Purdue University Department of Physics

Physics 24100

Electricity & Optics

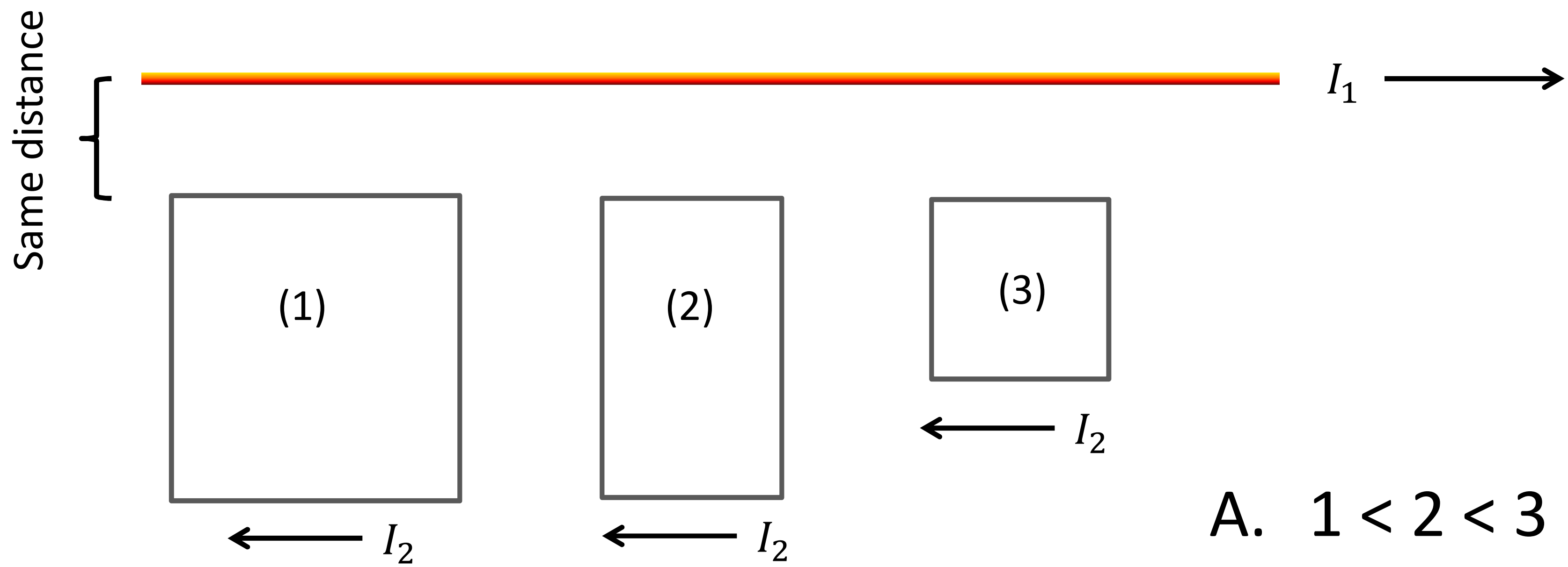
Lecture 15 – Chapter 28 sec. 1-3

Fall 2012 Semester

Matthew Jones

Clicker Question

- Rank the current loops in order of increasing force:

