Lecture 26: 04/23/2024

- Announcements
  - Last assignment is posted
  - Faraday's law and EM spectrum (Ch 13/16.5)
  - Omit Ch 14
  - Review session? Tuesday 5-6? Thursday?

- Last Time
  - Earth B-field (problem 7-3)
  - Ampere's Law – field in a solenoid
  - Magnetic properties

- Today
  - Faraday's Law – Induced voltage

Review session

Tuesday April 30 at 5 pm?

Thursday May 2 at 11 am?

Thursday at 5 pm?

Faraday and Ampere in words

- AMPERE: A current produces a magnetic field circling around it.

- FARADAY: A changing magnetic flux produces an electric field circling around it.

Maxwell's Equations

$$\oiint \vec{E}\cdot d\vec{A} = \frac{Q_{enclosed}}{\epsilon_0}$$ To calculate E for symettrical charges.

$$\oiint \vec{B}\cdot d\vec{A} = 0$$ Cannot have North magnet w/o a South pole.

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enclosed}$$ To calculate B for symettrical currents.

$$\oint \vec{E}\cdot d\vec{l} = -\frac{d\Phi}{dt}$$ Magnetic induction! Generators! Light!

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

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Faraday's Law

$$\oint \vec{E}\cdot d\vec{l} = -\frac{d\Phi}{dt}$$ A changing flux makes a circling E-field

$$\varepsilon \stackrel{\text{def}}{=} \oint \vec{E}\cdot d\vec{l}$$ An E-field in a loop is a voltage (or EMF)

$$\Phi_B = \int \vec{B}\cdot d\vec{A}$$ Flux is average B-field dotted with area

$$\Phi_B = \vec{B}\cdot\vec{A}$$ When B is uniform, flux formula is simpler

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

Faraday’s Law

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$$\varepsilon = -\left(\vec{A}\cdot\frac{d\vec{B}}{dt} + \vec{B}\cdot\frac{d\vec{A}}{dt}\right)$$ The product rule! ¿

$$\varepsilon = -\vec{A}\cdot\frac{d\vec{B}}{dt}$$ A changing B-field through a loop makes voltage.

$$\varepsilon = -\vec{B}\cdot\frac{d\vec{A}}{dt}$$ A constant B and a changing loop makes voltage. ¿

Magnetic Flux

In the picture below, the square loop is 10 cm on a side and the angle shown is sixty degrees. The B-field shown by red arrows is a uniform 0.08 T in magnitude. What is the total magnetic flux?

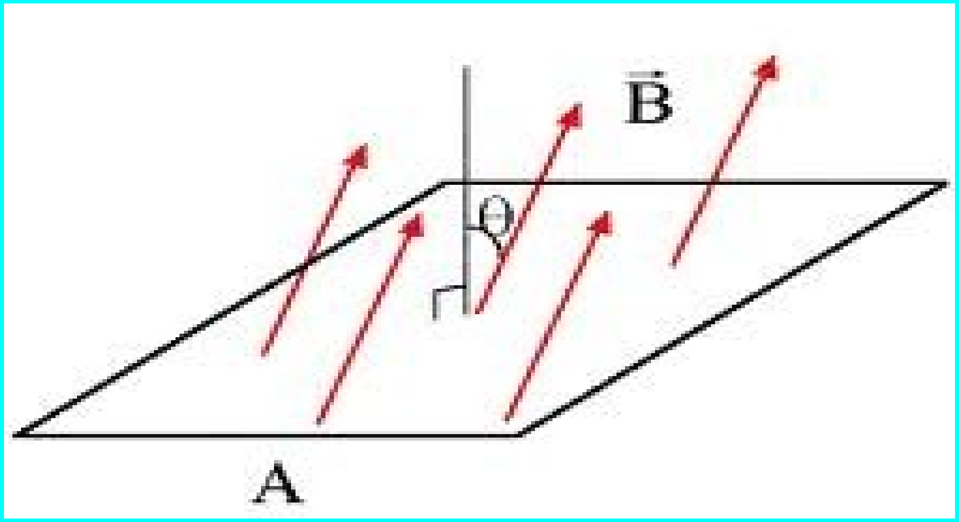
(A) $8\times10^{0}\,\mathrm{T\cdot m^2}$

