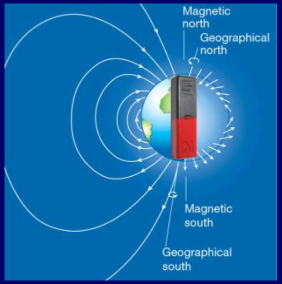
Physics 102: Lecture 10

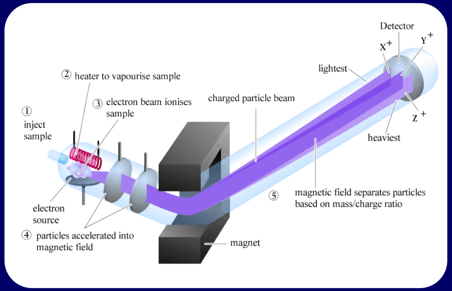
Faraday's Law

Changing Magnetic Fields create Electric Fields

Last Two Lectures

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

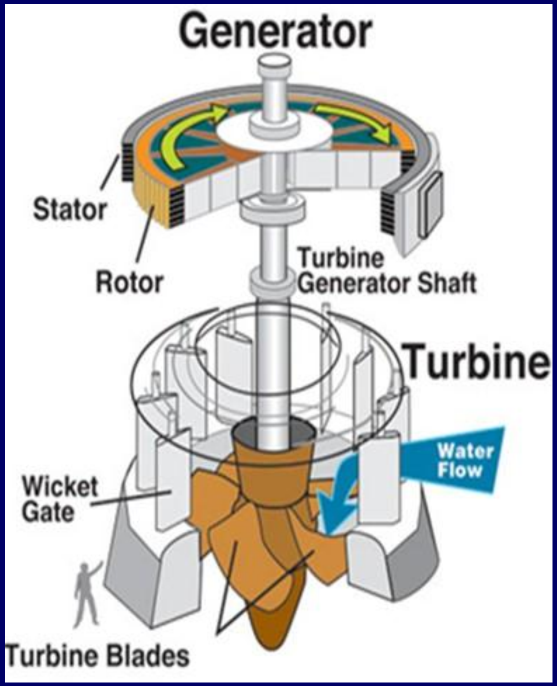




Today

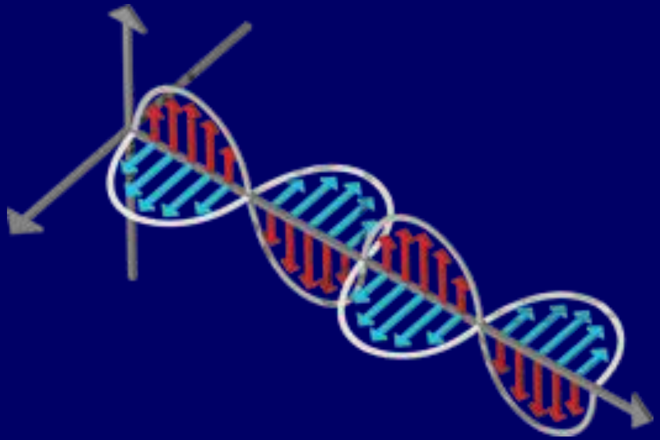
Changing magnetic flux creates a voltage

