# *PH2200 Formula Sheet*

## Electric Fields

$$\vec{F}_{12} = \frac{k_e q_1 q_2}{r^2}\hat{r} \qquad k_e = \frac{1}{4\pi\varepsilon_o}$$

$$\vec{E} = \lim_{q_o \to 0} \frac{\vec{F}_e}{q_o}$$

$$\vec{E} = \frac{k_e q}{r^2}\hat{r}$$

$$\vec{E} = \sum_i \vec{E}_i = \sum_i \frac{k_e q_i}{r_i^2}\hat{r}_i$$

$$\vec{E} = \int d\vec{E} = \int \frac{k_e dq}{r^2}\hat{r}$$

## Gauss's Law

$$\Phi_E = \int \vec{E} \cdot d\vec{A}$$

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{in}}{\varepsilon_\circ}$$

$$E = \frac{\sigma}{\varepsilon_\circ} \text{ at conductor surface}$$

## Electric Potential

$$\Delta U = -q_o \int_A^B \vec{E} \cdot d\vec{s}$$

$$\Delta V_{A\to B} = \frac{\Delta U}{q_o} = -\int_A^B \vec{E} \cdot d\vec{s}$$

$$V(r) = \frac{k_e q}{r}$$

$$V = \sum_i \frac{k_e q_i}{r_i}$$

$$V = \int \frac{k_e dq}{r}$$

$$U = \frac{k_e q_1 q_2}{r_{12}}$$

$$E_x = -\frac{dV}{dx}$$

## Capacitance and Dielectrics

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

$$C = \frac{\varepsilon_\circ A}{d} \quad \text{parallel-plate capacitor}$$

$$\frac{C}{l} = \frac{1}{2k_e \ln\left(\frac{b}{a}\right)} \quad \text{cylindrical capacitor}$$

$$C = \frac{ab}{k_e(b-a)} \quad \text{spherical capacitor}$$

$$C_{eq} = C_1 + C_2 + C_3 + \ldots \quad \text{parallel}$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots \quad \text{series}$$

$$U = \frac{Q^2}{2C} = \tfrac{1}{2}Q\Delta V = \tfrac{1}{2}C(\Delta V)^2$$

$$u_E = \tfrac{1}{2}\varepsilon_\circ E^2$$

$$C = \kappa C_o$$

## Current and Resistance

$$I_{av} = \frac{\Delta Q}{\Delta t}$$

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

$$I_{av} = nqv_d A$$

$$\vec{J} = nq\vec{v}_d$$

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

$$R = \frac{\Delta V}{I}$$

$$\rho = \frac{1}{\sigma}$$

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

$$\rho = \rho_o[1 + \alpha(T - T_o)]$$

$$\mathbf{P} = I\Delta V$$

$$\mathbf{P} = I^2 R = \frac{(\Delta V)^2}{R}$$

## Direct Current Circuits

$$R_{eq} = R_1 + R_2 + R_3 + \ldots \quad \text{series}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \quad \text{parallel}$$

