Physics 202, Lecture 16

Today’s Topics

- Faraday’s Law (Ch 31)
- Review Lenz’s Law
- Faraday’s Law Explained
- Example: Electric Generator
- Motional Emf

- Expected Preview: Ch 31
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 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: 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 $\varepsilon$ will:</th>
</tr>
</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>
</tr>
</tbody>
</table>

Note: “Current” may not actually produced if no circuit.
Examples of Lenz’s Law

(a) 

(b) $I$ increasing 

(c) $I$ decreasing
Demo: Eddy Current
Faraday’s Law of Induction

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    → does not have to be real conducting circuit
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\[ \Phi_B = \int B \cdot dA \]
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

\[ \Phi_B = \int \mathbf{B} \cdot d\mathbf{A} \]
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**
Motional emf

- If a conducting segment are in relative motion (cut through) with a magnetic field, an emf is produced.
  - Motional emf is produced by the magnetic force on the free particles inside the conductor
  - Faraday’s law is also valid for this type of emf

Exercise:
show that the motional emf in the left fig. is $\varepsilon = Blv$
Motional emf

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show that the motional emf in the left fig. is \( \varepsilon = Blv \)
Appendix: Motional emf of a Sliding Bar (1)

Show that $\varepsilon = vLB$

Method 1: By argument of $F_B$ on the free electron $F_B = evB$ downwards, which cause the negative charge to accumulate at the low end. 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) created is $\varepsilon = EL = vLB$
Demo: Electric Generator

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

\[ \theta = \omega t \]
What Produces emf? Induced Electric Field

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

\[ \oint E \cdot ds = -\frac{d\Phi_B}{dt} \]

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
- Text Fig. 31.15 is not generally correct.

valid for any closed path