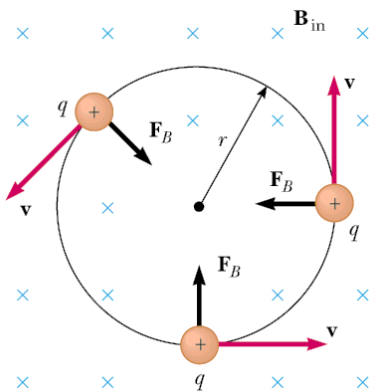
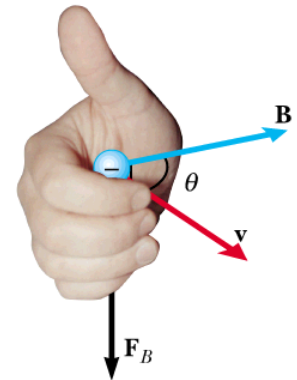
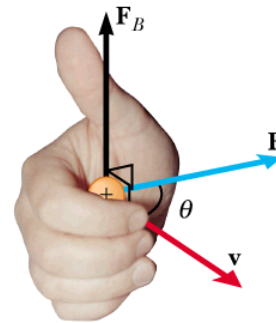
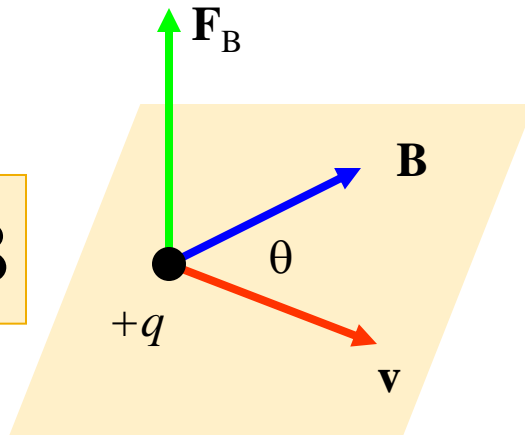


Overall Story

- **Magnetic fields** are generated by moving charges
- These fields can exert a **magnetic force** on other moving charged particles and objects.
- Changing magnetic fields can **induce** currents and vice versa.

Magnetic Force and Charges

$$\vec{F}_B = q\vec{v} \times \vec{B}$$

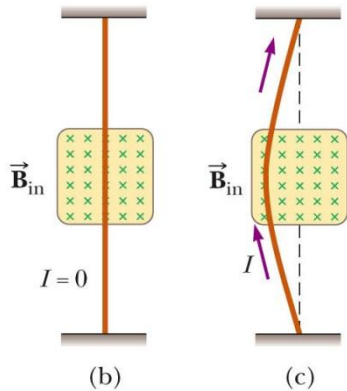


$$F_B = qvB = m \frac{v^2}{r}$$

$$\omega = \frac{v}{r} = \frac{qB}{m} \longrightarrow \text{Cyclotron frequency}$$

$$r = \frac{mv}{qB} \quad T = \frac{2\pi r}{v} = \frac{2\pi}{\omega} = \frac{2\pi m}{qB}$$

Magnetic Force and Currents

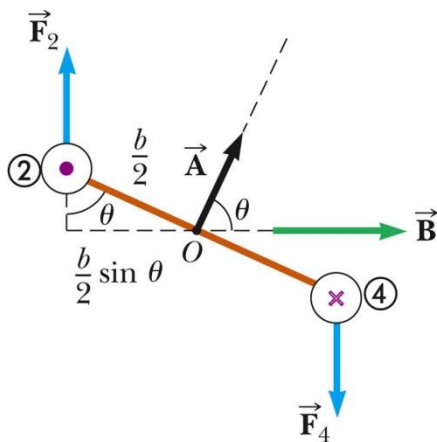
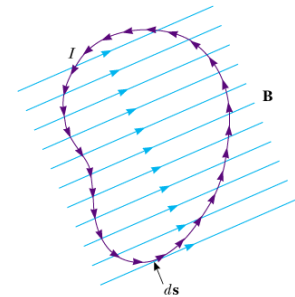


