

Physics 2426 - Formula List

■ Coulomb's Law

$$F = k_e \frac{|Q_1||Q_2|}{r^2} \quad (\text{magnitude of the force})$$

$$\vec{F}_{21} = k_e Q_1 Q_2 \frac{\hat{r}_{12}}{r_{12}^2} \quad \text{where} \quad \frac{\hat{r}_{12}}{r_{12}^2} = \frac{\vec{r}_{12}}{r_{12}^3}$$

and where \vec{r}_{12} is the vector from Q_1 to Q_2 .

Charge quantization: $Q = ne$, n is an integer.

■ Electric Field

$$\vec{E} = \vec{F}/q_0 \quad \text{or} \quad \vec{E} = \lim_{q_0 \rightarrow 0} \vec{F}/q_0$$

$$\vec{F} = Q\vec{E} \quad (\text{force on charge } Q)$$

Point Charge: $\vec{E} = k_e Q \frac{\hat{r}}{r^2} = k_e Q \frac{\vec{r}}{r^3}$, $E = k_e \frac{|Q|}{r^2}$

Discrete: $\vec{E} = k_e \sum_i Q_i \frac{\hat{r}_i}{r_i^2} = k_e \sum_i Q_i \frac{\vec{r}_i}{r_i^3}$

Continuous: $\vec{E} = k_e \int \frac{\hat{r}}{r^2} dq = k_e \int \frac{\vec{r}}{r^3} dq$

$$\vec{E} = k_e Q \frac{z}{(R^2 + z^2)^{3/2}} \hat{z} \quad (z \text{ from center of uniform ring})$$

■ Electric Flux

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

For uniform field and flat surface: $\Phi = \vec{E} \cdot \vec{A}$

Dot Product: $\vec{A} \cdot \vec{B} = AB \cos \theta = A_x B_x + A_y B_y + A_z B_z$

■ Gauss's Law

$$\oint \vec{E} \cdot d\vec{A} = \frac{1}{\epsilon_0} Q_{in}$$

Spherical Symmetry:

$$\oint \vec{E} \cdot d\vec{A} = \frac{1}{\epsilon_0} Q_{in} \implies E 4\pi r^2 = \frac{1}{\epsilon_0} Q_{in} \implies \vec{E} = k_e \frac{Q_{in}}{r^2} \hat{r}$$

Cylindrical Symmetry:

$$\oint \vec{E} \cdot d\vec{A} = \frac{1}{\epsilon_0} Q_{in} \implies E 2\pi r \ell = \frac{1}{\epsilon_0} Q_{in} \implies \vec{E} = \frac{1}{2\pi \epsilon_0} \frac{Q_{in}/\ell}{r} \hat{r}$$

■ Potential and Potential Energy

$$V = U/q_0, \quad \Delta U = Q \Delta V$$

For a charge distribution: $U = k_e \sum_{i < j} \frac{Q_i Q_j}{r_{ij}}$

Conservation of Energy: $K_i + U_i = K_f + U_f$, where $K = \frac{1}{2} m v^2$

■ Potential due to Charges

Point Charge: $V = k_e \frac{Q}{r}$

Discrete: $V = k_e \sum_i \frac{Q_i}{r_i}$, Continuous: $V = k_e \int \frac{dq}{r}$

■ Potential and Electric Field

$$\Delta V = -\int \vec{E} \cdot d\vec{r}, \quad \Delta V = -\vec{E} \cdot \Delta \vec{r} \quad (\text{uniform } \vec{E})$$

$$E_x = -\frac{\partial V}{\partial x} \quad \text{and for } y \text{ and } z. \quad \text{also } E_r = -\frac{\partial V}{\partial r}$$

■ Conductors in Electrostatics

Inside: $\vec{E} = \vec{0}$, voltage is const., no excess charge.

