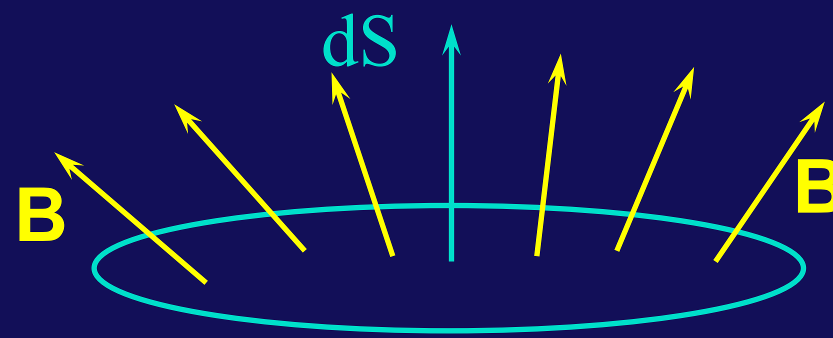
Faraday's Law



The Practical

- **We are near the end of the course**
  - **A tip: Don't get behind on the SmartPhysics and HW's**

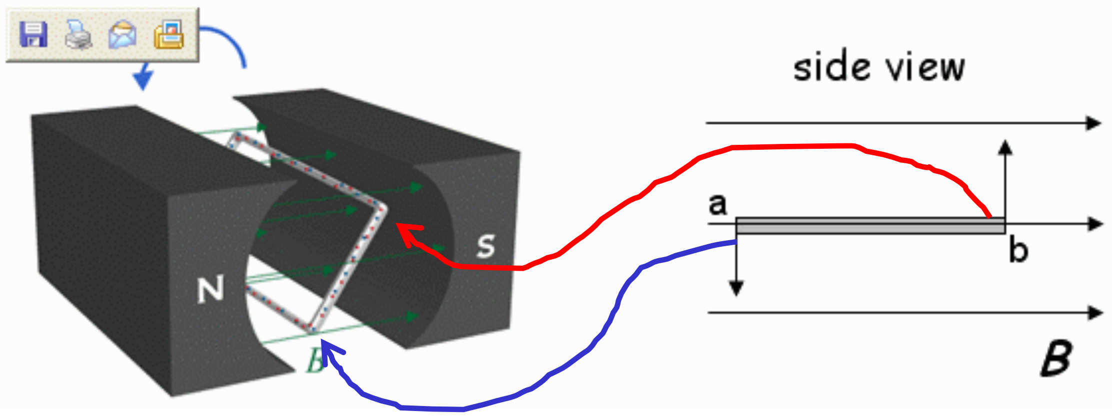
A Few things for the Homework

(These are concepts from electric fields that translate directly)

- Magnetic susceptibility – mu for B is the same as epsilon for E
- Gauss's law for B fields

