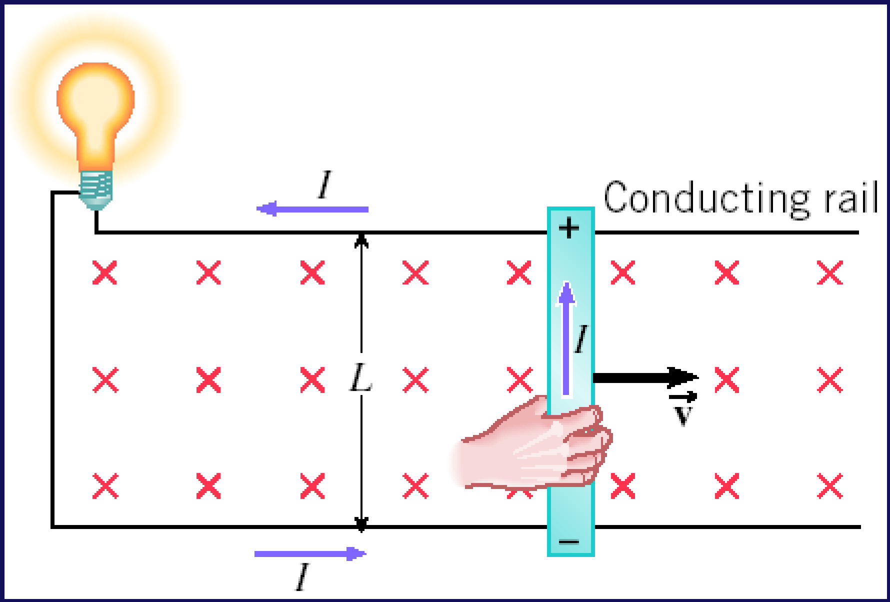
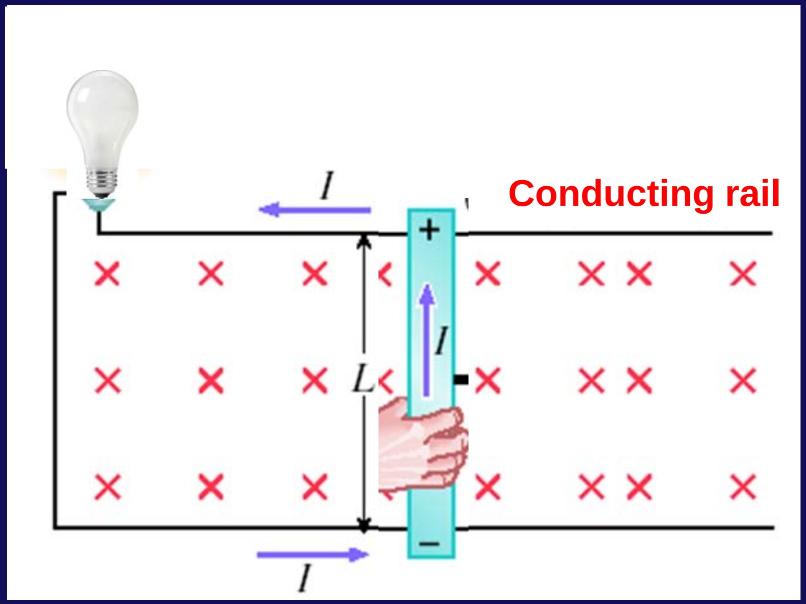
Motional EMF



Toward Faraday's Law

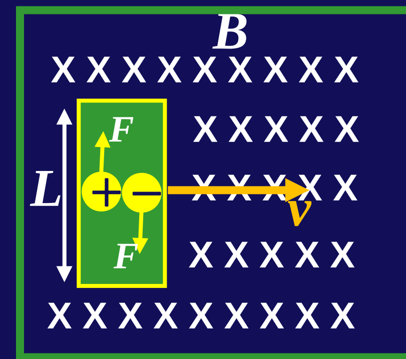
Move a conductor in a magnetic field



1. Bar moves
2. EMF produced
3. Current flows
4. Bulb glows

The Big Idea is the induced emf

When a conductor moves through a region containing a magnetic field:



Magnetic forces are exerted on the charge carriers in the conductor

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

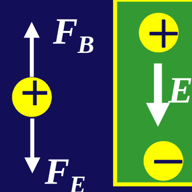
Forces produce a charge separation in the conductor: + charges, - charges opposite F

This charge distribution creates an electric field in the conductor

The equilibrium distribution is reached when the forces from the electric and magnetic fields cancel

$$qvB = qE$$

$$E = vB$$



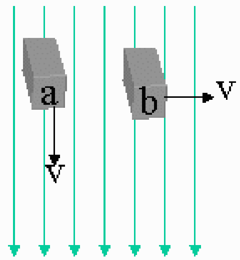
The equilibrium electric field produces a potential difference (*emf*) in the conductor

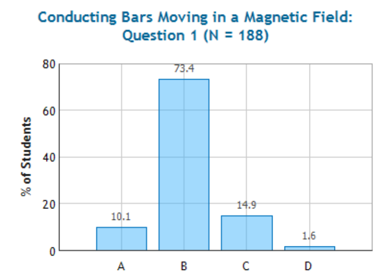
$$V = EL \rightarrow V = vBL$$

CheckPoint 2

Two identical conducting bars (shown in end view) are moving through a vertical magnetic field. Bar (a) is moving vertically and bar (b) is moving horizontally.

$$\vec{F} = q\vec{v} \times \vec{B}$$





2) Which of the following statements is true?

A ◯ A motional emf exist in the bar for case (a), but not (b)

B ◯ A motional emf exist in the bar for case (b), but not (a)

C ◯ A motional emf exist in the bar for both cases (a) and (b)

D ◯ A motional emf exist in the bar for neither case (a) nor (b)

Bar *a*

Moves along B direction

No force on charges

No E field

No emf

Bar *b*

Moves perpendicular to B

Opposite forces on charges

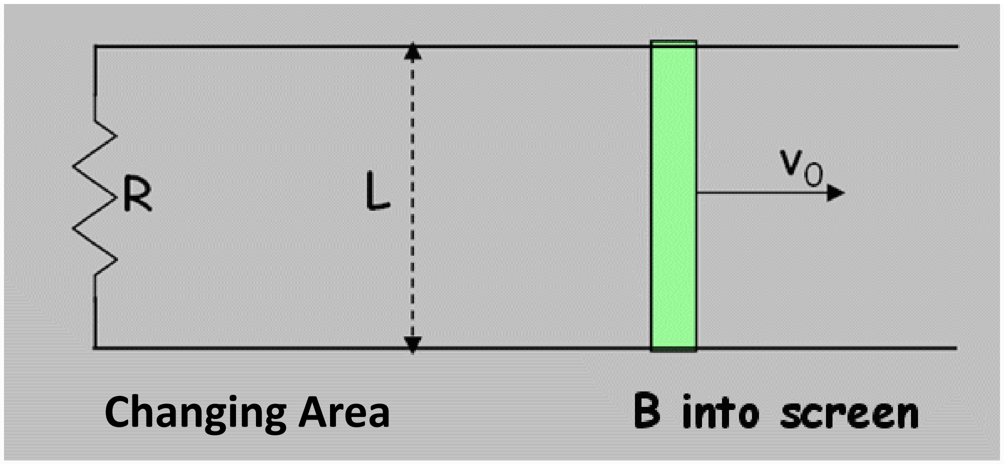
Charges separate

$E = vB$

$emf = EL = vBL$

CheckPoint

A conducting bar (green) rests on two frictionless wires connected by a resistor as shown.