(B) $8\times10^{-2}\,\mathrm{T\cdot m^2}$

(C) $8\times10^{-4}\,\mathrm{T\cdot m^2}$

(D) $6.9\times10^{-4}\,\mathrm{T\cdot m^2}$

(E) $4.0\times10^{-4}\,\mathrm{T\cdot m^2}$



Faraday's Law

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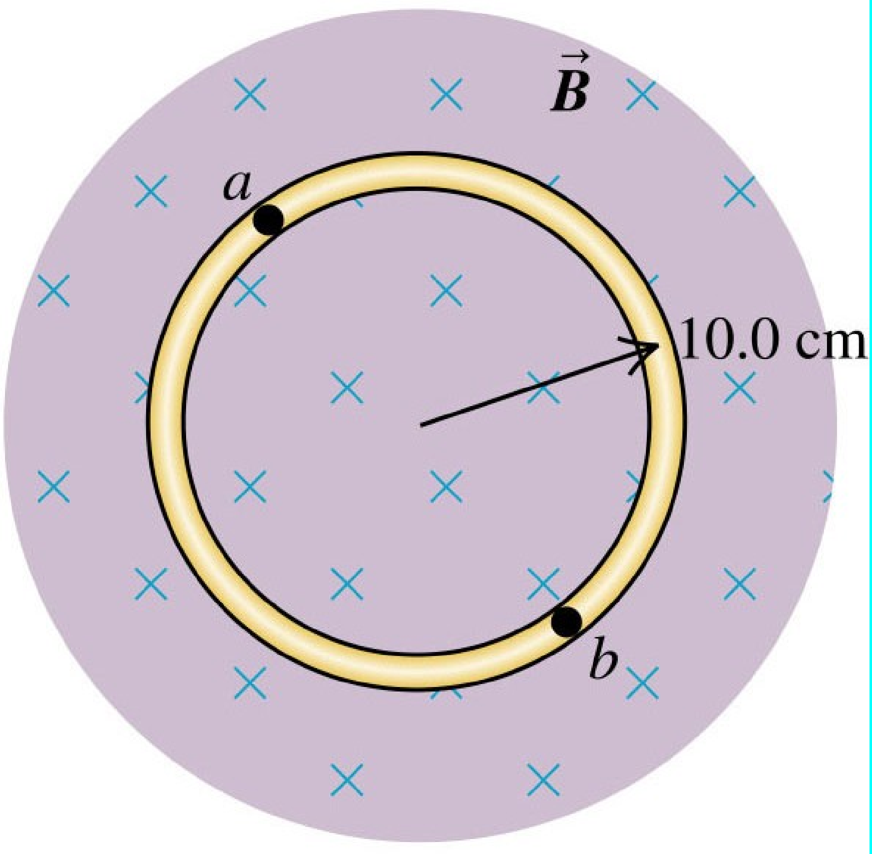
A circular loop of wire is in a region of spatially uniform magnetic field.

The magnetic field decreases from 1 Tesla to zero in 2 seconds.

Which case of Faraday's law do we use?



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

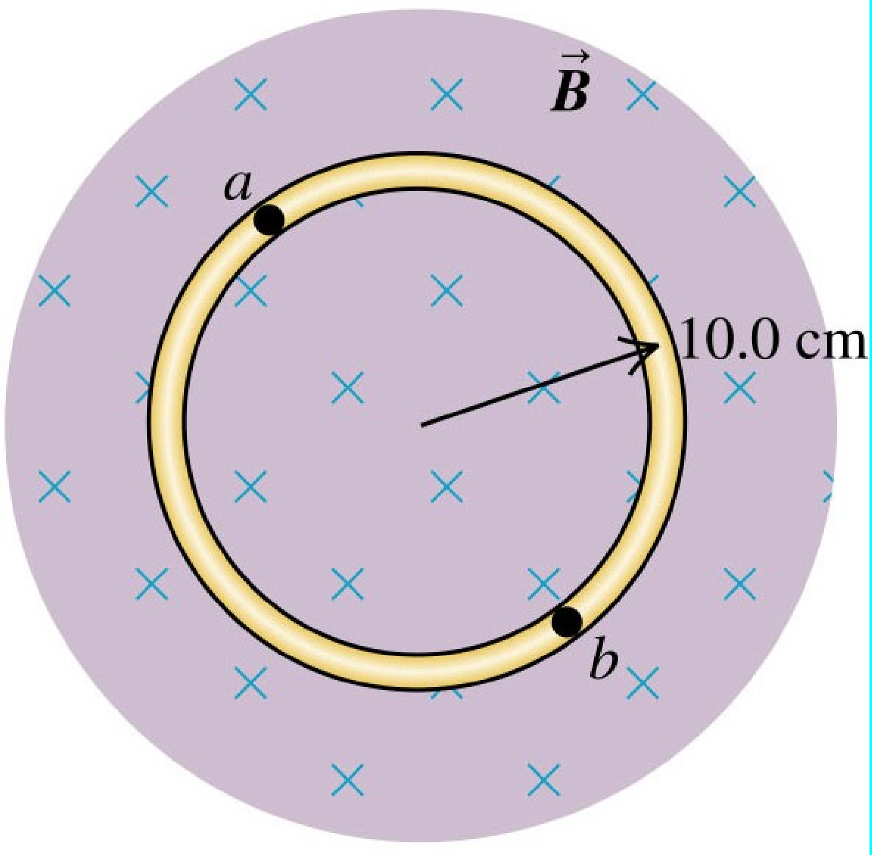
(B) $\varepsilon = -\vec{B} \cdot \frac{d\vec{A}}{dt}$

(C) $\varepsilon = IR$

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

The magnetic field decreases from 1 Tesla to zero in 2 seconds.

What is dB/dt?