A Quick Reminder to get started today

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



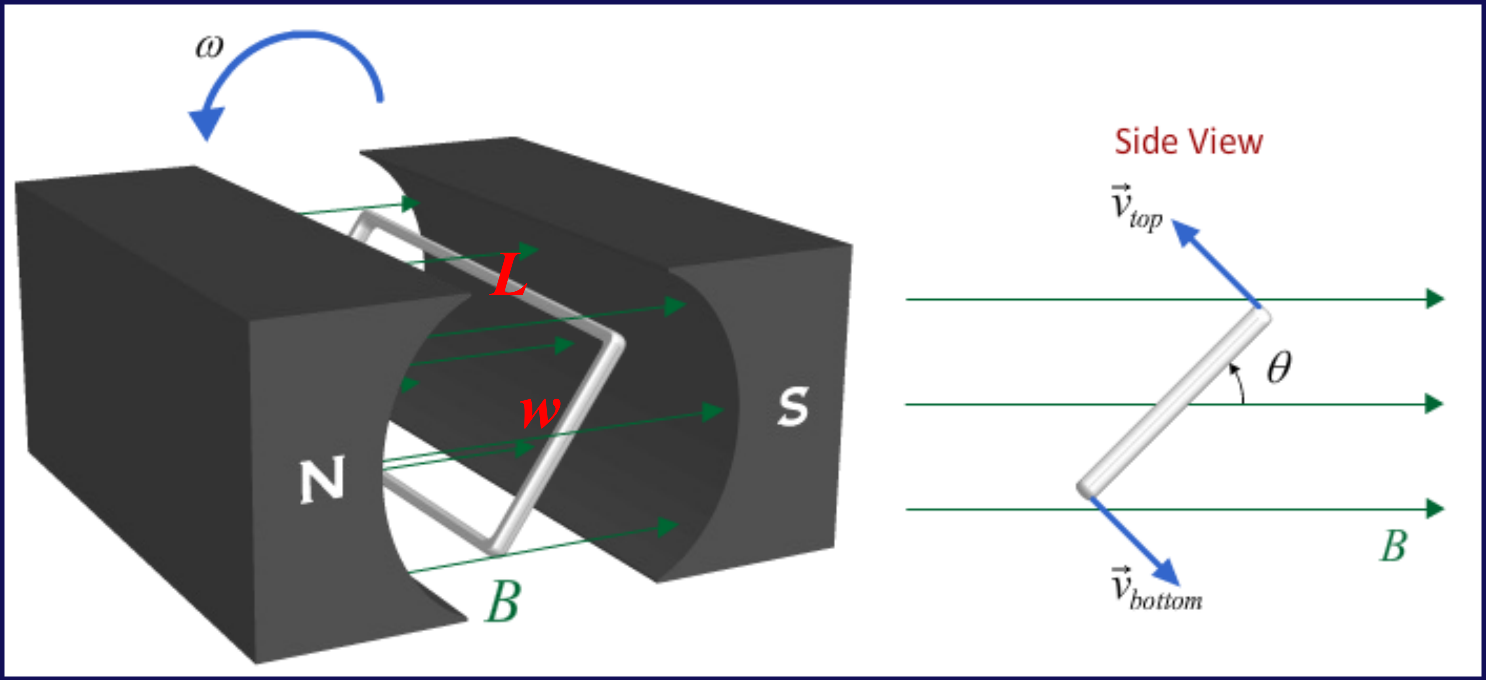
We will use Lenz' Law: EMF directed to oppose the change in flux through the loop

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

1. **As loop rotates up, flux "enters" from left to right**
2. **The loop produces an EMF to oppose this.**
3. **EMF drives a current around the loop**
4. **Direction of current in loop must create magnetic field (or flux through loop) that points from right to left**
5. **Curl right hand along a to b and around top of loop into page; your thumb points to the left**

