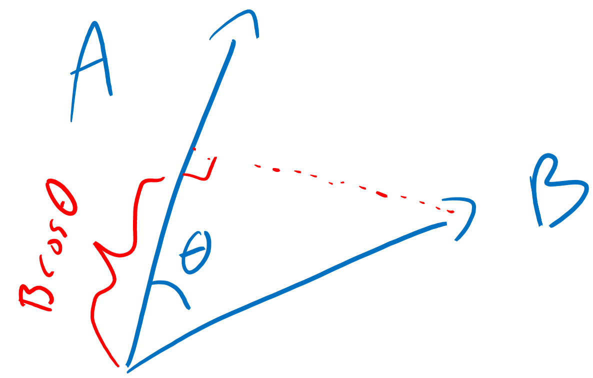
CHAPTER 21:

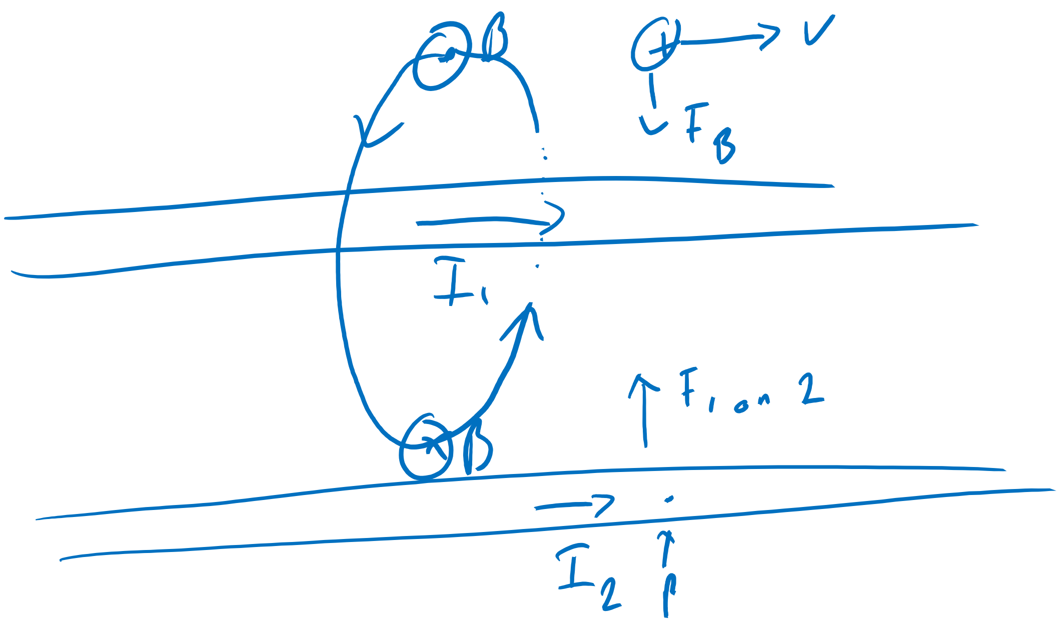
Review

Math:

- Dot product : $\vec{A} \cdot \vec{B} = AB\cos\theta$



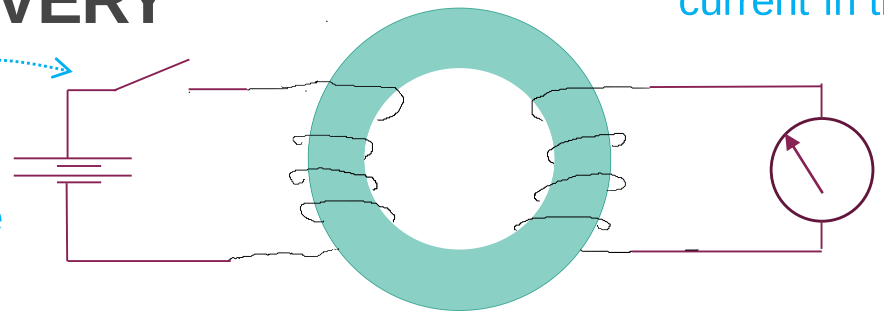
- Current as a source of magnetic field
- Force on a moving charge
- Force on a current-carrying wire