Faraday's and Lenz's Laws



Generators

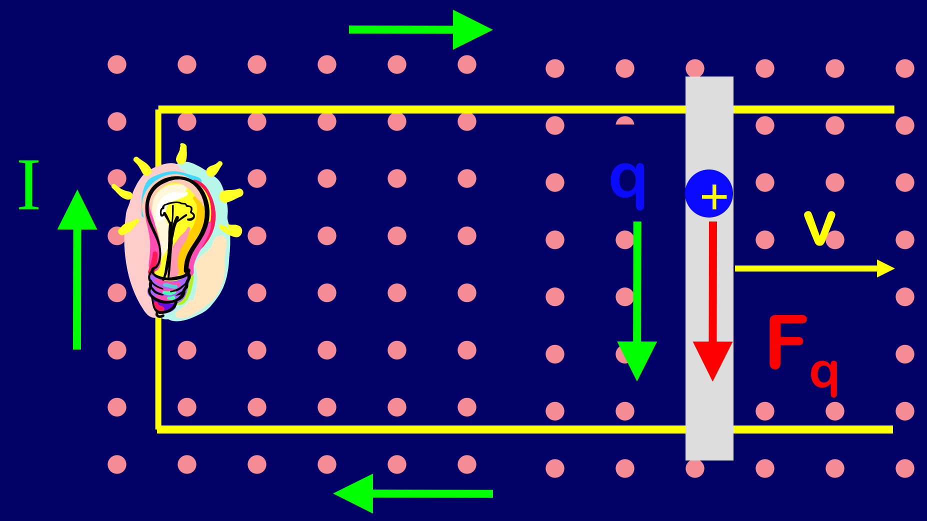
Transformers



Electromagnetic Waves

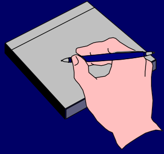
Motional EMF

- 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 <u>acts like a battery</u> (i.e. generates EMF)!!

(Recall that e- actually move, opposite current)

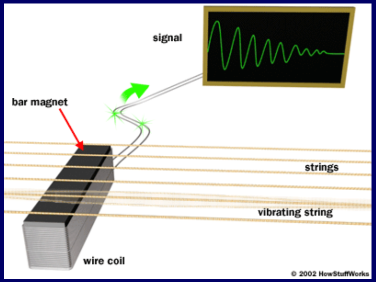


Faraday's Law of Induction:

"induced EMF" = rate of change of magnetic flux

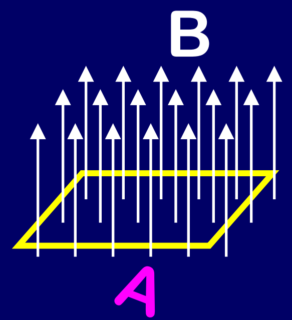
$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_\mathrm{f} - \Phi_\mathrm{i}}{t_f - t_i}$$

- 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

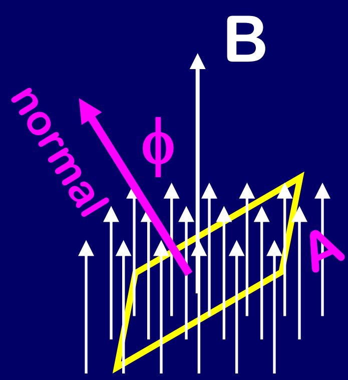
- "Counts" number of field lines through loop.



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

Magnetic flux Φ = B A

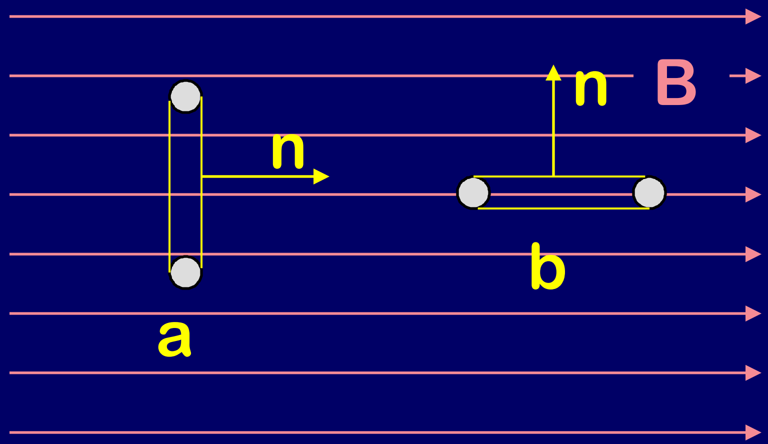
(Units Tm^2 = Wb)



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

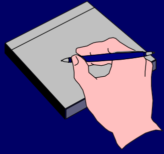
ϕ is angle between normal and B

CheckPoint 1.2



Compare the flux through loops a and b.

