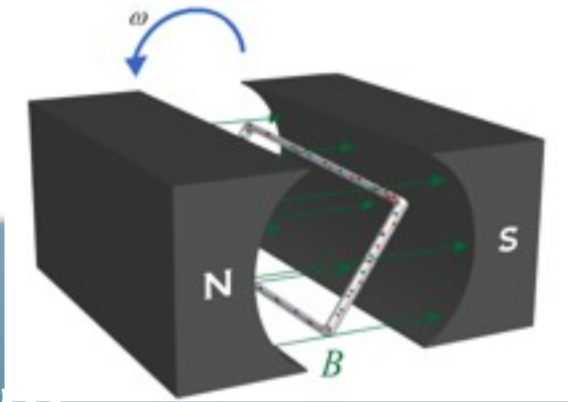
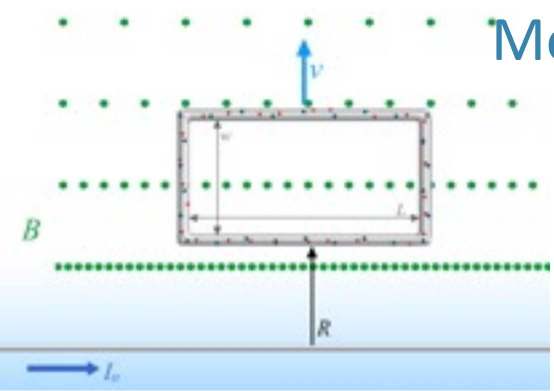
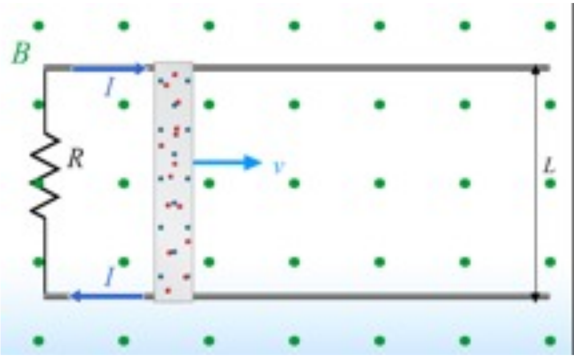


Electricity & Magnetism
Lecture 16

Today's Concept:

Motional EMF



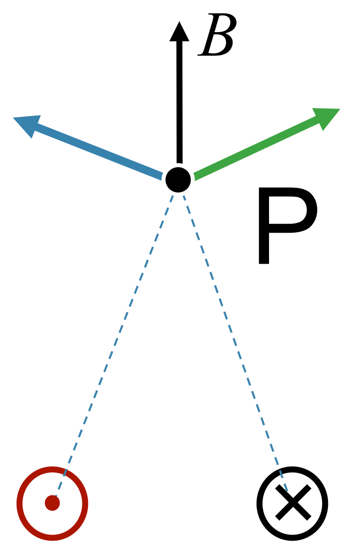


Kamran is sick today

Please be nice.

Correction: Adding Magnetic Fields

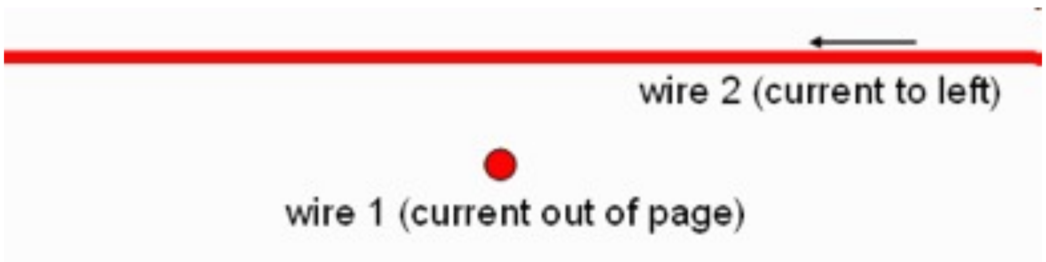
Two long wires carry opposite current



What is the direction of the magnetic field above, and midway between the two wires carrying current – at the point marked "P"?

