

$$R = 0.08206 \text{ liter atm K}^{-1} \text{ mole}^{-1} = 8.314 \text{ J K}^{-1} \text{ mole}^{-1} \quad N_0 = 6.02 \times 10^{23} \text{ mole}^{-1}$$

$$J = \text{kg m}^2 \text{ s}^{-2} \quad h = 6.6262 \times 10^{-34} \text{ J s}$$

### Kinetic Theory

$$\langle U_{tr} \rangle = \frac{3}{2} kT \quad \langle u^2 \rangle = \frac{3RT}{M} = \frac{3kT}{m}$$

### Collision Frequency (per molecule)

$$z = 4\sqrt{\pi} \frac{N}{V} \sigma^2 \frac{RT}{M}^{\frac{1}{2}}$$

### Total Collision Frequency (per volume)

$$Z = \frac{N}{V} \frac{z}{2} = 2\sqrt{\pi} \frac{N}{V} \sigma^2 \frac{RT}{M}^{\frac{1}{2}}$$

### Mean free path      rms displacement

$$l = \frac{1}{\sqrt{2}\pi \frac{N}{V} \sigma^2} \quad \langle d^2 \rangle^{\frac{1}{2}} = \sqrt{N} l$$

### Diffusion      Fick's 1<sup>st</sup> and 2<sup>nd</sup>

$$J_x = -D \frac{dc}{dx}_t \quad \frac{dc}{dt}_x = D \frac{d^2c}{dx^2}_t$$

$$D = \frac{kT}{f} \quad f = 6\pi\eta r \quad \eta = \text{viscosity}$$

$$V_{\text{sphere}} = \frac{4}{3}\pi r^3 \quad V_{\text{displaced}} = \bar{v}_2 \rho$$

### Sedimentation

$$s = \frac{m(1 - \bar{v}_2 \rho)}{f} \quad M = \frac{RTs}{D(1 - \bar{v}_2 \rho)}$$

### Equilibrium Centrifugation

$$M = \frac{2RT}{\omega^2(1 - \bar{v}_2 \rho)} \frac{d(\ln c)}{d(x^2)} \quad \omega = 2\pi\nu$$

$$[\eta] = \nu(\bar{v}_2 + \delta_1 \nu_1^0)$$

### Boltzmann Distribution

$$P_i = \frac{N_i}{N} = \frac{g_i e^{-\frac{E_i}{kT}}}{\sum_j g_j e^{-\frac{E_j}{kT}}}$$

### Kinetics (but know how to derive simple ones)

$$\frac{dc}{dt} = k \quad c_2 - c_1 = k(t_2 - t_1)$$

$$-\frac{dc}{dt} = kc \quad \ln \frac{c_2}{c_1} = -k(t_2 - t_1)$$

$$-\frac{dc}{dt} = kc^2 \quad \frac{1}{c_2} - \frac{1}{c_1} = k(t_2 - t_1)$$

$$-\frac{dc}{dt} = kc_A c_B \quad \frac{1}{c_{A_1} - c_{B_1}} \ln \frac{c_{A_2} c_{B_1}}{c_{A_1} c_{B_2}} = k(t_2 - t_1)$$

### Kinetics – Arrhenius

$$k = A e^{-\frac{E_a}{RT}}$$

### Kinetics – Eyring (Transition State Theory)

$$k = \frac{k_B T}{h} e^{-\frac{G^\ddagger}{RT}} = \frac{k_B T}{h} e^{-\frac{S^\ddagger}{R}} e^{-\frac{H^\ddagger}{RT}}$$

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$$F = 96,485 \text{ coulombs (mol electrons)}^{-1} = 96,485 \text{ J eV}^{-1}$$

### General

$$E_2 - E_1 = q + w$$

$$H = E + PV = E + nRT$$

$$G = H - TS$$

$$dE = -PdV + TdS$$

$$dH = VdP + TdS$$

$$dG = VdP - SdT$$

$$C = \frac{\partial q}{\partial T} \quad dS = \frac{dq_{rev}}{T} \quad S = k \ln N$$

### Ideal Gas

$$PV = nRT$$

$$\bar{C}_v = \frac{3}{2}R \quad \bar{C}_p = \frac{5}{2}R \quad (\text{monoatomic})$$

### Phase Transition at Equilibrium

$$S = \frac{H}{T} \quad (\text{why?})$$

### Osmotic / Vapor Pressure / etc

$$= \frac{nRT}{V} = cRT \quad \ln a_A = -\frac{\bar{V}_A}{RT}$$

$$\ln a_A = \frac{H_{vap}}{R} \left( \frac{1}{T_{boil}} - \frac{1}{T_o} \right) = \frac{H_{fus}}{R} \left( \frac{1}{T_o} - \frac{1}{T_{freeze}} \right)$$

### Work

$$w = - \int_{V_1}^{V_2} P_{ex} dV \quad (\text{gases, } PdV \text{ work})$$

$$w = -EIt \quad (\text{Electrical}) \quad w = Fd \quad (\text{linear})$$

### PV Work only

$$E_2 - E_1 = q_v = n \int_{T_1}^{T_2} \bar{C}_v dT$$

$$H_2 - H_1 = q_p = n \int_{T_1}^{T_2} \bar{C}_p dT$$

### Gibbs Free Energy

$$\frac{G(T_2)}{T_2} - \frac{G(T_1)}{T_1} = - \int_{T_1}^{T_2} \frac{H(T)}{T^2} dT$$

$$G = G^\circ + RT \ln Q$$

$$G_{\text{transfer phase 1 to phase 2}} = n RT \ln \frac{a_A^{\text{phase 2}}}{a_A^{\text{phase 1}}} + FZV$$

### van't Hoff

$$\frac{d(\ln K)}{d(1/T)} = -\frac{H^\circ}{R}$$

$$\ln \frac{K_2}{K_1} = -\frac{H^\circ}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)$$

### Ligand Binding

$$\frac{v}{[A]} = K(n - v) \quad \frac{f}{(1-f)} = K[A]^n$$

| Solid H <sub>2</sub> O at 0°C                                     | Liquid H <sub>2</sub> O  | Gaseous H <sub>2</sub> O at 100°C                               |
|---|--|---|
| Density = 0.915 g cm <sup>-3</sup>                                | Density = 0.99 g cm <sup>-3</sup>                              | Density = 5.88 x 10 <sup>-4</sup> g cm <sup>-3</sup>            |
| Vapor Pressure = 4.579 Torr                                       | Absolute Molar Entropy   | Heat of condensation = -2257 kJ kg <sup>-1</sup>                |
| Absolute Molar Entropy = 41.0 J K <sup>-1</sup> mol <sup>-1</sup> | 70 J K <sup>-1</sup> mol <sup>-1</sup>                         | = -40.66 kJ mol <sup>-1</sup>                                   |
| Heat of melting = 333.4 kJ kg <sup>-1</sup>                       | Spec heat capacity = 4.18 kJ K <sup>-1</sup> kg <sup>-1</sup>  | Spec heat capacity = 1.874 kJ K <sup>-1</sup> kg <sup>-1</sup>  |
| = 6.007 kJ mol <sup>-1</sup>                                      | Molar heat capacity = 75.4 J K <sup>-1</sup> mol <sup>-1</sup> | Molar heat capacity = 33.76 J K <sup>-1</sup> mol <sup>-1</sup> |
| Spec heat capacity = 2.113 kJ K <sup>-1</sup> kg <sup>-1</sup>    |  |   |
| Molar heat capacity = 38.07 J K <sup>-1</sup> mol <sup>-1</sup>   |  |   |