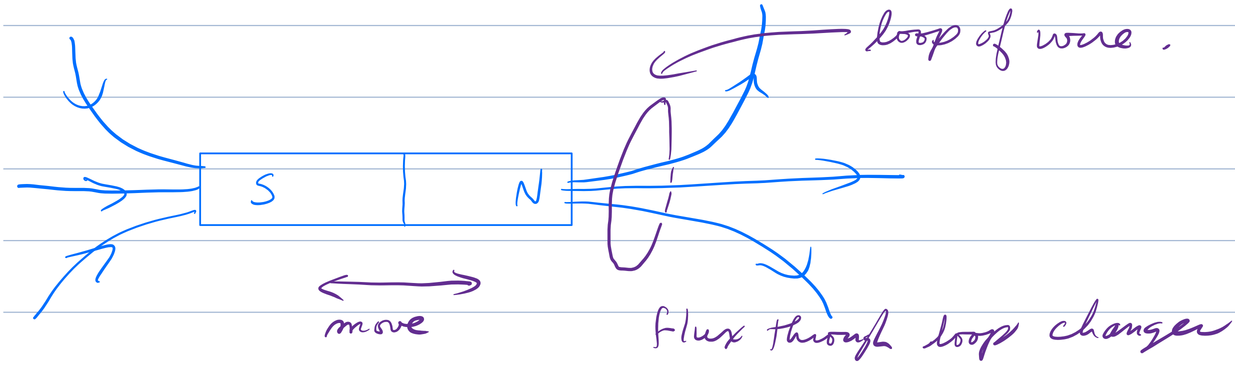
25.1: Induced currents.

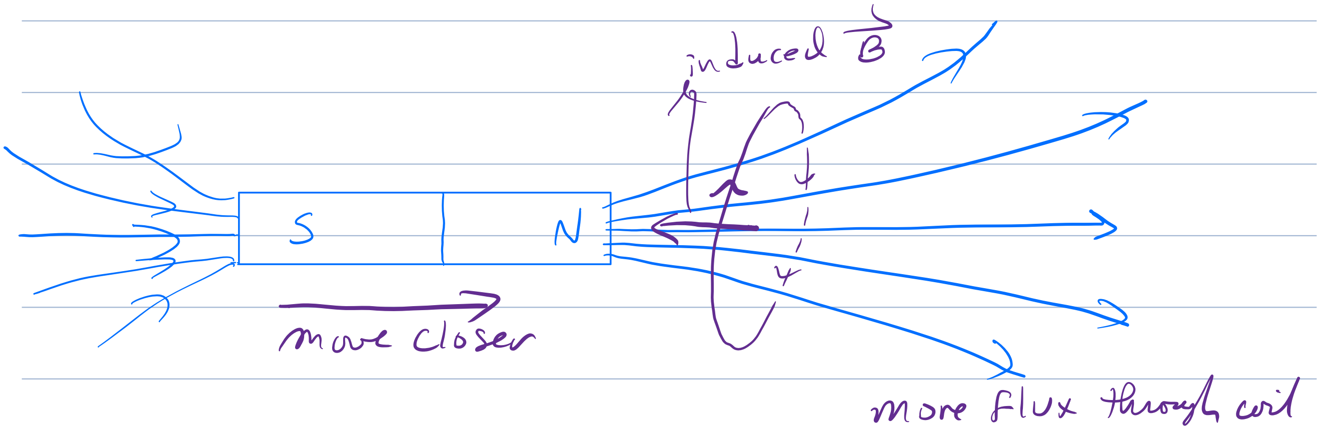
We have seen that electric currents produce magnetic fields. In this chapter, we explore the reverse process: using changing magnetic fields to produce electric currents. One key thing we will observe is that we need *changing* magnetic flux to produce an emf.