(A) 0

(B) $\frac{dB}{dt} = 1.0\ T/s$

(C) $\frac{dB}{dt} = 2.0\ T/s$

(D) $\frac{dB}{dt} = -2.0\ T/s$

(E) $\frac{dB}{dt} = -0.5\ T/s$

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

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

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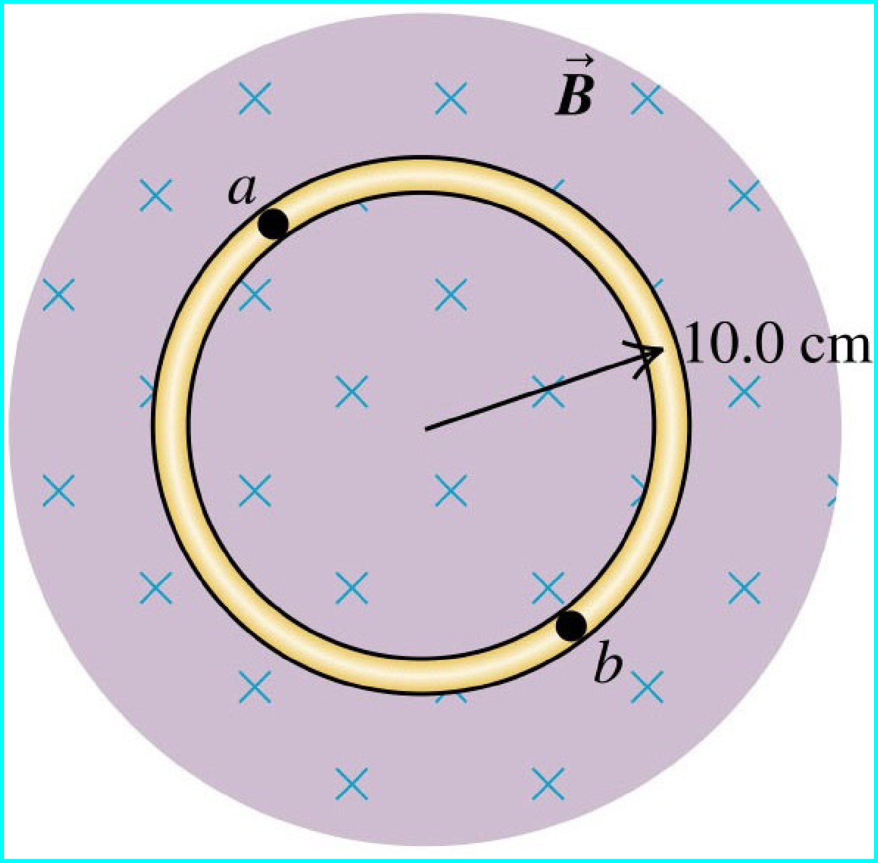
Induced EMF Magnitude is?



(A) $\pi/50\ \mathrm{V}$

(B) $\pi/100\ \mathrm{V}$

(C) $\pi/200\ \mathrm{V}$

(D) $100\pi\ \mathrm{V}$

(E) $50\pi\ \mathrm{V}$

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

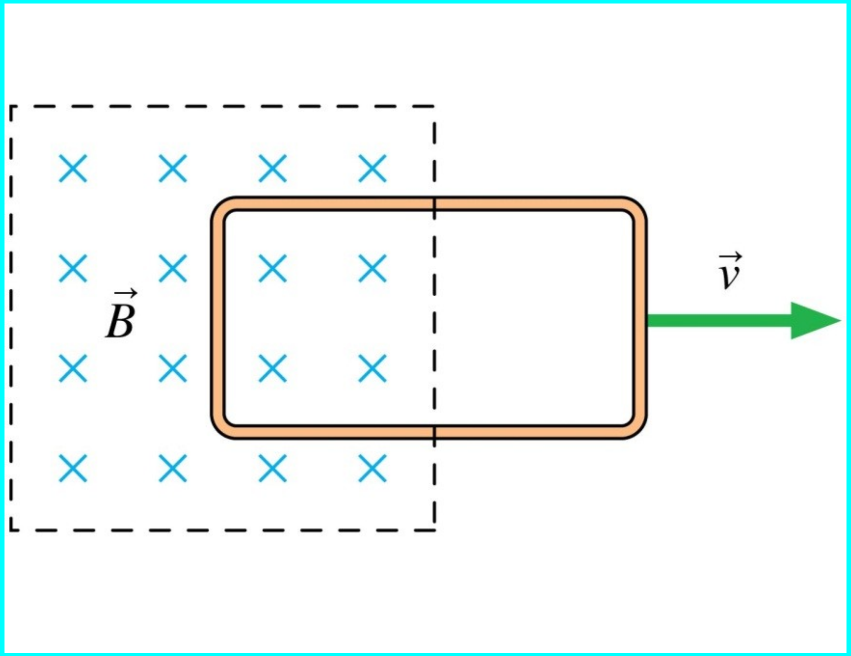
Clicker

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 form of Faraday's Law do we use?

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

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

(C) $C = \varepsilon_0 \frac{A}{d}$



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.

- L is 10 cm, v = 300 m/s, B=50 mT, w=20 cm
- What is magnitude of induced voltage?

