'ormula Sheet

Iaxwell's Equations:

$$\oint \vec{E}\cdot d\vec{A} = \frac{Q_{\text{encl}}}{\epsilon_0} \quad \text{(Gauss's law for } \vec{E}\text{)}$$

$$\oint \vec{B}\cdot d\vec{A} = 0 \quad \text{(Gauss's law for } \vec{B}\text{)}$$

$$\oint \vec{B}\cdot d\vec{l} = \mu_0\left(i_C + \epsilon_0 \frac{d\Phi_E}{dt}\right)_{\text{encl}} \quad \text{(Ampere's law)}$$

$$\oint \vec{E}\cdot d\vec{l} = -\frac{d\Phi_B}{dt} \quad \text{(Faraday's law)}$$

.orrentz Force Law:

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

;tanding Waves:

$$f_n = n\frac{\upsilon}{2L} = nf_1 \quad (n = 1,2,3,\ldots)$$

)oppler effect:

$$f_L = \frac{\upsilon + \upsilon_L}{\upsilon + \upsilon_S} f_S$$

Iechanical Waves:

$$\upsilon = \lambda f \quad \text{(periodic wave)}$$

$$y(x,t) = A\cos\left[\omega\left(\frac{x}{\upsilon} - t\right)\right] = A\cos\left[2\pi f\left(\frac{x}{\upsilon} - t\right)\right] \quad \text{(sinusoidal w}$$

$$y(x,t) = A\cos\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right] \quad \text{(sinusoidal wave movin}$$

$$y(x,t) = A\cos(kx - \omega t) \quad \text{(sinusoidal wave moving ir}$$

$$\frac{\partial^2 y(x,t)}{\partial x^2} = \frac{1}{\upsilon^2}\frac{\partial^2 y(x,t)}{\partial t^2} \quad \text{(wave equation)}$$

$$\upsilon = \sqrt{\frac{F}{\mu}} \quad \text{(speed of a transverse wave on a string)}$$

$$P_{\text{av}} = \frac{1}{2}\sqrt{\mu F}\,\omega^2 A^2 \quad \text{(average power, sinusoidal wave on a string)}$$

$$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2} \quad \text{(inverse-square law for intensity)}$$

$$y(x,t) = y_1(x,t) + y_2(x,t) \quad \text{(principle of superposition)}$$

Electric Field:

$$F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2} \quad \text{(Coulomb's law: force between two point cha}$$

$$\vec{E} = \frac{\vec{F}_0}{q_0} \quad \text{(definition of electric field as electric force per unit cha}$$

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r} \quad \text{(electric field of a point charge)}$$

$$\tau = pE\sin\phi \quad \text{(magnitude of the torque on an electric dipole)}$$

$$\vec{\tau} = \vec{p}\times\vec{E} \quad \text{(torque on an electric dipole, in vector form)}$$

$$U = -\vec{p}\cdot\vec{E} \quad \text{(potential energy for a dipole in an electric field)}$$

lectric Potential:

$$W_{a\to b} = U_a - U_b = -(U_b - U_a) = -\Delta U$$ (work done by a conservative

$$U = \frac{1}{4\pi \epsilon_0}\frac{qq_0}{r}$$ (electric potential energy of two point charges q and q_0)

$$U = \frac{q_0}{4\pi \epsilon_0}\left(\frac{q_1}{r_1}+\frac{q_2}{r_2}+\frac{q_3}{r_3}+\cdots\right) = \frac{q_0}{4\pi \epsilon_0}\sum_i \frac{q_i}{r_i}$$ (point charge q_0 and collectio

$$V = \frac{U}{q_0} = \frac{1}{4\pi \epsilon_0}\frac{q}{r}$$ (potential due to a point charge)

$$V = \frac{U}{q_0} = \frac{1}{4\pi \epsilon_0}\sum_i \frac{q_i}{r_i}$$ (potential due to a collection of point charge)

$$V = \frac{1}{4\pi \epsilon_0}\int \frac{dq}{r}$$ (potential due to a continuous distribution of charg

