

7.1 Real Gases and Ideal Gases

I. Ideal Gas

A.) Accurate depiction of P-V-T relationship for real gases

i.) obtain expansion work & equil. const K_p

B.) Deficiencies of microscopic model

1.) Gas molecules are point masses, but molecules occupy finite volume

2.) molecules in gas don't interact, but real gas molecules interact w/ one another through a potential

II. Real Gas

A.) P-V-T relationship of real & ideal gas is the same at low densities & high temp.

B.) At high density & low temp, molecular interactions can be neglected.

7.2 Equations of State for Real Gases and their Range of Applicability:

I. Eqn. of State for Real Gases

A.) Van der Waals Eqn. of state: $P = \frac{RT}{V_m - b} - \frac{a}{V_m^2} = \frac{nRT}{V - nb} - \frac{n^2a}{V^2}$

B.) Redlich-Kwong Eqn of state: $P = \frac{RT}{V_m - b} - \frac{a}{\sqrt{T}} \frac{1}{V_m(V_m+b)} = \frac{nRT}{V - nb} - \frac{n^2a}{\sqrt{T}} \frac{1}{V(V+nb)}$

i.) a = measure of the attractive part of intermolecular potential

ii.) b = measure of minimum ^{volume} ~~value~~ that a mole of molecules can occupy

a) @ 426 K (all 3 eqns - include ideal gas) correctly reproduce P-V behavior w/ ideal gas having largest error.

b) eqns differ greatly at 310 K

C.) Beattie-Bridgeman Eqn of state: (need to experimentally obtain 5 parameters to use)

$$P = \frac{RT}{V_m^2} \left[1 - \frac{C}{V_m T^3} \right] (V_m + B) - \frac{A}{V_m^2} \quad \text{with } A = A_0 \left(1 - \frac{a}{V_m} \right) \quad \& \quad B = B_0 \left(1 - \frac{b}{V_m} \right)$$

D.) Virial Eqn of state: $P = RT \left[\frac{1}{V_m} + \frac{B(T)}{V_m^2} + \dots \right]$

1.) most firmly grounded in theory

2.) a series expansion is always valid in its convergence range

3.) $B(T)$, $C(T)$, and so on are known as virial coefficients

4.) series doesn't converge at high P where V_m is small

5.) If $B(T)$ neg. (pos), attractive (repulsive) part of potential dominates at value T

a.) As volume of system dec, pressure inc. rapidly as V dec. $\Rightarrow P \uparrow, V \downarrow$

b.) Temp-dependent equil. pressure called vapor pressure of liquid

i.) as volume dec, system becomes single-phase system again

c.) temp at which range of V_m shrunk to single value called critical temp, T_c

i.) When $T=T_c$, isotherm exhibits an inflection pt so: $(\frac{\partial P}{\partial V_m})_{T=T_c} = 0$ & $(\frac{\partial^2 P}{\partial V_m^2})_{T=T_c} = 0$

A.) $T_c, P_c, V_c \Rightarrow$ are called critical constants that describe the phase diagram of a pure substance.

- d) Parameters a and b for the Van der Waals and Redlich-Kwong eqn of states are chosen to best represent real gas data & can be done by using P, V & T at critical pts. T_c, V_c , & P_c .
- e.) Maxwell construction: the oscillating region is replaced by horizontal line for area above & below
 - a.) used in generating isotherms

7.3 The Compression Factor

I. Compression Factor (z)

$$A) \text{Eqn: } z = \frac{V_m}{V_{\text{ideal}}} = \frac{PV_m}{RT}$$

- i.) For ideal gas, $z=1$ for all values of P and V_m
 - a.) For $z>1$, real gas exerts greater pressure than ideal gas
 - b.) For $z<1$, real gas exerts smaller pressure than ideal gas for same values of T & V_m

2.) Compression factor for given gas is function of temp.

