Lecture 27: 04/25/2024

- Announcements
  Review Session – In class Tuesday
  5 pm at Library on April 30

- Last Time
  Faraday's Law – Induced voltage

- Today
  - Faraday's Law/Lenz's Law
  - Generators
  - Light!

Faraday's Law

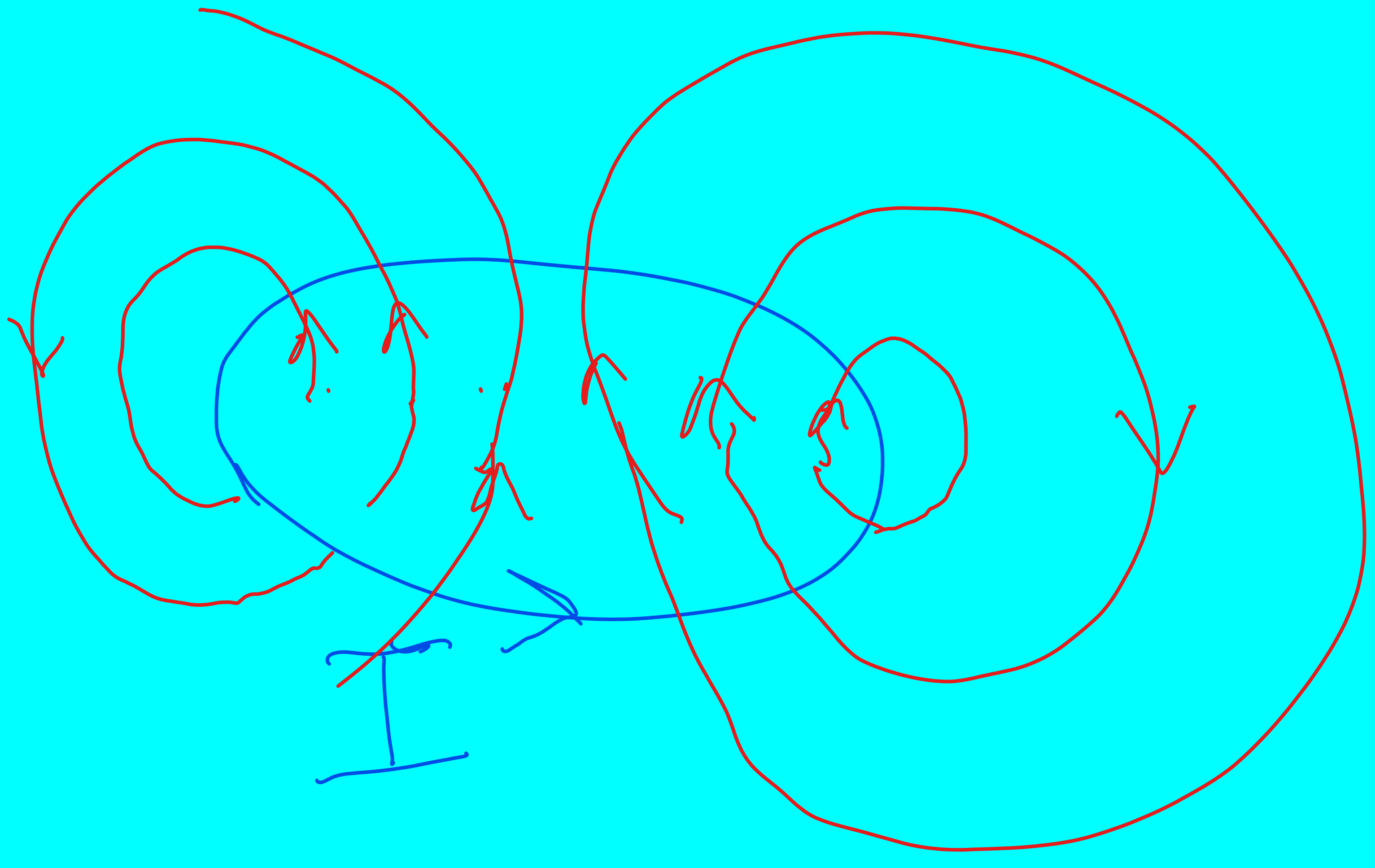
$$\varepsilon = -\frac{d}{dt}\vec{B}\cdot\vec{A}$$ The form of Faraday's law we will use

Three ways to get an induced EMF ...

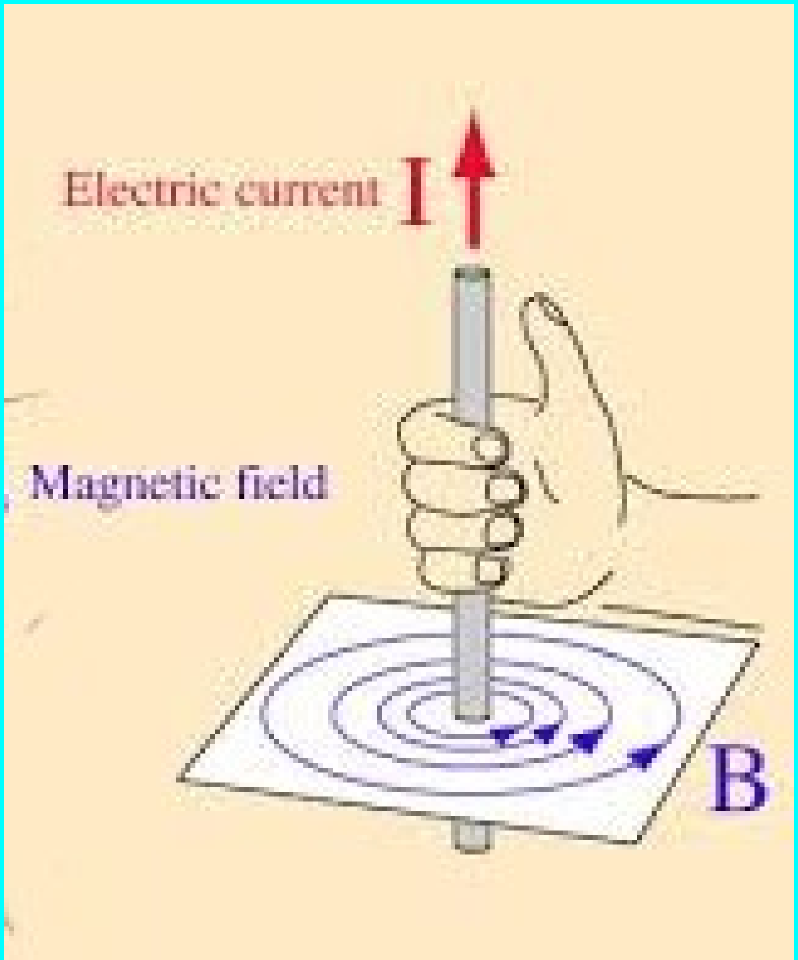
$$\varepsilon = -\vec{A}\cdot\frac{d\vec{B}}{dt}$$ Constant loop area but a changing B-field. ¿

