

Physics 102: Lecture 10

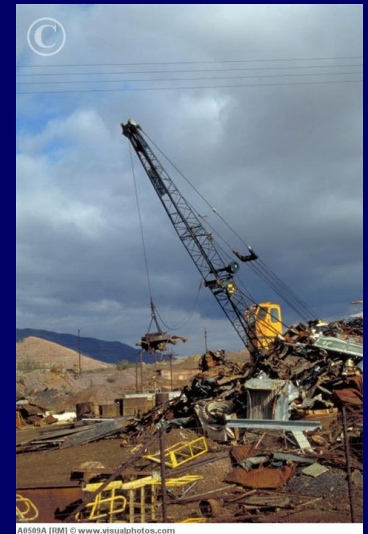
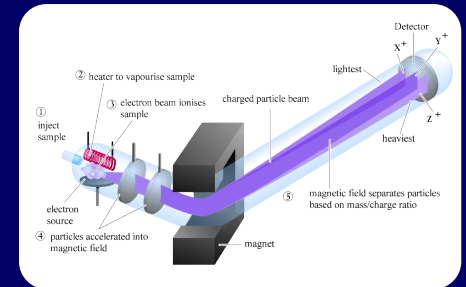
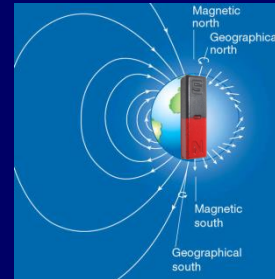
Faraday's Law

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

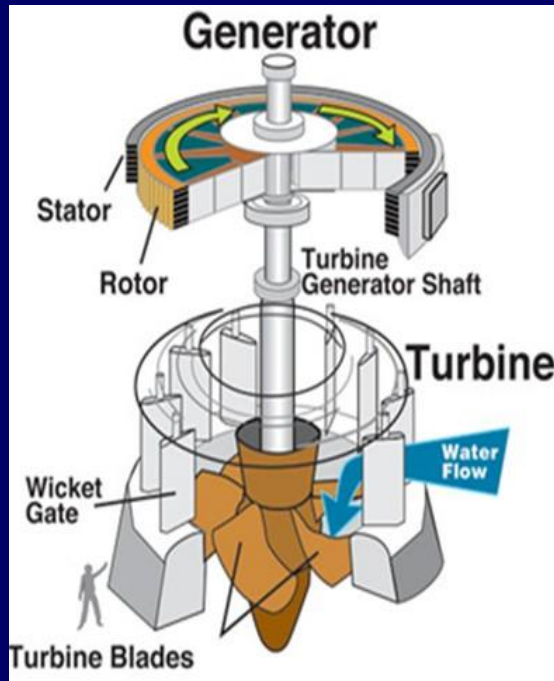
- Magnetic fields
- Forces on moving charges and currents
- Torques on current loops
- Magnetic field created by
 - Long straight wire
 - Solenoid