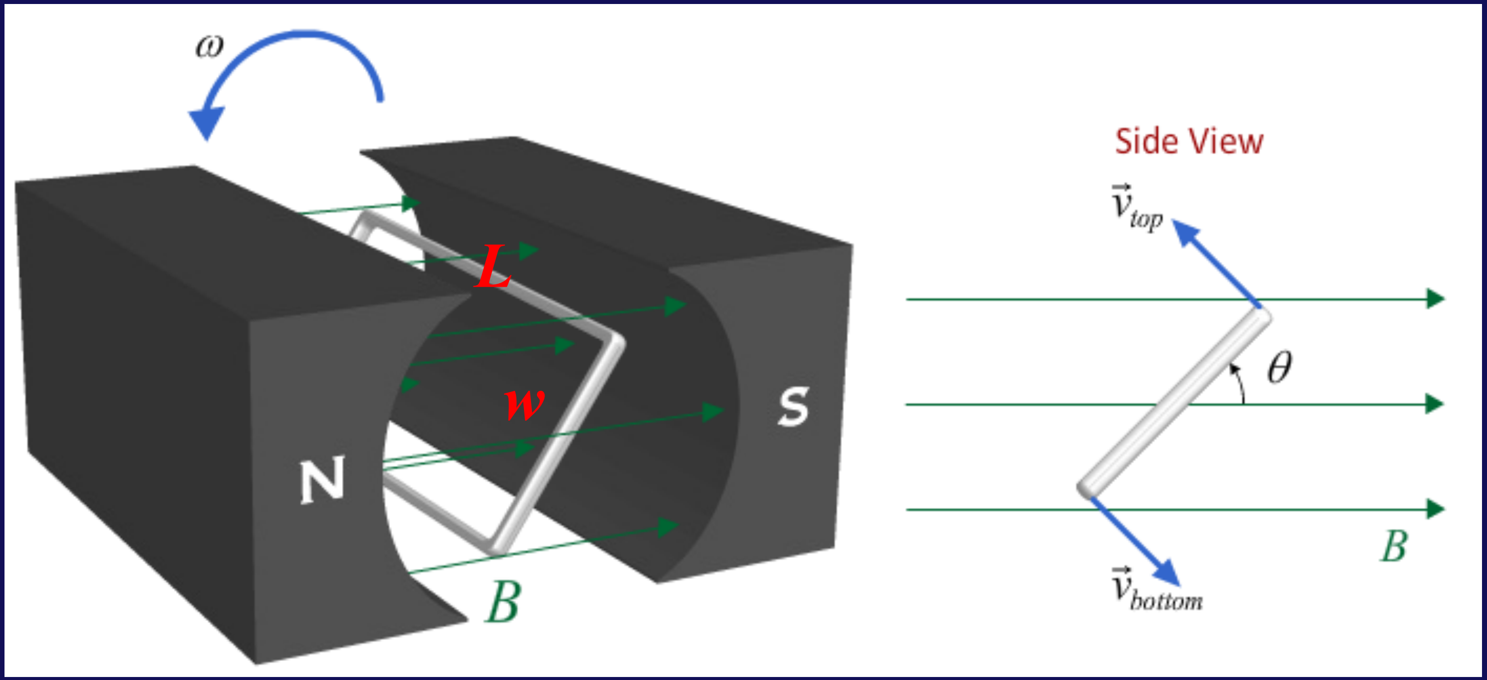
Now a Clicker



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

Now a 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

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

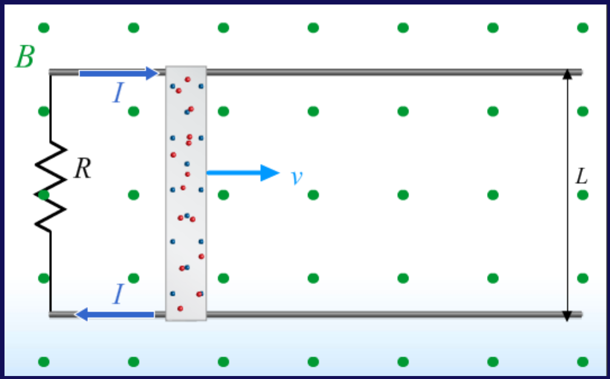
Largest for $\theta = 0$ (v perp to B)

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

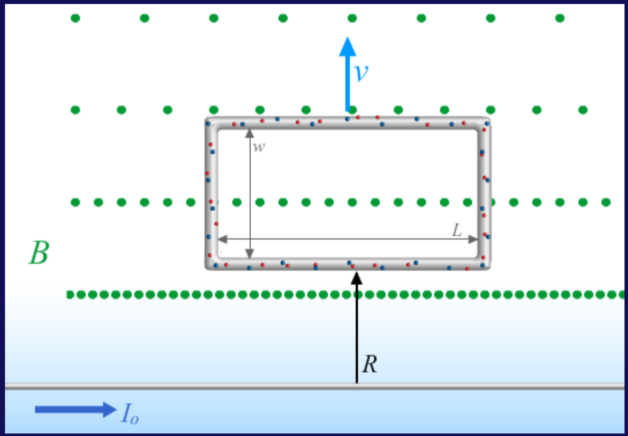
$\left(\frac{w}{2}\right)\omega = v$

Wednesday's Observations

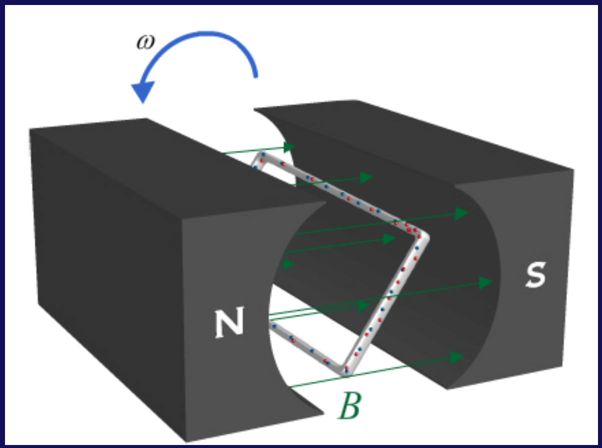
EMF Observed when …



Change Area of loop



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



Change orientation of loop relative to B

Today: Formalize it with Faraday's Law

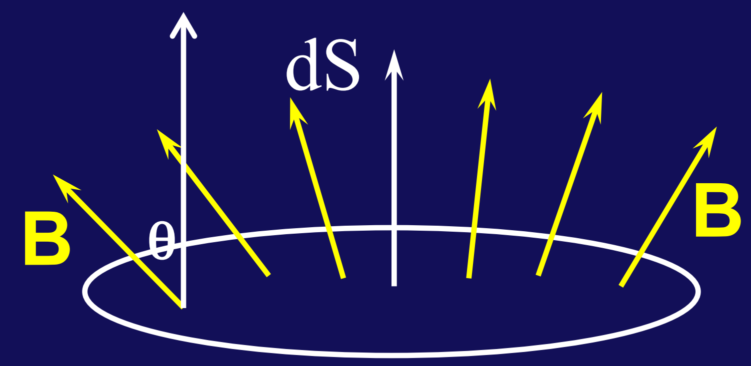
$$\Phi \equiv \vec{B} \cdot \vec{A}$$

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

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.

