

# Physics 102: Lecture 10

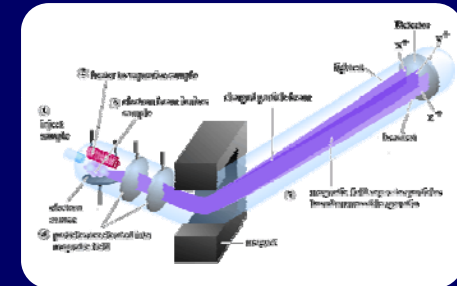
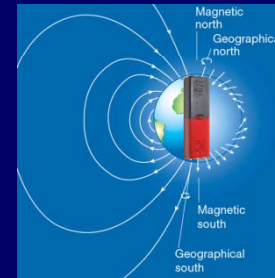
## Faraday's Law

Changing Magnetic Fields create Electric Fields

- Exam 1 tonight
- Be sure to bring your ID and go to correct room
- All you need is a #2 pencil, calculator, and your ID
  - No cell phones
  - No iPods, iPads, laptops, etc.
- CHEATING – we will prosecute!

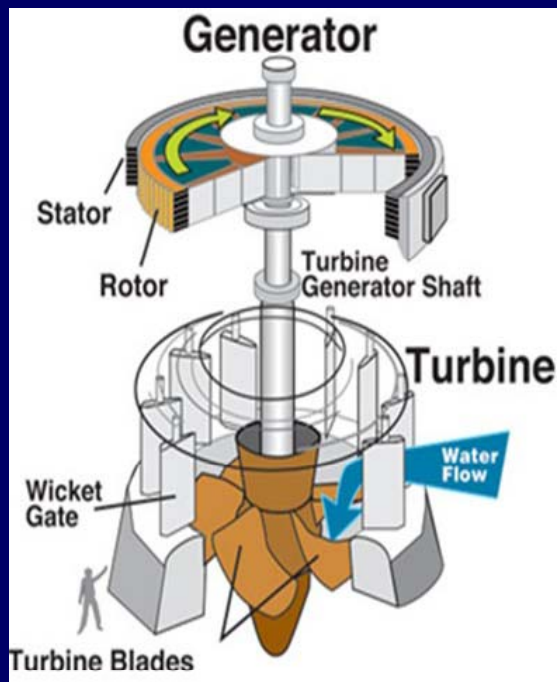
# Last Two Lectures

- Magnetic fields
- Forces on moving charges and currents
- Torques on current loops
- Magnetic field created by
  - Long straight wire
  - Solenoid



# Today

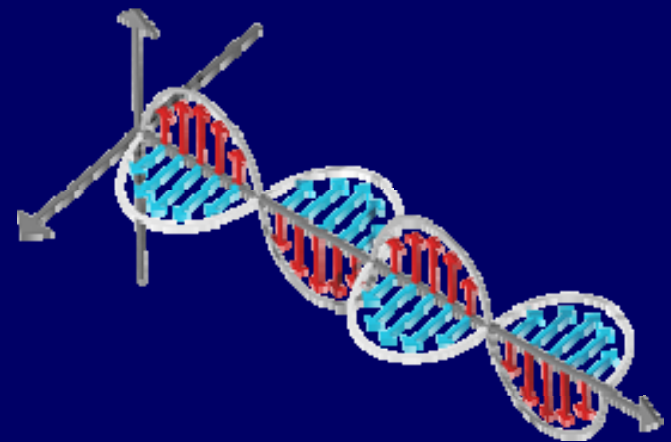
## Changing magnetic flux creates a voltage Faraday's and Lenz's Laws