Today

Changing magnetic flux creates a voltage

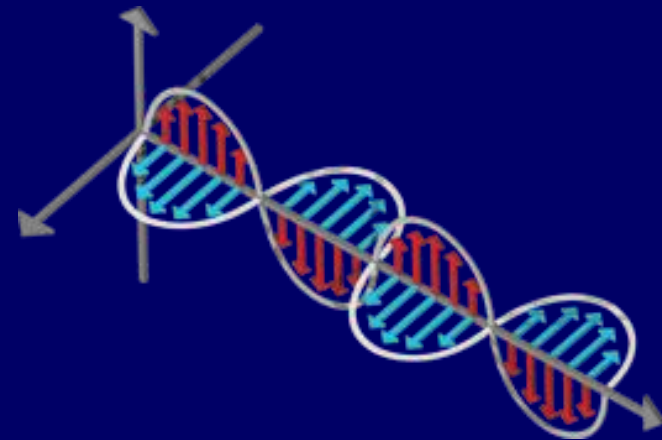
Faraday's and Lenz's Laws



Generators



Transformers

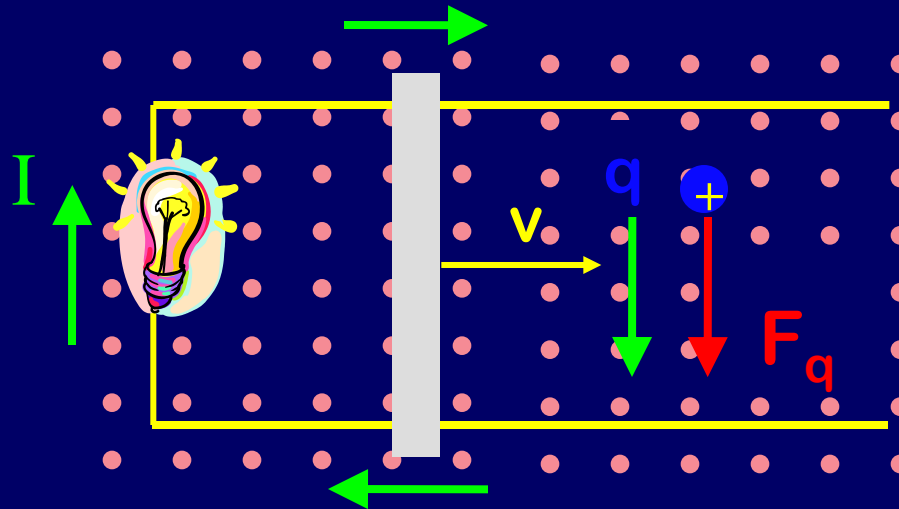


Electromagnetic Waves

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)!!

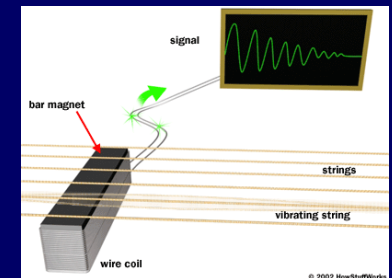


Faraday's Law of Induction:

“induced EMF” = rate of change of magnetic flux

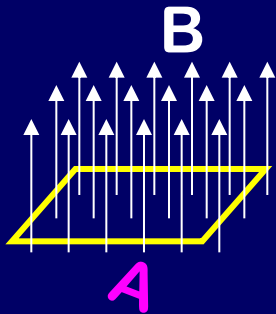
$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_f - \Phi_i}{t_f - t_i}$$

- The principle that unifies electricity and magnetism
- Key to many things in E&M
 - Generating electricity
 - Electric guitar pickups
 - Credit card readers



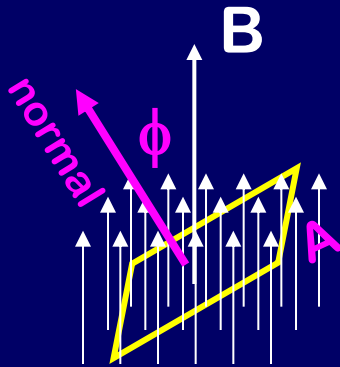
First a definition: Magnetic Flux

- “Counts” number of field lines through loop.



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

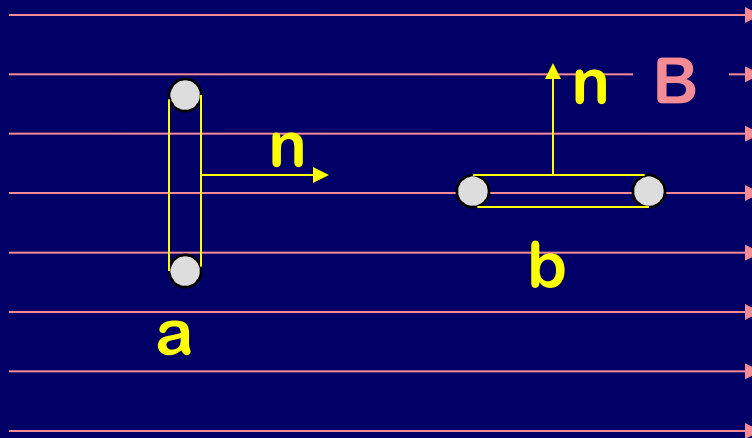
Magnetic flux $\Phi = B A$
(Units $\text{Tm}^2 = \text{Wb}$)