- a.) $T=200\text{K}$, z dec. w/ pressure
- b.) $T=400\text{K}$, z inc. linearly w/ temp.
- c.) functional dependence also predicted by Redlich-Kwong eqn
- d.) Van der Waals eqn predicts that initial slope is 0, & z inc. slowly w/ P .

i.) both temp $z \rightarrow 1$ as $P \rightarrow 0$

$$\text{ii.) variation of compression factor w/ } P, \text{ const. } T \Rightarrow \left(\frac{\partial z}{\partial P}\right)_T = \left(\frac{\partial^2 z}{\partial [RT/V_m]}\right)_T = \frac{1}{RT} \left(\frac{\partial z}{\partial [1/V_m]}\right)_T$$

A.) VdW in ideal gas: $1/V_m \rightarrow 0$

$$\text{B.) Result: } \left(\frac{\partial z}{\partial P}\right)_T = \frac{b}{RT} - \frac{a}{(RT)^2}$$

3.) Boyle temp. (T_B): $T_B = \frac{a}{RB}$

a.) T_B diff. for each gas

b.) At Boyle temp both $z \rightarrow 1$ and $\left(\frac{\partial z}{\partial P}\right)_T \rightarrow 0$ as $P \rightarrow 0$

i.) exhibited by an ideal gas

c.) only at $T=T_B$, a real gas exhibits ideal behavior as $P \rightarrow 0$ w/ respect to $\lim_{P \rightarrow 0} \left(\frac{\partial z}{\partial P}\right)_T$

i.) above Boyle temp, $\left(\frac{\partial z}{\partial P}\right)_T > 0$ as $P \rightarrow 0$

ii.) below T_B , $\left(\frac{\partial z}{\partial P}\right)_T < 0$ as $P \rightarrow 0$

A.) $\lim_{P \rightarrow 0} \left(\frac{\partial z}{\partial P}\right)_T$ always pos. at high temp b/c $b - \frac{a}{(RT)^2} \rightarrow b > 0$ as $T \rightarrow \infty$

B.) molecules feel repulsive part of potential for $T >> T_B$.

C.) $T << T_B$, $\lim_{P \rightarrow 0} \left(\frac{\partial z}{\partial P}\right)_T$ always neg. b/c molecules feel attractive part of potential

D.) for high values of P , $z > 1$ for all gases

d.) If $\lim_{P \rightarrow 0} \left(\frac{\partial z}{\partial P}\right)_T < 0$ for a gas, $T < T_B$ & attractive part of potential dominates

e.) If $\lim_{P \rightarrow 0} \left(\frac{\partial z}{\partial P}\right)_T > 0$ for a gas, $T > T_B$ & repulsive part of potential dominates.

7.4 The Law of Corresponding States

I. Law of Corresponding States

$$A.) T_r = \frac{T}{T_c}$$

$$B.) P_R = \frac{P}{P_C}$$

$$C.) V_{mr} = \frac{V_m}{V_{mc}}$$

i.) If two gases have the same value of T_r, P_r, V_{mr} they are in corresponding states.

a.) Values of P, V, T can be diff. for two gases in corresponding states

$$D.) \text{Van der Waals in corresponding states: } P_r P_C = \frac{R T_r T_c}{V_{mr} V_{mc} - b} - \frac{a}{V_{mr}^2 V_{mc}^2}$$

$$\text{i.) replacing } T_c, V_{mc}, P_c: P_c = \frac{a}{27b^2} V_{mc} = 3b, T_c = \frac{8}{27Rb}$$

$$\text{a.) Eqn becomes: } \frac{a P_r}{27b^2} = \frac{8a T_r}{27b(3b V_{mr} - b)} - \frac{a}{9b^2 V_{mr}^2} \text{ or } P_r = \frac{8 T_r}{3 V_{mr}} - \frac{3}{V_{mr}^2}$$

i.) material-dependent quantities enter through values of P_c, T_c, V_c rather than through a & b .

ii.) law implicitly assumes that two parameters are sufficient to describe an intermolecular potential.

