Lecture 17

- Electricity and Magnetism
  - Induced voltages and induction
  - Lenz’s law
  - Generators and motors

http://www.physics.wayne.edu/~apetrov/PHY2140/

Chapter 20
Lightning Review

Last lecture:

1. Induced voltages and induction
   - Induced EMF
   - Faraday’s law
   - Motional EMF

Review Problem: A long, straight wire carries a steady current \( I \). A rectangular conducting loop lies in the same plane as the wire, with two sides parallel to the wire and two sides perpendicular. Suppose the loop is pushed toward the wire as shown. Given the direction of \( I \), the induced current in the loop is
   1. clockwise.
   2. counterclockwise.
   3. need more information

\[
B = \mu_0 n I \\
\Phi = BA \cos \theta \\
I = -N \frac{\Delta \Phi}{\Delta t} \\
I = Blv
\]
Review 1: right hand rule
Review 2: EMF polarity and current direction

Current flows from + to – terminal of the battery (source of EMF)

Electrons move in the opposite direction.
20.4 Lenz’s law revisited

Application of Lenz's law will tell us the direction of induced currents, the direction of applied or produced forces, and the polarity of induced emf's.

Lenz's law says that the induced current will produce magnetic flux opposing this change. To oppose an increase into the page, it generates magnetic field which points out of the page, at least in the interior of the loop. Such a magnetic field is produced by a counterclockwise current (use the right hand rule to verify).
Lenz’s law: energy conservation

We arrive at the same conclusion from energy conservation point of view.

The preceding analysis found that the current is moving counterclockwise (ccw). Suppose that this is not so.

- If the current \( I \) is clockwise (cw), the direction of the magnetic force, \( BIL \), on the sliding bar would be right.
- This would accelerate the bar to the right, increasing the area of the loop even more.
- This would produce even greater force and so on.
- In effect, this would generate energy out of nothing violating the law of conservation of energy.

Our original assertion that the current is cw is not right, so the current is ccw!
The induced flux seeks to counteract the change.
Example: direction of the current

Find the direction of the current induced in the resistor at the instant the switch is closed.
Applications of Magnetic Induction

Tape / Hard Drive / ZIP Readout

- Tiny coil responds to change in flux as the magnetic domains (encoding 0’s or 1’s) go by.

Question: How can your VCR display an image while paused?

Credit Card Reader

- Must swipe card
  - generates changing flux
  - Faster swipe → bigger signal
20.5 Generators

Generators and motors are two of the most important applications of induced emf (magnetic inductance).

A generator is something that converts mechanical energy to electrical energy.

- Alternating Current (AC) generator
- Direct Current (DC) generator

A motor does the opposite, it converts electrical energy to mechanical energy.
AC generator

Compute EMF

- It is only generated in BC and DA wires
- EMF generated in BC and DA would be

\[ I_{FG} = I_{HE} = Blv_{\perp} \]

- Thus, total EMF is

\[ I = 2Blv_{\perp} = 2Blv\sin\theta \]

- If the loop is rotating with \( \omega \)

\[ I = 2Blv\sin\omega t = 2Bl\left(\frac{a}{2}\omega\right)\sin\omega t \]

as \( v = r\omega = a\omega/2 \)
AC generator (cont)

- Generalize the result to N loops

\[ I = NBA\omega \sin \omega t \]

EMF generated by the AC generator

where we also noticed that \( A = la \)

- Note: \( I_{q_{el}} = NBA\omega \) is reached when \( \omega t = 90^\circ \) or \( 270^\circ \)
DC generator

By a clever change to the rings and brushes of the ac generator, we can create a dc generator, that is, a generator where the polarity of the emf is always positive. The basic idea is to use a single split ring instead of two complete rings. The split ring is arranged so that, just as the emf is about to change sign from positive to negative, the brushes cross the gap, and the polarity of the contacts is switched. The polarity of the contacts changes in phase with the polarity of the emf—the two changes essentially cancel each other out, and the emf remains always positive. The emf still varies sinusoidally during each half cycle, but every half cycle is a positive emf.
Motors

A motor is basically a generator running in reverse. A current is passed through the coil, producing a torque and causing the coil to rotate in the magnetic field. Once turning, the coil of the motor generates a *back emf*, just as does the coil of a generator. The back emf cancels some of the applied emf, and limits the current through the coil.
Example: coil in magnetic field

A coil of area 0.10 m² is rotating at 60 rev/s with its axis of rotation perpendicular to a 0.20T magnetic field. (a) If there are 1000 turns on the coil, what is the maximum voltage induced in the coil? (b) When the maximum induced voltage occurs, what is the orientation of the coil with respect to the magnetic field?
20.6 Eddy currents (application)

Magnetic Levitation (Maglev) Trains

- Induced surface ("eddy") currents produce field in opposite direction
  - Repels magnet
  - Levitates train

Maglev trains today can travel up to 310 mph
  - Twice the speed of Amtrak’s fastest conventional train!

May eventually use superconducting loops to produce B-field
  - No power dissipation in resistance of wires!