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

$$pV = nRT$$
$$pV = NkT$$
$$v_{rms} = \sqrt{\frac{3RT}{m}}$$
$$C_P = C_V + R$$
$$\gamma = \frac{C_P}{C_V}$$
$$\lambda = vt_{mean} = \frac{V}{4\pi\sqrt{2}r^2 N}$$

† indicates 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

$$\vec{F} = q\vec{E}$$
$$\Delta U = q\Delta V$$
$$W_{a\to b} = U_a - U_b = -\Delta U$$
$$V_{ab} = \int_a^b \vec{E} \cdot d\vec{l}$$
$$\vec{E} = -\nabla V$$

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

$$C = \frac{Q}{V}$$
$$\text{parallel: } C_{eq} = \sum_i C_i$$
$$\text{serial: } \frac{1}{C_{eq}} = \sum_i \frac{1}{C_i}$$
$$\text{Parallel-plate: } C = \epsilon_0 \frac{A}{d}$$
$$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$$
$$u = \frac{1}{2}\epsilon_0 E^2$$
$$\text{dielectric: } C = KC_0 \ \epsilon = K\epsilon_0$$

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

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

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

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v} \times \hat{r}}{r^2}$$
$$\vec{B} = \int \frac{\mu_0}{4\pi}\frac{Id\vec{l} \times \hat{r}}{r^2}$$
$$|B| = \frac{\mu_0 I}{2\pi r} \ \infty \text{ straight wire}$$
$$|B| = \frac{\mu_0 I}{2R} \ \text{ center of loop}$$
$$|B| = \mu_0 nI \ \infty \text{ solenoid}$$
$$|B| = \frac{\mu_0 NI}{2\pi r} \ \text{toroidal solenoid}$$

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

$$E_{max} = cB_{max}$$

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

$$c = \lambda f$$

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$$

$$P = \oint \vec{S} \cdot d\vec{A}$$

$$I = S_{av} = \frac{E_{max} B_{max}}{2\mu_0}$$

$$p_{rad} = \frac{S_{av}}{c} \text{ absorbed}$$

$$p_{rad} = \frac{2S_{av}}{c} \text{ reflected}$$

Light Propagation

$$n = \frac{c}{v}$$

$$\lambda = \frac{\lambda_0}{n}$$

$$n_a \sin\theta_a = n_b \sin\theta_b$$

$$\sin\theta_c = \frac{n_b}{n_a} \quad (TIR)$$

$$I = I_0 \cos^2 \varphi$$

Mirrors and Lenses

$$f = \frac{R}{2}$$

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$m = \frac{y'}{y} = -\frac{s'}{s}$$

Constants

$$R = 8.3145 \frac{J}{mol \cdot K}$$

$$N_A = 6.02 \times 10^{23}$$

$$k_B = \frac{R}{N_A} = 1.38 \times 10^{-23} \frac{J}{mol \cdot K}$$

$$q_e = e = -1.602 \times 10^{-19} C$$

$$k = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \frac{N \cdot m^2}{C^2}$$

$$c = 3.00 \times 10^8 m/s$$

$$m_e = 9.11 \times 10^{-31} kg$$

$$m_p = 1.67 \times 10^{-27} kg$$