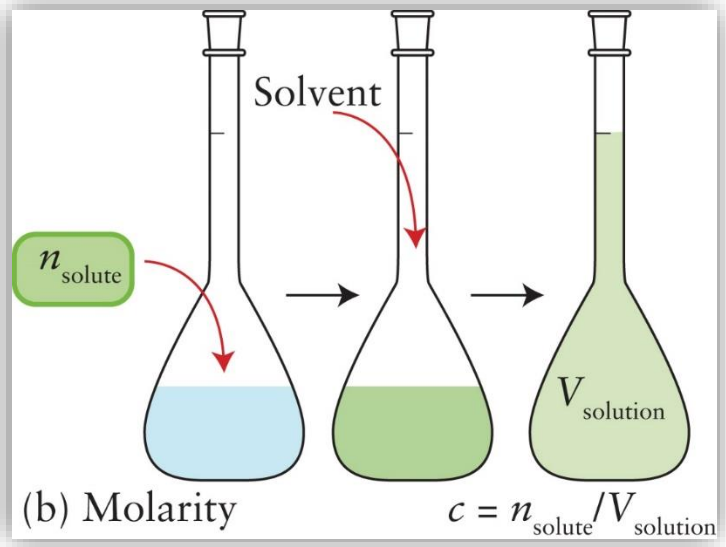
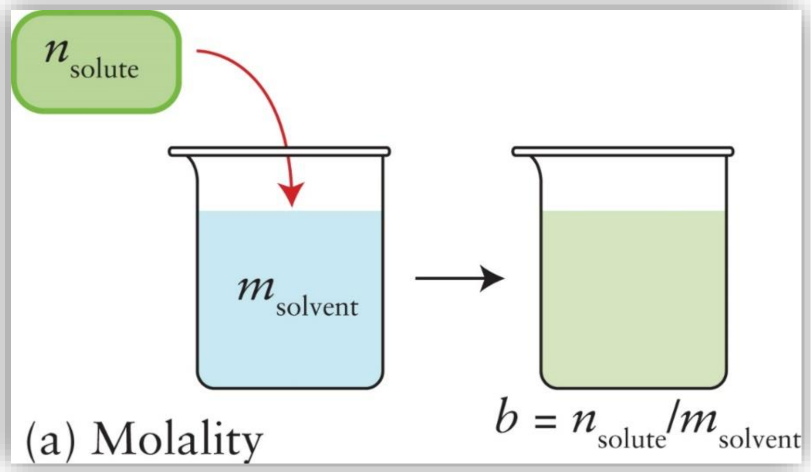
- For a solute J, types of concentrations are
  - Molarity or molar concentration, c_J or [J], in mol per L (solution)
  - Mole fraction, x_J
  - Molality, b_J or m, in mol per kg (solvent)
  - ppm, ppmv (or ppm (v/v)), ppm (m/m)





Topic 5E. Molality

TABLE 5E.1 Relations Between Mole Fraction, Molarity, and Molality*

Conversion	Expression
amount of solute present from molality	$n_{\text{solute}} = bm_{\text{solvent}}$
mass of solute present from molality	$m_{\text{solute}} = bm_{\text{solvent}}M_{\text{solute}}$
molality from mole fraction	$b = \dfrac{x_{\text{solute}}}{(1 - x_{\text{solute}})M_{\text{solvent}}}$
mole fraction from molality	$x_{\text{solute}} = \dfrac{bM_{\text{solvent}}}{1 + bM_{\text{solvent}}}$
molality from molarity	$b = \dfrac{c}{d - cM_{\text{solute}}}$
molarity from molality	$c = \dfrac{bd}{1 + bM_{\text{solute}}}$

**Symbols and units:*
n: amount (mol); m: mass (kg).
b: molality ($\text{mol}\cdot\text{kg}^{-1}$); c: molarity (molar concentration, $\text{mol}\cdot\text{L}^{-1}$); x: mole fraction (unitless).
d: mass density of solution ($\text{g}\cdot\text{mL}^{-1} = \text{g}\cdot\text{cm}^{-3} = \text{kg}\cdot\text{L}^{-1}$); M: molar mass ($\text{kg}\cdot\text{mol}^{-1}$).

