Course Updates

http://www.phys.hawaii.edu/~varner/PHYS272-Spr10/physics272.html

Reminders:

1) Assignment #8 → due now

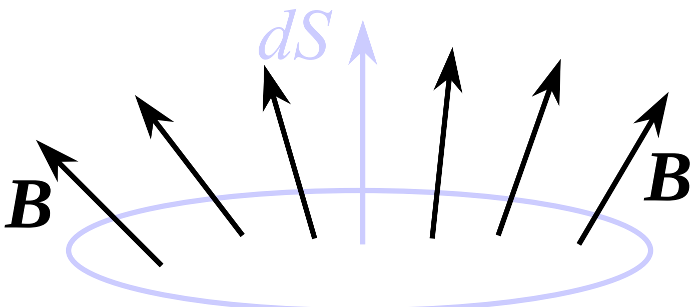
2) Assignment #9 posted by Friday (due Mar 29)

3) Chapter 29 this week (start Inductance)

4) Quiz on Friday (Chap 27 – 28)

Induction

Faraday's Law



$$\Phi_B \equiv \int \vec{B} \bullet d\vec{S}$$

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

Electromagnetic Induction

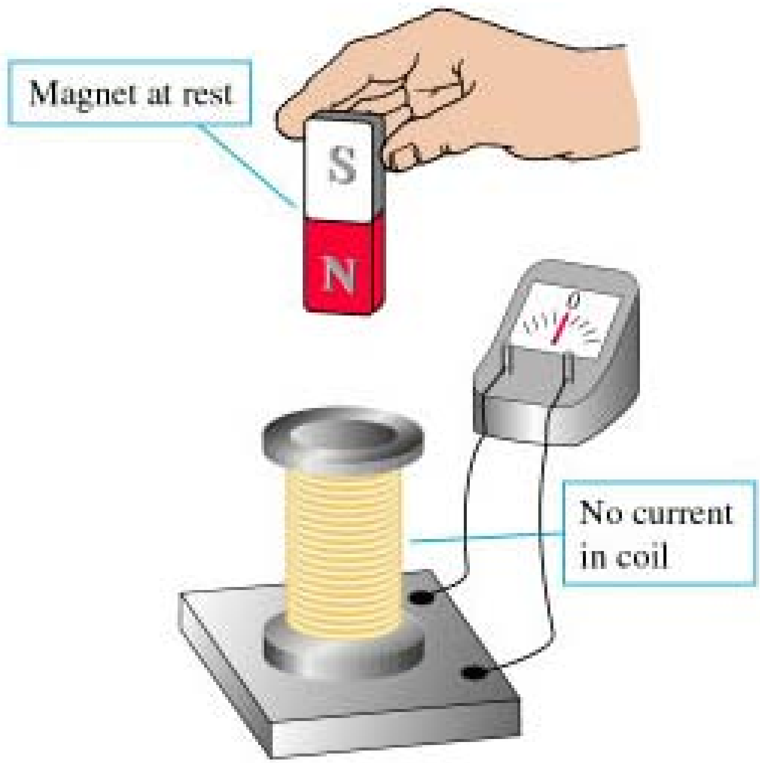
So far we have studied electric fields created from charges and constant magnetic fields created by moving charges.

NOW we investigate effects of time varying magnetic fields on loops and we will find electric fields are *induced* in the loops which creates EMF or current to flow.