$$\sum I_{in} = \sum I_{out}$$

$$\sum_{closed\ loop} \Delta V = 0$$

$$q(t) = C\mathbf{E}(1 - e^{-t/RC}) \quad \text{charging}$$

$$I(t) = \frac{\mathbf{E}}{R}e^{-t/RC} \quad \text{charging}$$

$$q(t) = Qe^{-t/RC} \quad \text{discharging}$$

$$I(t) = -\frac{Q}{RC}e^{-t/RC} \quad \text{discharging}$$

## Magnetic Fields

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

$$F_B = |q|vB\sin\theta$$

$$\vec{F}_B = I\ \vec{L} \times \vec{B}$$

$$d\vec{F}_B = Id\vec{s} \times \vec{B}$$

$$\vec{\mu} = NI\vec{A}$$

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

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

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

$$r = \frac{mv}{qB}, \ \omega = \frac{qB}{m}$$

## Sources of the Magnetic Field

$$d\vec{B} = \frac{\mu_o}{4\pi}\frac{Id\vec{s} \times \hat{r}}{r^2}$$

$$B = \frac{\mu_o I}{2\pi a} \quad \text{long straight wire}$$

$$\frac{F_B}{l} = \frac{\mu_o I_1 I_2}{2\pi a}$$

$$\oint \vec{B} \cdot d\vec{s} = \mu_o I$$

$$B = \frac{\mu_o NI}{2\pi r} \quad \text{toroid}$$

$$B = \mu_o \frac{N}{l} I = \mu_o nI \quad \text{solenoid}$$

$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

$$\oint \vec{B} \cdot d\vec{A} = 0$$

## Faraday's Law

$$\mathbf{E} = -N\frac{d\Phi_B}{dt}$$

$$\mathbf{E} = -Blv$$

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

## Inductance

$$\mathcal{E}_L = -N\frac{d\Phi_B}{dt} = -L\frac{dI}{dt}$$

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

$$L = \frac{\mu_o N^2 A}{l} \quad \text{solenoid}$$

$$I = \frac{\mathcal{E}}{R}(1 - e^{-Rt/L}) \quad \text{rising current}$$

$$I = \frac{\mathcal{E}}{R}e^{-Rt/L} \quad \text{decaying current}$$

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

$$u_B = \frac{B^2}{2\mu_\circ}$$

$$M_{12} = \frac{N_2\Phi_{12}}{I_1} = M_{21} = \frac{N_1\Phi_{21}}{I_2} = M$$

$$\mathcal{E}_2 = -M_{12}\frac{dI_1}{dt} \quad \textit{and} \quad \mathcal{E}_1 = -M_{21}\frac{dI_2}{dt}$$

$$Q = Q_{\max}\cos(\omega t + \phi)$$

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

$$U = U_C + U_L$$

$$= \frac{Q_{\max}^2}{2C}\cos^2\omega t + \frac{LI_{\max}^2}{2}\sin^2\omega t$$

## Alternating Current Circuits

$$I_{rms} = 0.707 I_{\max}$$

$$\Delta V_{rms} 0.707 V_{\max}$$

$$X_L = \omega L$$

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

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

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

$$\mathcal{P}_{av} = I_{rms}\Delta V_{rms}\cos\phi$$

$$\mathcal{P}_{av} = I_{rms}^2 R$$

$$I_{rms} = \frac{\Delta V_{rms}}{\sqrt{R^2 + (X_L - X_C)^2}}$$

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

$$I_1\Delta V_1 = I_2\Delta V_2$$

## Electromagnetic Waves

$$\oint_S \vec{E}\cdot d\vec{A} = \frac{Q}{\varepsilon_o}$$

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

$$\oint \vec{E}\cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

$$\oint \vec{B}\cdot d\vec{s} = \mu_o I + \varepsilon_o\mu_o\frac{d\Phi_E}{dt}$$

$$c = \frac{1}{\sqrt{\varepsilon_o\mu_o}}$$

$$f\lambda = c$$

$$\frac{E_{\max}}{B_{\max}} = \frac{E}{B} = c$$

$$\vec{S} = \frac{\vec{E}\times\vec{B}}{\mu_\circ}$$

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

$$u_B = u_E = \tfrac{1}{2}\varepsilon_o E^2 = \frac{B^2}{2\mu_o}$$

$$u_{av} = \tfrac{1}{2}\varepsilon_o E_{\max}^2 = \frac{B_{\max}^2}{2\mu_o}$$

$$p = \frac{U}{c} \quad P = \frac{S}{c} \quad \text{complete absorption}$$

$$p = \frac{2U}{c} \quad P = \frac{2S}{c} \quad \text{complete reflection}$$

## The Nature of Light and the Laws of Geometric Optics

$$\theta'_1 = \theta_1$$

$$n_1\sin\theta_1 = n_2\sin\theta_2$$

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

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

$$\sin\theta_c = \frac{n_2}{n_1} \quad (\text{for } n_1 > n_2)$$

## Geometric Optics

$$M = \frac{h'}{h}$$

$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R} = \frac{1}{f}$$

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

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

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

## Physical Constants

$$k_e = 8.988\times 10^9\, N\cdot m^2/C^2$$

$$\varepsilon_o = 8.854\times 10^{-12}\, C^2/N\cdot m^2$$

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

$$m_{electron} = 9.109\times 10^{-31}\, kg$$

$$m_{proton} = 1.672\times 10^{-27}\, kg$$

$$\mu_\circ = 4\pi\times 10^{-7}\, T\cdot m/A$$

$$c = \frac{1}{\sqrt{\varepsilon_\circ\mu_\circ}} = 2.998\times 10^8\, m/s$$

## Useful Geometry

*Circle*
Area = $\pi r^2$
Circumference = $2\pi r$

*Sphere*
Surface area = $4\pi r^2$
Volume = $\frac{4}{3}\pi r^3$

*Cylinder*
Lateral surface area = $2\pi rL$
Volume = $\pi r^2 L$