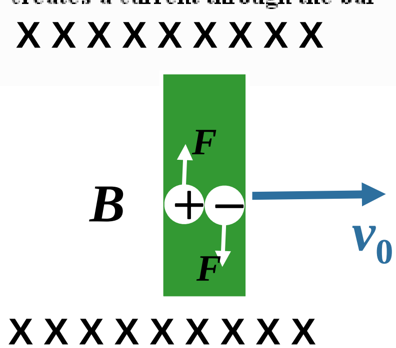


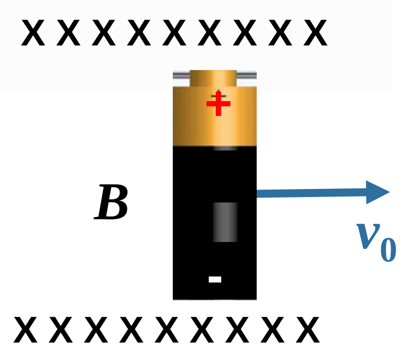
The entire apparatus is placed in a uniform magnetic field pointing into the screen, and the bar is given an initial velocity to the right.

4) The motion of the green bar creates a current through the bar

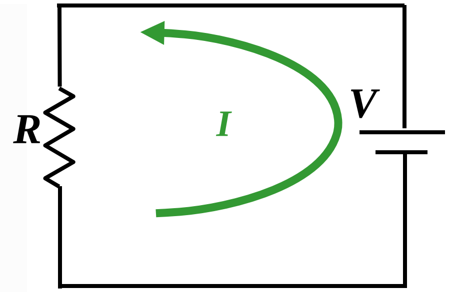
A ○ going up

B ○ going down





Equivalent circuit



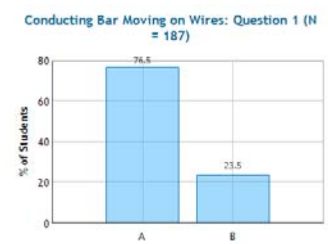
Bar

Opposite forces on charges

Charge separation

$E = v_0 B$

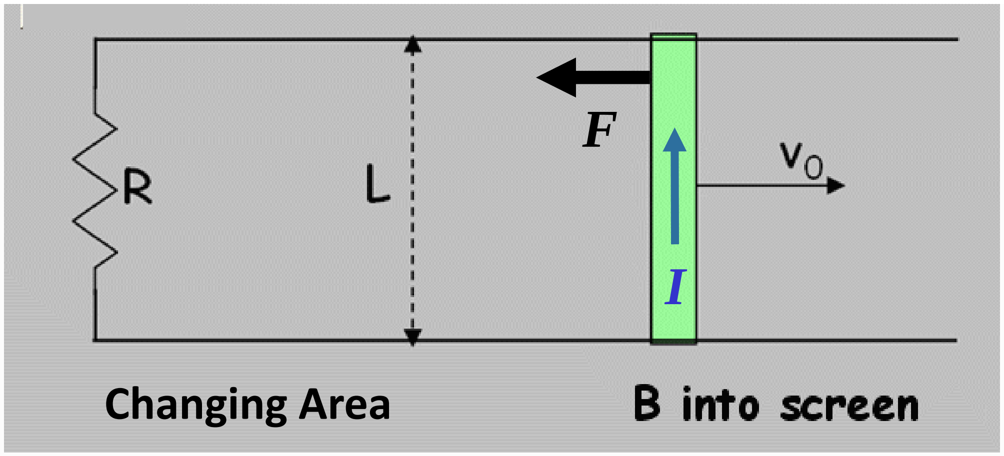
$emf = EL = v_0 BL$



$F_b = qv_0 B$ $F_b = qv_0 B$

CheckPoint

A conducting bar (green) rests on two frictionless wires connected by a resistor as shown.



The entire apparatus is placed in a uniform magnetic field pointing into the screen, and the bar is given an

The current through this bar results in a force on the bar

- A ◯ down
- B ◯ up
- C ◯ right
- D ◯ left
- E ◯ into the screen
- ◯ out of the screen

$$\vec{F} = I\vec{L} \times \vec{B}$$

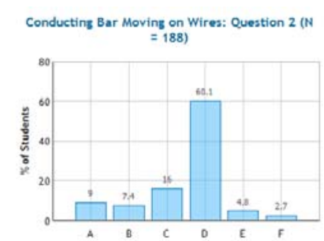
F **points to left**

$$F = \left(\frac{vBL}{R}\right)LB \quad \longrightarrow \quad P = Fv = \left(\frac{vBL}{R}\right)LBv = V^2/R$$

