PHY294H

- Professor: Joey Huston
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- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday
  - hand-in problem for Wed Mar. 16: 33.54
- Quizzes by iclicker (sometimes hand-written)
- Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so
- Have a great Spring Break!
Flux in non-uniform field

- The situations we’ve been considering so far have had a uniform field, so it’s easy to calculate the flux.

- But we may encounter situations where the field is not uniform, and we can still calculate the flux

\[
d\Phi_B = \vec{B} \cdot d\vec{A}
\]

\[
\Phi_B = \int \vec{B} \cdot d\vec{A}
\]
What if $I=(50A)\times t$, i.e. the current changes with time. The magnetic flux will change with time and there will be an emf induced.
An example of eddy current braking: A square loop with length \( l \) is shot with velocity \( v_0 \) into a uniform B field that is perpendicular to the plane of the loop. The loop has mass \( m \), resistance \( R \) and enters the B field at time \( t = 0 \) s. Assume that the loop is moving to the right along the x-axis and that the B field begins at \( x = 0 \) m.

1) Find an expression for the loop’s velocity as a function of time as it enters the B field. Ignore gravity and assume that the back edge of the loop doesn’t enter the B field.
An example of eddy current braking: A square loop with length $l$ is shot with velocity $v_0$ into a uniform $B$ field that is perpendicular to the plane of the loop. The loop has mass $m$, resistance $R$ and enters the $B$ field at time $t = 0 \text{ s}$. Assume that the loop is moving to the right along the $x$-axis and that the $B$ field begins at $x = 0 \text{ m}$.

1) Find an expression for the loop’s velocity as a function of time as it enters the $B$ field. Ignore gravity and assume that the back edge of the loop doesn’t enter the $B$ field.

$$v = v_0 e^{-\frac{l^2B^2}{mR}t}$$
An example of eddy current braking: A square loop with length $l$ is shot with velocity $v_0$ into a uniform B field that is perpendicular to the plane of the loop. The loop has mass $m$, resistance $R$ and enters the B field at time $t = 0$ s. Assume that the loop is moving to the right along the x-axis and that the B field begins at $x = 0$ m.

2) Using the following values make a graph of the velocity vs time:

$v_0 = 10$ m/s, $l = 10$ cm, $m = 1.0$ g, $R = 0.0010$ Ω and $B = 0.10$ T

$$v = v_0 e^{-\frac{l^2 B^2}{mR} t}$$

Note that the loop stops in less than 0.05 seconds
Now to a puzzle

- Suppose I have a conducting coil outside a perfect solenoid.
- The current inside the solenoid is increasing with time resulting in an increasing magnetic field inside the solenoid.
- There is no field outside the solenoid.
- Is there a current induced in the coil?
- If so, how does the coil know the magnetic field inside the solenoid is changing?
Example

- A 4.0 cm diameter loop with resistance 0.01 Ω surrounds a 2.0 cm diameter solenoid. The solenoid is 10 cm long, has 100 turns, and carries the current shown in the graph. A positive current is CCW when seen from the left. Determine the current in the loop as a function of time.
Suppose I have a conducting loop in a region of increasing magnetic field. There’s a current induced in a direction to oppose the increase in magnetic field. But if there’s a current flowing, there must be an electric field responsible, an electric field tangent to the loop. This electric field is caused by the changing magnetic field and is called an induced electric field.
Suppose I lose the conductor but otherwise keep the situation the same.

There’s still an induced electric field (pinwheel pattern) caused by the changing magnetic field.

- Changing magnetic fields create electric fields.

Note that the electric field lines do not originate on positive charges nor terminate on negative charges.

It’s a non-Coulomb electric field.

- As opposed to a Coulomb electric field.
- Both exert a force on electric charges.

(b)

Induced electric field $\vec{E}$

Region of increasing $\vec{B}$
The magnetic field is decreasing. Which is the induced electric field?

E. There’s no induced field in this case.
The magnetic field is decreasing. Which is the induced electric field?

The field is the same direction as induced current would flow if there were a loop in the field.

E. There’s no induced field in this case.
A changing magnetic field creates an electric field.

To complete the symmetry, Maxwell hypothesized that a changing electric field also creates a magnetic field:

- an induced magnetic field not tied to currents
- oriented in the opposite direction as the induced electric field
- still just an inspired hypothesis by Maxwell

A changing electric field creates an induced magnetic field.
Electromagnetic waves

Maxwell: Could self-sustaining electric and magnetic fields be established?

- changing magnetic fields creating electric fields
- changing electric fields creating magnetic fields
- fields continually created through induction without any reliance on charges or currents

Maxwell predicted that the waves would travel with a speed

Mathematics in the next chapter

\[ v_{\text{em wave}} = \frac{1}{\sqrt{\mu_o e_o}} = 3 \times 10^8 \text{ m/s} \]
Electromagnetic waves

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Me sitting in Maxwell’s chair

Brilliant!

Me sitting in Sheldon’s chair
Transformer

- Two coils are wrapped around an iron core
  - left coil is called the primary coil; has an incident voltage $V_1 \cos \omega t$
  - right coil is called the secondary coil
- An alternating current through the first coil causes an oscillating flux through the second coil and thus an induced emf $V_2 \cos \omega t$
  - total flux through each coil depends on the number of turns

$$V_2 = \frac{N_2}{N_1} V_1$$

- Depending on the ratio of $N_2/N_1$, $V_2$ can be transformed to a higher voltage than $V_1$, or to a lower voltage

Higher voltages are usually used for long distance power transmission. Why?
Inductors

- A capacitor is a good way of producing a uniform electric field
  - it also stores energy in the form of the electric field
- A solenoid is a useful way of producing a uniform magnetic field
  - and we’ll find can also store energy in the form of the magnetic field
- Define the inductance $L$ of a circuit element as the ratio of the magnetic flux it holds to the current flowing through it
  \[ L = \frac{N\phi_m}{I} \]

The larger the inductance, the larger flux can be held for a given current. Remember, the larger the capacitance, the larger charge that can be held for a given voltage.

Unit of inductance is the Henry

$1 \text{H} = 1 \text{Tm}^2/\text{A}$
Inductors in circuits

- We’ll encounter inductors in circuits in the future
- The voltage drop across an inductor is proportional to the rate of change of current though it (and can be large)

\[
\Delta V_{\text{R}} = -IR
\]

\[
\Delta V_{\text{L}} = -L \frac{dI}{dt}
\]

The potential always decreases.

The potential decreases if the current is increasing.

The potential increases if the current is decreasing.

The current decreases rapidly after the switch opens.