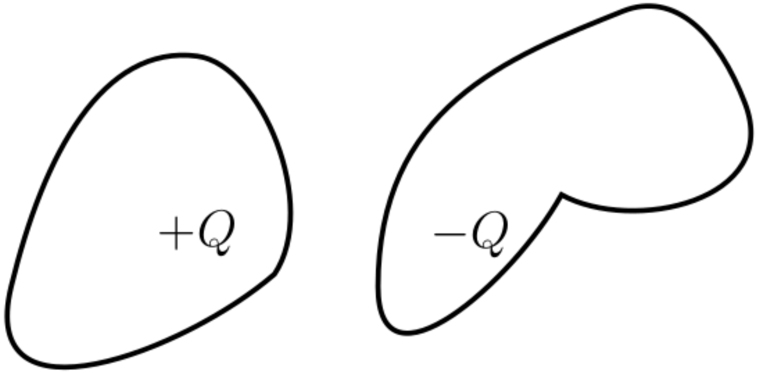
Lecture 28: 04/30/2024

- Announcements
  Review Session – Now
  5 pm at Library on April 30
  Do that final HW and practice test!!

- Last Time
  - Faraday's Law/Lenz's Law
  - Generators
  - Light!

- Today
  Exam 2 review
  Right hand rules
  Fields and Forces



Problem 1: Two conductors with equal and opposite charges.

1. In the figure above, two oddly shaped conductors are insulated from each other, forming a capacitor. When charges +Q and -Q are present the potential difference between the conductors is measured to be 7.0 V. Both charges are doubled without moving either conductor. What is the new potential difference? A. 28V B. 14V C. 7V D. 3.5V E. 1.75V F. Need to know the exact values of Q to answer.

2. Electric potential is usually expressed in 'Volts'. What other SI units are equivalent to a volt? (only one correct answer)
A. N/C B. V/m C. J/C D. $N \cdot m$

3. Three capacitors of 12 μF each are connected in series. What is the equivalent capacitance of this combination?

A. 36 μF B. 12 μF C. 9 μF D. 4 μF E. 3 μF

4. If you buy a car battery you will find that it has an EMF of 12 Volts. You could try to make a car battery at home by wiring eight AA batteries (EMF=1.5 Volts each) in series. Explain briefly why your homemade battery would not start your car. (No equations or numbers are needed for this answer.)

5. You are told that the electric potential at some point "P" is 42 Volts. You are told nothing about the potential at any other points. Can you determine the electric field at "P"? If so, how? If not, why not?

6. When an electric vehicle (EV) stops it can store its kinetic energy in a large capacitor. An experimental EV needs to store 50,000 Joules in a 10-Farad capacitor. To what voltage must the capacitor charge to store this much energy?

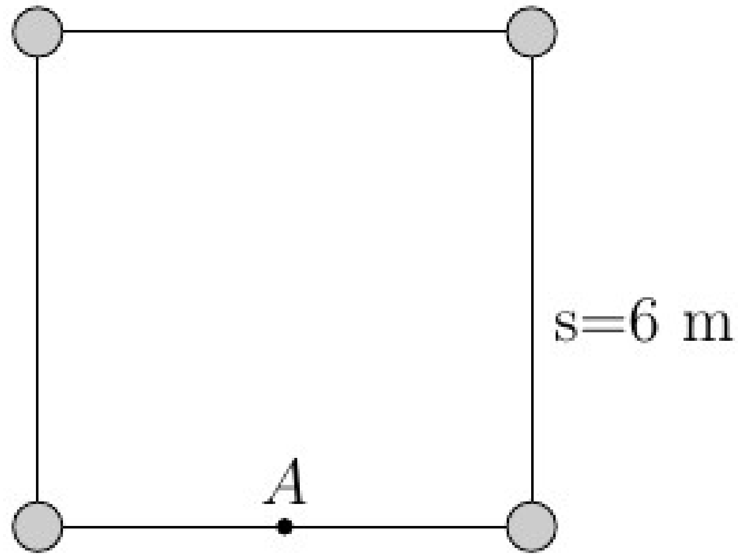
7. A parallel-plate capacitor is made from two metal disks with radius 10 cm each. The space between the plates is entirely filled by a one-mm-thick teflon disk.

(a) What is the capacitance of this arrangement?

(b) What is the electric field in the teflon when 10 Volts is applied between the plates?

8. A vampire is drinking human blood through a straw. Because human blood conducts electricity reasonably well (see table below), Buffy the vampire slayer will electrocute them by running two amperes of current through the straw while the vampire is drinking. The straw is 20 cm long and 2 mm in diameter.

What potential difference (voltage) does Buffy need to apply between the two ends of the straw to electrocute the vampire?



Problem 9: Four equal positive charges each with Q=5 nC are arranged in a square with side length 6 meters.

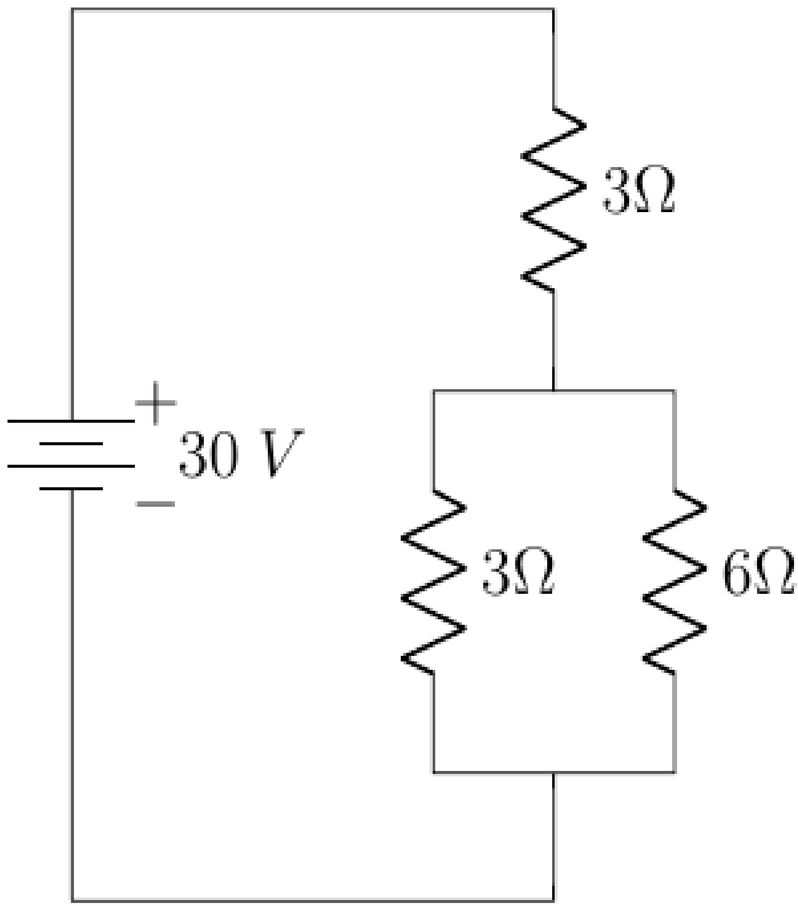
9. Four equal positive charges each with Q=5 nC are arranged in a square with side $s = 6\ m$ as shown. Point A is centered on the bottom edge.

(a) What is the potential (relative to infinity) of point A?

(b) A 3 g ball charged to 3 mC is released from rest at point A. What is it's speed when it is far from the square?

10. A circuit with a 30 V battery is shown in the figure.

(a) How much current is drawn from the battery?
(b) How much total power is drawn from the battery?
(c) What is the current through the 6 Ω resistor?



Problem 10: Circuit with 30 V battery and three resistors.

Important Concepts – Charge

- Charge is the thing that both creates and "feels" electromagnetic forces.
- Charge and electrostatic forces are the foundation of all chemistry and biology.
- We don't actually know what charge "is". We only know what it "does".
- (We don't really know what mass "is" either … why it resists acceleration or why it "feels" gravity)

Important Concepts – Current

- Current is moving charges.
- Electronics works on current, charge and voltage.
- Current can be used to produce magnetic forces because a "neutral" wire can still have a huge current.
  - To have equally strong electric forces the wire would need to be in vacuum or else it would constantly be making sparks.

Theme of Course

- Electromagnetic forces are most usefully thought of in terms of fields.
- Charges, moving or unmoving, create electric fields
- Moving Charges, and Currents create magnetic fields

Important Concepts

- Gauss's Law – Explains how to calculate an electric field from charges (in symmetrical cases)
- Ampere's Law – Explains how to calculate a magnetic field from currents (in symmetrical cases)
- Faraday's Law – One field can create another field!

