Physics 102: Lecture 10

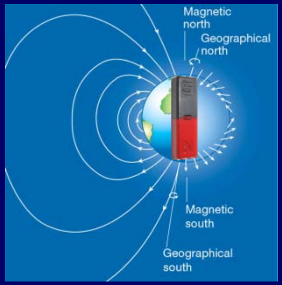
Faraday's Law

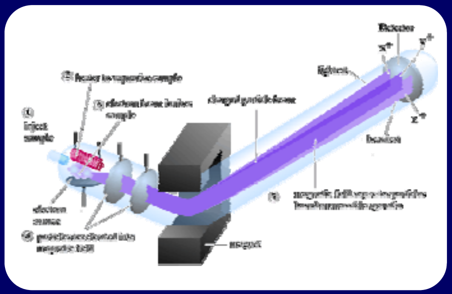
Changing Magnetic Fields create Electric Fields

- 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

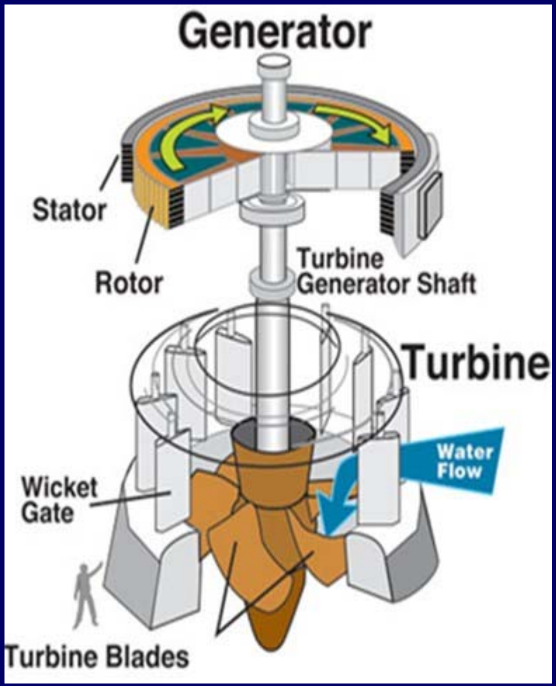


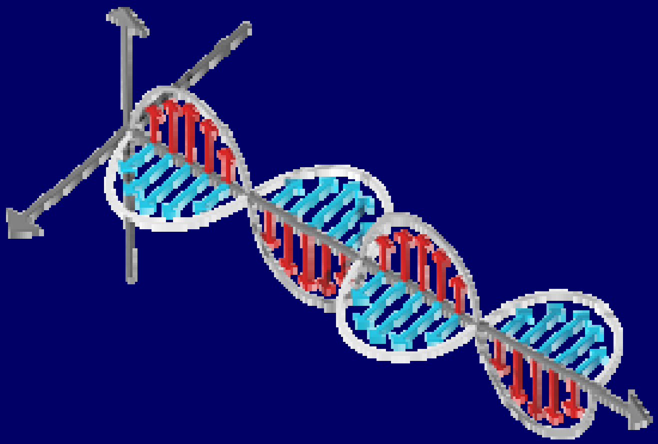


Today

Changing magnetic flux creates a voltage

Faraday's and Lenz's Laws





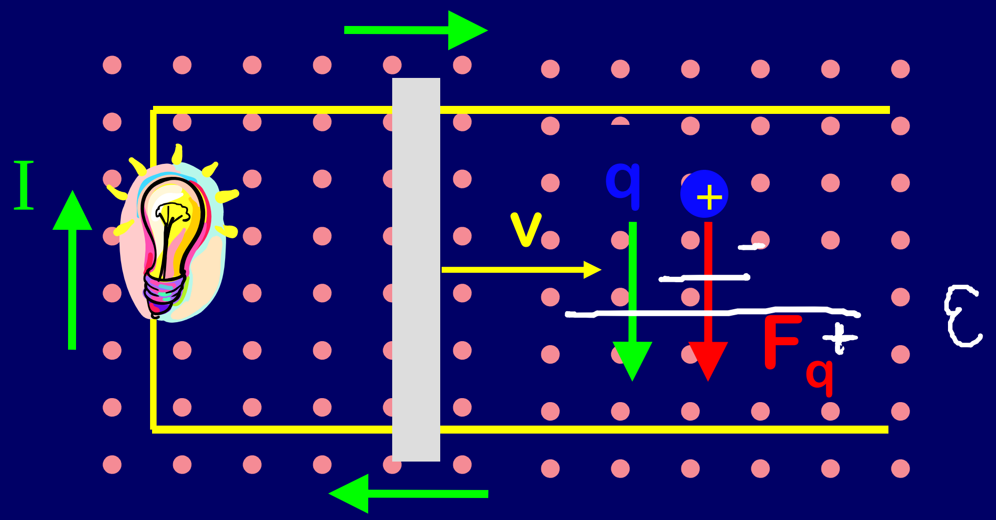
Generators

Transformers

Electromagnetic Waves

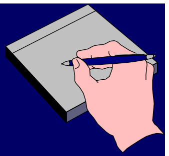
Motional EMF

- 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)!!

(Recall that e- actually move, opposite current)

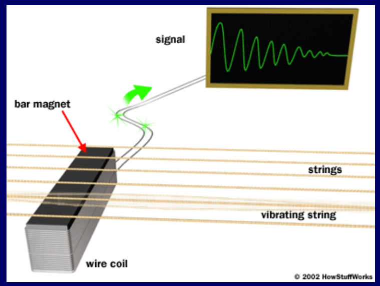


Faraday's Law of Induction:

"induced EMF" = rate of change of magnetic flux