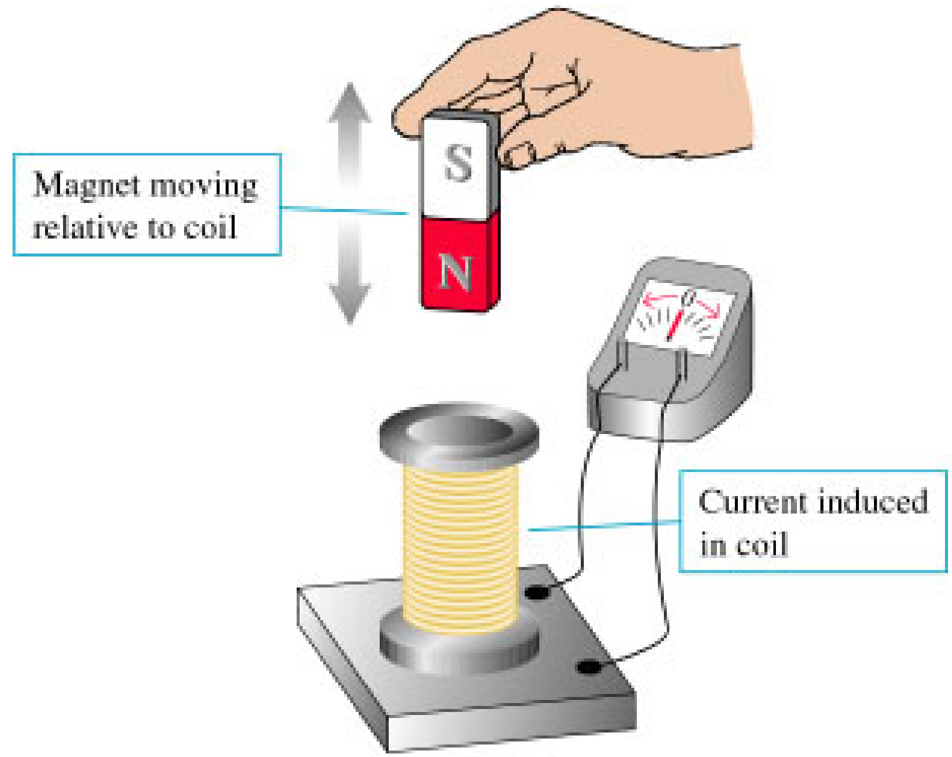
This leads to the very important Maxwell's 3rd law, which is called Faraday's Law. Electric generators are based on the physics of Electromagnetic induction and Faraday's law.

Faraday's Law (chap 29.1-2)

Changing magnetic fields create electric fields

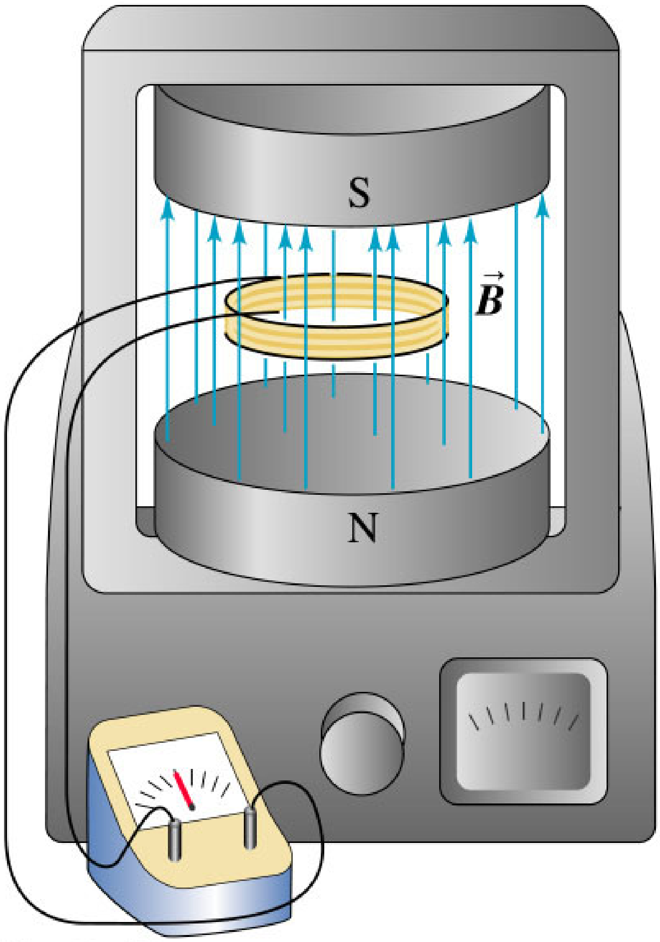


Stationary magnet has fixed magnetic field in the loop and creates NO current in loop