- A changing magnetic field will create an electric field
- A changing electric field will create a magnetic field
- Together they make an electromagnetic field which is infrared, visible and ultraviolet light, radio, microwaves, Xrays, and gamma rays

- Electric fields are responsible for capacitance
- Magnetic fields are responsible for inductance

Important Concepts – Potential

- Potential – Also called Voltage, is energy/charge.
  It expresses an energy difference between two points.

- It is a simpler way to calculate motions from electric forces.
- It is a key concept in understanding electrical circuits.

Important Concepts – Capacitance

- Capacitors store electric energy
- Capacitors store charge
- Capacitance relates charge to potential.
- Larger capacitors store more charge for the same potential

Important Concepts – Resistance

- Resistance is a consequence of atomic "friction"
- It turns electrical energy into heat
- In electronics, it has the important function of preventing all of the current from discharging at once!

Equations of Magnetism – Forces

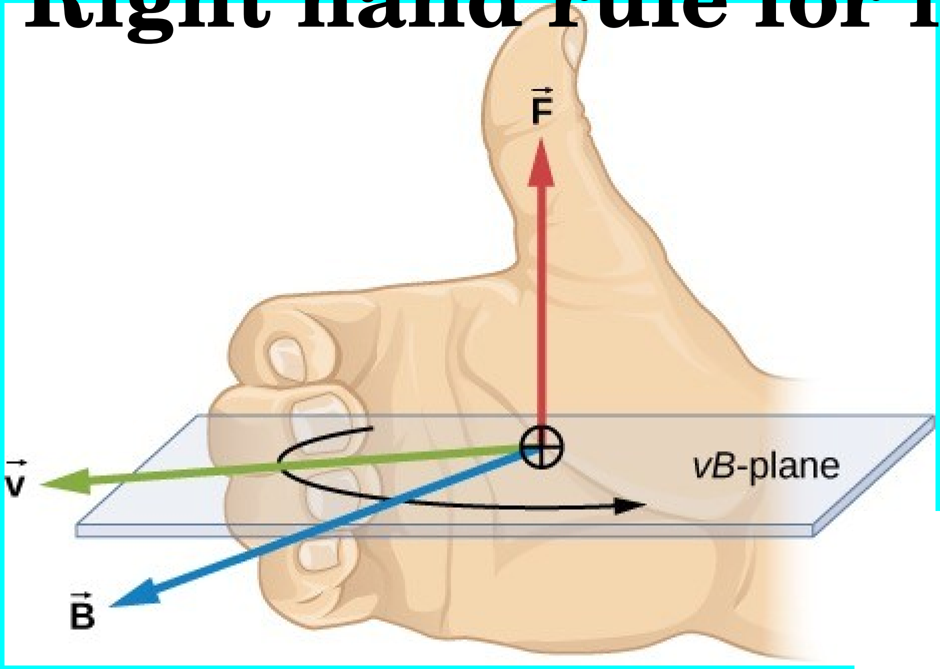
$\vec{F} = Q\,\vec{v} \times \vec{B}$ Force on charge Q

$\vec{F} = I\,\vec{L} \times \vec{B}$ Force on current I

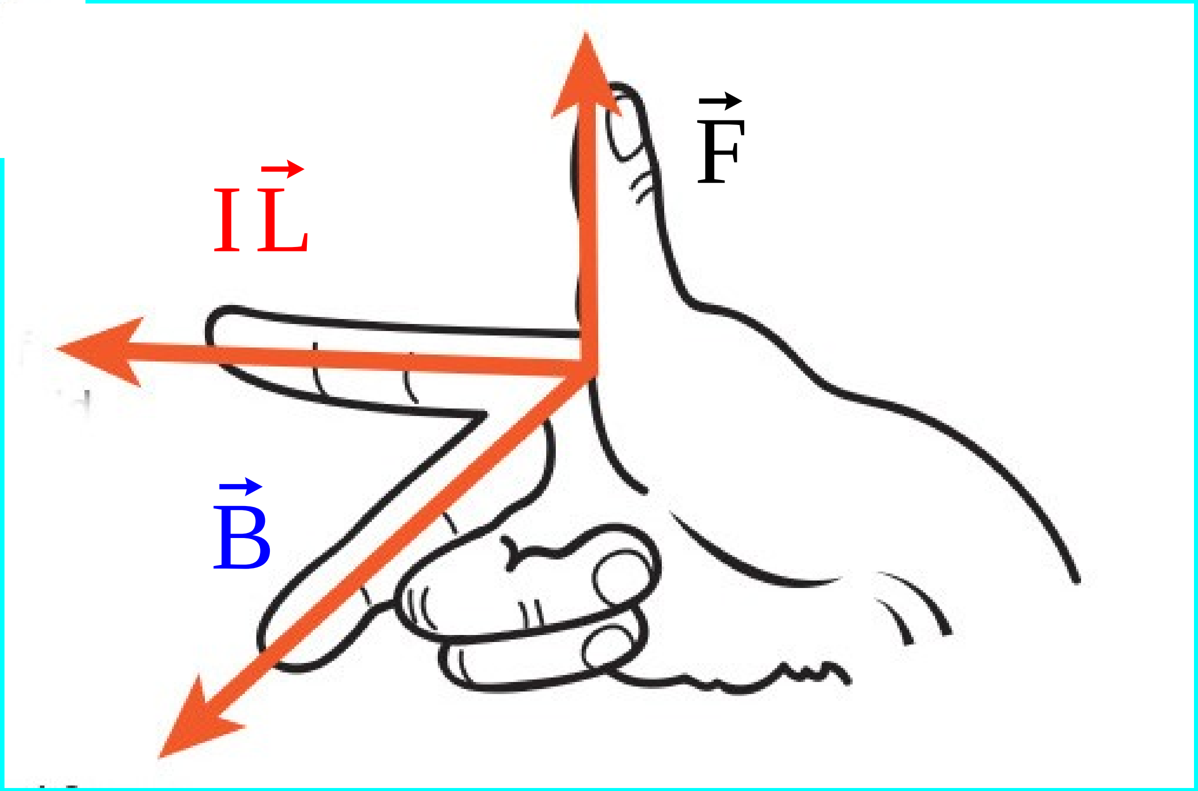
Equations of Electricity – Forces

$\vec{F} = Q\,\vec{E}$ Force on charge Q

Right hand rule for forces



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



Equations of Magnetism – Fields

$$\vec{B} = \frac{\mu_0 I}{2\pi r}\hat{\phi}$$ Field of Infinite wire

$$\vec{B} = \frac{\mu_0 I}{2a}\hat{z}$$ Field in center of wire loop

$$\vec{B} = \mu_0 s n I \hat{z}$$ Field of an infinite coil (solenoid)

Equations of Electricity – Fields

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q\hat{r}}{r^2}$$ Field of point charge

$$\vec{E} = \frac{1}{2\pi\epsilon_0}\frac{\lambda\hat{r}}{r}$$ Field of line charge