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

ϕ is angle between normal and B

CheckPoint 2.1



“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) $\Phi_a > \Phi_b$

62%

2) $\Phi_a < \Phi_b$

38%



Faraday's Law of Induction:

“induced EMF” = rate of change of magnetic flux

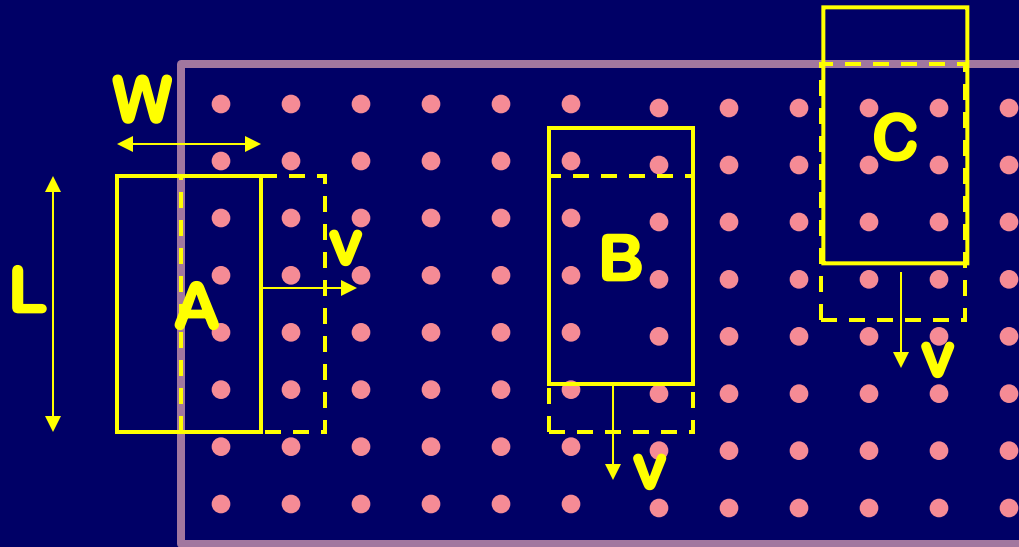
$$\varepsilon = - \frac{\Delta \Phi}{\Delta t} = - \frac{\Phi_f - \Phi_i}{t_f - t_i}$$

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

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



ACT: Change Area



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

A moves right - gets 4 more field lines.

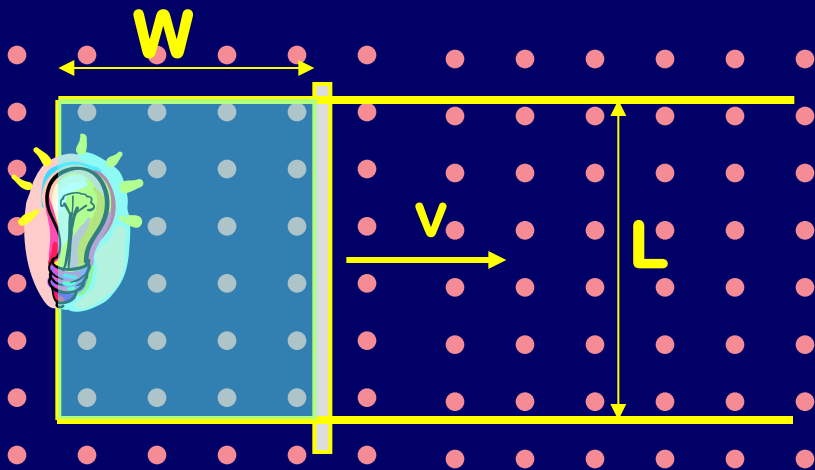
B moves down - gets 0 more field lines.

C moves down - only gets 2 more lines.