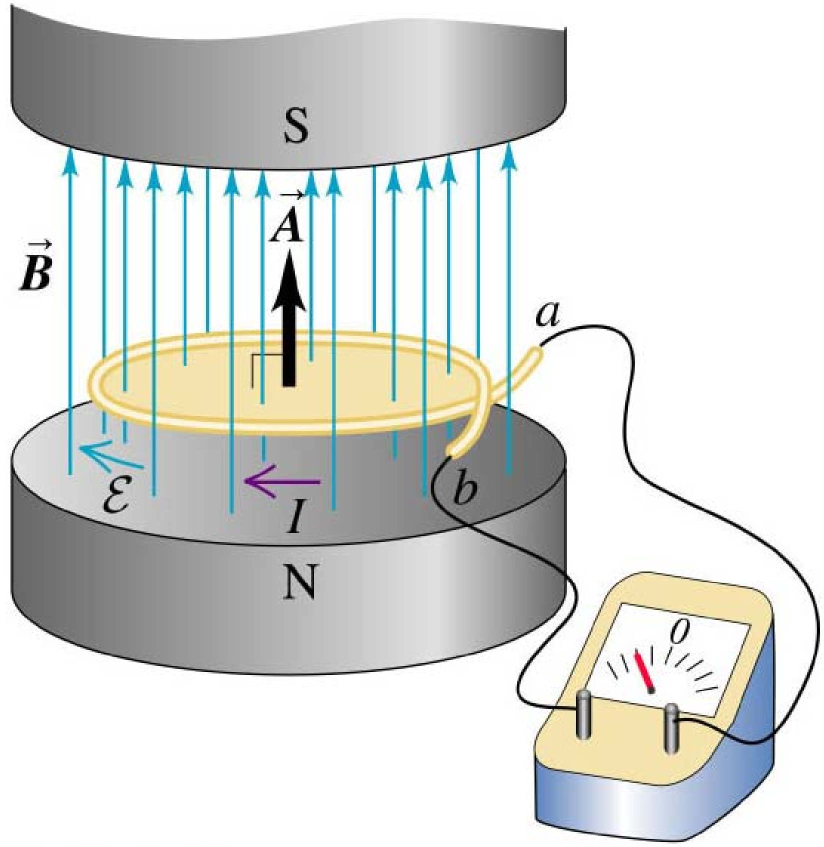


Moving magnet causes changing magnetic field in loop and creates current in loop

Coil fixed in an electromagnet; constant or changing magnetic field



Magnetic field constant
NO current in loop



Magnetic field increasing
Current in loop

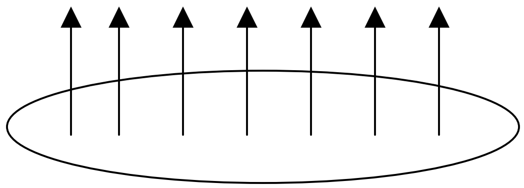
Faraday's Law of Induction

Recall the definition of magnetic flux is $\Phi_B = \int \vec{B} \cdot d\vec{A}$

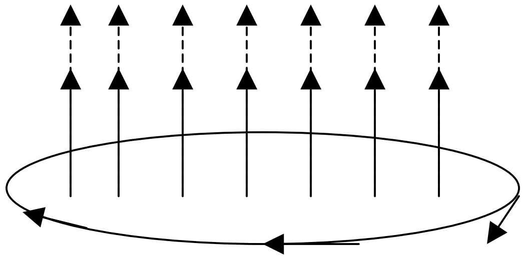
Faraday's Law is the induced EMF in a closed loop equal the negative of the time derivative of magnetic flux change in the loop,

$$\varepsilon = -\frac{d}{dt}\int \vec{B} \cdot d\vec{A} = -\frac{d\Phi_B}{dt}$$

Tricky part is Figuring out the EMF direction



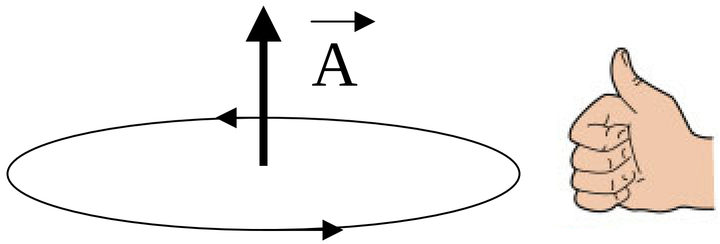
Constant B field, no induced EMF in loop



