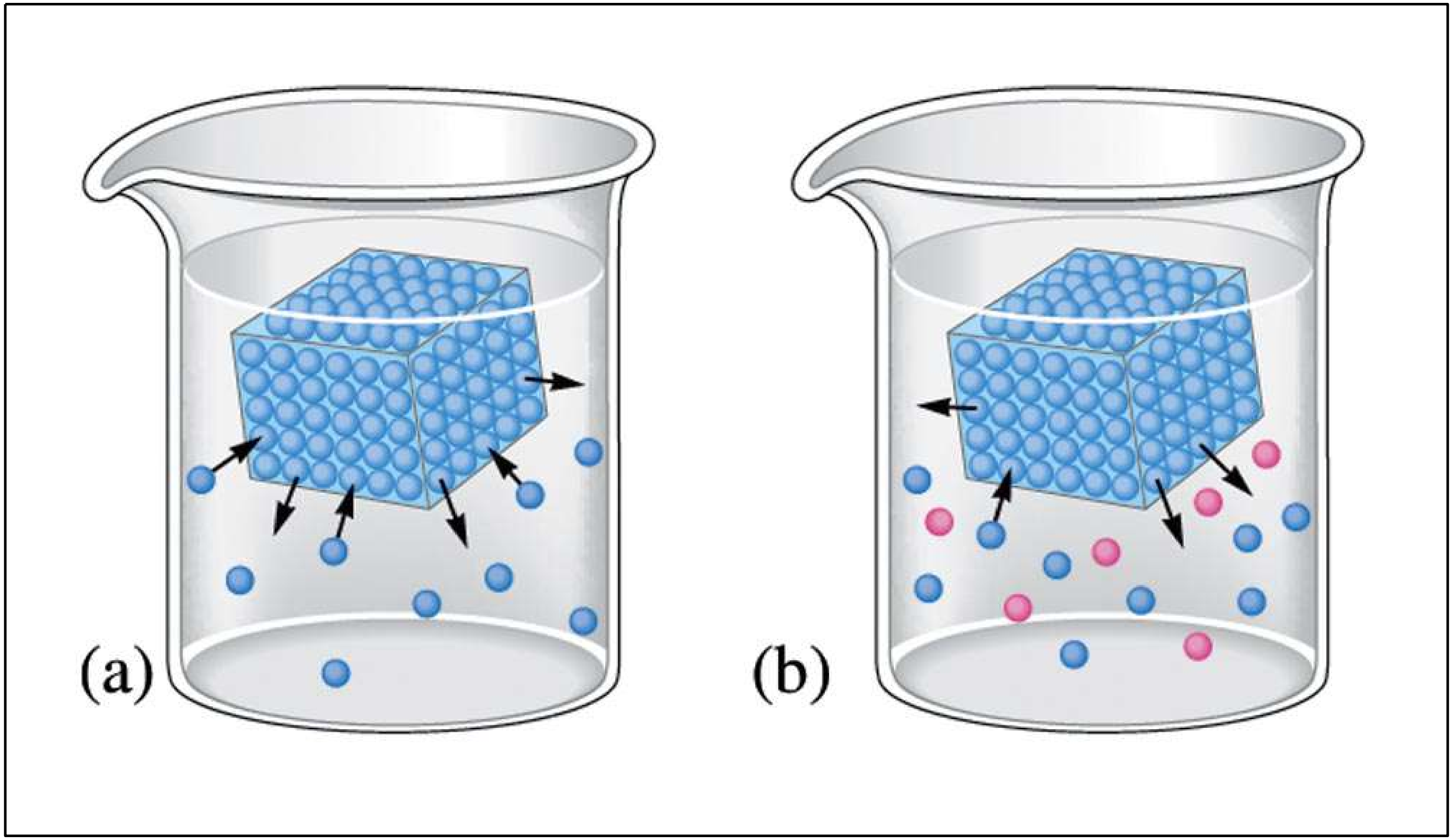


Table 11.5 Molal Boiling-Point Elevation Constants (K_b) and Freezing-Point Depression Constants (K_f) for Several Solvents

TABLE 11.5 Molal Boiling-Point Elevation Constants (K_b) and Freezing-Point Depression Constants (K_f) for Several Solvents

Solvent	Boiling Point (°C)	K_b (°C · kg/mol)	Freezing Point (°C)	K_f (°C · kg/mol)
Water (H_2O)	100.0	0.51	0	1.86
Carbon tetrachloride (CCl_4)	76.5	5.03	−22.99	30.
Chloroform ($CHCl_3$)	61.2	3.63	−63.5	4.70
Benzene (C_6H_6)	80.1	2.53	5.5	5.12
Carbon disulfide (CS_2)	46.2	2.34	−111.5	3.83
Ethyl ether ($C_4H_{10}O$)	34.5	2.02	−116.2	1.79
Camphor ($C_{10}H_{16}O$)	208.0	5.95	179.8	40.

Figure 11.15 (a) Ice in Equilibrium with Liquid Water (b) Ice in Equilibrium with Liquid Water Containing a Dissolved Solute



The Addition of Antifreeze Lowers the Freezing Point of Water in a Car's Radiator

React 7

Consider two solutions. In solution A, you add 1.0 (measurement needed) of table sugar to 1.0 L of water. In solution B, you add 1.0 mole of table salt to 1.0 L of water.