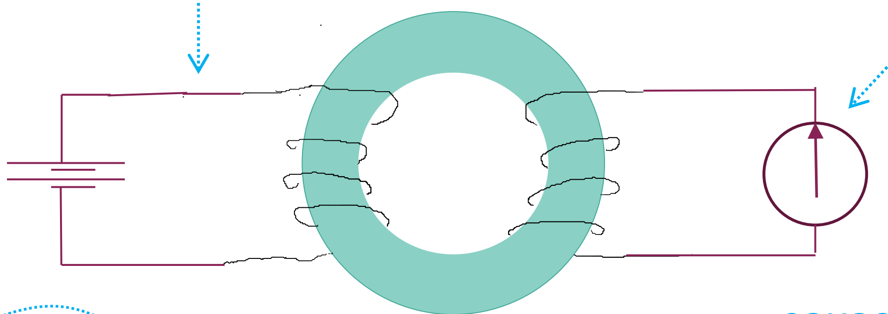
FARADAY’S DISCOVERY

… causes a momentary current in the right circuit.

Faraday noticed that closing the switch in the left circuit…

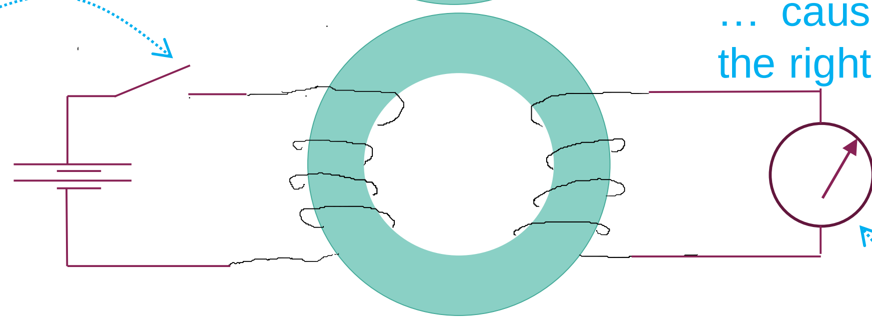


When the switch is closed, no current is detected in the secondary circuit.



Opening the switch in the left circuit…

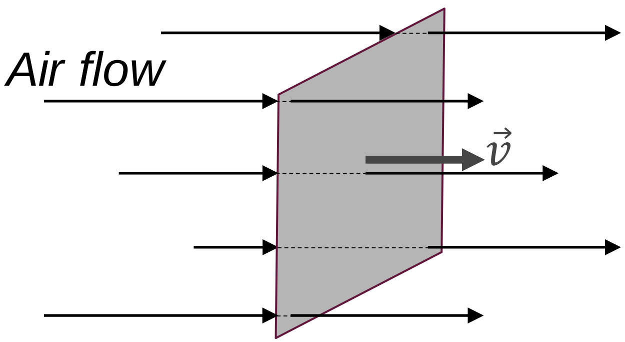
… causes a momentary current in the right circuit.



Direction of the current is opposite to the one observed when the switch was closed.

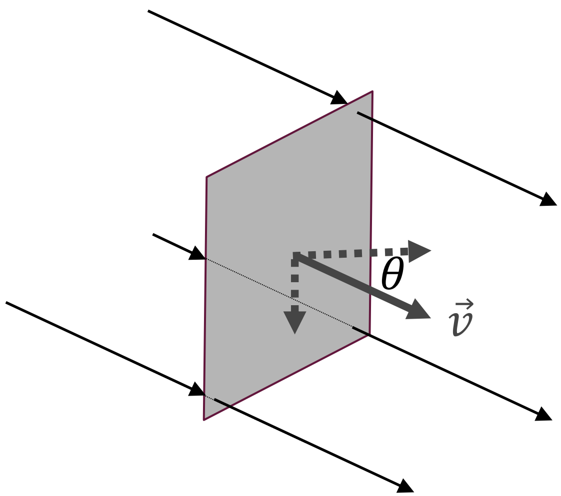
21.2 THE IDEA OF FLUX

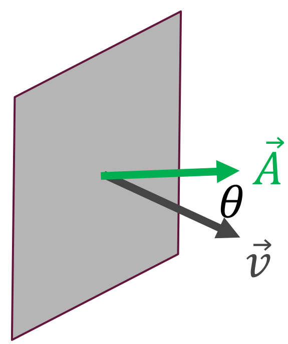
Let's aim a wide airstream of uniform velocity $\vec{v}$ at a small square loop of area A

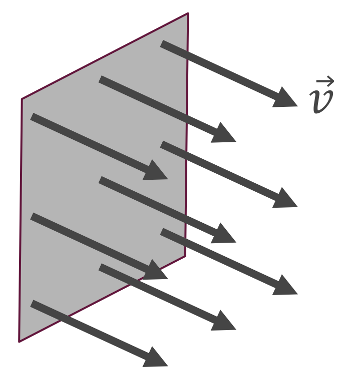


A uniform airstream of velocity $\vec{v}$ us perpendicular to the plane of a square loop area A.