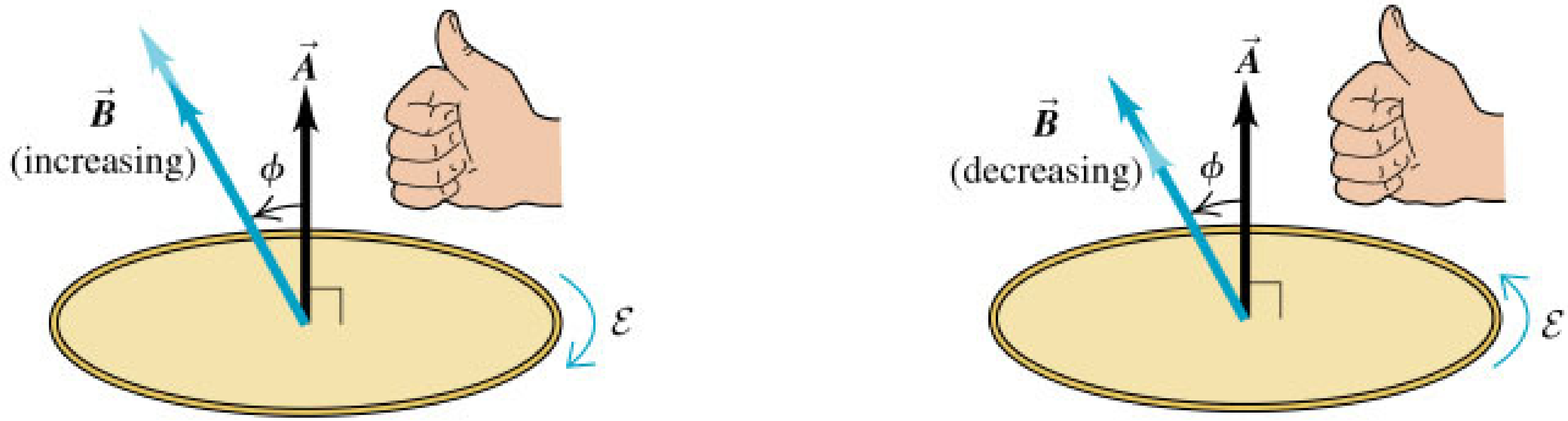
changing B field, causes induced EMF in loop

Getting the sign EMF in Faraday's Law of Induction

Define the loop and an area vector, A, who magnitude is the Area and whose direction normal to the surface.



The choice of vector A direction defines the direction of EMF with a right hand rule. Your thumb in A direction and then your fingers point to positive EMF direction.

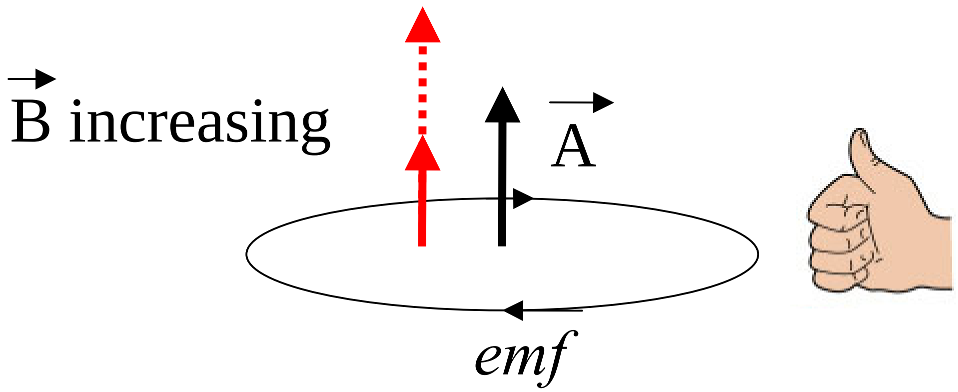


Positive flux ($\Phi_B > 0$)
Flux becoming more positive $\left(\frac{d\Phi_B}{dt} > 0\right)$
Induced emf is negative ($\mathcal{E} < 0$)

(a)

Positive flux ($\Phi_B > 0$)
Flux becoming less positive $\left(\frac{d\Phi_B}{dt} < 0\right)$
Induced emf is positive ($\mathcal{E} > 0$)

(b)