Example

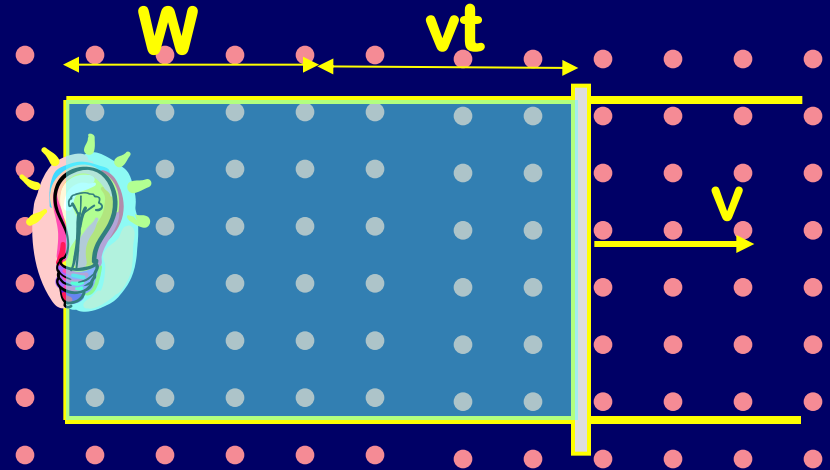


Faraday: Change Area



$t=0$

$$\Phi_i = BLW$$



t

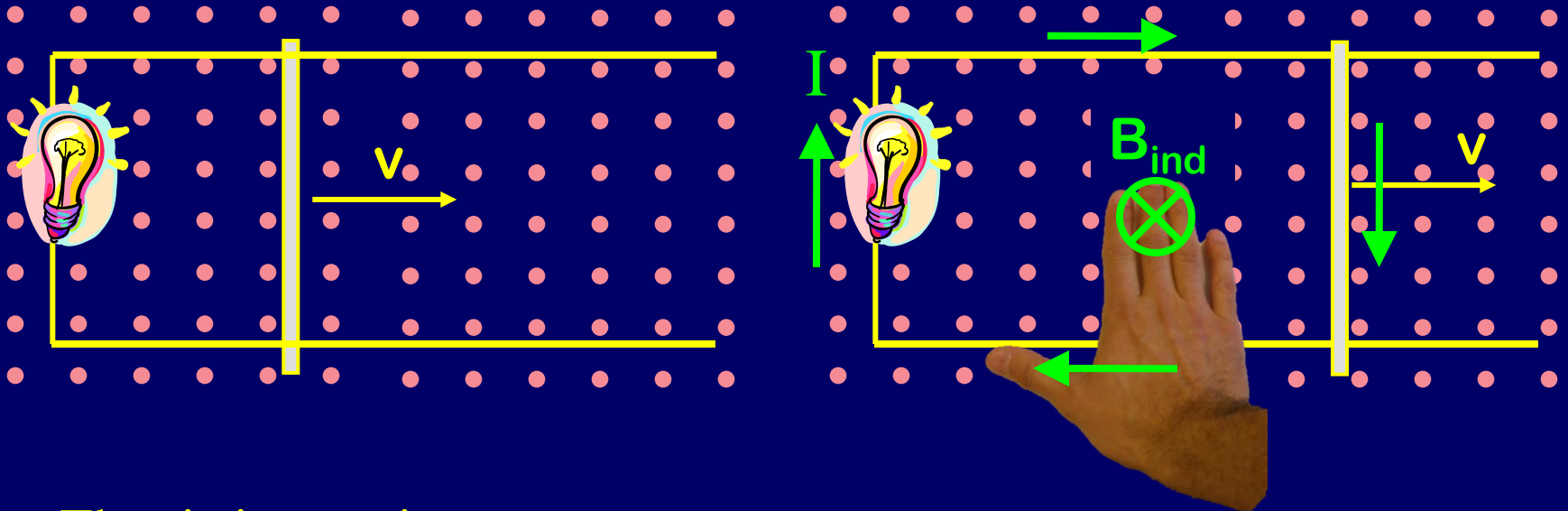
$$\Phi_f = BL(W+vt)$$

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

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

What about the sign of the EMF?

Lenz's Law (EMF direction)



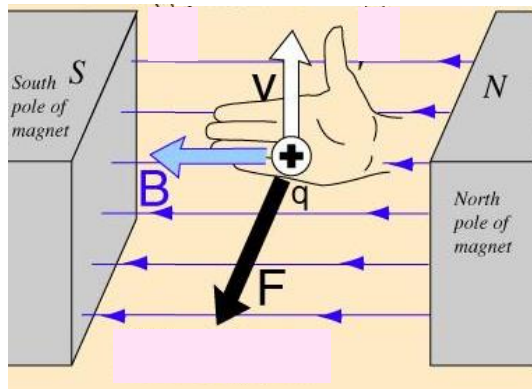
- Flux is increasing
- Induced current is clockwise
- Current loop generates induced B field
 - from RHR2, into page, opposite external B field!