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

We will also talk about this

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

Quick Flux Clickers

Suppose you double the magnetic field in a given region and quadruple the area through which this magnetic field exists. The effect on the flux through this area would be to

A. Leave it unchanged
B. Double it
C. Quadruple it
D. Increase by factor of 6
E. Increase it by factor of 8

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

$B' \rightarrow 2B$
$A' \rightarrow 4A$
$\Phi'_B \rightarrow 8\,\Phi_B$

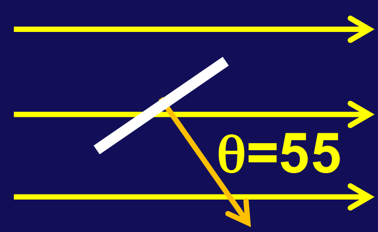
Flux Clicker

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

A 3.0-cm by 5.0-cm rectangular coil has 100 turns. Its axis makes an angle of 55º with a uniform magnetic field of 0.35 T. What is the magnetic flux through this coil?

A. 3.0×10^{-4} Wb
B. 4.3×10^{-4} Wb
C. 3.0×10^{-2} Wb
D. 4.3×10^{-2} Wb
E. 5.3×10^{-2} Wb

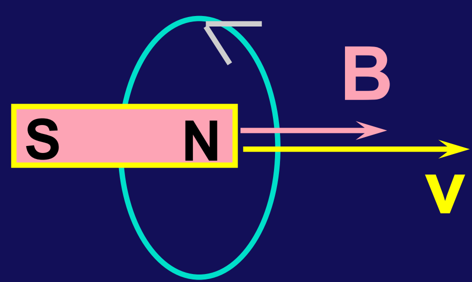
Area = .03 x 0.05 = .0015 m^2
x 100 turns
cos(55) = 0.57
Φ_B = (0.35 T)(100)(.0015)(.57) = 0.03 Wb

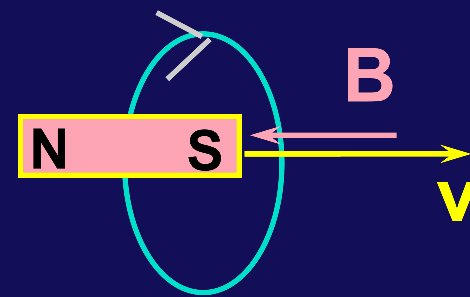


Reminder: Lenz's Law

- Lenz's Law:

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

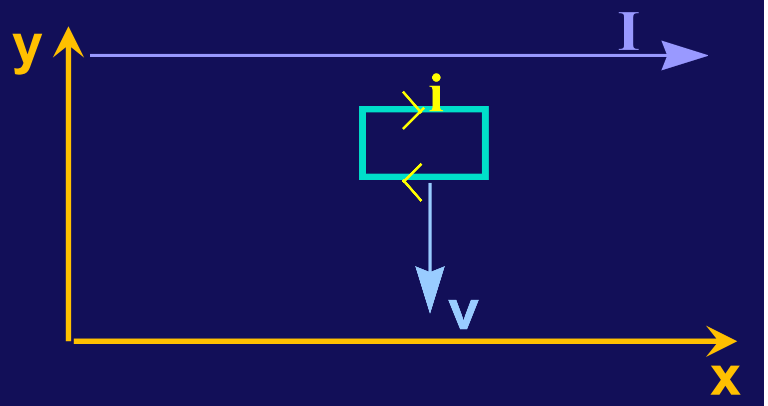




Clicker - checkup

A conducting rectangular loop moves with constant velocity v in the -y direction and a constant current I flows in the +x direction as shown.

What is the direction of the induced current in the loop?