$$\vec{E} = \frac{\sigma}{\epsilon_0}\hat{n}$$ Field of plane charge

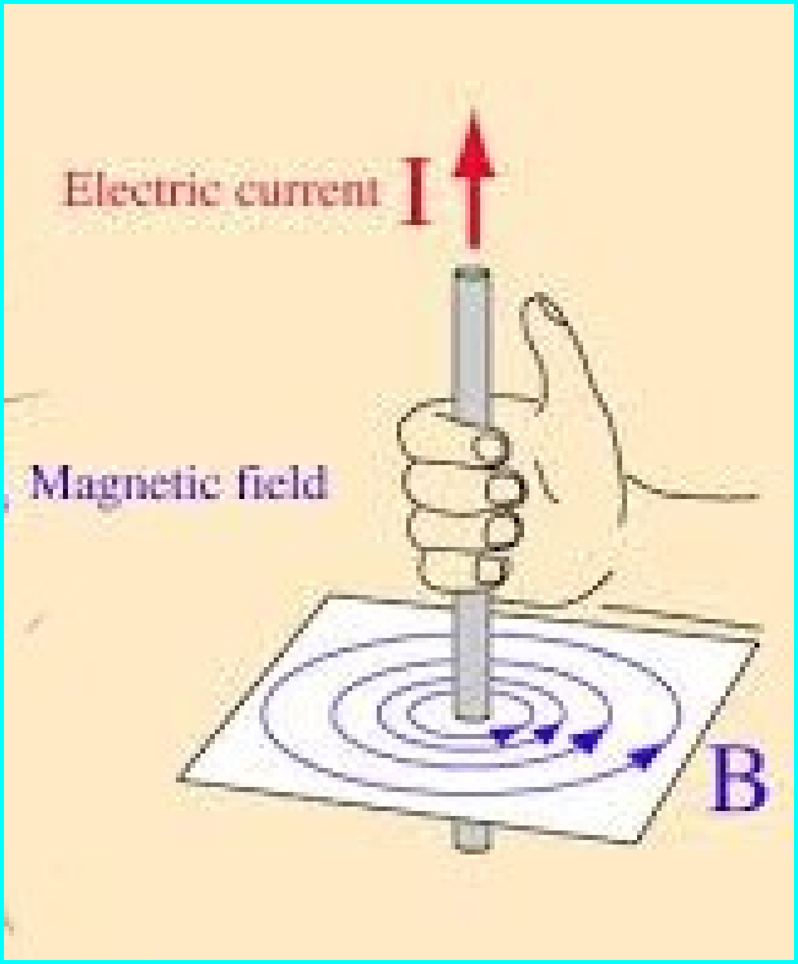
Equations of Magnetism – Biot-Savart

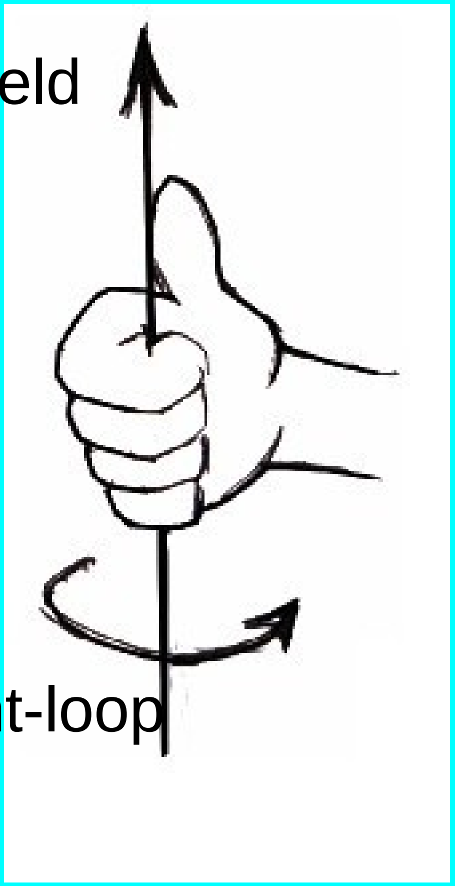
$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{L} \times \hat{r}}{r^2}$$ Field of current segment

Equations of Electricity – Fields

$$d\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{dq\, \hat{r}}{r^2}$$ Field of point charge

Hitch-hikers rule for fields

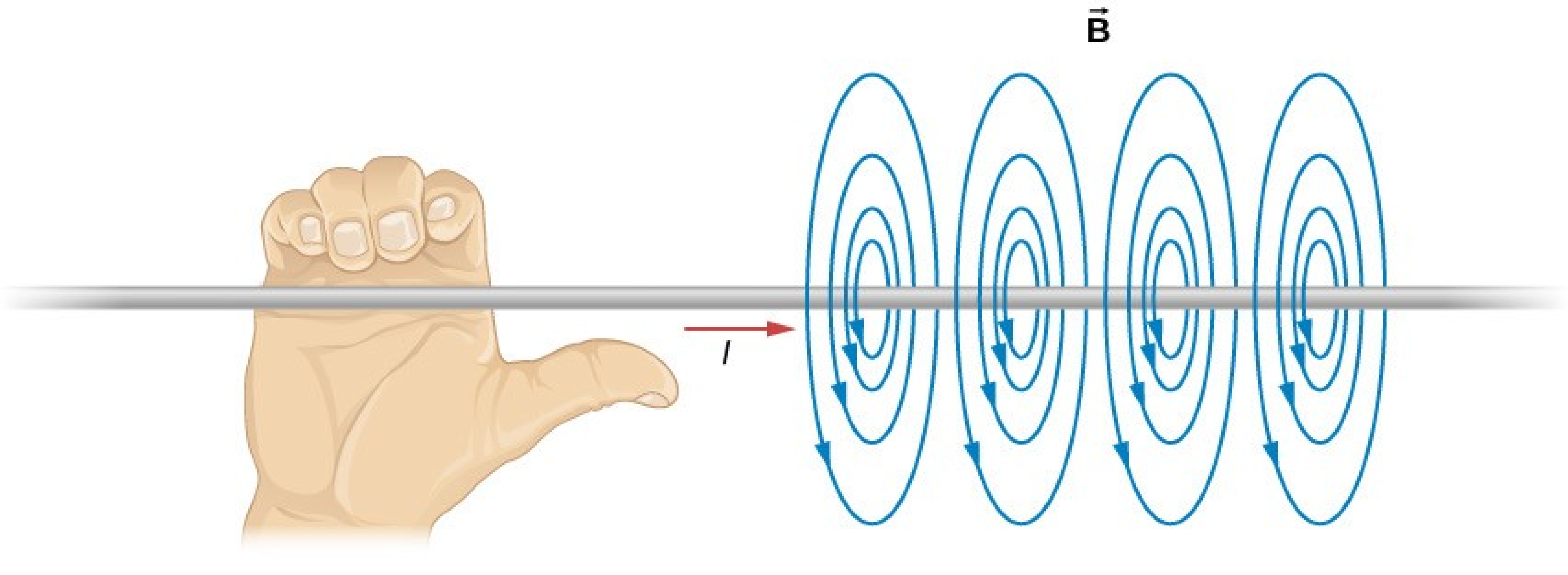


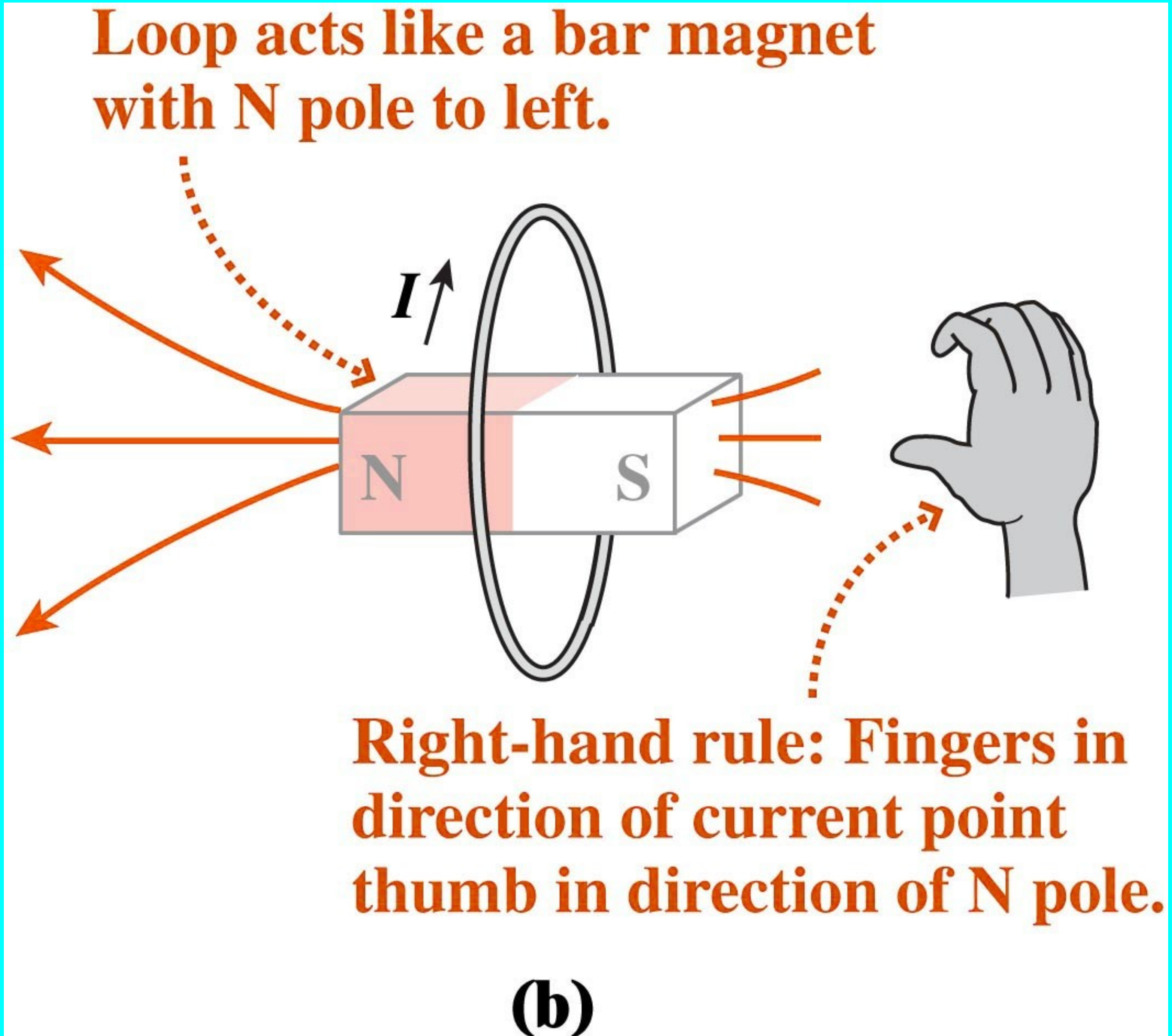


Problem

- Two horizontal wires 3 meters long carry 15 Amperes directed to the right. They are separated by 1 cm.