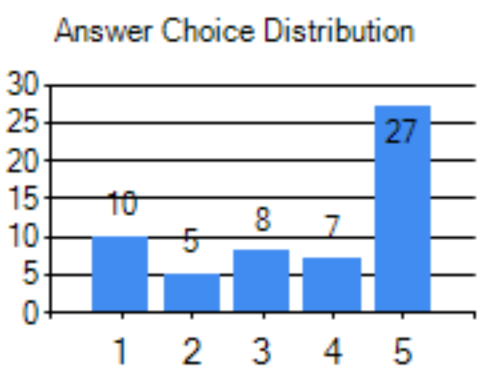
A) Left B) Right C) Up D) Down E) Zero

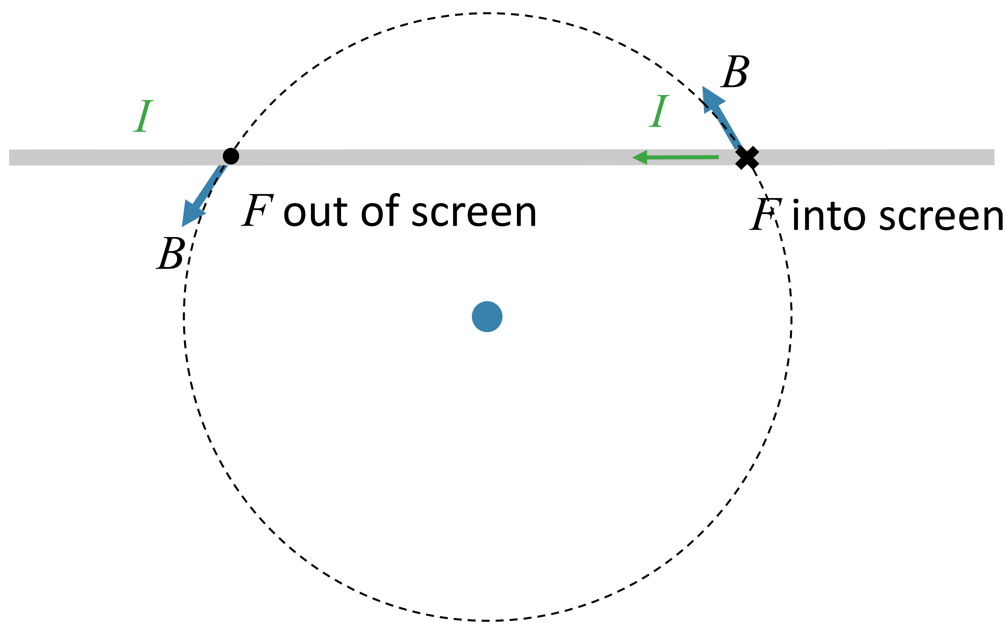
Also: CheckPoint 9



In the above situation, what is the net torque on wire 2 due to wire 1?

A) Up B) Down C) Into Screen D) Out of screen E) Zero

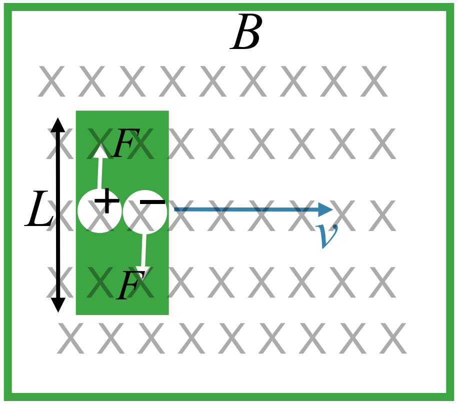




http://www.huffingtonpost.com/2012/02/21/dog-standing-on-things_n_1292295.html#s713069

The Big Idea

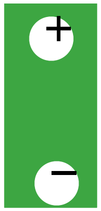
When a conductor moves through a region containing a magnetic field:



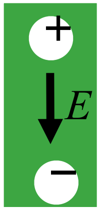
Magnetic forces may be exerted on the charge carriers in the conductor

$$\vec{F} = q\vec{v} \times \vec{B}$$

These forces produce a charge separation in the conductor



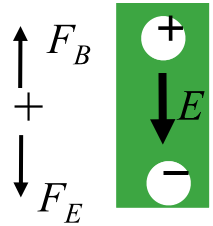
This charge distribution creates an electric field in the conductor



The equilibrium distribution is reached when the forces from the electric and magnetic fields cancel

$$qvB = qE$$

$$E = vB$$

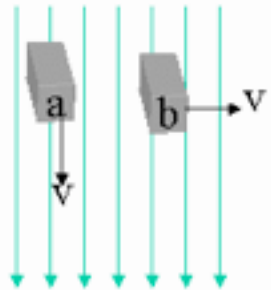


The equilibrium electric field produces a potential difference *(emf)* in the conductor

$$V = EL \rightarrow V = vBL$$

CheckPoint 2

Two identical conducting bars (shown in end view) are moving through a vertical magnetic field. Bar (a) is moving vertically and bar (b) is moving horizontally.



