Chapter 31 HW

4/5, 8/9, 15/13, 17/18, 22-24/20-22, 28, 37, 43, 49/50, 57/60

Due Tuesday Nov 18th
Turn in Thursday, Nov 20th, Exam Day

Print out and use NEW equation sheet for the Exam!

Practice Exam online: PRACTICE TAKING THE EXAMS!!!
Compare E & B

Electric Force and Field

\[ F_{12} = k \frac{q_1 q_2}{r^2} \hat{r} \quad E_1 = k \frac{q_1}{r^2} \hat{r} \]

Magnetic Force and Field

\[ F = qv \times B \quad B = \frac{\mu_0 I}{4\pi} \int \frac{ds \times \hat{r}}{r^2} \]
Maxwell’s Equations

Gauss’s law (electric):
\[ \oiint_S \mathbf{E} \cdot d\mathbf{A} = \frac{q}{\varepsilon_0} \]

Gauss’s law in (magnetic):
\[ \oiint_S \mathbf{B} \cdot d\mathbf{A} = 0 \]

Faraday’s law:
\[ \oint_{\partial S} \mathbf{E} \cdot d\mathbf{s} = -\frac{d\Phi_B}{dt} \]

Ampere-Maxwell law
\[ \oint_{\partial S} \mathbf{B} \cdot d\mathbf{s} = \mu_0 I + \mu_0 \frac{d\Phi_E}{dt} \]
Michael Faraday

• 1791 – 1867
• British physicist and chemist
• Great experimental scientist
• Contributions to early electricity include:
  – Invention of motor, generator, and transformer
  – Electromagnetic induction
  – Laws of electrolysis
Induction

• An induced current is produced by a changing magnetic field
• There is an induced emf associated with the induced current
• A current can be produced without a battery present in the circuit
• Faraday’s law of induction describes the induced emf
Generator Effect: EM Induction

A changing magnetic flux induces an EMF.

Magnet moves in a stationary coil.
EM Induction

The induced EMF produces a current that produces a magnetic field that opposes the original changing magnetic field.

To find the direction of the induced current:
1. Determine the flux change: Increasing? Decreasing?
2. The induced B field will be opposite. Find that.
3. Find the current with the RHR to produce the induced B field.
EM Induction

The magnet is pushed into the coil. What is the direction of the induced current?
Faraday’s Law of Induction

\[ \varepsilon = -N \frac{d\Phi}{dt} \]

Michael Faraday
(1791 - 1867)
**FLUX**

The amount of FLOW perpendicular to a surface!

**Magnetic FLUX**

\[ d\Phi = B \cdot dA \]

\[ d\Phi = B\cos\theta dA \]

\[ \Phi = \int B \cdot dA \]

The flux depends on the magnitude of the B field, the area, A, it intersects and the angle between them. Changes in B, A or \( \square \) produce a change in the magnetic flux.
Magnetic Flux

Magnetic Flux: $\Phi_B = BA \cos \theta$

Maximum Flux
$\theta = 0$

Minimum Flux
$\theta = 90$

Maximum Flux
$\theta = 180$
Faraday’s Law of Induction

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

$$\mathcal{E} = \int_{closed} E \cdot ds = -\frac{d\Phi_B}{dt} = -\frac{d}{dt} \int_{open} B \cdot dA$$

The emf induced in a closed loop is directly proportional to the time rate of change of the magnetic flux through the loop. The electric field is path dependent – E is NOT conservative.
Electric Potential Difference
For and Electrostatic Field

As a + particle moves from A to B, its electric potential difference is:

\[ V_B - V_A \equiv \Delta U / q_0 = -\int_A^B \mathbf{E}(r) \cdot d\mathbf{r} \]

For an electrostatic field, \( \mathbf{E} \) is conservative and around a closed loop

\[ V_B - V_A = -\int_A^B \mathbf{E}(r) \cdot d\mathbf{r} = 0 \]

A positive test charge will gain kinetic energy and lose potential energy as it ‘rolls down’ the electric hill from A to B.
Faraday’s Law

\[ \mathcal{E}_{\text{induced}} = -N \frac{d\Phi_{\text{ext}}}{dt} \]

- \( \mathcal{E}_{\text{induced}} \): Emf that drives the induced current (nonconservative)
- \( N \): number of loops
- \( d\Phi_{\text{ext}}/dt \): How quickly you change the number of external field lines through one loop.