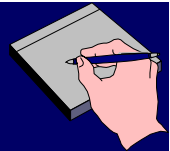
Generators



Transformers

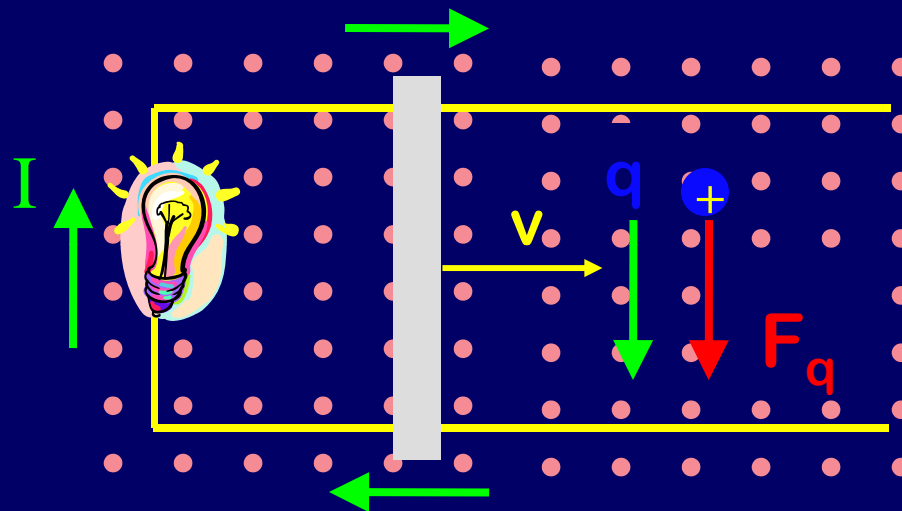


Electromagnetic Waves

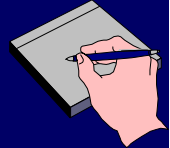


# Motional EMF

- A metal bar slides with velocity  $v$  on a track in a uniform  $B$  field



- Moving + charges in bar experience force down (RHR1)
- Electrical current driven clockwise!
- Moving bar acts like a battery (i.e. generates EMF)!!



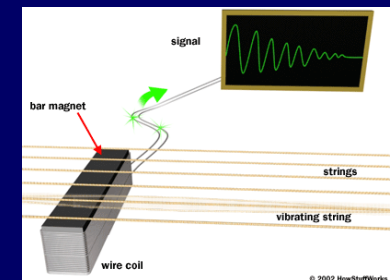
# Faraday's Law of Induction:

“induced EMF” = rate of change of magnetic flux

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_f - \Phi_i}{t_f - t_i}$$

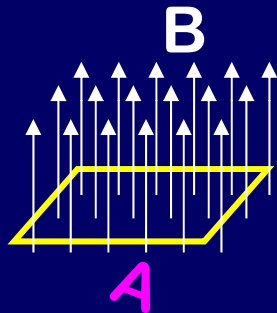
- The principle that unifies electricity and magnetism
- Key to many things in E&M

- Generating electricity
- Electric guitar pickups
- Credit card readers



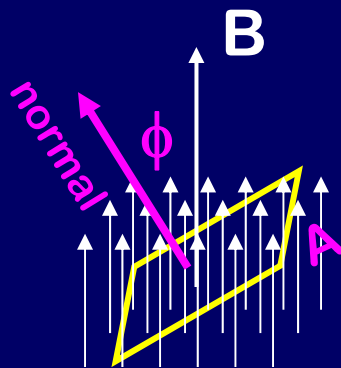
# First a definition: Magnetic Flux

- “Counts” number of field lines through loop.



Uniform magnetic field,  $B$ , passes through a plane surface of area  $A$ .