A.) assumption best for molecules that are spherical b/c potential indep. of molecular orientation

iii) real gas exerts a smaller pressure than an ideal gas in range of $T_r < 1$, $P_r < 5.5$, $z < 1$ as $T_r < 2$

iv.) for $z > 1$ for $P_r > 7$ for all values of T_r & all values of P_r if $T_r > 4$, real gas exerts larger pressure than ideal gas

$$2.) \text{Error} = 100\% \cdot \frac{z-1}{z}$$

a.) ideal gas is in error by less than 30% in range of T_r, P_r where repulsive part dominates if $P_r < 8$

b.) error is as great as -300% in range of T_r, P_r where attractive part dominates

c.) error greatest near $T_r=1$ b/c reduced temp & liq/gas coexist phase

d.) at or above T_c , real gas more compressible than ideal (critical temp)

$$E.) \text{van der Waals: } z_c = \frac{P_c V_c}{R T_c} = \frac{1}{R} \times \frac{a}{27b^2} \times 3b \times \frac{27Rb}{8a} = \frac{3}{8}$$

i.) predicts critical compressibility is indep. of parameters $a, b \Rightarrow$ same for all gases

7.5 Fugacity and the Equilibrium Constant for Real Gases

I. Equilibrium const. for mixture of reactive gases

$$A.) \text{pure ideal gas: } \mu(T, P) = \mu^\circ(T) + RT \ln \frac{P}{P^\circ}$$

$$B.) \text{real gas: } \mu(T, P) = \mu^\circ(T) + RT \ln \frac{f}{f^\circ}$$

i.) f = fugacity, viewed as the effective pressure that real gas exerts

a.) attractive range of intermolecular potential: $G_m^{\text{real}} < G_m^{\text{ideal}}$ & $f < P$

b.) repulsive range of intermolecular potential: $G_m^{\text{real}} > G_m^{\text{ideal}}$ & $f > P$

2.) fugacity has limiting behavior that $f \rightarrow P$ as $P \rightarrow 0$

a.) f° (standard state of fugacity) \Rightarrow is the value that fugacity would have if gas behaved ideally at 1 bar pressure.

$$ii) f = p^*$$

C.) Real or ideal gas at const. T : $dG_m = V_m dP$

$$i.) \therefore d\mu_{ideal} = V_m^{ideal} dP \Leftrightarrow d\mu_{real} = V_m^{real} dP$$

a) Since $V_m^{ideal} \neq V_m^{real}$, chemical potential of real gas will change differently with pressure than the chemical potential of ideal gas

$$i.) \text{difference: } d\mu_{real} - d\mu_{ideal} = (V_m^{real} - V_m^{ideal}) dP$$

$$ii.) \text{integrate: } \int_{P_i}^P (d\mu_{real} - d\mu_{ideal}) = [\mu_{real}(P) - \mu_{real}(P_i)] - [\mu_{ideal}(P) - \mu_{ideal}(P_i)] \\ = \int_{P_i}^P (V_m^{real} - V_m^{ideal}) dP$$

$$iii.) \text{Let } P_i \rightarrow 0, \mu_{real}(P_i) = \mu_{ideal}(P_i)$$

$$A.) \mu_{real}(P) - \mu_{ideal}(P) = \int_0^P (V_m^{real} - V_m^{ideal}) dP'$$

$$B.) \ln f = \ln P + \frac{1}{RT} \int_0^P (V_m^{real} - V_m^{ideal}) dP'$$

$$C.) \ln f = \ln P + \int_0^P \frac{z-1}{P'} dP' \text{ or } f = P \exp \left[\int_0^P \left(\frac{z-1}{P'} \right) dP' \right] \text{ or } f = \gamma(P, T) P$$

i.) proportionality factor γ , called fugacity coefficient \Rightarrow depends on P & T

D.) fugacity coefficient, γ

1.) $\gamma \rightarrow 1$ as $P \rightarrow 0$

2.) $\gamma(P, T) > 1$ if $(z-1)/P > 0$

3.) $\gamma(P, T) < 1$ if $(z-1)/P < 0$

4.) If $T > T_B$, then $\gamma(P, T) > 1$ for all pressures

a) Not true for high values of P_r

5.) γ can be graphed as a function of T_r & P_r

Chapt 8: Phase Diagrams & the Relative Stability of Solids, Liquids & Gases

8.1) what Determines the Relative Stability of Solid, Liquid & Gas phases?

