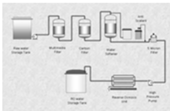

Lecture 22-23
Chemistry 163B W2020
Colligative Properties
Challenged Penpersonship Notes

1

colligative properties of solutions

colligative
One entry found.
Main Entry: col·li·ga·tive
Pronunciation: ˈkä-lə-ˌgā-tiv, kə-ˈli-gə-tiv
Function: *adjective*

: depending on the number of particles (as molecules) and not on the nature of the particles <pressure is a *colligative property*>

http://www.merriam-webster.com/dictionary/colligative

2

quantitative treatment of colligative properties

A. Freezing point depression
B. Boiling Point Elevation
C. Osmotic Pressure

3

quantitative treatment of colligative properties

Handout #53 **<u>Colligative Properties</u>**

from relationships for Chem 163B final:

Colligative properties:

- freezing point lowering:

$$\gamma_B X_B = \exp\left[-\frac{\Delta \bar{H}_{melting}}{R}\left[\frac{1}{T_f} - \frac{1}{T_f^\bullet}\right]\right] \qquad T_f = \frac{T_f^\bullet \Delta \bar{H}_{B\,melting}}{\Delta \bar{H}_{B\,melting} - RT_f^\bullet \ln(\gamma_B X_B)}$$

- boiling point elevation:

$$\gamma_B X_B = \exp\left[\frac{\Delta \bar{H}_{vaporization}}{R}\left[\frac{1}{T_{bp}} - \frac{1}{T_{bp}^\bullet}\right]\right] \qquad T_{bp} = \frac{T_{bp}^\bullet \Delta \bar{H}_{B\,vaporization}}{\Delta \bar{H}_{B\,vaporization} + RT_{bp}^\bullet \ln(\gamma_B X_B)}$$

- osmotic pressure:

$$\pi = \frac{-RT\ln(\gamma_B X_B)}{\bar{V}_B} \qquad \pi \approx \frac{n_A RT}{V_B} = \frac{n_{solute} RT}{V_{solvent}} \quad \textit{for dilute solution}$$

(hopefully) reassuring ??

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quantitative treatment of colligative properties

I. The pure solvent (component B) is originally in equilibrium in the two phases.
II. Addition of solute (component A) lowers the chemical potential of the solvent in the solution phase
III. Temperature (freezing point depression, boiling point elevation) or pressure (osmotic pressure) must be altered to reestablish equilibrium between the solution and the pure solvent phase.
IV. Obtain relationships between X_A or X_B and change in T or P.

It's as easy as I., II., III.,IV.

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freezing point depression (solid ⇄ liquid [solution])

I. pure solvent is originally in equilibrium in the two phases

solid is pure "solvent" B
X_B ***= mole fraction solvent B in solution***
X_A ***= mole fraction solute A in liquid***

$$\textit{pure solid}_B^\bullet \rightleftarrows \textit{pure liquid}_B^\bullet \quad \textit{at } T_f^\bullet \equiv \text{the normal melting point}\left(T_{fusion}^\bullet\right)$$

$$\mu_B^{s\bullet}(T_f^\bullet) = \mu_B^{\ell\bullet}(X_B = 1, T_f^\bullet)$$

$$\Delta\mu_B(T_f^\bullet) = \mu_B^{\ell\bullet}(T_f^\bullet) - \mu_B^{s\bullet}(T_f^\bullet) = 0$$

$$\Delta\bar{H}(T_f^\bullet) = \Delta\bar{H}_{B\,melting} > 0$$

for solid ⇄ liquid

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freezing point depression (solid ⇄ liquid [solution])

II. Still at $T_f^\bullet$, add solute A to solvent with resulting mole fractions X_A and X_B

μ_B^{soln} lowers

$$\mu_B^\ell(X_B, T_f^\bullet) \text{ is now chemical potential of solvent (B) in solution}$$