2) Which of the following statements is true?

A ○ A motional emf exist in the bar for case (a), but not (b)

B ○ A motional emf exist in the bar for case (b), but not (a)

C ○ A motional emf exist in the bar for both cases (a) and (b)

D ○ A motional emf exist in the bar for neither case (a) nor (b)

Bar a

No force on charges

No charge separation

No E field

No emf

Bar b

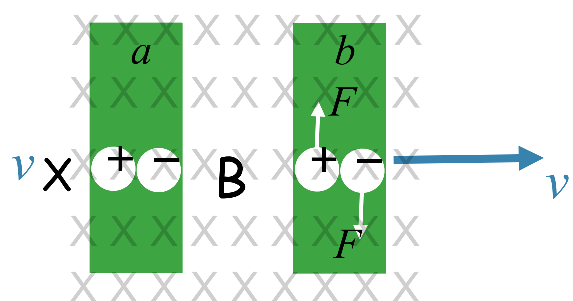
Opposite forces on charges

Charge separation

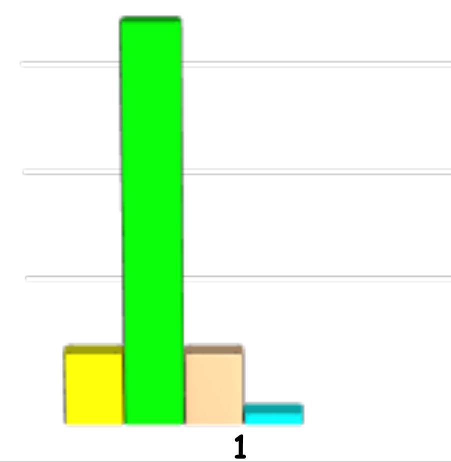
$E = vB$

$emf = EL = vBL$

Rotate picture by 90°

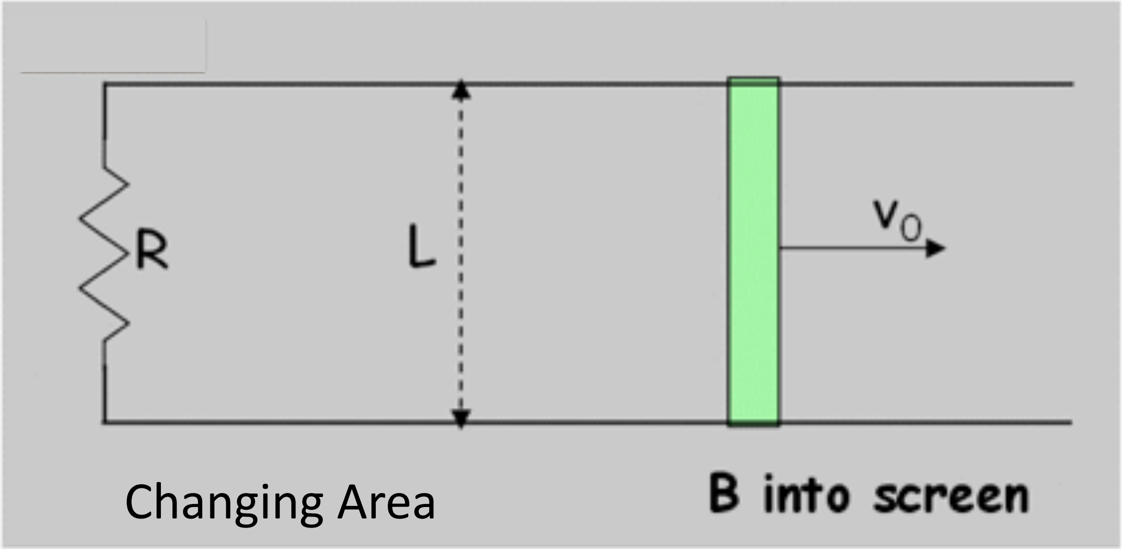


$F_a = 0$ $\quad$ $F_b = qvB$



CheckPoint 4

A conducting bar (green) rests on two frictionless wires connected by a resistor as shown.



