

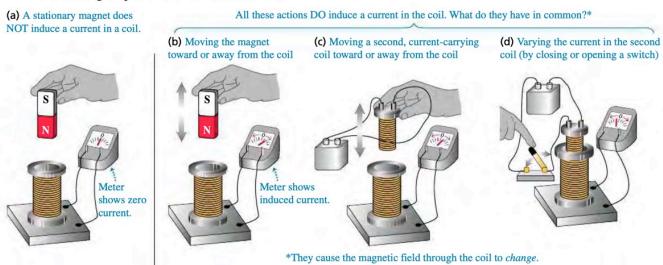
INDUCTION

- energy in our world is not generated by a battery but by another source (GPE, hydroelectric, geothermal, etc.). These convert energy via **induction**

Table of contents

- Faraday's law, relating induced EMF to magnetic flux in any loop
- Lenz's Law, predicting direction of induced EMF & current.
- how to calculate EMF induced in conductor moving through \vec{B} .
- how changing magnetic flux generates circulating electric field
- how eddy currents arise in metal that moves in magnetic field.

Experiments by Faraday & Henry show that changing \vec{B} induces current.



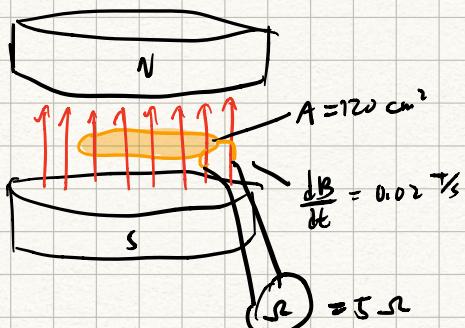
FARADAY'S LAW

$$\mathcal{E} = - \frac{d\Phi_B}{dt}$$

or

$$\mathcal{E} = - N \frac{d\Phi_B}{dt} \quad (\text{ solenoid})$$

Ex:



$$\Phi_B = \int \vec{B} \cdot d\vec{A} = \vec{B} \cdot A$$

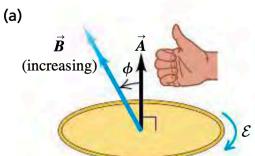
$$\mathcal{E} = - \frac{d\Phi_B}{dt} = - A \cdot \frac{d\vec{B}}{dt} = -(0.012) / 0.02$$

$$\mathcal{E} = - 0.24 \text{ mV}$$

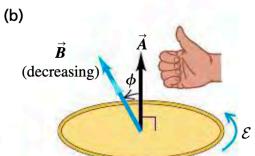
$$I_{ind} = \frac{\mathcal{E}}{R} = \frac{0.24 \times 10^{-3}}{5} = 0.048 \text{ mA}$$

* replacing loop w/ insulator makes current 0 but EMF constant.

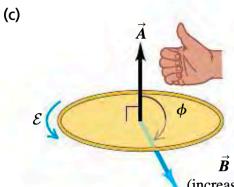
Determining direction of ϵ :



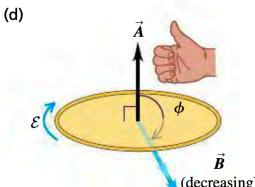
- Flux is positive ($\Phi_B > 0$) ...
- ... and becoming more positive ($d\Phi_B/dt > 0$).
- Induced emf is negative ($\epsilon < 0$).



- Flux is positive ($\Phi_B > 0$) ...
- ... and becoming less positive ($d\Phi_B/dt < 0$).
- Induced emf is positive ($\epsilon > 0$).



- Flux is negative ($\Phi_B < 0$) ...
- ... and becoming more negative ($d\Phi_B/dt < 0$).
- Induced emf is positive ($\epsilon > 0$).