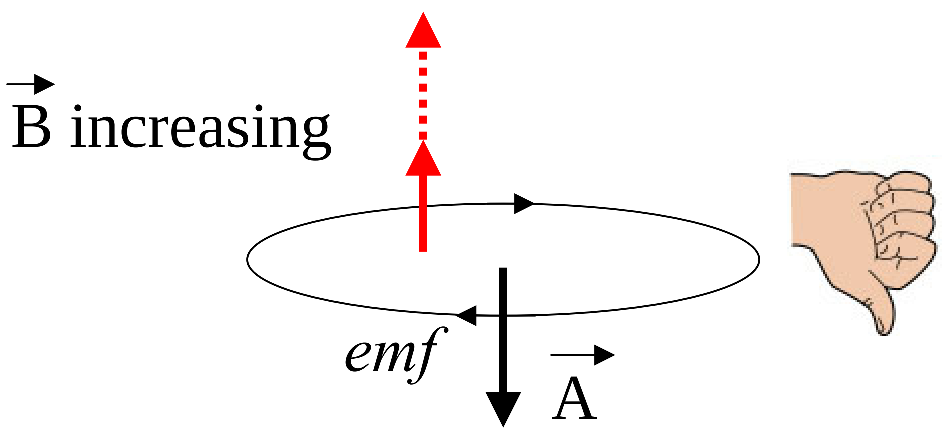


If we defined the area vector up, then

$$\frac{d\Phi_B}{dt} > 0$$

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

and emf is negative and it flows opposite to fingers



If we defined the area vector down, then

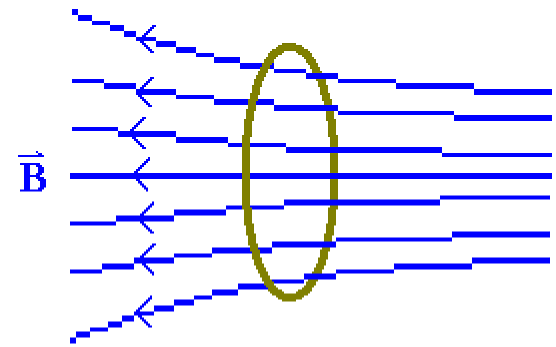
$$\frac{d\Phi_B}{dt} < 0$$

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

and emf is positive and it flows same direction as fingers

We get SAME results for EMF direction if A up or down

Examples:



A copper loop is placed in a non-uniform magnetic field. The magnetic field does not change in time. You are looking from the right.

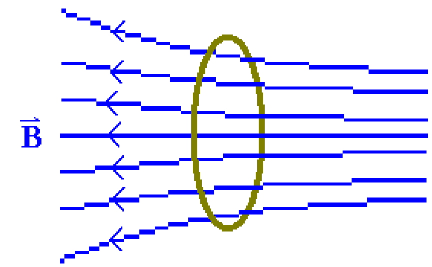
1) Initially the loop is stationary. What is the induced current in the loop?

a) zero
b) clockwise
c) counter-clockwise

2) Now the loop is moving to the right, the field is still constant. What is the induced current in the loop?

a) zero
b) clockwise
c) counter-clockwise

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



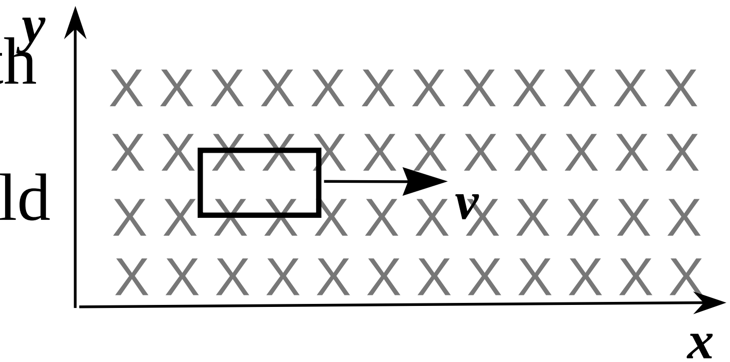
When the loop is stationary: the flux through the ring does not change!!!
$\Rightarrow d\Phi/dt = 0 \quad \Rightarrow$ there is no emf induced and no current.

When the loop is moving to the right: the magnetic field at the position of the loop is increasing in magnitude. $\Rightarrow |d\Phi/dt| > 0$
$\Rightarrow$ there is an emf induced and a current flows through the ring.

Use Lenz' Law to determine the direction: The induced emf (current) opposes the change!
The induced current creates a B field at the ring which opposes the increasing external B field.

More examples

- A conducting rectangular loop moves with constant velocity v in the $+x$ direction through a region of constant magnetic field B in the $-z$ direction as shown.

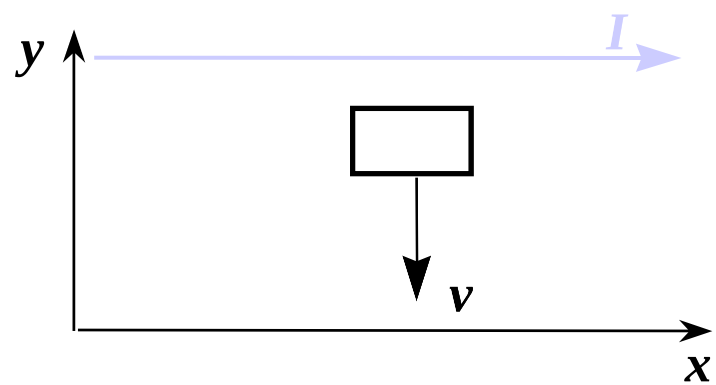


2A

- What is the direction of the induced current in the loop?