1) $\Phi_a > \Phi_b$ 2) $\Phi_a < \Phi_b$



Faraday's Law of Induction:

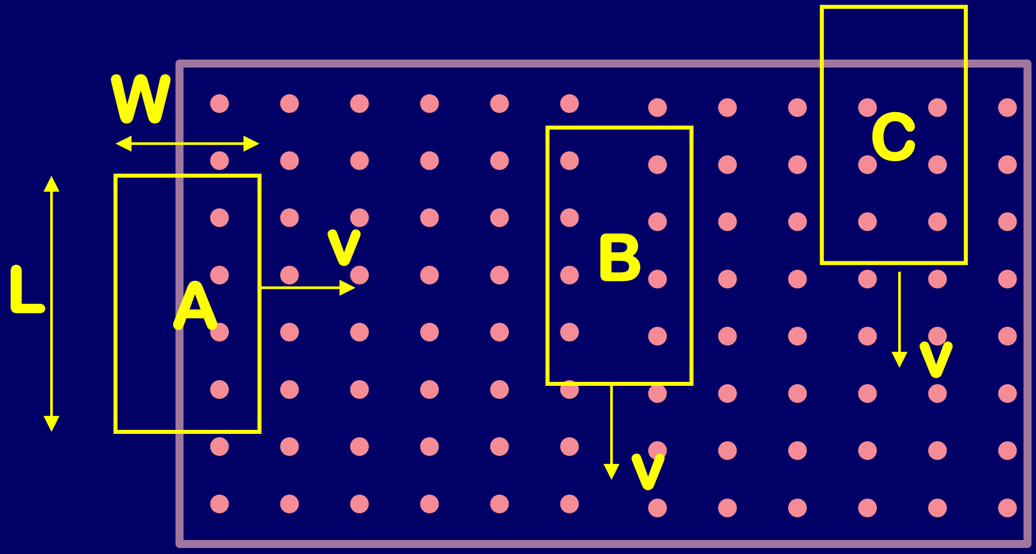
"induced EMF" = rate of change of magnetic flux

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

Since Φ= B A cos(ϕ), 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



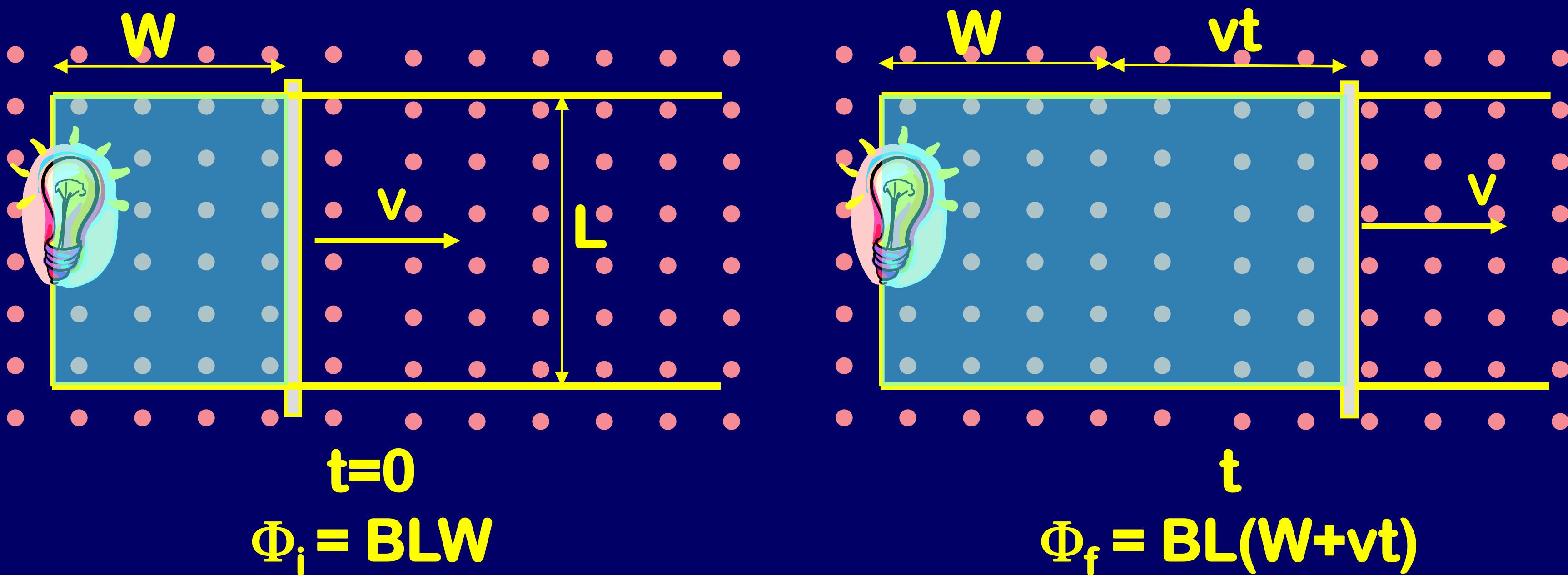
Which loop has the greatest induced EMF at the instant shown above?