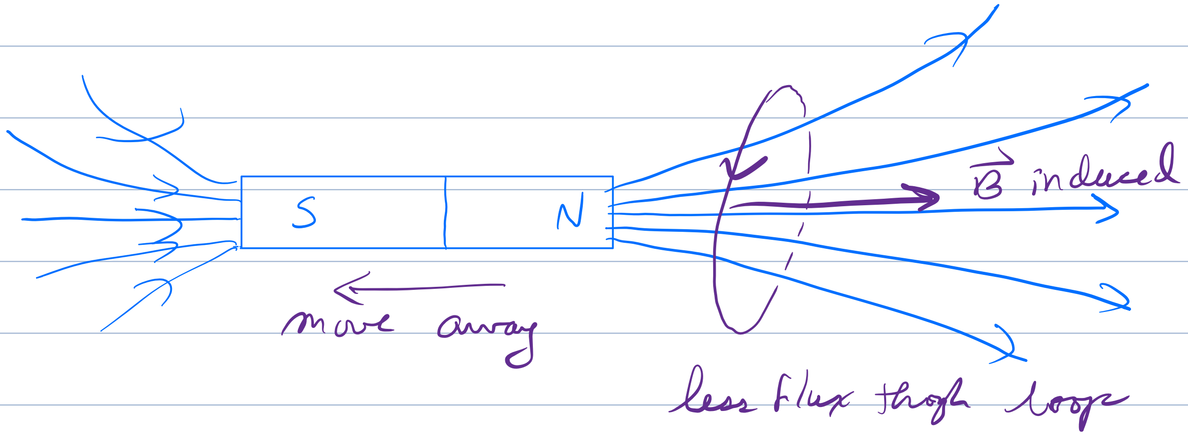
Examples:

- Inducing current in a coil with a magnet
    changing magnetic field induces a current in a coil



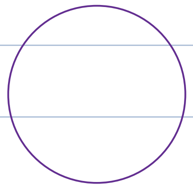
- Direction of induced current in a coil
    Increasing magnetic flux causes an opposing current.
    Decreasing magnetic flux causes a current in the opposite direction. Generally, we observe that the induced current opposes the original change in magnetic flux. We will pay attention both the *magnitude* and *direction* of the induced current



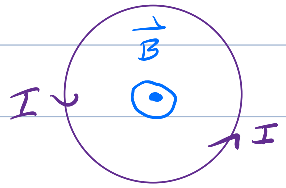


- Current in one coil induces current in a second coil. The direction of the induced current opposes the *change* in magnetic flux.

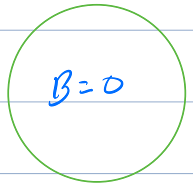
Original coil, power off



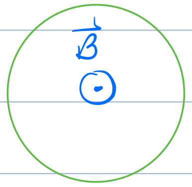
Original coil, power on



Place 2nd coil in front.
Look at flux through it.
Power off, flux = 0.

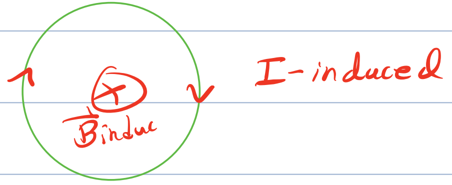


Look at 2nd coil. Power on. Flux is not 0.



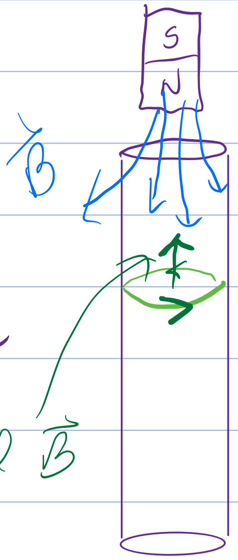
$\vec{B}$ due to 1st coil passes through second coil.

Induced current opposes change



Drop tube: Drop a magnet down an aluminum tube:

flux through the ring increases

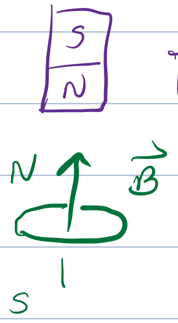


induced $\vec{B}$

flux

Net result

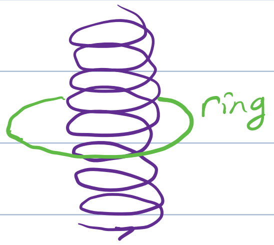
These repel, slowing down the magnet.