Energy

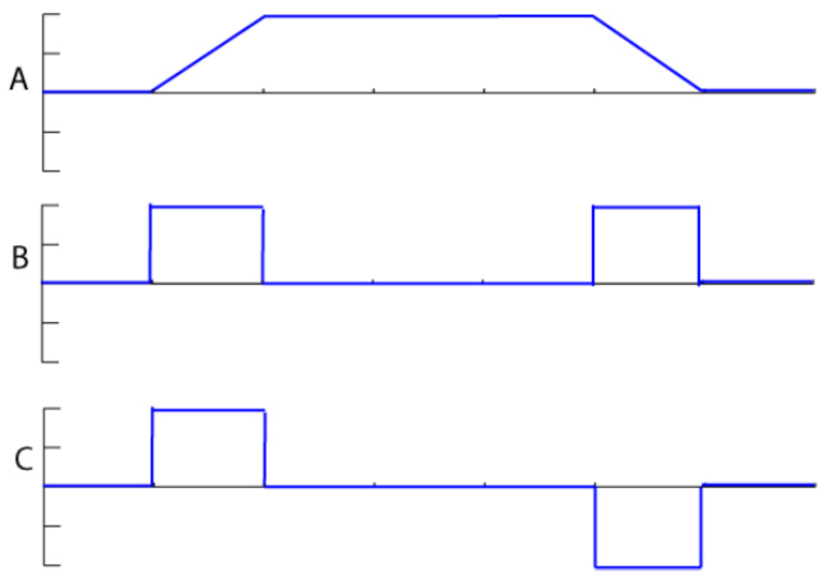
External agent must exert force F to the right to maintain constant v

This energy is dissipated in the resistor!

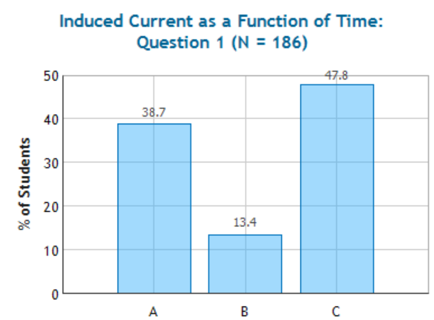


CheckPoint 11

A wire loop travels to the right at a constant velocity. Which plot best represents the induced current in the loop as it travels from left of the region of magnetic field, through the magnetic field, and then entirely out of the field on the right side.



Let's step through this one. The responses were uncertain



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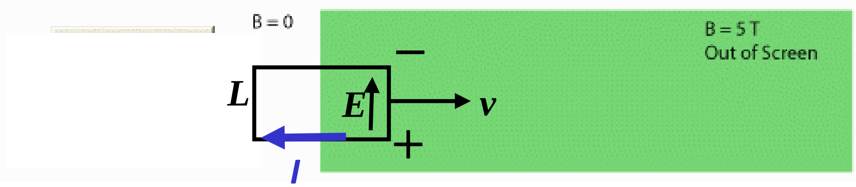
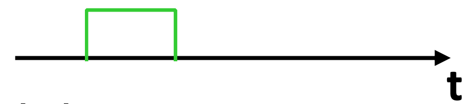
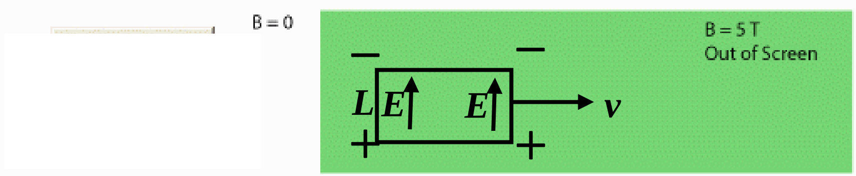
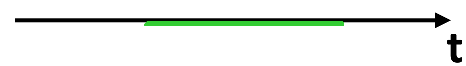