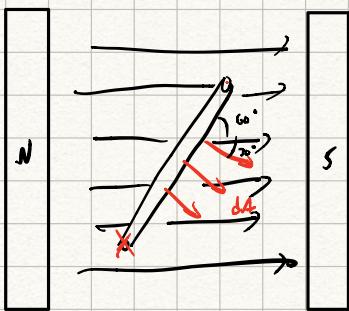
- Flux is negative ($\Phi_B < 0$) ...
- ... and becoming less negative ($d\Phi_B/dt > 0$).
- Induced emf is negative ($\epsilon < 0$).

• point thumb in dir. of \vec{A} .

↳ if ϵ positive, w/ fingers
if ϵ negative, aginst fingers

Ex: 500-loop circular wire coil w/ $r = 0.04 \text{ m}$.

\vec{B} makes angle of 60° with coil, $\frac{dB}{dt} = -0.12 \text{ T/s}$.



$$\begin{aligned}\Phi_B &= \int \vec{B} \cdot d\vec{A} \\ &= \vec{B} \cos 30^\circ \int dA \\ &= \vec{B} (\pi (0.04)^2 (\cos 30^\circ)) \\ &= 4.353 \times 10^{-5} \vec{B}\end{aligned}$$

$$\epsilon = 500 \frac{d\Phi_B}{dt} = -2.177 \frac{d\vec{B}}{dt} = 0.4353 \text{ V}$$

Direction: CCW when thumb // dA.



$$\Phi_B$$

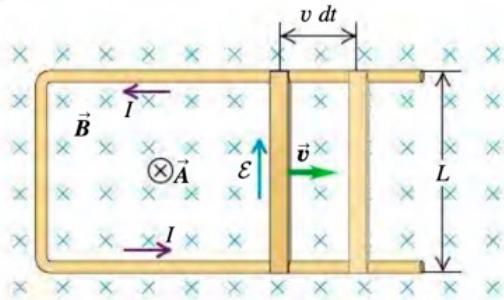
$$\epsilon = -\frac{d\Phi_B}{dt}$$



$$\Phi_B = BA \cos(\omega t)$$

$$\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{1}{dt} (BA \cos(\omega t)) = -B A \sin(\omega t)$$

Cx:



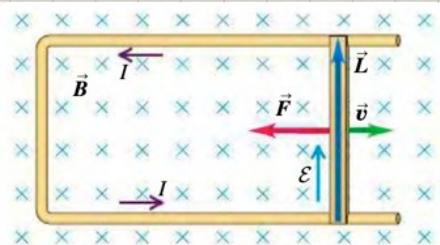
We slide a conducting bar across wire with speed v . Induced EMF, and power?

- $\vec{B} \uparrow$, so \vec{B}_{out} points out of the paper and I flows CCW.
- $\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d(B \cdot A)}{dt} = -B \frac{dA}{dt} = -B \frac{L(v dt)}{dt} = -BLv$

Let resistance be R .

$$P_{dissipated} = I^2 R = \left(\frac{BLv}{R} \right)^2 R = \frac{B^2 L^2 V^2}{R}$$

$$\vec{F} = IL \times \vec{B}$$

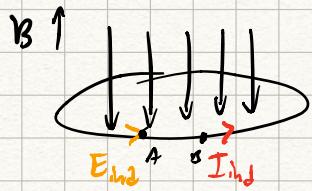


$$\text{Since } L \perp B, \quad \vec{F} = ILB = \frac{BLV}{R} \cdot LB = \frac{B^2 L^2 V}{R}$$

$$P_{app} = FV = \frac{B^2 L^2 V^2}{R}$$

Notice that $P_{app} = P_{diss}$

relation to electric field



- current is driven by an induced electric field.
- $\oint \vec{E} \cdot d\vec{l} \neq 0$!! Worthily, going around closed loop means no change in voltage.
↳ Voltage will change here!

$$\oint \vec{E} \cdot d\vec{l} = - \frac{d\Phi_B}{dt} = - \frac{d}{dt} \iint \vec{B} \cdot d\vec{s}$$