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

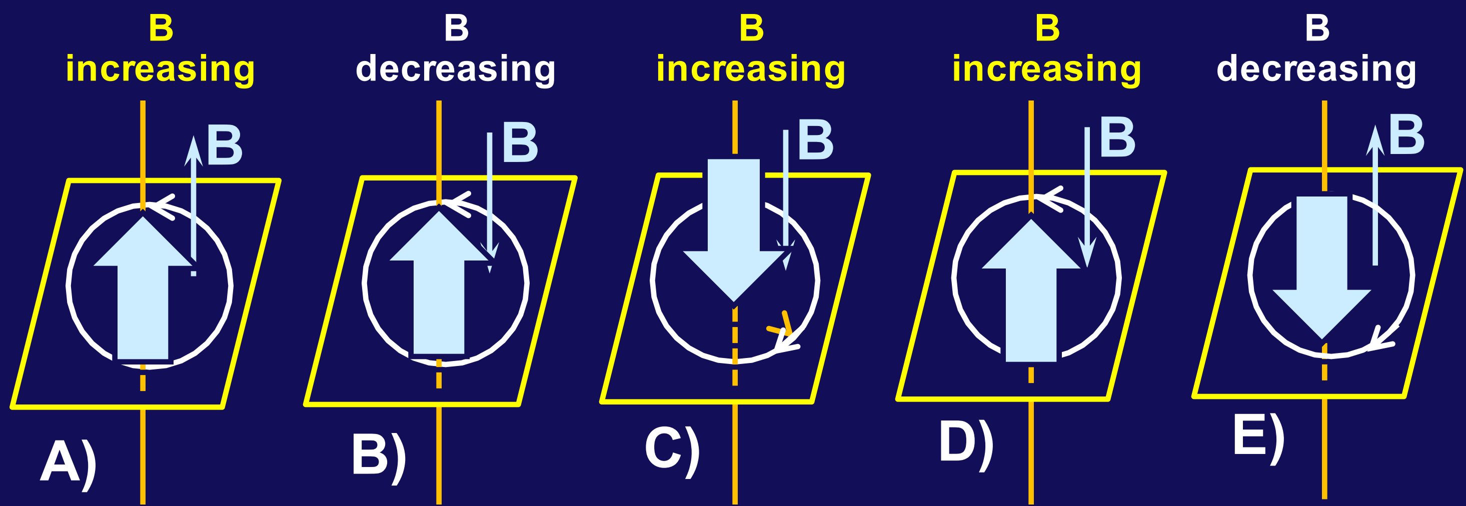
The flux through this loop DOES change in time since the loop is moving from a region of higher magnetic field to a region of lower field.

By Lenz' Law, an EMF will be induced which will oppose the change of flux.

The current i is induced in the clockwise direction to restore the flux.

Flux Clicker (look closely)

A loop rests in the *xy* plane. The *z* axis is normal to the plane. The direction of the changing flux is indicated by the arrow on the *z* axis. The diagram that correctly shows the direction of the resultant induced current in the loop is



A) No
Flux is increasing in +z;
Current adds flux in +z direction

B) No
Flux is reduced in –z;
need to add flux in –z

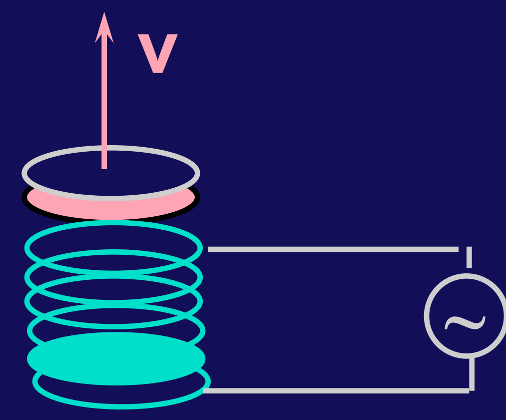
C) No
Flux is increasing in –z;
need to add flux in +z

D) YES !!
Flux is increasing in –z;
Current adds flux in +z

E) No
Flux is getting smaller;
in +z;
need to add flux in +z

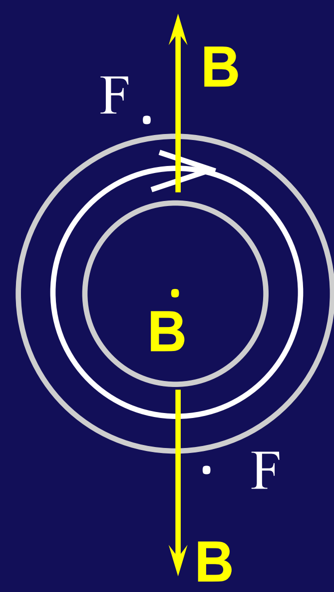
Demo E&M Jumping Rings

- Connect solenoid to a source of alternating voltage.
- The flux through the area ⊥ to axis of solenoid therefore changes in time.



side view

- A conducting ring placed on top of the solenoid will have a current induced in it opposing this change.