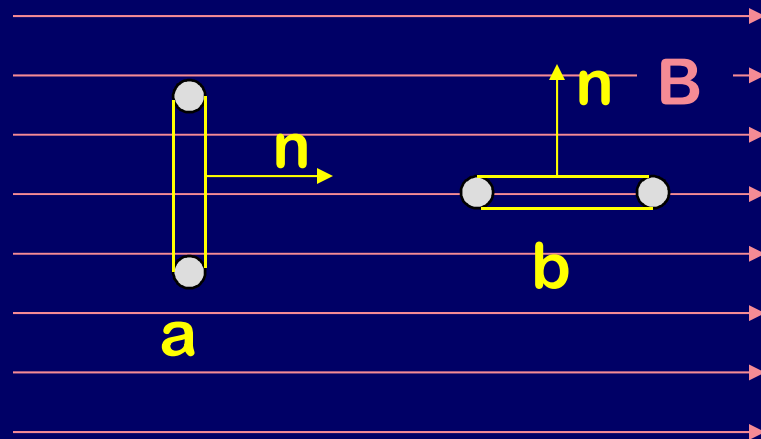
Magnetic flux  $\Phi = B A$   
(Units  $\text{Tm}^2 = \text{Wb}$ )



Magnetic flux  $\Phi \equiv B A \cos(\phi)$

$\phi$  is angle between normal and  $B$

# CheckPoint 1.2



“more lines pass through its surface in that position.”

$$\Phi_A = B A \cos(0) = BA$$

$$\Phi_B = B A \cos(90) = 0$$

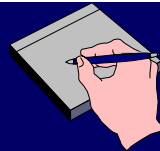
Compare the flux through loops a and b.

1)  $\Phi_a > \Phi_b$

68%

2)  $\Phi_a < \Phi_b$

32%



# Faraday's Law of Induction:

“induced EMF” = rate of change of magnetic flux

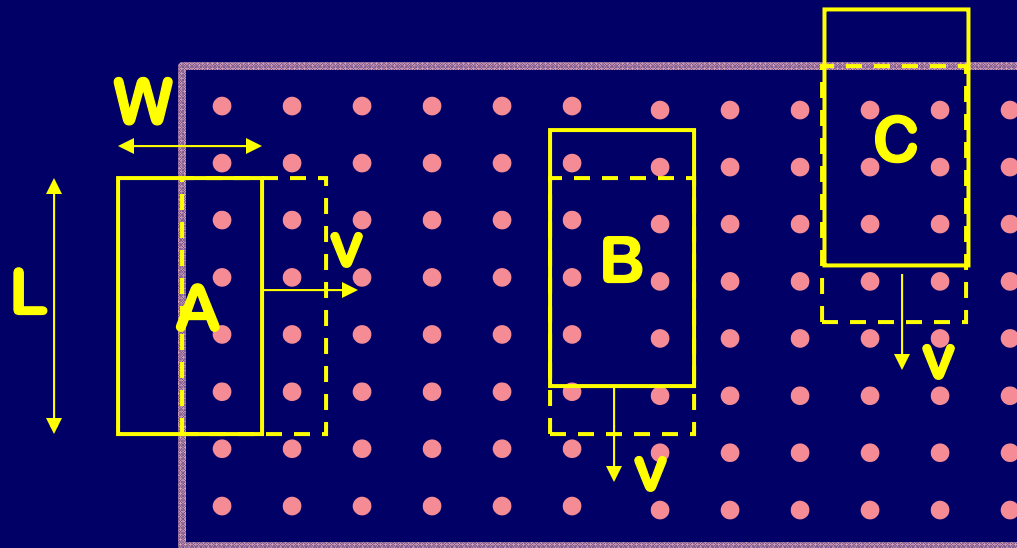
$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_f - \Phi_i}{t_f - t_i}$$

Since  $\Phi = B A \cos(\phi)$ , 3 things can change  $\Phi$

1. Area of loop (*covered by flux*)
2. Magnetic field B
3. Angle  $\phi$  between normal and B



# ACT: Change Area



$$|\mathcal{E}| = \frac{\Delta\Phi}{\Delta t}$$

Which loop has the greatest induced EMF at the instant shown above?