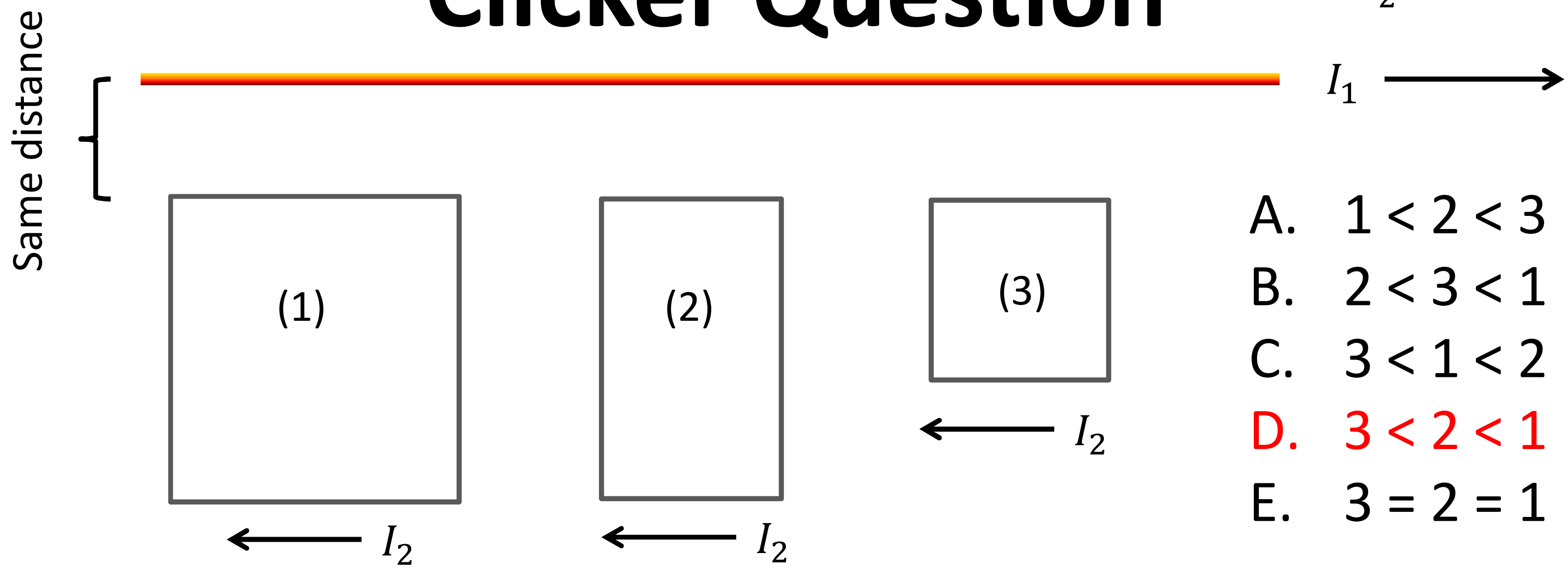


$$\frac{dF_{12}}{d\ell_2} = \frac{\mu_0}{4\pi}\frac{2I_1\ I_2}{R}$$

A. 1 < 2 < 3
B. 2 < 3 < 1
C. 3 < 1 < 2
D. 3 < 2 < 1
E. 3 = 2 = 1

Clicker Question

$$\frac{dF_{12}}{d\ell_2} = \frac{\mu_0}{4\pi}\frac{2I_1\,I_2}{R}$$



A. 1 < 2 < 3
B. 2 < 3 < 1
C. 3 < 1 < 2
D. 3 < 2 < 1
E. 3 = 2 = 1

- Forces on the sides parallel to I_1 are opposite
- The force on the near side is greater when it is longer:
  - Therefore (2) < (1)
- The force is smaller when the side is farther from I_1
  - Therefore (3) < (2)

General Review

So far we have covered:

- **Electrostatics**
  - Forces on charge q in an electric field
  - Electric fields produced by q
- **Magnetostatics**
  - Forces on charge q moving in a magnetic field
  - Magnetic field produced by motion of q

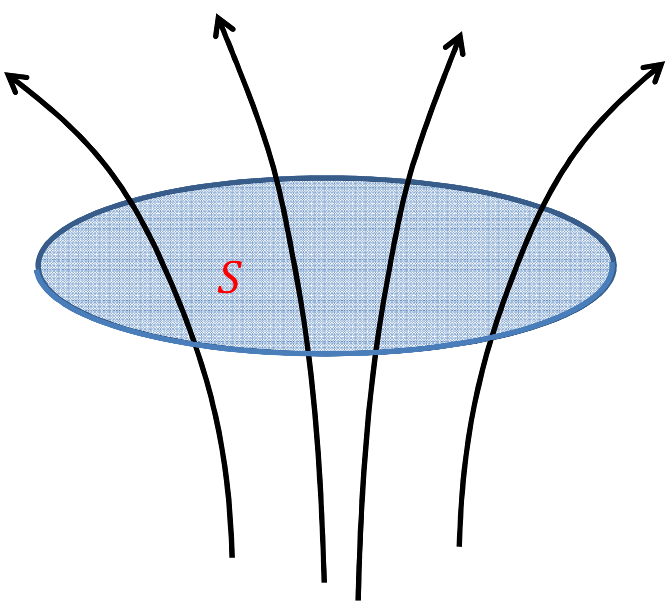
Next we consider **Electrodynamics:**

- A changing magnetic field produces an electric field
- A changing electric field produces a magnetic field

Magnetic Flux

- We define magnetic flux in the same way we defined electric flux:

$$\phi_e = \int_S \hat{n} \cdot \vec{E}\, dA \qquad \phi_m = \int_S \hat{n} \cdot \vec{B}\, dA$$



Faraday's Law of Magnetic Induction

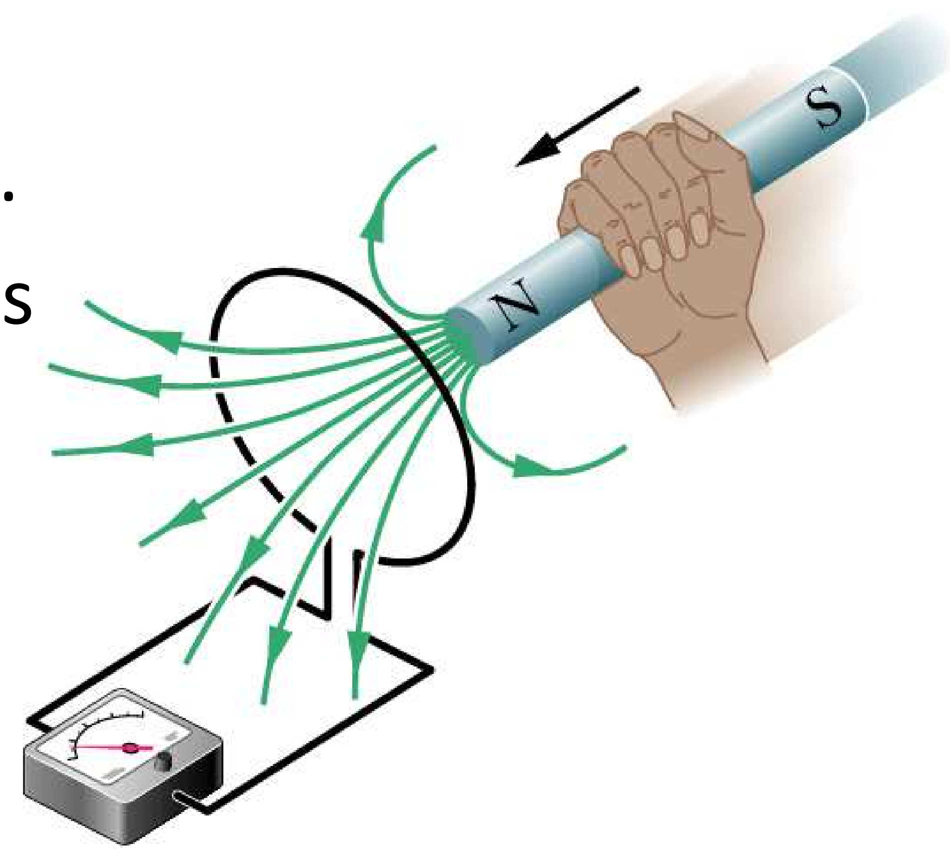
- A change in magnetic flux through a conducting loop induces a current in the loop.
- What causes the charges in the conductor to move? An electromotive force, Ɛ…

$$\mathcal{E} = -\frac{d\phi_m}{dt}$$

- Another way to think about it:
  - Changing magnetic flux induces an electric field
  - This changes the electric potential of the charge carriers

Demonstration

- When a bar magnet is moved in the vicinity of a loop of wire, the magnetic flux through the loop will change.
- A current is induced…
- Faster motion induces a larger current.
- No current when the motion stops.