A moves right

B moves down

C moves down

Faraday: Change Area

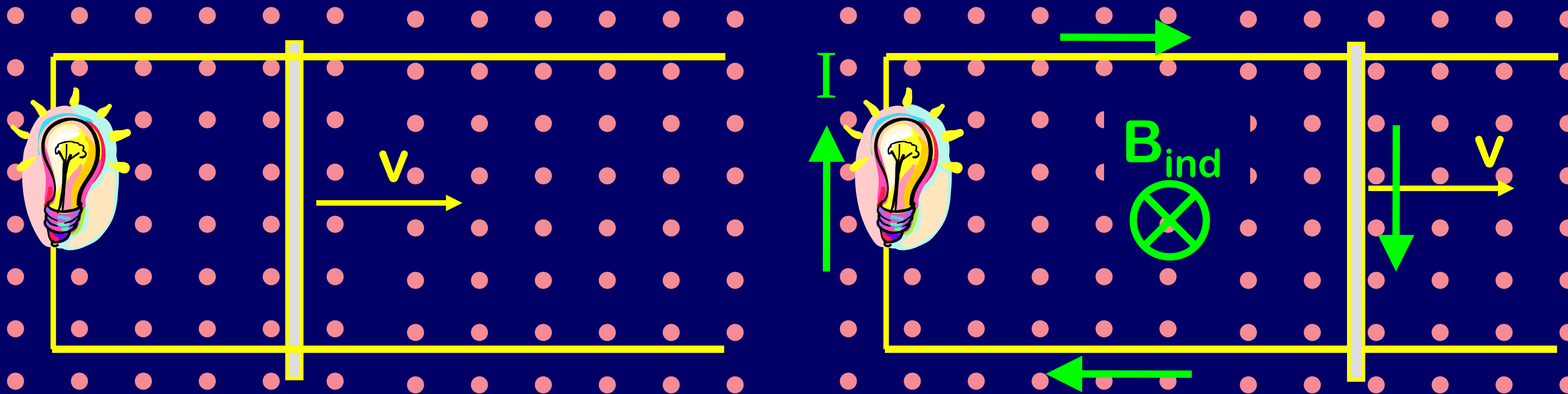


$$\boxed{\Phi = B\,A\cos(\phi)}$$

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 <u>sign</u> of the EMF?

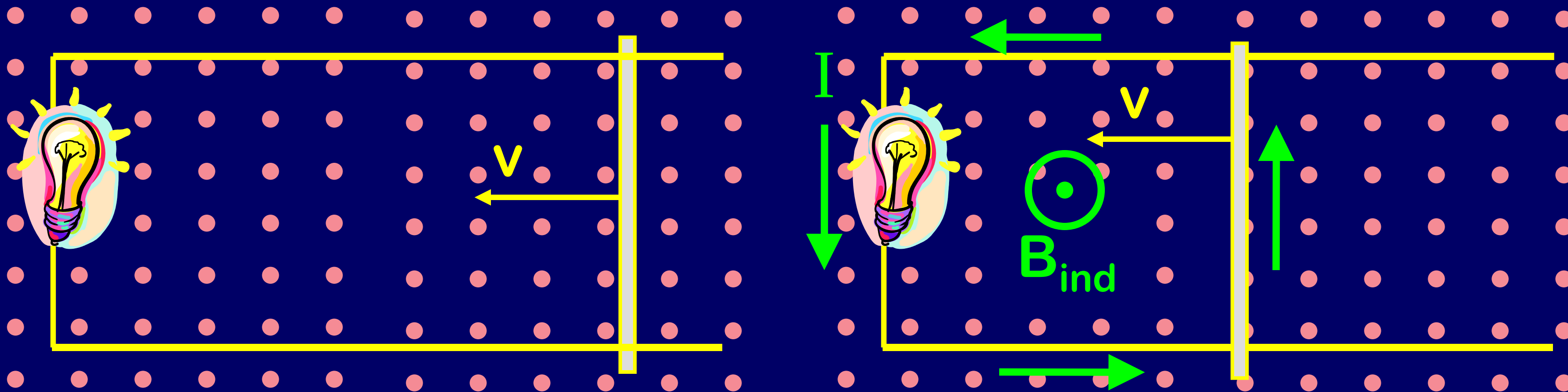
Lenz’s Law (EMF direction)



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

What happens if the velocity is <u>reversed</u>?