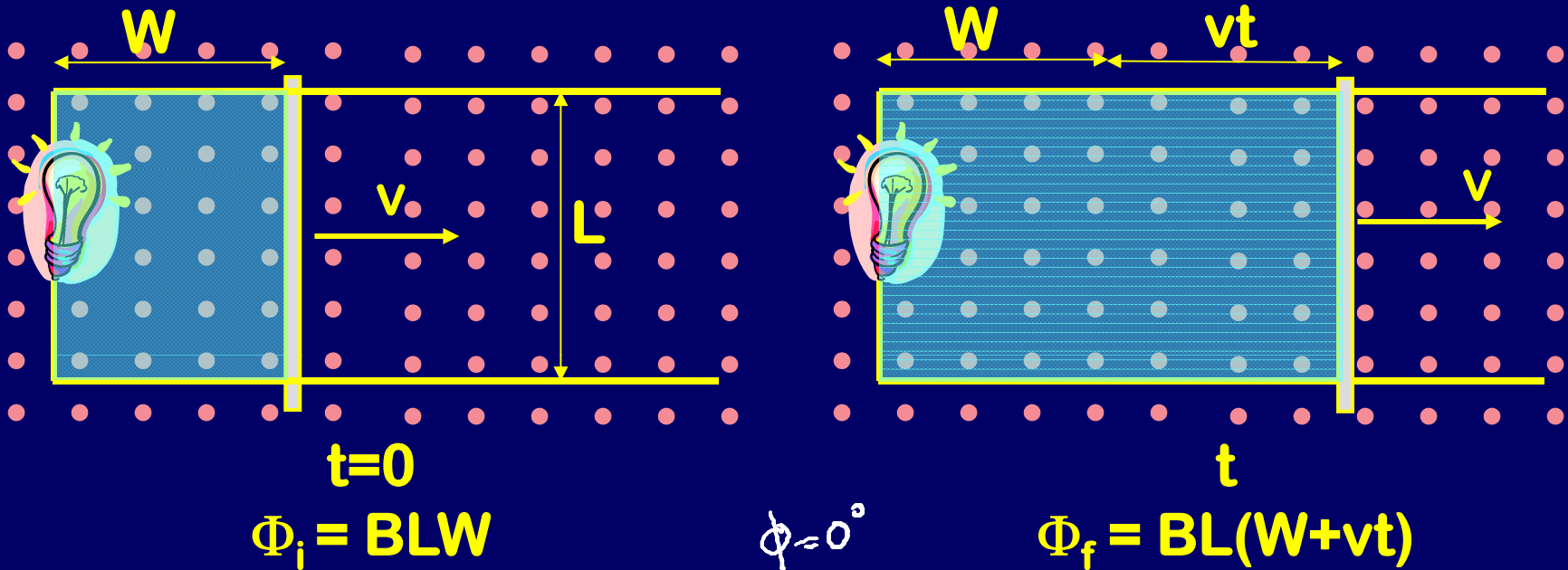
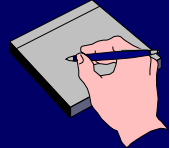
**A moves right - gets 4 more field lines.**