What happens if the velocity is reversed?

Summary of Right-Hand Rules

RHR 1

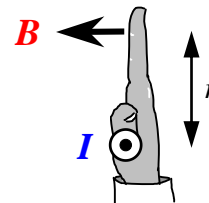
Force on moving q



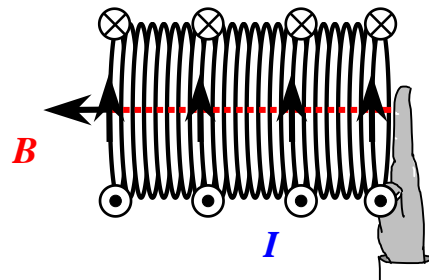
RHR 2

B field from current I

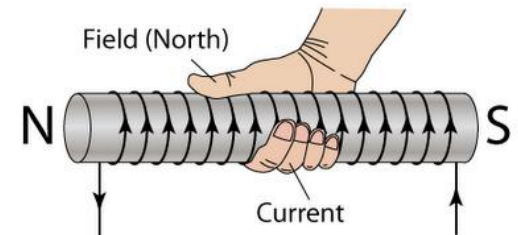
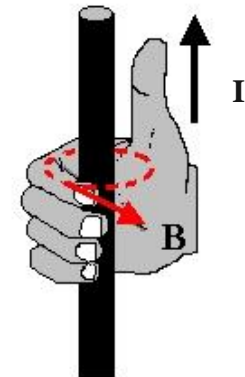
Straight wire



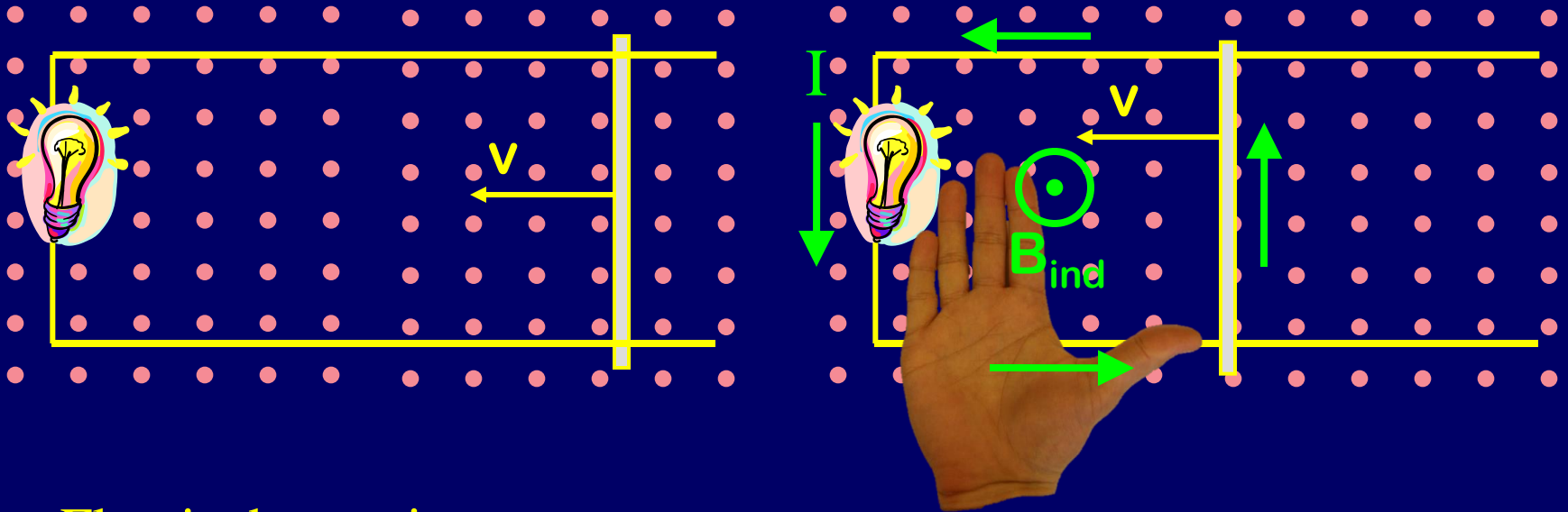
Solenoid



Alternate

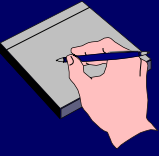


Lenz's Law (EMF direction)



