

$$\Delta E = E_2 - E_1 = h\nu$$

$$\hbar = \frac{h}{2\pi}$$

$$\nu = \frac{c}{\lambda} = c\tilde{\nu}$$

$$\tilde{\nu} = \frac{1}{\lambda}$$

$$E_\nu = \left(\nu + \frac{1}{2}\right) h\nu_0 = \left(\nu + \frac{1}{2}\right) hc\tilde{\nu}_0$$

$$\tilde{\nu}_0 = \frac{1}{2\pi c} \sqrt{\frac{k}{\mu}}$$

$$\mu = \frac{m_1 m_2}{m_1 + m_2}$$

$$E_J = hB[J(J+1)] = hc\tilde{B}[J(J+1)]$$

$$\tilde{B} = \frac{h}{8\pi^2 cI}$$

$$I = \mu r^2$$

$$\tilde{B}_\nu = \tilde{B}_e - \tilde{\alpha}_e \left(\nu + \frac{1}{2}\right)$$

$$F(J) = \tilde{B}_\nu[J(J+1)] - \tilde{D}J^2(J+1)^2$$

$$\tilde{\nu} = G(\nu) - G(0) = \nu\tilde{\nu}_e - \tilde{x}_e\tilde{\nu}_e\nu(\nu+1)$$

$$G(\nu) = \left(\nu + \frac{1}{2}\right)\tilde{\nu}_e - \left(\nu + \frac{1}{2}\right)^2\tilde{x}_e\tilde{\nu}_e$$

$$\tilde{D}_0 = \tilde{D}_e - \frac{\tilde{\nu}_e}{2} + \frac{\tilde{\nu}_e\tilde{x}_e}{4}$$

$$\hat{H}\psi = E\psi$$

$$P_{12} \propto | \langle \mu_{12} \rangle |^2 \delta(E_2 - E_1 - h\nu)$$

$$\langle \mu_{12} \rangle = \int_\tau \psi_2^* \hat{H}_1 \psi_1 d\tau$$

$$\hat{H}_{NZ} = \frac{-g_N \beta_N B_0 (1-\sigma)}{\hbar} \hat{I}_z$$

$$\hat{I}_x \alpha = \frac{\hbar}{2} \beta$$

$$\hat{I}_y \alpha = \frac{i\hbar}{2} \beta$$

$$\hat{I}_z \alpha = \frac{\hbar}{2} \alpha$$

$$\hat{I}_x \beta = \frac{\hbar}{2} \alpha$$

$$\hat{I}_y \beta = \frac{-i\hbar}{2} \alpha$$

$$\hat{I}_z \beta = \frac{-\hbar}{2} \beta$$

$$\Delta E = h\nu = g_N \beta_N B_0 (1-\sigma)$$

$$\hat{H}_1 = \frac{-g_N \beta_N B_1}{\hbar} \hat{I}_x$$

$$\delta_1 - \delta_2 = \frac{\nu_1 - \nu_2}{\nu_{spec}} * 10^6 \text{ppm}$$

$$PV = nRT$$

$$\bar{V} = \frac{V}{n}$$

$$P\bar{V} = RT$$

$$Z = \frac{P\bar{V}}{RT}$$

$$P = \rho gh$$

$$P_A = X_A P_T$$

$$X_A = \frac{n_A}{n_{total}}$$

$$\sum_{i=1}^{\#comp} X_i = 1$$

$$\rho = \frac{PM}{RT}$$

$$P = \frac{RT}{(\bar{V}-b)} - \frac{a}{\bar{V}^2}$$

$$\left(\frac{\partial P}{\partial \bar{V}}\right)_{T=T_c} = 0$$

$$\left(\frac{\partial^2 P}{\partial \bar{V}^2}\right)_{T=T_c} = 0$$

$$Z = 1 + B_{2P} * P + B_{3P} * P^2 + \dots$$

$$Z = 1 + B_{2V} * \frac{1}{\bar{V}} + B_{3V} * \frac{1}{\bar{V}^2} + \dots$$

$$B_{2V} = \lim_{\bar{V} \rightarrow 0} \frac{1}{\bar{V}} \left( \frac{\partial Z}{\partial \left(\frac{1}{\bar{V}}\right)} \right)_T$$

$$P_j(N, V, T) = \frac{e^{-\beta E_j(N, V)}}{Q(N, V, T)}$$

$$Q(N, V, T) = \sum_{j=1}^n e^{-\beta E_j(N, V)}$$

$$\beta = \frac{1}{k_B T}$$

$$\langle E \rangle = U = - \left( \frac{\partial \ln Q}{\partial \beta} \right)_{N, V} = k_B T^2 \left( \frac{\partial \ln Q}{\partial T} \right)_{N, V}$$

$$C_V = \left( \frac{\partial \langle E \rangle}{\partial T} \right)_{N, V} = \left( \frac{\partial U}{\partial T} \right)_{N, V}$$

$$\langle P \rangle = k_B T \left( \frac{\partial \ln Q}{\partial V} \right)_{N, T}$$

$$R = k_B N_A$$

$$Q = q^N$$

$$Q = \frac{q^N}{N!}$$

$$q = \sum_{i=E \text{ levels}} g_i e^{-\beta E_i}$$

$$Q = \frac{(q_{elec}q_{trans}q_{vib}q_{rot})^N}{N!} \quad q_{elec} \cong g_1 e^{-\beta E_i}$$

$$q_{trans} = \left(\frac{2\pi mk_B T}{h^2}\right)^{3/2} * V = \left(\frac{2\pi m}{\beta h^2}\right)^{3/2} * V \quad q_{rot} = \frac{T}{\sigma \Theta_{rot}}, \quad \Theta_{rot} = \frac{h^2}{8\pi^2 I k_B} = \frac{hB}{k_B}$$