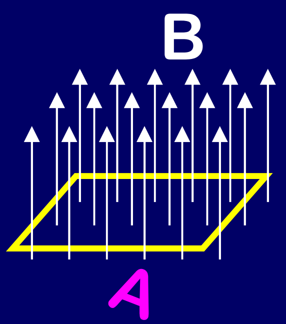
$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_\mathrm{f} - \Phi_\mathrm{i}}{t_f - t_i}$$

- 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

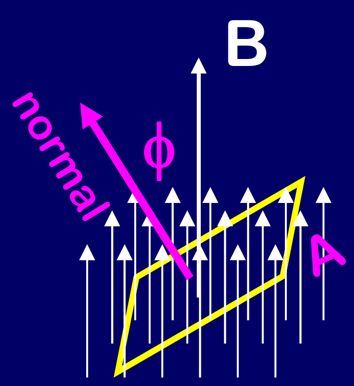
- "Counts" number of field lines through loop.



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

Magnetic flux $\Phi = B\,A$

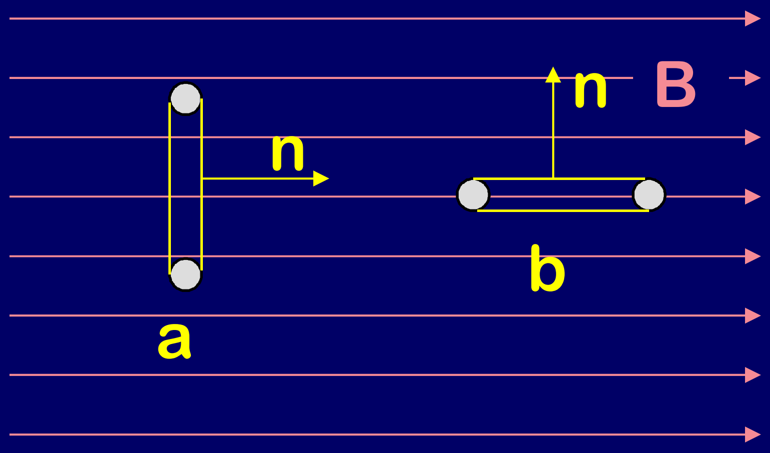
(Units Tm^2 = Wb)



Magnetic flux $\boxed{\Phi \equiv B\,A\cos(\phi)}$

ϕ is angle between normal and B

CheckPoint 2.1



"more lines pass through its surface in that position."

Φ_A = B A cos(0) = BA

Φ_B = B A cos(90) = 0

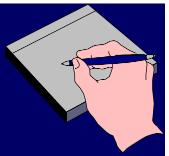
Compare the flux through loops a and b.