- How do the freezing points of each solution compare to water?
- How do the freezing points of each solution compare to each other?

React 8

- Why is molality used (not molarity) for colligative properties?

React 9

- You take 20.0 g of a sucrose ($C_{12}H_{22}O_{11}$) and NaCl mixture and dissolve it in 1.0 L of water. The freezing point of this solution is found to be -0.426°C. Assuming ideal behavior, calculate the mass percent composition of the original mixture, and the mole faction of sucrose in the original mixture.

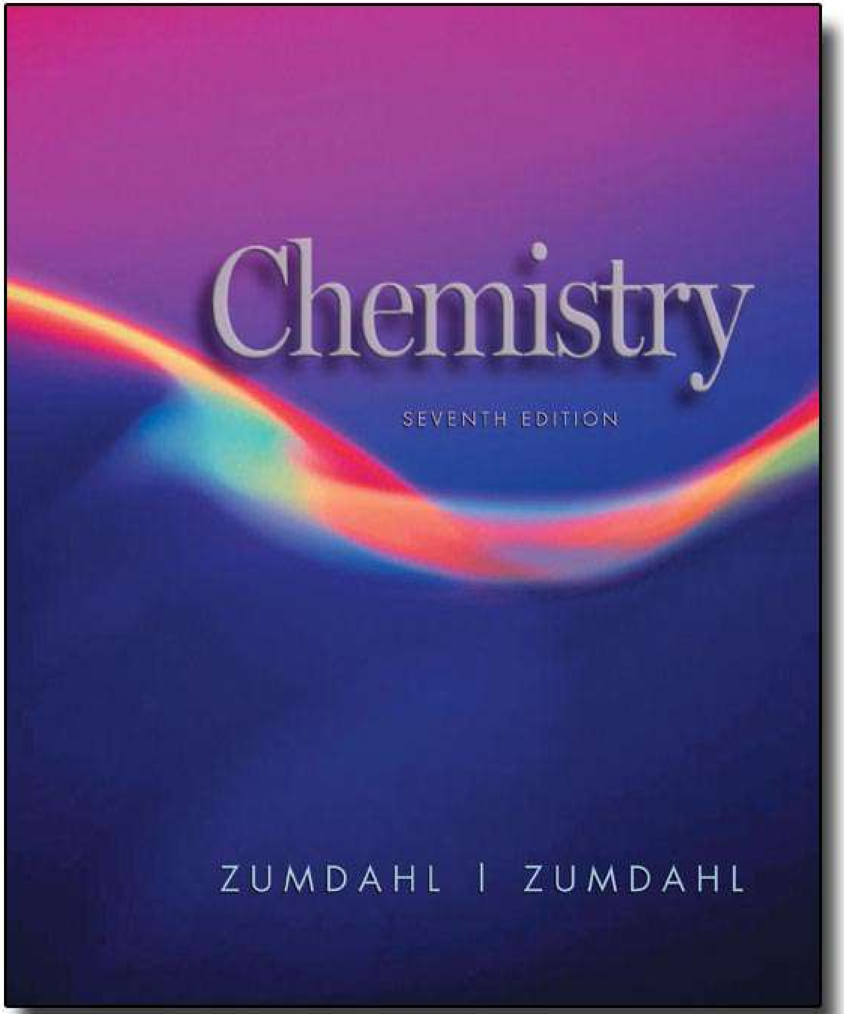
React 10

The freezing point of an aqueous solution is –2.79°C.

a) Determine the boiling point of this solution.

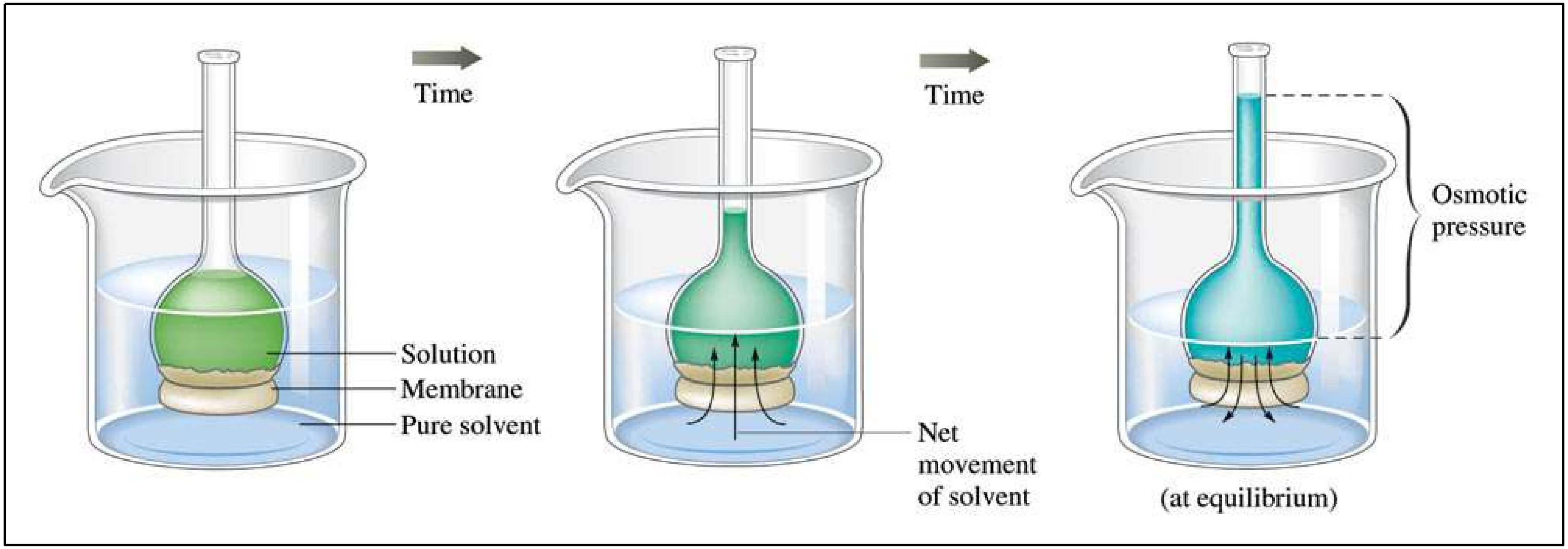
b) Determine the vapor pressure (in mm Hg) of this solution at 25°C (the vapor pressure of pure water at 25°C is 23.76 mm Hg).