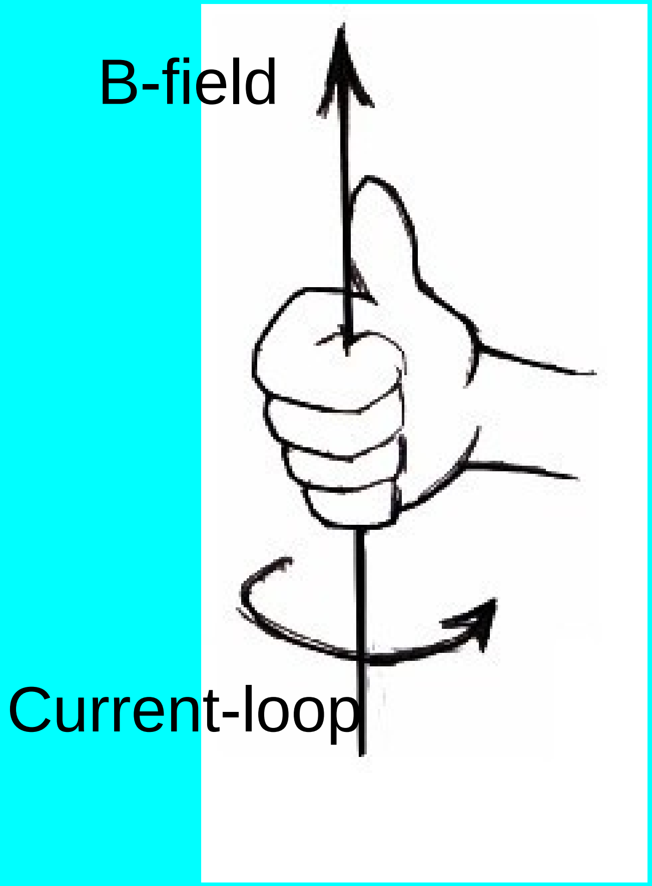
$$\varepsilon = -\vec{B}\cdot\frac{d\vec{A}}{dt}$$ Constant B but a changing loop area. ¿

$$\varepsilon = -\frac{d}{dt}\vec{B}\cdot\vec{A}$$ Area & B constant but their dot product changes.



Two ways to use the hitch-hikers rule.





Remember magnetic moments?

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

If current flows clockwise, which way does the magne

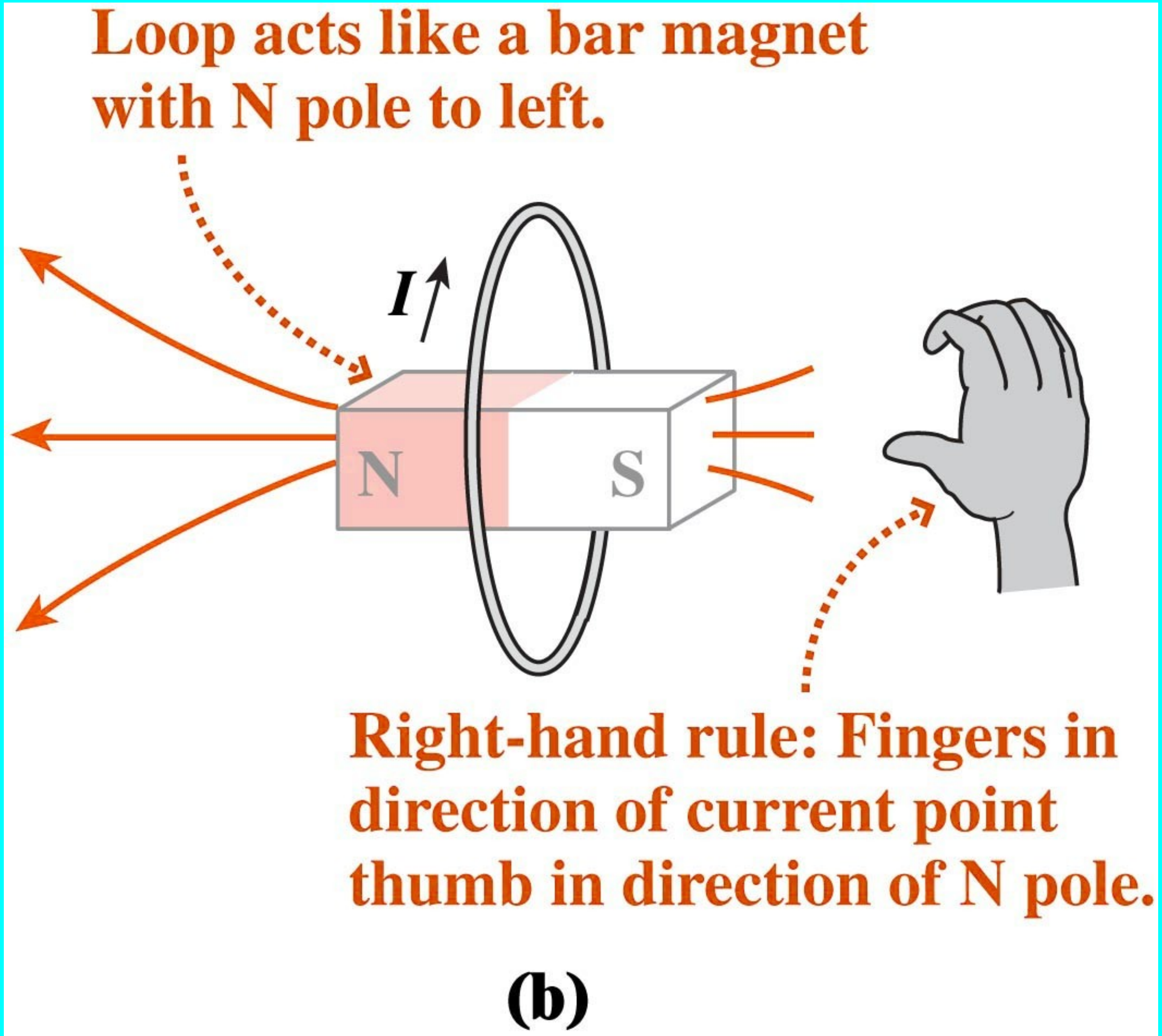
(A) Counter−clockwise

(B) Right

(C) Out of Page

(D) Into Page

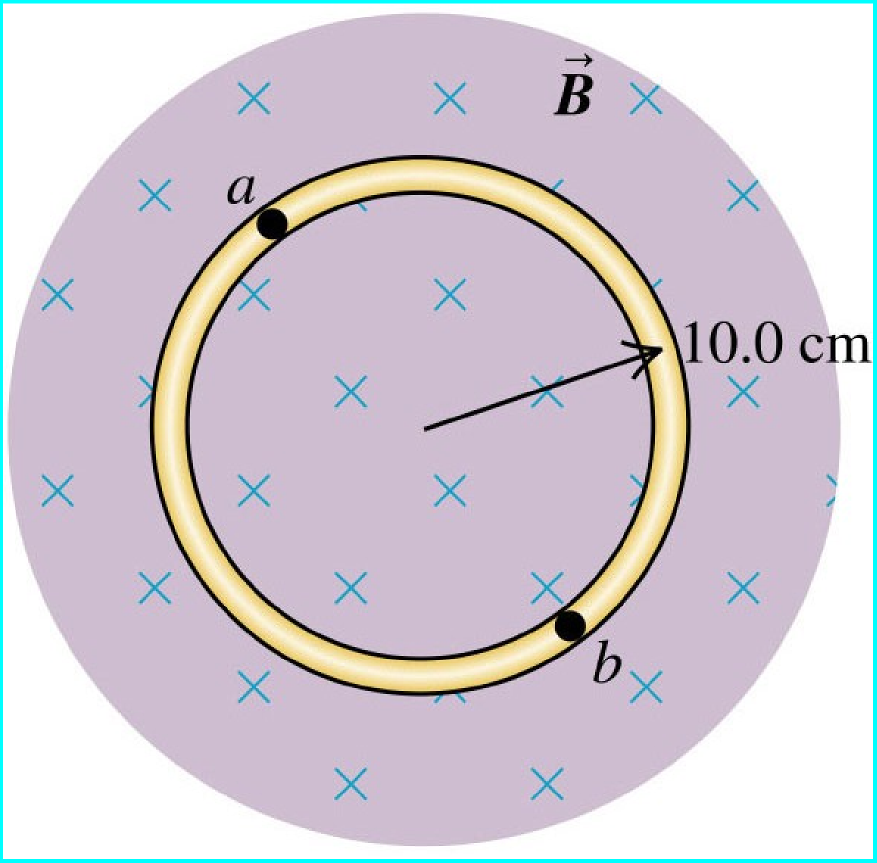
(E) Down


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)

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 Magnitude is?