At surface: $\vec{E} \perp$ surface and $E = \sigma/\epsilon_0$

■ Capacitance

$$Q = CV, \quad C \text{ is the capacitance.}$$

$C = \kappa C_0$, where C_0 = empty cap. and dielectric const. = $\kappa \geq 1$

$$C_0 = \frac{\epsilon_0 A}{d} \quad (\text{|| plate}), \quad C_0 = \frac{1}{k_e \left(\frac{1}{a} - \frac{1}{b}\right)} \quad (\text{sph.}), \quad C_0 = \frac{2\pi \epsilon_0 \ell}{\ln(b/a)} \quad (\text{cyl.})$$

■ Energy

$$U = \frac{1}{2} C V^2 = \frac{Q^2}{2C} = \frac{1}{2} QV \quad (\text{energy in a cap.})$$

$$u = \frac{\epsilon_0}{2} E^2 = \frac{\text{Energy}}{\text{Volume}} \quad (\text{energy density in a field})$$

■ Electric Dipoles

Dipole Moment: $\vec{p} = Q\vec{d}$, \vec{d} from $-Q$ to Q

Torque: $\vec{\tau} = \vec{p} \times \vec{E}$, $\tau = p E \sin \theta$, Pot. Energy: $U = -\vec{p} \cdot \vec{E}$

■ Current and Current Density

$$I = \frac{dQ}{dt} \quad \text{is the current through surface.}$$

\vec{J} is the current density. $I = \int_{\text{surface}} \vec{J} \cdot d\vec{A}$, $I = JA$ (for a wire)

■ Drift Velocity

$$I = n|q|v_d A, \quad \vec{J} = nq\vec{v}_d$$

$$n = \frac{\# \text{ of charge carriers}}{\text{vol.}}, \quad q = \text{charge of charge carriers}, \quad v_d = \text{drift velocity}$$

■ Ohm's Law

$$V = IR, \quad R = \frac{\rho L}{A}, \quad \vec{J} = \sigma \vec{E}$$

$$\sigma = \text{conductivity}, \quad \rho = \frac{1}{\sigma} = \text{resistivity}$$

■ Temperature Dependence

$$\Delta T = T - T_0$$

$$\Delta R = \alpha R_0 \Delta T, \quad R = R_0(1 + \alpha \Delta T), \quad \Delta \rho = \alpha \rho_0 \Delta T, \quad \rho = \rho_0(1 + \alpha \Delta T)$$

■ Power

$$\mathcal{P} = VI, \quad \text{For a resistor: } \mathcal{P} = VI = I^2 R = \frac{V^2}{R}$$

■ Combinations of Resistors

Series: $R_{eq} = R_1 + R_2 + \dots$, Parallel: $R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \dots\right)^{-1}$

Node Reduction: $R'_{ij} = \frac{R_i R_j}{R_{ij}}$, where $R_{ij} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)^{-1}$

■ Combinations of Capacitors

Series: $C_{eq} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \dots\right)^{-1}$, Parallel: $C_{eq} = C_1 + C_2 + \dots$

■ Kirchhoff's Rules

Junctions: $\sum I_{in} = \sum I_{out}$, Loops: $0 = \sum \Delta V$

■ Cross or Vector Product

$$\vec{A} \times \vec{B} = \hat{u} AB \sin \theta, \quad \text{right hand rule} \Rightarrow \hat{u}$$

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix} = \hat{x} \begin{vmatrix} A_y & A_z \\ B_y & B_z \end{vmatrix} - \hat{y} \begin{vmatrix} A_x & A_z \\ B_x & B_z \end{vmatrix} + \hat{z} \begin{vmatrix} A_x & A_y \\ B_x & B_y \end{vmatrix}$$

■ Magnetic Force on Particle

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

$\vec{v} \perp$ to uniform $\vec{B} \implies$ circle with $r = \frac{mv}{|Q|B}$

■ Magnetic Force on Wire

$$\vec{F} = I \int d\vec{r} \times \vec{B}$$

$\vec{F} = I\vec{\ell} \times \vec{B}$ (straight segment, uniform field)

$V_{Hall} = v_d B L$ (Hall Voltage)

■ Magnetic Dipoles

Dipole Moment: $\vec{\mu} = NI\vec{A}$ (N is # of turns)

Torque: $\vec{\tau} = \vec{\mu} \times \vec{B}$, $\tau = \mu B \sin \theta$, Pot. Energy: $U = -\vec{\mu} \cdot \vec{B}$