c) Explain any assumptions you make in solving a and b.



Osmotic Pressure

Osmotic Pressure



React 11

- A plant cell has a natural concentration of 0.25 *m*. You immerse it in an aqueous solution with a freezing point of –0.246°C. Will the cell explode, shrivel, or do nothing?

Osmosis

loading...

Figure 11.17 Osmosis can be Prevented by Applying Pressure to the Solution

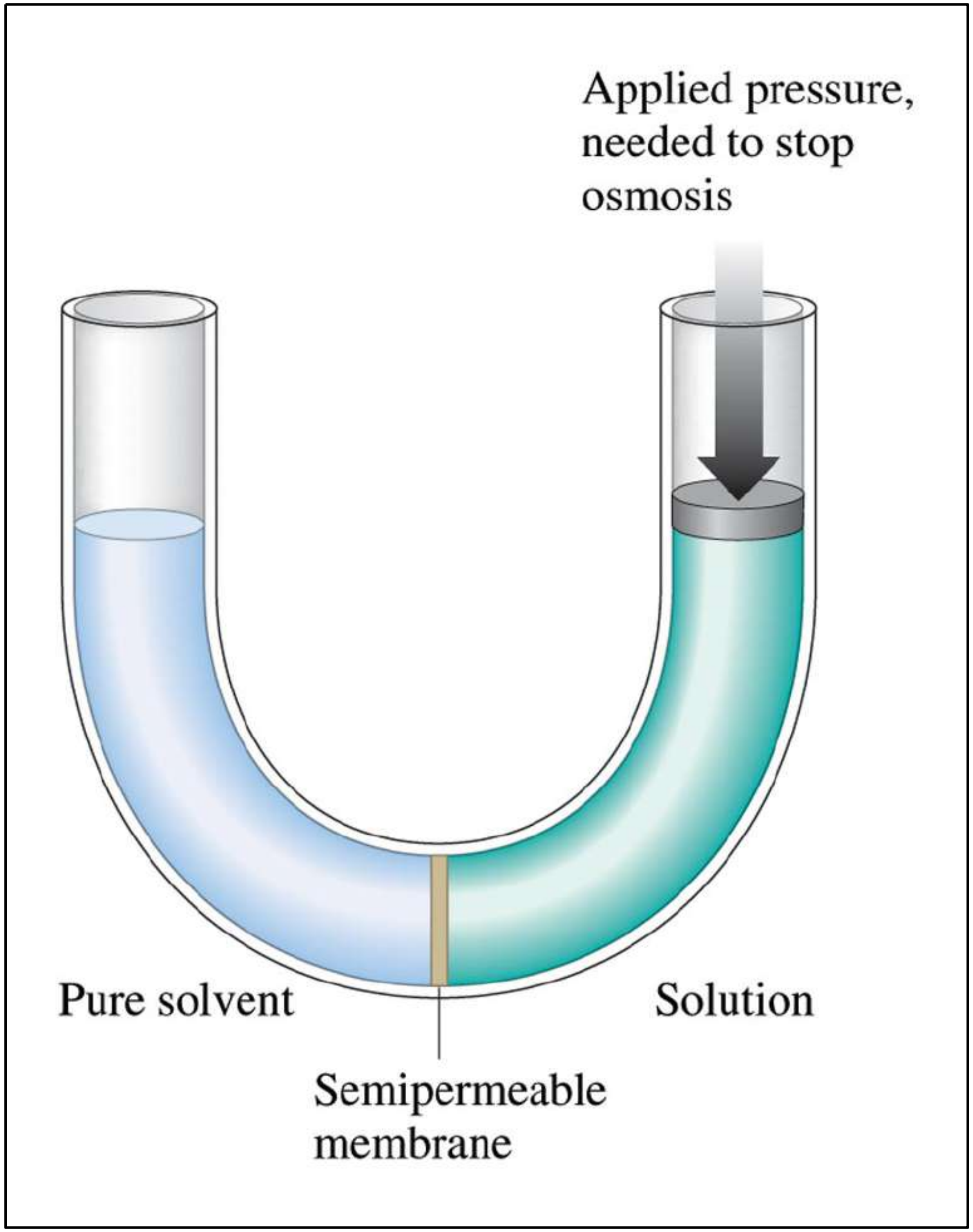
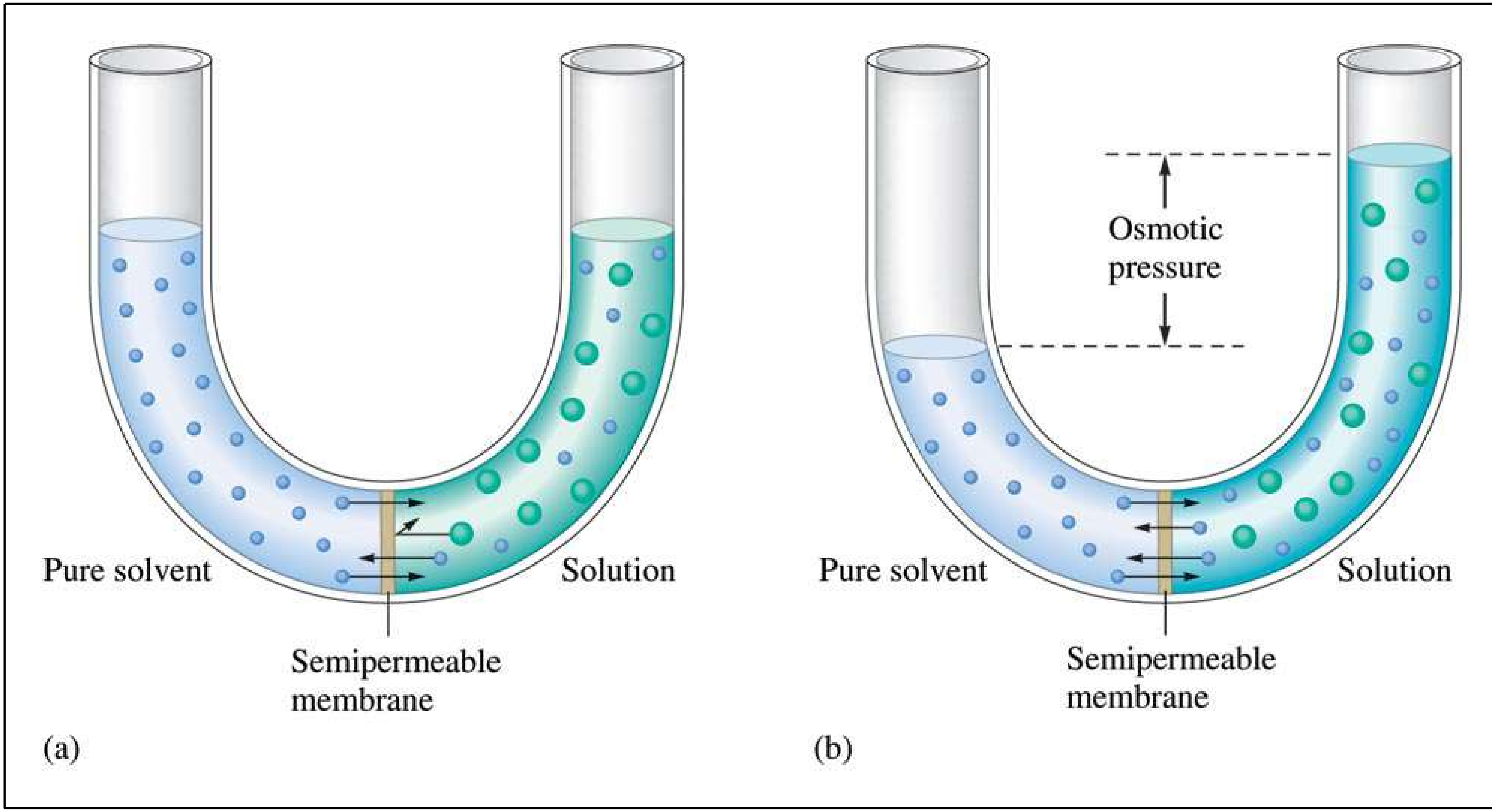