$$\vec{F}_B = I\vec{L} \times \vec{B}$$

For a straight wire in a uniform field

$$\vec{F}_B = 0$$

For a loop of current in a uniform field



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$$\vec{\tau} = I\vec{A} \times \vec{B}$$

$$\vec{\mu} = I\vec{A}$$

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

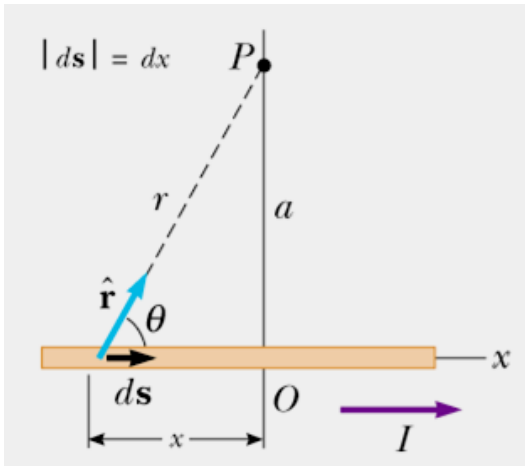
$$U = -\vec{\mu} \cdot \vec{B}$$



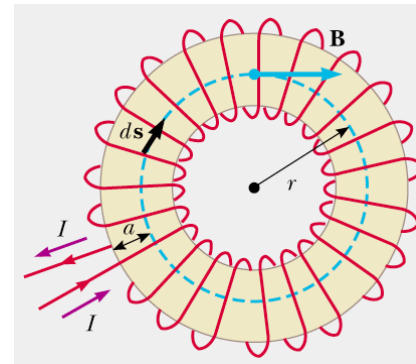
Sources of Magnetic Field

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

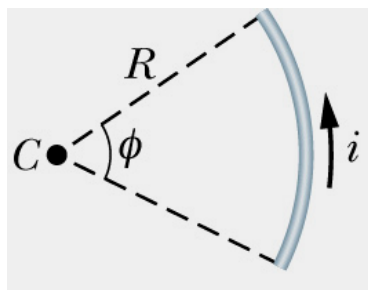
$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}} = \mu_0 I$$