- Flux is decreasing
- Induced current is counterclockwise
- 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

$$I = \mathcal{E}/R = vBL/R$$

- Direction of Current

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

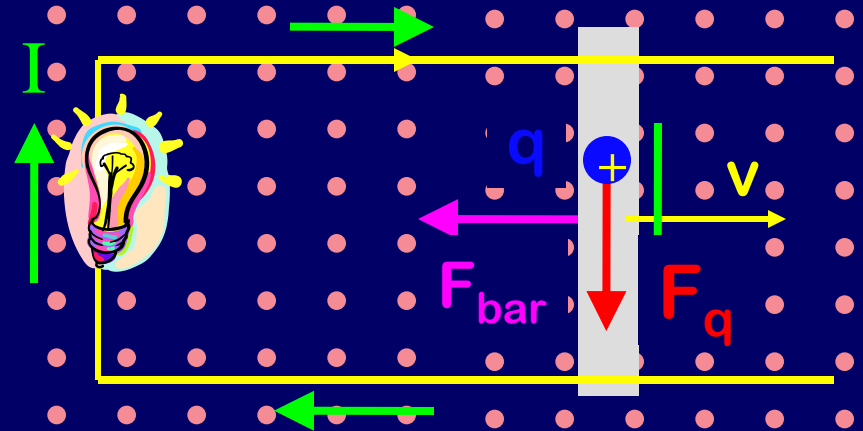
- B field generates force on current-carrying bar

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

- Careful! There are two forces:

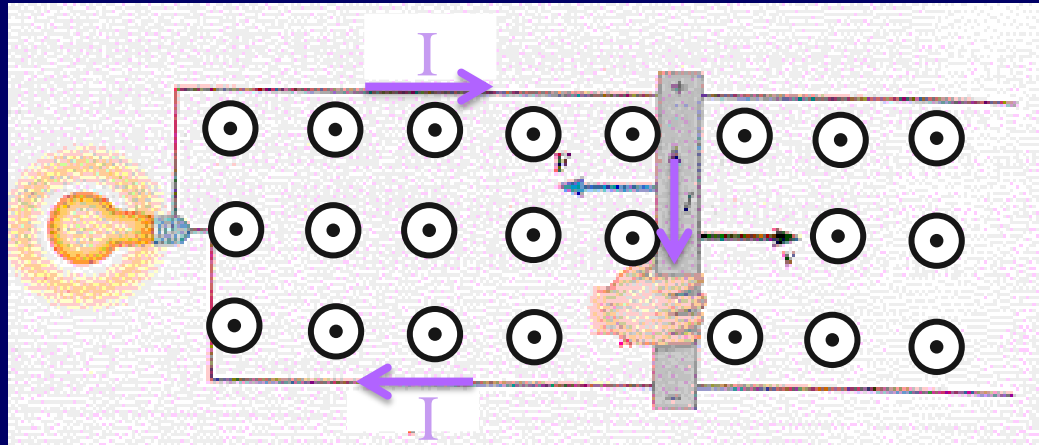
F_{bar} = force on bar from induced current

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...

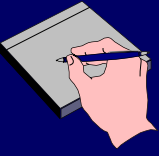


To keep the bar moving at the same speed, the force supplied by the hand will have to:

- 22% • Increase
- 67% • Stay the Same
- 11% • 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

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

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

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



ACT: Induction cannon (Demo)