Changes in Magnetic Flux

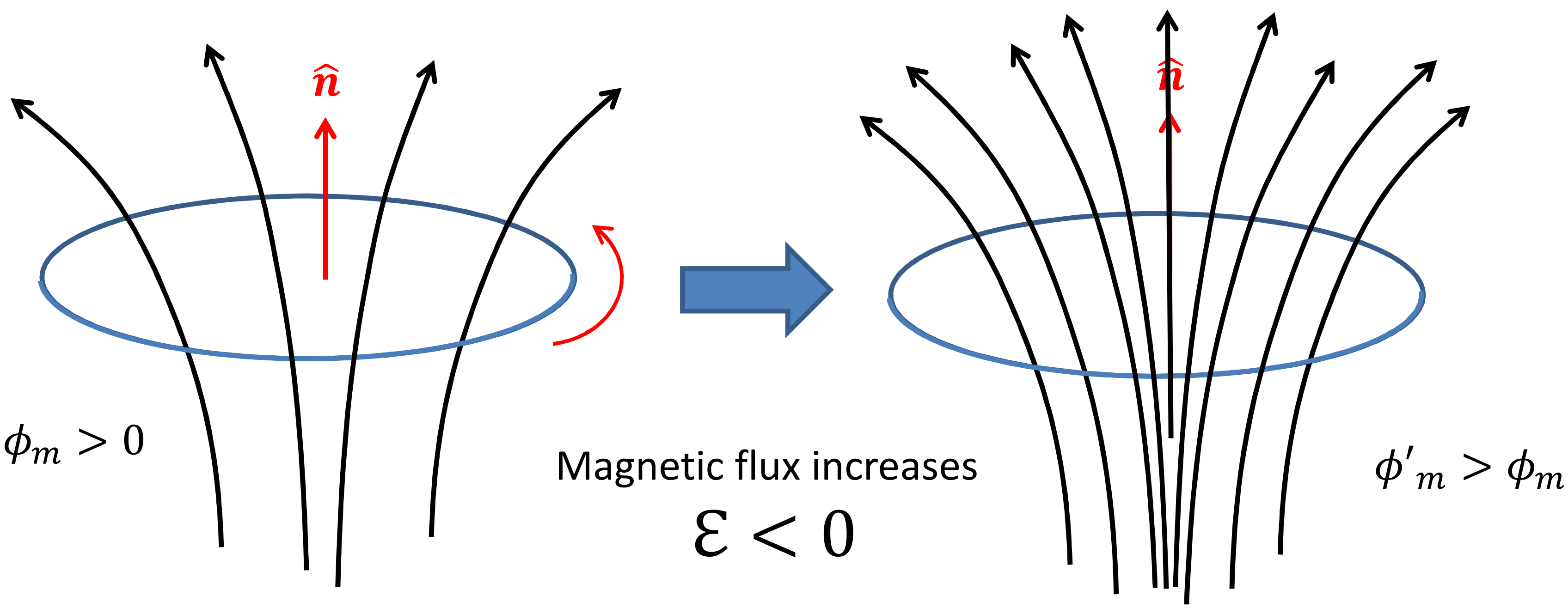
- The magnetic flux through a loop can change in various ways:
  - The magnetic field could change
  - The source of the magnetic field could move
  - The loop could move in a non-uniform field
  - The orientation of the loop could change
  - Others?
- Examples…

Changes in Magnetic Flux

$$\phi_m = \int_S \hat{n} \cdot \vec{B}\, dA$$

Use the right hand rule!

- Only depends on the component of $\vec{B}$ perpendicular to the plane of the loop.