Figure 11.18 Osmotic Pressure



Patient Undergoing Dialysis

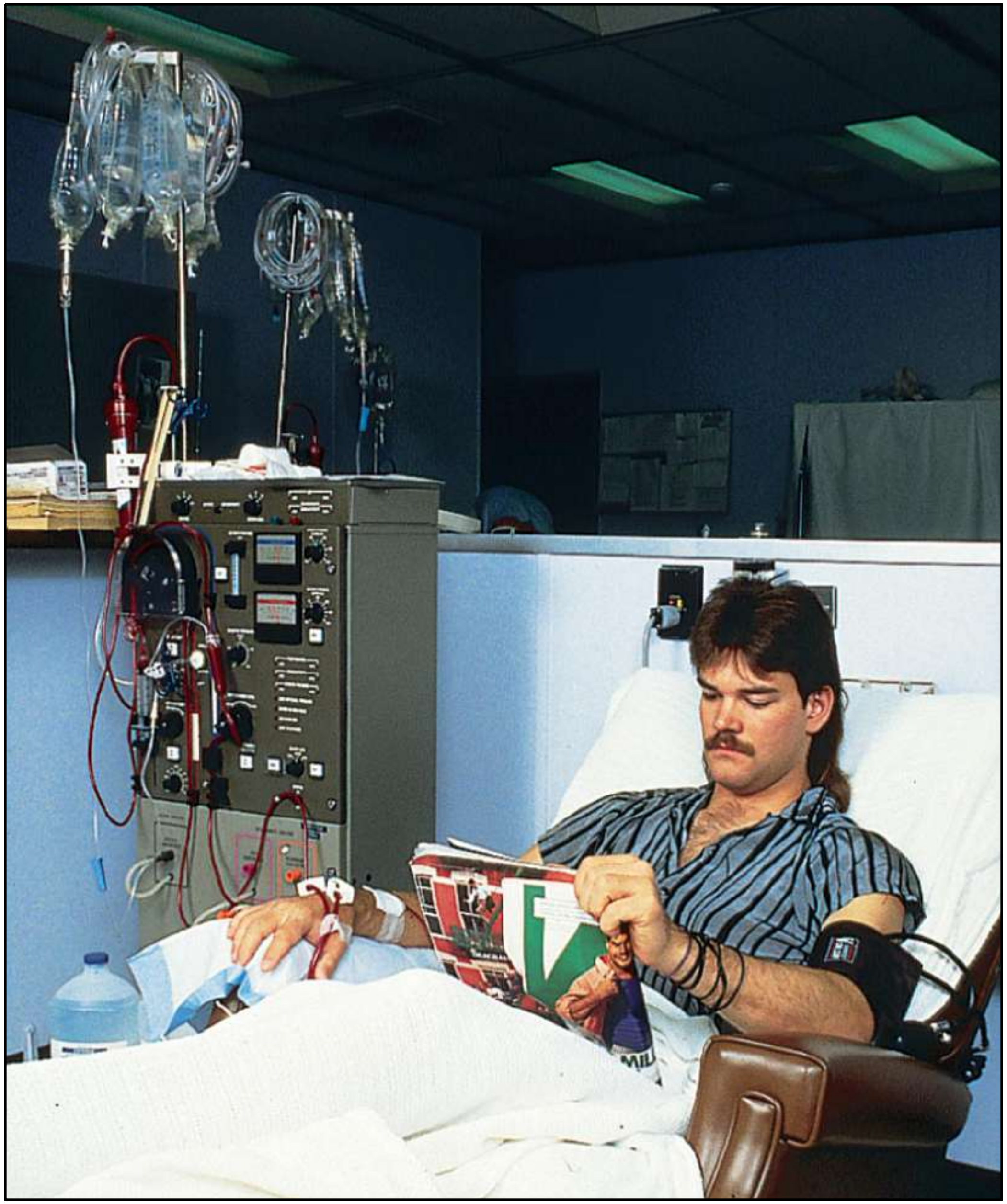