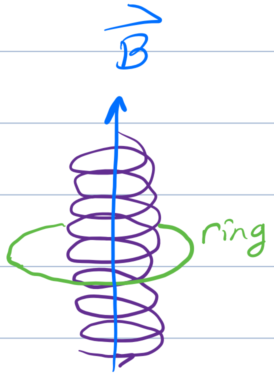
falling bar magnet

induced dipole

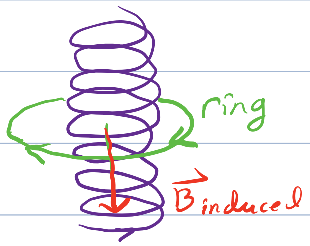
- Ring toss: The direction of the induced current opposes the change in magnetic flux. The effect is that the ring and coil repel each other.



coil,
power off.

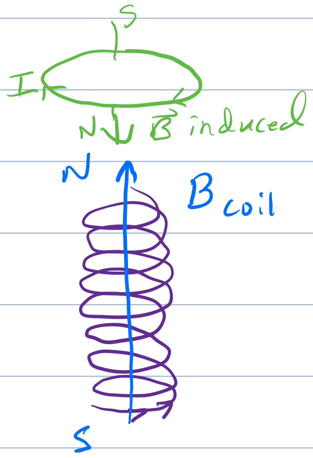


coil,
power on.



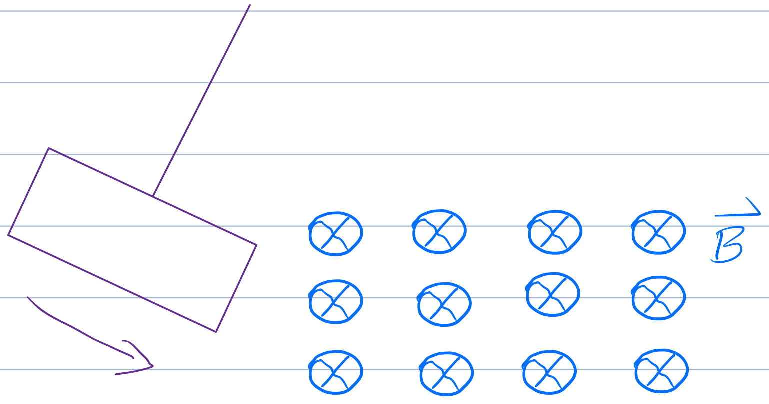
Ring, induced
current and field.

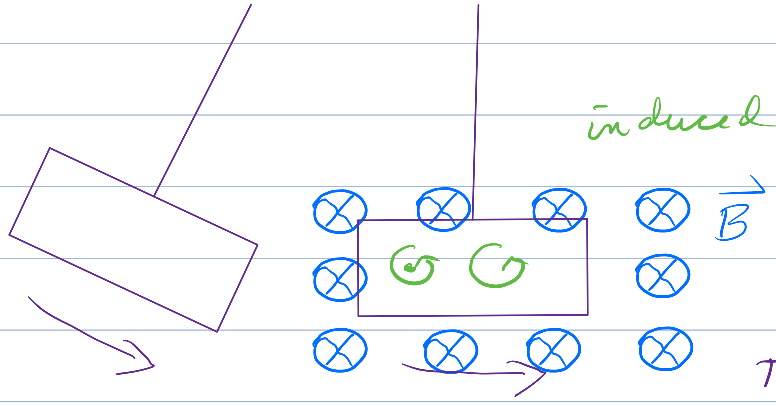
Net effect:



The north poles repel.

- Eddy current braking: Using induced currents for magnetic braking.