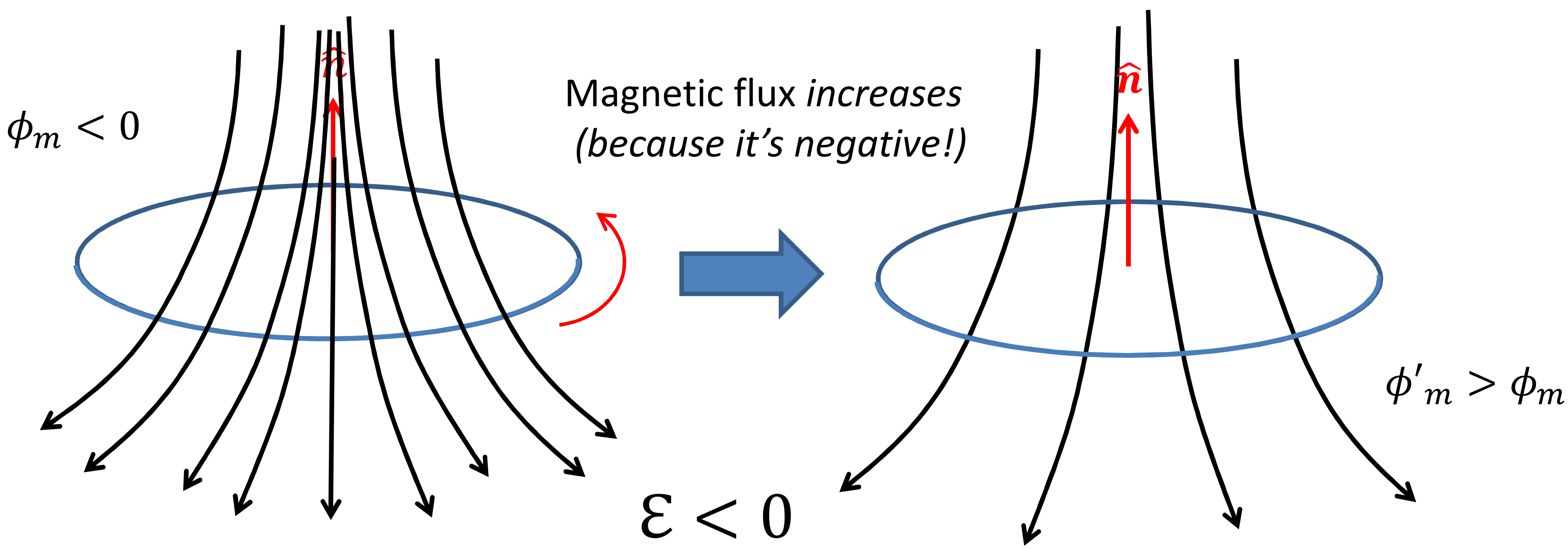


Changes in Magnetic Flux

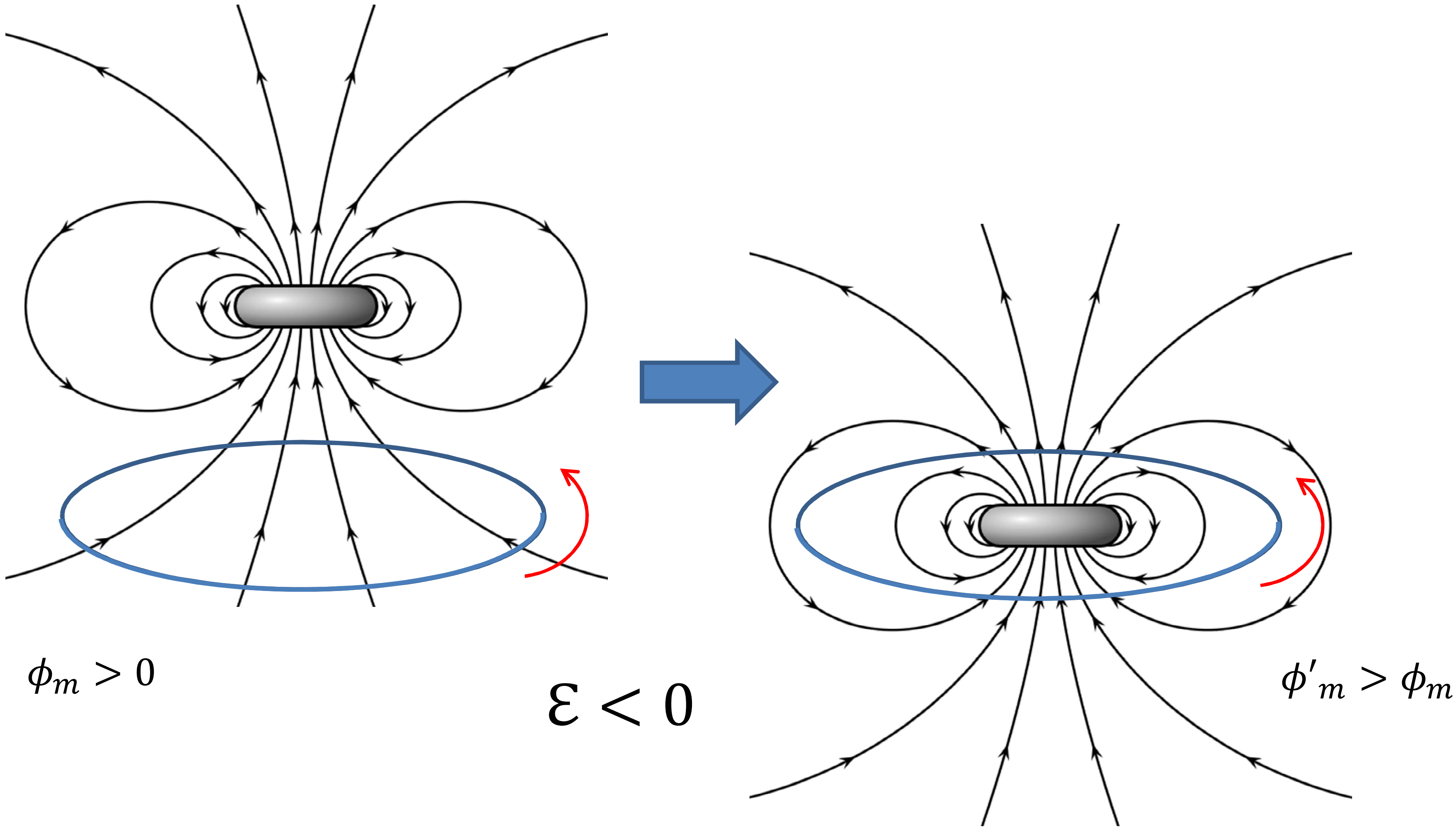
$$\phi_m = \int_S \hat{n} \cdot \vec{B}\, dA$$

Use the right hand rule!

- Only depends on the component of $\vec{B}$ perpendicular to the plane of the loop.