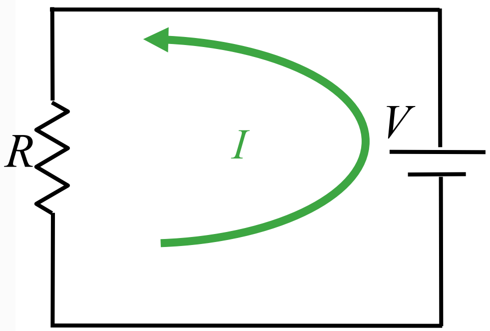
The entire apparatus is placed in a uniform magnetic field pointing into the screen, and the bar is given an initial velocity to the right.

4) The motion of the green bar creates a current through the bar

A ○ going up

B ○ going down

Equivalent circuit



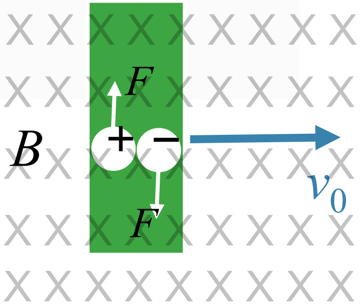
Bar

Opposite forces on charges

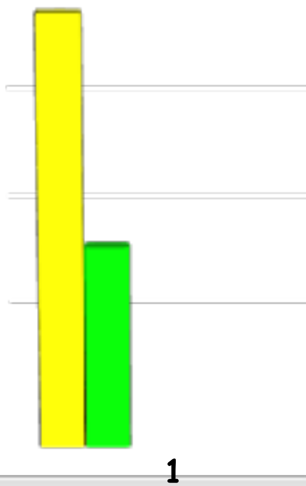
Charge separation

$E = v_0 B$

$emf = EL = v_0 BL$

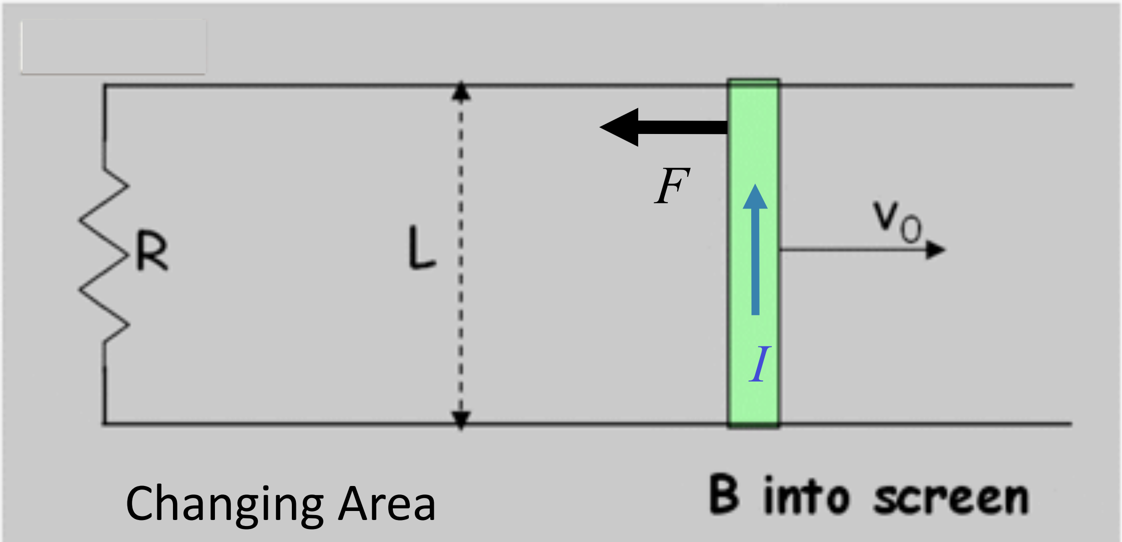


$F_b = q v_0 B$



CheckPoint 5

A conducting bar (green) rests on two frictionless wires connected by a resistor as shown.