(A) $\pi/30\,\mathrm{V}$

(B) $\pi/3\,\mathrm{V}$

(C) $3\times10^{-2}\pi\,\mathrm{V}$

(D) $3\pi\,\mathrm{V}$

(E) $3\times10^{1}\pi\,\mathrm{V}$

$$A = \pi(.1)^2 = \pi \times 10^{-2}\ m^2$$

$$\frac{dB}{dt} = \frac{\Delta B}{\Delta t} = 3/10^{-3} = 3\times10^{3}$$

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

Faraday's Law

Changing magnetic fluxes produce electric fields and hence voltages.

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

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

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

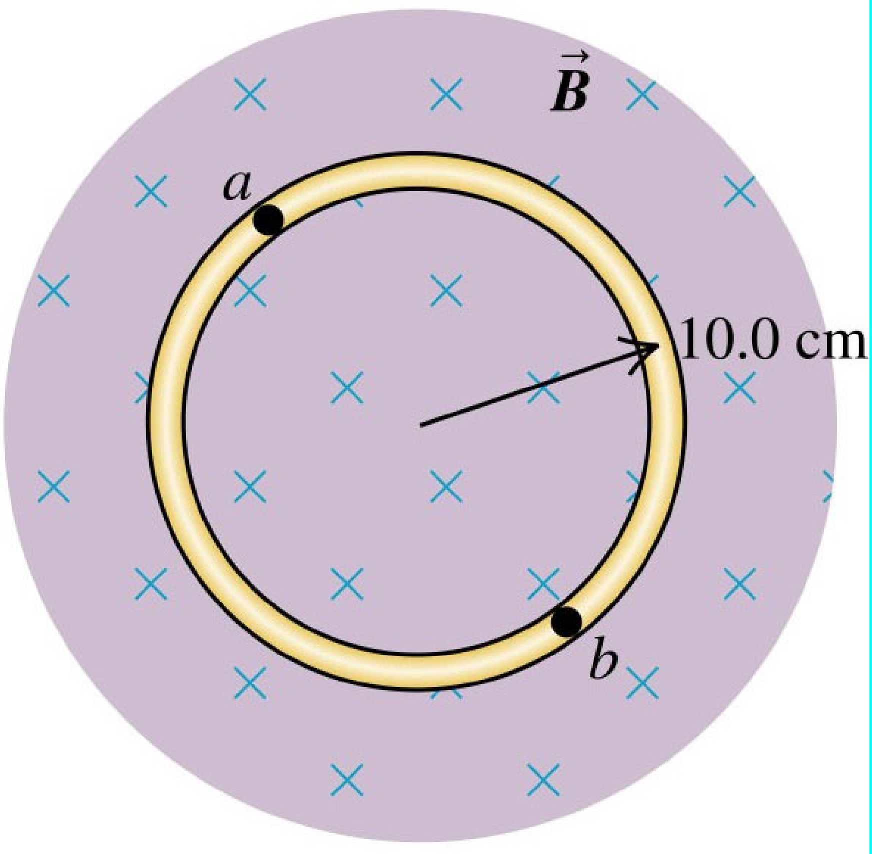
Figure out how the flux is changing.

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

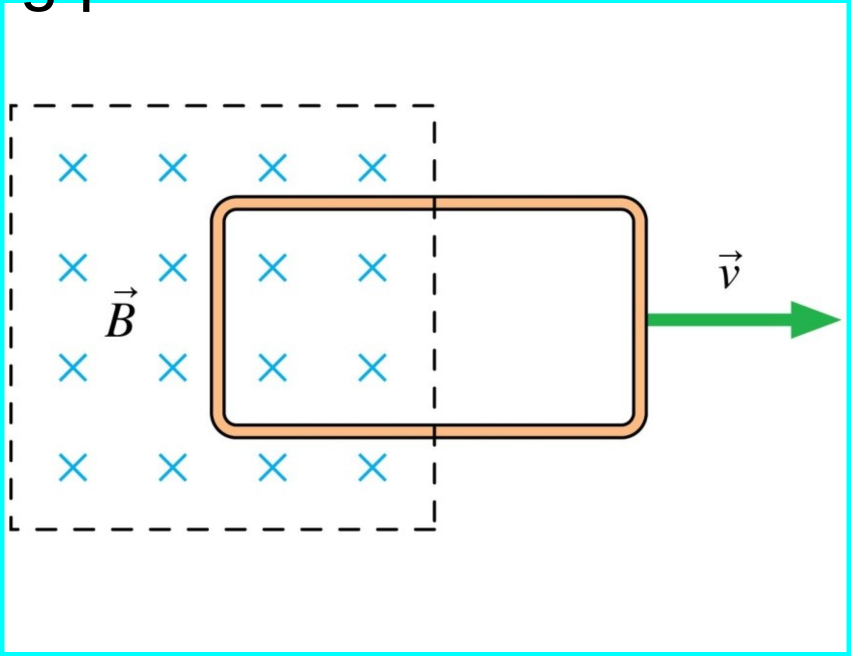
B. the induced emf is counterclockwise

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 $\alpha = 200\ \mathrm{s}^{-1}$.

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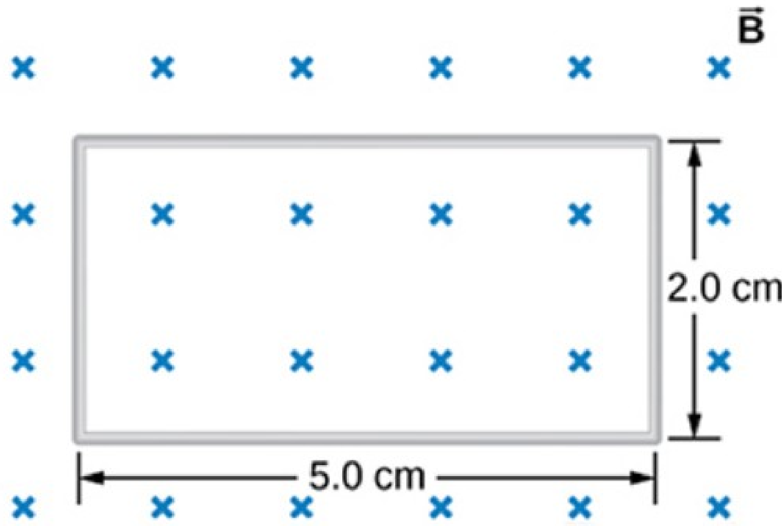


$A = 5\ \text{cm} \times 2\ \text{cm} = 10^{-3}\ \text{m}^2$

$B = B_0 e^{-\alpha t}$ $\quad B_0 = .25\ \text{T}$

$\alpha = 200\ \frac{1}{s}$

$\mathcal{E} = A \frac{d}{dt} B$

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

$\frac{dB}{dt} = \alpha e^{-\alpha t} B_0$

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

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.

