Section 14.4
Colligative Properties

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Colligative Properties

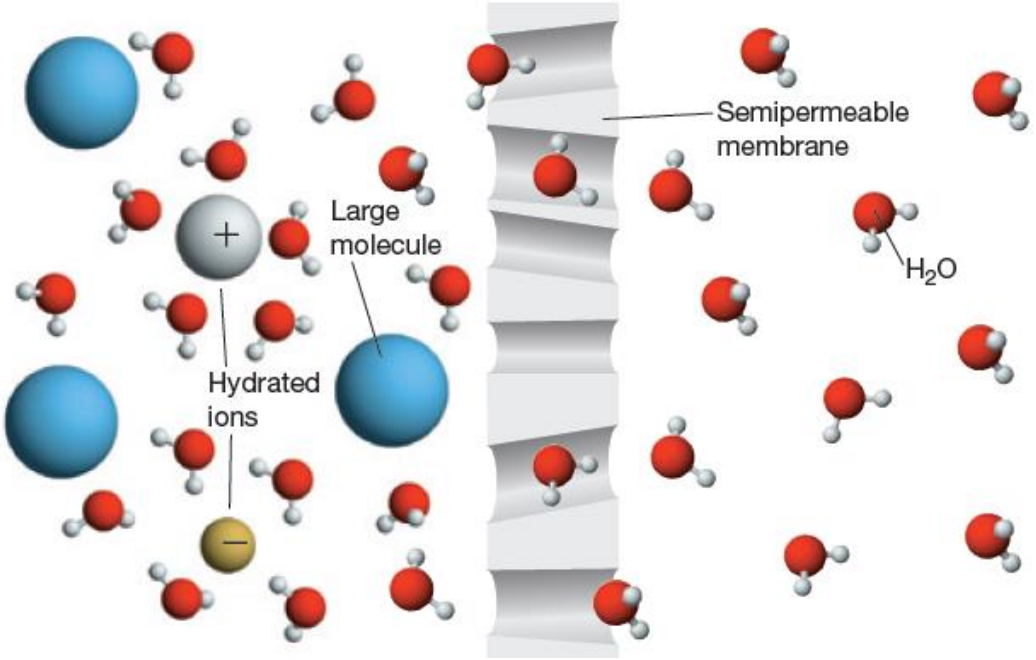
In this section…

a. Osmotic pressure
b. Vapor pressure lowering
    i. Distillation
c. Boiling point elevation
d. Freezing Point depression

Colligative Properties:

Properties of the *solvent* that change upon dissolution of a *solute*

Key #1: This all involves solute particles "blocking" molecules from leaving the liquid state:



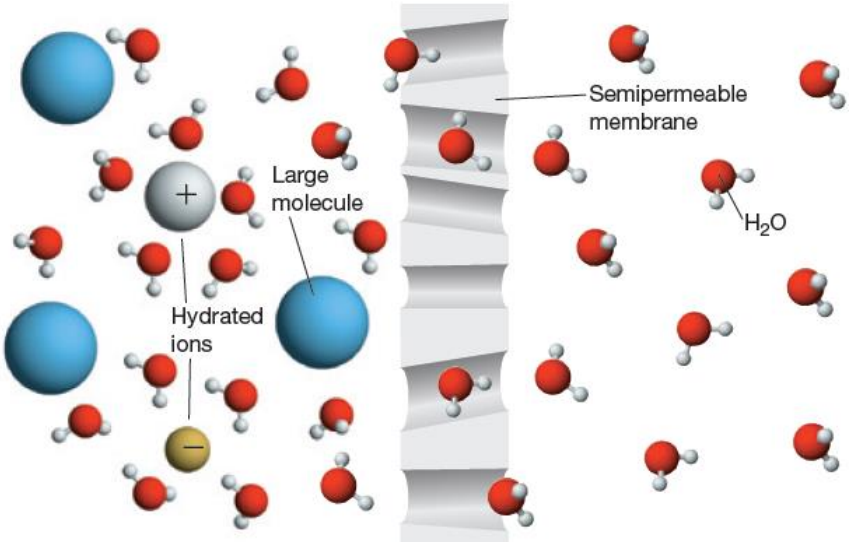
Key# 2: It does not matter what the solute is, just how many particles (molecules or ions are present)

Osmotic pressure

Osmotic pressure is the amount of pressure required to prevent the flow of a solvent across a semipermeable membrane.

$$\Pi = cRTi$$

c = solution concentration (mol/L)
R = ideal gas constant (0.082057 L · atm/K · mol)
T = temperature (K)
i = van't Hoff factor