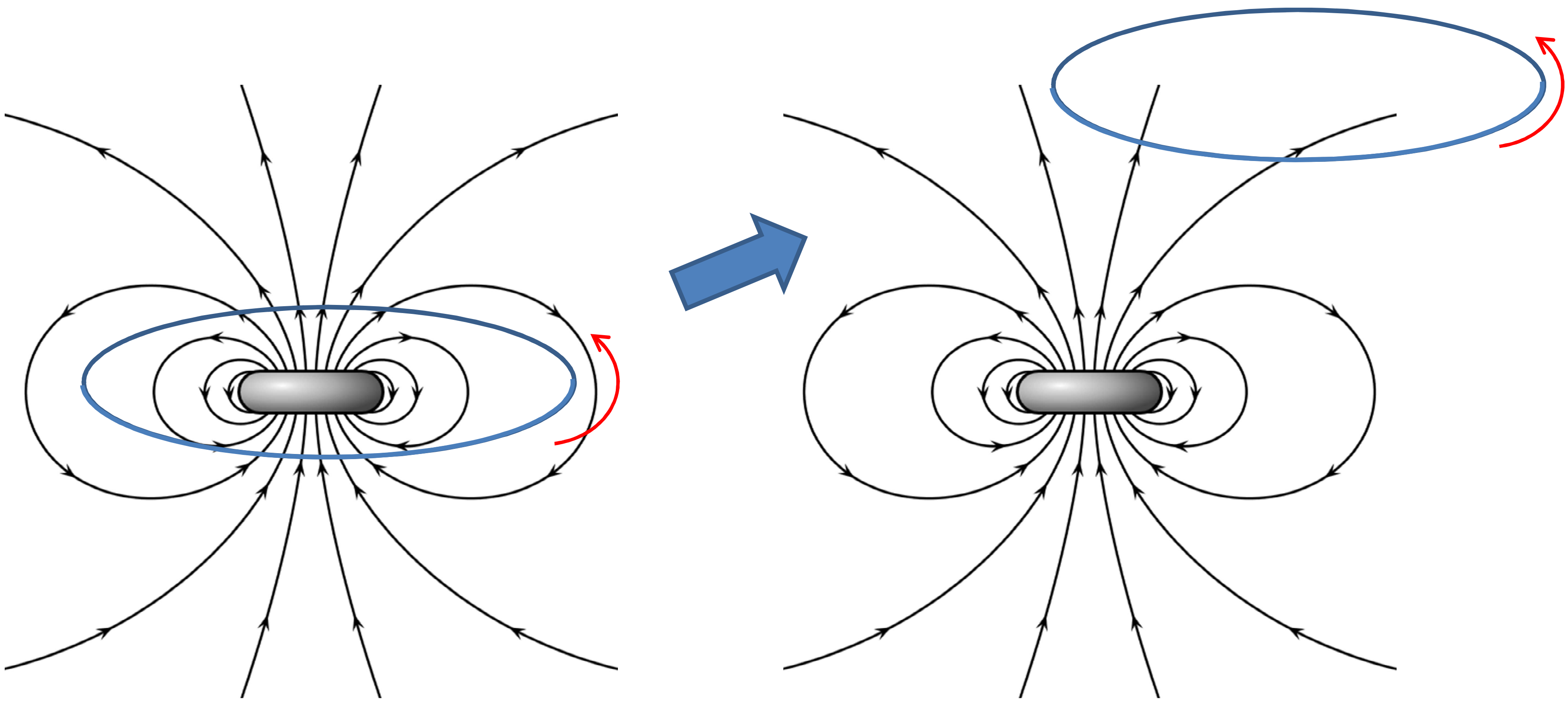
Changes in Magnetic Flux



Magnetic flux increases

Changes in Magnetic Flux

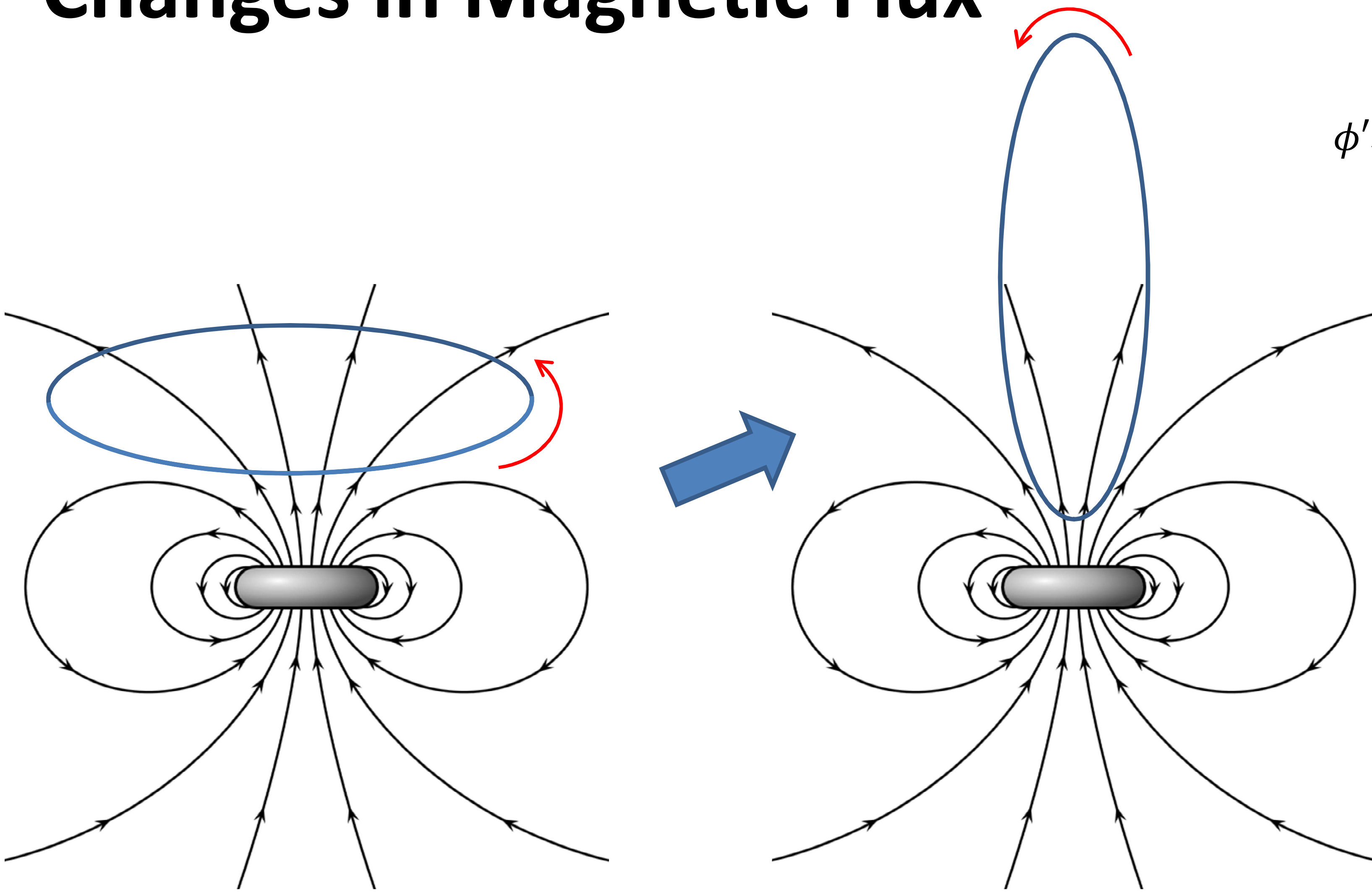
$\phi'_m < \phi_m$



$\phi_m > 0$

Magnetic flux decreases $\mathcal{E} > 0$

Changes in Magnetic Flux



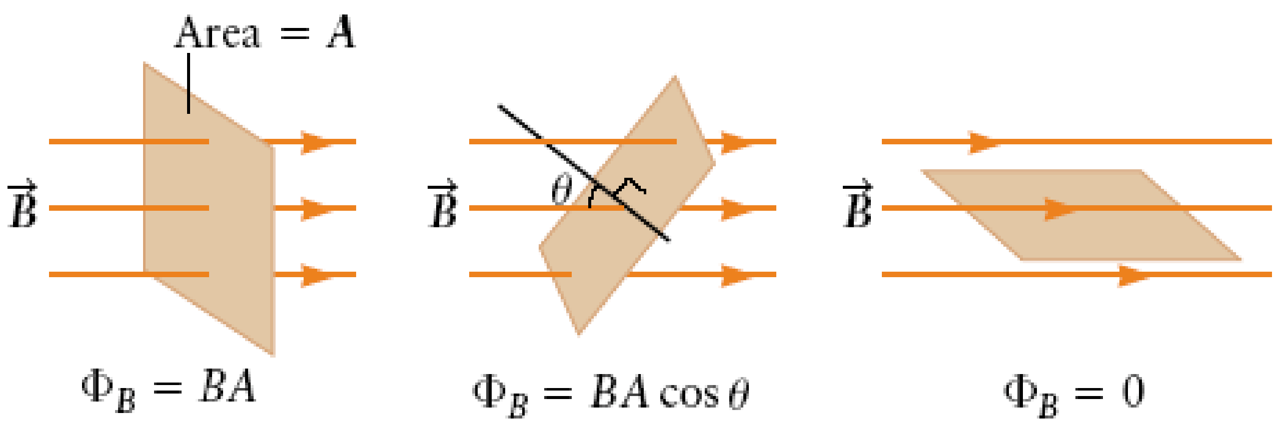
$\phi'_m = 0$

$\phi_m > 0$ Magnetic flux decreases $\varepsilon > 0$

Calculating Magnetic Flux