1) $\Phi_a > \Phi_b$

2) $\Phi_a < \Phi_b$

63%

37%



Faraday's Law of Induction:

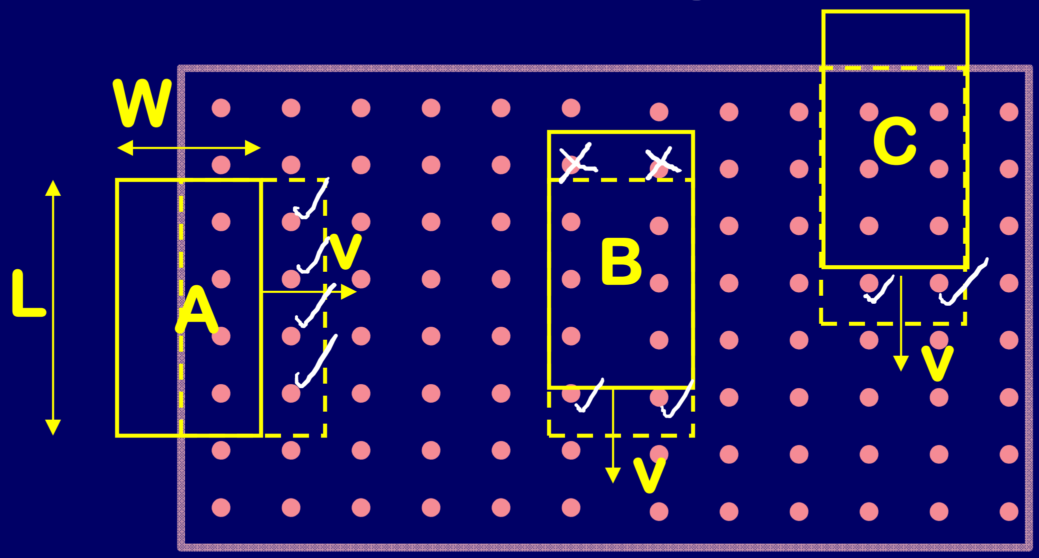
"induced EMF" = rate of change of magnetic flux

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_{\mathrm{f}} - \Phi_{\mathrm{i}}}{t_f - t_i}$$

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



$B_{outside} = 0$

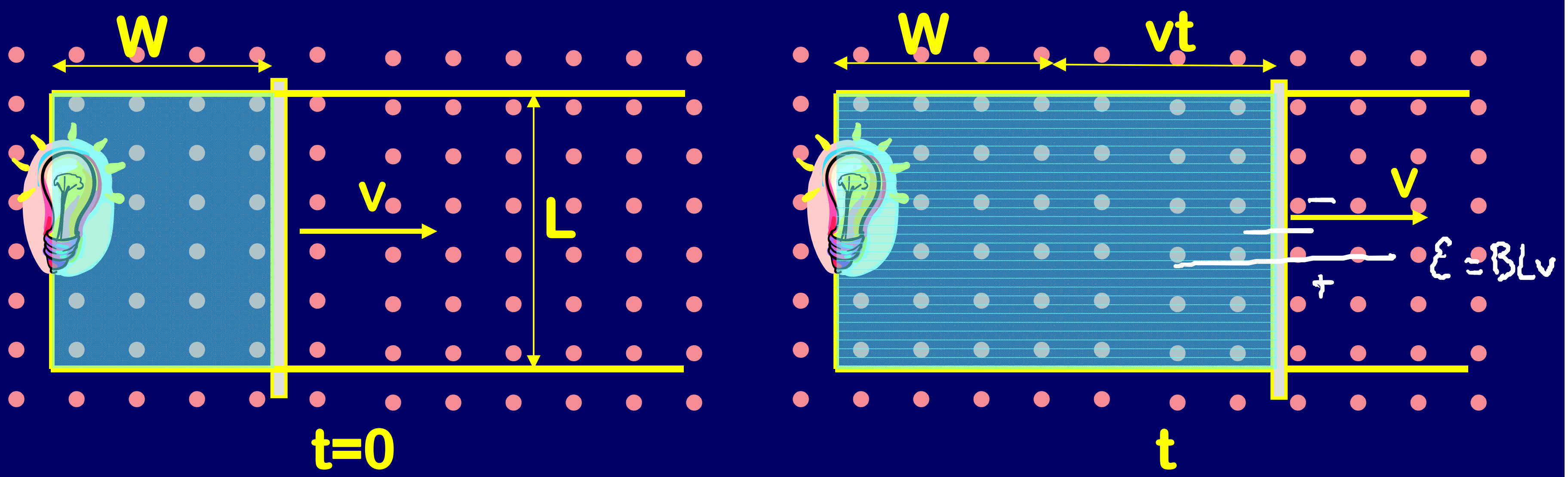
Which loop has the greatest induced EMF at the instant shown above?