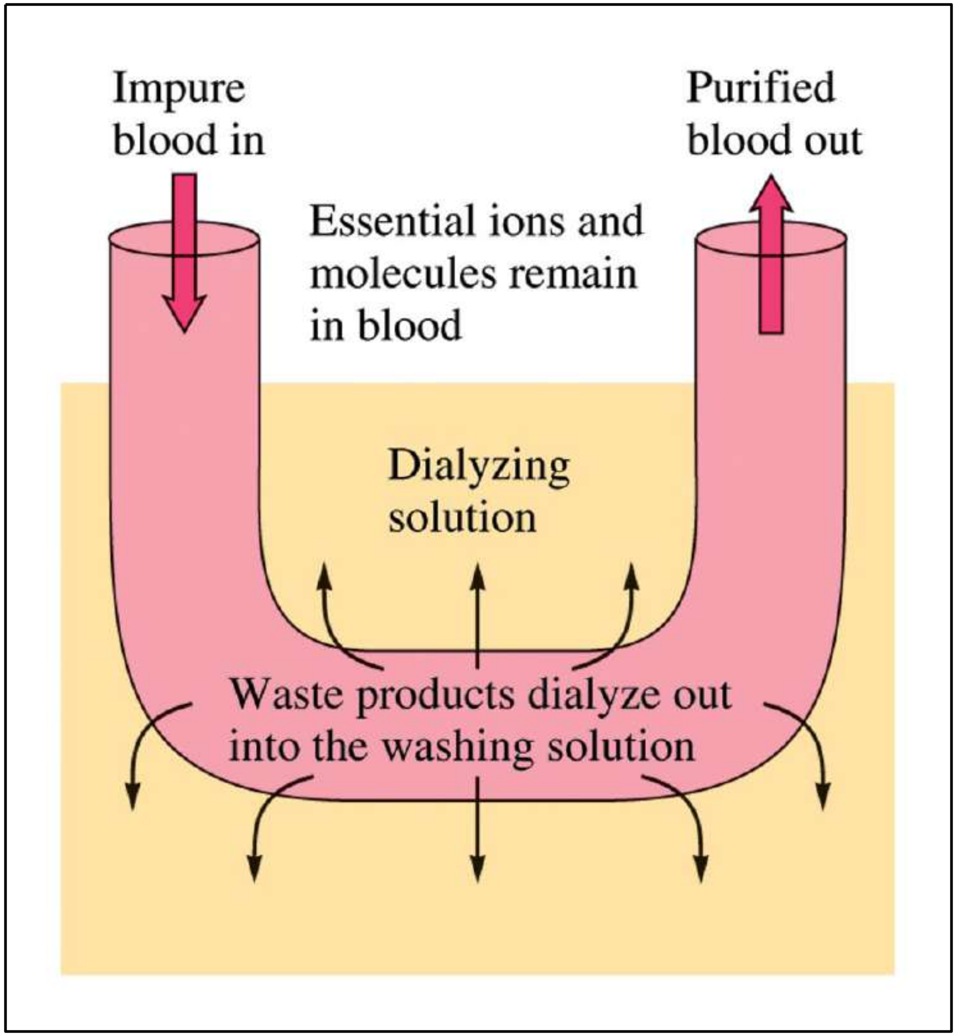
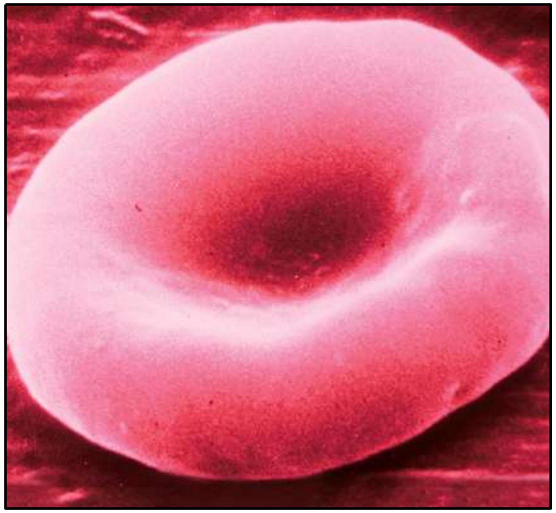
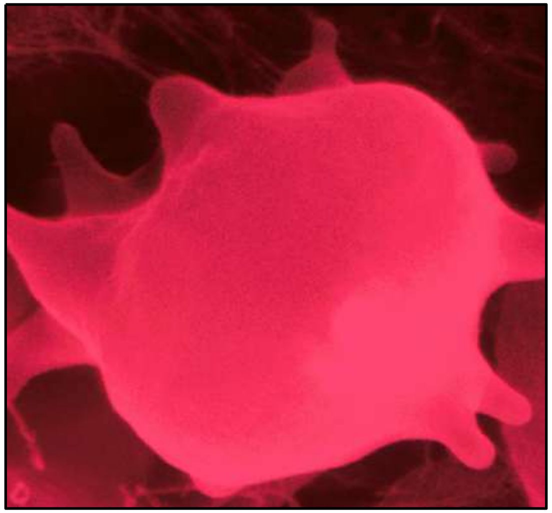