(a) **ccw** (b) **cw** (c) **no induced current**

- **A conducting rectangular loop moves with constant velocity v in the $-y$ direction and a constant current I flows in the $+x$ direction as shown.**



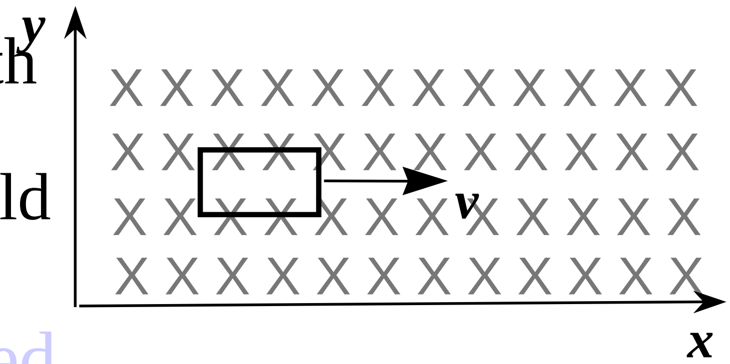
2B

- **What is the direction of the induced current in the loop?**

(a) **ccw** (b) **cw** (c) **no induced current**

Ex. 2A

- A conducting rectangular loop moves with constant velocity v in the $+x$ direction through a region of constant magnetic field B in the $-z$ direction as shown.



2A

– What is the direction of the induced current in the loop?

(a) **ccw** (b) **cw** (c) **no induced current**

- There is a non-zero flux Φ_B passing through the loop since B is perpendicular to the area of the loop.

- Since the velocity of the loop and the magnetic field are CONSTANT, however, this flux DOES NOT CHANGE IN TIME.

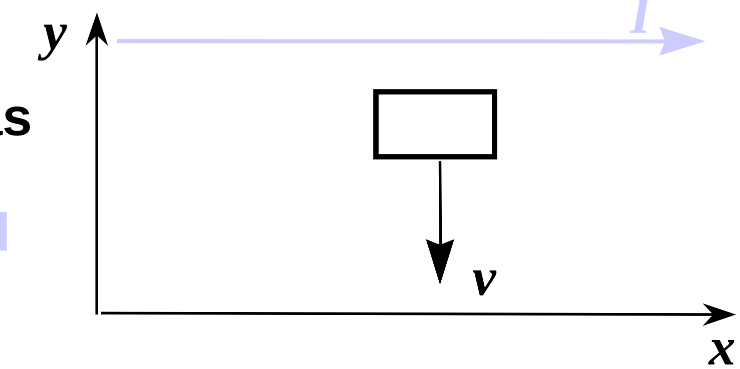
- Therefore, there is NO emf induced in the loop; NO current will flow!!

Ex. 2B

• **A conducting rectangular loop moves with constant velocity v in the $-y$ direction and a constant current I flows in the $+x$ direction as shown.**