■ Biot-Savart Law

$$\vec{B} = \frac{\mu_0 I}{4\pi} \int d\vec{s} \times \frac{\hat{r}}{r^2}$$

$$\vec{B} = \hat{z} \frac{\mu_0 I}{4\pi R} \theta \quad (\text{at center of arc in } xy\text{-plane})$$

$$\vec{B} = \hat{z} \frac{\mu_0 I}{2} \frac{R^2}{(R^2 + z^2)^{3/2}} \quad (z \text{ from center of circle})$$

$$B = \frac{\mu_0 I}{4\pi a} (\sin \phi_2 - \sin \phi_1) = \frac{\mu_0 I}{4\pi a} \left(\frac{x_2}{\sqrt{x_2^2 + a^2}} - \frac{x_1}{\sqrt{x_1^2 + a^2}} \right) \quad (\text{segment})$$

$$B = \frac{\mu_0 I}{2\pi r} \quad (\text{distance } r \text{ from long wire})$$

■ **Ampere's Law** $\oint \vec{B} \cdot d\vec{r} = \mu_0 I_{\text{inside}}$
 $B = \mu_0 n I$, $n = \frac{\text{\# of turns}}{\text{length}}$ (inside long solenoid)

■ **Magnetic Flux** $\Phi_m = \int \vec{B} \cdot d\vec{A}$

For uniform field and flat surface: $\Phi = \vec{B} \cdot \vec{A}$

■ **Faraday's Law** $\mathcal{E} = -N \frac{d\Phi}{dt}$, $\vec{\mathcal{E}} = -N \frac{\Delta\Phi}{\Delta t}$

AC Generator: $\Phi = B A \cos \omega t \implies \mathcal{E}(t) = N B A \omega \sin \omega t$

■ **Motional EMF**

moving rod: $\mathcal{E} = B \ell v$ ($\vec{B} \perp \vec{v} \perp \text{rod}$)

rotating rod: $\mathcal{E} = \frac{1}{2} B \ell^2 \omega$ ($\vec{B} \parallel \text{axis} \perp \text{rod}$)

■ **Lenz's Law**

Direction of Φ is dir. of field through loop.

$\frac{d\Phi}{dt}$ is same as (opposite to) dir. of Φ when increasing (decreasing).

Φ_{induced} dir. is opposite to dir. of $\frac{d\Phi}{dt}$.

Get direction of \mathcal{E} or I by Right Hand Rule.

■ **Maxwell's Equations**

$\oint \vec{E} \cdot d\vec{A} = \frac{1}{\epsilon_0} Q_{\text{in}}$, $\oint \vec{B} \cdot d\vec{A} = 0$

$\oint \vec{B} \cdot d\vec{r} = \mu_0 I_{\text{in}} + \mu_0 \epsilon_0 \frac{d\Phi_e}{dt}$, $\oint \vec{E} \cdot d\vec{r} = -\frac{d\Phi_m}{dt}$

■ **Inductance** Mutual: $\mathcal{E}_2 = -M \frac{dI_1}{dt}$, Self: $\mathcal{E} = -L \frac{dI}{dt}$

Long Solenoid: $L = \mu_0 n^2 A \ell = \mu_0 \frac{N^2}{\ell} A$

Energy in Inductor: $U = \frac{1}{2} L I^2$

■ **Energy Density** $u = \frac{1}{2\mu_0} B^2$ (in magnetic field)

$u = u_e + u_m = \frac{\epsilon_0}{2} E^2 + \frac{1}{2\mu_0} B^2$ (in electromagnetic field)

■ **RC Circuits** $\tau = RC = \text{time const.}$, $\mathcal{E} = \text{EMF}$

Discharging: $Q(t) = Q_0 e^{-t/\tau}$ Charging: $Q(t) = C \mathcal{E} (1 - e^{-t/\tau})$

■ **RL Circuits** $\tau = \frac{L}{R} = \text{time const.}$

Current Growth: $I(t) = \frac{\mathcal{E}}{R} (1 - e^{-t/\tau})$, Current Decay: $I(t) = I_0 e^{-t/\tau}$

■ **LC Circuits** $\omega_0 = \frac{1}{\sqrt{LC}}$, $Q(t) = Q_{\text{max}} \cos(\omega_0 t + \phi)$

■ **LCR Circuits** $Q(t) = Q_0 e^{-\gamma t} \cos(\omega t + \phi)$, $\gamma = \frac{R}{2L}$, $\omega = \sqrt{\omega_0^2 - \gamma^2}$

■ **General AC Circuits** $\omega = 2\pi f$, $V_{\text{rms}} = \frac{1}{\sqrt{2}} V_{\text{max}}$, $I_{\text{rms}} = \frac{1}{\sqrt{2}} I_{\text{max}}$

$I(t) = I_{\text{max}} \cos \omega t$, $V(t) = V_{\text{max}} \cos(\omega t + \phi)$