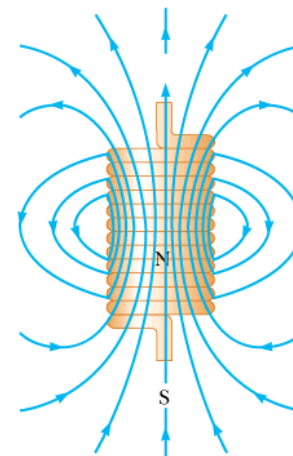
$$B = \frac{\mu_0 I}{2\pi a}$$



$$B = \frac{\mu_0 N I}{2\pi r}$$



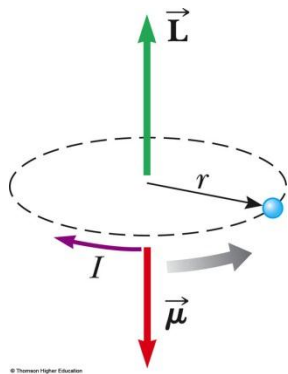
$$B = \frac{\mu_0 i \phi}{4\pi R}$$



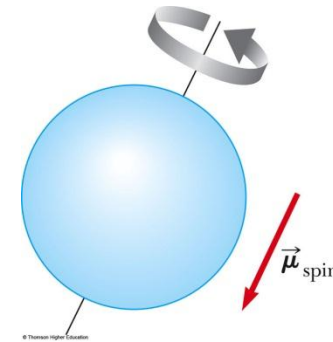
$$B = \mu_0 n I$$

Natural Sources of Magnetism

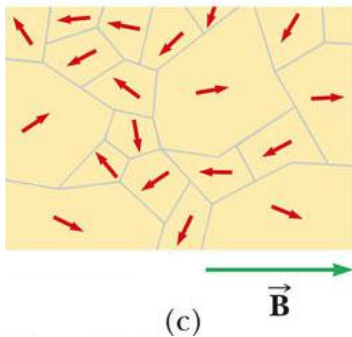
Orbital Magnetic Moment
of an Electron



Spin Magnetic Moment
of an Electron



Ferromagnetism



Paramagnetism

Induced orbital
magnetic moment

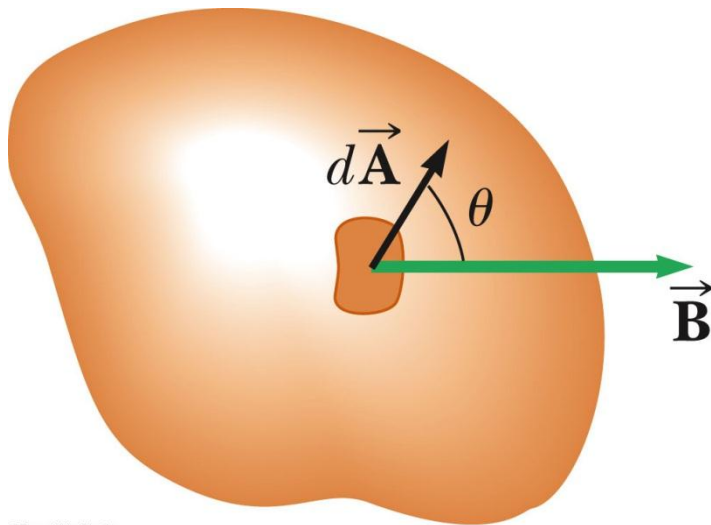
Diamagnetism

Induced internal field

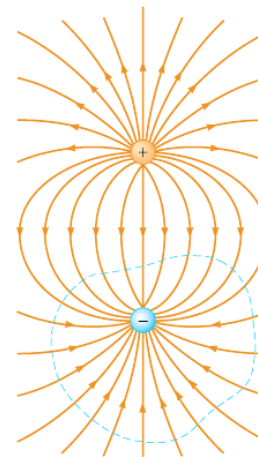
Magnetic Flux

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

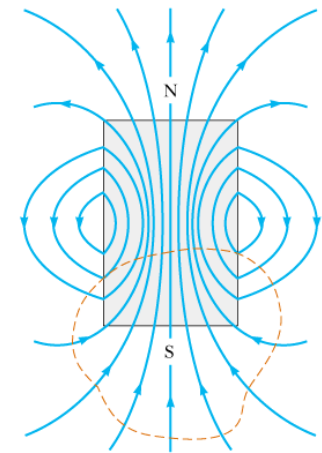
$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0$$