The entire apparatus is placed in a uniform magnetic field pointing into the screen, and the bar is given an initial velocity to the right.

5) The current through this bar results in a force on the bar

A ○ down
B ○ up
C ○ right
D ○ left
E ○ into the screen
○ out of the screen

Counterclockwise Current

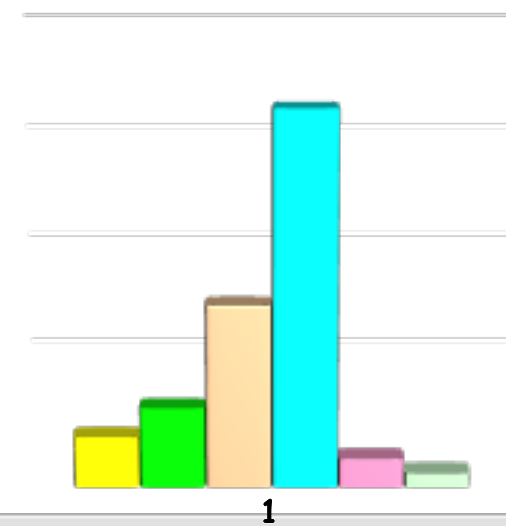
$$\vec{F} = I\vec{L} \times \vec{B} \longrightarrow F \text{ points to left}$$

$$F = \left(\frac{vBL}{R}\right) LB \longrightarrow P = Fv = \left(\frac{vBL}{R}\right) LBv = I^2 R$$

Energy

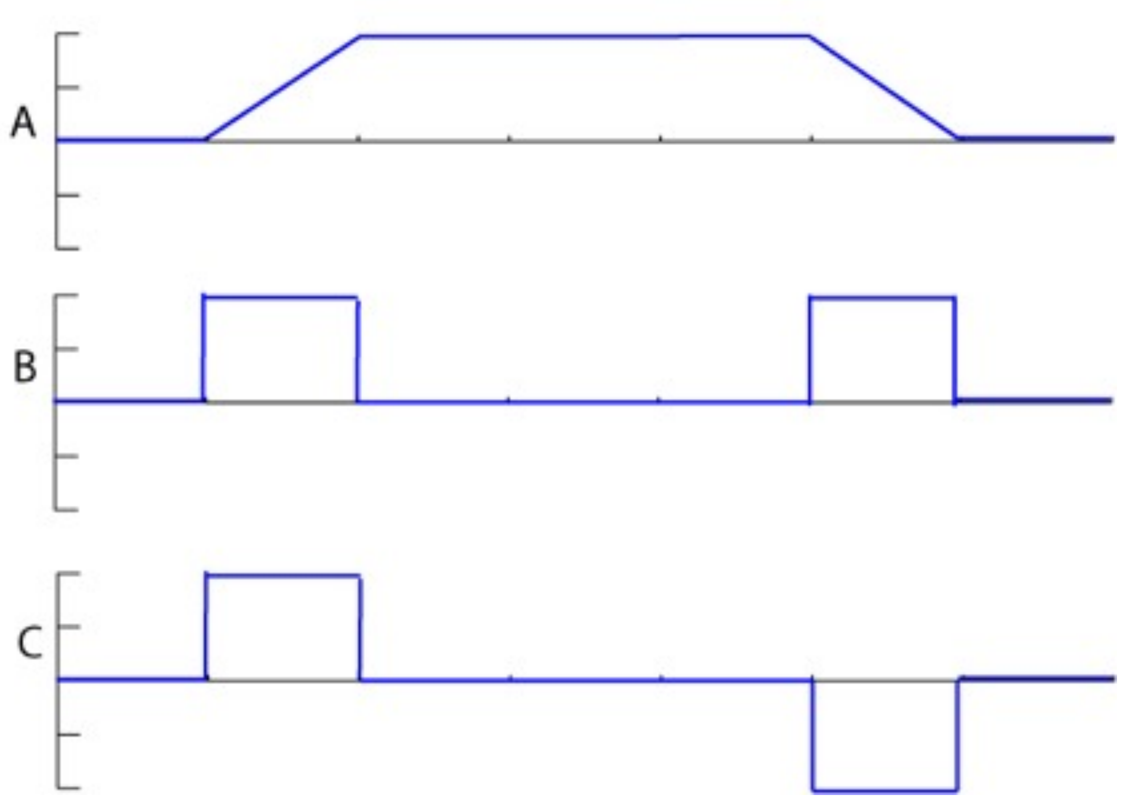
External agent must exert force F to the right to maintain constant v

This energy is dissipated in the resistor!