I. Phases

A.) Def: form of matter that's uniform w/ respect to chemical composition & state of aggregation of both micro & macro scales

B.) Stability @ const. temp & pressure is Gibbs energy, $G(T, P, n)$

$$i.) \text{chemical potential, } \mu, \text{ for pure substance: } \mu = \left(\frac{\partial G}{\partial n} \right)_{T, P} = \left(\frac{\partial [n G_m]}{\partial n} \right)_{T, P} = G_m$$

a.) $n = \#$ of moles of substance in system

$$b.) d\mu = dG_m \Rightarrow d\mu = -S_m dT + V_m dP$$

$$i.) \mu \text{ varies w/ changes in } P \& T: \left(\frac{\partial \mu}{\partial T} \right)_P = -S_m \text{ & } \left(\frac{\partial \mu}{\partial P} \right)_T = V_m$$

A.) since S_m & V_m pos., μ dec. as temp inc. & μ inc. as pressure dec.

ii.) endothermic ($\Delta H > 0$) $\Rightarrow S \rightarrow l \rightarrow g$ & entropy: $\Delta S = \Delta H + \text{transition}/T$

$$A.) T \text{ inc. so } P \text{ explained by } \left(\frac{\partial \mu}{\partial T} \right)_P = -S_m \text{ & } S_m^{\text{gas}} > S_m^{\text{liq}} > S_m^{\text{solid}}$$

C.) boiling pt elevation, inc. P: $V_m^{\text{gas}} \gg V_m^{\text{liq}} > 0$

D.) freezing pt elevation, inc. P: $V_m^{\text{liq}} > V_m^{\text{solid}}$

E.) freezing pt depression, inc P: $V_m^{\text{liq}} < V_m^{\text{solid}}$

- 1.) $S \rightarrow l$ is energetically unfavorable w/ respect to $s \rightarrow g$
 - a.) solid sublimes & transition T_s called sublimation temp.
 - b.) P at which μ vs. T curves for all 3 phases intersect called triple pt.

8.2 The Pressure-Temperature Phase Diagram

I. Phase Diagram

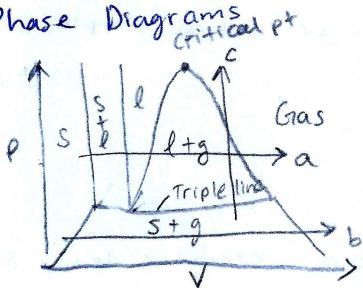
- A.) Determined experimentally b/c material-specific forces b/w atoms determine temp & pressure @ which diff. phases are stable.
- B.) P-T phase diagram - displays stability regions for a pure substance
 - 1.) triple pt: all three phases coexist
 - 2.) coexistence curve: all P,T pts for which same two phases coexist at equil.
 - a) curves are: s-g, s-l, g-s
 - i.) s-g & l-g always pos.
 - ii.) s-l can be pos or neg.
- C.) Def: boiling pt of substance is temp @ which vapor pressure of substance = P_{ext}
- D.) Def: standard boiling temp: temp at which vapor press. of subs = 1 bar
- E.) Def: normal boiling temp: temp @ which " " = 1 atm
 - 1.) P = vapor pressure of substance
 - 2.) If solid more dense than liq. \rightarrow slope of curve pos. & melting temp inc. w/ P
 - 3.) If solid less dense than liq. \rightarrow slope neg. & melting temp dec. w/ P
 - a.) boiling pt always inc. w/ pressure
 - b.) s-g coexistence curve ends at triple pt
 - c.) l-s " extends indefinitely
 - d.) l-g curve ends at critical pt where $T=T_c$ & $P=P_c$
 - e.) substance for which $T>T_c$ & $P>P_c$ called supercritical fluids
 - f.) $\Delta H = \Delta H_{\text{sublimation}} = \Delta H_{\text{fusion}} + \Delta H_{\text{vaporization}}$
 - A.) If T below triple pt temp, liq. exists at equilibrium only if slope of l-s coexistence curve is neg.

