Physics 102 recently

Basic principles of magnetism

• Lecture 10 – magnetic fields & forces
• Lecture 11 – magnetic dipoles & current loops
• Lecture 12 – currents & magnetic fields

Connection between electricity & magnetism

• Lecture 13 – motional EMF & Lenz’ law
• Lecture 14 – Faraday’s law of induction
• Lecture 15 – electromagnetic waves
Today we will...

• Learn how electric fields are created from...
  Motion in magnetic fields ("motional EMF")
  Changing magnetic fields

• Learn *Lenz’ law*: principle unifying electricity and magnetism

• Apply these concepts:
  Magnetoreception
  Electrical generators & hybrid cars
CheckPoint 1: Moving bar

A conducting bar moves in a uniform external $B$ field at speed $v$

Magnetic force pushes $-$ electrons to top, leaves $+$ charge at bottom of bar

Separated $+$ and $-$ charge induces $E$ field & $\Delta V$

At equilibrium, forces must sum to zero

$$F_B = qvB_{\text{ext}} = F_E = qE_{\text{ind}}$$

Moving bar acts like a battery!

*Motional EMF*

Phys. 102, Lecture 13, Slide 4
Magnetoreception in sharks

Sharks can sense changes in magnetic fields

Shark do not have magnetic organelles like magnetotactic bacteria, but they do have “ampullae of Lorenzini”, which sense $E$ field

Model of magnetoreception in sharks: motional EMF from moving in $B$ field generates $E$ field detected by ampullae

Phys. 102, Lecture 13, Slide 5
Motional EMF

Bar slides with speed $v$ on a conducting track in a uniform $B$ field

Can moving bar drive current around the circuit?

+ charges in moving bar experience force down

Electrical current induced clockwise!

(Recall that $e^-$ actually move, opposite current)

$$\varepsilon = vB_{ext}L \quad I = \frac{vB_{ext}L}{R_{bulb}}$$

Phys. 102, Lecture 13, Slide 6
The conducting bar moves to the right in the opposite $B$ field

Which way does the current flow?

A. Clockwise
B. Counterclockwise
C. The current is zero
**ACT: Two metal bars**

Circuit now has two metal bars moving right at the same speed $v$

Which way does the current flow?

A. Clockwise
B. Counterclockwise
C. The current is zero
Motional EMF and force

Where does the energy come from to generate electricity?

Moving bar carries current, so $B$ field exerts a force $F_{\text{bar}}$

\[ F_{\text{bar}} = ILB_{\text{ext}} \sin \theta \]

$F_{\text{bar}}$ opposes $v$, so bar decelerates

To maintain constant $v$, you must provide external force $F_{\text{ext}}$ opposing $F_{\text{bar}}$

$F_{\text{ext}}$ does the work to generate electrical energy

Note: $F_{\text{bar}}$ is NOT $F_{B}$ which drives current around loop.

Phys. 102, Lecture 13, Slide 9
**Electrical generators**

Motional EMF is the basis for modern electrical generation

Instead of sliding bar, use spinning loop in $B$ field

External torque (from turbine, gas engine, etc.)

Phys. 102, Lecture 13, Slide 10
**ACT: CheckPoint 2.2**

The $B$ field is now reversed and points **into** the page.

To keep the bar moving at the same speed, the hand must supply:

A. A force to the right
B. A force to the left
C. No force, the bar slides by inertia
Changing B field

Now loop is fixed, but $B$ field changes

If $B_{ext}$ increases, current $I$ flows clockwise

If $B_{ext}$ decreases, current $I$ flows counterclockwise

If $B_{ext}$ is constant, no current flows

What is changing here and in previous cases? Magnetic flux $\Phi$!
**Magnetic flux**

Flux “counts” number of $B$ field lines passing through a loop

\[
\Phi \equiv BA \cos \phi
\]

- $\Phi$: Magnetic flux
- $B$: Magnetic field
- $A$: Area inside loop filled with $B$ field
- $\phi$: Angle between normal vector and $B$ field

Unit: Wb ("Weber")

\[1 \text{ Wb} = 1 \text{ T} \cdot \text{m}^2\]

Angle $\phi$ affects how many $B$ field lines pass through loop

Top view: $B$ field in loop

Side view: $B$ field normal

Phys. 102, Lecture 13, Slide 13
CheckPoint 3.1

Compare the flux through loops $a$ and $b$

A. $\Phi_a > \Phi_b$

B. $\Phi_a < \Phi_b$

C. $\Phi_a = \Phi_b$
Magnetic flux practice

A solenoid generating a $B$ field is placed inside a conducting loop. What happens to the flux $\Phi$ through the loop when...

\[ \Phi \equiv BA \cos \varphi \]

The area of the solenoid increases?
The current in the solenoid increases?
The area of the loop increases?
Lenz’s law

Induced EMF $\varepsilon$ opposes change in flux $\Phi$

If $\Phi$ increases:
- $\varepsilon$ generates new $B$ field
- opposite external $B$ field

If $\Phi$ decreases:
- $\varepsilon$ generates new $B$ field
- along external $B$ field

If $\Phi$ is constant:
- $\varepsilon$ is zero

One principle explains all the previous examples!
Lenz’s law: changing loop area

**EX 1**
- $A \& \Phi$ increases
- $\varepsilon$ generates $B_{\text{ind}}$ opposite $B_{\text{ext}}$

**EX 2**
- $A \& \Phi$ decreases
- $\varepsilon$ generates $B_{\text{ind}}$ along $B_{\text{ext}}$

**EX 3**
- $A \& \Phi$ remains constant
- $\varepsilon$ is zero

$\varepsilon$ opposes change in flux $\Phi$

*Phys. 102, Lecture 13, Slide 17*
**ACT: Lenz’ law: changing B field**

A loop is placed in a uniform, increasing $B$ field

In which direction does the induced $B$ field from the loop point?

A. Into the page
B. Out of the page
C. There is no induced $B$ field
ACT: moving loops

Three loops are moving in a region containing a uniform $B$ field. The field is zero everywhere outside.

In which loop does current flow \textit{counterclockwise} at the instant shown?

A. Loop A \hspace{1cm} B. Loop B \hspace{1cm} C. Loop C

$\varepsilon$ \textit{opposes change} in flux $\Phi$
A solenoid is driven by an *increasing* current. A loop of wire is placed around it. In which direction does current in the loop flow?

A. Clockwise  
B. Counterclockwise  
C. The current is zero
Induction cannon

A solenoid is driven by an increasing current. A loop of wire is placed around it.

Current loop and solenoid behave like magnetic dipoles
Opposite currents = opposite polarities
Like poles repel, so loop shoots up!

Recall Lect. 11
Summary of today’s lecture

• Electric fields are created from
  Motion in magnetic fields ("motional EMF")
  Changing magnetic fields

• Lenz’ Law: EMF $\varepsilon$ _opposes change_ in flux $\Phi$

  $\varepsilon$ does NOT oppose $\Phi$
  $\varepsilon$ opposes change in $\Phi$

Lenz’ law gives direction of EMF
Faraday’s law gives us magnitude of EMF (next lecture!)