emf **on right: clockwise current.**

Now coil is entirely in the loop





no current because ***emf*****(left) =** ***emf*****(right)**

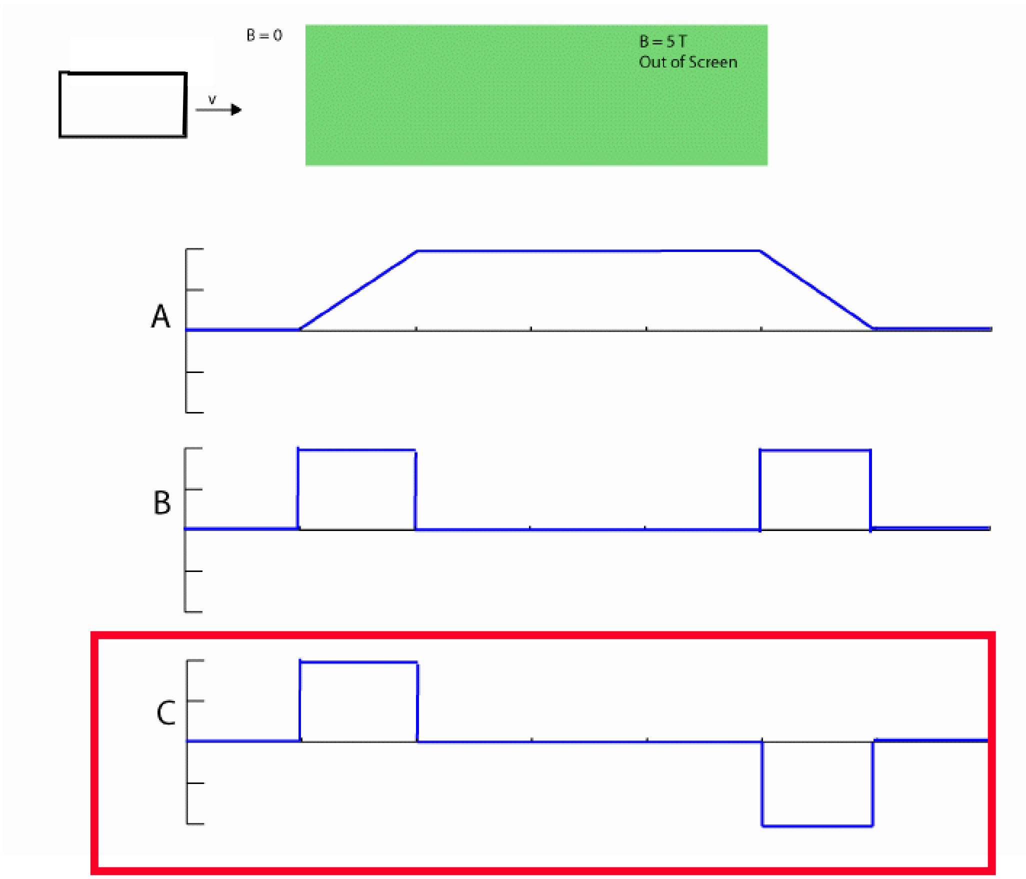
Leading and trailing sides have charge separation

$emf = BLv - BLv = 0$ **(no current)**

Now coil is partially out of the loop

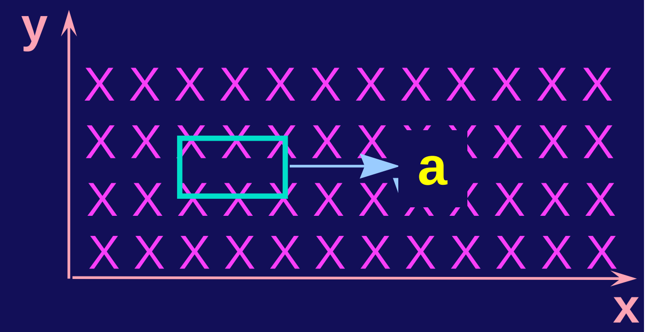
emf **on left: counter-clockwise current.**

A wire loop travels to the right at a constant velocity. Which plot best represents the induced current in the loop as it travels from left of the region of magnetic field, through the magnetic field, and then entirely out of the field on the right side.



Clicker

- A conducting rectangular loop is *accelerated* in the +x direction through a region of constant magnetic field B in the -z direction as shown.
  - What is the direction of the induced current in the loop?