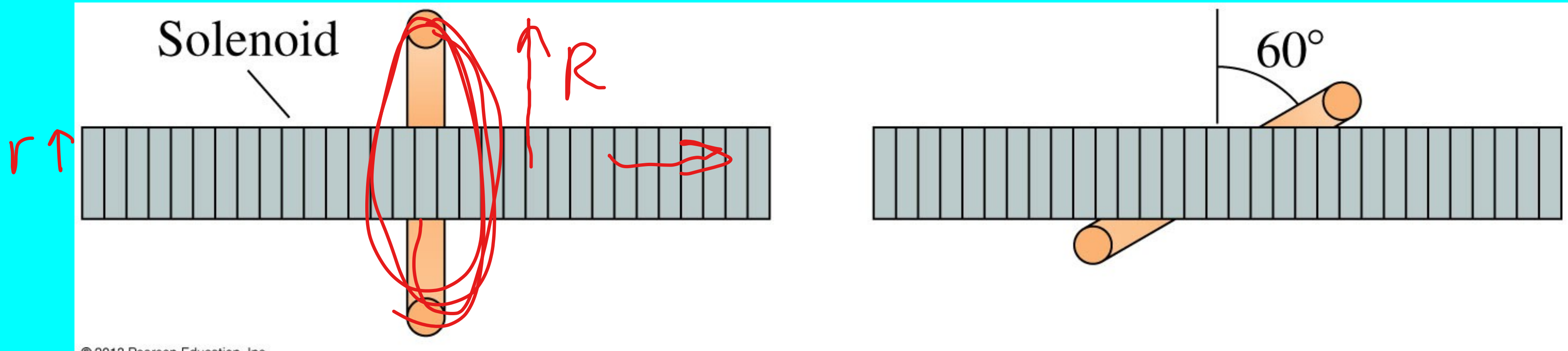
$$[A]\ \Phi_1=\pi r^2 B,\ \Phi_2=\pi r^2 B\cos(60)$$

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

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

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

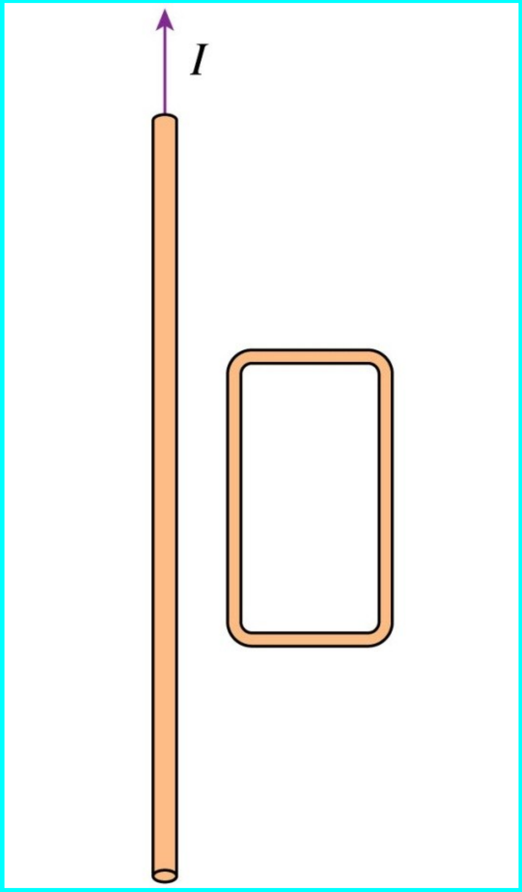
$$[E]\ \Phi_1=\pi r^2 B,\ \Phi_2=\pi r^2 B$$



Clicker

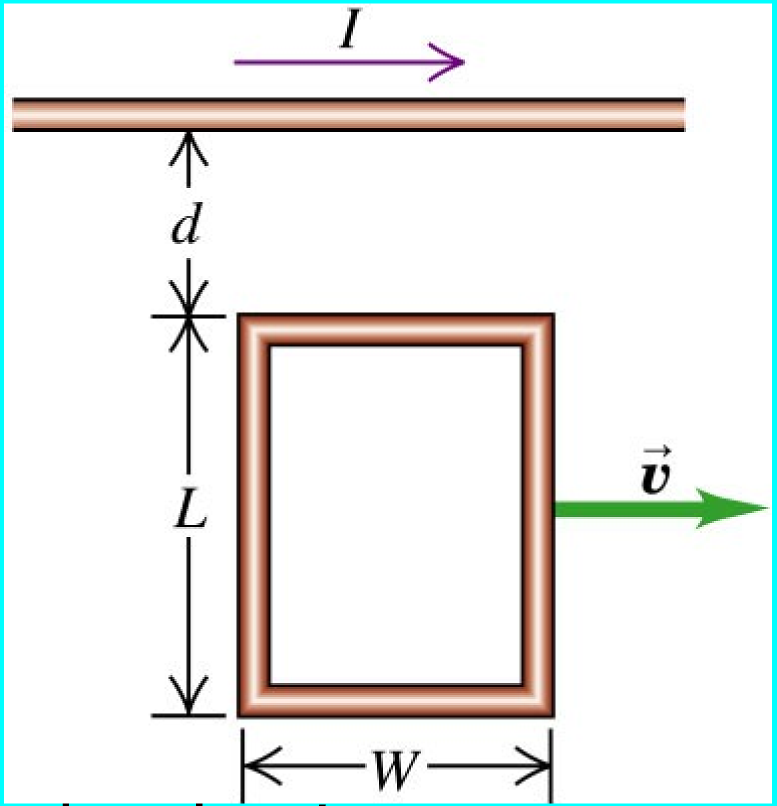
The current in the straight wire is decreasing. Which is true?

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

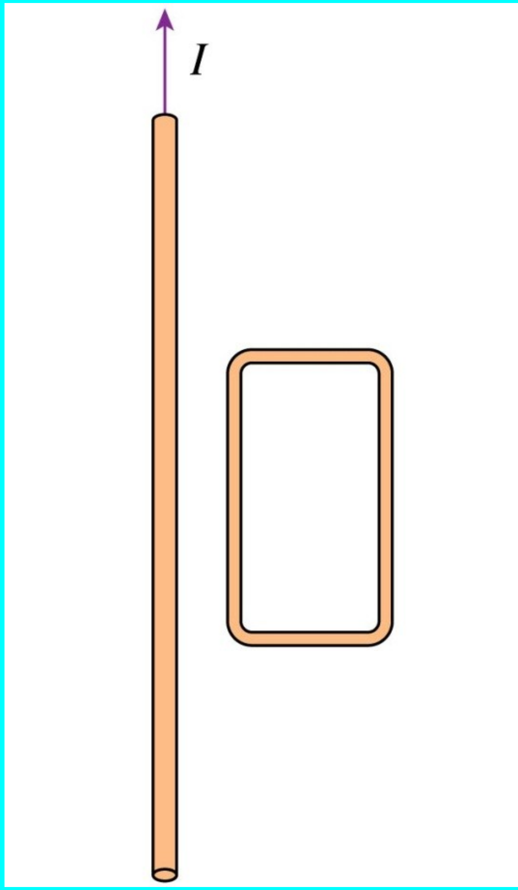
D. the induced current is CCW and proportional to I^2

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.