$$q_{vib} = \frac{e^{-\Theta_{vib}/2T}}{1 - e^{-\Theta_{vib}/T}}, \quad \Theta_{vib} = \frac{h\nu_0}{k_B}$$

$$w = - \int_{V_1}^{V_2} P_{ext} dV + w' \quad w = -nRT \ln \frac{V_2}{V_1} \quad dU = \delta q + \delta w$$

$$H = U + PV \quad dU = TdS - pdV$$

$$A = U - TS \quad dH = TdS + VdP$$

$$G = H - TS \quad dA = -SdT - pdV$$

$$dS = \frac{\delta q_{rev}}{T} \quad dG = -SdT + VdP$$

$$\left(\frac{\partial P}{\partial S}\right)_V = -\left(\frac{\partial T}{\partial V}\right)_S \quad \left(\frac{\partial V}{\partial S}\right)_P = \left(\frac{\partial T}{\partial P}\right)_S \quad \left(\frac{\partial S}{\partial V}\right)_T = -\left(\frac{\partial P}{\partial T}\right)_V$$

$$\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P \quad \Delta Y = \int_{T_1 V_1}^{T_2 V_2} \left(\frac{\partial Y}{\partial T}\right)_V dT + \left(\frac{\partial Y}{\partial V}\right)_T dV$$

$$\Delta Y = \int_{T_1 P_1}^{T_2 P_2} \left(\frac{\partial Y}{\partial T}\right)_P dT + \left(\frac{\partial Y}{\partial P}\right)_T dP \quad C_V = \left(\frac{\partial U}{\partial T}\right)_V \quad C_P = \left(\frac{\partial H}{\partial T}\right)_P$$

$$\frac{C_V}{T} = \left(\frac{\partial S}{\partial T}\right)_V \quad \frac{C_P}{T} = \left(\frac{\partial S}{\partial T}\right)_P \quad V = V_0 e^{\alpha T - \kappa P}$$

$$\alpha = \frac{1}{V} \left(\frac{\partial V}{\partial T}\right)_P \quad \kappa = -\frac{1}{V} \left(\frac{\partial V}{\partial P}\right)_T \quad \left(\frac{\partial z}{\partial x}\right)_y = -\left(\frac{\partial z}{\partial y}\right)_x \left(\frac{\partial y}{\partial x}\right)_z$$

$$\left(\frac{\partial z}{\partial x}\right)_y = \frac{1}{\left(\frac{\partial x}{\partial z}\right)_y} \quad 1 = -\left(\frac{\partial z}{\partial y}\right)_x \left(\frac{\partial y}{\partial x}\right)_z \left(\frac{\partial x}{\partial z}\right)_y \quad \left(\frac{\partial f}{\partial x}\right)_y = \left(\frac{\partial f}{\partial z}\right)_y \left(\frac{\partial z}{\partial x}\right)_y$$

$$T_f = T_i + \mu_{JT}(P_f - P_i) \quad \mu_{JT} = \frac{T\left(\frac{\partial V}{\partial T}\right)_P - V}{C_P} \quad Max\ eff = \frac{-w}{q} = 1 - \frac{T_C}{T_H}$$

$$C.O.P = \frac{q_c}{w} = \frac{T_C}{T_H - T_C} \quad C_P - C_V = T \left(\frac{\partial P}{\partial T}\right)_V \left(\frac{\partial V}{\partial T}\right)_P$$

$$\Delta_r \bar{H}_T^0 = \sum_{prod} \nu_p \Delta_f \bar{H}_T^0(prod) - \sum_{reac} \nu_r \Delta_f \bar{H}_T^0(reac)$$

$$\Delta_r \bar{S}_T^0 = \sum_{prod} \nu_p \bar{S}_T^0(prod) - \sum_{reac} \nu_r \bar{S}_T^0(reac)$$

$$\Delta_r \bar{G}_T^0 = \Delta_r \bar{H}_T^0 - T \Delta_r \bar{S}_T^0 \quad \Delta_r \bar{G}_{298}^0 = \sum_{prod} \nu_p \Delta_f \bar{G}_{298}^0(prod) - \sum_{reac} \nu_r \Delta_f \bar{G}_{298}^0(reac)$$

$$\Delta_r \bar{H}_T^0 = \Delta_r \bar{H}_{298}^0 + \int_{298}^T \Delta_r \bar{C}_p^0 dT \quad \Delta_r \bar{C}_p^0 = \sum_{prod} \nu_p \bar{C}_p^0(prod) - \sum_{reac} \nu_r \bar{C}_p^0(reac)$$

$$\Delta_r \bar{S}_T^0 = \Delta_r \bar{S}_{298}^0 + \int_{298}^T \frac{\Delta_r \bar{C}_p^0}{T} dT$$

$$\mu_i = \left( \frac{\partial G}{\partial n_i} \right)_{T,P,n_j}$$

$$\frac{dP}{dT} = \frac{\Delta_{\text{trans}} \bar{S}}{\Delta_{\text{trans}} \bar{V}} = \frac{\Delta_{\text{trans}} \bar{H}}{T \Delta_{\text{trans}} \bar{V}}$$

$$\ln \left( \frac{P_2}{P_1} \right) = \frac{\Delta_{\text{vap}} \bar{H}}{R} \left( \frac{1}{T_1} - \frac{1}{T_2} \right)$$

$$\ln \left( \frac{P_2}{P_1} \right) = \frac{\Delta_{\text{sub}} \bar{H}}{R} \left( \frac{1}{T_1} - \frac{1}{T_2} \right)$$

$$P_2 - P_1 = \frac{\Delta_{\text{fus}} \bar{H}}{\Delta_{\text{fus}} \bar{V}} \ln \left( \frac{T_2}{T_1} \right)$$