**B moves down - gets 0 more field lines.**

**C moves down - only gets 2 more lines.**

# Example

## Faraday: Change Area

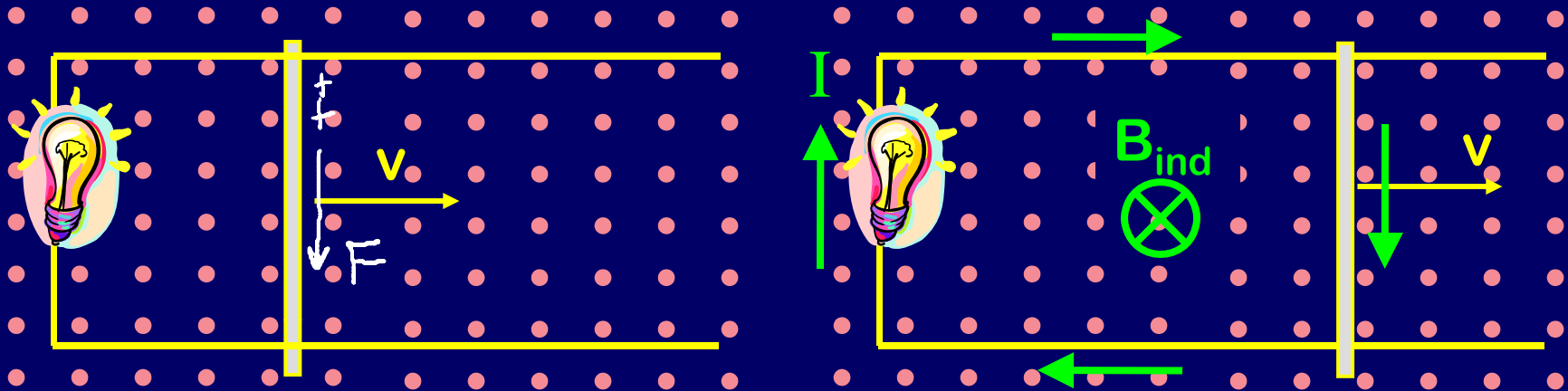
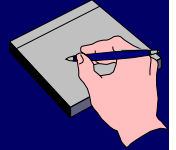


$$\Phi = B A \cos(\phi)$$

$$\text{EMF Magnitude: } |\varepsilon| = \frac{\Delta\Phi}{\Delta t} = \frac{\Phi_f - \Phi_i}{t - 0} = \frac{BL(\cancel{W} + vt) - \cancel{BLW}}{t - 0} = BLv$$

What about the sign of the EMF?

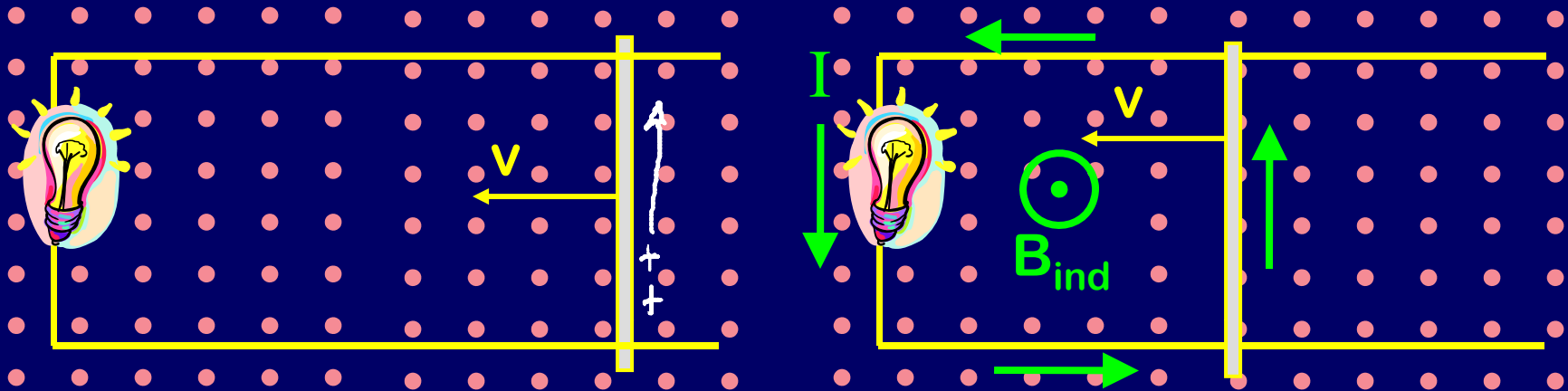
# Lenz's Law (EMF direction)



- Flux is increasing
- Induced current is clockwise
- Current loop generates induced B field
  - from RHR2, into page, opposite external B field!