- What is the magnetic field one cm above the bottom wire?
- What is the force on the top wire?




Loop acts like a bar magnet with N pole to left.
I
N
S
Right-hand rule: Fingers in direction of current point thumb in direction of N pole.
(b)

Problem

- Two horizontal wires 3 meters long carry 15 Amperes directed to the right. They are separated by 1 cm.

- What is the magnetic field one cm above the bottom wire?

Remember magnetic moments?

$$\vec{m} = I\,\vec{A}$$

If current flows clockwise,
magnetic north pole and field is into page.

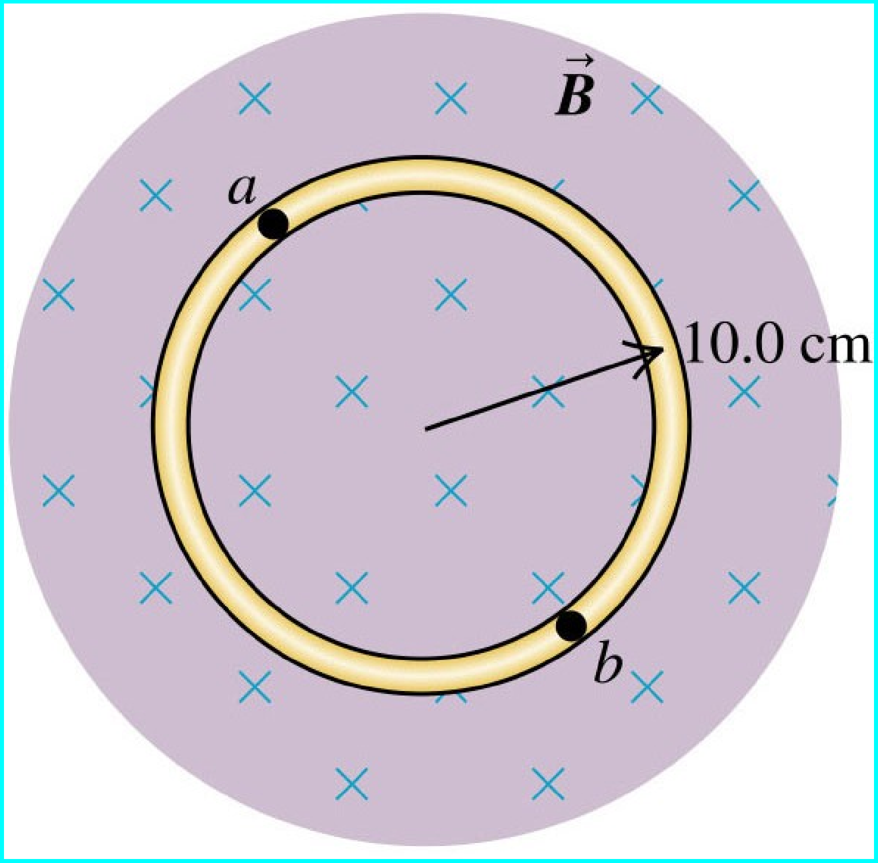
This is also how you figure out the direction to oppose in Lenz's law.

A circular loop of wire is in a region of spatially uniform magnetic field.

The magnetic field increases from from zero to 3 Tesla in one millisecond.

Induced EMF Direction is

COUNTERCLOCKWISE



$$\varepsilon = -\vec{A} \cdot \frac{d\vec{B}}{dt}$$

Faraday's Law

Changing magnetic fluxes produce electric fields and hence voltages.

$$\Phi_B = \vec{B} \cdot \vec{A} \qquad\qquad \varepsilon = \frac{-d\Phi_B}{dt}$$

Lenz's Law
(the minus sign in Faraday's law)

Changing fluxes produce currents which would oppose the changing flux or create a moment that opposes flux.

Using Lenz's Law

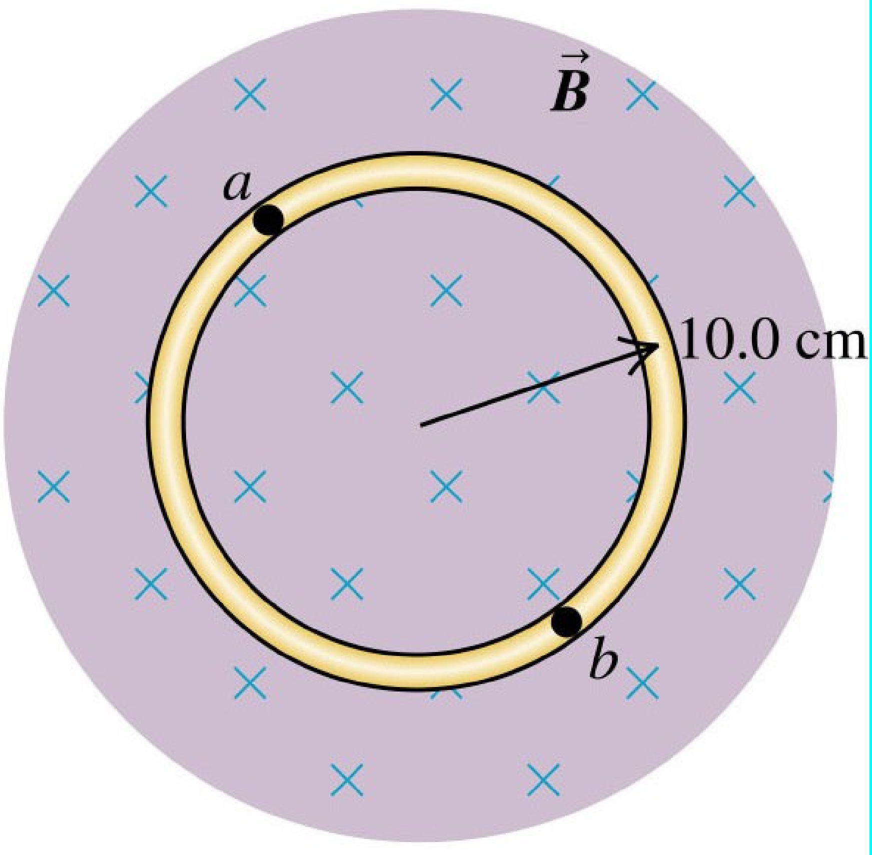
Figure out how the flux is changing.

Figure out what current what produce that change in flux.

The induced current is opposite to that.

A circular loop of wire is in a region of spatially uniform magnetic field. The magnetic field is directed into the plane of the figure.