- If the surface is a plane over which the magnetic field is constant, then

$$\phi_m = \int_S \hat{n} \cdot \vec{B} dA = BA\cos\theta$$



Units of magnetic flux: Webers… $1\,Wb = 1\,T \cdot m^2$

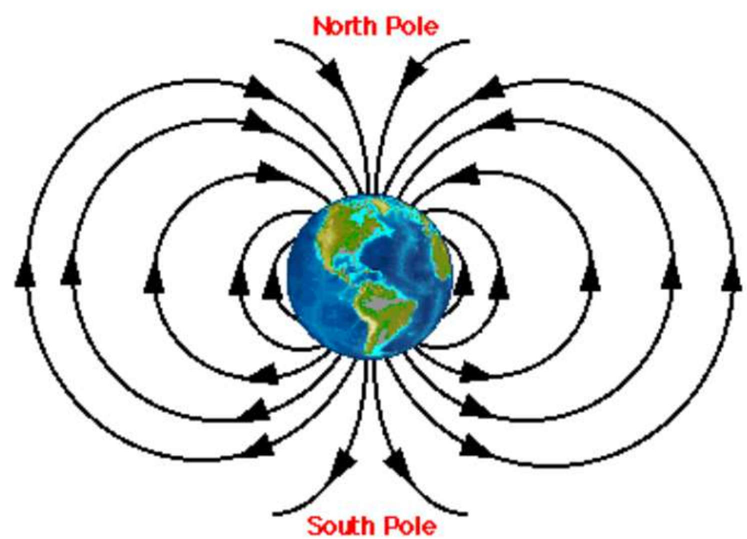
Clicker Question

- A loop of wire in the Earth's magnetic field has its normal vector pointing north.
- It is rotated so that its normal vector is pointing south.
- How did the magnetic flux through the loop change?