Osmotic pressure: Example

The nonvolatile, nonelectrolyte TNT (trinitrotoluene), $C_7H_5N_3O_6$ (227.10 g/mol), is soluble in benzene (C_6H_6). Calculate the osmotic pressure generated when 14.3 g of TNT is dissolved in 242 mL of a benzene solution at 298 K.

$$\Pi = cRTi$$

c = solution concentration (mol/L)
R = ideal gas constant (0.082057 L $\cdot$ atm/K $\cdot$ mol)
T = temperature (K)
i = van't Hoff factor

Effect of Ions: i = van't Hoff factor

Ideal Van't Hoff factors:

NH_3

KCl

$CaCl_2$

$FeBr_3$

Osmotic pressure: the van’t Hoff Factor

What is the osmotic pressure of a solution containing 0.249 g $CaCl_2$ dissolved In 151 mL of an aqueous solution at 298 K?

The van’t Hoff factor in this solution is 2.8.

$$\Pi = cRTi$$

c = solution concentration (mol/L)
R = ideal gas constant (0.082057 L · atm/K · mol)
T = temperature (K)
i = van’t Hoff factor

Osmotic pressure: the van’t Hoff Factor

What is the osmotic pressure of a solution containing 0.249 g $CaCl_2$ dissolved In 151 mL of an aqueous solution at 298 K?

What does a van’t Hoff factor of 2.8 really mean?

Using osmotic pressure to determine molar mass

In a laboratory experiment, a student found that a 229.5-mL aqueous solution containing 11.34 g of a compound had an osmotic pressure of 15.4 mm Hg at 298 K. The compound was also found to be nonvolatile and a nonelectrolyte. What is the molar mass of this compound?

$$\Pi = cRTi$$

c = solution concentration (mol/L)
R = ideal gas constant (0.082057 L · atm/K · mol)
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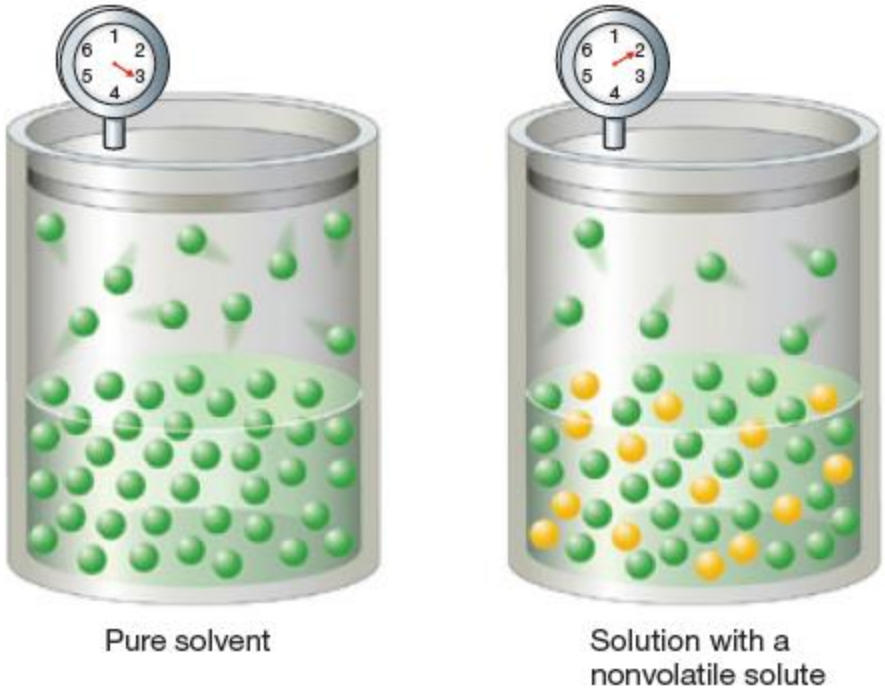
Vapor Pressure Lowering: The Concept

The presence of a nonvolatile solute blocks solvent molecules from escaping to the gas phase.

$P_{solution} \alpha \chi_{solvent}$



Vapor Pressure Lowering: Raoult's Law Example

$$P_{solution} = P^{o}_{solvent} \times \chi_{solvent} \times i$$

The vapor pressure of hexane (C_6H_{14}) at 50 °C is 399 mm Hg. What is the vapor pressure of a solution consisting of 70.0 g hexane and 0.100 mol of a solute that is a nonvolatile nonelectrolyte?