The flow rate $\Phi \propto Av$ and when $\vec{v} \perp A$







The component of the $\vec{v}$ that is perpendicular to the loop is

$$v_{\perp} = v\cos\theta$$

The area vector $\vec{A}$ is perpendicular to the surface, $\measuredangle\left(\vec{A}, \vec{v}\right) = \theta$ and $\left|\vec{A}\right| = A$

Flow rate (flux)

$$\Phi = Av\cos\theta$$

$$\therefore \Phi = \vec{A} \cdot \vec{v}$$

MAGNETIC FLUX

The **magnetic flux** is the amount of magnetic field that passes through a surface. For a uniform magnetic field

$$\Phi_B = BA\cos\theta$$

Unit: $1\ \text{weber} = 1\ \text{Wb} = 1\text{T}\cdot\text{m}^2$

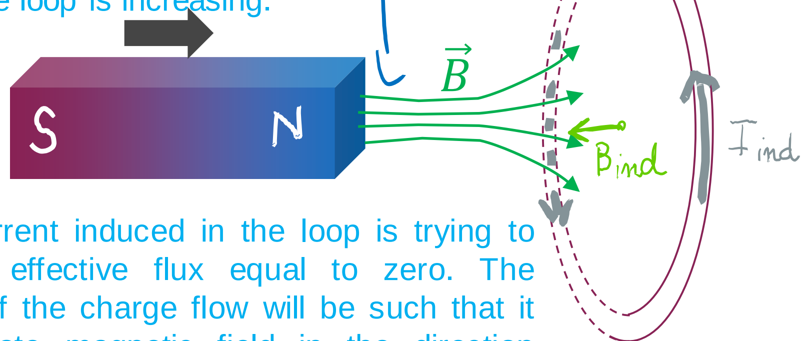
Note:

$$Flux\ through\ a\ closed\ 3D\ surface\ is\ zero.$$

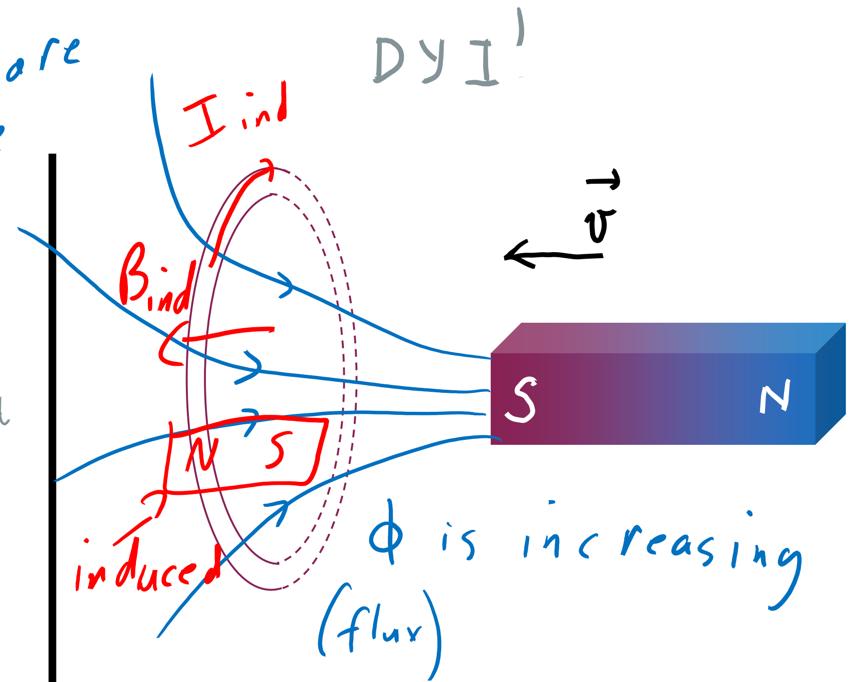
(same number of lines enter & leave)