At $T_f^\bullet$ the original freezing temperature

$$\Delta\mu_B^{s\to\ell}(T_f^\bullet) = \mu_B^\ell(X_B, T_f^\bullet) - \mu_B^s(T_f^\bullet)$$

$$\Delta\mu_B^{s\to\ell}(T_f^\bullet) = RT_f^\bullet \ln(\gamma_B X_B)$$ "proof"

$$\Delta\mu_B^{s\to\ell}(T_f^\bullet) < 0$$

so at $T_f^\bullet$ the forward reacton (melting of the solid) would now occur spontaneously

7

freezing point depression (solid ⇄ liquid [solution])

III. Alter temperature to restore equilibrium $T_f^\bullet \to T_f$ $\left(\frac{\partial \frac{\Delta\mu}{T}}{\partial T}\right)_P = -\frac{\Delta H}{T^2}$

calculate $\Delta\mu$: $T_f^\bullet \to T_f$

solvent at new T_f — *solvent at $T_f^\bullet$* — *change $T_f^\bullet \to T_f$*

$$\left(\frac{\Delta\mu_B(T_f)}{T_f}\right)_P = \left(\frac{\Delta\mu_B(T_f^\bullet)}{T_f^\bullet}\right)_P - \int_{T_f^\bullet}^{T_f} \frac{\Delta\bar{H}_{B\,melting}}{T^2}\,dT$$

but at new T_f: want

$$\left(\frac{\Delta\mu_B(T_f)}{T_f}\right)_P = 0 \text{ since at 'new' equilibrium } T_f,\ \Delta\mu_B(T_f, X_B^{(\ell)}) = 0$$

with: $\Delta\mu_B(T_f^\bullet) = RT_f^\bullet \ln(\gamma_B X_B)$ from II

one gets:

$$0 = R\ln(\gamma_B X_B) + \left[-\int_{T_f^\bullet}^{T_f} \frac{\Delta\bar{H}_{B\,melting}}{T^2}\,dT\right]$$

change in $\Delta\mu_B$ due to adding solute — *change in $\Delta\mu_B$ due to temperature change*

extra:

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freezing point lowering

IV. Obtain relationships between X_B and change in T

$$R\ln(\gamma_B X_B) = \int_{T_f^\bullet}^{T_f} \frac{\Delta\bar{H}_{B\,melting}}{T^2}\,dT \quad \textit{from III}$$

$$R\ln(\gamma_B X_B) = -\Delta\bar{H}_{B\,melting}\left[\frac{1}{T_f} - \frac{1}{T_f^\bullet}\right]$$

since lhs < 0 and $\Delta H_{melting} > 0$

$$\left[\frac{1}{T_f} - \frac{1}{T_f^\bullet}\right] > 0 \quad T_f < T_f^\bullet$$

freezing point ***depression***

$$T_f = \frac{T_f^\bullet \Delta\bar{H}_{B\,melting}}{\Delta\bar{H}_{B\,melting} - RT_f^\bullet \ln(\gamma_B X_B)} \quad (\sim \text{eqn 9.32 E\&R}_{4th})$$

extra:

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boiling point elevation (cooking veggies in salt water !!)

Colligative properties:

- freezing point lowering:

$$\gamma_B X_B = \exp\left[-\frac{\Delta\bar{H}_{melting}}{R}\left[\frac{1}{T_f} - \frac{1}{T_f^\bullet}\right]\right] \qquad T_f = \frac{T_f^\bullet \Delta\bar{H}_{B\,melting}}{\Delta\bar{H}_{B\,melting} - RT_f^\bullet \ln(\gamma_B X_B)}$$

- boiling point elevation:

$$\gamma_B X_B = \exp\left[\frac{\Delta\bar{H}_{vaporization}}{R}\left[\frac{1}{T_{bp}} - \frac{1}{T_{bp}^\bullet}\right]\right] \qquad T_{bp} = \frac{T_{bp}^\bullet \Delta\bar{H}_{B\,vaporization}}{\Delta\bar{H}_{B\,vaporization} + RT_{bp}^\bullet \ln(\gamma_B X_B)}$$