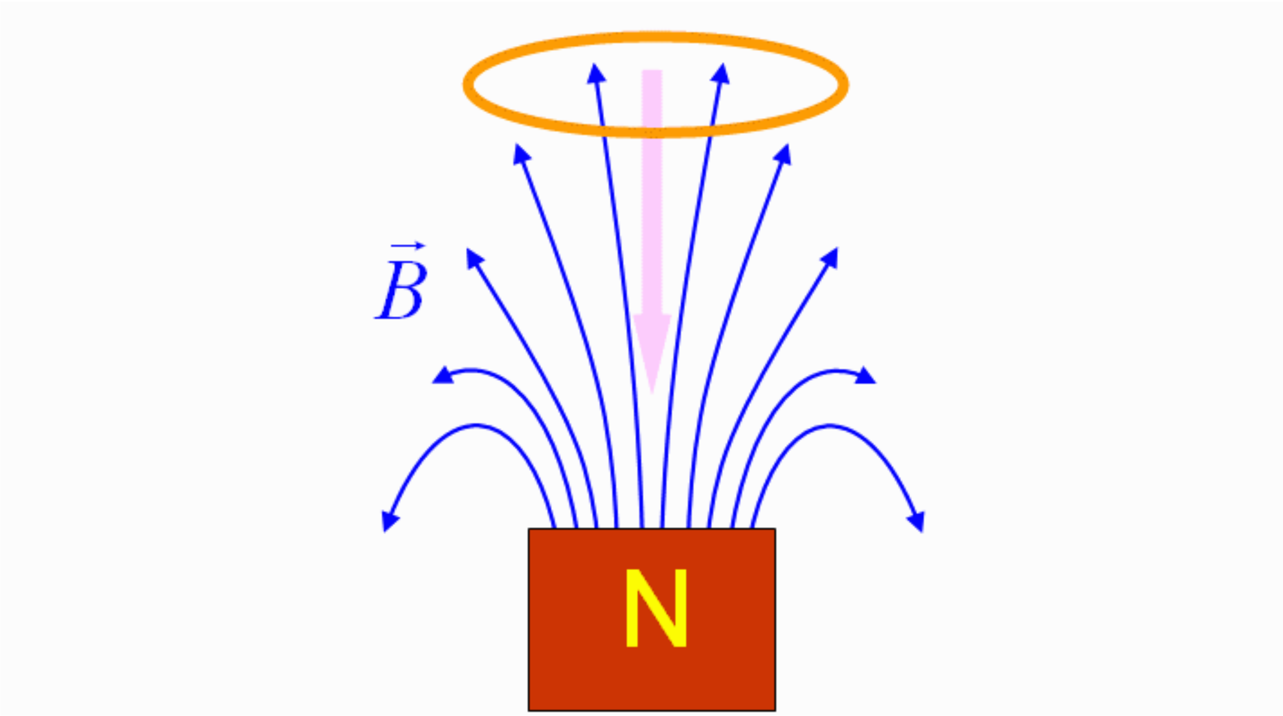


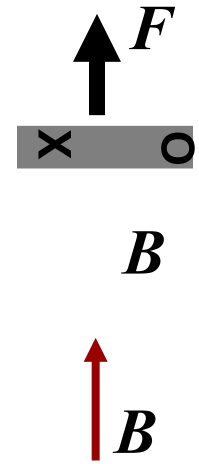
- There will then be a force on the ring since it contains a current which is circulating in the presence of a magnetic field.

top view

Think about this for a minute ...

A horizontal conducting ring is dropped from rest above the north pole of a permanent magnet