Lenz's Law

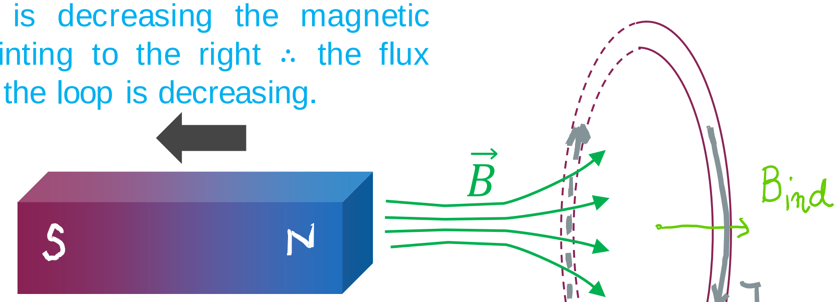
1. A magnet is moving towards the loop, it is bringing stronger magnetic field pointing to the right ∴ the flux through the loop is increasing.



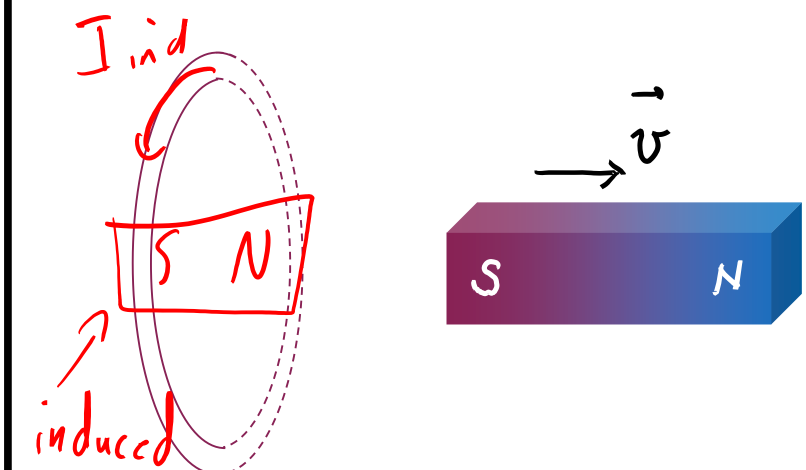
2. The current induced in the loop is trying to keep the effective flux equal to zero. The direction of the charge flow will be such that it would create magnetic field in the direction opposing $\vec{B}$ (as it is increasing)



1. A magnet is moving away from the loop, it is decreasing the magnetic field pointing to the right ∴ the flux through the loop is decreasing.



2. The current induced in the loop is trying to keep the flux through it. The direction of the charge flow will be such that it would crea ate magnetic field in the direction matching $\vec{B}$ (as it is decreasing).



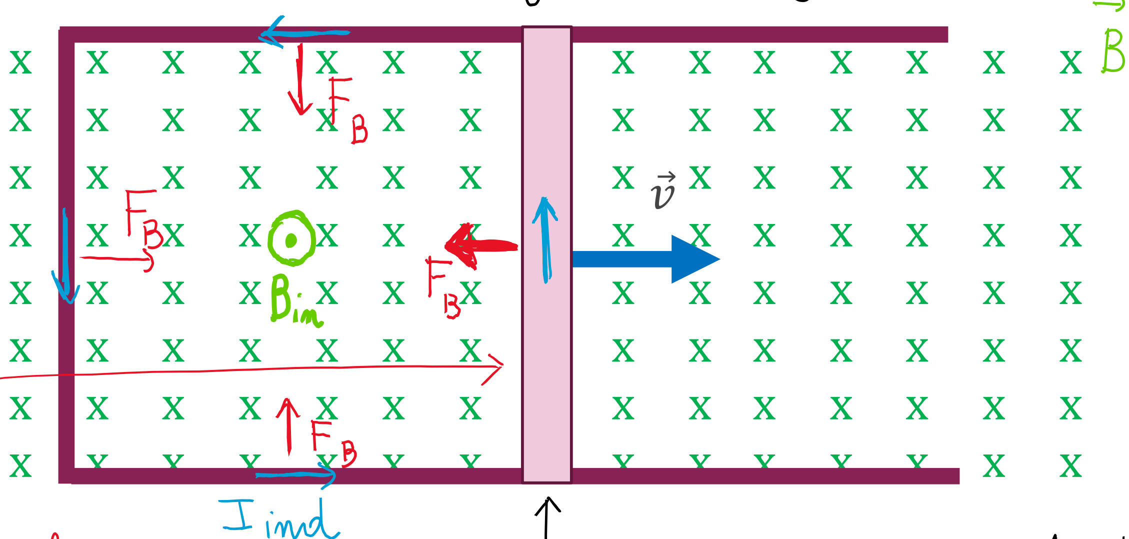
Lenz's Law – A bit differently

What if – instead of moving the magnet and changing the field, we would place a loop in a uniform magnetic field and increased its size?

