Phys 2426 2017-10-12 Lec 12

So Far ...

Electric Field ($\vec{E}$)

- $q \rightarrow \vec{E} \rightarrow \vec{F}_E$
- $E \leftrightarrow V \rightarrow I$
  $R \nearrow$

IV Magnetic Field ($\vec{B}$)

- $(q\vec{v}$ or $I) \rightarrow \vec{B} \rightarrow \vec{F}_B$

Electromagnetism

- $dE/dt \rightarrow \vec{B}$ loops
  (Displacement Current)
- $dB/dt \rightarrow \vec{E}$ loops
  (Faraday's Law)

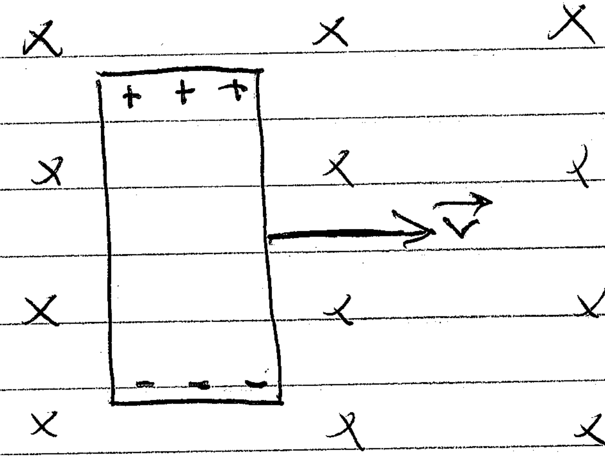
Important Results:

- Induced Voltage
- EM Radiation (Radio, Light)

(2)

Motional EMF – voltage generated in a conductor moving in a B field.

$\hat{B} = (\text{in})$



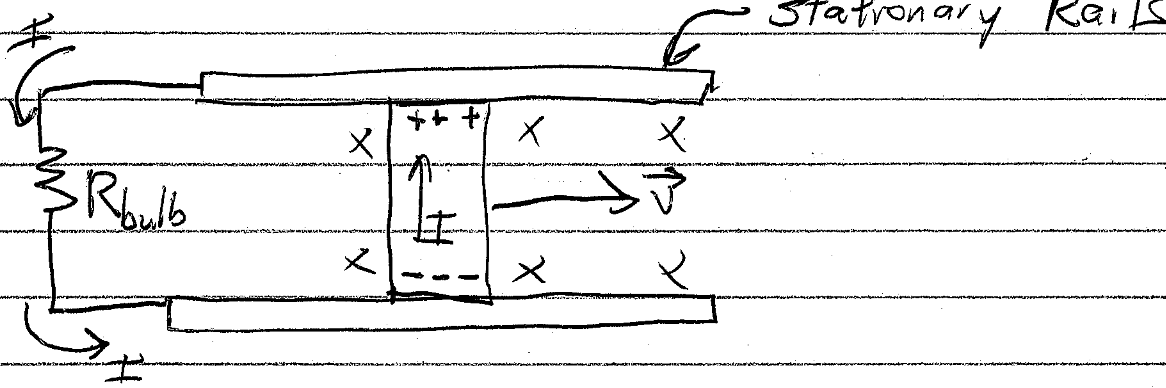
- Metal made of ⊕ and ⊖.
- Mobile because it's a conductor.
- F_B is: Up for ⊕
  Down for ⊖
- Charges gather at ends.
- Buildup stops when $F_E = F_B$
- Induced E in bar: $qE = qvB$
  $E = vB$
- EMF (Voltage) between ends:

$$\Delta V = \mathcal{E} = E\ell = vB\ell$$

EMF ↗ ↑ Elec Field

③

Using motional EMF to power a bulb



Generated EMF : $\mathcal{E} = vBl$

Induced Current : $I = \mathcal{E}/R_{bulb}$

Side-Effect: $\vec{F}_B = I\vec{l} \otimes \vec{B}$

$\hat{F}_B = (\text{Left})$ $\hat{v} = (\text{Right})$

$$F_B = IlB$$

Power Input: $P = \vec{F}_{app} \cdot \vec{v}$
$= IlBv$

Power Output: $P = \mathcal{E}\,I = vBl\,I$

4

Ex: $B = 1.0\ T$, $v = 25\ m/s$, $\ell = 0.1\ m$ $\Big\}$ $\mathcal{E} = vB\ell = 2.5\ V$

Connect to $R = 5\Omega$ $\qquad I = \frac{2.5V}{5\Omega} = 0.5\ A$

Power supplied to R: $\quad P = \mathcal{E} I = 1.25\ W$

Drag Force:

$$\begin{aligned} F &= I\ell B \\ &= (0.5A)(0.1\ m)(1.0T) \\ &= 0.05\ N \end{aligned}$$

Mechanical Power

$$\begin{aligned} P &= F \cdot v \\ &= (0.05\ N)(25\ m/s) \\ &= 1.25\ W \end{aligned}$$

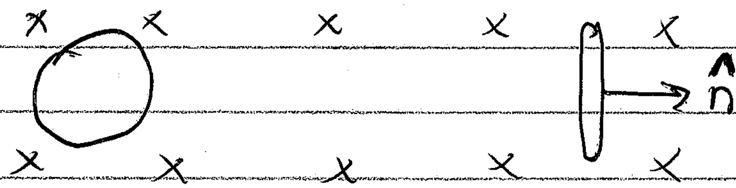
Ways to generate EMF:

- Motional EMF
- Varying $|B|$
- Rotating $\hat{B}$

$\Big\}$ Faraday's Law

$$\Phi_B = \iint \vec{B} \cdot d\vec{A} = \vec{B} \cdot \hat{n} A = BA\cos\theta \qquad \mathcal{E} = -\frac{d\Phi_B}{dt}$$

$\Phi_B = BA\cos\theta$ ← Single-loop Flux



$\hat{n}$ = into page
$\theta = 0$
$\cos\theta = 1$

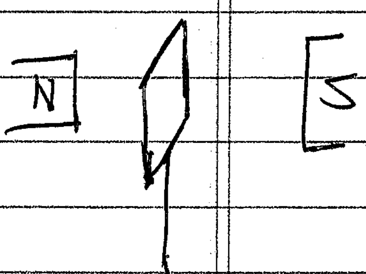
$\hat{n}$ = (right)
$\theta = 90°$
$\cos\theta = 0$

Practical coil has many loops:

$$\Phi_B = NBA\cos\theta$$ Total Flux

Spinning Loop: $\omega = d\theta/dt$ = rotation in rad/s

$$\mathcal{E} = -\frac{d\Phi}{dt} = -NBA(-\sin\theta)\,\omega$$



$$\mathcal{E} = NBA\omega\sin\theta$$

Maximum $\mathcal{E} = NBA\omega$ (Generator)

Compare $\tau = NBAI\sin\theta$
Max $\tau = NBAI$ (Motor)

6

Torque of a generator:

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

EMF of a motor:

- Initially $\omega = 0$, no EMF.
  Lots of current flows — high τ.
- When ω reaches maximum:
  Lots of $\mathcal{E}$ opposes current.
  Motor spins with low $P = VI$
- When attached to a load:
  τ requires I, which flows because your load slowed ω.