A moves right - gets 4 more field lines.

B moves down - gets 0 more field lines.

C moves down - only gets 2 more lines.

Faraday: Change Area



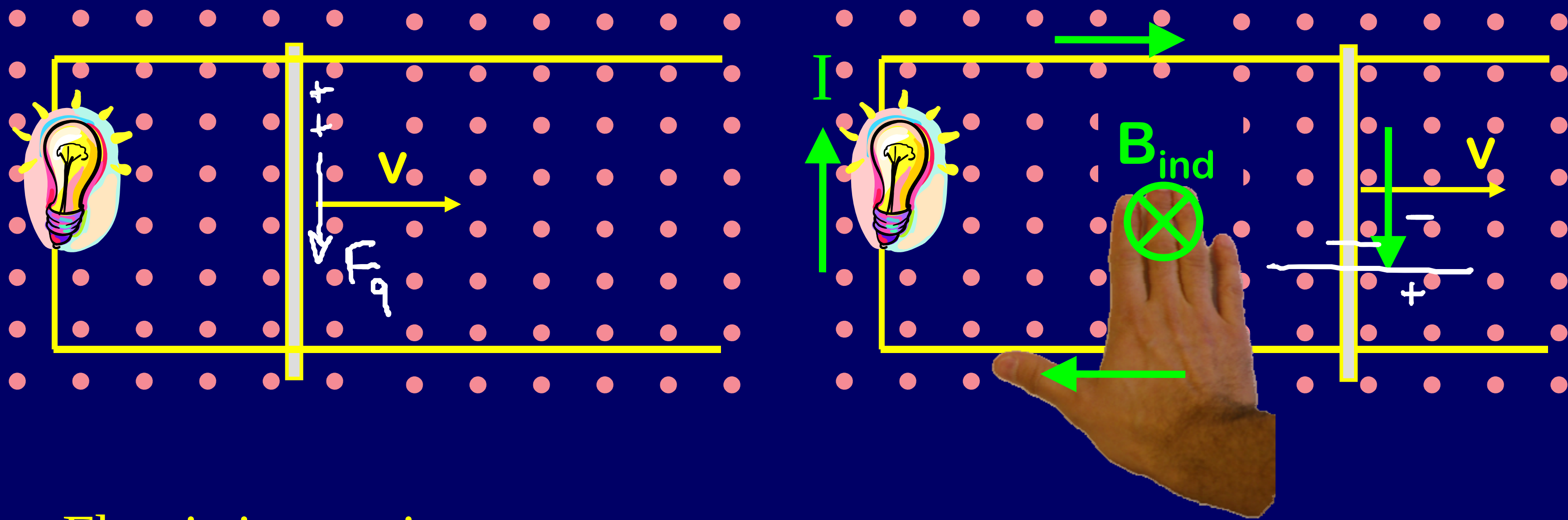
Φ_i = BLW $\qquad$ Φ_f = BL(W+vt)

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

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

What about the sign of the EMF?

Lenz's Law (EMF direction)



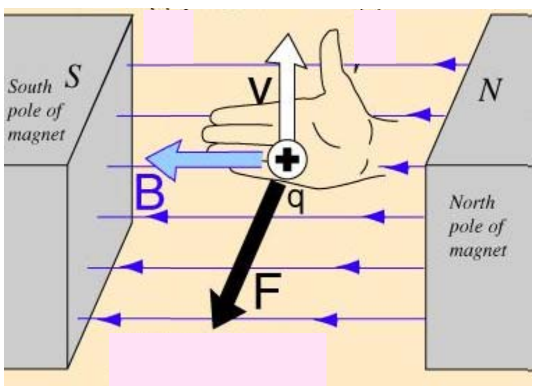
- Flux is increasing
- Induced current is clockwise
- Current loop generates induced B field
  – from RHR2, into page, opposite external B field!

What happens if the velocity is reversed?