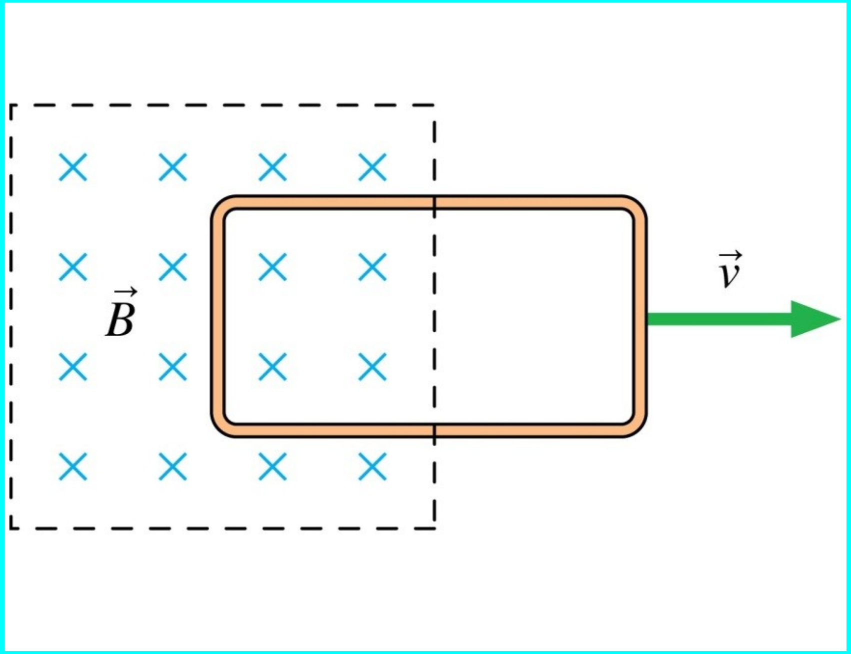
(A) $\varepsilon = 3.0\,\text{V}$

(B) $\varepsilon = 1.5\,\text{V}$

(C) $\varepsilon = 1.5\,\mu_0\,\text{V}$

(D) $\varepsilon = 1.0\,\text{mV}$

(E) $\varepsilon = 3.0\,\text{mV}$



Faraday's Law

Changing magnetic fluxes produce electric fields and hence voltages.

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

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

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.

Remember magnetic moments?

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

If current flows counter-clockwise, direction of $\vec{m}$?