If the magnetic field magnitude is *increasing*,



A. the induced emf is clockwise

B. the induced emf is counterclockwise

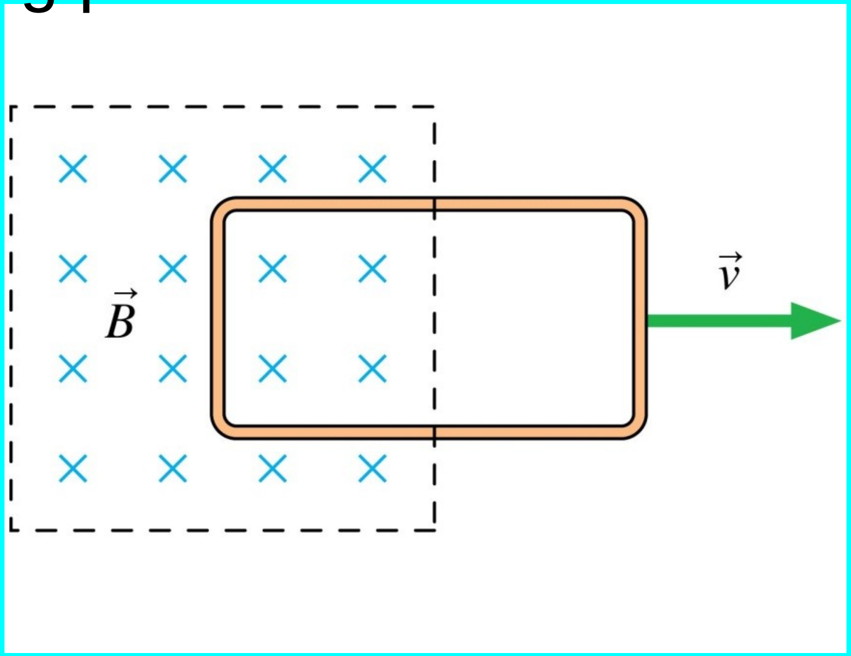
C. the induced emf is zero

D. answer depends on the rate of change of the field

Clicker

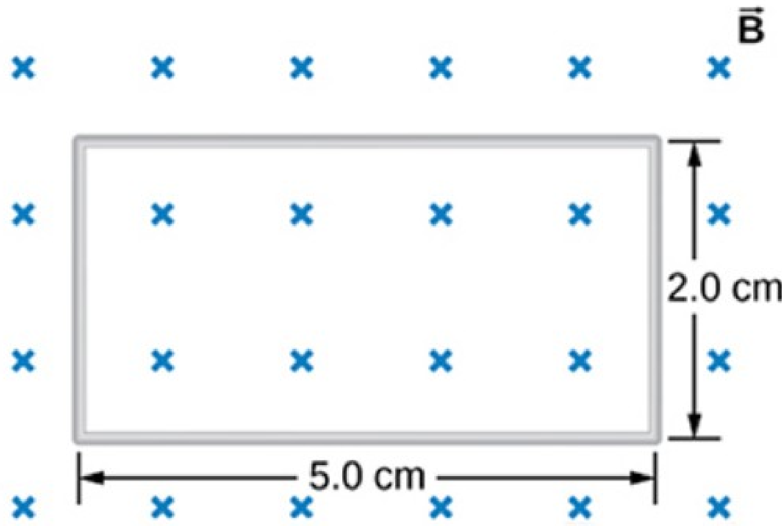
The magnetic field is confined to the region inside the dashed lines; it is zero outside. The metal loop has length L and width w and is being pulled out of the magnetic field. Which is true?

A. There is a clockwise induced current in the loop.
B. There is a counterclockwise induced current in the loop.
C. There is no induced current in the loop.



Problem 7: A single-turn rectangular wire loop has a resistance equal to 1.4 Ω and the dimensions shown in the drawing. The magnetic field at all points inside the loop varies according to $B = B_0 e^{-\alpha t}$, where $B_0 = 0.25$ T and $\alpha = 200\ \mathrm{s}^{-1}$.

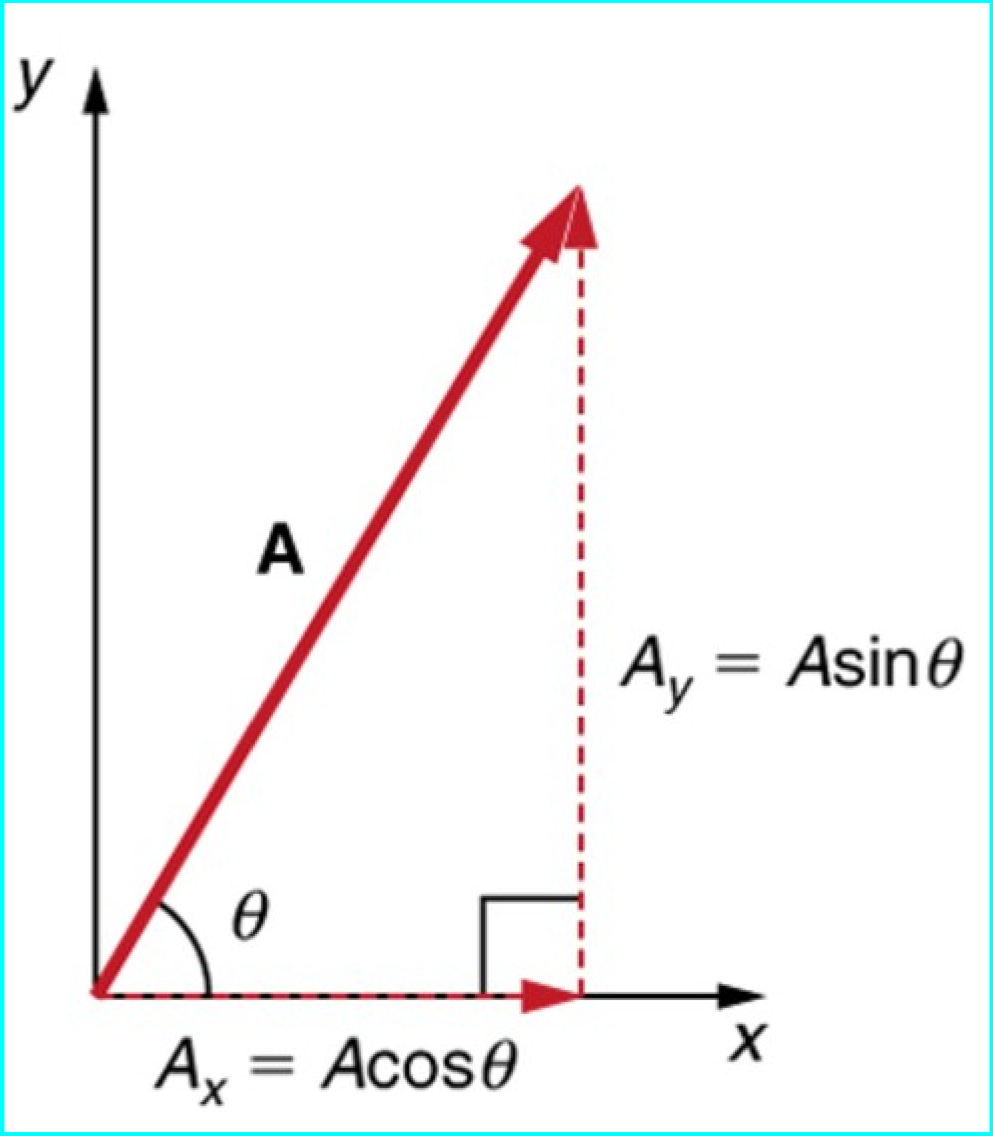
richard.sonnenfeld@nmt.edu

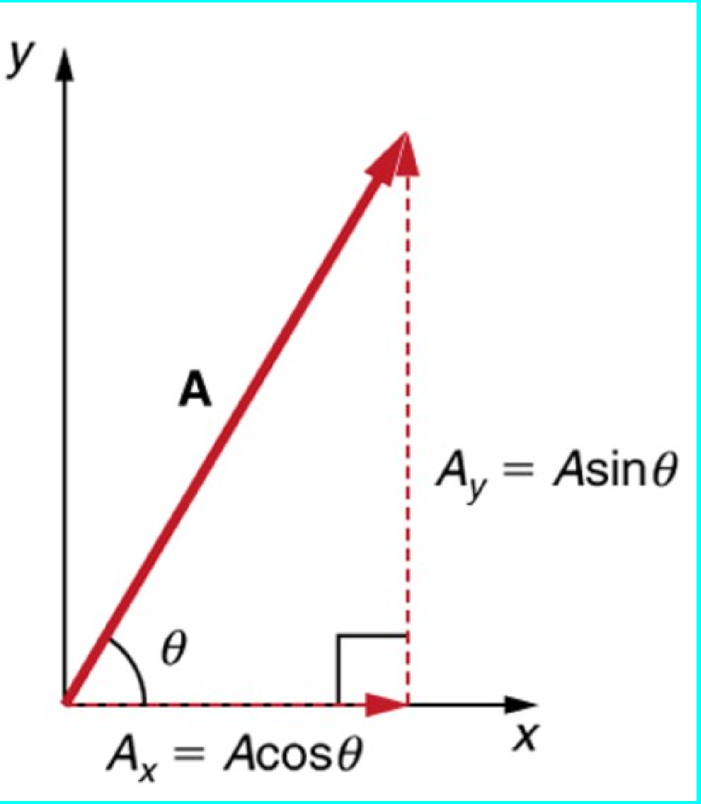


Part (a) What is the magnitude, in amperes, of the current induced in the loop at $t = 1.0$ ms?
Numeric : A numeric value is expected and not an expression.
I_1 = ____ A