8.3 The Phase Rule

- I. Coexistence of ~~two~~ phases, α & β , γ
 - A.) $\mu_\alpha(T, P) = \mu_\beta(T, P)$ \leftarrow two phases (α & β)
 - B.) Three phases coexist @ equil (α & β , γ): $\mu_\alpha(T, P) = \mu_\beta(T, P) = \mu_\gamma(T, P)$
 - i.) a system of pure substances has 2 degrees of freedom
 - C.) J.W Gibbs derived phase rule, which links the # of degrees of freedom to the # of phases in a system of equil.
 - i.) pure substance: $F = 3 - p$
 - a.) $F = \# \text{ of degrees of freedom}, p = \# \text{ of phases}$

8.4 The Pressure-Volume and Pressure-Volume-Temperature Phase Diagrams

I. Phase Diagrams

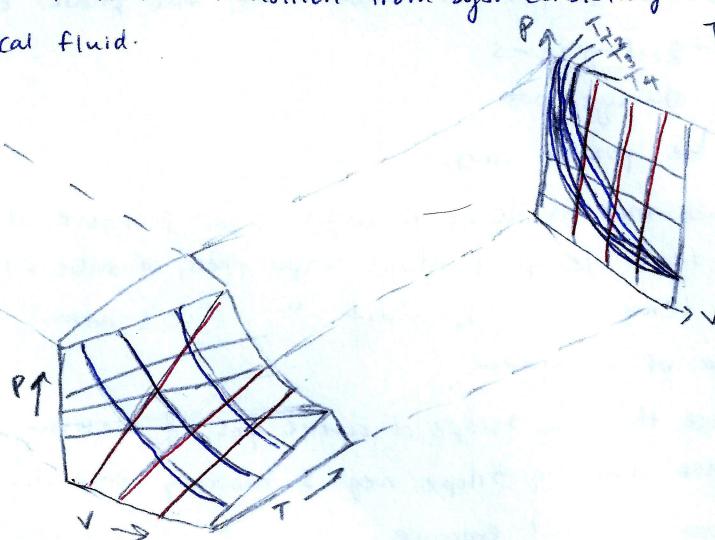
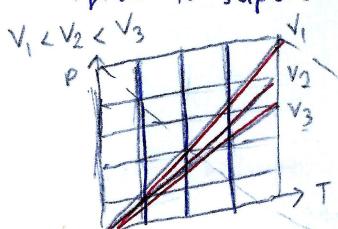


- A) P-V phase diagram displays single- & 2-phase coexistence regions, a critical pt, & a triple line.
- For substance in which $V_m^{\text{liq}} > V_m^{\text{solid}}$
 - Process a. is $s \rightarrow g$ by inc. temp in isobaric process for which P greater than triple pt pressure.

3) Process b, is an isobaric transition from $s \rightarrow g$ for P below triple pt pressure

a.) known as freeze drying

4.) Process c, shows const. volume transition from sys. consisting of solid & vapor in equil. to supercritical fluid.