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

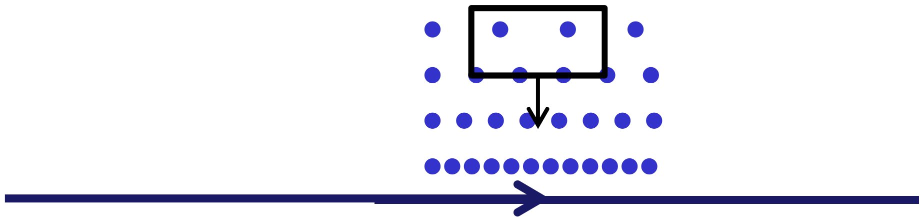
A non-zero flux Φ_B passes through the loop (here B is perpendicular to the area of the loop)

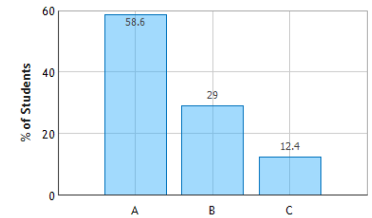
Velocity of the loop is changing, BUT the magnetic flux through the loop is always the same. DOES NOT CHANGE IN TIME.

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

Checkpoint

A conducting rectangular loop moves with velocity v towards an infinite straight wire carrying current as shown.





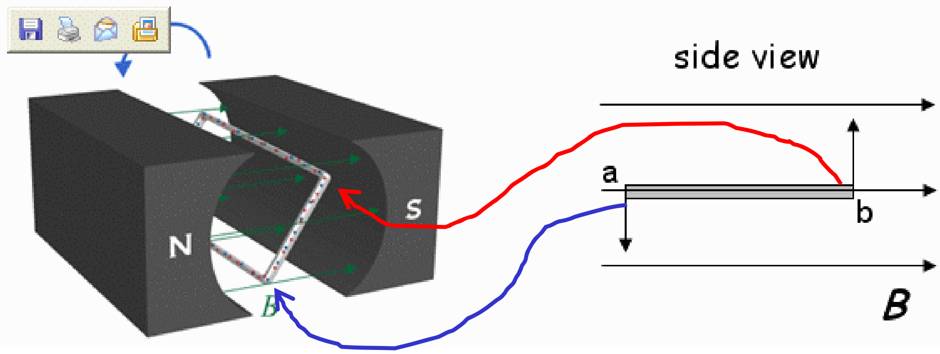
In which direction is the induced current in the loop?

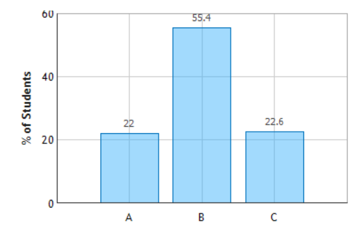
A) Clockwise
B) Counter-clockwise
C) There is no induced current in the loop

1. **Magnetic field at bottom larger.**
2. **Force on positive charges at bottom wire is to left.**
3. **Clockwise current in the loop.**

Checkpoint: Changing Orientation

8) A rectangular loop rotates in a region containing a constant magnetic field as shown.





The side view of the loop is shown at a particular time during the rotation. At this time, what is the direction of the induced (positive) current in segment ab?

- ○ from *b* to *a*
- ○ from *a* to *b*
- ○ there is no induced current in the loop at this time

First, let's talk just about the induced I in wire

1. **As "b" goes up, v x B is into the page**
2. **As "a" goes down, v x B is out of the page**
   - ***Which way is the current then flowing ?***
3. **At you at "a", away from you at "b" implies .**
   - ***From a to b***

A jet flies in a region where the *B* field points upward. Which part of the plane becomes negatively charged?

A. No part becomes charged
B. Its right wing
C. Its left wing
D. Its bottom
E. Its top
F. Its tail

A jet flies in a region where the B field points upward. Which part of the plane becomes negatively charged?

