ELECTRICITY & MAGNETISM CHEAT SHEET

1. Electrostatics

Coulomb's Law:

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}\hat{r}$$

Where $k_e = \frac{1}{4\pi\varepsilon_0} \approx 8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}$.

Electric Field (Point Charge):

$$\mathbf{E} = \frac{\mathbf{F}}{q} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

Electric Potential (V):

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}, \quad \mathbf{E} = -\nabla V$$

Potential Energy (U):

$$U = qV = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

Electric Dipole Moment:

$$\mathbf{p} = q\mathbf{d}$$

Torque in field: $\tau = \mathbf{p} \times \mathbf{E}$
Potential Energy: $U = -\mathbf{p} \cdot \mathbf{E}$

2. Gauss's Law

Electric Flux:

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

Gauss's Law (Integral Form):

$$\Phi_E = \oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q_{\text{enc}}}{\varepsilon_0}$$

4. Current & Circuits

Current Definition:

$$I = \frac{dQ}{dt} = nqv_d A$$

Ohm's Law:

$$V = IR \quad \text{or} \quad \mathbf{J} = \sigma \mathbf{E} = \frac{1}{\varrho}\mathbf{E}$$

Resistance:

$$R = \varrho \frac{L}{A}$$

Electrical Power:

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

Kirchhoff's Rules:

- **Junction Rule:** $\sum I_{\text{in}} = \sum I_{\text{out}}$
- **Loop Rule:** $\sum \Delta V = 0$

5. Magnetostatics

Magnetic Force:

$$\mathbf{F}_B = q(\mathbf{v} \times \mathbf{B}) \quad \text{(Point Charge)}$$

$$\mathbf{F}_B = I(\mathbf{L} \times \mathbf{B}) \quad \text{(Current Wire)}$$

Lorentz Force:

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

Biot-Savart Law:

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

Ampere's Law:

$$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I_{\text{enc}}$$

Common Magnetic Fields:

- Long straight wire: $B = \frac{\mu_0 I}{2\pi r}$
- Solenoid: $B = \mu_0 n I$
- Toroid: $B = \frac{\mu_0 N I}{2\pi r}$

6. Electromagnetic Induction

Magnetic Flux:

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

Faraday's Law of Induction:

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

Lenz's Law: Induced current opposes the change in flux.

Inductance (L):

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

Energy in Inductor:

$$U_B = \frac{1}{2}LI^2$$

7. Maxwell's Equations

1. Gauss's Law for Electricity:

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\varepsilon_0} \quad \left(\nabla \cdot \mathbf{E} = \frac{\varrho}{\varepsilon_0}\right)$$

2. Gauss's Law for Magnetism:

$$\oint \mathbf{B} \cdot d\mathbf{A} = 0 \quad \left(\nabla \cdot \mathbf{B} = 0\right)$$

3. Faraday's Law:

$$\oint \mathbf{E} \cdot d\mathbf{s} = -\frac{d\Phi_B}{dt} \quad \left(\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}\right)$$

4. Ampere-Maxwell Law:

$$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I_{\text{enc}} + \mu_0\varepsilon_0\frac{d\Phi_E}{dt} \quad \left(\nabla \times \mathbf{B} = \mu_0\mathbf{J} + \mu_0\varepsilon_0\frac{\partial \mathbf{E}}{\partial t}\right)$$

8. EM Waves & Diagrams

Speed of Light in Vacuum:

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = \frac{E}{B} \approx 3 \times 10^8 \text{ m/s}$$

Poynting Vector (Energy Flux):

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