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Electric Field Lines



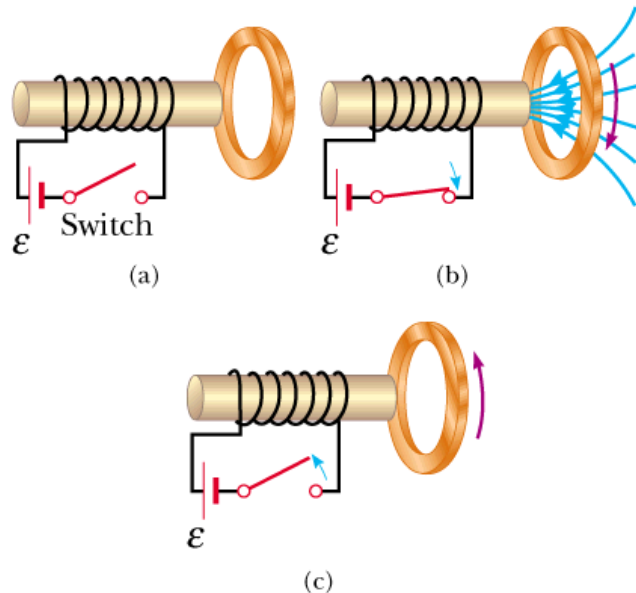
Magnetic Field Lines

Faraday's and Lenz's Laws

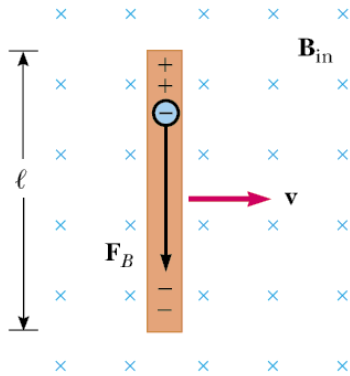
$$\mathcal{E} = -N \frac{d\Phi_B}{dt}$$

$$\oint \mathbf{E} \cdot d\mathbf{s} = -N \frac{d\Phi_B}{dt}$$

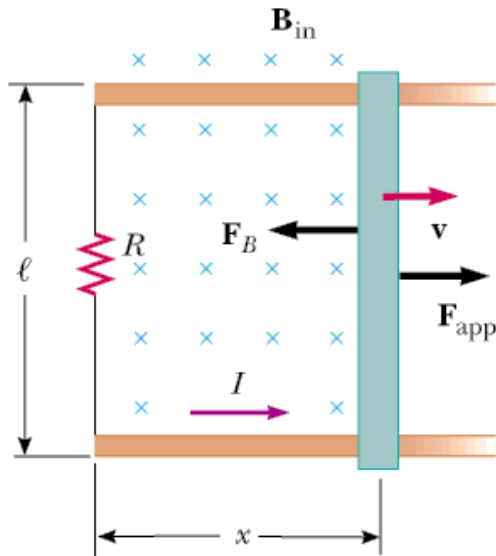
The polarity of the induced emf is such that it tends to produce a current that creates a magnetic flux to oppose the change in magnetic flux through the area enclosed by the current loop.



Motional EMF



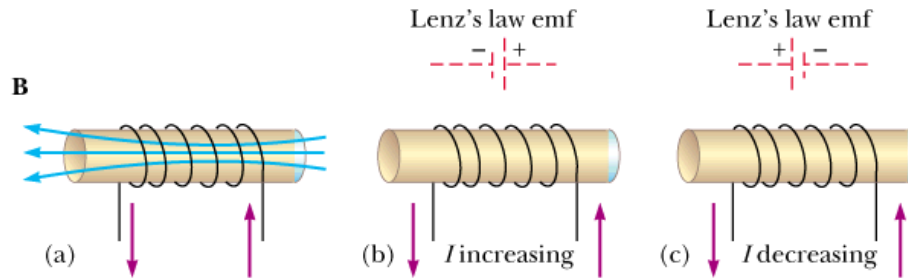
$$\Delta V = \mathcal{E}l = Blv$$



$$F_{app} = F_B = IlB$$

$$\mathcal{P} = F_{app}v = (IlB)v = \frac{B^2 l^2 v^2}{R} = \frac{\mathcal{E}^2}{R}$$