Topic 5F. Colligative Properties

Colligative Properties

- Colligative properties
  The properties depend on the relative amounts of solute and solvent, but not on the chemical identity of the solute.
- Examples
  1. Boiling point (T_b) elevation
  2. Freezing point (T_f) depression
  3. Osmosis

Boiling-Point Elevation

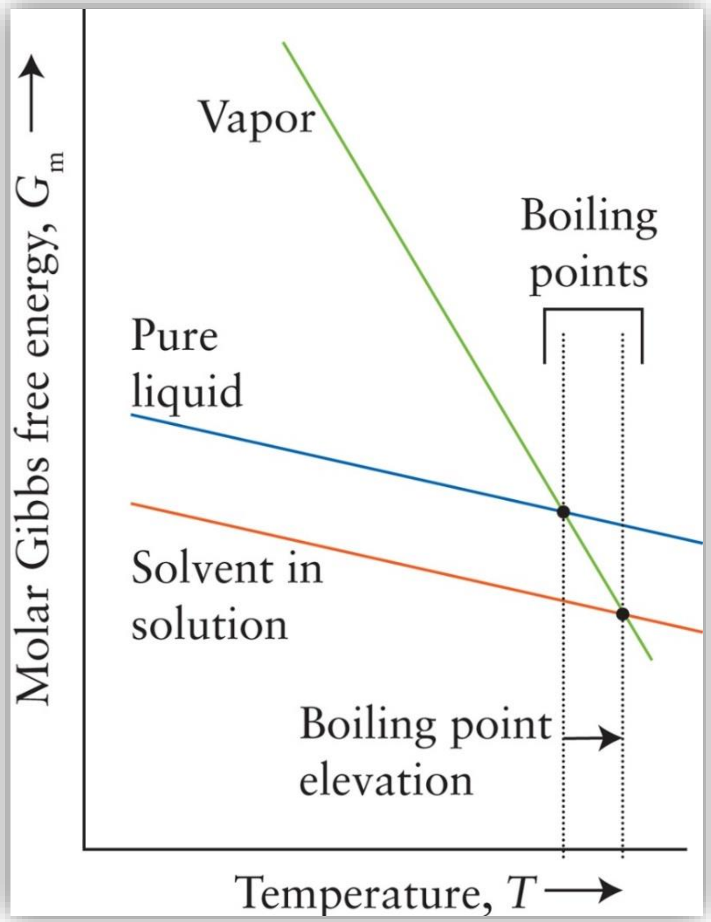
- Boiling-point elevation

  $\Delta T_b = k_b \cdot b_{solute}$

  k_b: boiling-point constant

  b_{solute}: molality of solute

- Can be explained by
  - Entropy increase ($G_m = H_m - TS_m$)
  - Vapor pressure decrease