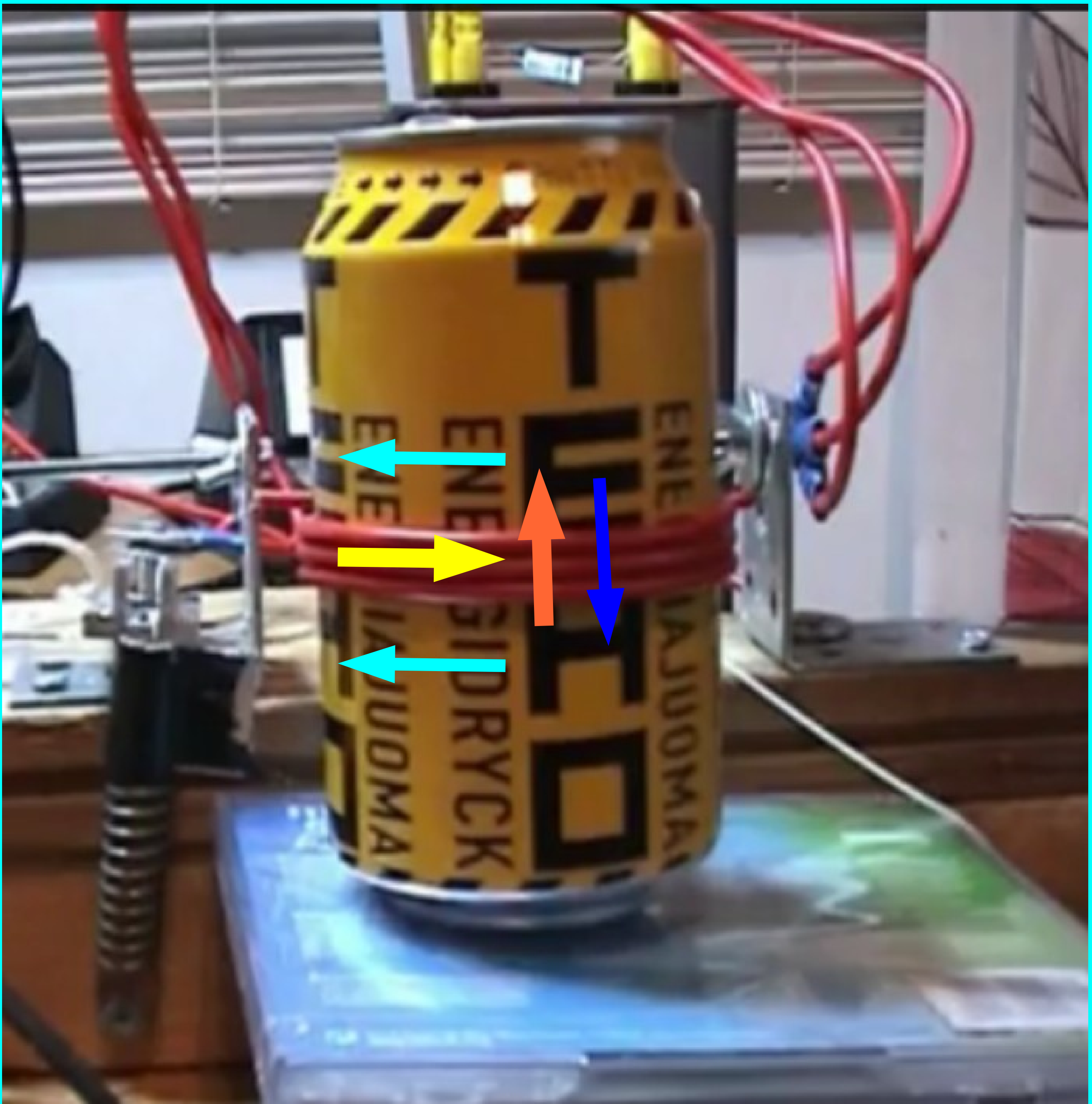
RECAP

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

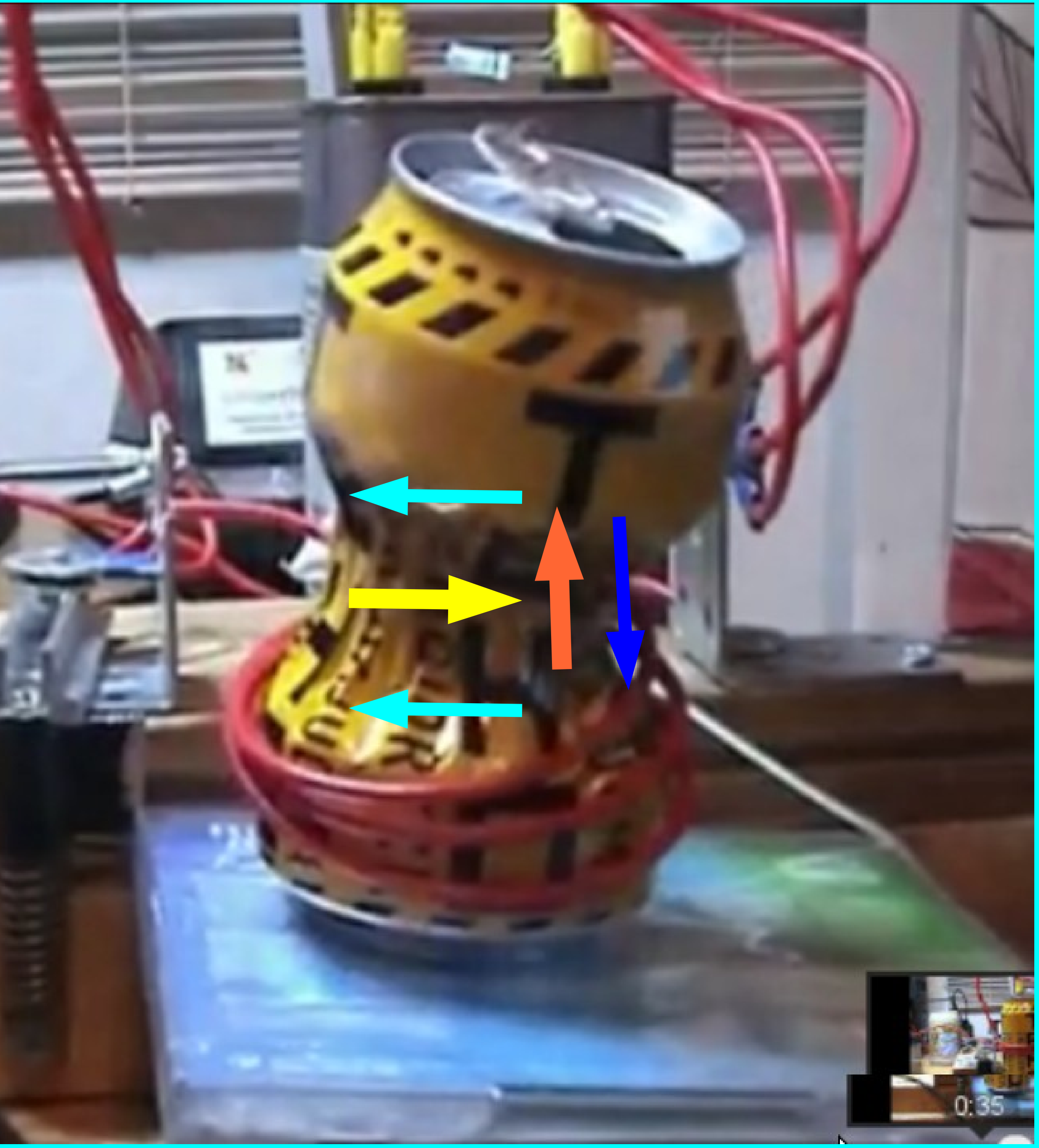
B induced

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

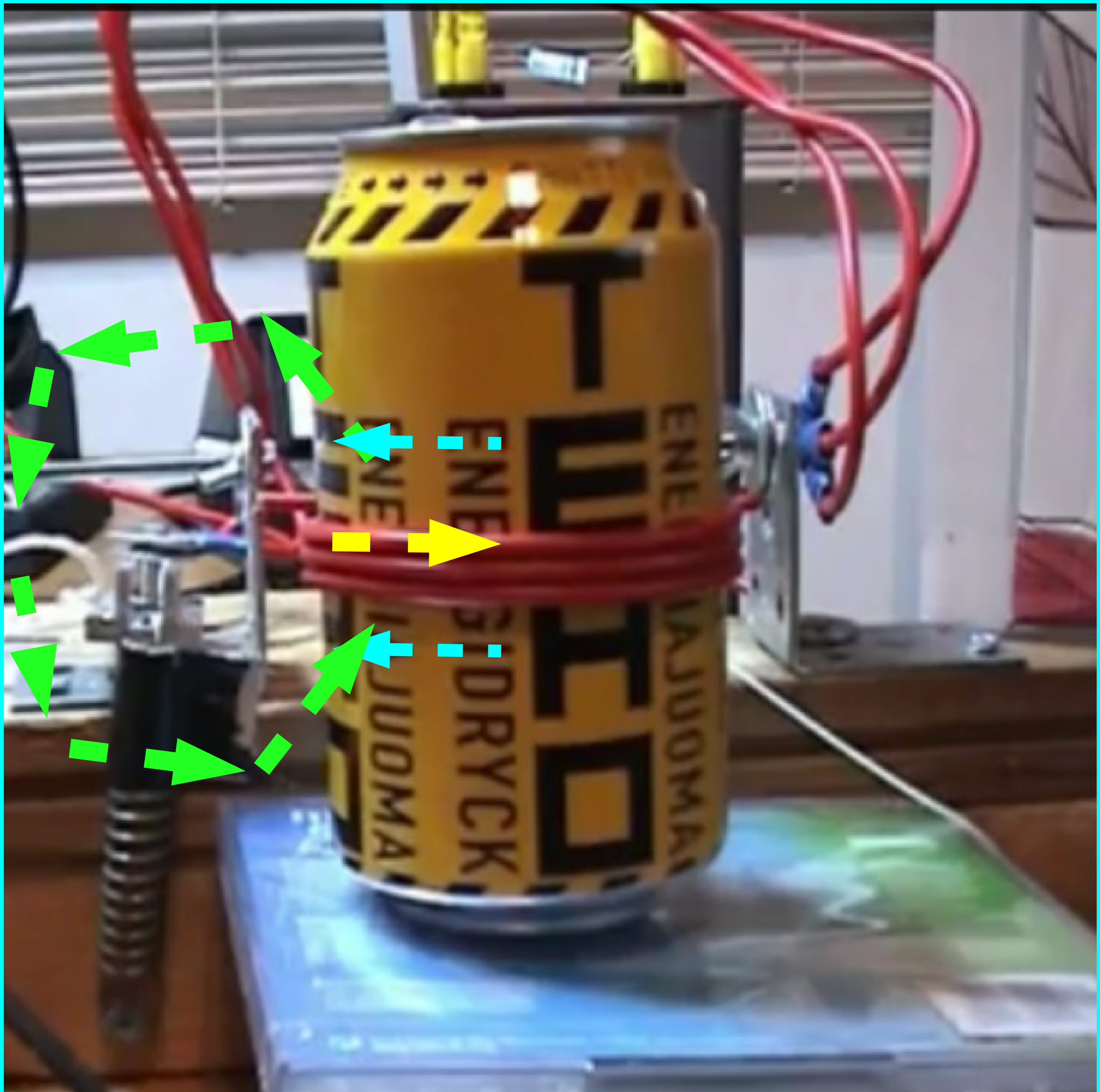
B induced

F induced is radially inward

Can stretcher!