2B

• **What is the direction of the induced current in the loop?**



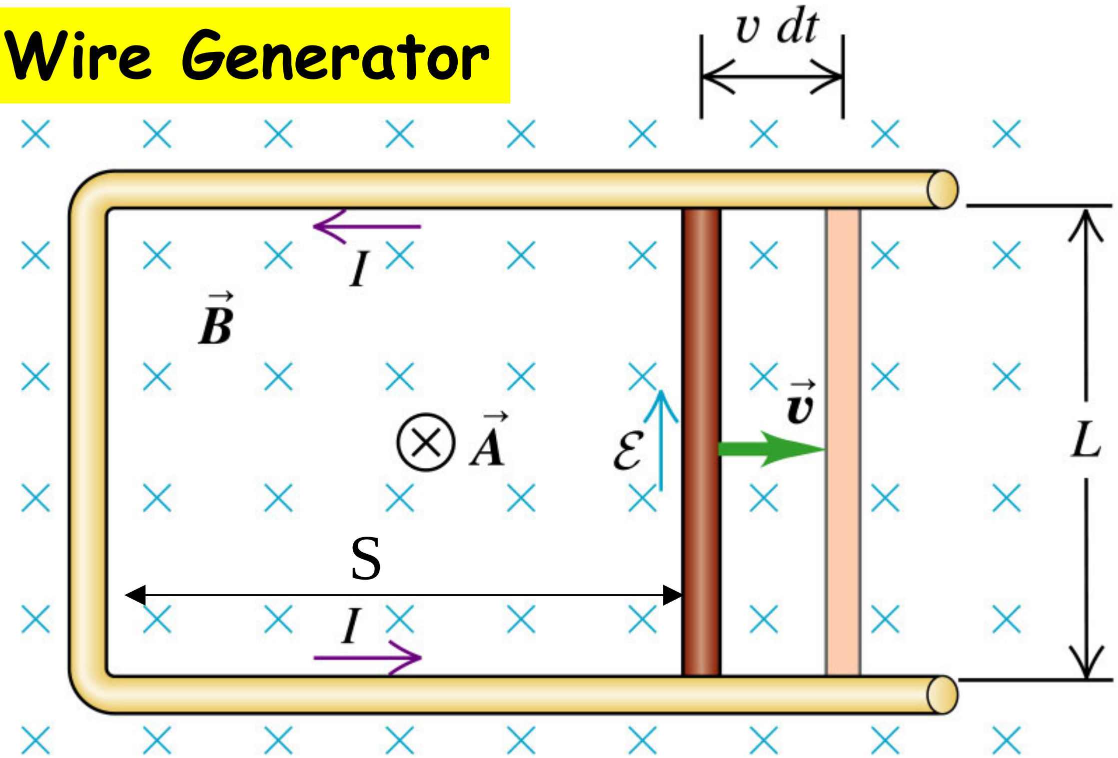
(a) ccw **(b) cw** **(c) no induced current**

• The flux through this loop DOES change in time since the loop is moving from a region of higher magnetic field to a region of lower field.

• Therefore, by Lenz' Law, an emf will be induced which will oppose the change in flux.

• Current is induced in the clockwise direction to restore the flux.

Slide Wire Generator

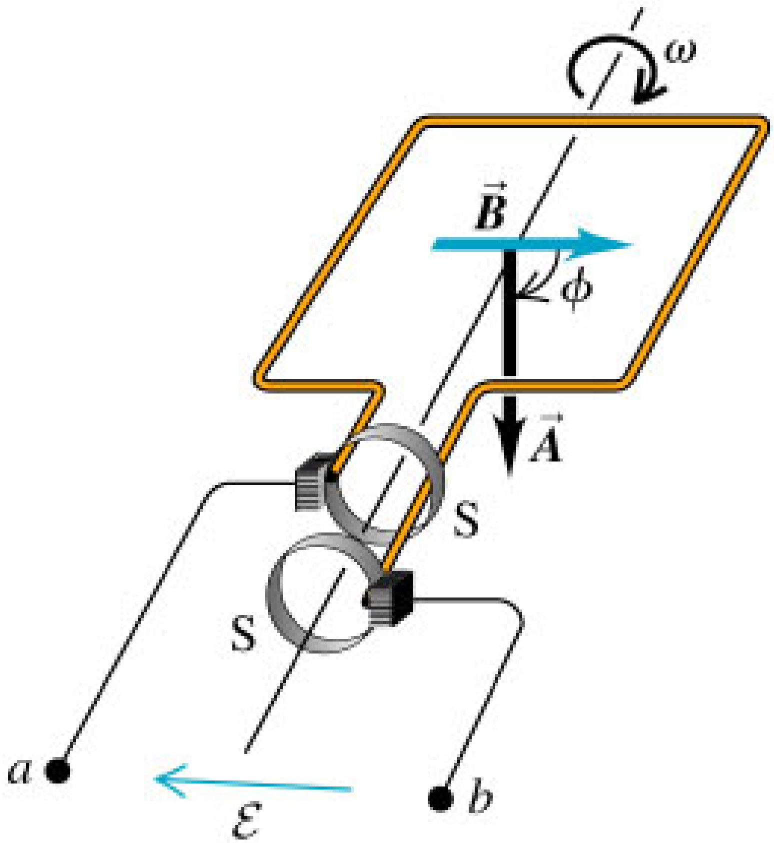


The area is LS(t) and dS/dt equals velocity of slider

$$\varepsilon = -\frac{d}{dt}\Phi_B = -\frac{d}{dt}\int \vec{B} \bullet d\vec{A} = -\frac{d}{dt}\int B\,dA$$

$$= -\frac{d}{dt}BA = -\frac{d}{dt}BLS = -BL\frac{d}{dt}S = -BLv$$

Alternator Generator



Wire loop area A rotates with respect to constant magnetic field.