Freezing-Point Depression

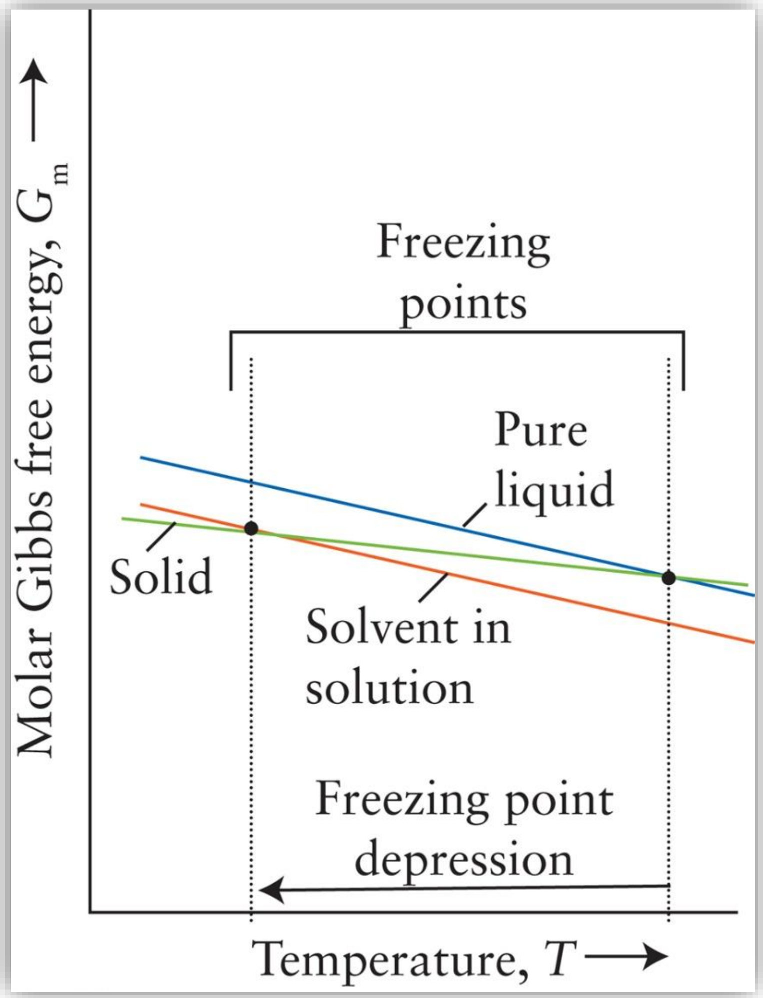
- Freezing-point depression

  $\Delta T_f = k_f \cdot b_{solute}$

  k_f: freezing-point constant

  b_{solute}: molality of solute

- Cryoscopy



Boiling-Point and Freezing-Point Constants

TABLE 5F.1 Boiling-Point and Freezing-Point Constants

Solvent	Freezing point/°C	k_f/ (K·kg·mol^{-1})	Boiling point/°C	k_b/ (K·kg·mol^{-1})
acetone	−95.35	2.40	56.2	1.71
benzene	5.5	5.12	80.1	2.53
camphor	179.8	39.7	204	5.61
carbon tetrachloride	−23	29.8	76.5	4.95
cyclohexane	6.5	20.1	80.7	2.79
naphthalene	80.5	6.94	217.7	5.80
phenol	43	7.27	182	3.04
water	0	1.86	100.0	0.51

van't Hoff Factor

- In electrolytes, $\Delta T_b = i\, k_b \bullet b_{solute}$; $\Delta T_f = i\, k_f \bullet b_{solute}$
- *i*: van't Hoff *i* factor, number of dissolved species
- Examples of *i*
  - For a dilute solution ($< 10^{-3}$ M), NaCl: $i = 2$ (Na^+, Cl^-); $CaCl_2$: $i = 2$ (Ca^{2+}, $2Cl^-$)
  - HCl in toluene: $i = 1$; HCl in water: $i = 2$
  - Weak acid HA dissociating 5%, $i = 0.95 + (0.05 \bullet 2) = 1.05$

Osmosis

- Osmosis: the flow of solvent through a membrane into a more concentrated solution (spontaneous process)
- Osmotic pressure: the pressure needed to stop the flow of solvent; isotonic