- boiling point elevation and freezing point depression similar except for sign change
(due to X_B^ℓ product in melting, reactant in vaporization)

- $\gamma_B X_B < 1$ and $\Delta\bar{H}_{vaporization} > 0$ implies that $\left[\frac{1}{T_{bp}} - \frac{1}{T_{bp}^\bullet}\right] < 0$

so $T_{bp} > T_{bp}^\bullet$ **HIGHER BOILING POINT with salt**

HANDOUT #53

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non-volatile ionic solutes in vapor pressure and colligative properties

for X_B, mole fraction solvent,

$$X_B = X_{solvent} = \frac{n_{solvent}}{n_{solvent} + n_{(total\ solute\ particles)}}$$

NaCl → Na^+ + Cl^-

1 mole → 2 moles 'particles'

HW7 #52b

in mole fraction : moles solute = total moles ions

n moles salt $M^{2+}(X^-)_2 \to$ *n moles* M^{2+} + 2*n moles* X^-

3*n moles solute*

$$X_{H_2O} = \frac{moles\ H_2O}{(moles\ H_2O + 3\times moles\ salt)}$$

molality =**m**= (moles solute)/(1000 g solvent)
molarity =M= (moles solute)/(1L solution)

HW8 #58

$$A_xB_y(s) \rightleftarrows xA^{(soln)} + yB^{(soln)}$$ 'K_{sp} molality reference'

$$K_{sp} = \frac{(a_{A\,soln})^x (a_{B\,soln})^y}{(a_{AB\,solid})} = \frac{\left(\gamma_\pm [m_A]/1\text{m}\right)^x \left(\gamma_\pm [m_B]/1\text{m}\right)^y}{1}$$

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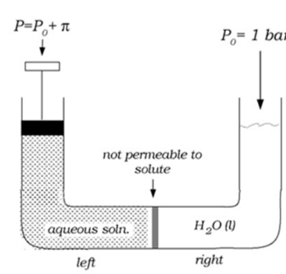
Osmotic Pressure Equilibrium



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osmotic pressure (solution [solvent + solute] ⇄ pure solvent)

I. pure solvent at P_{left} is originally in equilibrium with pure solvent at P_{right} ; i.e. $P_{left}=P_{right}=P_0$

$$\text{pure liquid}_B^{\bullet}(P_0,left) \rightleftarrows \text{pure liquid}_B^{\bullet}(P_0,right) \quad at\ T$$

'left' and 'right' refer to compartments separated by solute impermeable membrane

$$\mu_B^{\bullet}(P_0,left)=\mu_B^{\bullet}(P_0,right)$$

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osmotic pressure (II add solute to left compartment)

II. in left hand compartment add solute A to solvent with resulting mole fractions X_A and X_B

add X_A solute to liquid in 'left' compatment resulting in X_B for solvent

lectures 20-21 slide #20

$$\mu_B^{\ell}(P_0,left)=\mu_B^{\ell\bullet}(P_0,left)+RT\ln(\gamma_B X_B) < \mu_B^{\ell\bullet}(P_0,right)$$

$$\mu_B^{\ell}(P_0,left)<\mu_B^{\ell\bullet}(P_0,right)$$

so the solvent B moves spontaneously left ← right
(i.e. diluting solution on left)

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osmotic pressure (III, alter pressure)

III. alter Pressure: $P_{left} \rightarrow (P_0+\pi)_{left}$ to restore equilibrium

$$solution\,(X_B,P_0+\pi,left) \rightleftarrows pure\ solvent(P_0,right)$$

want: $\boldsymbol{\mu}_{\text{solution}}(X_B,P_0+\pi,left)=\boldsymbol{\mu}^{\bullet}_{\text{pure solvent}}(P_0,right)$

how does μ change with pressure?

