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Magnetic Effect of Current and Magnetism

Biot-Savart Law

A current element $I d\vec{l}$ produces a magnetic field at point P located at vector position \vec{r} from the element:

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{l} \times \vec{r}}{r^3}$$

Magnitude form:

$$dB = \frac{\mu_0}{4\pi} \frac{I dl \sin \theta}{r^2}$$

Direction is given by right-hand rule.

Magnetic Fields Due to Current Configurations

- **Finite straight wire:** $B = \frac{\mu_0 I}{4\pi R} (\sin \alpha_1 + \sin \alpha_2)$
- **Infinite wire:** $B = \frac{\mu_0 I}{2\pi R}$
- **Circular arc (at center):** $B = \frac{\mu_0 I \phi}{4\pi R}$
- **Circular loop (center):** $B = \frac{\mu_0 I}{2R}$
- **Circular loop (on axis):** $B = \frac{\mu_0 N I R^2}{2(R^2 + x^2)^{3/2}}$
- **Solenoid (center):** $B = \mu_0 n I$
- **Toroid:** $B = \frac{\mu_0 N I}{2\pi r}$

Ampere's Circuital Law

Line integral of magnetic field along a closed loop equals μ_0 times total current enclosed:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I$$

Lorentz Force on a Moving Charge

Magnetic force on charge q moving with velocity \vec{v} in \vec{B} field:

$$\vec{F}_m = q(\vec{v} \times \vec{B})$$

With electric field:

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

If $\vec{v} \perp \vec{B}$, path is circular: $r = \frac{mv}{qB}$, $T = \frac{2\pi m}{qB}$, $f = \frac{qB}{2\pi m}$.

Force on Current-Carrying Conductor

$$\vec{F} = I(\vec{l} \times \vec{B})$$

Magnitude: $F = IlB \sin \theta$

Force Between Two Parallel Wires

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Same direction: attractive. Opposite: repulsive.

Torque on a Current Loop

$$\vec{\tau} = \vec{M} \times \vec{B}, \quad \vec{M} = NIA$$

$$\tau = NIAB \sin \alpha$$

Moving Coil Galvanometer

$$I = \left(\frac{C}{NAB} \right) \theta = K\theta$$

Current Sensitivity: $S_I = \frac{\theta}{I} = \frac{NAB}{C}$

Voltage Sensitivity: $S_V = \frac{I}{V} = \frac{NAB}{CR}$

Earth's Magnetism

- Magnetic Declination (θ): angle between geographic and magnetic meridians
- Dip (δ): angle between total field B_e and horizontal
- Horizontal component: $H = B_e \cos \delta$
- Vertical component: $V = B_e \sin \delta$

Also: $B_e = \sqrt{H^2 + V^2}$, $\tan \delta = \frac{V}{H}$

Bar Magnet

Axial Field:

$$B = \frac{\mu_0 2M}{4\pi r^3} \quad (l^2 \ll r^2)$$

Equatorial Field:

$$B = \frac{\mu_0 M}{4\pi r^3} \quad (l^2 \ll r^2)$$

Tangent Law

$$B = H \tan \theta$$

Magnetic Properties

- Permeability: μ , Relative: $\mu_r = \mu/\mu_0$
- Intensity: H
- Magnetization: I
- Susceptibility: $\chi_m = \frac{I}{H}$, $\mu_r = 1 + \chi_m$

Types:

- Diamagnetic: $\chi_m < 0$, $\mu_r < 1$ (e.g., Bismuth)
- Paramagnetic: $\chi_m > 0$, $\mu_r > 1$ (e.g., Aluminum)
- Ferromagnetic: $\chi_m \gg 1$, $\mu_r \gg 1$ (e.g., Iron)