Remember - it's all about flux

Flux $\propto$ B & A

The system will try to reduce the flux any way it can. Induced current will try to reduce "net" $\vec{B}$



$\vec{B}_{ind}$ is out of the page to do that

induced current is CCW

now there is a current - carrying wire in external $\vec{B}$ field $\rightarrow$ F_B on the wires

area is increasing, B stays the same

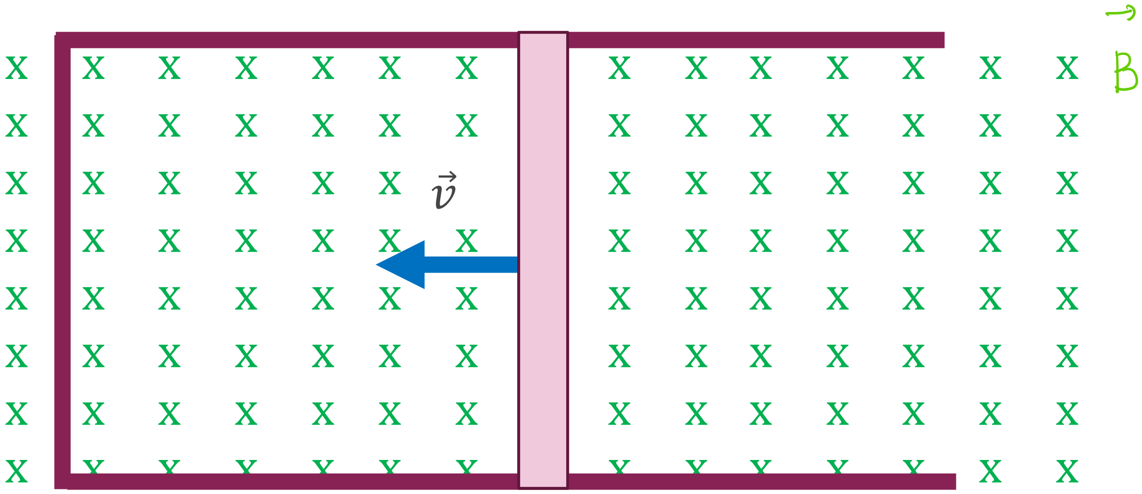
FLUX ↑

Induced field is like a three-year-old: opposes everything you're trying to get them to do

LENZ'S LAW – A BIT DIFFERENTLY

Ok, what if we DECREASE THE SIZE?

