**Induced EMF**

**Generators, Transformers**

**Physics 122**

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**Concepts**

- Electric generator
- Magnetic flux
- Induced EMF

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**Electric motor ↔ electric generator**

- **Electric motor:**
  - electric energy → mechanical.
  - Current loop rotates in magnetic field
- **Electric generator:**
  - mechanical → electric energy
  - conductor loop rotating in magnetic field produces electric current
Magnetic flux

- If magnetic field is rain — magnetic flux is the amount of water in a bucket accumulated per unit of time:
  \[ \Phi = B \cdot A = BA \cos \theta \]

- Magnetic flux is measured in Weber:
  \[ 1 \text{Wb} = 1 \text{Tm}^2 \]

Three ways to change flux:
- Change B
- Change A
- Change \( \theta \)

Faraday’s Law of induction

- Changing magnetic flux induces emf (voltage),
- Acts like a battery!

\[ \text{emf} = -N \frac{d\Phi}{dt} \]

Lenz’s Law: conservatism of nature

- An induced emf always gives rise to a current whose magnetic field opposes the original change in flux:
  - Flux decreases \( \Rightarrow \) internal \( B_{int} \) (created by the induced current) is in the same direction as the external \( B_{ext} \)
  - Flux increases \( \Rightarrow \) \( B_{int} \) – in the opposite direction to \( B_{ext} \)
  - Determine current direction using 1st right hand rule
Moving conductor

- A conducting rod is moving to the right on a U-shaped conductor in a uniform magnetic field → flux is increasing
  \[\frac{d\Phi}{dt} = B l v dt\]

- Induced emf:
  \[\text{emf} = \frac{d\Phi}{dt} = B l v\]

- Induced electric field:
  \[E = \frac{\text{emf}}{l} = v B\]

Electric generator

- Electric generator:
  - conductor loop rotating in magnetic field produces
  - Alternating electric current AC
  - Angle between B and \(\vec{A}\) \(\theta = \omega t\)
  - Flux:
    \[\Phi = B A \cos \omega t\]

- Induced emf:
  \[\text{emf} = -N \frac{d\Phi}{dt} = -N B A \frac{d \cos \omega t}{dt}\]
  \[\text{emf} = N B A \omega \sin \omega t\]

Alternating current (AC)

- Emf changes sign → current changes the direction
  \[\text{emf} = \text{emf}_0 \sin \omega t\]

\[V = V_0 \sin \omega t\]

\[V_0 = NBA \omega\]

\[I = I_0 \sin \omega t\]

\[I_0 = \frac{V_0}{R_{eq}}\]

\[V = V_0 \sin \omega t\]
Transformer

- If all flux goes through the core:

\[ V_p = N_p \frac{d\Phi}{dt} \]
\[ V_s = N_s \frac{d\Phi}{dt} \]

\[ \frac{V_s}{V_p} = \frac{N_s}{N_p} \]

- If energy is conserved

\[ I_p V_p = I_s V_s \]

\[ \frac{I_s}{I_p} = \frac{N_p}{N_s} \]

- If efficiency \( \varepsilon < 100\% \)

\[ I_s V_s = \varepsilon I_p V_p \]

- Power transmission

- High voltage \( \rightarrow \) low current \( \rightarrow \) power loss in power line resistance is lower:

\[ P_{\text{loss}} = I^2 R \]

Power is dissipated only in resistors!!!
**Power transmission**

- 65kW is transmitted over two 0.100 Ohm lines.
- \( V = 120 \rightarrow 1200V \rightarrow 120V \), \( \varepsilon = 99\% \)
- Compare losses to power transmission at 120V

\[
P_{\text{loss}}(\text{transformer}) = (1 - \varepsilon)P \\
P_{\text{loss}}(\text{resistor}) = I^2R
\]

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**Moving conductor – eddy currents**

- \( A \) increases \( \Phi \) increases
  - Induced current creates \( B_{int} \) opposite to external \( B_{ext} \)
- \( I \) down
- Now we have a current in magnetic field \( \Rightarrow \) there is a force acting on it
  - The direction of this force is opposite to \( v \)
  - Conservatism of nature
  - Currents created in conductors moving through the magnetic field – eddy currents – work to resist the change

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**Electric generator – counter torque**

- Loop is rotating cw
- Induced currents experience force in magnetic field \( \Rightarrow \) resultant torque on the loop cw – counter torque
- Nature resists change.
Electric motor – counter emf

- Current loop in magnetic field
- Magnetic field creates a torque that rotates the loop
- Changing flux $\Rightarrow$ emf
- Based on conservatism – this emf will try to create a current in the opposite direction to the original current - **counter emf**.
- Current is large at the beginning and is decreased later on.