Comprehensive Formula Sheet for LSU Physics 2102

- **Constants and Definitions:**

$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C^2/Nm^2}$
$c = 3.00 \times 10^8\,\mathrm{m/s^2}$
$\mu_B = 9.27 \times 10^{-24}\,\mathrm{J/T}$
$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
Area of a circle: $A = \pi r^2$

$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9\,\mathrm{Nm^2/C^2}$
$e = 1.602 \times 10^{-19}\,\mathrm{C}$
$h = 6.63 \times 10^{-34}\,\mathrm{J \cdot s}$
$m_p = 1.673 \times 10^{-27}\,\mathrm{kg}$
Surface area of a sphere: $A = 4\pi r^2$

$\mu_0 = 4\pi \times 10^{-7}\,\mathrm{T \cdot m/A}$
$1eV = e(1V) = 1.602 \times 10^{-19}\,\mathrm{J}$
$g = 9.8\,\mathrm{m/s^2}$
$m_n = 1.675 \times 10^{-27}\,\mathrm{kg}$
Volume of a sphere $V = \frac{4}{3}\pi r^3$

- **Kinematics (for constant acceleration):**

$v = v_0 + at$ $\quad x - x_0 = \frac{1}{2}(v_0 + v)t$ $\quad x - x_0 = vt - \frac{1}{2}at^2$
$x - x_0 = v_0 t + \frac{1}{2}at^2$ $\quad v^2 = v_0^2 + 2a(x - x_0)$

- **Electric Fields and Forces:**

Field of point charge: $|\vec{E}| = k\frac{|q|}{r^2}$ Force on charged particle: $\vec{F} = q\vec{E}$ Coulomb's Law: $|\vec{F}| = k\frac{|q_1||q_2|}{r^2}$

Dipole moment: $\vec{p} = q\vec{d}$ Torque on dipole: $\vec{\tau} = \vec{p} \times \vec{E}$ Potential energy: $U = -\vec{p} \cdot \vec{E}$

Field of dipole, on axis, far from dipole: $\vec{E} = \frac{2k\vec{p}}{z^3}$ Uniform Charge Densities: $\lambda = \frac{Q}{L}$, $\sigma = \frac{Q}{A}$, $\rho = \frac{Q}{V}$

Electric flux: $\Phi_E = \int \vec{E} \cdot d\vec{A}$ Gauss's Law: $q_{enc} = \varepsilon_0 \oint \vec{E} \cdot \vec{A}$ Field of line charge: $|\vec{E}| = \frac{2k\lambda}{r}$

Field of infinite, non-conducting plane: $|\vec{E}| = \frac{\sigma}{2\varepsilon_0}$ Field of infinite conducting plane: $|\vec{E}| = \frac{\sigma}{\varepsilon_0}$

- **Electric Potential, Potential Energy, and Work:**

Potential difference: $V_f - V_i = -\int_i^f \vec{E} \cdot d\vec{s}$ In a uniform field: $\Delta V = -\vec{E} \cdot \vec{s} = -Es\cos\theta$

Field due to potential: $\vec{E} = -\nabla V$ Cartesian coordinates: $E_x = -\frac{\partial V}{\partial x}$, $E_y = -\frac{\partial V}{\partial y}$, $E_z = -\frac{\partial V}{\partial z}$

Cylindrical coordinates: $E_r = -\frac{\partial V}{\partial r}$ Spherical coordinates: $E_r = -\frac{\partial V}{\partial r}$

Potential of a point charge: $V = k\frac{q}{r}$ Potential of n point charges: $V = \sum_{j=1}^{n} V_j = k\sum_{j=1}^{n} \frac{q_j}{r_j}$

Electric potential energy: $\Delta U = q\Delta V = -W_{field}$

Potential energy of two point charges: $U_{12} = W_{ext} = q_2 V_1 = q_1 V_2 = k\frac{q_1 q_2}{r_{12}}$

- **Capacitance:** $C = V/Q$ Charge stored on capacitor: $Q = CV$

Capacitor with dielectric: $C = \kappa C_{air}$ Parallel plate capacitor: $C_{air} = \frac{\varepsilon_0 A}{d}$

Energy stored in capacitor: $U = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{Q^2}{2C}$ Energy density of E-field: $u_E = \frac{1}{2}\kappa\varepsilon_0|\vec{E}|^2$

Capacitors in parallel: $C_{eq} = \sum_i C_i$ Capacitors in series: $\frac{1}{C_{eq}} = \sum_i \frac{1}{C_i}$