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

Shorter vid. – necking



I and dI/dt

Counterclockwise

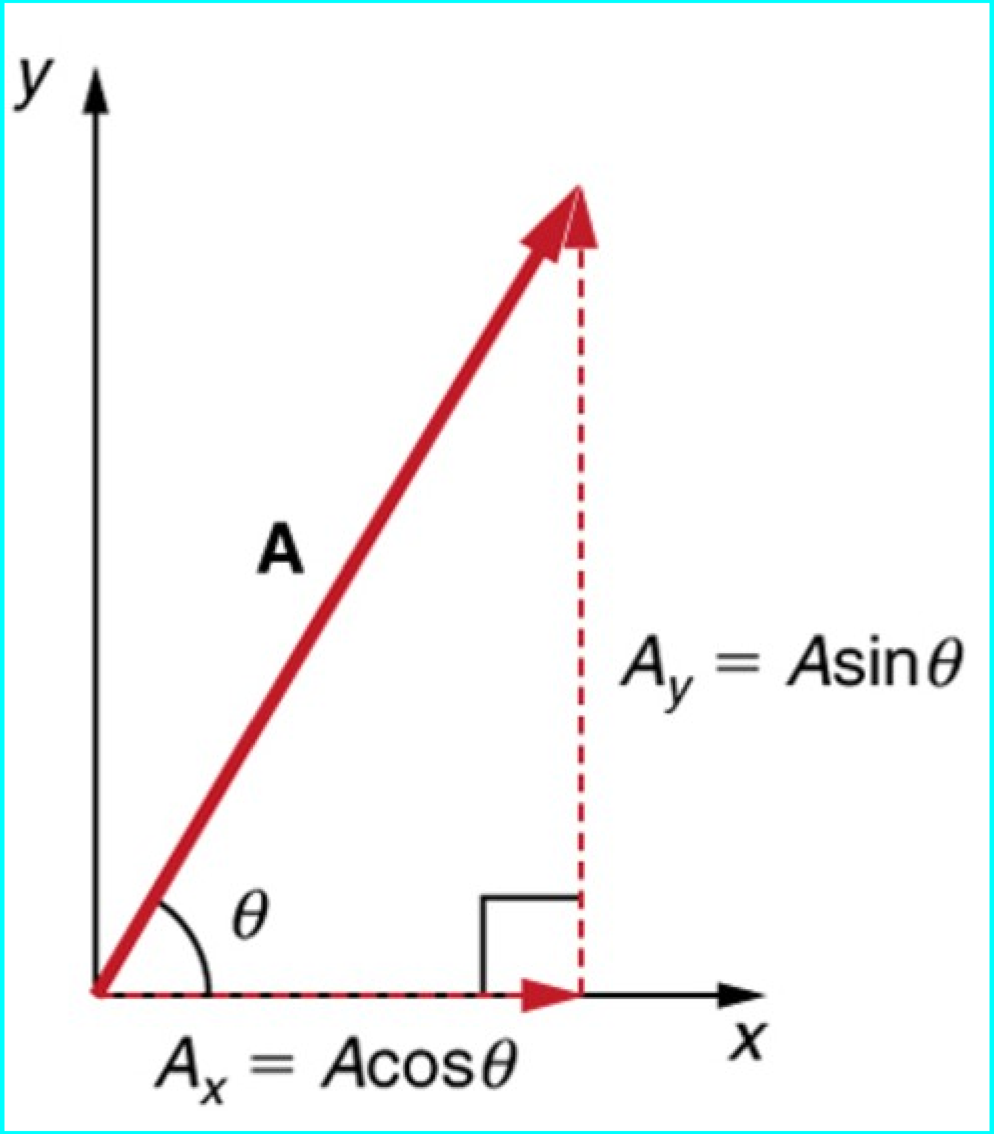
Bradial

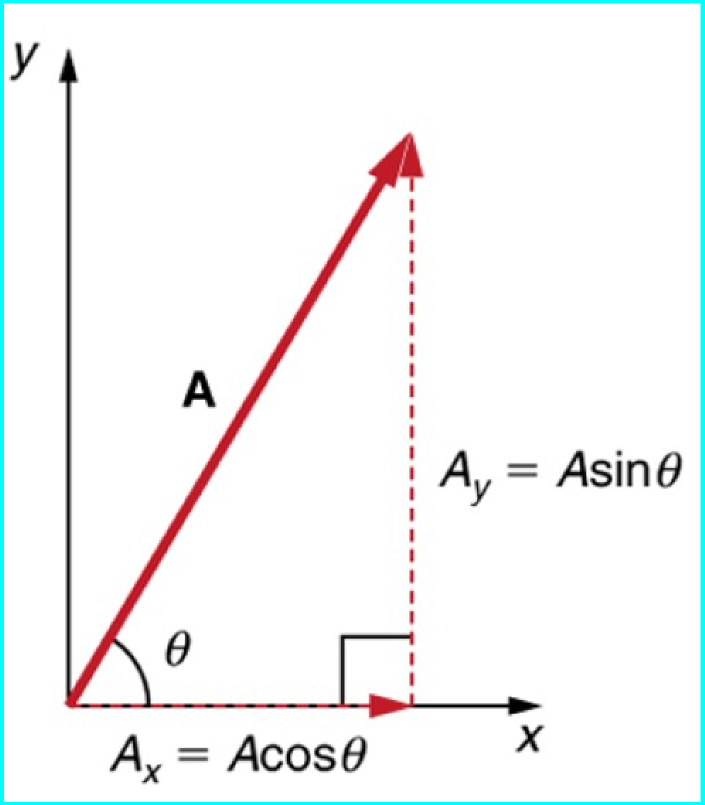
I induced

Clockwise

F induced stretches the
Can vertically

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





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

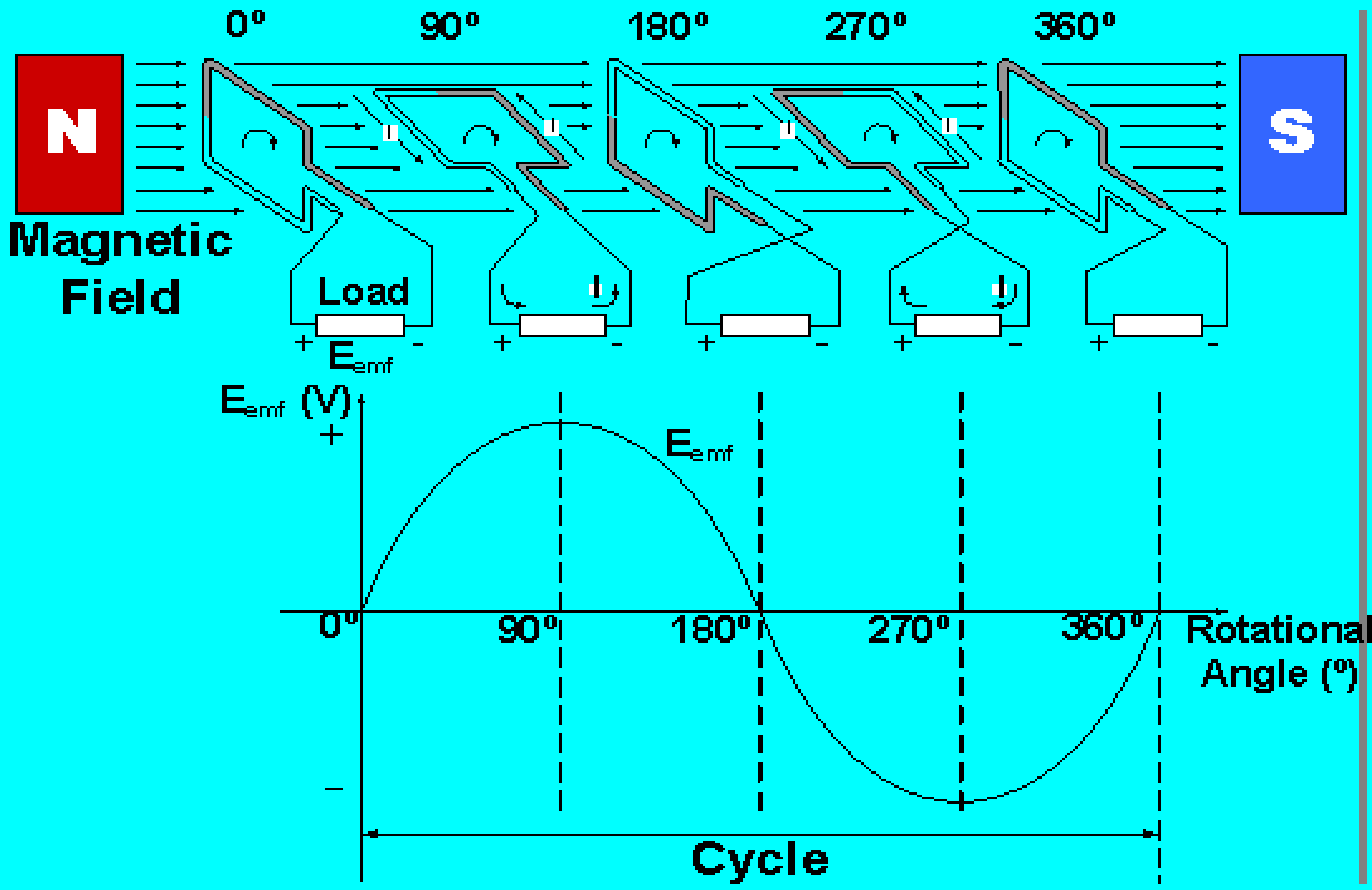
$$\vec{B} = B_0\,\hat{i}$$

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

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