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

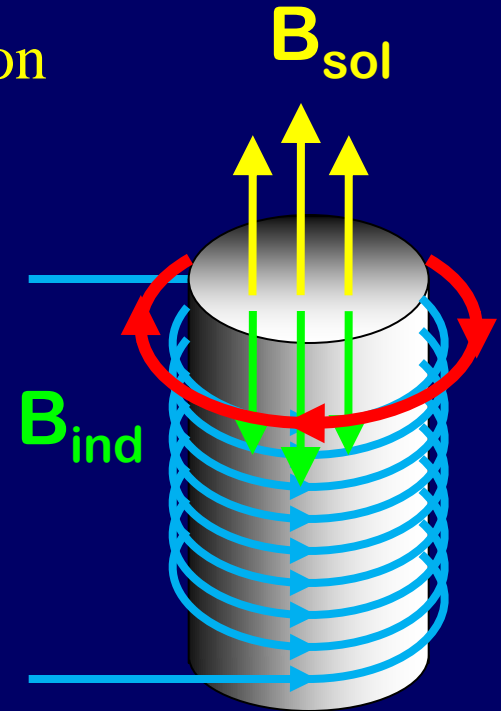
As current increases in the solenoid, what direction will induced current be in ring?

A. Same as solenoid

B. Opposite of solenoid

C. No current

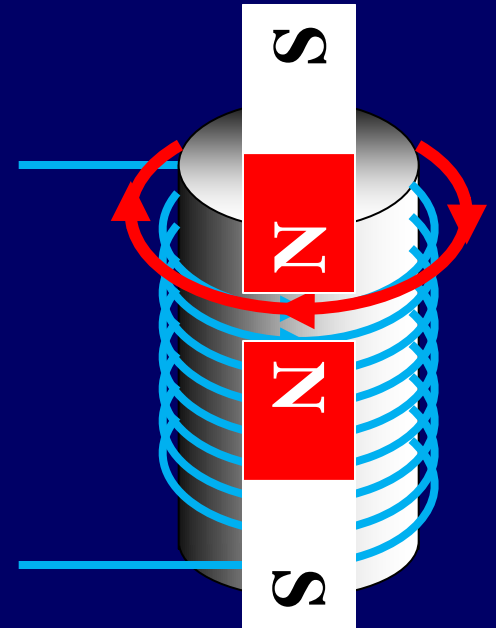
- B-field upwards \Rightarrow Flux thru loop upward increasing
- EMF will create opposite magnetic field (downwards)
- Induced loop current must be clockwise



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



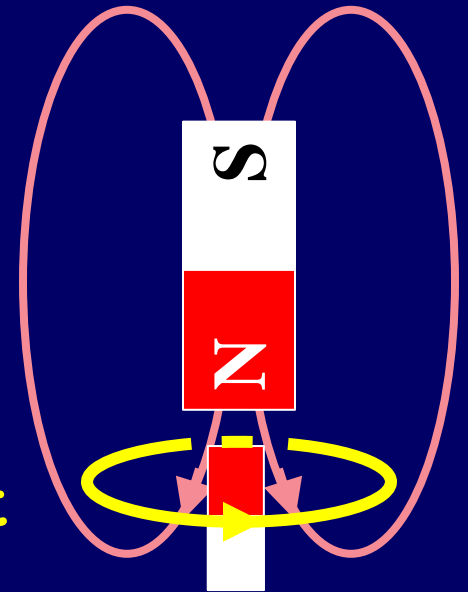


ACT: Change B (Demo)

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!



Example

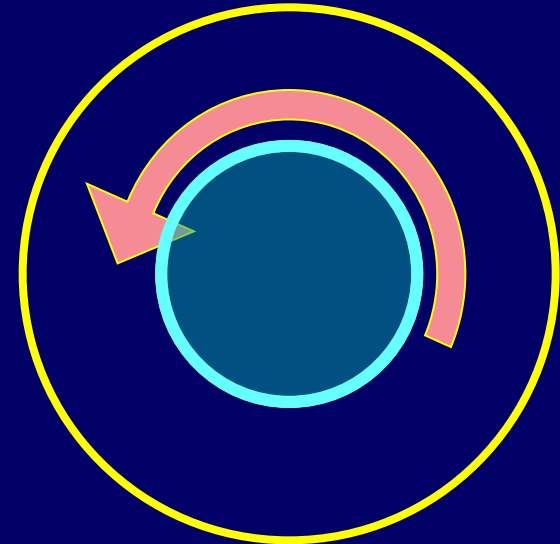
Magnetic Flux Example

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**



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



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 Φ

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

Next lecture 3. Angle ϕ between normal and B