$$\left(\frac{\partial\mu_B^{left}}{\partial P_{left}}\right)_T=\bar{V}_B \qquad \int_{P_0}^{P_0+\pi} d\mu_B^{left}(X_B)=\int_{P_0}^{P_0+\pi}\bar{V}_B\,dP$$

integrate

$$\mu_B^{left}(X_B,P_0+\pi)=\mu_B^{left}(X_B,P_0)+\left[P_0+\pi-P_0\right]\bar{V}_B$$

$$\mu_B^{left}(X_B,P_0+\pi)=\mu_B^{left}(X_B,P_0)+\pi\bar{V}_B$$

from II.

$$\mu_B^{left}(X_B,P_0+\pi)=\mu_B^{\bullet}(P_0)+RT\ln(\gamma_B X_B)+\pi\bar{V}_B$$

left with $P=P_0+\pi$ — *right with $P=P_0$*

$$\underbrace{\mu_B^{\bullet}(P_0)+RT\ln(\gamma_B X_B)+\pi\bar{V}_B}_{left}=\underbrace{\mu_B^{\bullet}(P_0)}_{right}$$

extra:

$$\pi=-\frac{RT\ln(\gamma_B X_B)}{\bar{V}_B}$$

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osmotic pressure (a little more manipulation)

IV. Obtain relationships between X_A and π, change in P

$$\pi=-\frac{RT\ln(\gamma_B X_B)}{\bar{V}_B}$$

$$for\ \gamma_B\approx 1 \quad and\ X_B=1-X_A$$

$$\pi=-\frac{RT\ln(1-X_A)}{\bar{V}_B}$$

further manipulations

$$\pi V_B=n_A RT$$

$$\pi V_{solution}=n_{solute}RT$$

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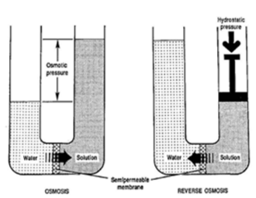
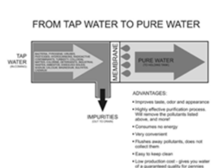
reverse osmosis





Water Systems
Aqua Technology
For the 21st Century

ESP Water Products.com

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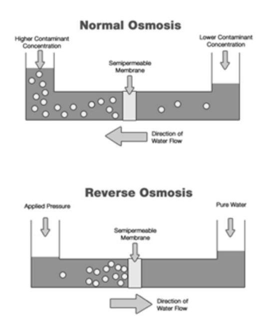
Reverse Osmosis



http://www.zenon.com/image/resources/glossary/reverse_osmosis/normal_osmosis.jpg

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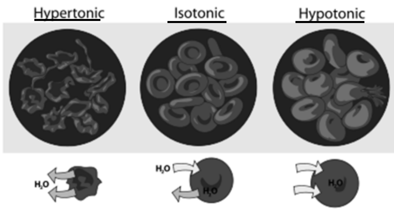
effect of osmosis on blood cells



salt	$X_{salt}^{outside} > X_{salt}^{inside}$	$X_{salt}^{outside} = X_{salt}^{inside}$	$X_{salt}^{outside} < X_{salt}^{inside}$	salt
	$X_{H_2O}^{outside} < X_{H_2O}^{inside}$	$X_{H_2O}^{outside} = X_{H_2O}^{inside}$	$X_{H_2O}^{outside} > X_{H_2O}^{inside}$	
water	$\mu_{H_2O}^{outside} < \mu_{H_2O}^{inside}$	$\mu_{H_2O}^{outside} = \mu_{H_2O}^{inside}$	$\mu_{H_2O}^{outside} > \mu_{H_2O}^{inside}$	water
	$outside \overset{H_2O}{\Leftarrow} inside$	$outside \overset{H_2O}{\Leftrightarrow} inside$	$outside \overset{H_2O}{\Rightarrow} inside$	
	collapse		**burst**	

hyponatremia

Woman dies after water-drinking contest

Water intoxication eyed in 'Hold Your Wee for a Wii' contest death

Associated Press
updated 7:24 p.m. PT, Sat., Jan. 13, 2007

SACRAMENTO, Calif. - A woman who competed in a radio station's contest to see how much water she could drink without going to the bathroom died of water intoxication, the coroner's office said Saturday.