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

An electric generator



What's $\frac{1}{\sqrt{\mu_0 \epsilon_0}}$?

$\mu_0 = 1.26 \times 10^{-6}$

$\epsilon_0 = 8.85 \times 10^{-12}$

$\mu_0 \epsilon_0 = 11.5 \times 10^{-18}$

$\sqrt{\mu_0 \epsilon_0} = 3.34 \times 10^{-9}$

$= .3 \times 10^{9}$

$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \simeq 3 \times 10^{8}$

Maxwell Correction to Ampere's Law

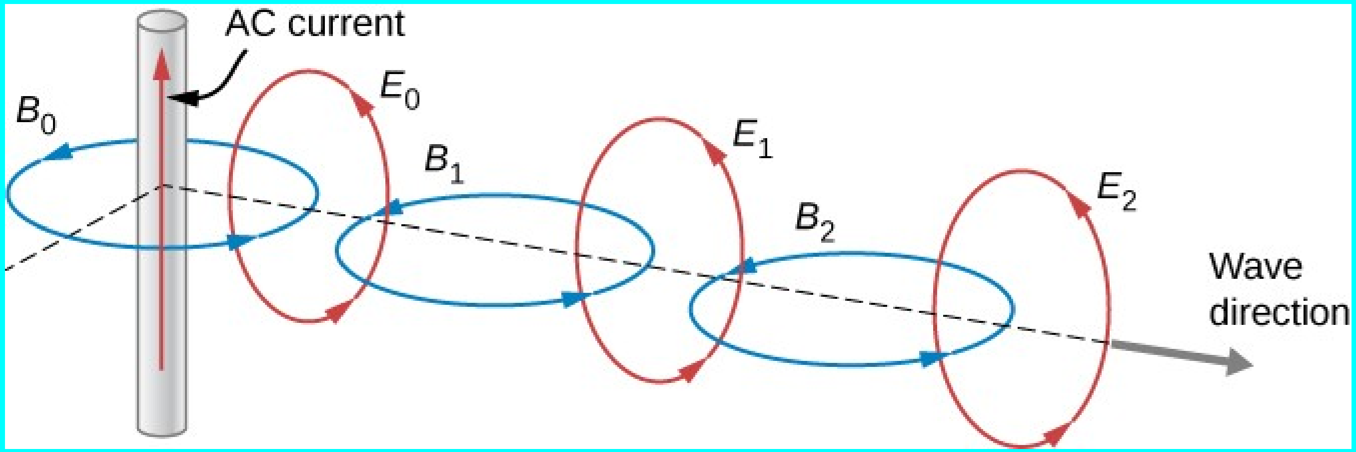
$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enclosed} \quad \text{Ampere's Law}$$