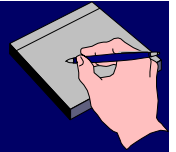
What happens if the velocity is reversed?

# Lenz's Law (EMF direction)



- Flux is decreasing
- Induced current is counterclockwise RHR1
- Current loop generates induced B field
  - from RHR2, out of the page, along external B field!

Induced EMF opposes change in flux



# Lenz's Law (EMF Direction)

Induced emf opposes change in flux

$$\varepsilon = - \frac{\Delta\Phi}{\Delta t} = - \frac{\Phi_f - \Phi_i}{t_f - t_i}$$

- If flux increases:

New EMF makes new field **opposite to** original field

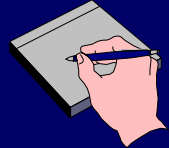
- If flux decreases:

New EMF makes new field **in same direction as** original field

EMF does NOT oppose B field, or flux!

EMF opposes the CHANGE in flux

# Motional EMF also creates forces



- Magnitude of current

$$I = \varepsilon/R = vBL/R$$

- Direction of Current

**Clockwise (+ charges go down thru bar, up thru bulb)**

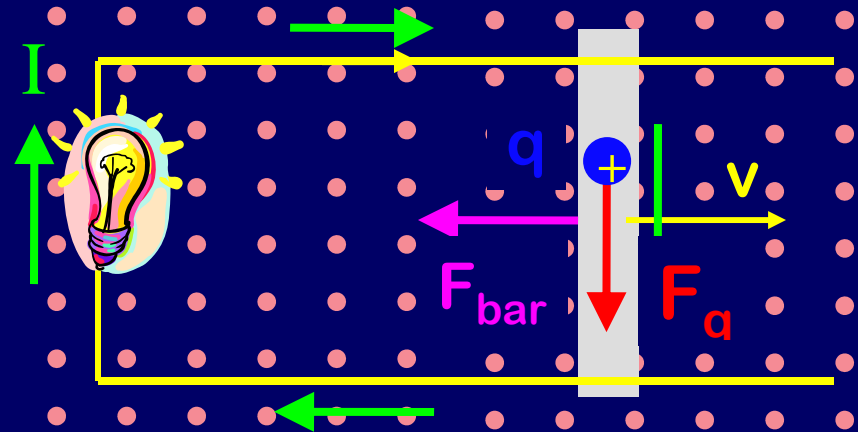
- B field generates force on current-carrying bar

$$F_{\text{bar}} = ILB \sin(\theta), \text{ to left (RHR1)} \quad F_{\text{bar}} \text{ opposes } v!$$

- Careful! There are two forces:

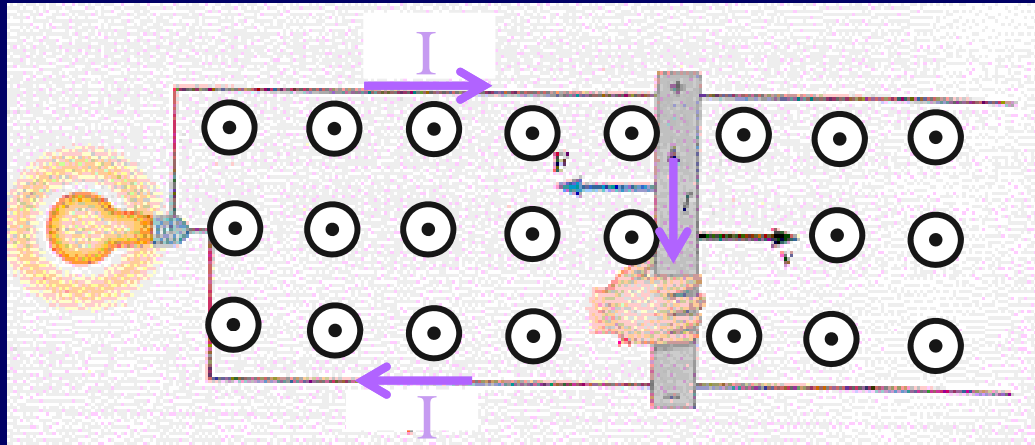
$F_{\text{bar}}$  = force on bar from induced current

$F_q$  = force on + charges in bar driving induced current



# CheckPoint 1.1

The field is reversed to point out of the page instead of in...