Jennifer Strange, 28, was found dead Friday in her suburban Rancho Cordova home hours after taking part in the "Hold Your Wee for a Wii" contest in which KDND 107.9 promised a Nintendo Wii video game system for the winner.

"She said to one of our supervisors that she was on her way home and her head was hurting her real bad," said Laura Rios, one of Strange's co-workers at Radiological Associates of Sacramento. "She was crying and that was the last that anyone had heard from her."

NBC VIDEO

Launch

Woman in water drinking contest dies
Jan. 15: Sacramento Bee reporter Christina Jewett talks to MSNBC-TV's Contessa Brewer about the death of a woman who had competed in a radio station contest.
MSNBC

quantitative treatment of colligative properties

Handout #53 Colligative Properties

from relationships for Chem 163B final:

Colligative properties:

- freezing point lowering:

$$\gamma_B X_B = \exp\left[-\frac{\Delta\bar{H}_{melting}}{R}\left[\frac{1}{T_f}-\frac{1}{T_f^\bullet}\right]\right] \qquad T_f = \frac{T_f^\bullet \Delta\bar{H}_{B\,melting}}{\Delta\bar{H}_{B\,melting} - RT_f^\bullet \ln(\gamma_B X_B)}$$

- boiling point elevation:

$$\gamma_B X_B = \exp\left[\frac{\Delta\bar{H}_{vaporization}}{R}\left[\frac{1}{T_{bp}}-\frac{1}{T_{bp}^\bullet}\right]\right] \qquad T_{bp} = \frac{T_{bp}^\bullet \Delta\bar{H}_{B\,vaporization}}{\Delta\bar{H}_{B\,vaporization} + RT_{bp}^\bullet \ln(\gamma_B X_B)}$$

- osmotic pressure:

$$\pi = \frac{-RT\ln(\gamma_B X_B)}{\bar{V}_B} \qquad \pi \approx \frac{n_A RT}{V_B} = \frac{n_{solute}RT}{V_{solvent}} \quad \textit{for dilute solution}$$

(hopefully) reassuring ??

End of Lectures 22-23

freezing point depression (solid ⇄ solution)

II. Still at $T_f^\bullet$, add solute A to solvent with resulting mole fractions X_A and X_B

for solid phase of B there is no change :

$$\mu_B^{s\bullet}(T_f^\bullet) = \mu_B^{solid}(T_f^\bullet)$$

for the solvent (B) in solution: *see lect 20-21 slide #20*

$$\mu_B^{\ell}(T_f^\bullet) \equiv \mu_B^{solvent} \equiv \mu_B^{\ell\,(in\ soln)}(T_f^\bullet) = \mu_B^{\ell\bullet}(T_f^\bullet) + RT_f^\bullet \ln(\gamma_B X_B)$$

$$\text{so now } \Delta\mu_B(T_f^\bullet) = \mu_B^{\ell}(T_f^\bullet) - \mu_B^{s\bullet}(T_f^\bullet) = \mu_B^{\ell\bullet}(T_f^\bullet) + RT_f^\bullet \ln(\gamma_B X_B) - \mu_B^{s\bullet}(T_f^\bullet)$$

but $\mu_B^{\ell\bullet}(T_f^\bullet) - \mu_B^{s\bullet}(T_f^\bullet) = 0$ *since pure liquid and solid are in equilibrium at* $T_f^\bullet$

$$thus\ \Delta\mu_B(T_f^\bullet) = RT_f^\bullet \ln(\gamma_B X_B) \quad < 0$$

⇧

freezing point depression (solid ⇄ solution)