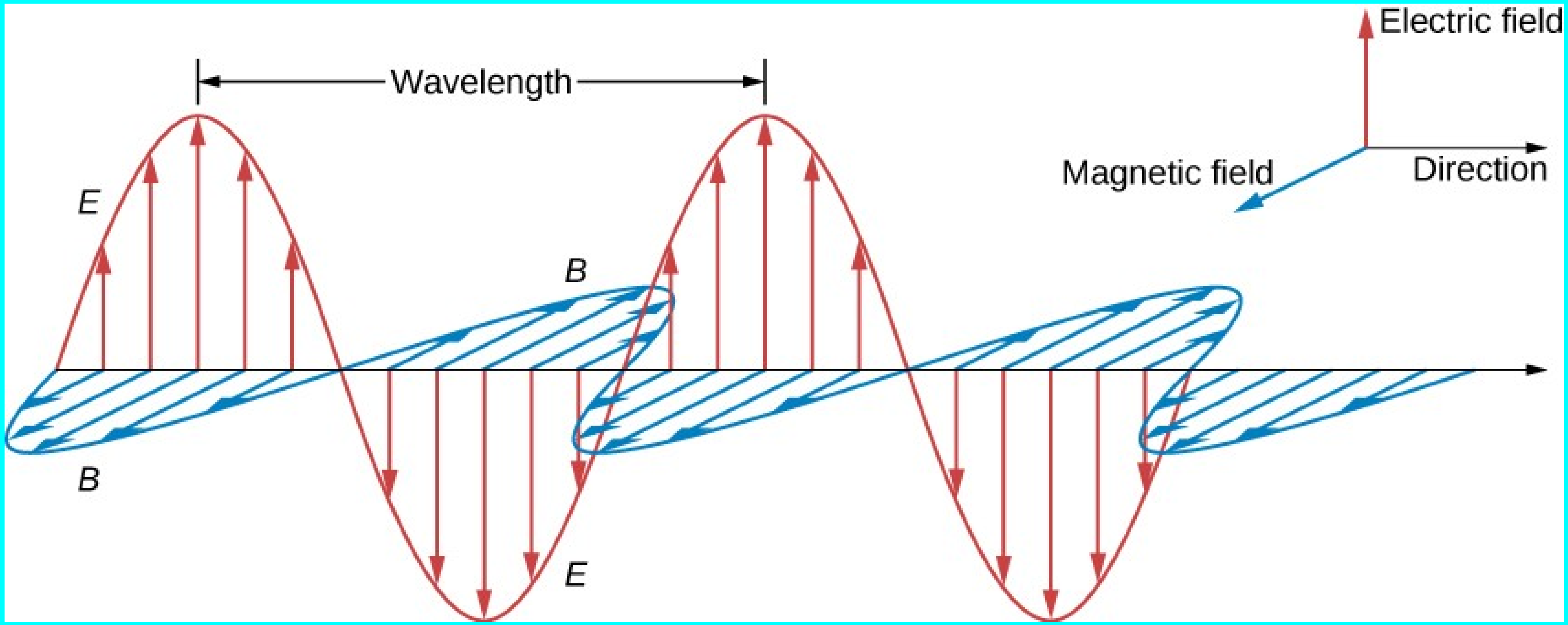
$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enclosed} + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

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

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

$$\oint \vec{B}\cdot d\vec{l} = \frac{1}{c^2} \frac{d\Phi_E}{dt}$$


AC current
E_0
B_0
B_1
E_1
B_2
E_2
Wave
direction



Electric field
Wavelength
Magnetic field
Direction
E
B
B
E

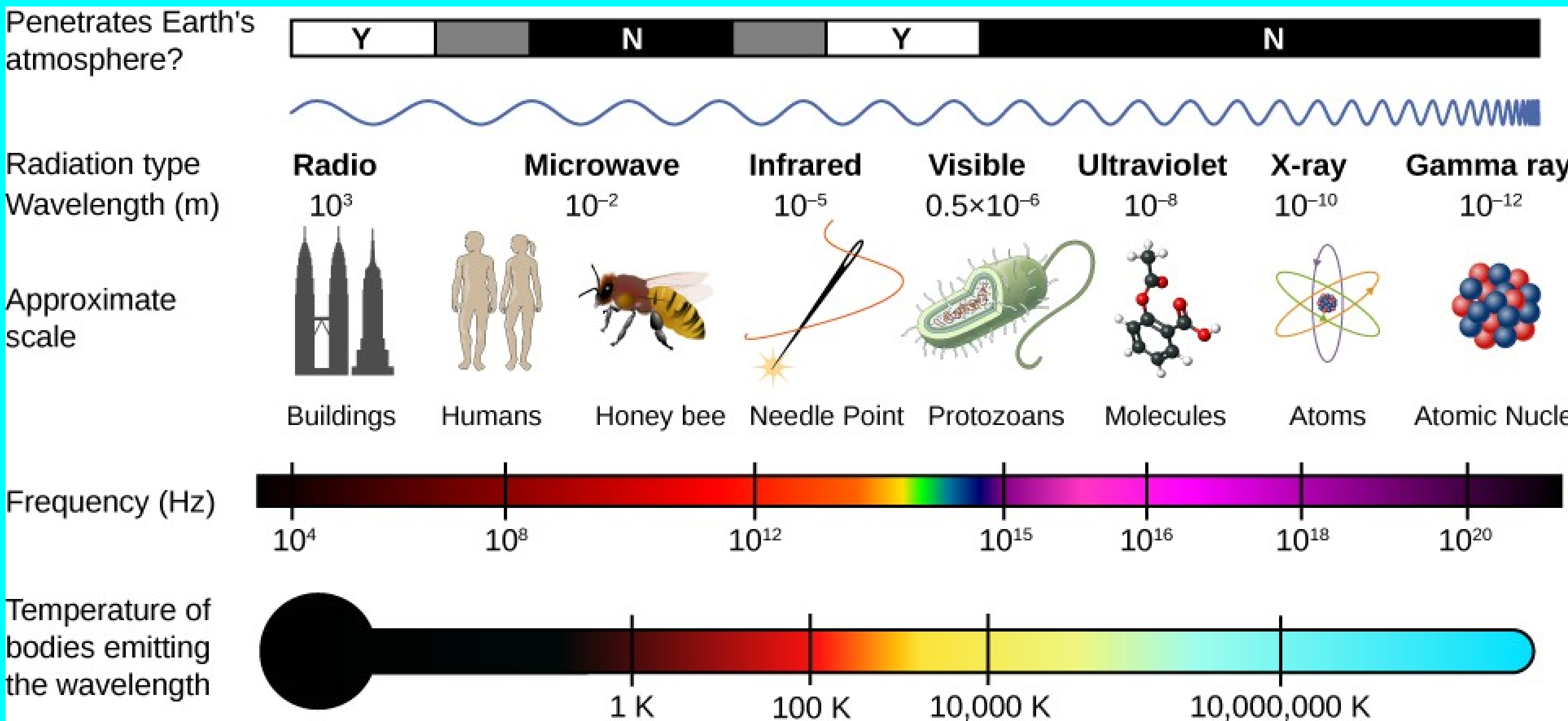
$$v = f\lambda$$

$$c = f\lambda$$

$$\omega = 2\pi f$$

$$v = c = \frac{\omega}{k}$$

$$E = E_0 \sin(kx - \omega t)$$


Penetrates Earth's atmosphere?
Y
N
Y
N
Radiation type
Wavelength (m)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma ray
10^{3}
10^{-2}
10^{-5}
0.5×10^{-6}
10^{-8}
10^{-10}
10^{-12}
Approximate scale
Buildings
Humans
Honey bee
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of bodies emitting the wavelength
1 K
100 K
10,000 K
10,000,000 K

And Yahweh said …

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} \qquad \oint \vec{E}\cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$ ¿

And Yahweh said ...

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} \qquad \oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

... and there was light