To keep the bar moving at the same speed, the force supplied by the hand will have to:

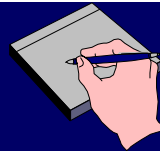
25% • Increase

63% • Stay the Same

12% • Decrease

$$F=ILB \sin(\theta)$$

**B and v still perpendicular ( $\theta=90$ ),  
so  $F=ILB$  just like before!**



# Faraday's Law of Induction:

“induced EMF” = rate of change of magnetic flux

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Since  $\Phi = B A \cos(\phi)$ , 3 things can change  $\Phi$

- ✓ 1. Area of loop (*covered by flux*)
2. Magnetic field B
3. Angle  $\phi$  between normal and B



# ACT: Induction cannon (Demo)

A solenoid is driven by an increasing current. A loop of wire is placed around it

$$B_{\text{sol}} \uparrow \quad \Phi \uparrow$$

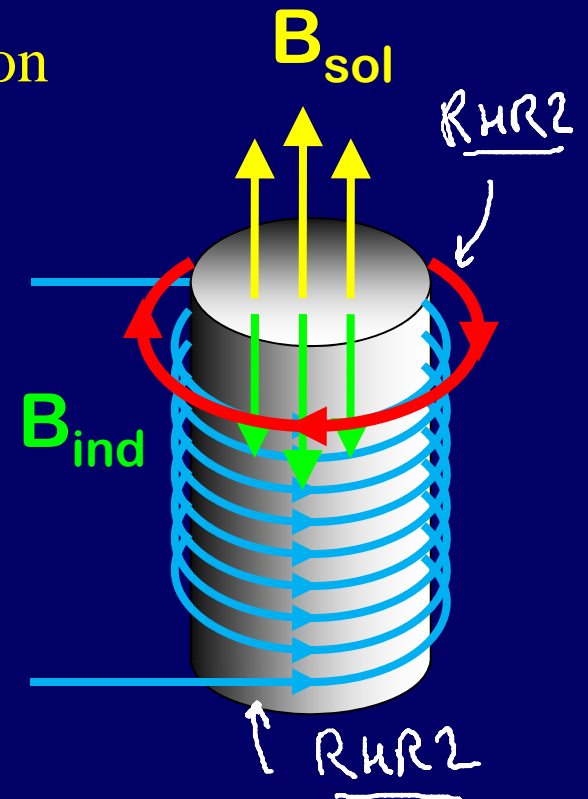
As current increases in the solenoid, what direction will induced current be in ring?

A. Same as solenoid

**B. Opposite of solenoid**

C. No current

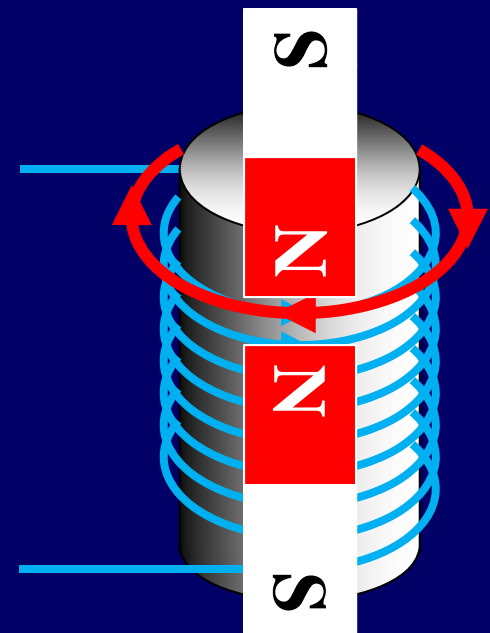
- B-field upwards => Flux thru loop upward increasing
- EMF will create opposite magnetic field (downwards)
- Induced loop current must be clockwise