III. Alter temperature to restore equilibrium $T_f^\bullet \rightarrow T_f$

$$\left(\frac{\partial \frac{\Delta\mu}{T}}{\partial T}\right)_P = -\frac{\Delta\bar{H}}{T^2}$$

$$\int_{T_f^\bullet}^{T_f} d\left(\frac{\Delta\mu_B}{T}\right)_P = -\int_{T_f^\bullet}^{T_f}\frac{\Delta\bar{H}_{B\,melting}}{T^2}dT$$

old stuff

$$\left(\frac{\Delta\mu_B(T_f)}{T_f}\right)_P - \left(\frac{\Delta\mu_B(T_f^\bullet)}{T_f^\bullet}\right)_P = -\int_{T_f^\bullet}^{T_f}\frac{\Delta\bar{H}_{B\,melting}}{T^2}dT$$

freezing point depression (solid □ solution)

III. Alter temperature to restore equilibrium *(continued)*

$$\left(\frac{\Delta\mu_B^{\ell}(T_f)}{T_f}\right)_P - \left(\frac{\Delta\mu_B^{s}(T_f^\bullet)}{T_f^\bullet}\right)_P = -\int_{T_f^\bullet}^{T_f}\frac{\Delta\bar{H}_{B\,melting}}{T^2}dT$$

$$\left(\frac{\Delta\mu_B(T_f)}{T_f}\right)_P = 0 \text{ since at 'new' equilibrium } T_f\ ,\ \Delta\mu_B(T_f) = 0$$

$$and\quad \left(\frac{\Delta\mu_B(T_f^\bullet)}{T_f^\bullet}\right)_P = R\ln(\gamma_B X_B) \quad from\ eqn\ in\ II.$$

$$-R\ln(\gamma_B X_B) = -\int_{T_f^\bullet}^{T_f}\frac{\Delta\bar{H}_{B\,melting}}{T^2}dT$$

$$R\ln(\gamma_B X_B) + \left[-\int_{T_f^\bullet}^{T_f}\frac{\Delta\bar{H}_{B\,melting}}{T^2}dT\right] = 0$$

change in $\Delta\mu_B$ due to adding solute *change in $\Delta\mu_B$ due to temperature change*

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freezing point lowering

IV. Obtain relationships between X_B and change in T

$$R\ln(\gamma_B X_B) = \int_{T_f^\bullet}^{T_f}\frac{\Delta\bar{H}_{B\,melting}}{T^2}dT$$

$\Delta\bar{H}_{B\,melting} \sim$ independent of T

$$R\ln(\gamma_B X_B) = -\Delta\bar{H}_{B\,melting}\left[\frac{1}{T_f} - \frac{1}{T_f^\bullet}\right]$$

since $lhs < 0 \Rightarrow T_f < T_f^\bullet$ (freezing point **depression**)

$$\boxed{\gamma_B X_B = \exp\left[-\frac{\Delta\bar{H}_{B\,melting}}{R}\left[\frac{1}{T_f} - \frac{1}{T_f^\bullet}\right]\right] \quad \text{(integration of eqn 9.31 E\&R)}}$$

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freezing point lowering

IV. Obtain relationships between X_B and change in T *(cont)*

$$\gamma_B X_B = \exp\left[-\frac{\Delta\bar{H}_{B\,melting}}{R}\left[\frac{1}{T_f} - \frac{1}{T_f^\bullet}\right]\right]$$

$$-\frac{R}{\Delta\bar{H}_{B\,melting}}\ln(\gamma_B X_B) + \frac{1}{T_f^\bullet} = \frac{1}{T_f}$$

$$T_f = \frac{T_f^\bullet \Delta\bar{H}_{B\,melting}}{\Delta\bar{H}_{B\,melting} - RT_f^\bullet\ln(\gamma_B X_B)} \quad (\sim \text{eqn 9.32 E\&R}_{4th})$$