- **Current:** $i = \frac{dq}{dt} = \int \vec{J} \cdot d\vec{A}$ Current density: $|\vec{J}| = \frac{i}{A}$ Drift velocity: $\vec{v}_d = \frac{\vec{J}}{ne}$

- **RESISTANCE**: $R = \frac{V}{i}$ Resistivity: $\rho = \frac{|\vec{E}|}{|\vec{J}|}$ T dependence: $\rho - \rho_0 = \rho_0 \alpha (T - T_0)$

  Resistance of conducting wire: $R = \rho \frac{L}{A}$ Potential across resistor: $V = iR$

  Power in electrical device: $P = iV$ Energy dissipated in resistor: $P = i^2 R = \frac{V^2}{R}$

  Electromotive force, emf: $\mathcal{E} = \frac{dW}{dq}$

  Resistors in series: $R_{eq} = \sum_i R_i$ Resistors in parallel: $\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$

- **KIRCHOFF'S RULES FOR DC CIRCUITS**:
  Loop Rule: The sum of potential changes around any closed loop must be zero.

  $$0 = \sum_j \Delta V_j$$

  Junction Rule: The current entering any junction equals the current leaving the junction.

  $$\sum_j i_{\mathbf{in},j} = \sum_j i_{\mathbf{out},j}$$

- **RC SERIES CIRCUIT**:

  Time constant: $\tau_C = RC$ Charging: $q(t) = C\mathcal{E}\left(1 - e^{-t/\tau_C}\right)$ Discharging: $q(t) = C\mathcal{E} e^{-t/\tau_C}$

- **MAGNETIC FIELDS AND FORCES**:

  Force on point charge: $\vec{F} = q\vec{v} \times \vec{B}$ Lorentz force: $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$ Force on wire: $\vec{F} = i\vec{L} \times \vec{B}$

  Circular motion: $qv_\perp B = \frac{mv_\perp^2}{r}$ Radius of path: $r = \frac{mv_\perp}{qB}$ Period of motion: $T = \frac{2\pi m}{qB}$

  Magnetic dipole: $\vec{\mu} = Ni\vec{A}$ Torque on dipole: $\vec{\tau} = \vec{\mu} \times \vec{B}$ Potential Energy: $U = -\vec{\mu} \cdot \vec{B}$

- **GENERATING MAGNETIC FIELDS**:

  Biot-Savart Law: $d\vec{B} = \frac{\mu_0}{4\pi} \frac{id\vec{s} \times \hat{r}}{r^2}$ Ampere's Law: $\oint \vec{B} \cdot d\vec{s} = \mu_0 i_{enc}$

  Field of long, straight wire: $|\vec{B}| = \frac{\mu_0}{4\pi} \frac{2i}{r}$ Field of circular arc: $|\vec{B}| = \frac{\mu_0}{4\pi} \frac{i}{r} \phi$

  Force between parallel wires: $|\vec{F}_{ab}| = \frac{\mu_0 i_a i_b}{2\pi d} L$ Field inside a solenoid: $|\vec{B}| = \mu_0 n i$

  Field of dipole, on axis, far from dipole: $\vec{B} = \frac{\mu_0}{2\pi} \frac{\vec{\mu}}{z^3}$

- **INDUCTION**:

  Magnetic flux: $\phi_B = \oint \vec{B} \cdot d\vec{A}$ Faraday's Law: $\mathcal{E} = -\frac{d\Phi_B}{dt}$ Induced E-field: $\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$

  Motional emf: $\mathcal{E} = BLv$ Faraday's Law for coil with N turns: $\mathcal{E} = -N\frac{d\Phi_B}{dt}$

- **INDUCTORS**:

  Self-Inductance (def): $L = \frac{N\Phi_B}{i}$ Solenoid inductor: $L = \mu_0 n^2 A l$ Emf across inductor: $\mathcal{E} = -L\frac{di}{dt}$

  Energy stored in inductor: $U = \frac{1}{2} L i^2$ Energy density of B-field: $u_B = \frac{1}{2\mu_0} |\vec{B}|^2$

- **RL CIRCUITS**:

  Time constant: $\tau_L = L/R$ Rising current: $i(t) = \frac{\mathcal{E}}{R}\left(1 - e^{-t/\tau_L}\right)$ Decaying current: $i(t) = \frac{\mathcal{E}}{R} e^{-t/\tau_L}$

- **LC Circuits**:

  Electric energy in capacitor: $U_E = \dfrac{q^2}{2C} = \dfrac{CV^2}{2}$ Magnetic energy in inductor: $U_B = \dfrac{Li^2}{2}$

  LC circuit oscillations: $q(t) = q_0 \cos(\omega t + \phi_0)$ $\omega = \frac{1}{\sqrt{LC}}$ $T = \frac{2\pi}{\omega}$ $f = \frac{1}{T}$