A. No part becomes charged
B. Its right wing
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D. Its bottom
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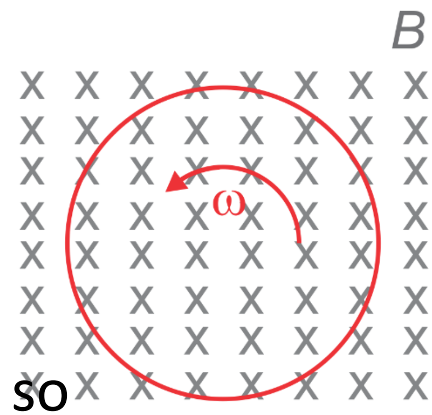
Field up, v forward,
force on + charges to right;
force on – charges to left.

Problem: *metallic disk rotating at circular*



E field at distance *r* from center:

$E = v\,B = \omega r\,B$

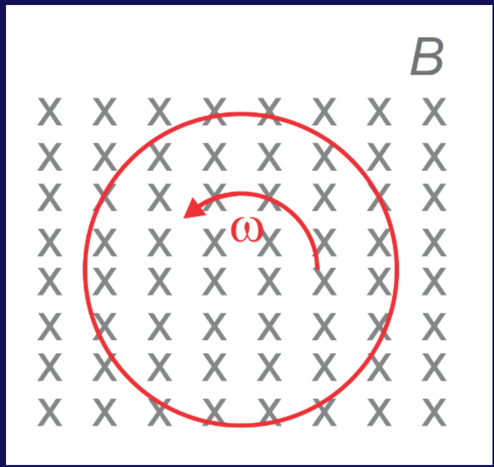
(charges re-accommodate until this happens so $F_{net} = 0$).

Then, potential difference

$\Delta V = -\int_0^a E\,dr = = -\omega a^2 B/2$

Where is it positive (center or edge?)

Problem: metallic disk rotating at circular speed ω in B field: what is the potential difference between the center and the edge?



E field at distance r from center:

$E = v\,B = \omega r\,B$

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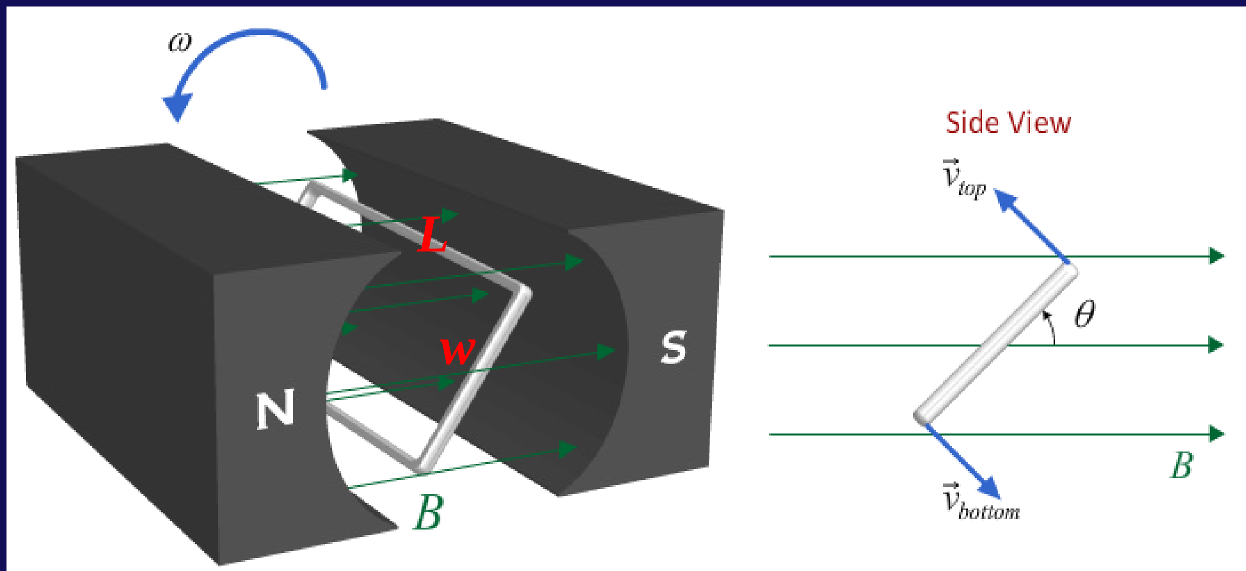
Then, potential difference

$\Delta V = - \int_0^a E\,dr = = -\omega a^2 B/2$

Where is it positive (center or edge?)