Summary of Right-Hand Rules

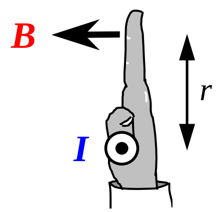
RHR 1	RHR 2	Alternate
Force on moving q	**B field from current I**	

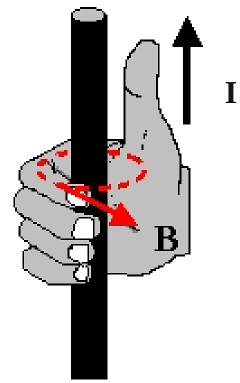
Force on moving q



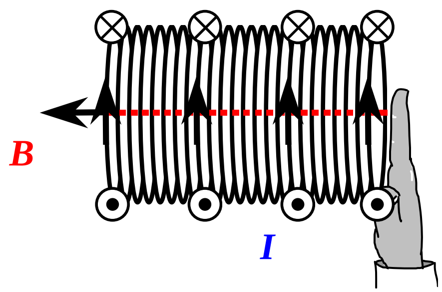
B field from current I

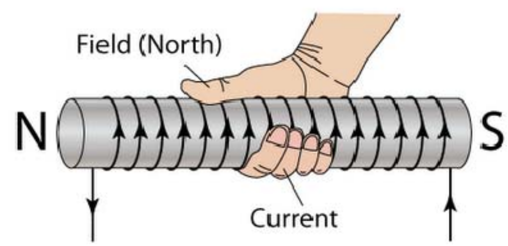
Straight wire



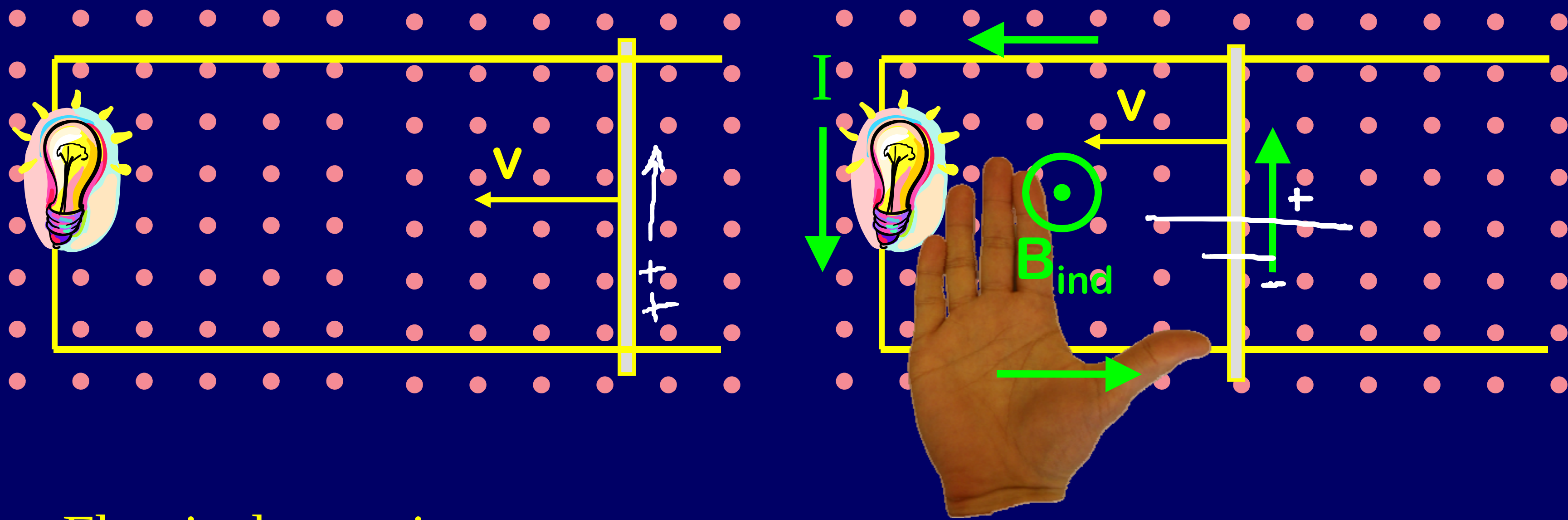


Solenoid



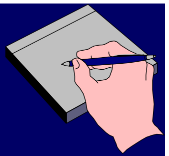


Lenz's Law (EMF direction)



- 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:

B ind B

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

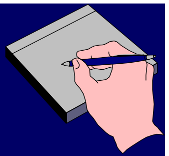
- If flux decreases:

B ind B

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

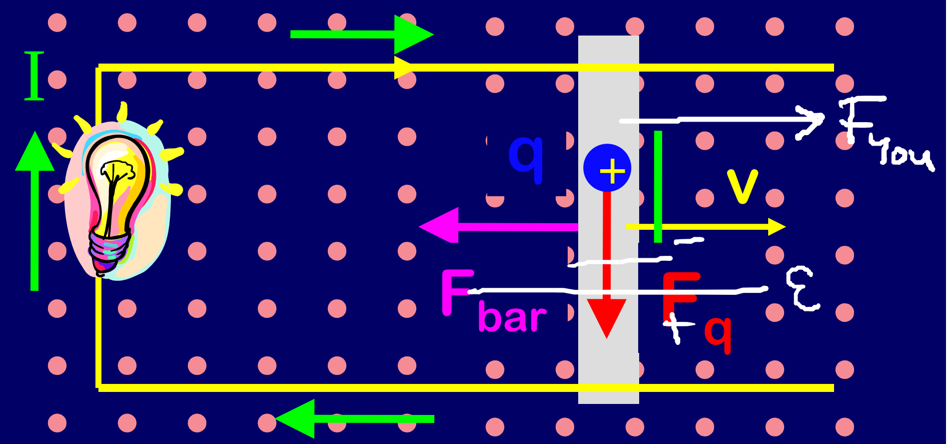
EMF does NOT oppose B field, or flux!
EMF opposes the CHANGE in flux

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

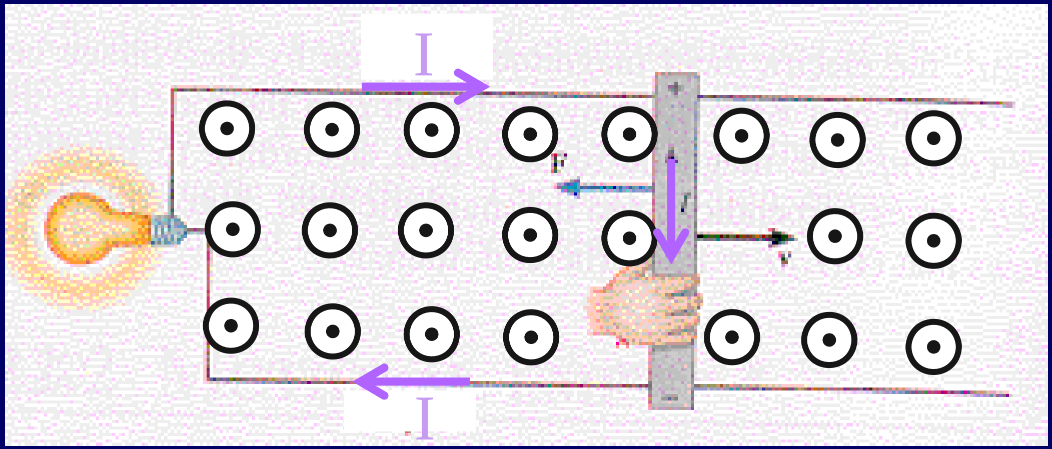
  $F_{bar} = ILB\sin(\theta)$, to left (RHR1) **$F_{bar}$ opposes v!**

- Careful! There are two forces:

  F_{bar} = force on bar from induced current
  F_q = force on + charges in bar <u>driving</u> 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(θ)

B and v still perpendicular (θ=90), so F=ILB just like before!

Faraday's Law of Induction:

"induced EMF" = rate of change of magnetic flux

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_\mathrm{f} - \Phi_\mathrm{i}}{t_f - t_i}$$

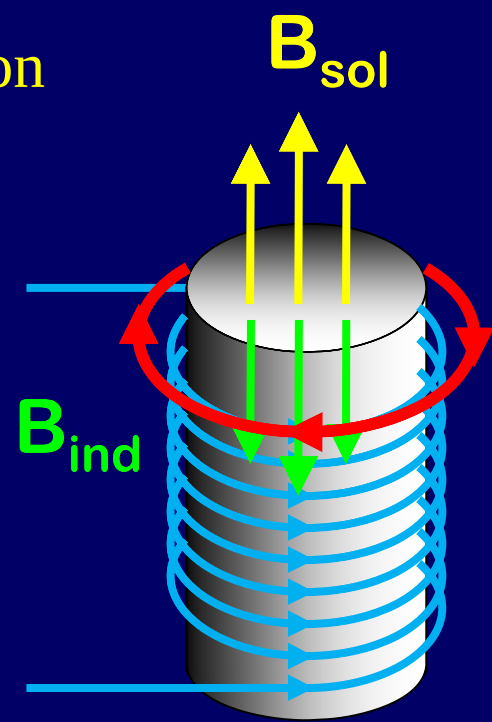
Since $\Phi = B\,A\cos(\phi)$, 3 things can change Φ