(A) Counter – clockwise

(B) Right

(C) Out of Page

(D) Into Page

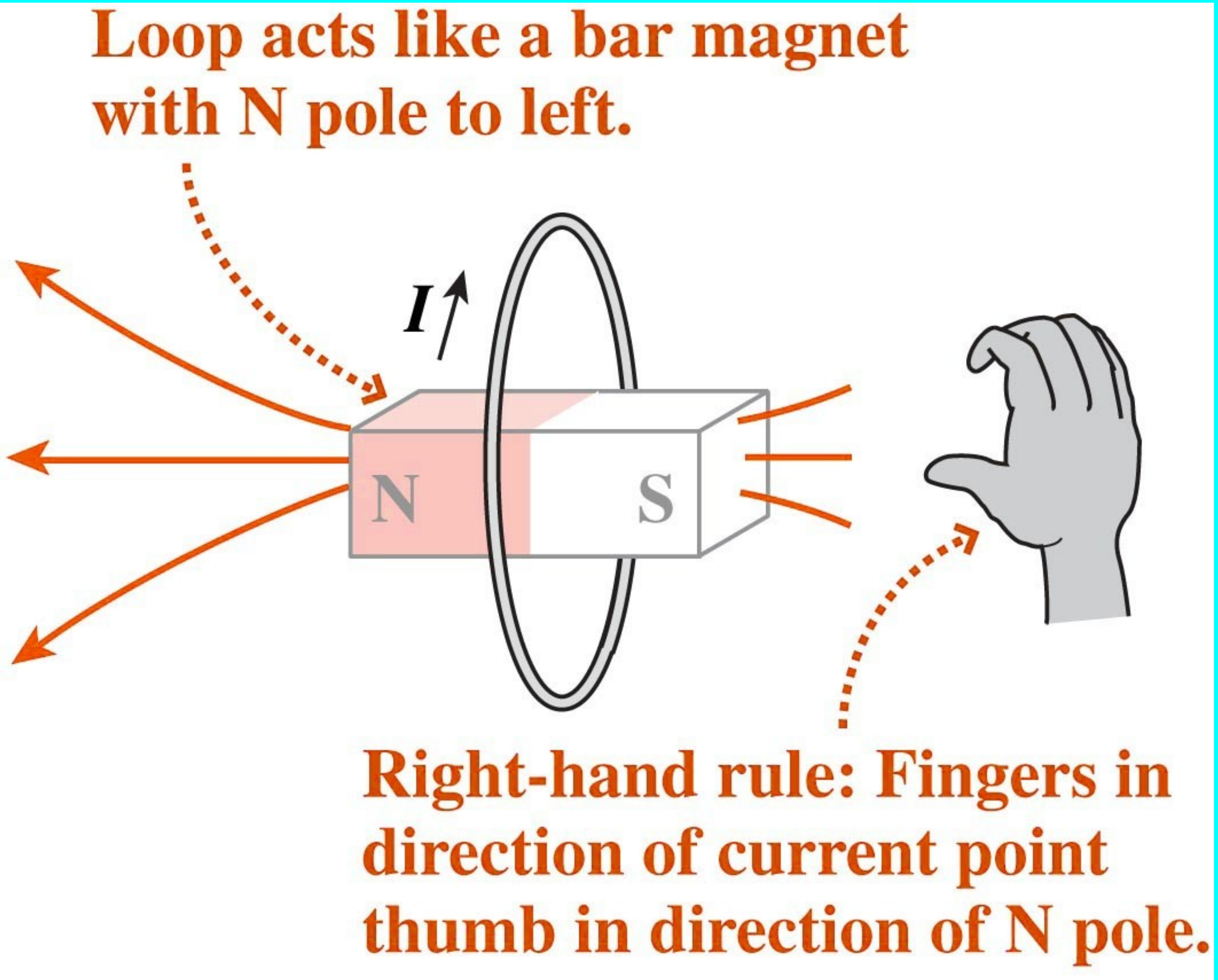
(E) Down

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

Figure out how the flux is changing.

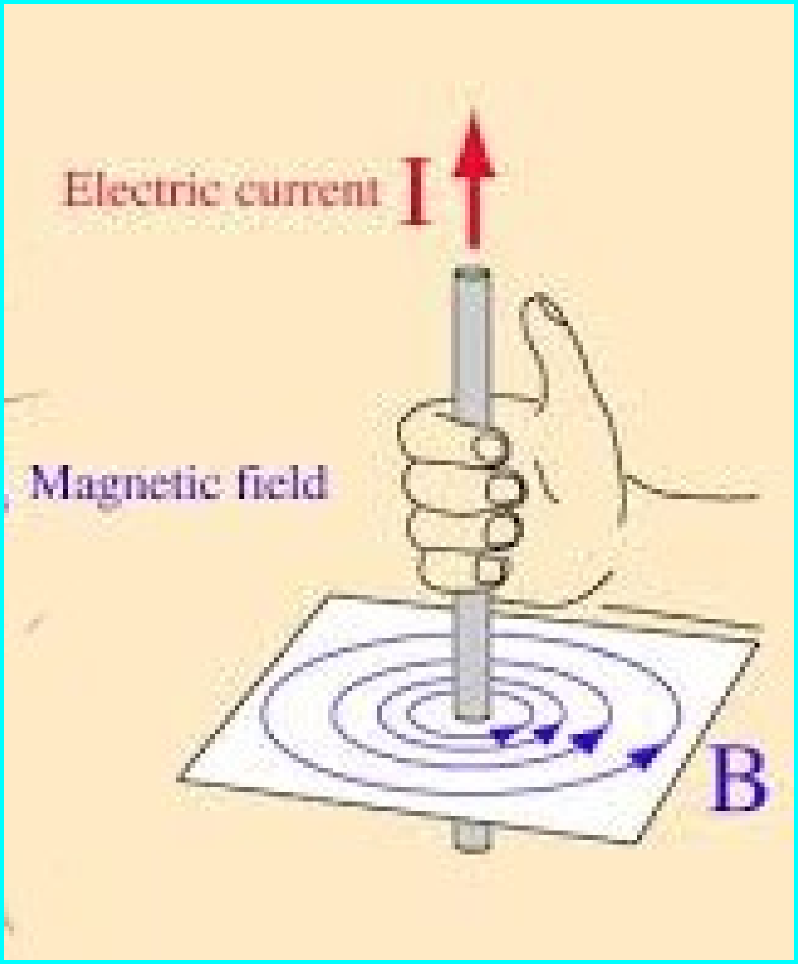
Figure out what current what produce that change in flux.

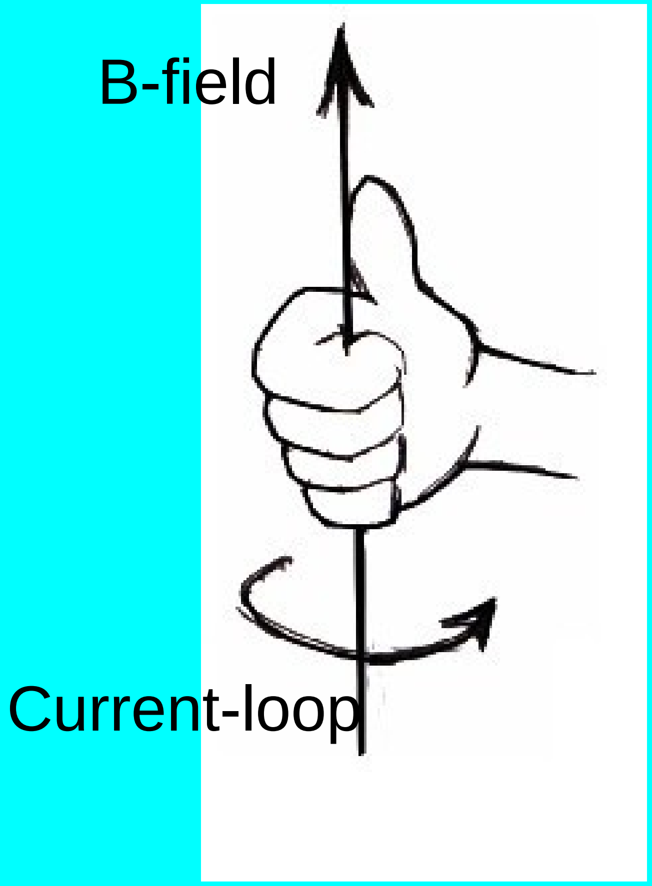
The induced current is opposite to that.