Like poles repel

→ $F_{total} < mg$

→ $a < g$

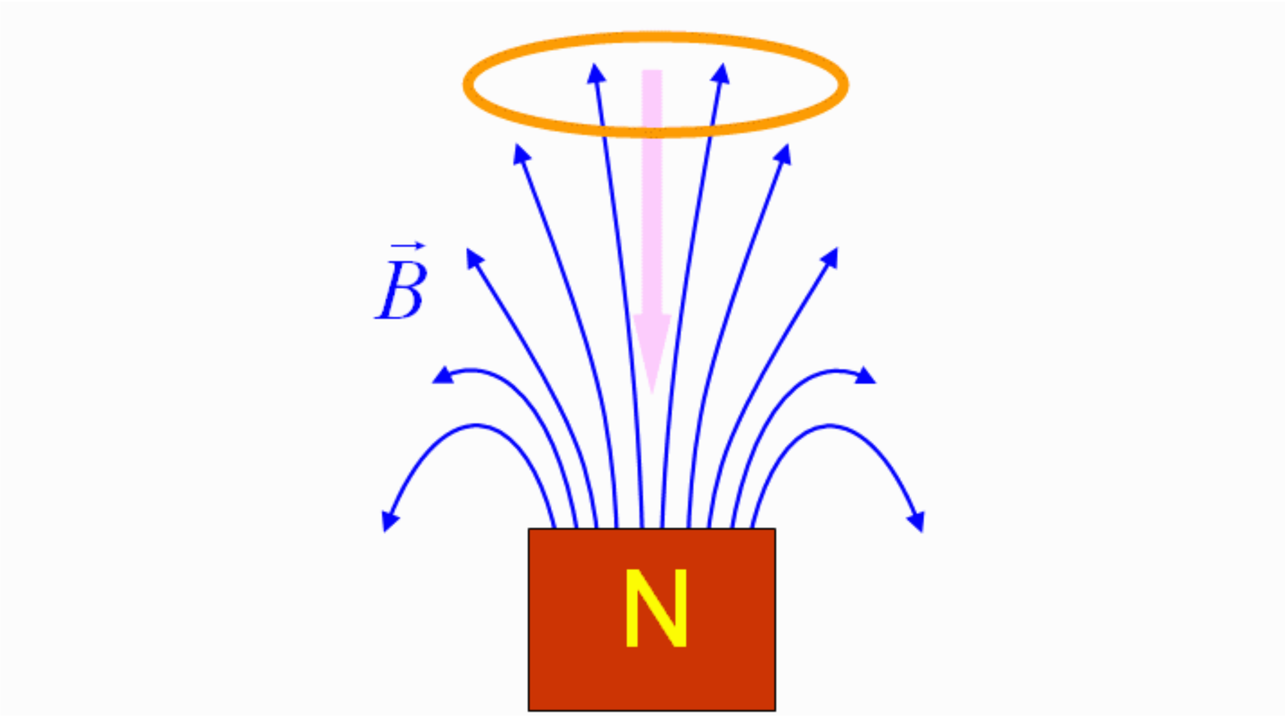
Will the acceleration a of the falling ring be any different than it would have been under the influence of just gravity (i.e, g) ?

a) a > g
b) a = g
c) a < g

B field increases upward as loop falls
Clockwise current (viewed from top) is induced

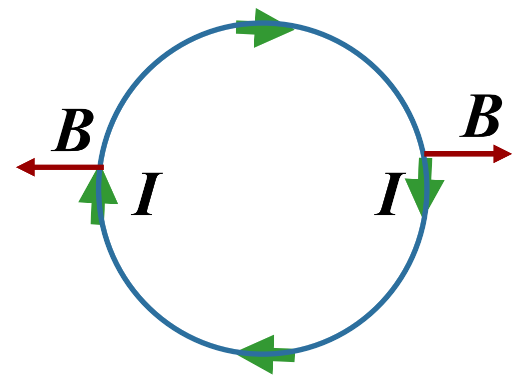
Think about this for a minute …

A horizontal conducting ring is dropped from rest above the north pole of a permanent magnet



HOW IT WORKS

Looking down



$IL \times B$ points UP

→ $F_{\text{total}} < mg$

→ $a < g$

Will the acceleration a of the falling ring be any different than it would have been under the influence of just gravity (i.e, g) ?

a) a > g
b) a = g
c) a < g

Preliminary Executive Summary:

Faraday's Law: $$emf = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$$ **where** $$\Phi_B \equiv \int \vec{B} \cdot d\vec{A}$$