Figure 11.19 Functioning of the Artificial Kidney



Red Blood Cells in Three Stages of Osmosis





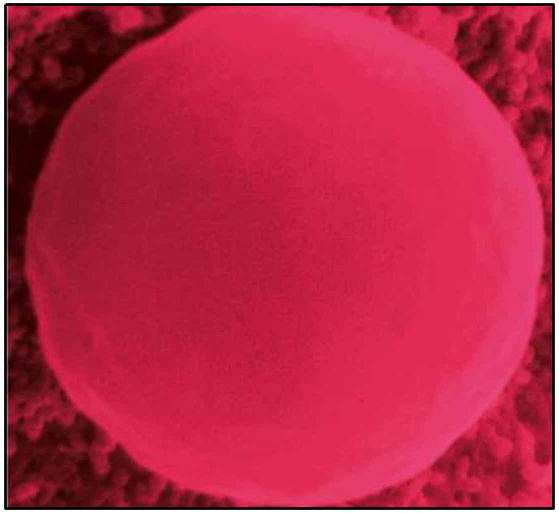


Figure 11.20 Reverse Osmosis

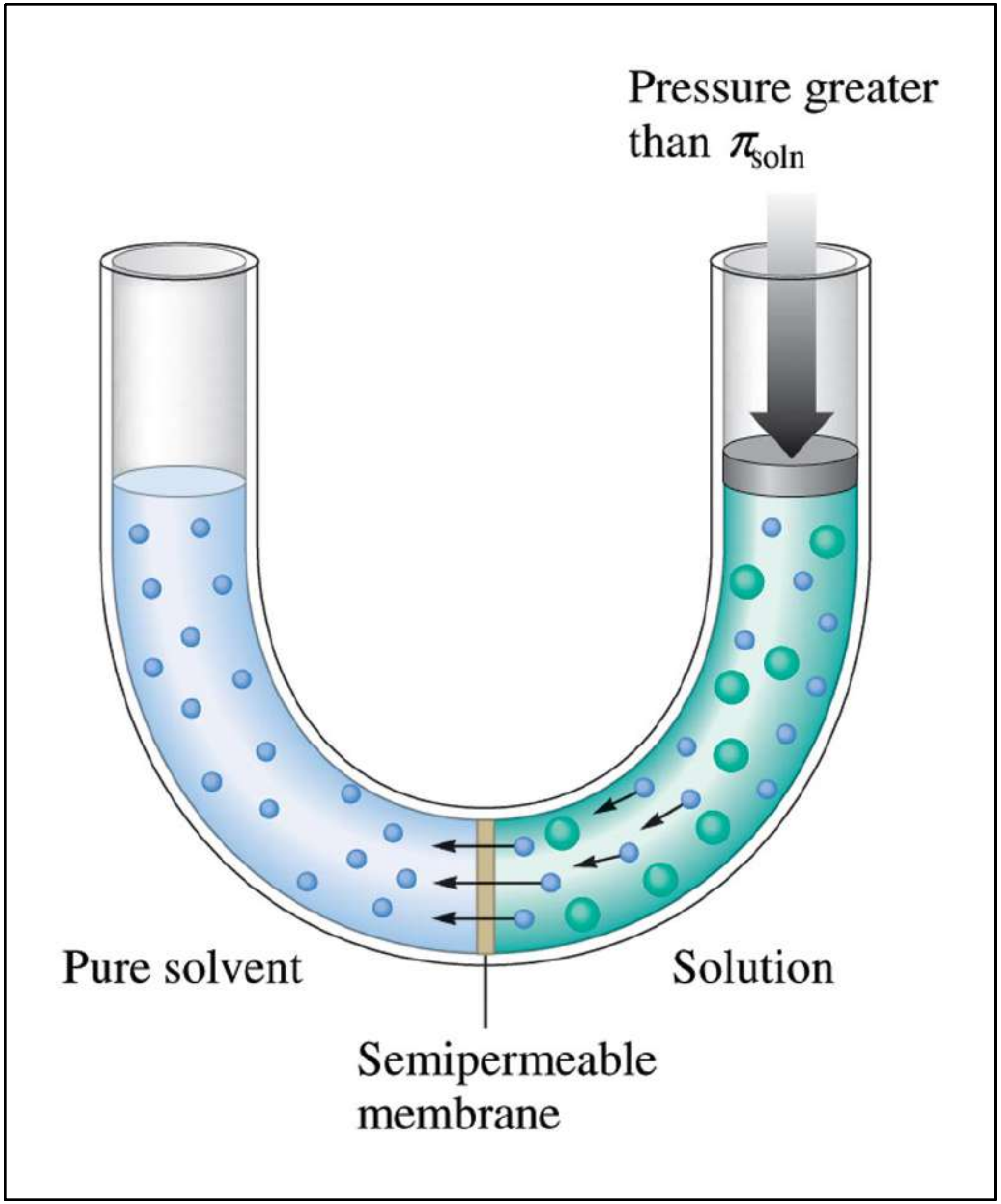
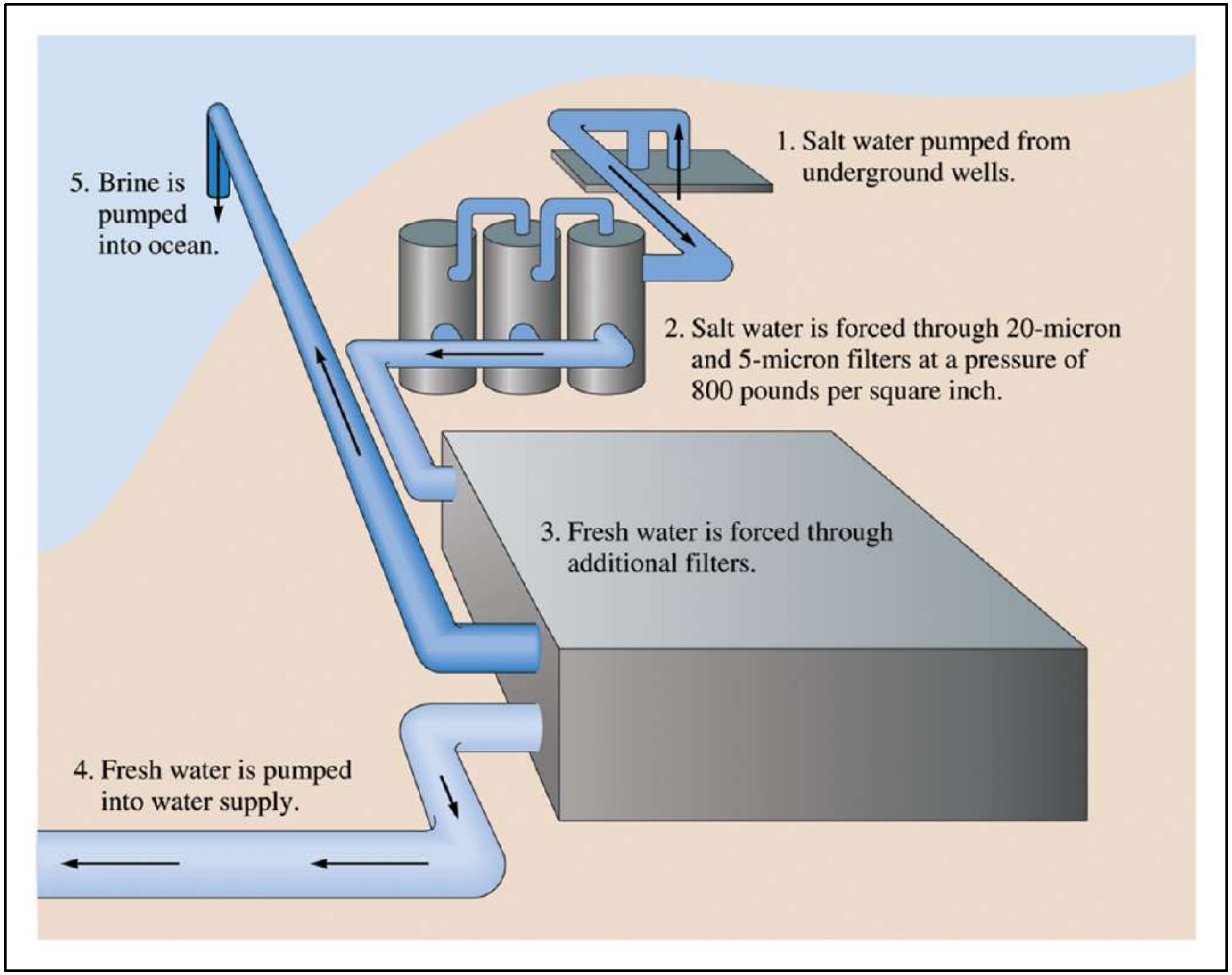