TRY LC & DISCUSS IN CLASS

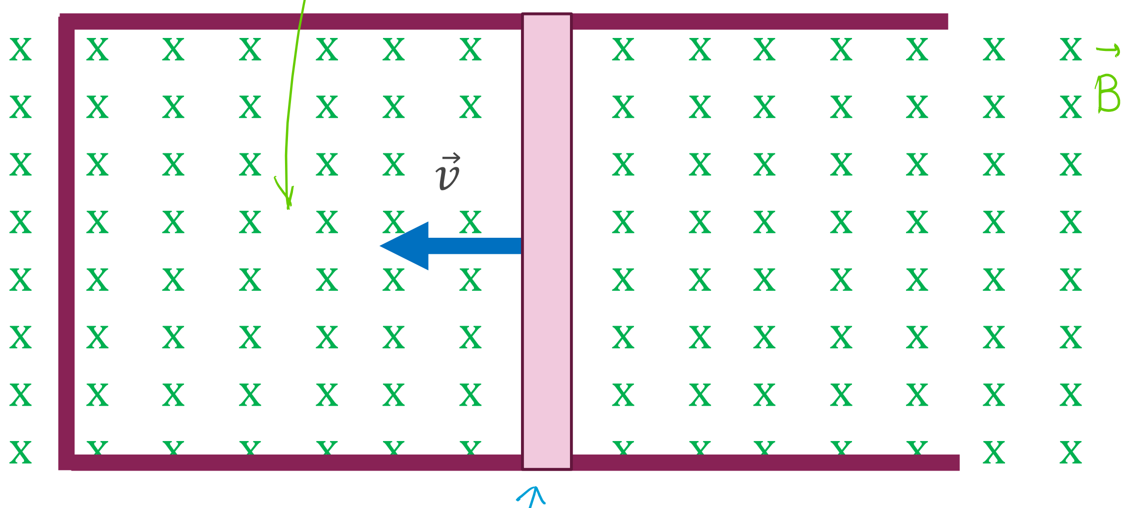


LENZ'S LAW – A BIT DIFFERENTLY

Ok, what if we DECREASE THE SIZE?

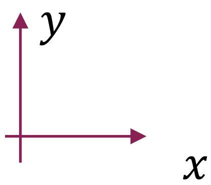
TRY LC & DISCUSS IN CLASS

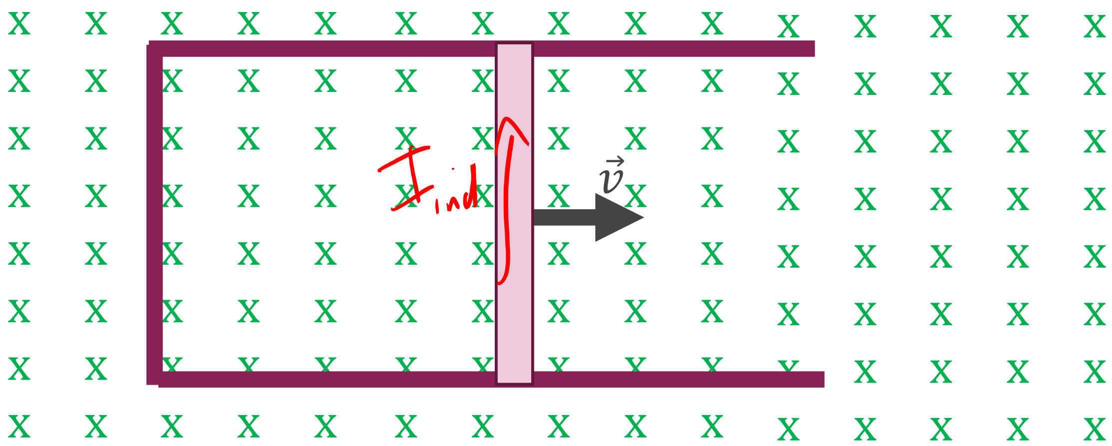
decreasing area → induced field tries to enhance what is already there



induced current needs to create $\vec{B}_{ind}$ into the page

Determine the direction of the magnetic force on the moving wire.

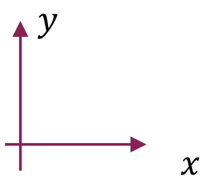


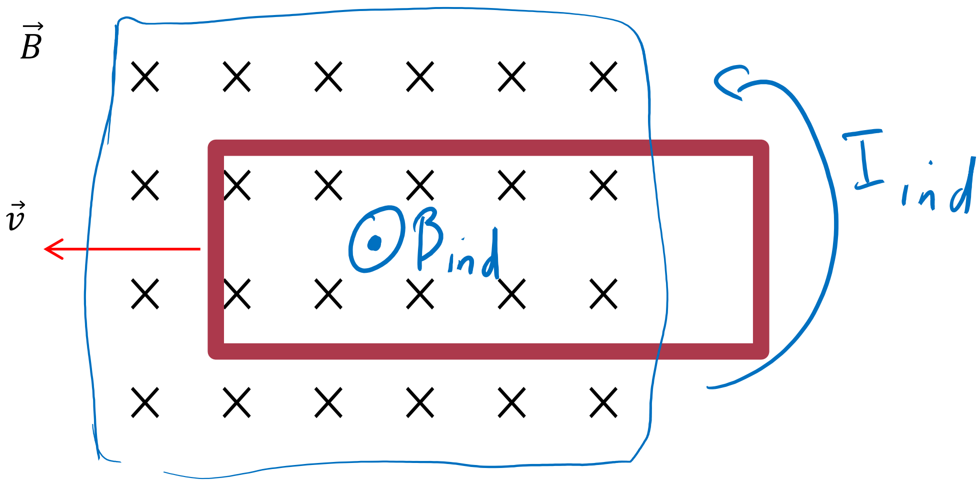


a) Right
b) Left
c) Up
d) Down
e) Out of the page
f) Into the page

Let's think about it together.