$$V_a - V_b = \int_a^b \vec{E}\cdot d\vec{l} = \int_a^b E\cos\phi\, dl$$ (potential difference as an integ

$$E_x = -\frac{\partial V}{\partial x} \quad E_y = -\frac{\partial V}{\partial y} \quad E_z = -\frac{\partial V}{\partial_z}$$ (components of $\vec{E}$ in te

$$\vec{E} = -\left(\hat{i}\frac{\partial V}{\partial x} + \hat{j}\frac{\partial V}{\partial y} + \hat{k}\frac{\partial V}{\partial z}\right)$$ ($\vec{E}$ in terms of V)

apacitance:

$$C = \frac{Q}{V_{ab}}$$ (definition of capacitance)

$$C = \frac{Q}{V_{ab}} = \epsilon_0 \frac{A}{d}$$ (capacitance of a parallel-plate capacitor in vacuum)

$$\frac{1}{C_{eq}} = \frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\ldots$$ (capacitors in series)

$$C_{eq} = C_1 + C_2 + C_3 + \ldots$$ (capacitors in parallel)

$$U = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$$ (potential energy stored in a capacitor)

$$u = \frac{1}{2}\epsilon_0 E^2$$ (electric energy density in a vacuum)

Current, Resistance, and Ohm's Law

$$I = \frac{dQ}{dt} = n|q|\upsilon_d A$$ (general expression for current)

$$\vec{J} = nq\vec{\upsilon}_d$$ (vector current density)

$$\rho = \frac{E}{J}$$ (definition of resistivity)

$$\rho(T) = \rho_0[1+\alpha(T-T_0)]$$ (temperature dependence of re

$$R = \frac{\rho L}{A}$$ (relationship between resistance and resistiv

$$V = IR$$ (relationship among voltage, current, and resis

$$V_{ab} = \varepsilon - Ir$$ (terminal voltage, source with internal resi

$$P = V_{ab}I$$ (rate at which energy is delivered to or extracted from a ci

$$P = V_{ab}I = I^2R = \frac{V_{ab}^2}{R}$$ (power delivered to a resistor

$$R_{eq} = R_1 + R_2 + R_3 + \ldots$$ (resistors in series)

$$\frac{1}{R_{eq}} = \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\ldots$$ (resistors in parallel)

$$\sum I = 0$$ (junction rule, valid at any junction)

$$\sum V = 0$$ (loop rule, valid for any closed loop)

$$q = C\varepsilon(1-e^{-t/RC}) = Q_f(1-e^{-t/RC})$$ (R-C circuit, charging cap

$$i = \frac{dq}{dt} = \frac{\varepsilon}{R}e^{-t/RC} = I_0 e^{-t/RC}$$ (R-C circuit, charging capacit

$$q = Q_0 e^{-t/RC}$$ (R-C circuit, discharging capacitor)

$$i = \frac{dq}{dt} = -\frac{Q_0}{RC}e^{-t/RC} = I_0 e^{-t/RC}$$ (R-C circuit, discharging cap

Magnetic Force and Magnetic Flux:

$$\vec{F} = q\vec{\upsilon} \times \vec{B}$$ (magnetic force on a moving charged particle)

$$\Phi_B = \int B_\perp \, dA = \int B\cos\phi \, dA = \int \vec{B} \cdot d\vec{A}$$ (magnetic flux through a surface)

$$\oint \vec{B} \cdot d\vec{A} = 0$$ (magnetic flux through any closed surface)

$$R = \frac{m\upsilon}{|q|B}$$ (radius of a circular orbit in a magnetic field)

$$\vec{F} = I\vec{l} \times \vec{B}$$ (magnetic force on a straight wire segment)

$$d\vec{F} = Id\vec{l} \times \vec{B}$$ (magnetic force on an infinitesimal wire section)

$$\tau = IBA\sin\phi$$ (magnitude of torque on a current loop)

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$ (vector torque on a current loop)

$$U = -\vec{\mu} \cdot \vec{B} = -\mu B\cos\phi$$ (potential energy for a magnetic dipole)