Figure 11.21b Machinery in the Desalination Plant for Catalina Island

Figure 11.21 (b) Machinery in the desalination plant for Catalina Island



React 12

- When 33.4 mg of a compound is dissolved in 10.0 mL of water at 25°C, the solution has an osmotic pressure of 558 torr. Calculate the molar mass of this compound.

Figure 11.22 In an Aqueous Solution a Few Ions Aggregate, Forming Ion Pairs that Behave as a Unit

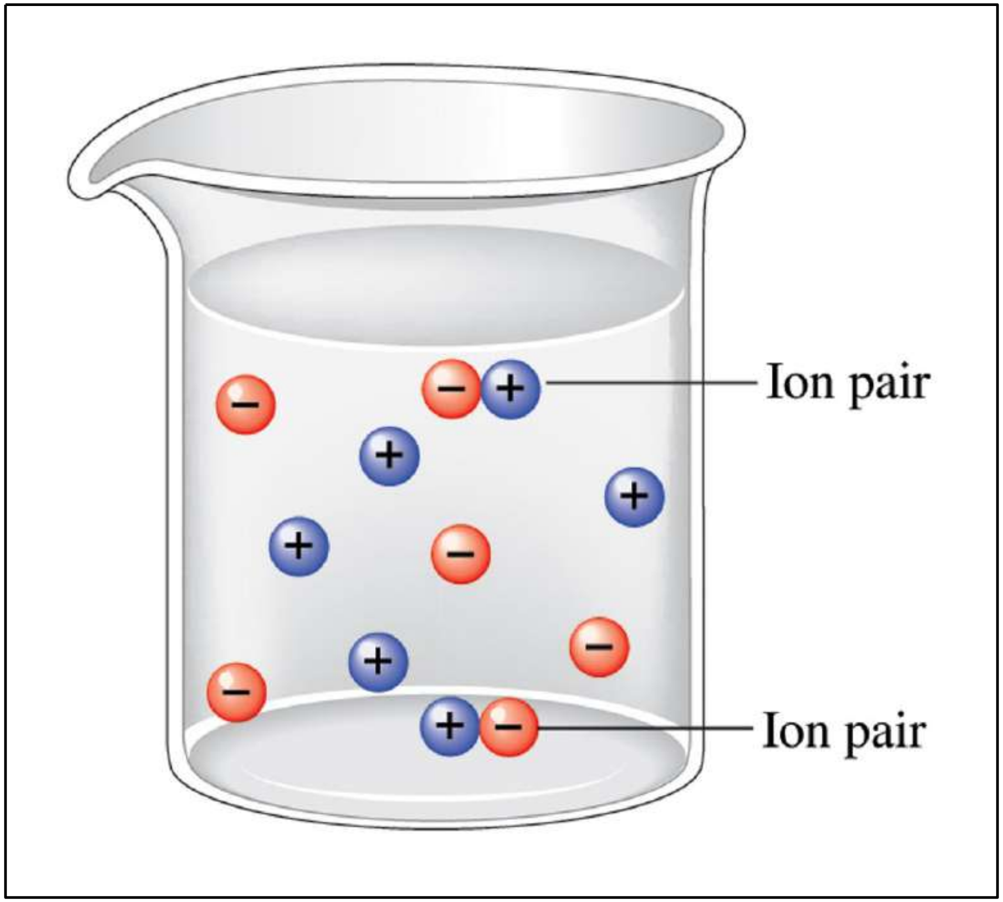


Table 11.6 Expected and Observed Values of the van't Hoff Factor for 0.05 m Solutions of Several Electrolytes

TABLE 11.6 Expected and Observed Values of the van't Hoff Factor for 0.05 *m* Solutions of Several Electrolytes

Electrolyte	*i* (expected)	*i* (observed)
NaCl	2.0	1.9
$MgCl_2$	3.0	2.7
$MgSO_4$	2.0	1.3
$FeCl_3$	4.0	3.4
HCl	2.0	1.9
Glucose*	1.0	1.0

*A nonelectrolyte shown for comparison.

React 13

- An aqueous solution is 1.00% NaCl by mass. Its density is 1.071 g/mL at 25°C. The observed osmotic pressure of this solution is 7.83 atm at 25°C.

a) What fraction of the moles in NaCl in this solution are ion pairs?

b) Calculate the freezing point that would be observed for this solution.

Figure 11.24 A Representation of Two Colloidal Particles