So Far...

Electric Field (\(\mathbf{E}\))
- \(q \rightarrow \mathbf{E} \rightarrow \mathbf{F}_E\)
- \(\mathbf{E} \leftrightarrow \mathbf{V} \rightarrow \mathbf{I} \rightarrow \mathbf{R}\)

Magnetic Field (\(\mathbf{B}\))
- \(qv \rightarrow \mathbf{B} \rightarrow \mathbf{F}_B\)

Electromagnetism
- \(\frac{d\mathbf{E}}{dt} \rightarrow \mathbf{B}\) loops (Displacement Current)
- \(\frac{d\mathbf{B}}{dt} \rightarrow \mathbf{E}\) loops (Faraday's Law)

Important Results:
- Induced Voltage
- EM Radiation (Radio, Light)
Motional EMF - voltage generated in a conductor moving in a B field.

\[ \hat{B} = \text{(in)} \times x \times x \times \]

- Metal made of $\oplus$ and $\ominus$.
- Mobile because it's a conductor.
- $F_B$ is: Up for $\oplus$ Down for $\ominus$.
- Charges gather at ends.
- Buildup stops when $F_E = F_B$.
- Induced $E$ in bar: $qE = qvB$.
  \[ E = vB \]
- EMF (voltage) between ends:
  \[ \Delta V = E = EL = vBL \]
  \[ EMF \rightarrow \uparrow \text{Elec Field} \]
Using motional EMF to power a bulb stationary rails

\[ \text{Generated EMF: } \varepsilon = vBl \]

\[ \text{Induced Current: } I = \frac{\varepsilon}{R_{\text{bulb}}} \]

\[ \text{Side-Effect: } \vec{F}_B = I\vec{l} \times \vec{B} \]

\[ \vec{F}_B = (\text{Left}) \quad \hat{v} = (\text{Right}) \]

\[ F_B = IILB \]

\[ \text{Power Input: } P = \vec{F}_{\text{app}} \cdot \hat{v} = IILBv \]

\[ P = \varepsilon I = vBLI \]
Ex: $B = 1.0 \ T$

$v = 25 \ m/s$

$l = 0.1 \ m$

$\varepsilon = vBL = 2.5 \ V$

Connect to $R = 5 \ \Omega$

$I = \frac{2.5V}{5\Omega} = 0.5 \ A$

Power supplied to $R$: $P = \varepsilon I = 1.25 \ W$

Drag Force: $F = IBL$

$= (0.5A)(0.1 \ m)(1.0 T)$

$= 0.05 \ N$

Mechanical Power

$P = F \cdot v$

$= (0.05 \ N)(25 \ m/s)$

$= 1.25 \ W$

Ways to generate EMF:

- Motional EMF
- Varying $|B|$
- Rotating $B$

*Faraday's Law*

$\Phi_B = \oint \vec{B} \cdot d\vec{A} = \vec{B} \cdot \hat{n} A$

$\varepsilon = -\frac{d\Phi_B}{dt}$

$= BA \cos \Theta$
\[ \Phi_B = BA \cos \Theta \quad \text{Single-loop Flux} \]

\[ \hat{n} = \text{into page} \quad \hat{n} = (\text{right}) \]
\[ \Theta = 0 \quad \Theta = 90^\circ \]
\[ \cos \Theta = 1 \quad \cos \Theta = 0 \]

Practical coil has many loops:
\[ \Phi_B = NBA \cos \Theta \quad \text{Total Flux} \]

Spinning loop:
\[ \omega = \frac{d\theta}{dt} = \text{rotation in rad/s} \]
\[ \varepsilon = -\frac{d\Phi}{dt} = -NBA (-\sin \Theta) \omega \]
\[ \varepsilon = NBA \omega \sin \Theta \]

Maximum \( \varepsilon = NBA \omega \) \text{ (Generator)}

Compare \( \omega I = NBA I \sin \Theta \)

Max \( \omega I = NBA I \) \text{ (Motor)}
Torque of a generator:

- Opposes motion when I flows,
- Makes it hard to spin the crank.

EMF of a motor:

- Initially \( w=0 \), no EMF.
  Lots of current flows - high \( I \).
- When \( w \) reaches maximum:
  Lots of \( E \) opposes current.
  Motor spins with low \( P=VI \).
- When attached to a load:
  \( I \) requires \( I \), which flows because your load slowed \( w \).