Chapter 25: Electromagnetic Induction and Waves

Section 25.1: Induced Currents

Electromagnetic Induction

- 1831: Faraday and Henry perform same experiment independently of one another
- Move a permanent magnet through a coil of wire: Look! Current!
- But how do you sustain this???

Section 25.2: Motional emf

Magnetic Force Creates Electric Field

- Move a conductor through a B field (where B and v are perpendicular)
- This is going to make charges move inside the conductor
- This will create a charge separation
- This will result in an internal E field within the conductor: $E = vB$

Field Creates Potential Difference

- Apply $V = Ed$, but now replace d with length of conductor l
- $E = V/l = vB$ or $V = vlB$
- This is the motional emf

Induced Current in a Circuit

- That motional emf can be used to create current
- Use Ohm's Law: $V = IR$ or $vlB = IR$
- Means $I = (vlB)/R$

Magnetic Drag

- You're going to have to apply an external force if you want to keep that wire moving
- The magnetic force created by the induced current acts opposite the motion
- Notice that we are talking about a new magnetic force that doesn't exist until the current flows

Motors and Generators

- Motor: electrical energy input, mechanical work output
- Generator: mechanical energy in, electrical work output

Section 25.3: Magnetic Flux and Lenz's Law

Magnetic Flux

- Use a closed loop of wire to "trap" or "lasso" magnetic field lines
- The more lines trapped, the greater the magnetic flux
- $\Phi = \int \boldsymbol{B} \cdot \boldsymbol{n} dA$
  $\boldsymbol{B}$: external magnetic field
  $\boldsymbol{n}$: vector perpendicular to the plane of the loop
  A: area of closed loop of wire

Dot Product Means Scalar

- Multiply parallel components
- When B is in the same plane as loop, $B \perp n$; flux is zero
- When B is perpendicular to loop, $B||n$; flux is max
- $\Phi = BAcos\theta$
  θ: angle between B and $\boldsymbol{n}$

Changing the Flux

- Change the magnetic field: increase the field strength, increase the flux
- Change the area enclosed by the loop: increase the area, increase the flux
- Change the orientation of the field or the loop:
  $B \perp n$; flux is zero
  $B||n$; flux is max

Lenz's Law

- When a magnetic flux induces a current in a loop of wire, the direction of the current produces a magnetic field to oppose the change in flux
- This explains why Faraday's law has the negative out front
- $B_f > B_i$: increasing field strength (direction unchanged)
  ΔB vector is positive (up)
  Flux is negative, since induced current must produce a new B field (down) that opposes ΔB (up)
- $B_f < B_i$:: decreasing field strength (direction unchanged)
  ΔB vector is negative (down)
  Flux is positive, since induced current must produce a new B field (up) that opposes ΔB (down)
- Note that this is analogous to the negative we saw with the spring force: $F = -kx$

Section 25.4: Faraday's Law

How Does the Induced Current Depend on the Magnet?

- A stronger magnet will induce a greater current
- A weaker magnet will induce a smaller current

How Does the Induced Current Depend on the Wire?

- The more coils, the greater the induced current
- The fewer coils, the less current induced
- For the same magnet, twice as many coils means twice as much current

How Does the Induced Current Depend on Motion?

- You can move the magnet, keeping the loop stationary
- You can move the loop and keep the magnet stationary
- Either way works just as well; you can even move both at the same time

How Does the Induced Current Depend on the Speed?

- Whether you move the magnet or the loop, the faster the motion, the more current induced
- If you move very slowly, you will induce no current at all

Faraday's Law

- An emf is induced in a closed loop of wire whenever the magnetic flux changes
- $\mathcal{E} = -N(\Delta\Phi/\Delta t)$
- $\mathcal{E}$: induced emf in loop
- N: number of turns in coil
- $\Delta\Phi/\Delta t$: rate of change of magnetic flux

Section 25.5: Electromagnetic Waves

Induced Fields

- Changing a magnetic field creates an electric field
- Changing an electric field creates a magnetic field
- Self-sustaining: this is an electromagnetic wave

Properties of EM Waves

- Transverse
- No medium required
- Speed = $\frac{1}{\sqrt{\epsilon_o \mu_o}} = c$
- Sounds like light to me

Polarization

- Proof that light is a transverse wave
- Longitudinal waves cannot be polarized

Parallel or Perpendicular?

- Examine a pair of polaroid sunglasses
- Turn them 90°; notice anything? (If you don't take them back, they are not polarized)
- Parallel polarizing filters = transmission
- Perpendicular polarizing filters = zero transmission

Section 25.6: The Photon Model

Particles of Energy

- Photons are massless
- $E = hf$
- h = Planck constant
- Energy of EM radiation increases linearly with frequency: double the frequency, double the energy
- Get enough photons together and the result is indistinguishable from a wave

Section 25.7: The Electromagnetic Spectrum

Frequency and Wavelength

- Low frequency = long wavelength
- High frequency = short wavelength
- Spectrum is continuous (as opposed to discrete)
- $c = \lambda f$
- c = speed of light in a vacuum, $3\text{x}10^8$ m/s
- Speed of light is constant for all types of EM radiation: radio waves travel at the same speed as ultraviolet light

Low Frequency EM Radiation

- Radio, television, radar
- Wavelengths about 1m and longer
- Frequencies about 10^8Hz and lower
- Low energy waves, no danger from exposure

Mid Frequency EM Radiation

- Microwave, infrared, visible
- Wavelengths range 0.1m–10^{-7}m
- Frequencies 10^9Hz–10^{15}Hz
- Energy level still pretty low; no danger from exposure

High Frequency EM Radiation

- UltravioleIt, x-ray, gamma ray
- Short wavelengths: 10^{-7}m–10^{-15}m
- High frequencies: 10^{16}Hz–10^{22} Hz
- These waves have high enough energy to damage you; increasing frequency decreases the safe exposure time