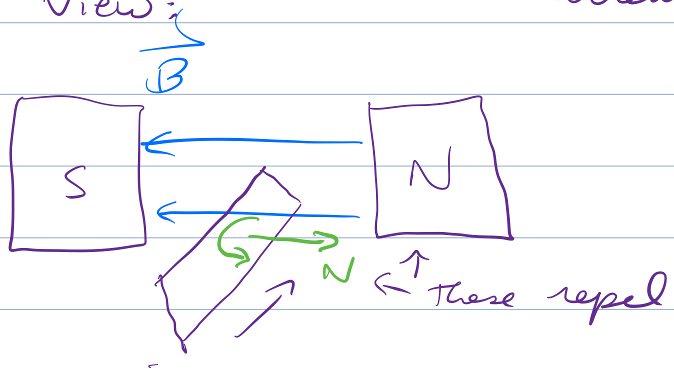




induced eddy currents create flux out of page

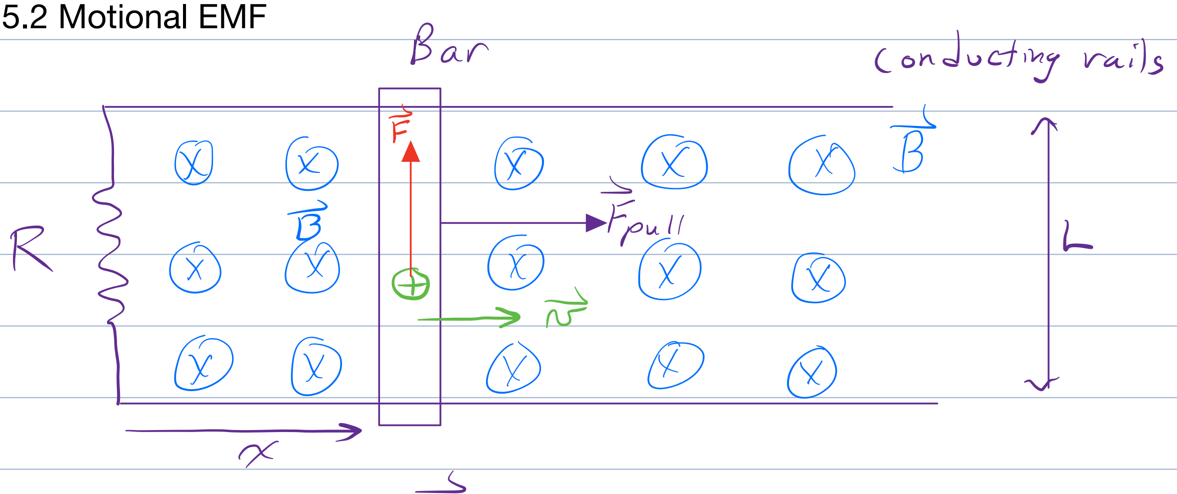
The flowing current dissipates energy.

side view:



Extract a general principle: **Lenz's Law:** A changing magnetic flux through a loop will induce an emf in that loop. The direction of that induced emf will tend to oppose the change in the flux. We will figure out the magnitude next.

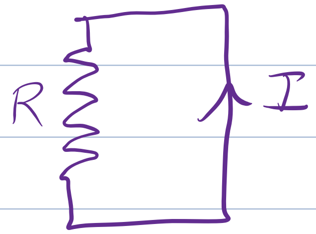
25.2 Motional EMF



Pull on bar $\vec{F}_{pull}$ so it moves with constant velocity $\vec{v}$. Charges in the rod feel a force $\vec{F} = q\vec{v} \times \vec{B}$ upward.

Net effect:

a current I flows.



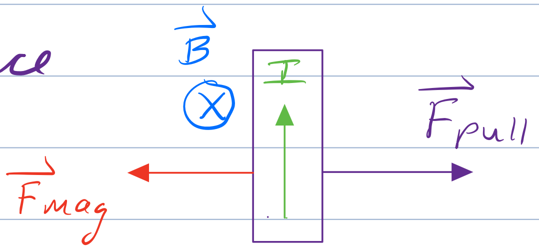
$\mathcal{E}$ = induced emf = $I \cdot R$

How large is $\mathcal{E}$?

Power in = Power out

$$F_{pull} \cdot v = \mathcal{E} I$$

Why do you need a force? To overcome the magnetic force



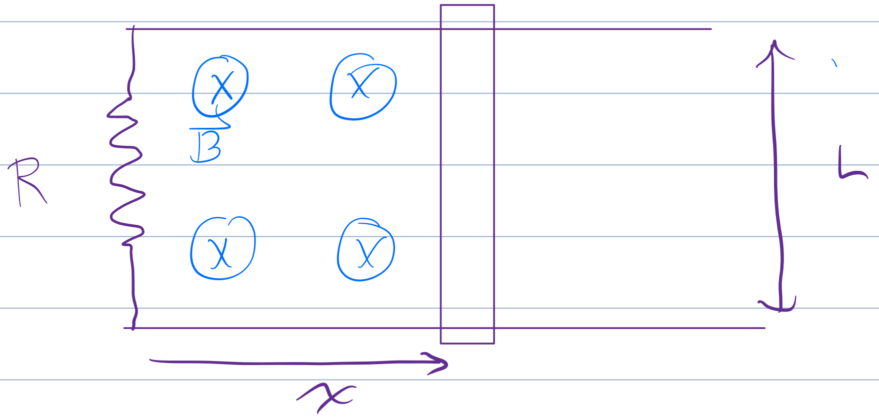
$(ILB)\,v = \mathcal{E}\, I$

or $\mathcal{E} = vLB$

"Motional emf" induced by a conductor moving in a magnetic field.