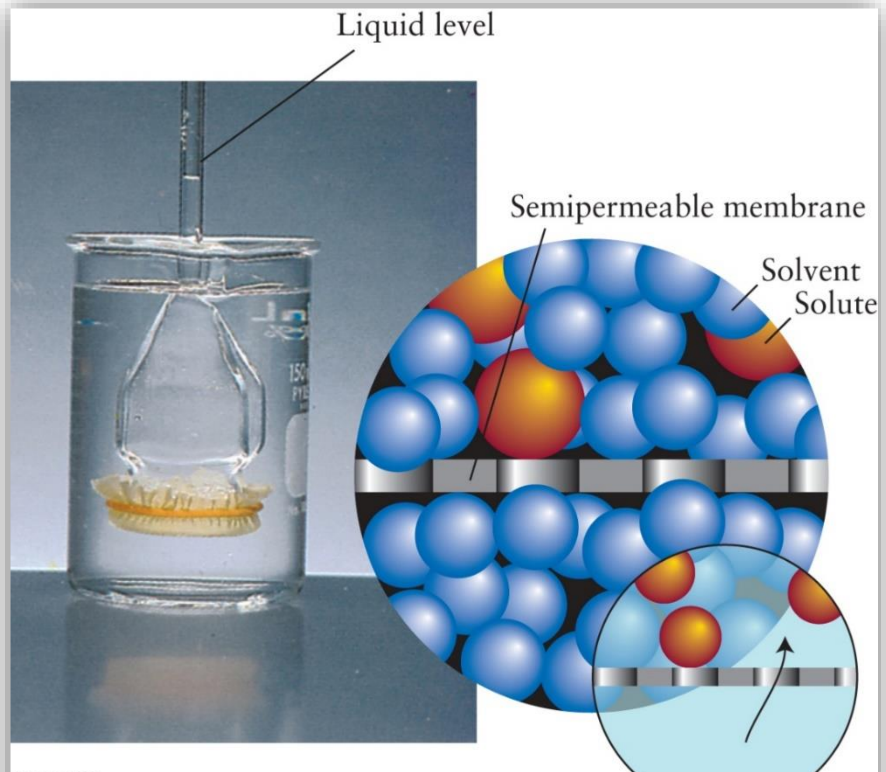
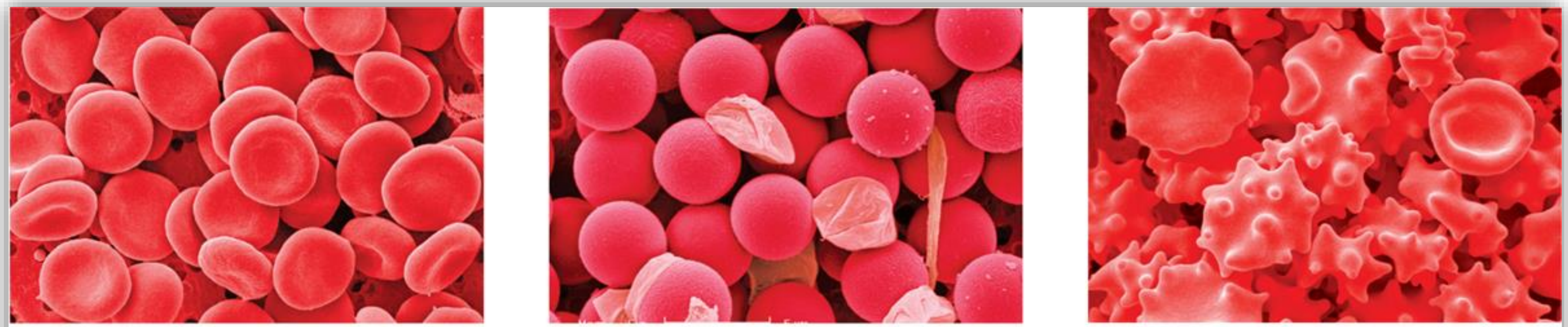


Figure 5F.3
Atkins, *Chemical Principles: The Quest for Insight*, 7e
W. H. Freeman & Company, © 2016 by P. W. Atkins, L. L. Jones, and L. E. Laverman
W. H. Freeman photo by Ken Karp

Osmosis

- Example of red blood cell



(a) (b) (c)

Osmosis

- van't Hoff Equation

  $\Pi = iRT \cdot c_{solute}$

  Π: osmotic pressure

  c_{solute}: molarity of solute
- Osmometry
- Reverse osmosis