Clicker



At what angle θ is *emf* the largest?

A) $\theta = 0$
B) $\theta = 45^o$
C) $\theta = 90^o$
D) *emf* is same at all angles

$\vec{v} \times \vec{B}$

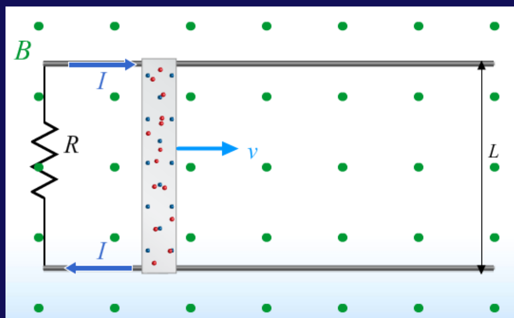
Largest for $\theta = 0$ (v perp to B)

$$\varepsilon = 2EL = 2\frac{F}{q}L = 2L\vec{v} \times \vec{B} = 2L\left(\frac{w}{2}\right)\omega B\cos\theta = \omega AB\cos(\omega t)$$

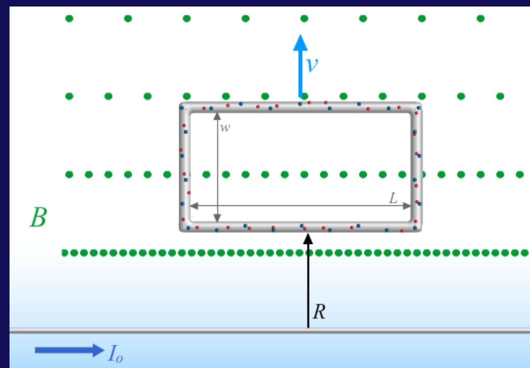
$= v$

Faraday's Law

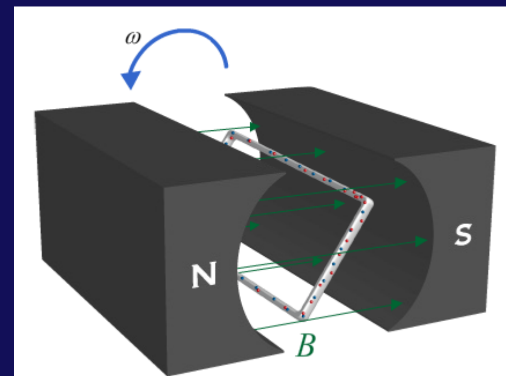
EMF Observed when …



Change Area of loop



Change magnetic field through loop (could also be B(t))



Change orientation of loop relative to B

All the above can be deduced from Faraday's Law

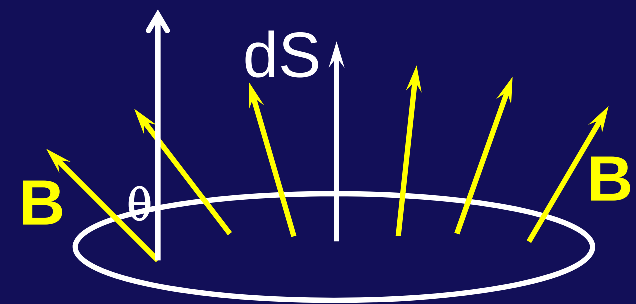
$$\Phi \equiv \vec{B} \cdot \vec{A}$$

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

Faraday's Law

- **Define the flux of the magnetic field through a surface (closed or open) from:**

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



- **Faraday's Law:**

The emf induced in a circuit is determined by the time rate of change of the magnetic flux through that circuit.

$$emf = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$$

The minus sign indicates direction of induced current (Lenz's Law).

Lenz's Law

- **Lenz's Law:**

  The induced current will appear in such a direction that it opposes the change in <u>flux</u> that produced it.