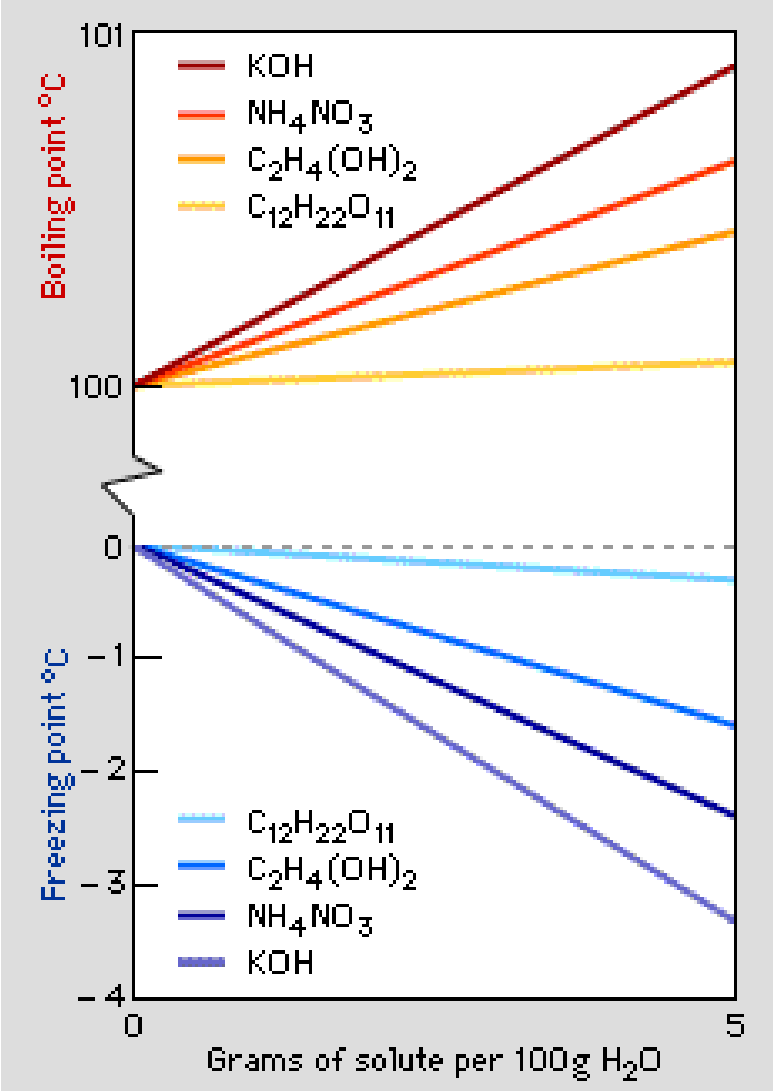
Distillation: Changing the composition of a mixture of volatile liquids

Vapor Pressures at 50 ^{o}C

Water	99 mm Hg
Ethanol	232 mmHg

Distill a 10% alcohol solution.

