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PHYSICAL CHEMISTRY ULTIMATE CHEAT SHEET

1. THERMODYNAMICS & THERMOCHEMISTRY

First Law of Thermodynamics:

$$\Delta U = q + w$$

Work Done (PV-Work):

$$w = -\int P_{\text{ext}} dV$$

- **Isothermal Reversible Expansion:**

$$w = -nRT \ln(\frac{V_2}{V_1})$$

- **Isochoric Process ($V =$ const):** $w = 0, \Delta U = q_v$
- **Isobaric Process ($P =$ const):** $q_p = \Delta H = \Delta U + P\Delta V$

Enthalpy & Heat Capacity:

$$H = U + PV$$

$$C_v = (\frac{\partial U}{\partial T})_V, \quad C_p = (\frac{\partial H}{\partial T})_P$$

$$C_p - C_v = R \quad \text{(for ideal gas)}$$

Adiabatic Process ($q = 0$):

$$TV^{\gamma-1} = \text{const}, \quad PV^{\gamma} = \text{const}, \quad \gamma = \frac{C_p}{C_v}$$

$$w = \Delta U = nC_{v,m}(T_2 - T_1)$$

Second & Third Laws (Entropy & Free Energy):

$$dS = \frac{dq_{\text{rev}}}{T}, \quad \Delta S_{\text{univ}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} \geq 0$$

$$G = H - TS \implies \Delta G = \Delta H - T\Delta S$$

- $\Delta G < 0$: Spontaneous process
- $\Delta G = 0$: Equilibrium

$$\Delta G^\circ = -RT \ln K_{\text{eq}}$$

2. CHEMICAL & IONIC EQUILIBRIUM

Equilibrium Constants:

$$K_p = K_c(RT)^{\Delta n_g}$$

Van 't Hoff Equation:

$$\frac{d \ln K}{dT} = \frac{\Delta H^\circ}{RT^2} \implies \ln(\frac{K_2}{K_1}) = -\frac{\Delta H^\circ}{R}(\frac{1}{T_2} - \frac{1}{T_1})$$

pH & Acid-Base Equilibria:

$$\text{pH} = -\log_{10}[\text{H}^+], \quad \text{pH} + \text{pOH} = 14 \quad (25^\circ\text{C})$$

$$K_w = [\text{H}^+][\text{OH}^-] = 10^{-14}$$

Henderson-Hasselbalch Equation (Buffers):

$$\text{pH} = \text{p}K_a + \log_{10}(\frac{[\text{A}^-]}{[\text{HA}]}) \quad \text{(Acidic Buffer)}$$

$$\text{pOH} = \text{p}K_b + \log_{10}(\frac{[\text{BH}^+]}{[\text{B}]}) \quad \text{(Basic Buffer)}$$

Solubility Product (K_{sp}): For $A_xB_y leftharpoonsxA^{y+} + yB^{x-}$:

$$K_{sp} = [A^{y+}]^x[B^{x-}]^y = (xs)^x(ys)^y = x^x y^y s^{x+y}$$

3. CHEMICAL KINETICS

Rate Law:

$$\text{Rate} = k[A]^m[B]^n$$

- **Zero-Order:** $[A]_t = [A]_0 - kt, \quad t_{1/2} = \frac{[A]_0}{2k}$
- **First-Order:** $[A]_t = [A]_0 e^{-kt}, \quad t_{1/2} = \frac{\ln 2}{k}$
- **Second-Order:** $1\frac{}{[A]_t - \frac{1}{[A]_0} = kt, \quad t_{1/2} = \frac{1}{k[A]_0}}$

Arrhenius Equation:

$$k = Ae^{-E_a/RT} \implies \ln k = \ln A - \frac{E_a}{RT}$$

$$\ln(\frac{k_2}{k_1}) = \frac{E_a}{R}(\frac{1}{T_1} - \frac{1}{T_2})$$

4. ELECTROCHEMISTRY

Nernst Equation:

$$E = E^\circ - \frac{RT}{nF}\ln Q = E^\circ - \frac{0.0591}{n}\log_{10} Q \quad (25^\circ\text{C})$$

Cell Potential & Free Energy:

$$\Delta G = -nFE_{\text{cell}}, \quad \Delta G^\circ = -nFE^\circ_{\text{cell}}$$

$$E^\circ_{\text{cell}} = \frac{0.0591}{n}\log_{10} K_{\text{eq}}$$

Conductance & Kohlrausch's Law:

$$\kappa = \frac{1}{\varrho}\cdot\frac{l}{A}, \quad \Lambda_m = \frac{\kappa \times 1000}{M}$$

$$\Lambda^0_m = v_+\lambda^0_+ + v_-\lambda^0_-$$

5. ATOMIC STRUCTURE & QUANTUM

Bohr Model (Hydrogen-like):

$$r_n = 0.529\frac{n^2}{Z}\ \text{Å}, \quad E_n = -13.6\frac{Z^2}{n^2}\ \text{eV}$$

Rydberg Formula:

$$\frac{1}{\lambda} = R_H Z^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

De Broglie & Heisenberg:

$$\lambda = \frac{h}{p} = \frac{h}{mv}, \quad \Delta x \Delta p \geq \frac{\hbar}{2}$$

Time-Independent Schrödinger Equation:

$$\hat{H}\psi = E\psi \implies -\frac{\hbar^2}{2m}\nabla^2\psi + V\psi = E\psi$$

6. GAS LAWS & REAL GASES

Ideal Gas Law:

$$PV = nRT = Nk_BT$$

Van der Waals Equation (Real Gases):

$$\left(P + a\frac{n^2}{V^2}\right)(V - nb) = nRT$$

- a: Corrects for intermolecular attractive forces.
- b: Corrects for finite molecular volume ($b = 4V_{\text{moles}}$).

Critical Constants:

$$V_c = 3b, \quad P_c = \frac{a}{27b^2}, \quad T_c = \frac{8a}{27Rb}$$

$$Z = \frac{PV}{nRT} \quad (Z = 1 \text{ for ideal gas})$$

7. SOLUTIONS & COLLIGATIVE PROPERTIES

Raoult's Law:

$$P_A = P^\circ_A x_A$$

Colligative Properties (with Van 't Hoff factor i):

1. **Relative Lowering of Vapor Pressure:**
$$\frac{P^\circ_A - P_A}{P^\circ_A} = i \cdot x_B$$
2. **Elevation of Boiling Point:**
$$\Delta T_b = i \cdot K_b \cdot m$$
3. **Depression of Freezing Point:**
$$\Delta T_f = i \cdot K_f \cdot m$$
4. **Osmotic Pressure:**
$$\Pi = i \cdot CRT$$
$$i = 1 + (n-1)\alpha \quad (\text{for dissociation})$$

8. SURFACE CHEMISTRY & CATALYSIS

Freundlich Adsorption Isotherm:

$$\frac{x}{m} = kP^{1/n} \implies \log\left(\frac{x}{m}\right) = \log k + \frac{1}{n}\log P$$

Langmuir Adsorption Isotherm:

$$\theta = \frac{KP}{1 + KP}$$