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 $B_{sol} = \mu_0 n I \propto I$

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



A. Same as solenoid

B. Opposite of solenoid

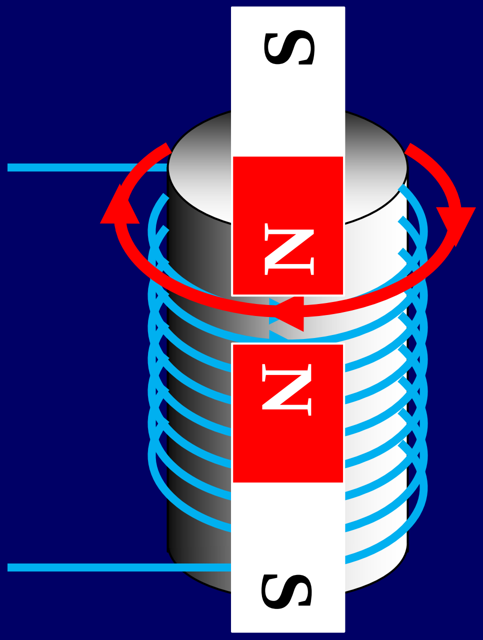
C. No current

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

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

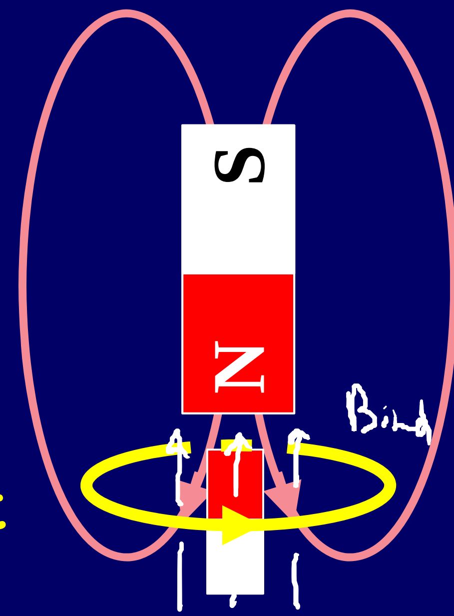


ACT: Change B (Demo)

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

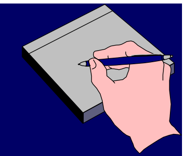
A. Up

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!

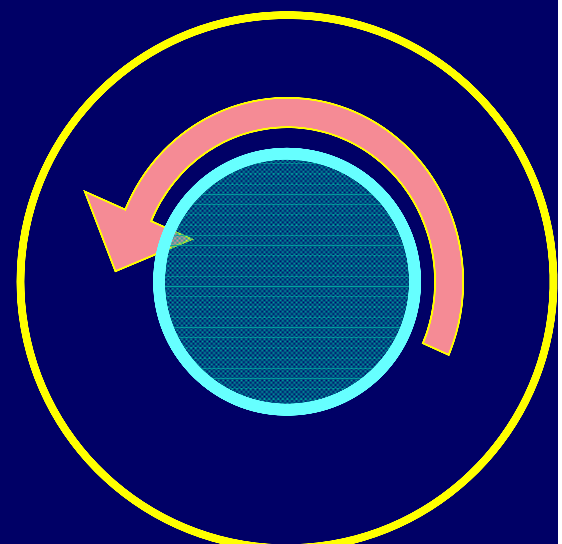
The force from the induced current opposes the falling magnet!



Example

Magnetic Flux Example

A solenoid ($B=\mu_o nI$) is inside a conducting loop. What happens to the flux through the loop when you…

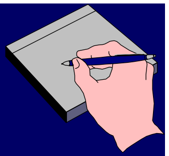


Increase area of solenoid **Increases**

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

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_\mathrm{f} - \Phi_\mathrm{i}}{t_f - t_i}$$

Lenz: Induced emf <u>opposes change</u> 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