Determine the direction of the magnetic current induced in this loop:

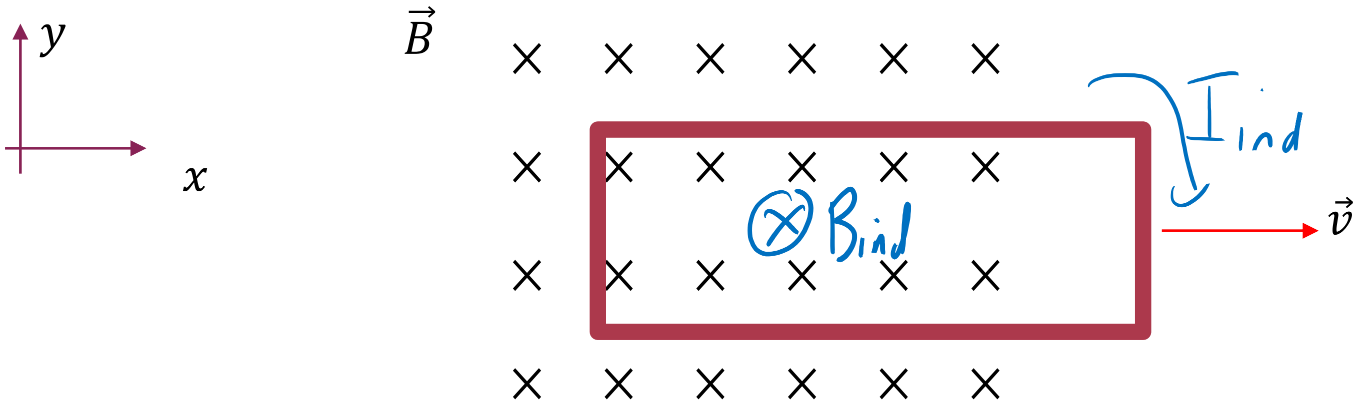




a) Induced current would be clockwise
b) Induced current would be counter-clockwise
c) There will be no current induced in the loop.

Learning Catalytics!

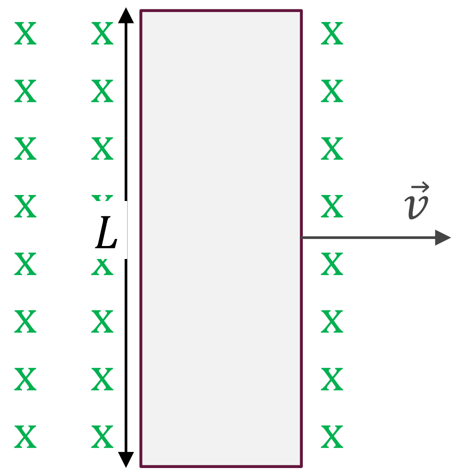
Determine the direction of the magnetic current induced in this loop:



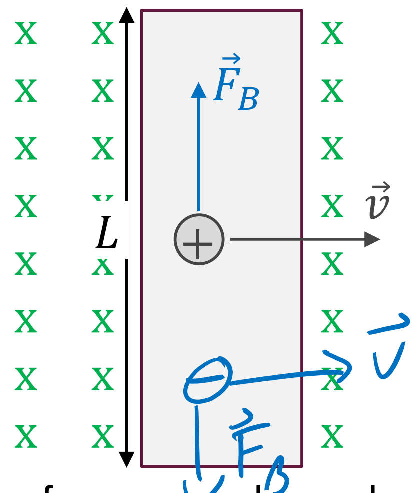
a) Induced current would be clockwise
b) Induced current would be counter-clockwise
c) There will be no current induced in the loop.

A WEIRD IDEA - MOTIONAL EMF

Consider a conductor of length L moving with velocity $\vec{v}$ through perpendicular uniform magnetic field $\vec{B}$.