Part (b) What is the magnitude, in amperes, of the current induced in the loop at $t = 20.0$ ms?
Numeric : A numeric value is expected and not an expression.
I_2 = ____ A

An electric generator works by Faraday's law + Trig!





$$\Phi_B = \vec{B}\cdot\vec{A}$$

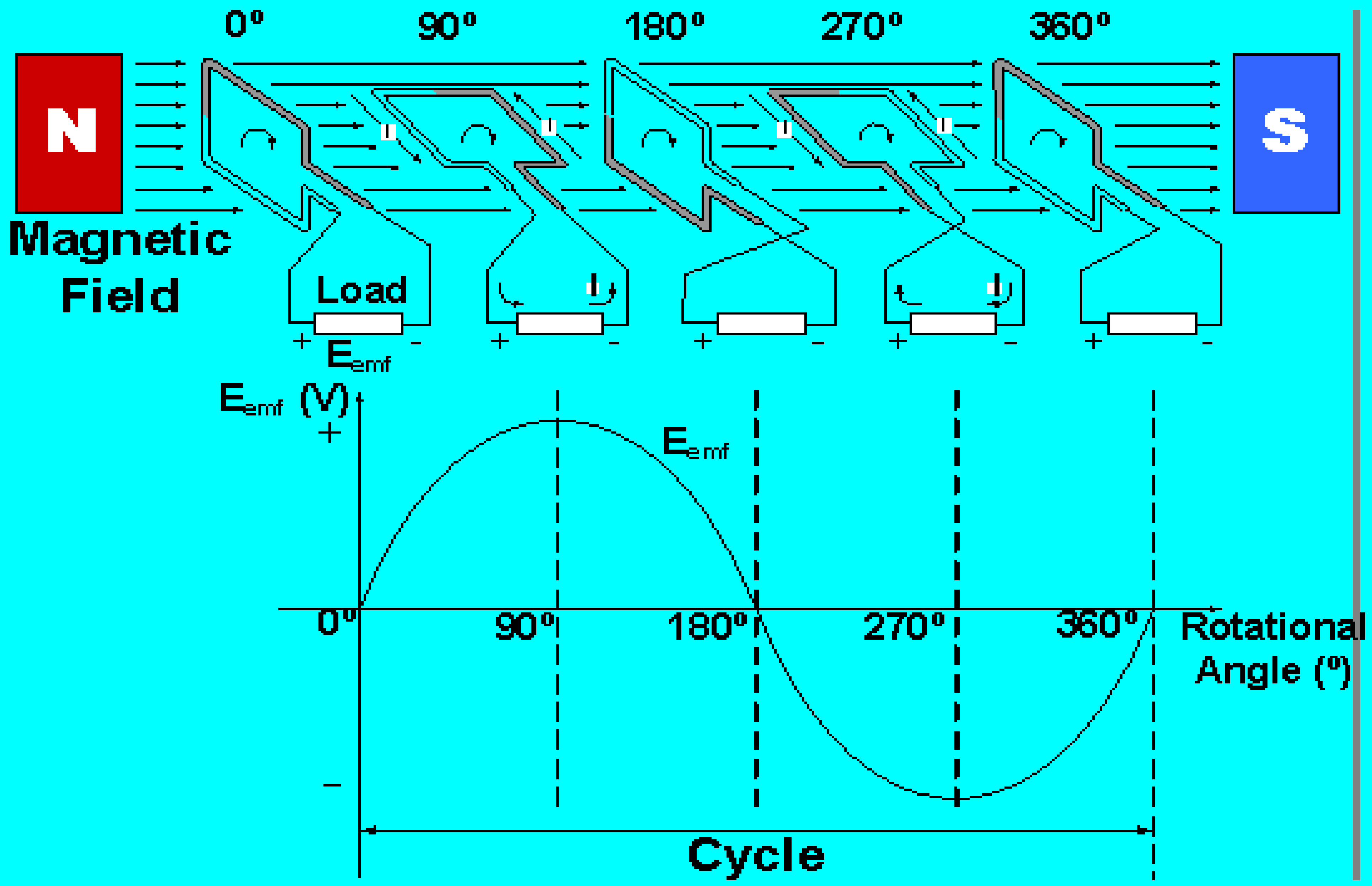
$$\vec{B} = B_0\,\hat{i}$$

$$\vec{A} = A_0\cos\theta\,\hat{i} + A_0\sin\theta\,\hat{j}$$

$$\vec{B}\cdot\vec{A} = B_0\,A_0\cos\theta$$

$$\vec{B}\cdot\vec{A}(t) = B_0\,A_0\cos\omega t$$

An electric generator



A solenoid has radius “r” and is surrounded by a hoop of radius “R”. The magnetic field inside the solenoid itself is “B”

- What is the flux through the large hoop in the two cases shown.

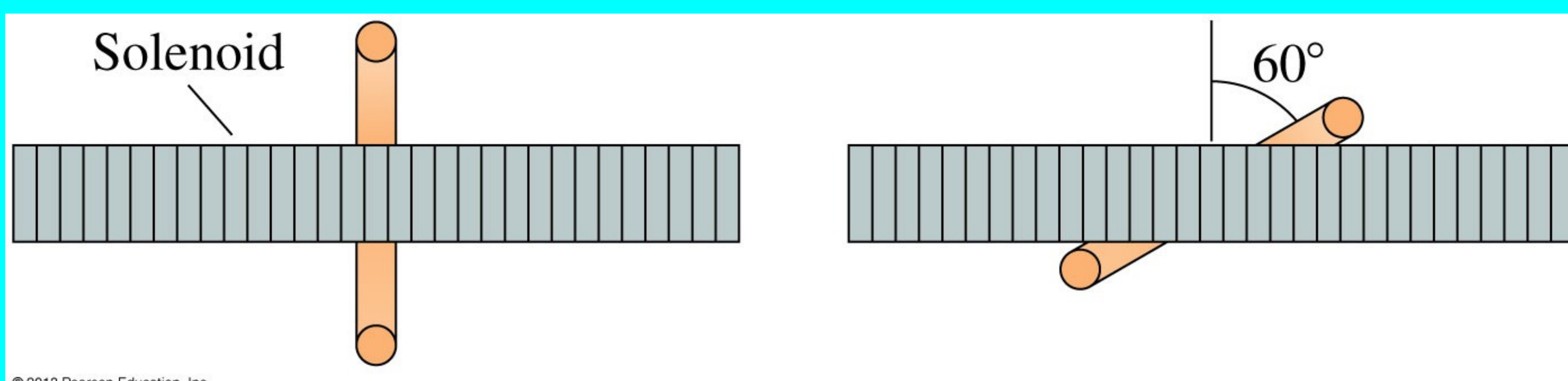
$[A]\ \Phi_1 = \pi r^2 B,\ \Phi_2 = \pi r^2 B \cos(60)$

$[B]\ \Phi_1 = \pi R^2 B,\ \Phi_2 = \pi R^2 B \cos(60)$

$[C]\ \Phi_1 = \pi r^2 B,\ \Phi_2 = \pi r^2 B \cos(30)$

$[D]\ \Phi_1 = \pi R^2 B,\ \Phi_2 = \pi R^2 B \cos(30)$

$[E]\ \Phi_1 = \pi r^2 B,\ \Phi_2 = \pi r^2 B$



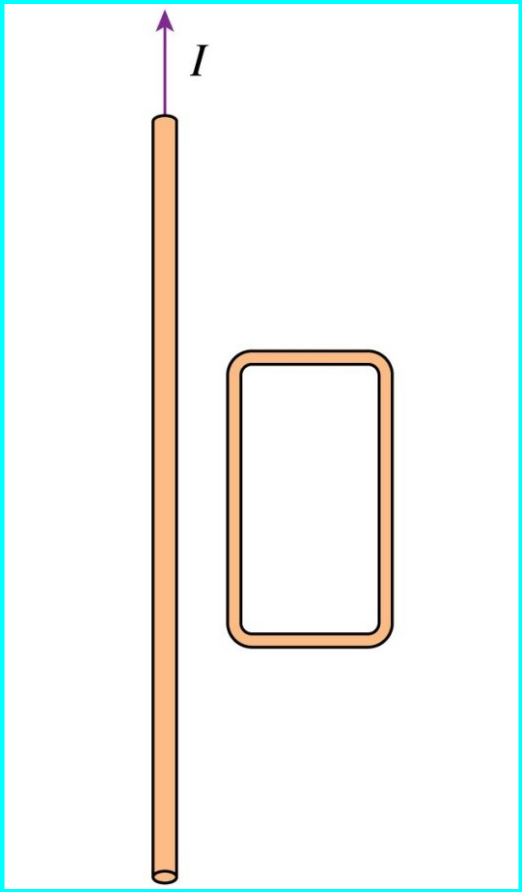
Thinking like a physicist

- In an unfamiliar situation, see if it can be simplified
- Consider what the fundamental (always true) relations are.
- Try to draw a picture.
- Try to break your analysis into pieces.

