Physics 202, Lecture 16

Today’s Topics

- Reminder of Lenz’s and Faraday’s Laws
- Motional EMF
- Electric Generators

Reminder: Midterm 2, Nov 2, 5:30-7:00pm
Exam 2 Reminder

Exam time: Wednesday, November 2, 5:30-7PM
Covering: Chapters 25-28 (Section 28.1-28.5), lecture material, lab material (E4,E6), and homework.
About 20 Multiple Choice Questions

Bring: Pen/pencil
      Calculator (no programming functionality!)
      1 single-sided formula sheet, self-prepared -- no photocopying!

Exam room assignment, special arrangements, other logistics, etc will be spelled out in a forthcoming email. A practice exam will be sent to you by email this week.
Lenz’s Law (Reminder)

- The emf due to change of magnetic flux tends to create a current which produces a magnetic field to compensate the change of original magnetic flux.
  - Note: Real current may or may not generated.
  - Lenz’s law is a convenient way to determine the direction of the emf due to magnetic flux change.
Review: Lenz’s Law

- Lenz’s law in plain words: the induced emf always tend 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>
</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>
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Note: “Current” may not actually produced if no circuit
Quizzes/Exercises: Determine Direction Of emf

- Indicate the direction of emf in the following cases:

  1. **|B| increases**
  2. **|B| decreases**
  3. **|B| decreases**
  4. **|B| increases**
  5. **|B| decreases**
  6. **|B| decreases**
  7. **|B| decreases**
  8. **|B| decreases**

- Path outside B

- or
Demo: Jumping Ring and more

switch on and the ring jumps

conducting ring
Demo: Guillotine Machine

Let’s see how a Physicist (me) would do it.
Faraday’s Law (Reminder)

- 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

\[ \Phi_B = \oint \mathbf{B} \cdot d\mathbf{A} \]
Methods to Change Magnetic Flux

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

- 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 Generators
A consequence of Lenz’s law is that motional emf would always tend to prevent the relative motion between a conductor and the magnetic field.
Motional emf of a Sliding Bar

- When the conducting bar is moving, the electrons inside are subject to a magnetic force:
  - Show that for the motion below, electrons are subject to 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 $\varepsilon = EL = vLB$. 

![Diagram showing electric field and forces](image)
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: \( \varepsilon = - \frac{d\Phi}{dt}, \quad \Phi = BA, \quad A = l x \)

\[ \Rightarrow \frac{d\Phi}{dt} = Bl \frac{dx}{dt} = Blv = | \varepsilon | \]
Demo: Electric Generator

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

\[ \theta = \omega t \]
Changing $B$

Imagine $\frac{dB}{dt} = c > 0$

\[ \mathcal{E} = -\frac{d\Phi_B}{dt} = -A \frac{dB}{dt} = -Ac = -\pi r^2 c \]

\[ \mathcal{E} = -\oint \vec{E} \, d\vec{l} = -2\pi r E \]

\[ E = \frac{rc}{2} \]
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

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