Inductance



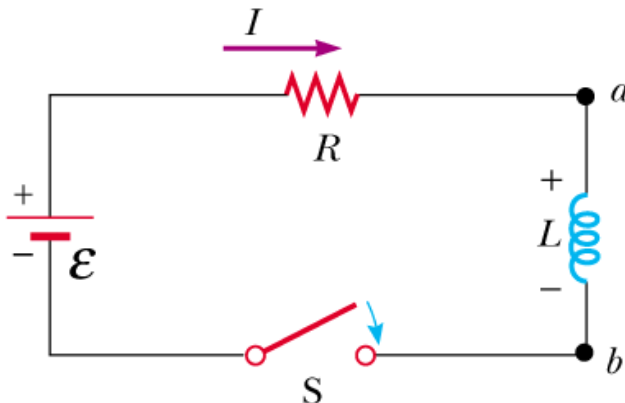
$$\mathcal{E}_L = -L \frac{dI}{dt}$$

$$L = \frac{N\Phi_B}{I}$$

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

$$u_B = \frac{U}{Al} = \frac{B^2}{2\mu_0}$$

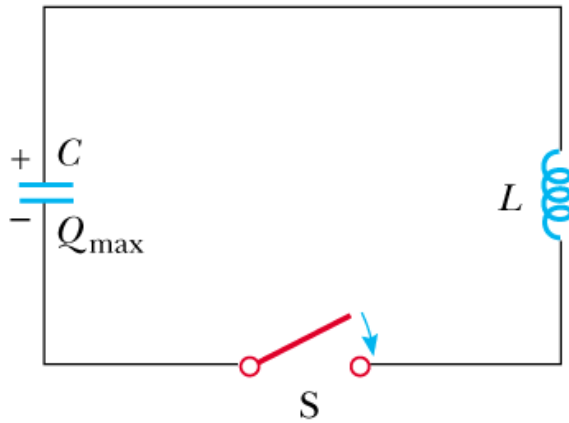
$$M_{12} = \frac{N_2\Phi_{12}}{I_1}$$



$$I = \frac{\mathcal{E}}{R} (1 - e^{-t/\tau})$$

$$\tau = \frac{L}{R}$$

LC Oscillators



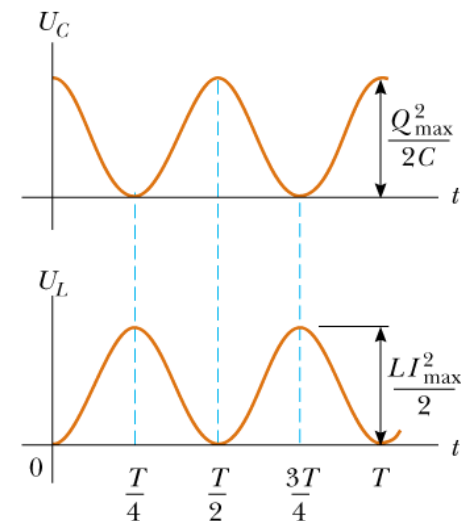
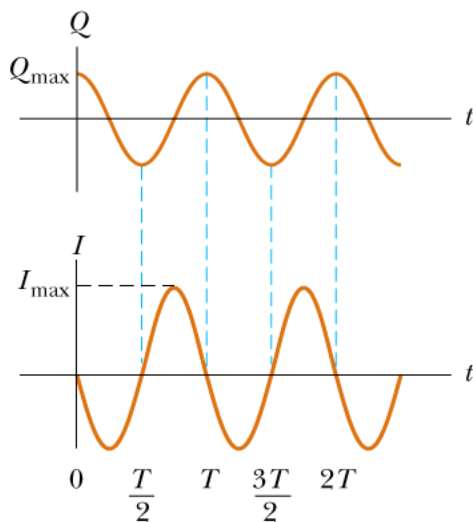
$$\omega = \frac{1}{\sqrt{LC}}$$