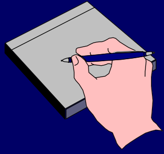
Lenz's Law (EMF direction)



- Flux is decreasing
- Induced current is <u>counterclockwise</u>
- Current loop generates induced B field
  – from RHR2, <u>out of the page</u>, along external B field!

Induced EMF <u>opposes change</u> in flux

Lenz's Law (EMF Direction)



Induced emf <u>opposes change</u> in flux

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

- If flux increases:

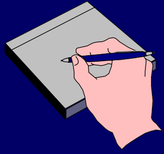
  New EMF makes new field **opposite** to original field

- If flux decreases:

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

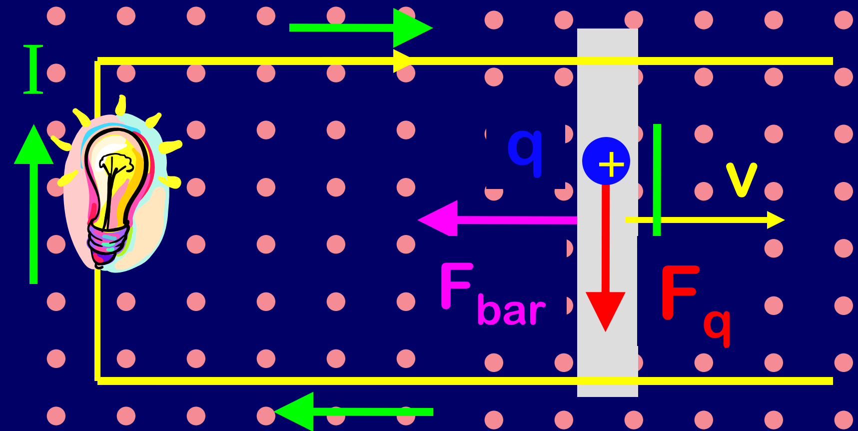
EMF does NOT oppose B field, or flux!
EMF opposes the <u>CHANGE</u> in flux

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

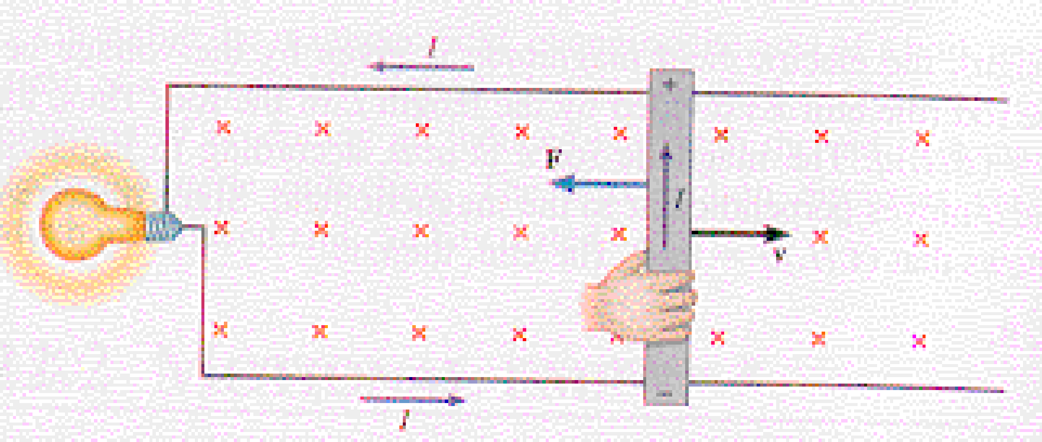
  $F_{bar} = ILB\sin(\theta)$, to left (RHR1) **$F_{bar}$ opposes v!**