- **RLC Circuits**:

  Damped charge oscillations: $q(t) = q_0 e^{-Rt/(2L)} \cos(\omega' t + \phi_0)$ where $\omega' = \sqrt{\omega^2 - \left(\dfrac{R}{2L}\right)^2}$

- **Maxwell's Equations**:

  Gauss's Law: $\oint_S \vec{E} \cdot d\vec{A} = \dfrac{q_{enc}}{\varepsilon_0}$ Gauss's Law (for $\vec{B}$): $\oint_S \vec{B} \cdot d\vec{A} = 0$ Faraday's Law: $\oint_C \vec{E} \cdot d\vec{s} = -\dfrac{d\Phi_B}{dt}$

  Ampere's Law: $\oint_C \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \dfrac{d\Phi_E}{dt} + \mu_0 i_{enc}$ Displacement current: $i_d = \varepsilon_0 \dfrac{d\Phi_E}{dt}$

- **Electromagnetic Waves**:

  Traveling in $\pm x$ direction: $\vec{E} = E_m \sin(kx \mp \omega t)$, and $\vec{B} = B_m \sin(kx \mp \omega t)$, with $E_m = cB_m$, and $\vec{E} \perp \vec{B}$

  Direction of travel: $\vec{E} \times \vec{B}$ Speed in vacuum: $c = \dfrac{1}{\sqrt{\varepsilon_0 \mu_0}}$ Wavelength: $\lambda = \dfrac{2\pi}{k}$ Frequency: $f = \dfrac{c}{\lambda}$

  Energy flow: $\vec{S} = \dfrac{1}{\mu_0} \vec{E} \times \vec{B}$ Intensity: $I = \dfrac{Power}{Area} = \dfrac{E_m^2}{2c\mu_0} = \dfrac{E_{rms}^2}{c\mu_0}$ where $E_{rms} = \dfrac{E_m}{\sqrt{2}}$

  Radiation force and pressure:

  Total Absorption: $F_r = \dfrac{IA}{c}$ and $P_r = \dfrac{I}{c}$ *Total Reflection*: $F_r = \dfrac{2IA}{c}$ and $P_r = \dfrac{2I}{c}$

- **Polarization**:

  Polarization direction: direction of $\vec{E}$ Unpolarized to polarized: $I = \dfrac{I_0}{2}$ Polarized to polarized: $I = I_0 \cos^2 \theta$

- **Reflection and Refraction**:

  Law of reflection: $\theta_i = \theta_r$ Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$ Critical angle: $\theta_c = \arcsin \dfrac{n_<}{n_>}$

  Index of refraction: $n = \dfrac{c}{v}$ Wavelength in medium: $\lambda_n = \dfrac{\lambda_{vac}}{n}$ Brewster angle: $\theta_{B,1} + \theta_{B,2} = 90^\circ$

- **Interference**:

  Constructive: $\dfrac{\Delta\phi}{2\pi} = m$ where $m = 0, 1, 2, \ldots$ Destructive: $\dfrac{\Delta\phi}{2\pi} = m + \dfrac{1}{2}$ where $m = 0, 1, 2, \ldots$

  Phase change (propagation): $\dfrac{\Delta\phi}{2\pi} = \dfrac{\Delta s}{\lambda}$ Phase change (reflection off of $n_>$): $\Delta\phi = \pi$

  Two-Slit Interference (point source... $a \ll \lambda$):

  Constructive: $d \sin\theta = m\lambda$ *Destructive*: $d\sin\theta = \left(m + \dfrac{1}{2}\right)\lambda$ *Order of fringe*: $m = 0, 1, 2, \ldots$

  Intensity: $I(\phi) = 4I_0 \cos^2 \dfrac{\phi}{2}$ *Phase difference*: $\phi = \dfrac{2\pi d}{\lambda} \sin\theta$

- **Diffraction**:

  Single-slit: $\dfrac{I(\phi)}{I_m} = \dfrac{\sin^2\alpha}{\alpha^2}$ Two-slit: $\dfrac{I(\phi)}{I_m} = \cos^2\beta \dfrac{\sin^2\alpha}{\alpha^2}$ Phase Parameters: $\alpha = \dfrac{\pi a}{\lambda}\sin\theta$ and $\beta = \dfrac{\pi d}{\lambda}\sin\theta$

  Diffraction minima: $a\sin\theta = m\lambda$ Interference minima: $d\sin\theta = \left(m + \dfrac{1}{2}\right)\lambda$ Order: $m = 0, 1, 2, \ldots$