B) The P-V-T diagram is for ideal gas, at constant pressure, constant volume and constant temp path (shown in gray, red, blue)

i) diagram shows substance that expands upon melting

8.5 Providing a Theoretical Basis for the P-T Phase Diagram

I. Phase Diagram

A) Chemical potential (α & β in equil): $\mu_A(P, T) = \mu_B(P, T)$

i) If macro. variables change : $P, T \rightarrow P + dP \Rightarrow \mu_A(P, T) + d\mu_A = \mu_B(P, T) + d\mu_B$

a) For 2 phases to remain in equil: $d\mu_A = d\mu_B$

2.) Since $d\mu$ can be expressed in terms of dT & $dP \Rightarrow d\mu_A = -S_{mA}dT + V_{mA}dP$ & $d\mu_B = -S_{mB}dT + V_{mB}dP$

a) $d\mu$ can be equated giving: $-S_{mA}dT + V_{mA}dP = -S_{mB}dT + V_{mB}dP$ or

$$(S_{mB} - S_{mA})dT = (V_{mB} - V_{mA})dP$$

B.) Clapeyron eqn: $\frac{dP}{dT} = \frac{\Delta S_m}{\Delta V_m}$

i) Eqn allows us to calculate slope of coexistence curve in P-T phase diagram if ΔS_m & ΔV_m known

$$\Delta G_{\text{fusion}} = \Delta H_{\text{fusion}} - T\Delta S_{\text{fusion}} = 0$$

$$1) \left(\frac{dP}{dT}\right)_{\text{fusion}} = \frac{\Delta S_{\text{fusion}}}{\Delta V_{\text{fusion}}} \approx \frac{22 \text{ J/mol K}}{\pm 4.0 \times 10^{-6} \text{ m}^3/\text{mol}} = \pm 55 \times 10^6 \text{ Pa/K} = \pm 55 \text{ bar/K}$$

a) Trouton's Rule: $\Delta S_{\text{vaporization}} \approx 90 \text{ J/mol K}$ for liq.

$$2) \left(\frac{dP}{dT}\right)_{\text{vaporization}} = \frac{\Delta S_{\text{fusion}}}{\Delta V_{\text{vaporization}}} \approx \frac{95 \text{ J/mol K}}{2.0 \times 10^{-2} \text{ m}^3/\text{mol}} \approx 4.8 \times 10^3 \text{ Pa/K} = 4.8 \times 10^{-2} \text{ bar/K}$$

8.6 Using the Clausius-Clapeyron Equation to Calculate Vapor Pressure as a Function of T

I. Clapeyron Eqn

$$A.) S-l \text{ coexistence curve: } \int \frac{P_f}{P_i} dP = \int_{T_i}^{T_f} \frac{\Delta S_{\text{fusion}}}{\Delta V_{\text{fusion}}} dT = \int_{T_i}^{T_f} \frac{\Delta H_{\text{fusion}}}{\Delta V_{\text{fusion}}} \frac{dT}{T} \approx \frac{\Delta H_{\text{fusion}}}{\Delta V_{\text{fusion}}} \int_{T_i}^{T_f} \frac{dT}{T}$$

$$1) \text{Simplified } P_f - P_i = \frac{\Delta H_{\text{fus}}}{\Delta V_{\text{fus}}} \ln \frac{T_f}{T_i} = \frac{\Delta H_{\text{fus}}}{\Delta V_{\text{fus}}} \ln \frac{T_i + \Delta T}{T_i} \approx \frac{\Delta H_{\text{fus}}}{\Delta V_{\text{fus}}} \frac{\Delta T}{T_i}$$

II. Clausius-Clapeyron Eqn

$$A.) \frac{dP}{dT} = \frac{\Delta S_{\text{vap}}}{\Delta V_{\text{vap}}} \approx \frac{\Delta H_{\text{vap}}}{TV_m} = \frac{P \Delta H_{\text{vap}}}{RT^2} \quad \& \quad \frac{dP}{P} = \frac{\Delta H_{\text{vap}}}{R} \frac{dT}{T^2}$$

$$1) \text{Assuming } \Delta H_{\text{vap}} \text{ remains const. over range of temp of interest: } \int \frac{P_f}{P_i} \frac{dP}{P} = \frac{\Delta H_{\text{vap}}}{R} \times \int_{T_i}^{T_f} \frac{dT}{T^2}$$

$$\text{and } \ln \frac{P_f}{P_i} = -\frac{\Delta H_{\text{vap}}}{R} \times \left(\frac{1}{T_f} - \frac{1}{T_i} \right)$$