- 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

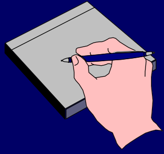
CheckPoint 1.1

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:

- Increase
- Stay the Same
- Decrease



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ACT: Induction cannon (Demo)

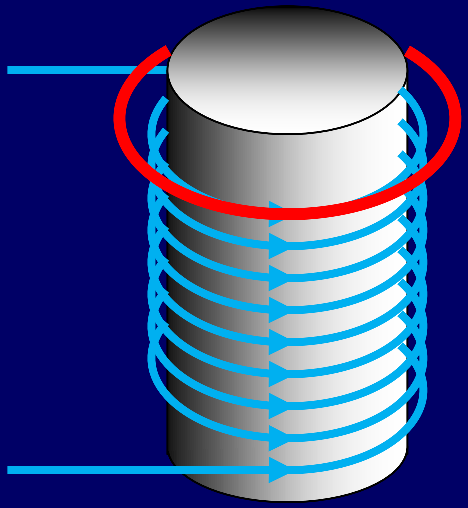
A solenoid is driven by an increasing current. A loop of wire is placed around it

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

A. **Same as solenoid**

B. **Opposite of solenoid**

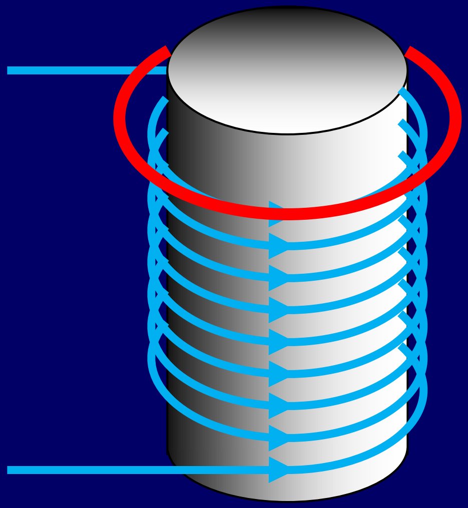
C. **No current**



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

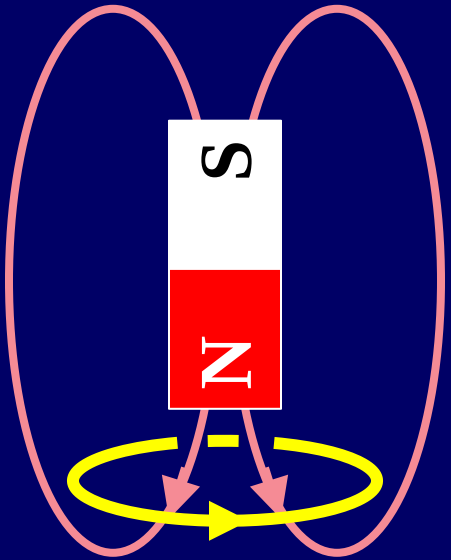


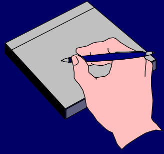
ACT: Change B (Demo)

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

A. Up

B. Down





Magnetic Flux Example

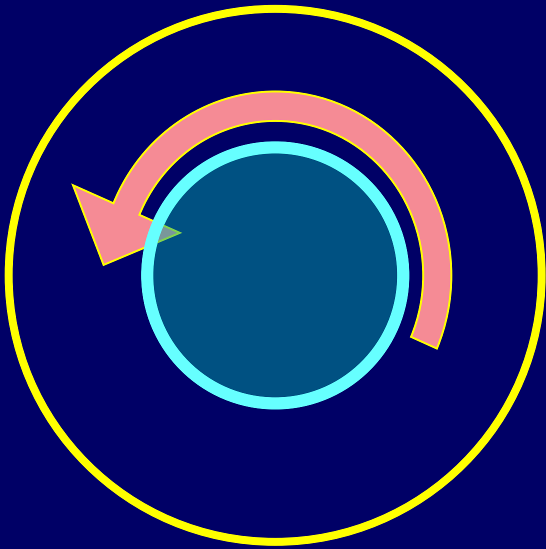
Example

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

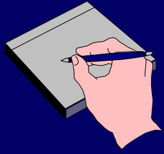
Increase area of solenoid

Increase area of loop

Increase current in solenoid



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



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