

Physics 251 Final Formula Sheet

Thermal Expansion

$$\Delta L = \alpha L_0 \Delta T$$

$$\beta = 3\alpha$$

Heat

$$Q = mc\Delta T$$

$$Q = \pm mL$$

$$Q = nC_V \Delta T$$

$$Q = nC_P \Delta T$$

Heat Current

$$H = k \frac{A}{L} (T_H - T_C)$$

$$Q = Ae\sigma T^4$$

Heat Engines

$$W = Q_H + Q_C$$

$$e = \frac{W}{Q_H}$$

$$e_{carnot} = 1 - \frac{T_C}{T_H}$$

Refrigerators

$$W = Q_H + Q_C$$

$$K = \frac{|Q_C|}{|W|}$$

$$K_{carnot} = \frac{T_C}{T_H - T_C}$$

Work

$$W = \int_{V_1}^{V_2} p dV$$

Ideal gases

$$pV = nRT$$

$$pV = NkT$$

$$v_{rms} = \sqrt{\frac{3RT}{m}}$$

$$C_P = C_V + R$$

$$\gamma = \frac{C_P}{C_V}$$

$$\lambda = vt_{mean} = \frac{V}{4\pi\sqrt{2}r^2N}$$

[†] indicates other formulas that are specific to ideal gases.

Cyclic Processes

$$\Delta U = 0$$

$$W = Q$$

Isochoric Processes

$$W = 0$$

$$Q = nC_V \Delta T$$

$$^{\dagger}\Delta U = nC_V \Delta T$$

Isobaric Processes

$$W = p\Delta V$$

$$Q = nC_P \Delta T$$

$$^{\dagger}\Delta U = nC_V \Delta T$$

Isothermal Processes

$$^{\dagger}\Delta U = 0$$

$$^{\dagger}W = nRT \ln \left(\frac{V_f}{V_i} \right)$$

$$^{\dagger}Q = nRT \ln \left(\frac{V_f}{V_i} \right)$$

Adiabatic Processes

$$Q = 0$$

$$\Delta U = W$$

$$^{\dagger}W = -nC_V \Delta T$$

$$^{\dagger}PV^{\gamma} = \text{constant}$$

$$^{\dagger}TV^{\gamma-1} = \text{constant}$$

Entropy

$$\Delta S = \int_1^2 \frac{dQ}{T}$$

Electric Fields

$$\vec{F} = q\vec{E}$$

$$\Delta U = q\Delta V$$

$$W_{a \rightarrow b} = U_a - U_b = -\Delta U$$

$$V_{ab} = \int_a^b \vec{E} \cdot d\vec{l}$$

$$\vec{E} = -\nabla V$$

Point Charges

$$\vec{E} = \frac{q}{4\pi\epsilon_0 r^2} \hat{r}$$

$$V = \frac{q}{4\pi\epsilon_0 r}$$

$$\vec{F} = \frac{q_1 q_2}{4\pi\epsilon_0 r^2} \hat{r}$$

$$U = \frac{q_1 q_2}{4\pi\epsilon_0 r}$$

Distributed Charges

$$\vec{E} = \int \frac{dq}{4\pi\epsilon_0 r^2} \hat{r}$$

$$V = \int \frac{dq}{4\pi\epsilon_0 r}$$

Collection of Charges

$$\vec{E}_T = \sum_i \vec{E}_i$$

$$U_T = \sum_{pairs} U_{ij}$$

Electric Dipoles

$$\vec{\tau} = \vec{p} \times \vec{E} = pE \sin \phi$$

$$U = -\vec{p} \cdot \vec{E} = -pE \cos \phi$$

“Elementary” E fields

$$\vec{E} = \frac{Q}{4\pi\epsilon_0 r^2} \hat{r} \text{ sphere}$$

$$\vec{E} = \frac{\lambda}{2\pi\epsilon_0 r} \hat{r} \text{ line}$$

$$\vec{E} = \frac{\sigma}{2\epsilon_0} \hat{n} \text{ plane}$$

Capacitors and Dielectrics

$$C = \frac{Q}{V}$$

$$\text{parallel: } C_{eq} = \sum_i C_i$$

$$\text{serial: } \frac{1}{C_{eq}} = \sum_i \frac{1}{C_i}$$

$$\text{Parallel-plate: } C = \epsilon_0 \frac{A}{d}$$

$$U = \frac{1}{2} CV^2 = \frac{Q^2}{2C} = \frac{1}{2} QV$$

$$u = \frac{1}{2} \epsilon_0 E^2$$

$$\text{dielectric: } C = KC_0 \quad \epsilon = K\epsilon_0$$

Current & Current Density

$$I = \frac{dq}{dt}$$

$$I = \iint \vec{J} \cdot d\vec{a}$$

$$J = nqv_d$$

Ohm's Law

$$\vec{E} = \rho \vec{J}$$

$$V = IR$$

Resistivity & Resistance

$$R = \int \rho \frac{dL}{A}$$

$$\rho = \rho_0 [1 + \alpha(T - T_0)]$$

Uniform currents

$$|E| = \frac{V}{L}$$

$$R = \rho \frac{L}{A}$$

$$|J| = \frac{I}{A}$$

Electric Power

$$P = IV$$

$$P = I^2 R$$

$$P = \frac{V^2}{R}$$

Resistors

$$\text{series: } R_{eq} = \sum_i R_i$$

$$\text{parallel: } \frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$$

$$\text{real battery: } V = \mathcal{E} - Ir$$

RC circuits

$$\tau = RC$$

charging:

$$I = I_0 e^{-\frac{t}{\tau}}$$

$$Q = Q_f \left(1 - e^{-\frac{t}{\tau}}\right)$$

discharging:

$$I = I_0 e^{-\frac{t}{\tau}}$$

$$Q = Q_0 e^{-\frac{t}{\tau}}$$

Magnetic Force

$$\vec{F} = q\vec{v} \times \vec{B}$$

$$d\vec{F} = Id\vec{l} \times \vec{B}$$

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

$$U = -\vec{\mu} \cdot \vec{B}$$

Cyclotron Motion

$$R = \frac{mv}{qB}$$

$$T = \frac{2\pi m}{qB}$$

$$\omega_c = \frac{qB}{m}$$

Magnetic Fields

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{q\vec{v} \times \hat{r}}{r^2}$$

$$\vec{B} = \int \frac{\mu_0}{4\pi} \frac{Id\vec{l} \times \hat{r}}{r^2}$$

$$|B| = \frac{\mu_0 I}{2\pi r} \quad \infty \text{ straight wire}$$

$$|B| = \frac{\mu_0 I}{2R} \quad \text{center of loop}$$

$$|B| = \mu_0 nI \quad \infty \text{ solenoid}$$

$$|B| = \frac{\mu_0 NI}{2\pi r} \quad \text{toroidal solenoid}$$

Mutual Inductance

$$M = \frac{N_1 \Phi_1}{I_2} = \frac{N_2 \Phi_2}{I_1}$$

$$\mathcal{E}_1 = -M \frac{dI_2}{dt}$$

$$\mathcal{E}_2 = -M \frac{dI_1}{dt}$$

Self Inductance

$$L = \frac{N\Phi}{I}$$

$$\mathcal{E} = -L \frac{dI}{dt}$$

$$U = \frac{1}{2} LI^2$$

RL circuits

$$\tau = \frac{L}{R}$$

charging:

$$I = I_f \left(1 - e^{-\frac{t}{\tau}}\right)$$

$$V_L = V_0 e^{-\frac{t}{\tau}}$$

discharging:

$$I = I_0 e^{-\frac{t}{\tau}}$$

$$V_L = V_0 e^{-\frac{t}{\tau}}$$

AC circuits

$$X_L = \omega L$$

$$X_C = \frac{1}{\omega C}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$\tan \phi = \frac{X_L - X_C}{R}$$

$$I = I_0 \cos \omega t$$

$$V = V_0 \cos(\omega t + \varphi)$$

$$V_0 = I_0 Z$$

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

$$P = \frac{1}{2} I_0^2 R = \frac{1}{2} I_0^2 Z \cos \varphi$$

AC circuits (resonance)

$$\varphi = 0$$

$$Z = R$$

$$\omega = \frac{1}{\sqrt{LC}}$$

$$X_L = X_C$$

Maxwell's Equations

$$\Phi_E = \oint_S \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\epsilon_0}$$

$$\Phi_B = \oint_S \vec{B} \cdot d\vec{A} = 0$$

$$\oint_C \vec{B} \cdot d\vec{l} = \mu_0 (i_c + \epsilon_0 \frac{d\Phi_E}{dt})_{encl}$$

$$\oint_C \vec{E} \cdot d\vec{l} = -\epsilon_0 \frac{d\Phi_B}{dt} = \mathcal{E}$$

Light

$$\begin{aligned}E_{max} &= cB_{max} \\c &= \frac{1}{\sqrt{\epsilon_0\mu_0}} \\c &= \lambda f \\\vec{S} &= \frac{1}{\mu_0} \vec{E} \times \vec{B} \\P &= \oint \vec{S} \cdot d\vec{A} \\I = S_{av} &= \frac{E_{max}B_{max}}{2\mu_0} \\p_{rad} &= \frac{S_{av}}{c} \text{ absorbed} \\p_{rad} &= \frac{2S_{av}}{c} \text{ reflected}\end{aligned}$$

Light Propagation

$$\begin{aligned}n &= \frac{c}{v} \\\lambda &= \frac{\lambda_0}{n} \\n_a \sin \theta_a &= n_b \sin \theta_b \\\theta_c &= \frac{n_b}{n_a} \quad (TIR) \\I &= I_0 \cos^2 \varphi\end{aligned}$$

Mirrors and Lenses

$$\begin{aligned}f &= \frac{R}{2} \\\frac{1}{f} &= \frac{1}{s} + \frac{1}{s'} \\\frac{1}{f} &= (n-1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right) \\m = \frac{y'}{y} &= -\frac{s'}{s}\end{aligned}$$

Constants

$$\begin{aligned}R &= 8.3145 \frac{J}{mol \cdot K} \\N_A &= 6.02 \times 10^{23} \\k_B = \frac{R}{N_A} &= 1.38 \times 10^{-23} \frac{J}{mol \cdot K} \\q_e = e &= -1.602 \times 10^{-19} C \\k = \frac{1}{4\pi\epsilon_0} &= 8.99 \times 10^9 \frac{N \cdot m^2}{C^2} \\c &= 3.00 \times 10^8 m/s \\m_e &= 9.11 \times 10^{-31} kg \\m_p &= 1.67 \times 10^{-27} kg\end{aligned}$$