$$\Phi_B = \int \vec{B} \bullet d\vec{A} = BA\cos\phi$$

If the angular frequency is ω, then

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

$$\frac{d}{dt}\Phi_B = -BA\omega\sin(\omega t)$$

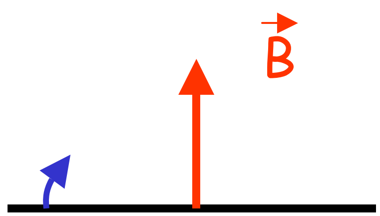
and EMF in the loop is

$$\varepsilon = -\frac{d}{dt}\Phi_B = BA\omega\sin(\omega t)$$

Y&F Problem 29.2

In a physics laboratory experiment, a coil with 200 turns enclosing an area of 122cm^2 is rotated in a time interval of 0.04s from a position where its plane is perpendicular to the earth's magnetic field to one where its plane is parallel to the field. The earth's magnetic field at the lab location is 6x10(-5)T.

What is the total magnetic flux through the coil before it is rotated?
What is the total magnetic flux through the coil after it is rotated?
What is the average emf induced in the coil?



$$\Phi_i = \int \vec{B} \bullet d\vec{A} = B\cos 0^o \int dA = BA$$

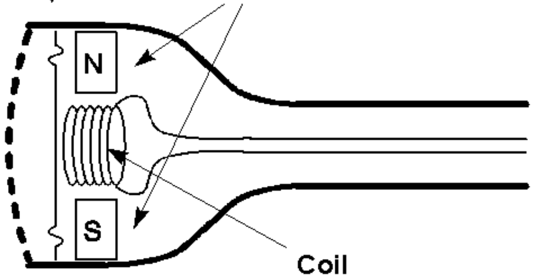
$$= (6x10^{-5}T)(0.0122m^2) = 7.31x10^{-7}Tm^2$$

$$\Phi_f = B\cos 90 A = 0$$

$$\bar{\varepsilon} = -\frac{(\Phi_f - \Phi_i)}{\Delta t} = +\frac{7.31x10^{-7}Tm^2}{0.04s} = 1.83x10^{-5}Tm^2$$

Applications of Magnetic Induction

- AC Generator
  - Water turns wheel
    - → rotates magnet
    - → changes flux
    - → induces emf
    - → drives current



- "Dynamic" Microphones
  (E.g., some telephones)
  - Sound
    - → oscillating pressure waves
    - → oscillating [diaphragm + coil]
    - → oscillating magnetic flux

More Applications of Magnetic Induction

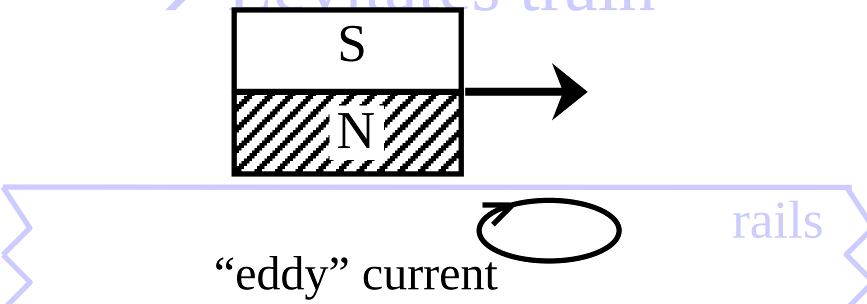
- Tape / Hard Drive / ZIP Readout
  - Tiny coil responds to change in flux as the magnetic domains (encoding 0's or 1's) go by.

    2007 Nobel Prize!!!!!!!!

- Credit Card Reader
  - Must swipe card
  - flux
  - signal

More Applications of Magnetic Induction

- Magnetic Levitation (Maglev) Trains
  - Induced surface ("eddy") currents produce field in opposite direction
    - → Repels magnet
    - → Levitates train



  - Maglev trains today can travel up to 310 mph

Summary

- Faraday's Law (Lenz's Law)
  - a changing magnetic flux through a loop induces a current in that loop

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

$$\Phi_B \equiv \int \vec{B} \bullet d\vec{S}$$

negative sign indicates that the induced EMF opposes the change in flux