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)

Two ways to use the hitch-hikers rule.

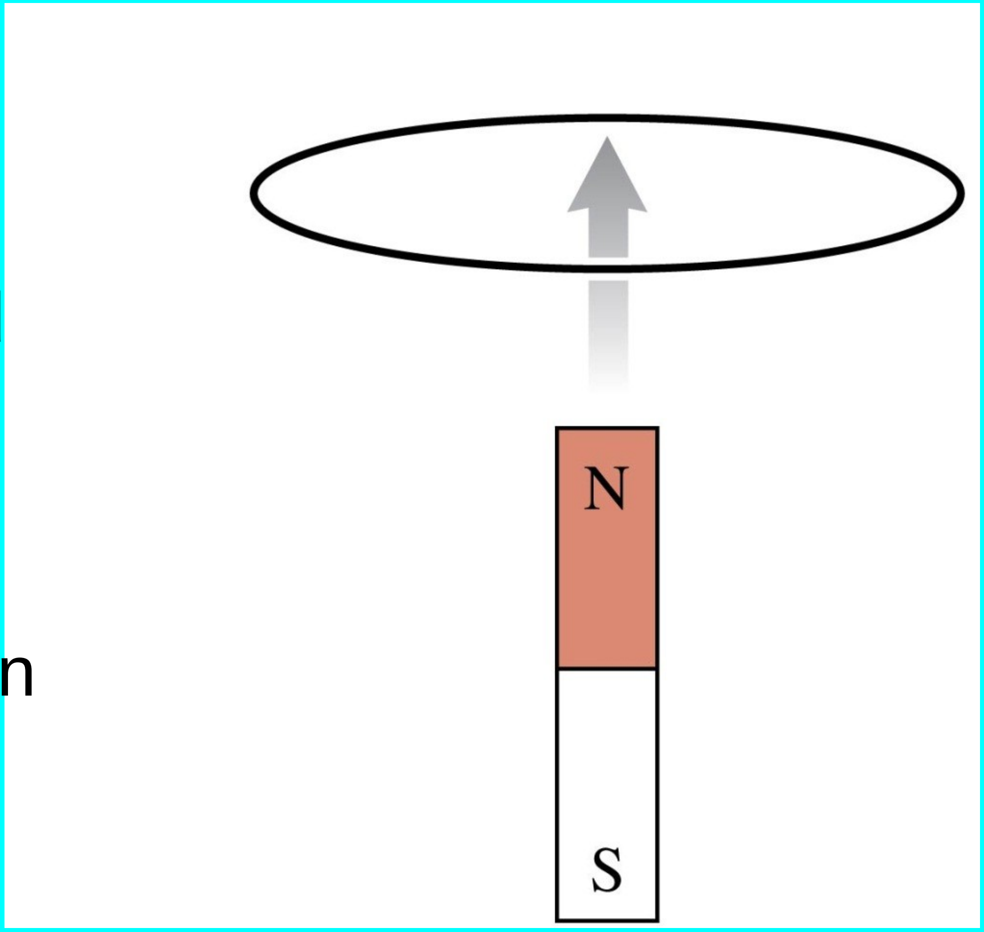




Figuring out direction of induced current

The bar magnet is pushed toward the center of a wire loop. 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.



