# Chapter 22: Electromagnetic Induction

## Essential Concepts and Summary

# Induced EMF and Induced Current

- Relative motion between magnet and coil produce an **induced current**
- The coil behaves as if it were a source of emf, known as **induced emf**
- Changing magnetic field induces an emf, and emf leads to an induced current
- The phenomenon of producing an induced emf with the aid of a magnetic field is called **electromagnetic induction**

# Motional EMF

- Separated charges on the ends of the moving conductor give rise to a **motional emf**, existing as long as rod is moving

$$F_{electric} = Eq = \frac{\xi}{L} q$$

$$F_{magnetic} = |q| vB = qvB$$

$$F_{electric} = F_{magnetic}$$

$$\frac{\xi}{L} q = qvB$$

$$\xi = vBL$$

# Magnetic Flux

- Magnetic flux is analogous to electric flux
- The quantity BA is the magnetic flux, represented by phi
- Unit is tesla x meter$^2$ (aka the Weber)
- If B isn't perpendicular, however, only use the component of B that is perpendicular to compute the magnetic flux (analogous to work)

$$\xi = \left(\frac{x - x_0}{t - t_0}\right) BL = \left(\frac{xL - x_0 L}{t - t_0}\right) B$$

$$\xi = \left(\frac{A - A_0}{t - t_0}\right) B = \frac{BA - BA_0}{t - t_0}$$

$$\xi = \frac{\Phi - \Phi_0}{t - t_0} = \frac{\Delta\Phi}{\Delta t}$$

$$\Phi = BA\cos(\phi)$$

$$1Wb = 1T \cdot 1m^2$$

# Faraday's Law

- When there is a change in flux through a loop of wire, an emf is induced in the loop.
- If it's through a coil, the induced emf is N times that induced by a single loop.
- SI Unit: Volt

$$\xi = -N\frac{\Delta\Phi}{\Delta t}$$

# Lenz's Law

"The induced emf resulting from a changing magnetic flux has a polarity that leads to an induced current whose direction is such that the induced magnetic field opposes the original flux change"

Strategy:

1. Determine if magnetic flux is increasing or decreasing
2. Find the direction of the induced field so that it **opposes the flux**
3. Having found the induced field, use RHR #2 to determine direction of induced current. Thus, polarity of induced current can be assigned

# Electric Generators

- Simplest form: rotating coil in uniform magnetic field
- This produces an alternating current.
- Electric motors produce **back emf** in proportion to their speed.

$$\xi = NAB\omega \sin(\omega t)$$

$$\xi = \xi_0 \sin(\omega t)$$

$$\omega = 2\pi f$$

$$I = \frac{V - \xi}{R}$$

# Mutual Inductance

- **Mutual Induction**: Changing current in one circuit induces an emf in another circuit
- The avg. emf in secondary coil is proportionate to change of current in primary coil.
- M is the proportionality constant, known as the **mutual inductance**

$$N_s \Phi_s : I_p$$

$$M = \frac{N_s \Phi_s}{I_p}$$

$$\xi_s = -N_s \frac{\Delta \Phi_s}{\Delta t}$$

M

$$\xi_s = -M \frac{\Delta I_p}{\Delta t}$$

# Self Inductance

- **Self Induction**: Effect in which changing current induces an emf in the same circuit
- L, constant of proportionality, is the **inductance,** or **self-inductance**, of the coil

$$N\Phi = LI$$

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

$$\xi = -N\frac{\Delta\Phi}{\Delta t}$$

M

$$\xi = -L\frac{\Delta I}{\Delta t}$$

# Energy Stored in an Inductor

- Like a capacitor, an inductor can store energy
- While current is rising, induced emf appears across the inductor, and thus confirming Lenz's law the polarity of the induced emf is opposite to that of the generator voltage

$$\Delta W = LI(\Delta I)$$

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

$$\frac{1}{2} LI^2 = \frac{1}{2} \mu_0 n^2 A l I^2$$

$$E = \frac{1}{2\mu_0} B^2 A l$$

$$\frac{Energy}{Volume} = \frac{1}{2\mu_0} B^2$$

# Transformers

- **Transformer:** device for increasing or decreasing AC voltage
- If a transformer steps up the voltage, the current is stepped down, conserving energy

$$\frac{\xi_s}{\xi_p} = \frac{N_s}{N_p}$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$