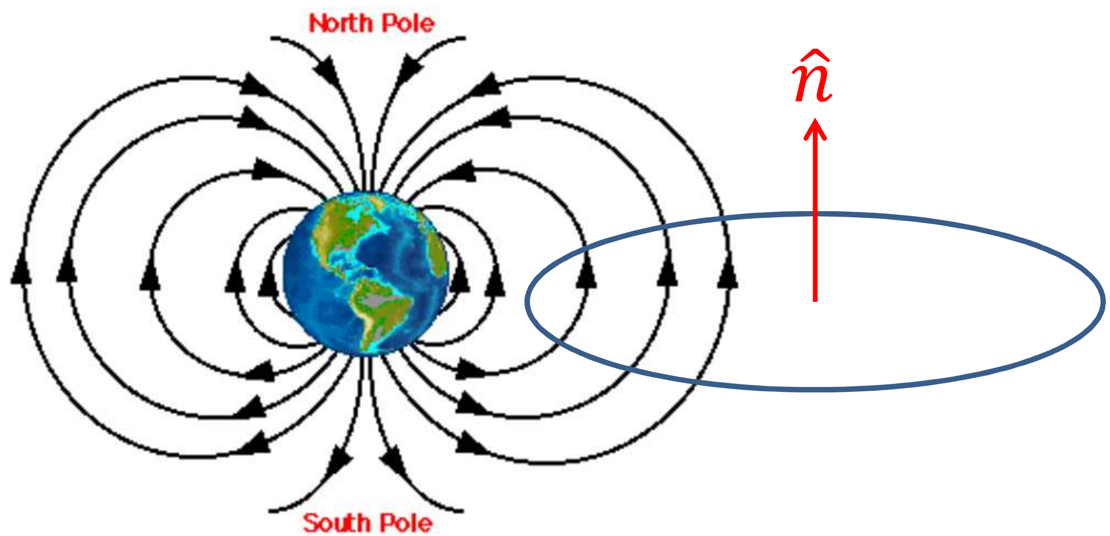
(a) $\phi_{final} > \phi_{initial}$

(b) $\phi_{final} < \phi_{initial}$

(c) $\phi_{final} = \phi_{initial}$



Clicker Question

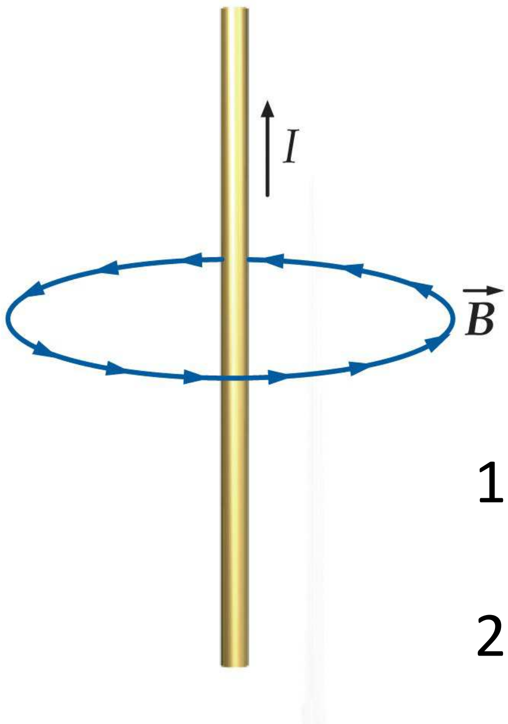


- Initial magnetic flux is positive
- Final magnetic flux is negative
- The flux decreased: $\phi_{final} < \phi_{initial}$

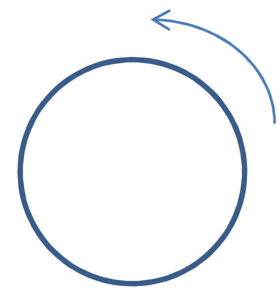
Lenz's Law

- Changing magnetic flux induces a current in a loop of wire.
- The induced current will create its own magnetic field.
- Lenz's Law: ***The induced magnetic field will oppose changes to the original magnetic field.***
  - If the flux is decreasing, the induced field will increase the flux will add to the applied field
  - If the flux is increasing the induced field will be opposite the applied field

Lenz's Law



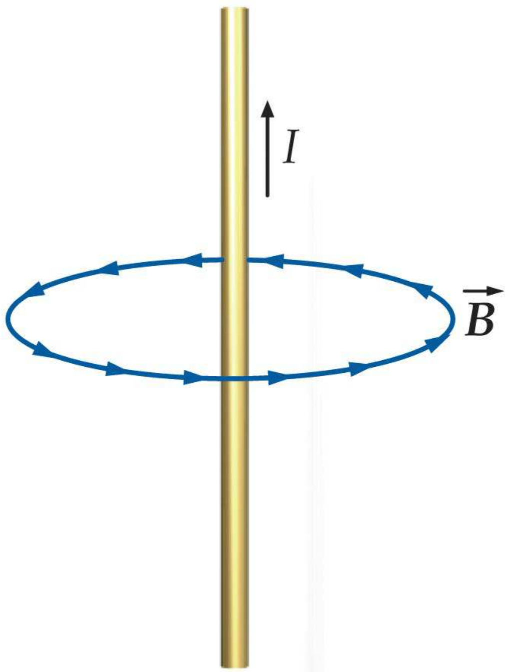
$$B = \frac{\mu_0 I_C}{2\pi R}$$

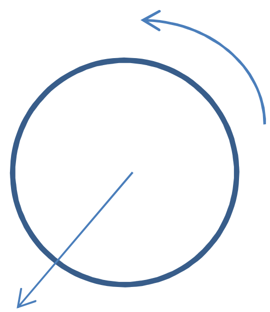


1. Pick an orientation for the loop
   - eg, counter-clockwise: $\hat{n}$ points out
2. Magnetic field is pointing in
   - Magnetic flux is negative
3. $|\vec{B}|$ increases as the loop gets closer
   - Magnetic flux is *decreasing*
4. ***Induced field will point out***

   (in the direction of $\hat{n}$)