Magnetic Field:

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{\upsilon} \times \hat{r}}{r^2}$$ (magnetic field of a point charge with constant veloci

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l} \times \hat{r}}{r^2}$$ (magnetic field of a current element)

$$B = \frac{\mu_0 I}{2\pi r}$$ (near a long, straight, current-carrying conductor)

$$\frac{F}{L} = \frac{\mu_0 II'}{2\pi r}$$ (two long, parallel, current-carrying conductors)

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{encl}}$$

Inductance and Displacement Current:

$$\varepsilon = -\frac{d\Phi_B}{dt}$$ (Faraday's law of induction)

$$\varepsilon = \upsilon BL$$ (motional emf; length and velocity perpendicular to u

$$\varepsilon = \oint (\vec{\upsilon} \times \vec{B}) \cdot d\vec{l}$$ (motional emf; closed conducting loo

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$ (stationary integration path)

$$i_D = \in \frac{d\Phi_E}{dt}$$ (displacement current)

$$M = \frac{N_2\Phi_{B2}}{i_1} = \frac{N_1\Phi_{B1}}{i_2}$$ (mutual inductance)

$$L = \frac{N\Phi_B}{i}$$ (self-inductance)

$$\varepsilon = -L\frac{di}{dt}$$ (self-induced emf)

$$U = L\int_0^I i \, di = \frac{1}{2}LI^2$$ (energy stored in an inductor)

$$u = \frac{B^2}{2\mu_0}$$ (magnetic energy density in vacuum)

$$u = \frac{B^2}{2\mu}$$ (magnetic energy density in a material)

$$\tau = \frac{L}{R}$$ (time constant for an *R*-*L* circuit)

$$\omega = \frac{1}{\sqrt{LC}}$$ (angular frequency of oscillation in an *L*-*C* circuit)

$$\omega' = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$ (underdamped *L*-*R*-*C* series circuit)

Electromagnetic Waves:

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \quad \text{(speed of electromagnetic waves in vacuum)}$$

$$\vec{E}(x,t) = \hat{j}E_{\max}\cos(kx - \omega t)$$
$$\vec{B}(x,t) = \hat{k}B_{\max}\cos(kx - \omega t)$$

$$E_{\max} = cB_{\max} \quad \text{(electromagnetic wave in vacuum)}$$

$$E_y(x,t) = E_{\max}\cos(kx + \omega t) \quad B_z(x,t) = -B_{\max}\cos(kx + \omega t)$$
$$\text{(sinusoidal electromagnetic plane wave, propagating in } -x\text{-direc}$$

$$\upsilon = \frac{1}{\sqrt{\epsilon\mu}} = \frac{1}{\sqrt{KK_m}}\frac{1}{\sqrt{\epsilon_0 \mu_0}} = \frac{c}{\sqrt{KK_m}} \quad \text{(speed of electromagnetic waves}$$

$$\vec{S} = \frac{1}{\mu_0}\vec{E}\times\vec{B} \quad \text{(Poynting vector in vacuum)}$$

$$n = \frac{c}{\upsilon} \quad \text{(index of refraction)}$$

$$\theta_r = \theta_a \quad \text{(law of reflection)}$$

$$n_a \sin\theta_a = n_b \sin\theta_b \quad \text{(law of refraction)}$$

Volume and Area Formulae:

Circle:

Area:	πr^2
Circumference:	$2\pi r$

Sphere:

Area:	$4\pi r^2$
Volume:	$4/3\ \pi r^3$

Cylinder:

Area:	$2\pi rl$
Volume:	$\pi r^2 l$

Fundamental Constants:

$c = 2.9979 \cdot 10^8$ m/s

$k = 9.0 \cdot 10^9$ Nm^2/ C^2

$\varepsilon_0 = 4\pi/k = 8.85 \cdot 10^{-12}$ C^2/ Nm^2

$\mu_0 = 4\pi \cdot 10^{-7}$ TA/m

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

$m_e = 9.11 \cdot 10^{-30}$ kg