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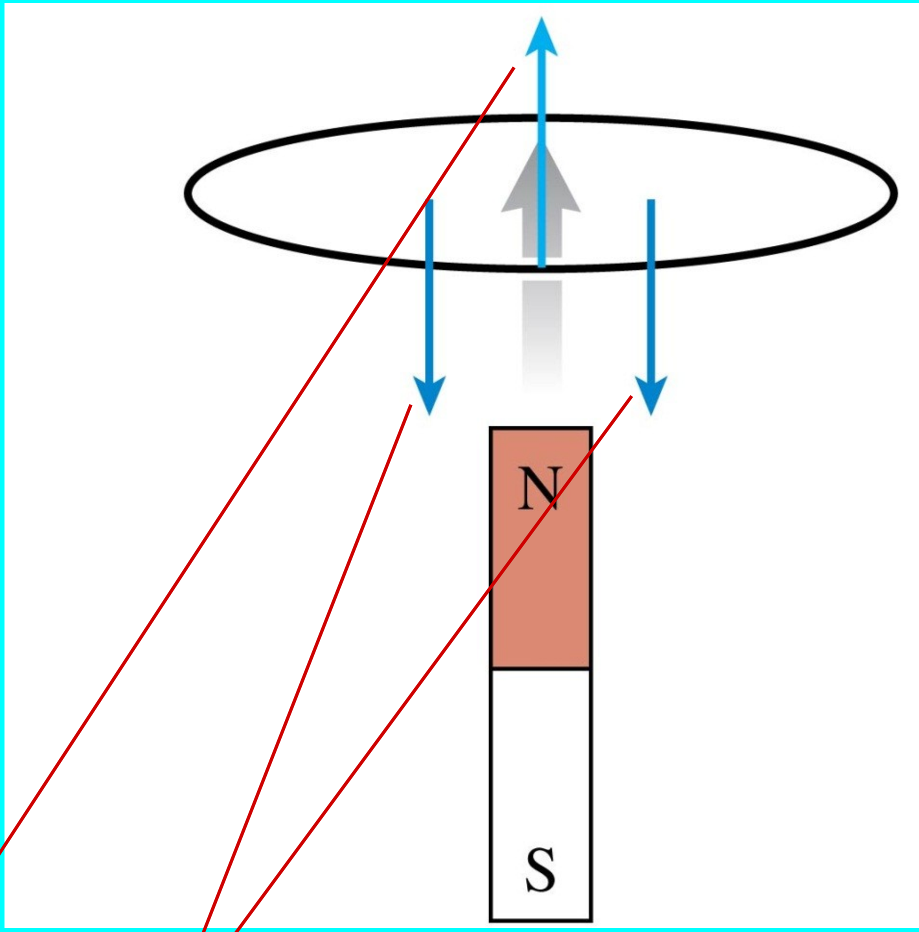
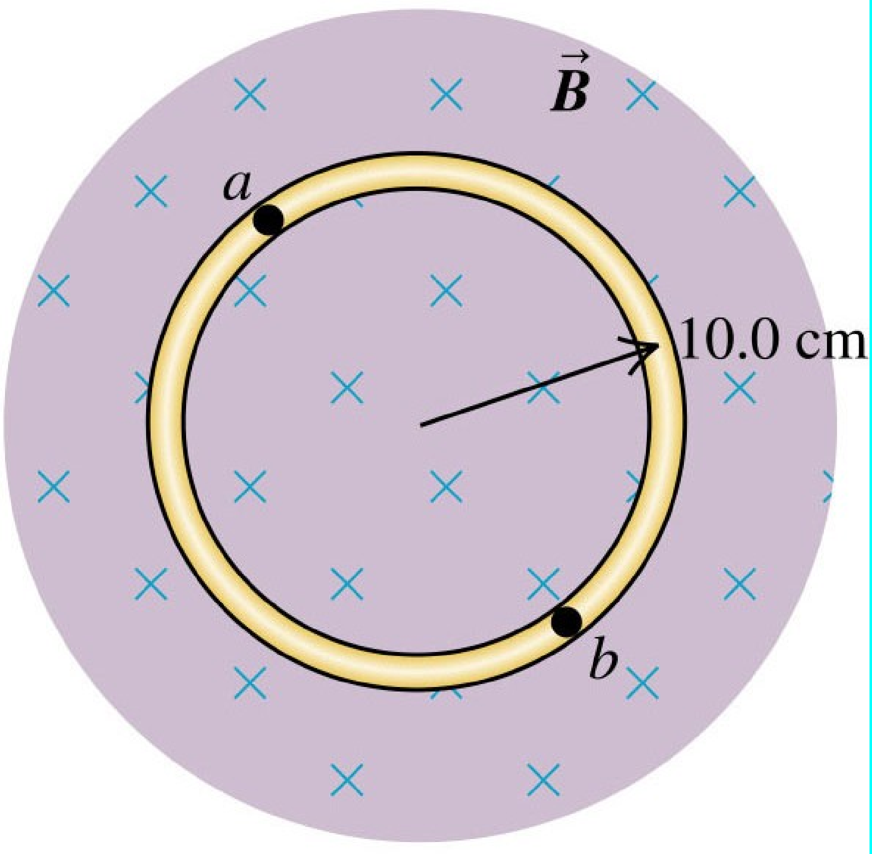


1. Upward flux from magnet is <u>increasing</u>.
2. To oppose the <u>increase</u>, the field of the induced current points down.
3. From the right-hand rule, a downward field needs a cw current.