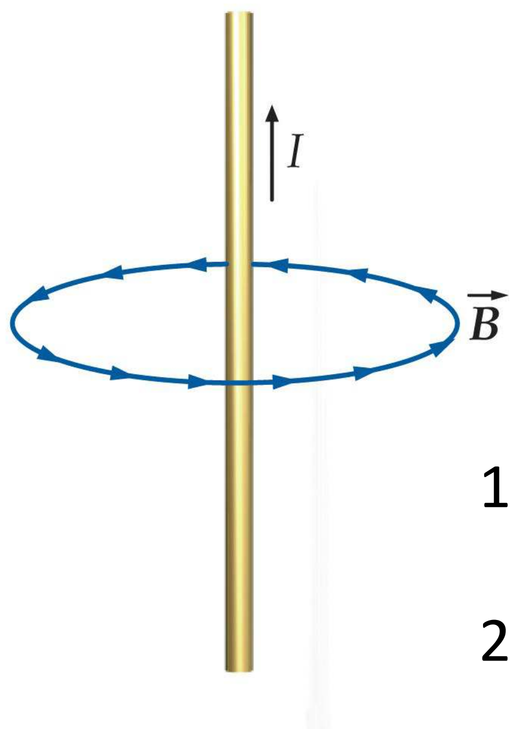
Lenz's Law

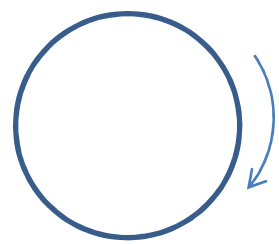




$$B = \frac{\mu_0 I_C}{2\pi R}$$

Lenz's Law





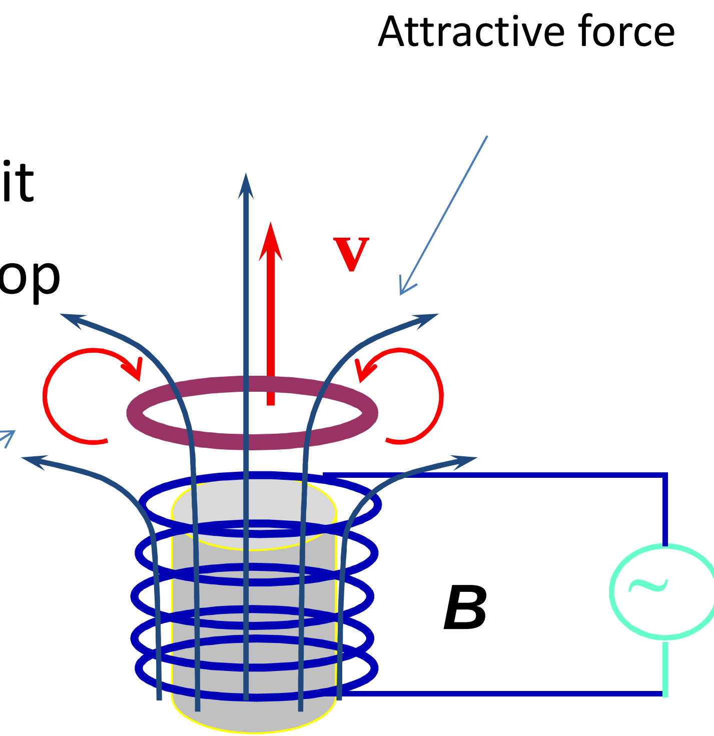
$$B = \frac{\mu_0 I_C}{2\pi R}$$

1. Pick an orientation for the loop
   - eg, counter-clockwise: $\hat{n}$ points out
2. Magnetic field is pointing in
   - Magnetic flux is negative
3. $\left|\vec{B}\right|$ decreases as the loop moves away
   - Magnetic flux is *increasing*
4. ***Induced field will point in***
   (opposite the direction of $\hat{\mathbf{n}}$)

Demonstration: The Electromagnetic Cannon

- An alternating voltage source produces a changing magnetic field in the solenoid.
- When the magnetic field increases, the induced current tries to oppose it
- The magnetic field induced in the loop will oppose changes in $\vec{B}$

- The magnetic forces fling the ring.



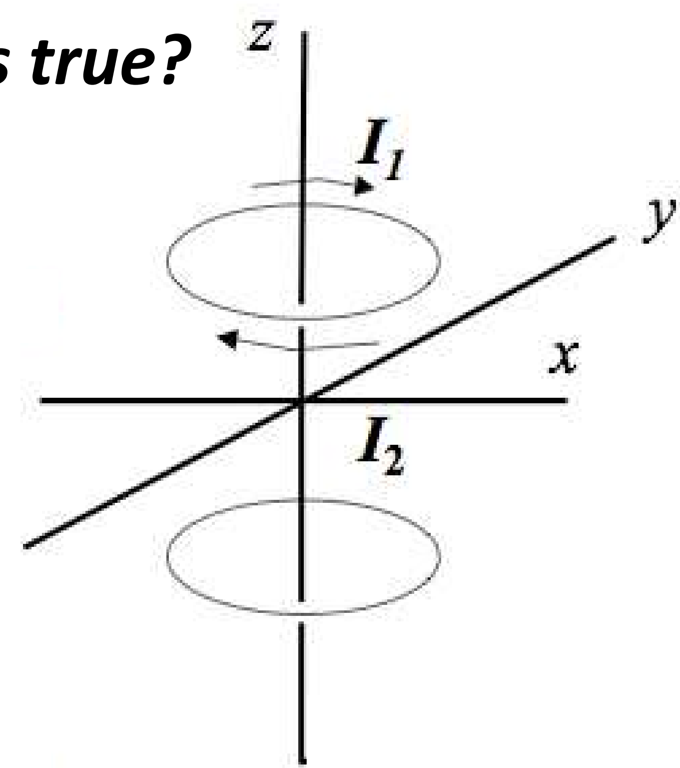
side view

Clicker Question

Two current loops are perpendicular to the z axis and are centered on the this axis.

- Current I_1 is clockwise.
- I_2 is the induced current in the bottom loop.

If I_2 is clockwise, which statement is true?



A. I_1 is decreasing in magnitude

B. I_1 is constant

C. I_1 is increasing in magnitude