$emf \longrightarrow$ current $\longrightarrow$ field

a) induced only when flux is changing
b) opposes the change

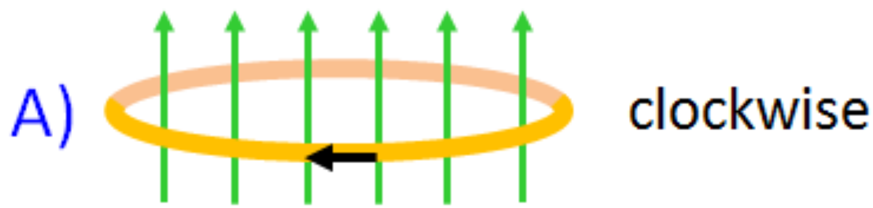
Flux in loop can change when …

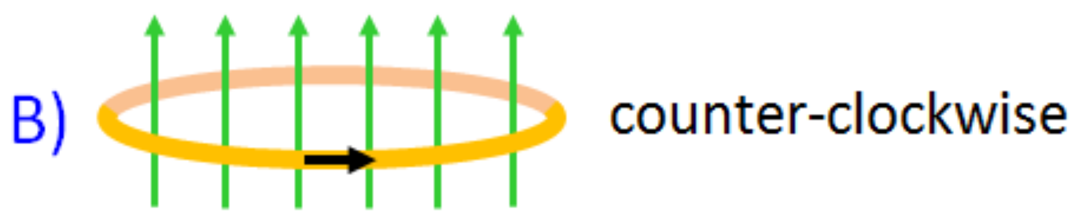
- **Magnitude of magnetic field varies in time**
- **Loop orientation with respect to field varies**
- **Size of loop varies**

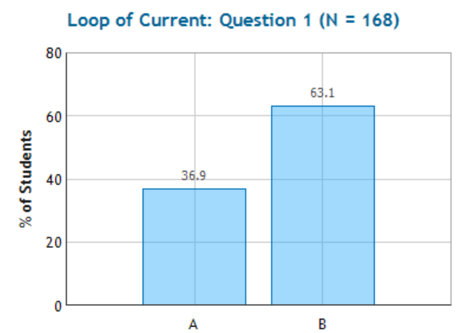
Checkpoint

Suppose a current flows in a horizontal conducting loop in such a way that the magnetic flux produced by this current points upward.

1) As viewed from above, in which direction is this current flowing?



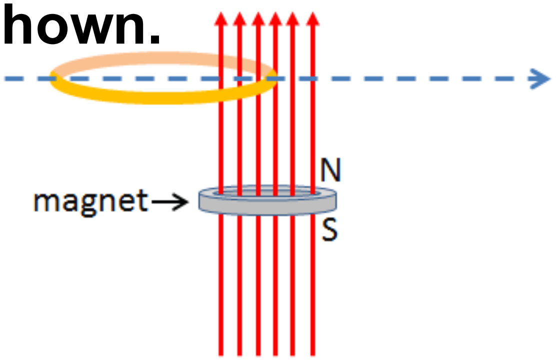


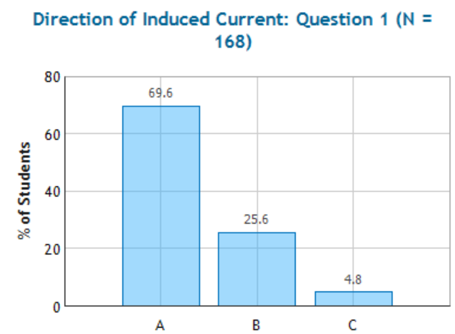


This is just the RHR
Put fingers in direction of current;
Thumb points in the field direction

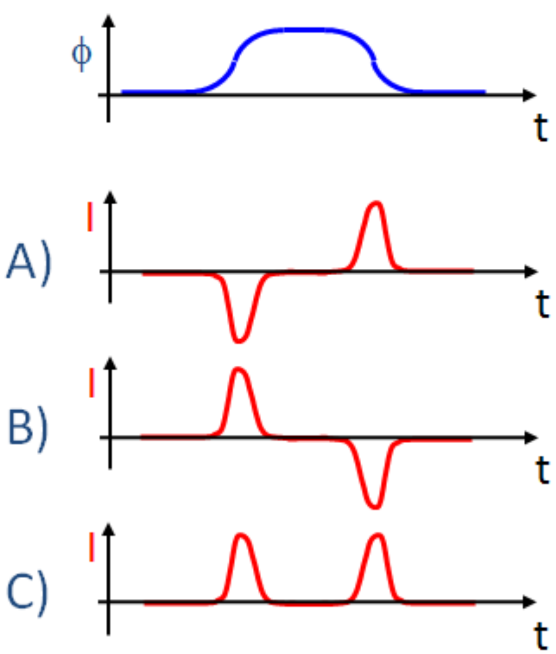
Checkpoint

A magnet makes the vertical magnetic field shown by the red arrows. A horizontal conducting loop passes though the field from left to right as shown.





The upward flux through the loop as a function of time is shown by the blue trace. Which of the red traces below best represents the current induced in the loop as a function of time as it passes over the magnet? (Positive means counter-clockwise as viewed from above):



1. **Enters, induced flux must point down → negative pulse**
2. **Middle no change**
3. **Leaving; flux must point up, positive pulse**