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

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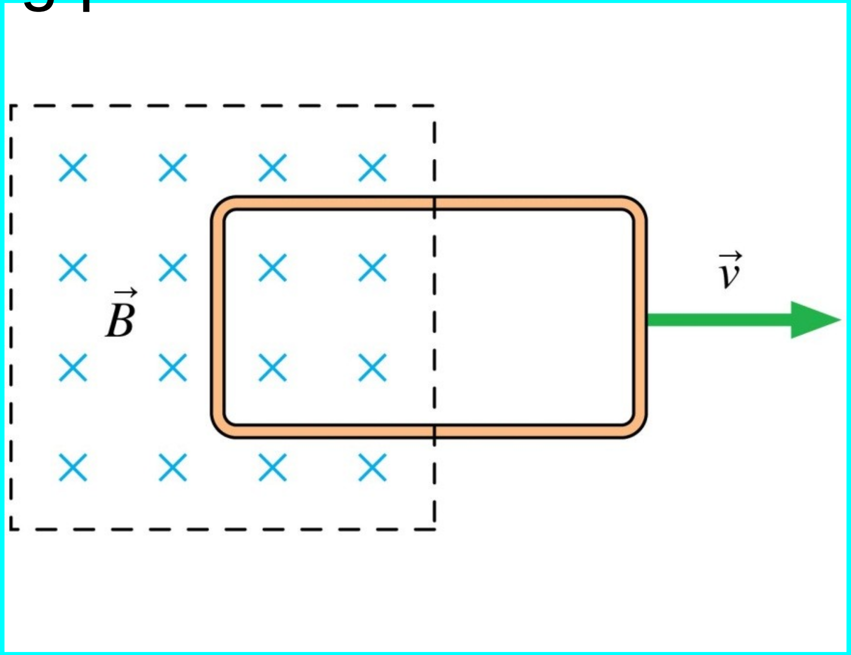

A. There is a clockwise induced current in the loop.
B. There is a counterclockwise induced current in the loop.
C. There is no induced current in the loop.

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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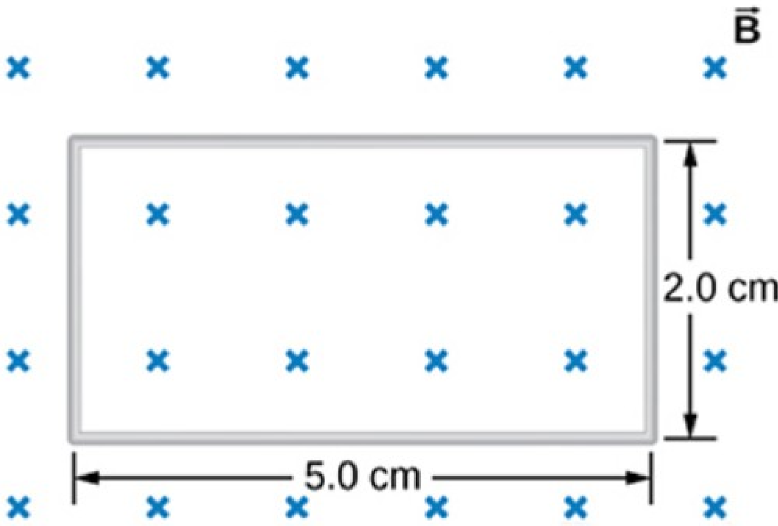


Part (a) What is the magnitude, in amperes, of the current induced in the loop at $t = 1.0$ ms?
Numeric : A numeric value is expected and not an expression.
I_1 = ____ A

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

Clicker

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.

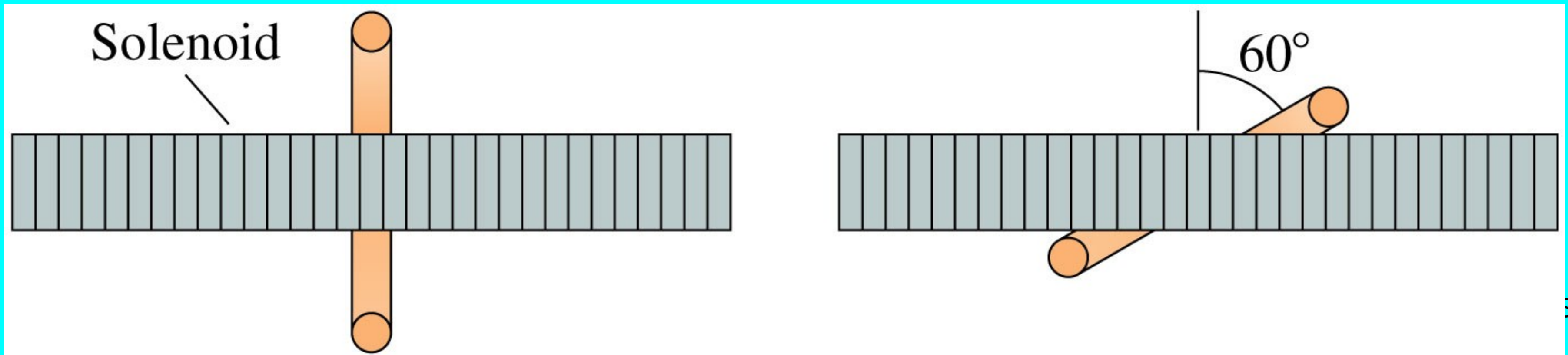
$$[A]\ \ \Phi_1=\pi r^2 B,\ \ \Phi_2=\pi r^2 B\cos(60)$$

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

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

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

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



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