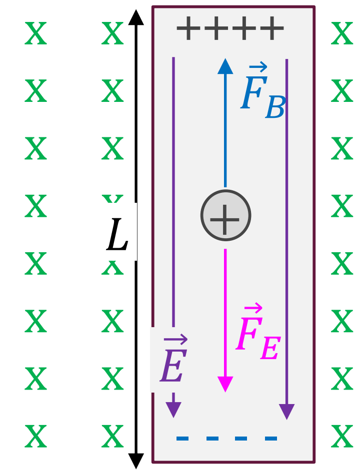


If the bar is moving with velocity $\vec{v}$, every charge inside the bar is moving with the same velocity $\vec{v}$ ...



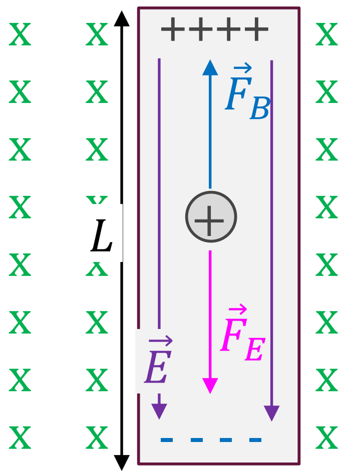
…therefore each charge experiences magnetic force $\vec{F}_B$.

Under the force, the positive charges start accelerating upwards, creating excess of positive charges at the top.



Charge separation creates electric field inside the conductor (no electrostatic equilibrium). As a result, carriers experience electric force $\vec{F}_E$ in addition to the magnetic force $\vec{F}_B$.

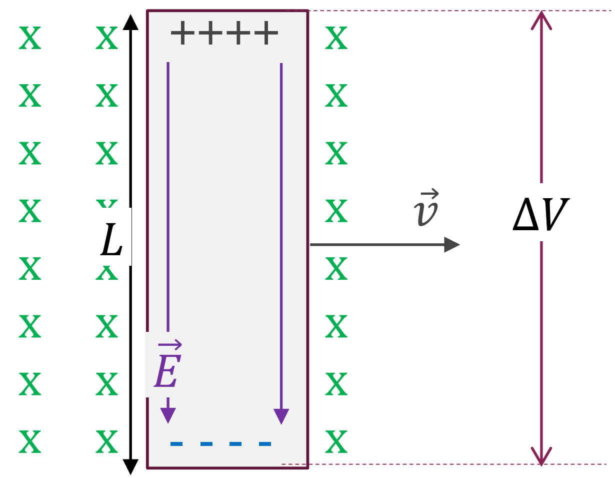
MOTIONAL EMF



Charges continue to separate until magnetic force $\vec{F}_B$ and electric force $\vec{F}_E$ have the same magnitude.

$$qvB = qE$$
$$E = vB$$

The charge separation stays constant (creating $\vec{E}$ and, therefore, potential difference $\Delta V = EL$) as long as the conductor is moving with velocity $\vec{v}$.



Potential difference

$$\Delta V = EL.$$

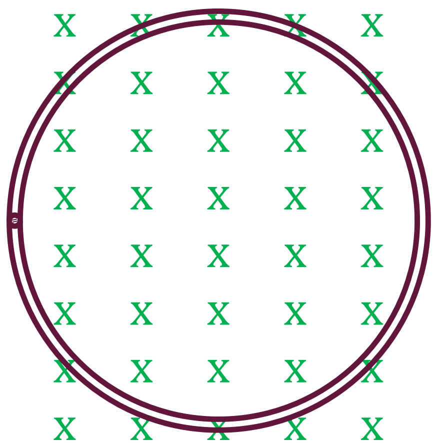
For the conductor moving in magnetic field, electric field inside is equal to

$$E = vB.$$

Combining the two equations leads to ***motional emf***

$$\Delta V = \mathcal{E} = vLB$$

So… if the magnetic field changes without the circuit, does it induce current?



Imagine you have a changing magnetic field – it creates EMF (potential difference) in space.

But … if there is a potential difference, there has to be an electric field pointing in the direction of the lower potential.

So if there was a charge in space, the **induced** electric field would move it around the circuit creating current and doing work

$$|W| = |q\Delta V| = F2\pi R$$

in one loop.

Some shocking things: $\Delta V\ around\ the\ loop\ is\ NOT\ zero$, it is actually equal to the change in flux!

$$q\frac{\Delta\Phi_B}{\Delta t} = qE2\pi R \rightarrow \frac{\Delta\Phi_B}{\Delta t} = 2E\pi R$$

This result is also valid in the absence of a conductor or charges.