Lenz’s law: the induced current in a loop is in the direction that creates a magnetic field that opposes the change in magnetic flux through the area enclosed by the loop.
EM Induction & Sound Reproduction
AC Generators

For a coil with \( N \) turns, area \( A \), turning at angular speed \( \omega \) the induced EMF is:

\[
\varepsilon = -N \frac{d \Phi}{dt} = -N \frac{d (BA \cos \theta t)}{dt} = -N \frac{d (BA \cos \omega t)}{dt}
\]

\[
\varepsilon = NAB \omega \sin \omega t
\]

\((\omega: \text{rad/s})\)
AC Generators
Generator Problem

The 500 turn square coil has sides of length 10.0 cm and is in a uniform 1.25 T magnetic field. Initially the coil is perpendicular to the field and then it is turned 90 degrees as shown in 0.05s.

a) Does the magnetic flux through the coil increase or decrease during the ¼ turn?
b) What is the average EMF induced?
c) At what time is the EMF maximum? What is the maximum EMF?
d) What is the frequency of the ac generated?
AC/DC Generators
Sources of Electrical Power

Solar doesn’t use a EM induction!!
Power Production
Coal, Nuclear, Oil or Gas:
It all comes down to making HOT WATER & STEAM to turn a turbine!
Wind & Tidal Turbines
Motors & Generators

Motor Effect

Magnetic Force on Moving Charges in Loop: Motor Effect

Generator Effect

Magnetic Field Changing through Loop: Generator Effect
Back emf: Motors & Inductors

• As the coil rotates in a magnetic field, an emf is induced
  – This induced emf always acts to reduce the current in the coil
  – The back emf increases in magnitude as the rotational speed of the coil increases

• The current in the rotating coil is limited by the back emf
  – The term *back emf* is commonly used to indicate an emf that tends to reduce the supplied current

• An Inductor Coil in a circuit is a Back EMF source: NEXT CHAPTER
Motional EMF

What is the direction of the induced current in the circuit? Draw the current on the circuit.
Motional emf

- A **motional emf** is the emf induced in a conductor moving through a constant magnetic field.
- The electrons in the conductor experience a force, \( \vec{F} = q\vec{v} \times \vec{B} \)
  that is directed along \( \ell \).
- The charges accumulate at both ends of the conductor until they are in equilibrium with regard to the electric and magnetic forces when:

\[
F = qvB = qE
\]

\[
E = vB
\]
Motional EMF

\[ \mathcal{E} = -N \frac{d\Phi}{dt} = -N \frac{d(AB \cos \theta)}{dt} = \frac{BdA}{dt} = B l \frac{dx}{dt} \]

\[ \mathcal{E} = Blv \]
Sliding Conducting Bar Circuit

- A bar moving through a uniform field and the equivalent circuit diagram
- Assume the bar has zero resistance and the stationary part of the circuit has a resistance $R$
- The induced current obeys Ohms Law

\[ \varepsilon = Blv \]

\[ I = \frac{|\varepsilon|}{R} = \frac{Blv}{R} \]
Forces on a Sliding Conducting Bar

• The applied force to the right must balance the magnetic force to keep the bar moving at constant speed. The force does work on the bar.

• The magnetic force on the induced current in the wire is opposite the motion of the bar.

\[
F_{Pull} = F_{mag} = \frac{\nu L^2 B^2}{R}
\]

\[
ILB = \left(\frac{\varepsilon}{R}\right)LB = \left(\frac{\nu LB}{R}\right)LB
\]
A conducting loop is halfway into a magnetic field. Suppose the magnetic field begins to increase rapidly in strength. What happens to the loop?

1. The loop is pushed upward, toward the top of the page.
2. The loop is pushed downward, toward the bottom of the page.
3. The loop is pulled to the left, into the magnetic field.
4. The loop is pushed to the right, out of the magnetic field.
5. The tension in the wires increases but the loop does not move.
A conducting loop is halfway into a magnetic field. Suppose the magnetic field begins to increase rapidly in strength. What happens to the loop?