Natural frequency of oscillation

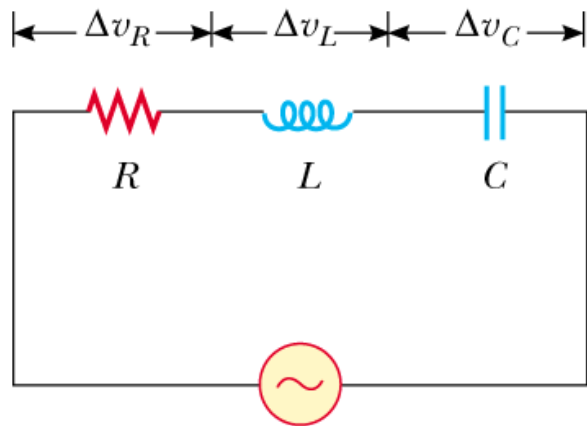
$$Q = Q_{\max} \cos \omega t$$

$$I = -\omega Q_{\max} \sin \omega t = -I_{\max} \sin \omega t$$

$$U = \frac{Q_{\max}^2}{2C}$$



RLC Circuits



$$X_C = \frac{1}{\omega C}$$

$$X_L = \omega L$$

$$\Delta v_R = I_{\max} R \sin \omega t = \Delta V_R \sin \omega t$$

$$\Delta v_L = I_{\max} X_L \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$\Delta v_C = I_{\max} X_C \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$\Delta v = \Delta V_{\max} \sin \omega t$$

$$i = I_{\max} \sin(\omega t - \phi)$$

$$\Delta V_{\max} = I_{\max} Z$$

$$Z \equiv \sqrt{R^2 + (X_L - X_C)^2} \quad \text{Impedance}$$

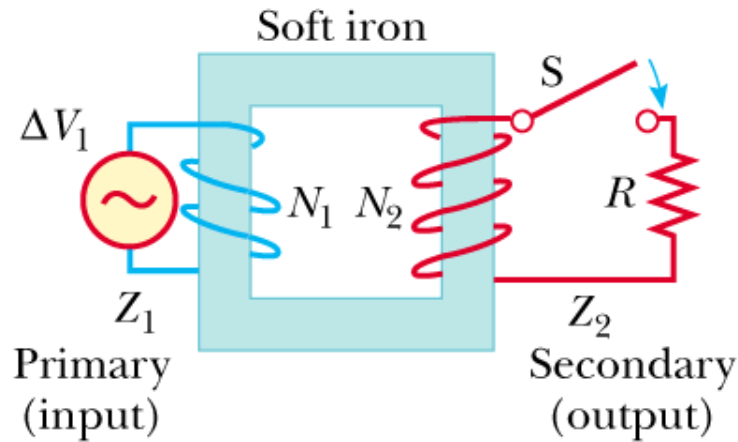
$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

$$\mathcal{P}_{av} = \frac{1}{2} I_{\max} \Delta V_{\max} \cos \phi = I_{rms}^2 R$$

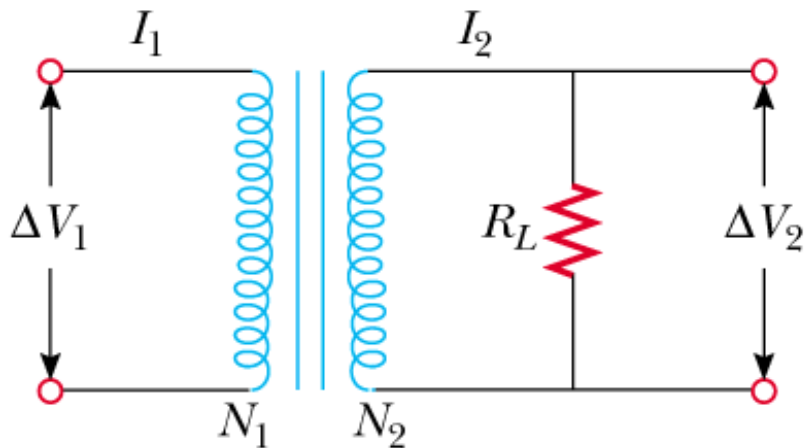
$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$Q = \frac{\omega_0}{\Delta \omega} = \frac{\omega_0 L}{R}$$

Transformers



$$\Delta V_2 = \frac{N_2}{N_1} \Delta V_1$$



$$R_{eq} = \left(\frac{N_1}{N_2} \right)^2 R_L$$