Clicker

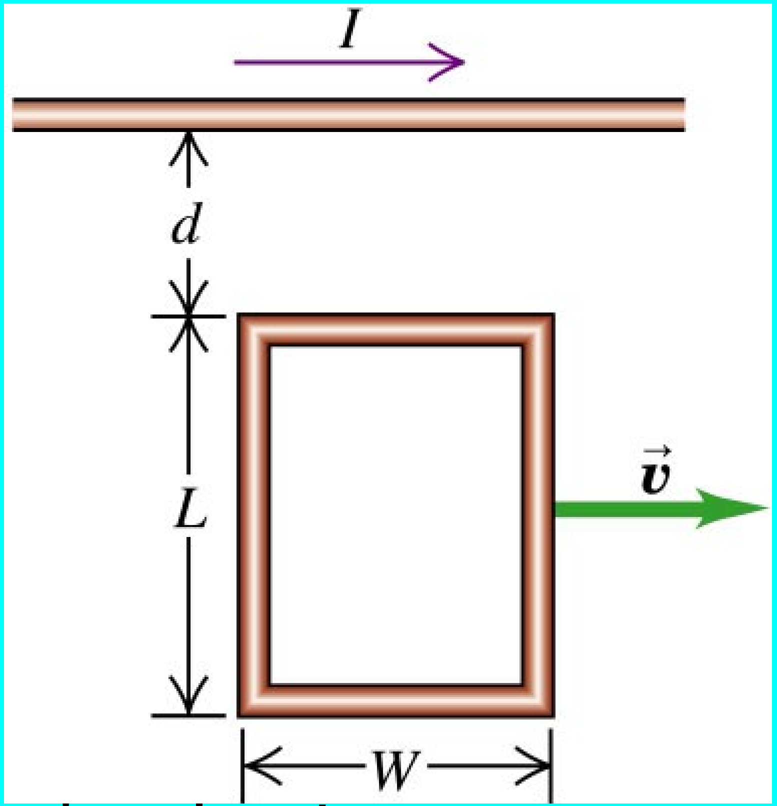
The current in the straight wire is decreasing. Which is true?

A. There is a clockwise induced current in the loop.
B. There is a counterclockwise induced current in the loop.
C. There is no induced current in the loop.



The rectangular loop of wire is being moved to the right at constant velocity. A constant current *I* flows in the long wire in the direction shown.

Which of the following statements about the current induced in the loop is *correct?*



A. the induced current is CW and proportional to *I*

B. the induced current is CCW and proportional to *I*

C. the induced current is CW and proportional to I^2

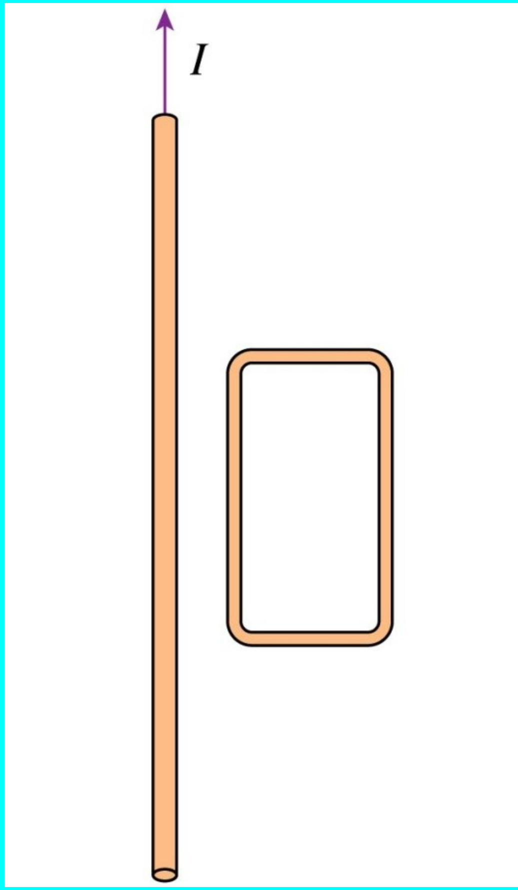
D. the induced current is CCW and proportional to I^2

E. there is no induced current

Clicker

The current in the straight wire is constant. The loop is moving to the right at constant speed. Which is true?

A. There is a clockwise induced current in the loop.
B. There is a counterclockwise induced current in the loop.
C. There is no induced current in the loop.



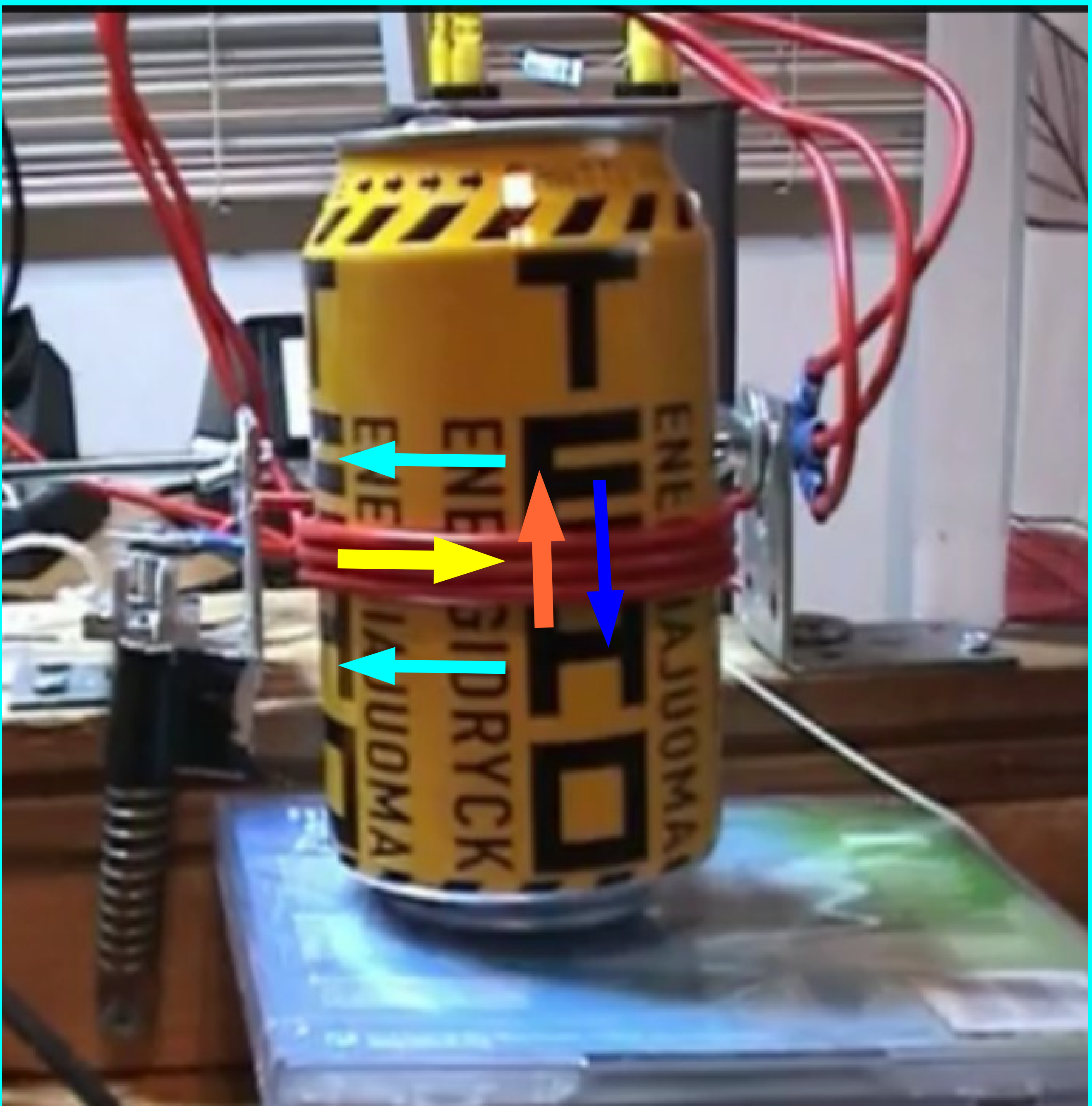
RECAP

http://tinyurl.com/can-crusher-slomo

Can crusher!