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**4. The loop is pushed to the right, out of the magnetic field.**
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Motional Emf

1. The conducting rod is moving to the right at a speed of 2.00 m/s in a direction perpendicular to a 15.0 T magnetic field. The rod has a length of 0.25 m and a negligible resistance. The light bulb has a resistance of 10.0Ω.

a) Show the direction of the magnetic force acting on the charges in the rod and how the charges polarize on the rod with a +/- at the ends.

b) What is the direction of the induced current in the circuit? Draw it on the picture.

c) Show the direction of the induced B-field inside the circuit.

d) Find the EMF produced by the rod and the current in the light bulb. Explicitly show how the units work out.

e) Find the force pulling the bar at a constant speed.

\[ \varepsilon = Blv \]

\[ I = \frac{|\varepsilon|}{R} = \frac{Blv}{R} \]

\[ F_{Pull} = F_{mag} = \frac{\nu L^2 B^2}{R} \]
Lenz’ Law

- The conducting bar slides on the two fixed conducting rails
- The magnetic flux due to the external magnetic field through the enclosed area increases with time
- The induced current must produce a magnetic field out of the page
  - The induced current must be counterclockwise
- If the bar moves in the opposite direction, the direction of the induced current will also be reversed
Is there an induced current in this circuit? If so, what is its direction?

1. Yes, clockwise
2. Yes, counterclockwise
3. No
Is there an induced current in this circuit? If so, what is its direction?

1. Yes, clockwise
2. Yes, counterclockwise
3. No
Faraday’s Law of Induction

\[ \mathcal{E} = -N \frac{d\Phi}{dt} \]

The emf induced in a closed loop is directly proportional to the time rate of change of the magnetic flux through the loop. But the E field is induced whether there is a loop or not!
Scottish physicist James Clerk Maxwell showed mathematically in the 1860s that light must be a combination of electric and magnetic fields that travel at the speed of light, c:

\[ c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3.0 \times 10^8 \text{ m/s} \]
Geomagnetic Induction and Thrust

The forces generated by this "electrodynamic" tether can be used to pull or push a spacecraft to act as a brake or a booster.
Incline Generator!
Why does the Ring Jump?

Lenz’s Law!
Eddy Currents

Current loops in moving currents create drag due to magnetic damping.
Eddy Currents, Final

- To reduce energy loses by the eddy currents, the conducting parts can
  - Be built up in thin layers separated by a nonconducting material
  - Have slots cut in the conducting plate
- Both prevent large current loops and increase the efficiency of the device

(b)
Eddy currents

When the conductor enters the magnetic field, what will be the direction of the induced magnetic field and current?
Eddy currents

What will be the direction of the magnetic force on the current in the conductor?
What will be the direction of the magnetic force on the current in the conductor?

The force slows the conductor.
EM Induction & National Security

In a Magnetic Pulse Induction metal detector, a magnetic pulse is sent from one side to the other side of the gate and is reflected back. Any metal will interfere with the magnetic pulse, adding an "echo" to the reflected pulse, making the time a fraction longer than it would without the metal.
What is the Direction of the Induced Currents?
A current-carrying wire is pulled away from a conducting loop in the direction shown. As the wire is moving, is there a cw current around the loop, a ccw current or no current?

1. There is a clockwise current around the loop.
2. There is a counterclockwise current around the loop.
3. There is no current around the loop.
A current-carrying wire is pulled away from a conducting loop in the direction shown. As the wire is moving, is there a cw current around the loop, a ccw current or no current?

1. There is a clockwise current around the loop.
2. There is a counterclockwise current around the loop.
3. There is no current around the loop.

✓ 1. There is a clockwise current around the loop.
   2. There is a counterclockwise current around the loop.
   3. There is no current around the loop.
Self-Induction & Back EMF

As a current increases in a coil, it produces a changing magnetic field which then induces a counter EMF or Back EMF that opposes the original change and reduces the driving EMF.

\[
E = -L \frac{\Delta I}{\Delta t}
\]

\[
L \equiv \text{Henry (H)} = \frac{V_s}{A} = \Omega_s
\]
Mutual Inductance

\[ E_2 = -M \frac{\Delta I_1}{\Delta t} \]

\[ M \equiv \text{Henry (H)} = \frac{V_s}{A} = \Omega_s \]
A traffic light sensor uses an inductance loop in the road. When a car sits on top of the loop, the inductance is changed due to the steel in the car. The sensor constantly tests the inductance of the loop in the road, and when the inductance rises, it knows there is a car waiting!
Traffic Loops

