Physics 202, Lecture 17

Today’s Topics

- Faraday’s Law (Ch 31)
- Review Lenz’s Law
- Demos
- Faraday’s Law Explained
- Motional Emf

- Expected Preview: Ch 31
Review: Faraday’s Law of Induction

- The emf induced in a “circuit” is proportional to the time rate of change of magnetic flux through the “circuit”.

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

- Notes:
  - “Circuit”: any closed path → does not have to be a real conducting circuit
  - The path/circuit does not have to be circular, or even planar

\[ \Phi_B = \int \mathbf{B} \cdot d\mathbf{A} \]
Review: Direction of Induced emf

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

- $\varepsilon > 0$, same as nominal direction
  - $\varepsilon < 0$, opposite

- Note that the nominal direction of $\varepsilon$ and the direction of vector A follows right hand rule

\[ \Phi_B = \int B \cdot dA \]
Review: Lenz’s Law

- Lenz’s law in plain words: the induced emf always tends to work against the original cause of flux change.

<table>
<thead>
<tr>
<th>Cause of $d\Phi_B/dt$</th>
<th>“Current” due to Induced $\mathcal{E}$ will:</th>
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</thead>
<tbody>
<tr>
<td>Increasing $B$</td>
<td>generate $B$ in opposite dir.</td>
</tr>
<tr>
<td>Decreasing $B$</td>
<td>generate $B$ in same dir.</td>
</tr>
<tr>
<td>Relative motion</td>
<td>subject to a force in opposite direction of relative motions</td>
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Note: “Current” may not actually produced if no circuit)
Examples of Lenz’s Law

(a) S N

(b) I increasing

(c) I decreasing

(b) I increasing

(c) I increasing
Demo: Eddy Current
Demo: Jumping Ring and more

Quick quiz: If the direction of the current is reversed, will the ring:

Still jumping up? Or Likely to be moving down?
Demo: Guillotine Machine

Let’s see how a Physicist (me) would do it.
Methods to Change Electric Flux

\[ \mathcal{E} = - \frac{d\Phi_B}{dt} = - \frac{d(BA \cos \theta)}{dt} \]

- Change of \( \Phi_B \rightarrow \) emf
- To change \( \Phi_B \):
  - Change \( B \rightarrow \) emf produced by an induced E field
  - Change \( A \rightarrow \) motional emf
  - Change \( \theta \rightarrow \) motional emf
  - Combination of above

electric generator
In the setting below, a magnetic force is acting against the motion of the moving rod. No matter which direction it moves.

→ Use Lenz Law to explain it.
Motional emf of a Sliding Bar

- When the conducting bar is moving, the electrons inside is subject to a magnetic force:
  - Show that for the motion below, electrons are subject a force downwards.
  - Show the magnitude of the force is evB per electron.
- Now electrons are moving downwards and accumulate at the lower end of the bar.

- This would create an electric field $E$ in direction shown.
  The electric field $E$ applies an upward force $F_E = eE$
  When balance $F_E = F_B$ $\Rightarrow E = vB$

The voltage (emf) is $\varepsilon = EL = vLB$
Moving Rod Again

- When forming a closed circuit, the induced emf drives a current in the rod in direction as shown.

Exercise: use $F_B = ILXB$ to verify the direction of $F_B$ as shown.
Use Faraday’s Law to Calculate Motional emf

- Faraday’s Law: $\mathcal{E} = -\frac{d\Phi}{dt}$, $\Phi = BA$, $A = lx$

$\Rightarrow \frac{d\Phi}{dt} = Bl \frac{dx}{dt} = Blv = |\mathcal{E}|$
Demo: Electric Generator

\[ \mathcal{E} = -N \frac{d\Phi_B}{dt} = -N \frac{d(AB \cos \theta)}{dt} = NAB \omega \sin(\omega t) \]

\[ \theta = \omega t \]
Another Generator Design: Rotating Magnets
What Produces emf? Induced Electric Field

- Whenever a magnetic field varies in time, an electric field is induced.

Notes:
- Induced E is not a conservative field.
- Induced E can exist in a location where no B field exists.
- Induced E is independent of circuit

\[ \int E \cdot ds = -\frac{d\Phi_B}{dt} \]  valid for any closed path