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osmotic pressure (III, alter pressure)

III. alter Pressure: $P_{left} \rightarrow (P_0 + \pi)_{left}$ to restore equilibrium

$$solution\ (X_B, P_0+\pi, left) \rightleftarrows pure\ solvent(P_0, right)$$

$$\left(\frac{\partial\mu_B^{left}}{\partial P_{left}}\right)_T = \bar{V}_B$$

$$\int_{P_0}^{P_0+\pi} d\mu_B^{left}(X_B) = \int_{P_0}^{P_0+\pi}\bar{V}_B dP$$

assuming solvent is incompressible

($\bar{V}_B$ doesn't change with pressure at constant T)

$$\mu_B^{left}(X_B, P_0+\pi) = \mu_B^{left}(X_B, P_0) + [P_0 + \pi - P_0]\,\bar{V}_B$$

$$\mu_B^{left}(X_B, P_0+\pi) = \mu_B^{left}(X_B, P_0) + \pi\bar{V}_B$$

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osmotic pressure (III, alter pressure, continued)

$$\mu_B^{left}(X_B, P_0+\pi) = \mu_B^{left}(X_B, P_0) + \pi\bar{V}_B$$

$$\mu_B^{left}(X_B, P_0+\pi) = \mu_B^\bullet(P_0) + RT\ln(\gamma_B X_B) + \pi\bar{V}_B$$

want π to restore equilibrium such that

$$\boldsymbol{\mu_B^{left}(X_B, P_0+\pi) = \mu_B^{\bullet right}(P_0)}$$

$$\underbrace{\mu_B^\bullet(P_0) + RT\ln(\gamma_B X_B) + \pi\bar{V}_B}_{left} = \underbrace{\mu_B^\bullet(P_0)}_{right}$$

$$\pi = -\frac{RT\ln(\gamma_B X_B)}{\bar{V}_B}$$

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osmotic pressure (a little more manipulation)

A=solute
B=solvent

$$\pi = -\frac{RT\ln(\gamma_B X_B)}{\bar{V}_B}$$

$$for\ \gamma_B \approx 1 \quad and\ X_B = 1 - X_A$$

$$\pi = -\frac{RT\ln(1 - X_A)}{\bar{V}_B}$$

$$\ln(1+x) \approx x \quad for\ small\ x \quad (i.e.\ dilute\ solution,\ X_A\ small)$$

$$\pi = \frac{X_A RT}{\bar{V}_B}$$

$$X_A = \frac{n_A}{n_A + n_B} \quad and\ n_A + n_B \approx n_B \quad for\ dilute\ solution$$

$$\pi \approx \frac{n_A RT}{n_B\bar{V}_B}$$

$$\pi V_B = n_A RT$$

$$\pi V_{solution} = n_{solute} RT$$

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colligative properties and nonvolatile solutes

- mole fraction solvent $X_B = n_B/n_{total}$
- for non-volatile solute A $P^{\bullet}_A = 0$
- concentrations frequently given in molality
  M=molarity=(moles solute)/(L solution)
  ‡**m**=molality=(moles solute)/(1000g solvent)
  moles H_2O/1000g solvent≈55.55 moles
  aqueous soln: $X_{solvent}$=55.55/(m+55.55)
- for ionic solvent (moles solute)=(total moles of ions)
- example: 2 **m** aqueous solution of $CaCl_2$ (complete dissociation)

$$X_{H_2O} = \frac{55.55\ \text{moles / kgH}_2\text{O}}{(2\ \text{moles solute/kgH}_2\text{O} \times 3\ \text{moles ions/moles solute}) + 55.55\ \text{moles / kgH}_2\text{O})} = .9025$$

‡ *however when referring to the molality of a specific ion, e.g. [Cl^-] from $CaCl_2$, the number of ions per mole of solute is already factored in*

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