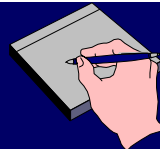


# Induction cannon (Demo)

A solenoid is driven by an increasing current. A loop of wire is placed around it

- Recall: current loop and solenoid behave like bar magnets
- Like poles repel! Loop shoots up





**Example**

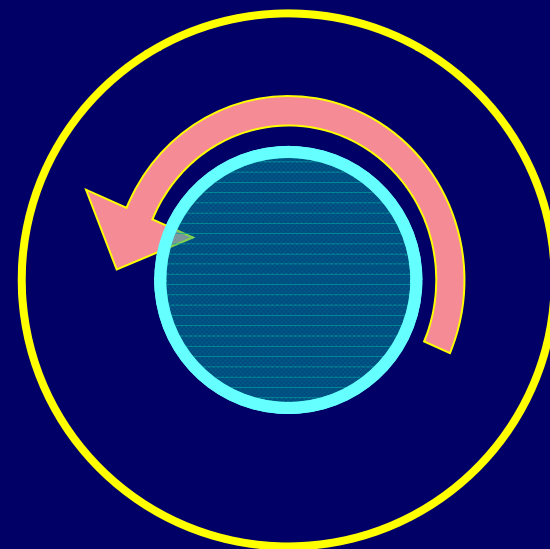
# Magnetic Flux Example

A solenoid ( $B = \mu_0 n I$ ) is inside a conducting loop. What happens to the flux through the loop when you...

Increase area of solenoid **Increases**

Increase area of loop **Nothing**

Increase current in solenoid **Increases**



$$\Phi \equiv B A \cos(\phi)$$



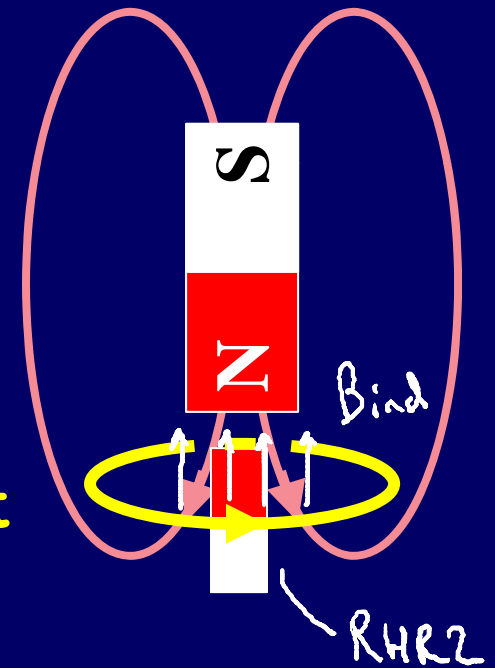
# ACT: Change B (Demo)

Which way is the magnet moving if it is inducing a current in the loop as shown?

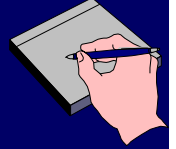
A. Up

B. Down

Field from magnet is down. Induced current creates field up - **opposite** original. So flux from magnet must be **increasing**. Magnet must be falling down!



The force from the induced current opposes the falling magnet!



# Faraday's and Lenz's Law

Faraday: Induced emf = rate of change of magnetic flux

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_f - \Phi_i}{t_f - t_i}$$

Lenz: Induced emf opposes change in flux

Since  $\Phi = B A \cos(\phi)$ , 3 things can change  $\Phi$

- ✓ 1. Area of loop
- ✓ 2. Magnetic field B

Next lecture 3. Angle  $\phi$  between normal and B