Controller Assigns Green Time

Conflict Monitor Checks Controller

Loop Detects Traffic

No Loop - Traffic Assumed Present
Metal Detectors

As the magnetic field pulses back and forth into the ground, it interacts with any conductive objects it encounters, causing them to generate weak magnetic fields of their own. The polarity of the object's magnetic field is directly pulsing upwards. The receiver coil detects the magnetic field produced by the object.
Transformers

\[
\frac{V_S}{V_P} = \frac{N_S}{N_P}
\]
EM Inductance: Transformers

Voltage and Current Change but Energy & Power DO NOT!

\[ P_P = P_S = I_S V_S = I_P V_S \]

\[ \frac{V_S}{V_P} = \frac{N_S}{N_P} \]

\[ \frac{P}{I_S} = \frac{N_S}{N_P} \]

\[ \frac{I_P}{I_S} = \frac{N_S}{N_P} \]

\[ V_S = \frac{N_S}{N_P} V_P \]

Step UP

\[ I_S = I_P \frac{N_P}{N_S} \]
Transformers

\[ V_S = \frac{N_S}{N_P} V_P \]

\[ I_S = I_P \frac{N_P}{N_S} \]

**Step Down**
- Decrease Voltage
- Increase Current

**Step UP**
- Increase Voltage
- Decrease Current
Transformers and Auto Ignition

Converting 12V to 40,000V
\[ V_S = \frac{N_S}{N_P} V_P \]

**Transformers**

\[ I_S = I_P \frac{N_P}{N_S} \]

**Power Transmission**

Step up Voltage Step Down Current to reduce Power loss.

(Modern transmission grids use AC voltages up to 765,000 volts.)
Advantages of AC Transmission

• Alternating Current can be transformed to ‘step’ the voltage up or down with transformers.

• Power is transmitted at great distances at HIGH voltages and LOW currents and then stepped down to low voltages for use in homes (240V) and industry (440V).

• Convert AC to DC with a rectifier in appliances.

AC is more efficient for Transmission & Distribution of electrical power than DC!
The Power Grid

Typical power plant can generate MegaWatts of Energy.
US consumption of electricity is 90 Quadrillion BTUs/year.
1 quad = $10^{15}$ Btu = $2.931 \times 10^{11}$ kW-hrs
Hetch Hetchy: 2 billion kW-hrs per year
Wind in CA: 4.5 million kW-hrs per year
War of Currents 1880’s

**Thomas Edison**, American inventor and businessman, pushed for the development of a DC power network.

**George Westinghouse**, American entrepreneur and engineer, backed financially the development of a practical AC power network.

**Nikola Tesla**, Serbian inventor, physicist, and electro-mechanical engineer, was instrumental in developing AC networks.
Edison's Publicity Campaign

Edison wired NYC with DC. He carried out a campaign to discourage the use of AC, including spreading information on fatal AC accidents, killing animals, and lobbying against the use of AC in state legislatures. Edison opposed capital punishment, but his desire to disparage the system of alternating current led to the invention of the electric chair. Harold P. Brown, who was at this time being secretly paid by Edison, constructed the first electric chair for the state of New York in order to promote the idea that alternating current was deadlier than DC.

The first electric chair, which was used to execute William Kemmler in 1890
In The Future…
Long Distance AC Power Transmission may not be needed!!!
Is AC Deadlier than DC?

• Low frequency (50 - 60 Hz) AC currents can be more dangerous than similar levels of DC current since the alternating fluctuations can cause the heart to lose coordination, inducing ventricular fibrillation, which then rapidly leads to death.

• High voltage DC power can be more dangerous than AC, however, since it tends to cause muscles to lock in position, stopping the victim from releasing the energised conductor once grasped.
Any practical distribution system will use voltage levels quite sufficient for a dangerous amount of current to flow, whether it uses alternating or direct current. Ultimately, the advantages of AC power transmission outweighed this theoretical risk, and it was eventually adopted as the standard worldwide after Nikola Tesla designed the first AC hydroelectric power plant at Niagara Falls, New York which started producing electrical power in 1895.