

## Vector Potential

$$\mathbf{B} = \nabla \times \mathbf{A}$$

From current density  $\mathbf{J}_{tot}(\mathbf{r}')$ :

$$\mathbf{A}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \frac{\mathbf{J}_{tot}(\mathbf{r}')}{R} dv'$$

From current line:

$$\mathbf{A}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \frac{I dl'}{R}$$

From long straight current path:

$$\mathbf{A} = \frac{\mu_0 I}{2\pi} \ln\left(\frac{1}{r}\right) \mathbf{e}_z$$

From point dipole :

$$\mathbf{A} = \frac{\mu_0}{4\pi} \frac{\mathbf{m} \times \mathbf{r}}{r^3}$$

## Magnetic Flow

$$\Phi = \int \mathbf{B} \cdot \mathbf{e}_n dS = \oint \mathbf{A} \cdot d\mathbf{l}$$

## Linked Flow

$$\Lambda = N\Phi$$

## Self-Inductance and Mutual Inductance

$$\Lambda_1 = L_1 I_1 + M I_2$$

$$\Lambda_2 = L_2 I_2 + M I_1$$

## Magnetic Field Strength

Ampere's Law:

$$\oint \mathbf{H} \cdot d\mathbf{l} = \int \mathbf{J} \cdot \mathbf{e}_n dS = I_{\text{inside}}$$

Connection between magnetization  $\mathbf{M}$ ,  $\mathbf{B}$  and  $\mathbf{H}$ :

$$\begin{cases} \mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M}) & \text{(holds generally)} \\ \mathbf{B} = \mu_r \mu_0 \mathbf{H} \end{cases}$$

## Equivalent Current Density

$$\mathbf{J}_m = \nabla \times \mathbf{M} \quad \text{volume current density}$$

$$\mathbf{J}_m = \nabla \times \mathbf{M} \quad \text{surface current density}$$

## Boundary Conditions

$$\begin{cases} \mathbf{e}_{n2} \times (\mathbf{H}_1 - \mathbf{H}_2) = \mathbf{J}_s \\ \mathbf{B}_n \text{ Continuous} \end{cases}$$

## Scalar Potential

From magnetic dipole  $\mathbf{m}$ :

$$V_m = \frac{1}{4\pi} \frac{\mathbf{m} \cdot \mathbf{e}_R}{R^2}$$

## Magnetic Pole Density

$$\begin{cases} \rho_m = -\nabla \cdot \mathbf{M} & \text{volume pole density} \\ \rho_{m,s} = \mathbf{e}_{n1} \cdot (\mathbf{M}_1 - \mathbf{M}_2) & \text{surface pole density} \end{cases}$$

## Magnetic Force Law

$$d\mathbf{F}_m = I d\mathbf{l} \times \mathbf{B}$$

## Magnetic moment for current loop

$$\mathbf{m} = \int I \mathbf{e}_n dS$$

## Torque on Magnetic Moment

$$\mathbf{T}_m = \mathbf{m} \times \mathbf{B}$$

## Maxwell's Voltage

$$|\mathbf{T}| = \frac{1}{2} \mathbf{B} \cdot \mathbf{H} \quad \mathbf{B} \text{ is a bisector to } \mathbf{e}_n \text{ and } \mathbf{T}$$

## Magnetic Energy

$$W_m = \frac{1}{2} \int \mathbf{J} \cdot \mathbf{A} dv = \frac{1}{2} \int \mathbf{B} \cdot \mathbf{H} dv = \frac{1}{2} \sum_i \sum_j L_{ij} I_i I_j$$

Two coils:

$$W_m = \frac{1}{2} L_1 I_1^2 + \frac{1}{2} L_2 I_2^2 + M I_1 I_2$$

**Reluctance**

$$R = \frac{1}{\mu_r \mu_0 S}$$