PHY 114 A General Physics II
11 AM-12:15 PM TR Olin 101

Plan for Lecture 13 (Chapter 31):

Faraday’s Law
1. Time varying magnetic flux $\rightarrow$ induced EMF
2. Electric generators and motors
3. Eddy currents

Remember to send in your chapter reading questions...

Comment on magnetic field directions:
Right-hand “thumb” rule for current-carrying wires
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Right-hand "thumb" rule for current-carrying wires

From HW:

Note: Forces from currents are very small:
For example, if \( I_1 = I_2 = 20 \, \text{A}, \ell = 1\, \text{m}, a = 0.01 \, \text{m}\)
\[
F = \frac{\mu_0 I_1 I_2}{2\pi a} = 0.008 \, \text{N}
\]

More webassign hints:

Consider the following figures:

\[
B(r) = \frac{J \ell}{4\pi a} (\sin \theta - \sin \theta')
\]

(i) A conducting loop in the shape of a square of edge length \( l = 0.43 \, \text{m} \) carries a current \( I = 8.00 \, \text{A} \) as shown above. Calculate the magnitude and direction of the magnetic field at the center of the square.

magnitude \( a^2 \)
direction : Select...

(ii) If the conductor is wrapped to form a circular loop, what is the value of the magnetic field at the center?
magnitude \( a^2 \)
direction : Select...

Summary:

Ampere's law:

Integral form: \( \oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I + \)\text{magnetic
Differential form: \( \nabla \times \mathbf{B} = \mu_0 \mathbf{J} \)

Faraday's law:

Integral form: \( \oint \mathbf{E} \cdot d\mathbf{A} = \frac{\partial \mathbf{B}}{\partial t} \)\text{per}
Differential form: \( \nabla \times \mathbf{E} = \frac{\partial \mathbf{B}}{\partial t} \)

Gauss's law:

Integral form: \( \int \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\varepsilon_0} \)
Differential form: \( \nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0} \)
Note:
\( \oint \mathbf{B} \cdot d\mathbf{A} = 0 \)
\( \nabla \cdot \mathbf{B} = 0 \)
Faraday's law

Effects of time-changing currents and fields

Magnetic flux:
\[ \Phi_b = \int \mathbf{B} \cdot d\mathbf{A} \]

In this case:
\[ \Phi_b = \mathbf{B} \cdot \mathbf{A} \]

Induced EMF:
\[ \mathcal{E} = \int \mathbf{E} \cdot ds \]

Faraday’s law
\[ \mathcal{E} = -\frac{d\Phi_B}{dt} \]

Examples of \( \frac{d\Phi_B}{dt} \):
- Field inside solenoid:
  \[ B = \frac{\mu_0 NI}{\ell} \]
- If \( I \) is changing with time:
  \[ \frac{dB}{dt} = \frac{\mu_0 N}{\ell} \frac{dI}{dt} \]

Faraday’s law
\[ \mathcal{E} = -\frac{d\Phi_B}{dt} \]

Examples of \( \frac{d\Phi_B}{dt} \):
\[ \frac{d\Phi_B}{dt} = \frac{d}{dt} (\mathbf{B} \cdot \mathbf{A}) = BA \frac{d\cos\theta}{dt} \]
Faraday's law
\[ \mathcal{E} = -\frac{d\Phi_B}{dt} \]

Example
\[ \frac{d\Phi_B}{dt} = -B_{in} \ell v \]
\[ \mathcal{E} = IR = -\frac{d\Phi_B}{dt} = B_{in} \ell v \]
\[ I = \frac{B_{in} \ell v}{R} \]

Consider the setup shown in the figure. What can cause the bar to move with velocity \( v \):
A. Evil physics professor
B. Applied force on bar pulling to right
C. Applied force on bar pulling to left
D. Magnetic forces

Consider the setup shown in the figure where current \( I \) is flowing through the mobile bar. What is the effect of the magnetic force acting on the bar?
A. It is too small to have an effect.
B. It has an effect in the same direction as the applied force.
C. It has an effect in the opposite direction as the applied force.
Field inside solenoid: 
\[ B = \frac{\mu_0 NI}{\ell} \]
If \( I \) is changing with time:
\[ dB = \frac{\mu_0 N}{\ell} \frac{dI}{dt} \]
Electric field induced at radius \( r \):
\[ E = \int E \cdot ds = E(2\pi r) = -\frac{d\Phi_B}{dt} = -\pi R^2 \frac{dB}{dt} \]
\[ E = -\frac{R^2}{2r} \frac{dB}{dt} = -\frac{R^2 \mu_0 N}{2r} \frac{dI}{dt} \]

Electric generator: 
An emf is induced in a loop that rotates in a magnetic field.
\[ \mathcal{E} = -N \frac{d}{dt} (BA \cos(\omega t)) = NBA \omega \sin(\omega t) \]
Electric generator:
\[
E = -N \frac{d(BA\cos(\omega t))}{dt} = NBA\omega \sin(\omega t)
\]
If the resistance in the generator coil is \( R \), current in the coil is given by:
\[
I = \frac{E}{R} = \frac{NBA\omega}{R} \sin(\omega t) = I_{\text{max}} \sin(\omega t)
\]

Torque on a current-carrying wire in a magnetic field

Recall that a generator has a current-carrying coil in a magnetic field.
A. No problem – that was in Chap. 29 and no longer relevant.
B. Generator coil will experience a torque which makes the coil spin faster.
C. Generator coil will experience a torque which makes the coil spin slower.

Electric generators and motors

Hybrid vehicles are designed so that their electric motors are equipped with circuits to take advantage of “regenerative” braking, effectively converting the motor to a generator to recharge the batteries when the breaks are activated.

Other uses for inductors
- Rechargeable electric toothbrush
- Induction heating cooking
Uses of Faraday’s law continued:

http://theinductionsite.com/how-induction-works.shtml

How Induction Cooking Works:

1. The element’s electronic component is not in the coil (the red band) that produces a high-intensity, electromagnetic field (represented by the orange line).
2. That field protrudes on the surface immediately adjacent to the coil, which generates heat. This is depicted on the next slide.
3. The heat generated in the cooking vessel is transferred to the vessel’s contents.
4. Nothing conducts the vessel affected by the field on the side of the element, so the element turns off, heat generation stops.