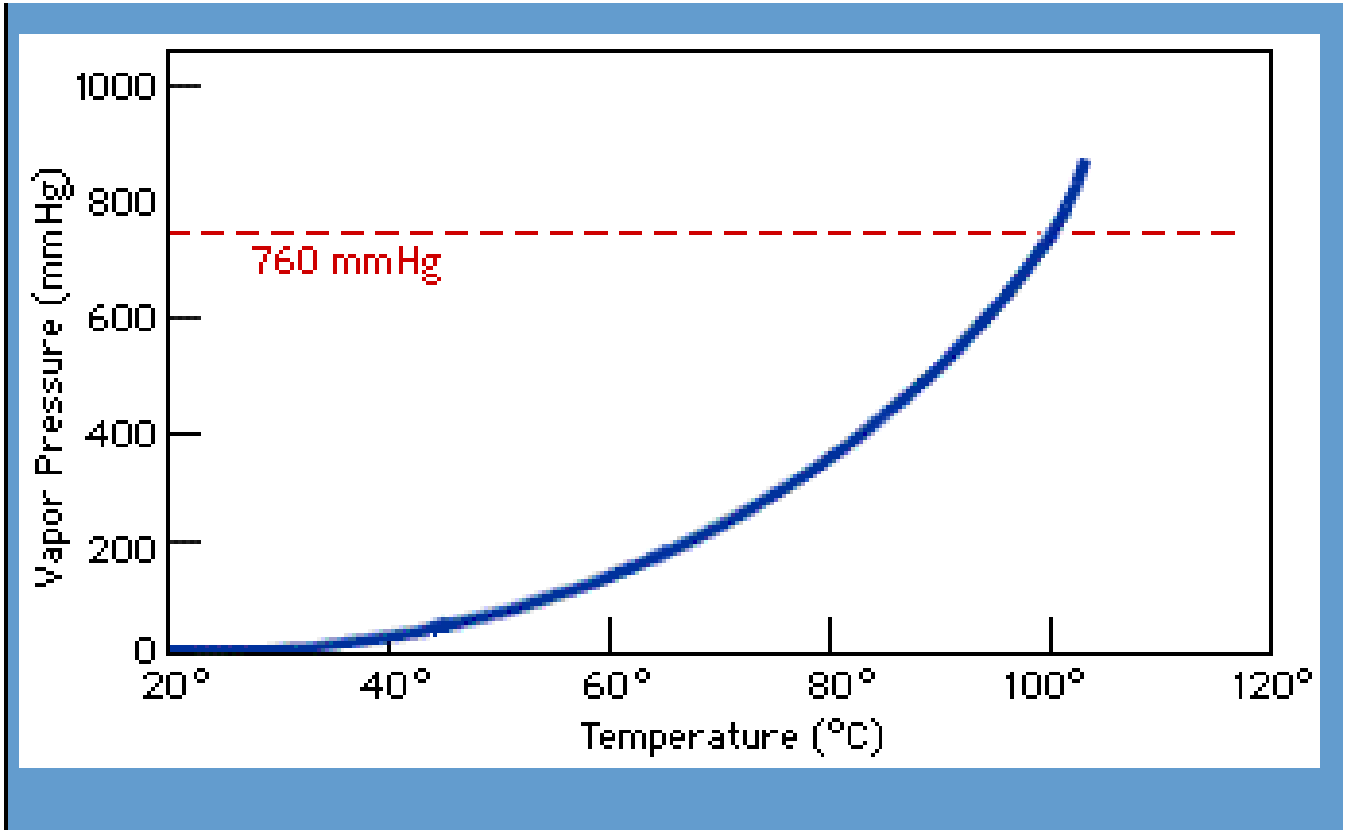
Freezing and Boiling Point Changes:



The presence of a solute keeps molecules in the liquid phase and therefore extends the temperature range the substance exists as a liquid.

Boiling Point Elevation: An extension of Vapor Pressure Lowering

The presence of a solute lowers the vapor pressure, meaning a higher temperature must be reached for the vapor pressure to reach 1 atm.



Boiling Point Elevation

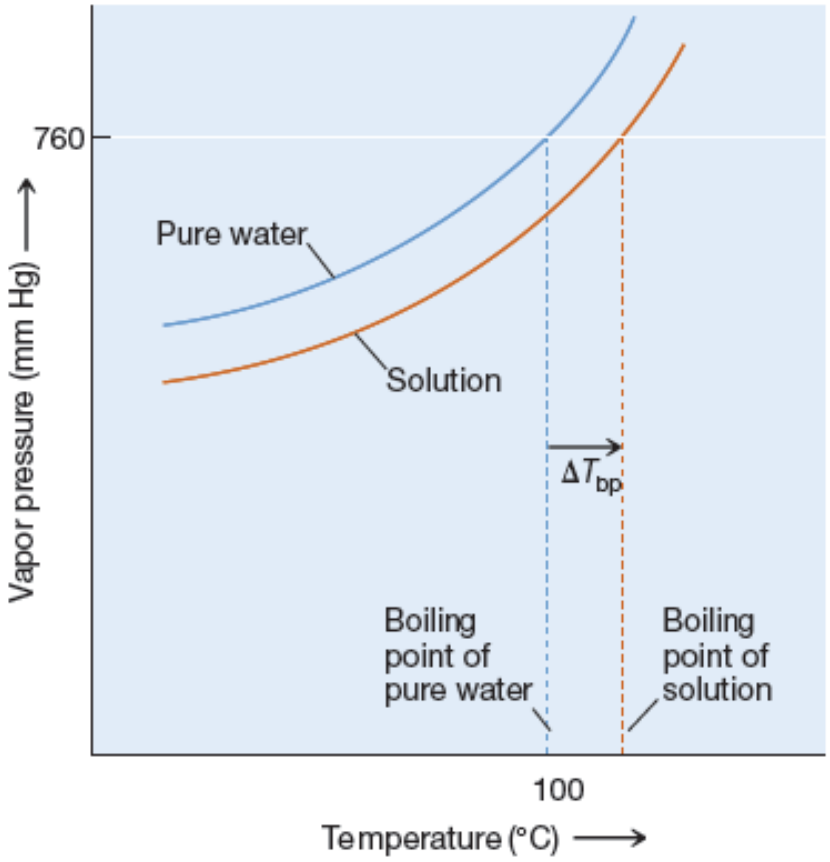


Table 13.4.1 Boiling Points and Elevation Constants for Common Solvents

Solvent	T_{bp} (°C)	K_{bp} (°C/*m*)
Water	100	0.512
Benzene	80.1	2.53
Acetic acid	118.1	3.07
Nitrobenzene	210.9	5.24
Phenol	182	3.56
Camphor	207.4	5.61