8.7 The Vapor Pressure of a Pure Substance Depends on the Applied Pressure

I. Partial Pressure

$$A.) \mu_{\text{liq}}(T, P) = \mu_{\text{gas}}(T, P) \text{ @ equil.}$$

$$1) \text{w/ respect to } P: \left(\frac{\partial \mu_{\text{liq}}(T, P)}{\partial P} \right)_T = \left(\frac{\partial \mu_{\text{gas}}(T, P)}{\partial P} \right)_T \left(\frac{\partial P}{\partial P} \right)_T$$

$$a) \text{since } d\mu = -S_m dT + V_m dP \text{ & } (\frac{d\mu}{dP})_T = V_m, \text{ then } V_m^{\text{liq}} = V_m^{\text{gas}} \left(\frac{\partial P}{\partial P} \right)_T \text{ or } \left(\frac{\partial P}{\partial P} \right)_T = \frac{V_m^{\text{liq}}}{V_m^{\text{gas}}}$$

$$b) \frac{RT}{P} dP = V_m^{\text{liq}} dP \text{ or } RT \int_{P_x}^P \frac{dP'}{P'} = V_m^{\text{liq}} \int_{P_x}^P dP'$$

$$i) \text{integrate: } RT \ln \left(\frac{P}{P_x} \right) = V_m^{\text{liq}} (P - P_x)$$

$$A.) \text{for water equil. vapor pressure: } P^* = 0.0316 \text{ bar, } P = 1 \text{ bar, } V_m^{\text{liq}} = 1.81 \times 10^{-5} \text{ m}^3/\text{mol}$$

$$B.) \ln \left(\frac{P}{P_x} \right) = \frac{V_m^{\text{liq}} (P - P_x)}{RT}, P = 1.0007 P^* \approx 0.0316 \text{ bar}$$

8.8 Surface Tension

I. Surface Tension

A.) N/m ← units: force over the surface of liq per unit length of surface perpendicular to force

1) work associated w/ creation of additional surface area at const V & T: $dA = \gamma d\sigma$

a.) A = helmholtz energy

b.) γ = surface tension

c.) σ = unit element of area

d.) for spontaneous process @ const V & T: $dA < 0$

2) If droplet radius inc. r to $r+dr$, area increases by $d\sigma$

$$a.) \sigma = 4\pi r^2 \text{ so } d\sigma = 8\pi r dr$$

b.) work expansion of droplet is $8\pi\gamma r dr$

$$c.) \frac{F}{\text{work/distance}} = 8\pi\gamma r$$

$$i.) \text{net effect of force: } 4\pi r^2 P_{\text{outer}} + 8\pi\gamma r = 4\pi r^2 P_{\text{inner}} \text{ or } P_{\text{inner}} = P_{\text{outer}} + \frac{2\gamma}{r}$$

$$A.) P_{\text{inner}} - P_{\text{outer}} \rightarrow 0 \text{ as } r \rightarrow \infty$$

$$B) P_1 - P_2 = \frac{2\gamma}{R_1} - \frac{2\gamma}{R_2} = 2\gamma \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

- 3.) Capillary rise def: liquid rise in liq. above level of 0 pressure due to net upward force produced by attraction of water molecules
- 4.) capillary depression def: where liq does not wet walls of container
- capillary rise or depression eqn: $h = 2\gamma/\rho gr$
- 5.) contact angle, θ , is liquid surface, difference in surface tension at s-l interface
- b.) Intermediate cases
- complete wetting $\Rightarrow \theta = 0^\circ$
 - nonwetting, complete $\Rightarrow \theta = 180^\circ$
- i) Pinner = $P_{outer} + \frac{2\gamma \cos \theta}{r}$ & $h = \frac{2\gamma \cos \theta}{\rho gr}$
- 7.) high tensile strength: Water supply to top of surface.