Magnetic Flux

Another interpretation:



Magnetic Flux $\Phi \equiv \underbrace{\begin{pmatrix}\text{effective}\\ \text{area}\end{pmatrix}}_{\text{more in a moment}} \cdot B$

area here $= L \cdot x$

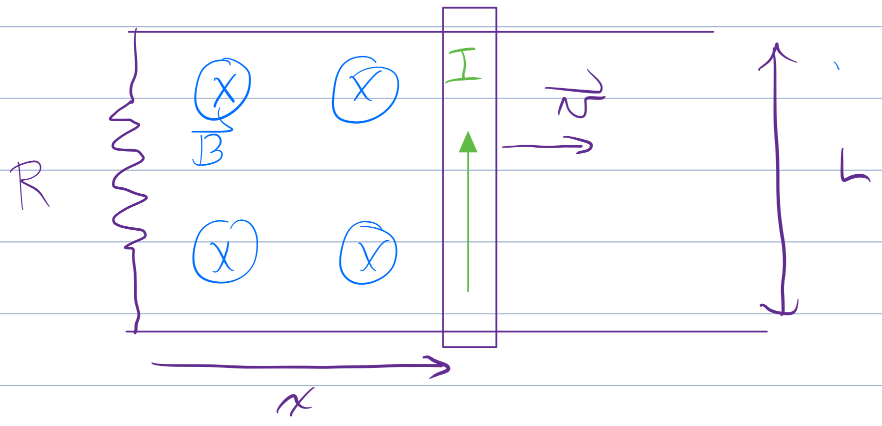
Rate at which area is changing is $L \cdot \frac{dx}{dt} = L \cdot v$

$$\therefore\ |\mathcal{E}| = BLv = \frac{d\Phi}{dt}$$

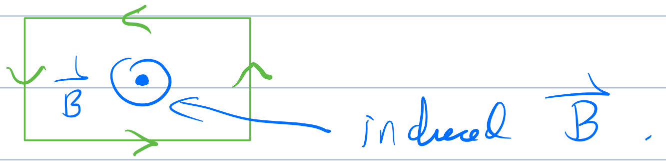
Faraday's Law:

$$\boxed{\mathcal{E} = -\frac{d\Phi}{dt}}$$

$-$ sign: Lenz's Law. The direction of the induced emf opposes the change in flux.



Induced current:



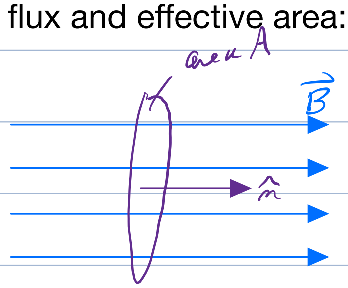
As the bar moves to the right, there is more flux into the page. The induced flux thus comes out of the page.

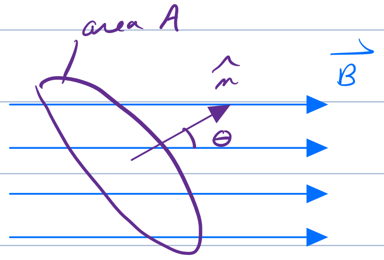
$$\Phi = \vec{B} \cdot \vec{A} = BA\cos\theta$$

$\vec{A} = A\hat{n}$

$\hat{n}$ points ⊥ to area.

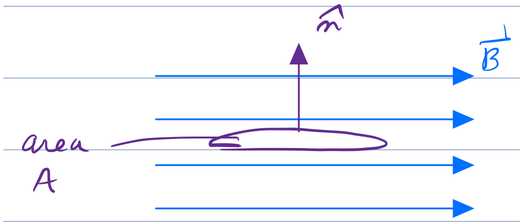
More on flux and effective area:





$\theta = 0$ $\Phi = BA$ is maximum

$\Phi = BA\cos\theta$ is less



$\theta = 90^\circ$ $\Phi = BA\cos 90^\circ = 0$.