http://tinyurl.com/can-crusher-necking

Shorter vid. – necking



I and dI/dt

Counterclockwise

Bz and dBz/dt

I induced

Clockwise

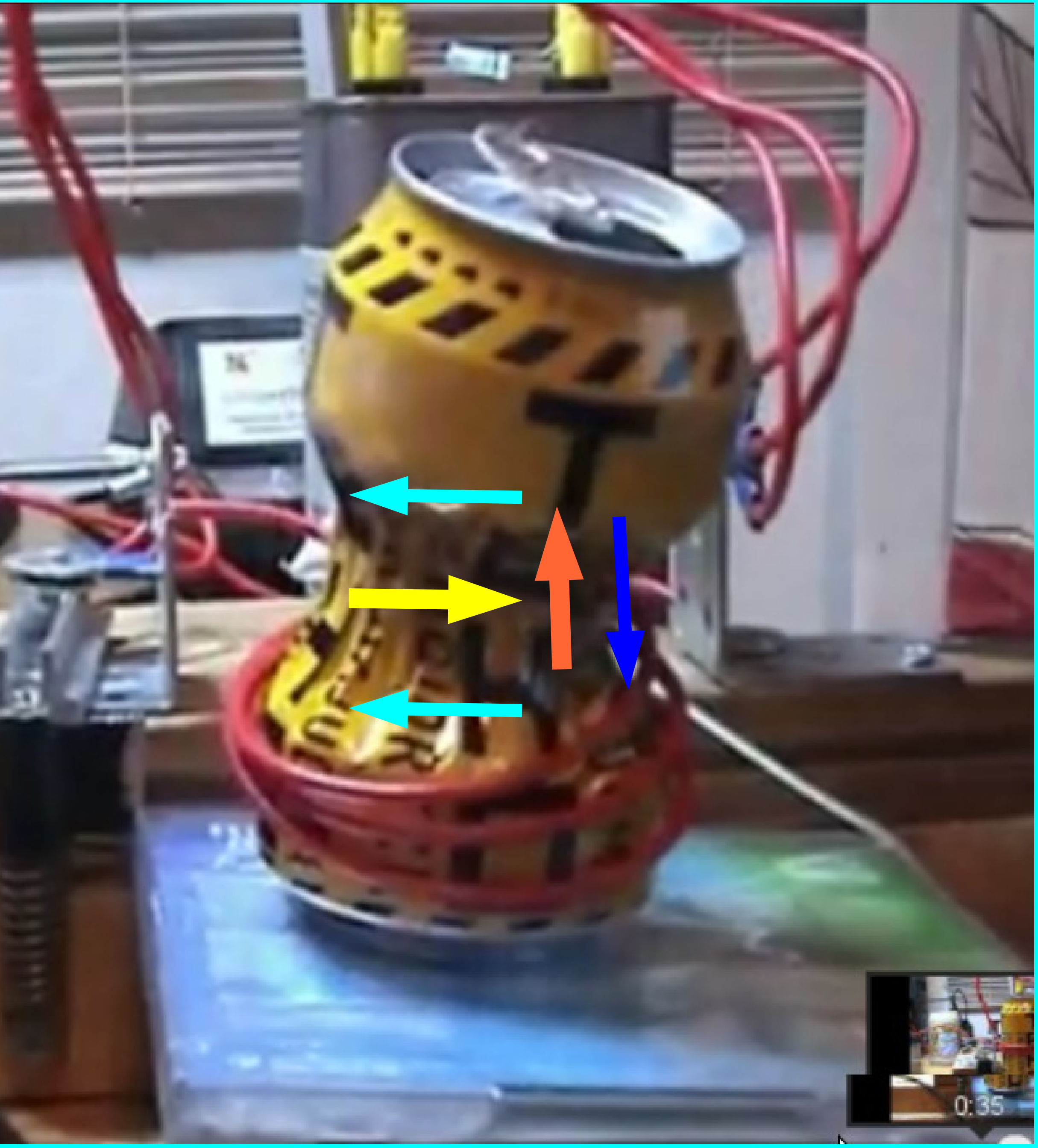
B induced

F induced

Can crusher!

http://tinyurl.com/can-crusher-necking

Shorter vid. – necking



I and dI/dt

Counterclockwise

Bz and dBz/dt

I induced

Clockwise

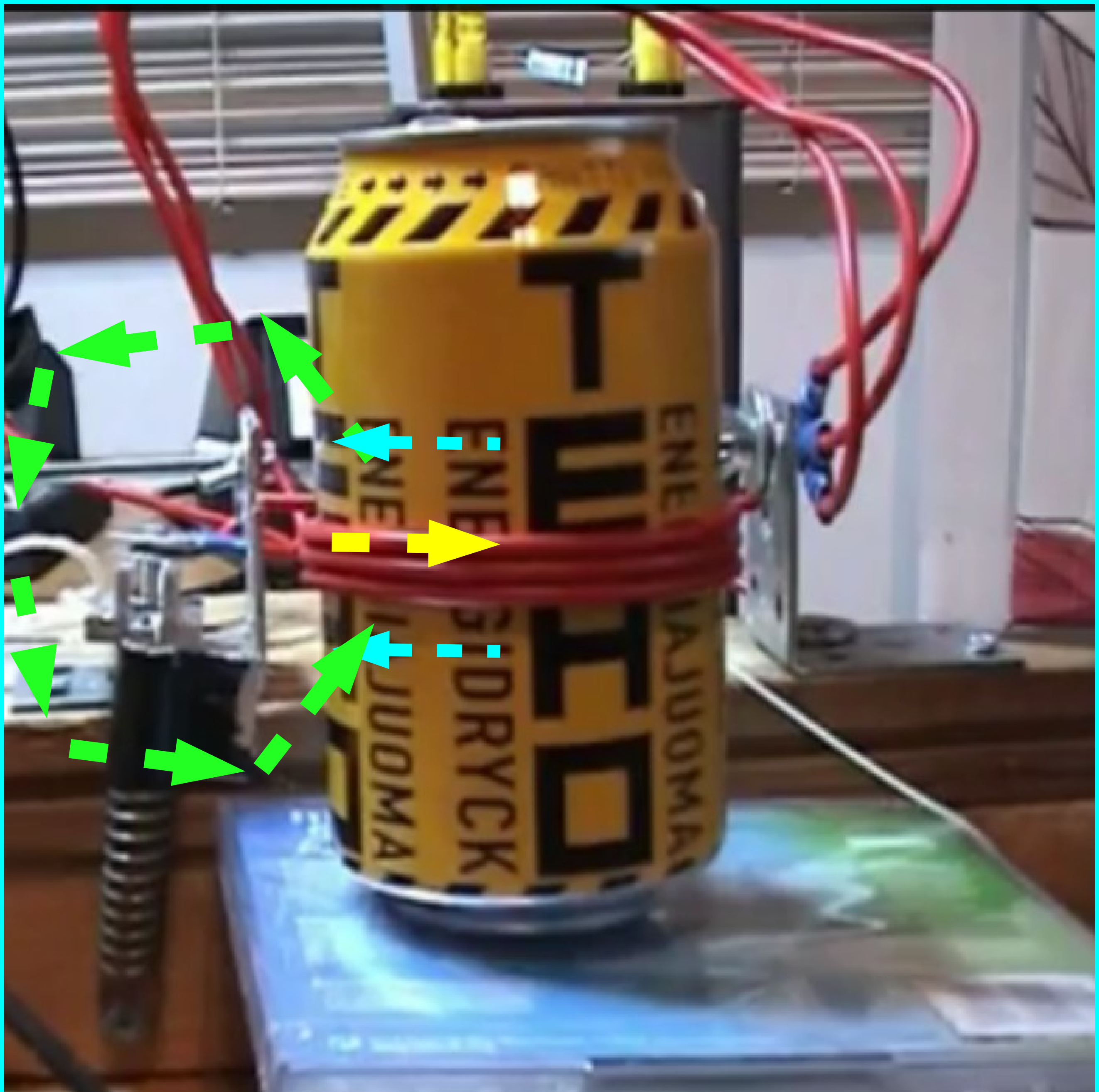
B induced

F induced is radially inward

Can stretcher!

http://tinyurl.com/can-crusher-slomo

Shorter vid. – necking



I and dI/dt

Counterclockwise

Bradial

I induced

Clockwise

F induced stretches the
Can vertically