$Z = \frac{V_{\text{max}}}{I_{\text{max}}} = \frac{V_{\text{rms}}}{I_{\text{rms}}}$ (Impedance), $\bar{P} = V_{\text{rms}} I_{\text{rms}} \cos \phi$ (Average Power)

	Z	ϕ
Just R	R	0
Just C	$X_C = \frac{1}{\omega C}$	$-90^\circ = -\frac{\pi}{2}$
Just L	$X_L = \omega L$	$90^\circ = \frac{\pi}{2}$

■ **Series RCL** $Z = \sqrt{R^2 + (X_L - X_C)^2}$, $\tan \phi = \frac{X_L - X_C}{R}$, $\bar{P} = I_{\text{rms}}^2 R$

Resonance: $Z = Z_{\text{min}} = R \iff X_L = X_C \iff \omega = \frac{1}{\sqrt{LC}}$

■ **Transformer** $\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$

■ **Electromagnetic Radiation in Vacuum**

$\vec{E} = \hat{y} E_{\text{max}} \cos(kx - \omega t)$, $\vec{B} = \hat{z} B_{\text{max}} \cos(kx - \omega t)$

$\omega = 2\pi f = \frac{2\pi}{T}$, $k = \frac{2\pi}{\lambda}$, $f\lambda = \frac{\omega}{k} = c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$, $c = \frac{E_{\text{max}}}{B_{\text{max}}} = \frac{E}{B}$

Intensity = $I = \frac{\text{Power}}{\text{Area}} = \frac{U}{A \Delta t}$, $I = \frac{E_{\text{max}}^2}{2\mu_0 c} = c \bar{u} = \bar{S}$, $\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$

■ **Radiation Pressure and Momentum**

Momentum carried by radiation: $p = \frac{U}{c}$, Pressure = $\frac{\text{Force}}{\text{Area}}$

	Momentum to Surface	Pressure on Surface
Perfect Absorber	$p = \frac{U}{c}$	$P = \frac{I}{c}$
Perfect Reflector	$p = 2 \frac{U}{c}$	$P = 2 \frac{I}{c}$
$\kappa = \text{fraction refl.}$	$p = (1 + \kappa) \frac{U}{c}$	$P = (1 + \kappa) \frac{I}{c}$

■ **In a Medium** $f\lambda = v = c/n$

At interface: $n_1 \lambda_1 = n_2 \lambda_2$

Snell's Law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$

Total Internal Refl.: $\theta_1 > \theta_c$ where $\sin \theta_c = \frac{n_2}{n_1}$

■ **Geometric Optics** $\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$, $m = \frac{h'}{h} = -\frac{s'}{s}$

Sph. Mirrors: $f = \frac{R}{2}$, $R > 0$ (concave), $R < 0$ (convex), $R \rightarrow \infty$ (flat)

Thin Lenses: $f > 0$ (converging), $f < 0$ (diverging)

Spherical Interface: $\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R}$, $m = \frac{h'}{h} = -\frac{n_1 s'}{n_2 s}$

Flat Interface: $\frac{s'}{s} = -\frac{n_2}{n_1}$, $m = \frac{h'}{h} = 1$

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

■ **Interference and Diffraction**

$\tan \theta = \frac{y}{L}$, Small θ or $y \ll L \implies \sin \theta = \frac{y}{L}$

Double Slit: Intensity: $I = I_{\text{max}} \cos^2 \left(\frac{\pi d \sin \theta}{\lambda} \right)$

Const. Int.: $d \sin \theta = m\lambda$, Dest. Int.: $d \sin \theta = \left(m + \frac{1}{2}\right)\lambda$

Diffraction Grating: Const. Int: $d \sin \theta = m\lambda$, Dest. Int. elsewhere

Single Slit: Destr. Int.: $a \sin \theta = m\lambda$, $m \neq 0$

Thin Films	Constructive Interference	Destructive Interference
$n < n'$	$2t = m \frac{\lambda}{n}$	$2t = \left(m + \frac{1}{2}\right) \frac{\lambda}{n}$
$n > n'$	$2t = \left(m + \frac{1}{2}\right) \frac{\lambda}{n}$	$2t = m \frac{\lambda}{n}$

Phase Shift on Reflection: $n < n' \implies 180^\circ$ shift, $n > n' \implies$ no shift

■ **Polarization** $I = \frac{1}{2} I_0$, $I = I_0 \cos^2 \theta$, $\tan \theta_p = \frac{n_2}{n_1}$ (Pol. \perp)