$$\Delta T_{\mathrm{bp}} = K_{\mathrm{bp}} m_{\mathrm{solute}} i$$

Boiling Point Elevation: Example

What is the boiling point of a solution containing 40.0 g I_2 and 250 g benzene (C_6H_6)?

$$\Delta T_{\text{bp}} = K_{\text{bp}} m_{\text{solute}} i$$

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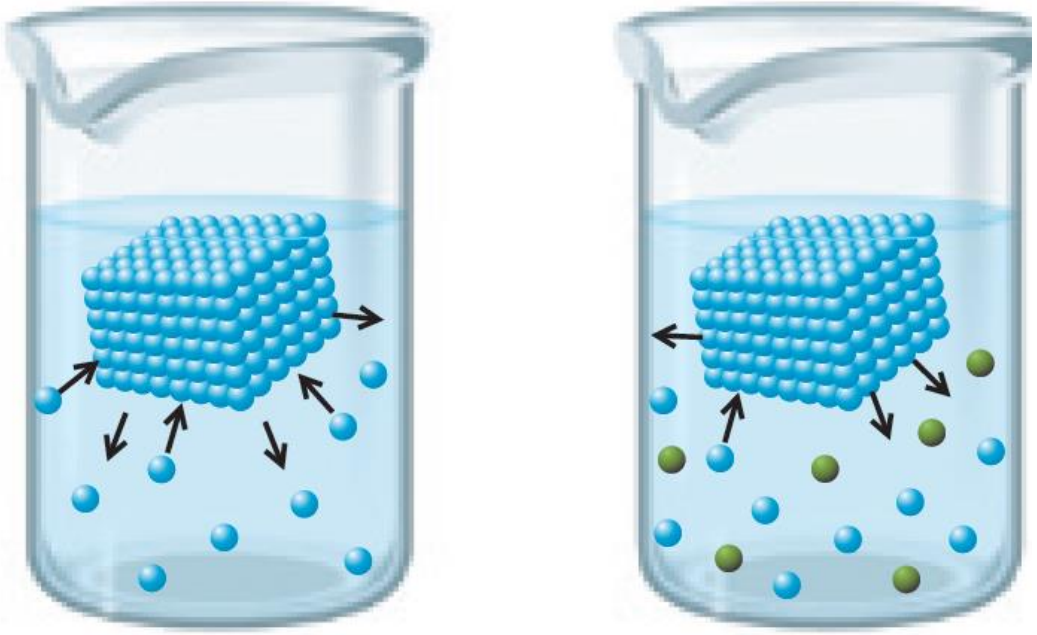
Use Boiling Point Elevation to Determine Molar Mass

0.315 g of an unknown compound (a nonvolatile nonelectrolyte) and 25 g of $CHCl_3$ has a boiling point of 62.09 °C. The normal boiling point of $CHCl_3$ is 61.70 °C. What is the molar mass of the compound?
(K_{bp} = 3.63 °C/*m* for $CHCl_3$)

$$\Delta T_{\text{bp}} = K_{\text{bp}} m_{\text{solute}} i$$

Freezing Point Depression



$$\Delta T_{\text{fp}} = K_{\text{fp}} m_{\text{solute}} i$$

Table 13.4.2 Freezing Points and Elevation Constants for Common Solvents

Solvent	T_{fp} (°C)	K_{fp} (°C/*m*)
Water	0	1.86
Benzene	5.5	5.12
Acetic acid	16.6	3.90
Nitrobenzene	5.7	7.00
Phenol	43	7.40
Camphor	178.4	40.0

Freezing Point Depression

What is the freezing point of a solution containing 40.0 g I_2, a nonelectrolyte, and 250 g benzene (C_6H_6)?

$$\Delta T_{\text{fp}} = K_{\text{fp}} m_{\text{solute}} i$$

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Freezing and Boiling Point Changes & Phase Diagrams