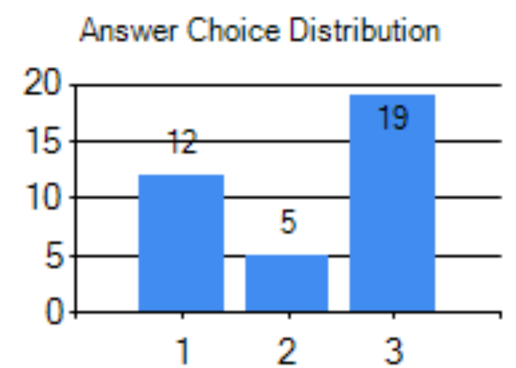


CheckPoint 11

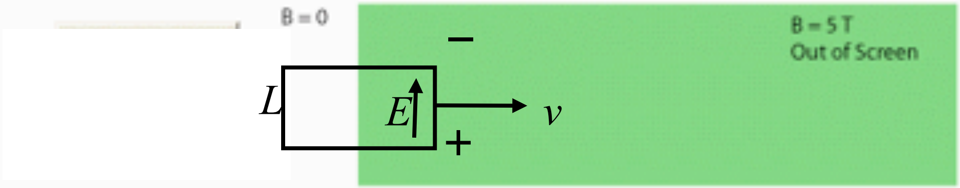
A wire loop travels to the right at a constant velocity. Which plot best represents the induced current in the loop as it travels from left of the region of magnetic field, through the magnetic field, and then entirely out of the field on the right side.

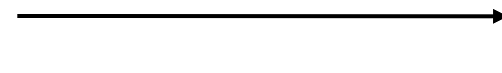


Let's step through this one



11) A wire loop travels to the right at a constant velocity. Which plot best represents the induced current in the loop as it travels from left of the region of magnetic field, through the magnetic field, and then entirely out of the field on the right side.

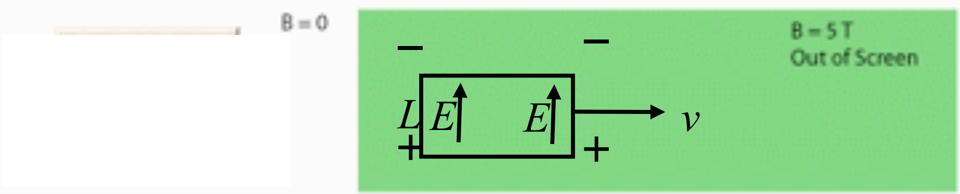


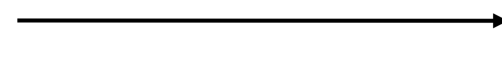


Only leading side has charge separation

$emf = BLv$ (cw current)

11) A wire loop travels to the right at a constant velocity. Which plot best represents the induced current in the loop as it travels from left of the region of magnetic field, through the magnetic field, and then entirely out of the field on the right side.

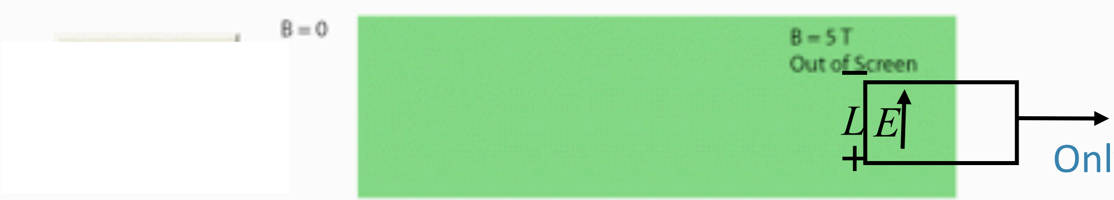


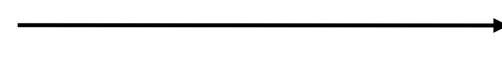


Leading and trailing sides have charge separation

$emf = BLv - BLv = 0$ (no current)

11) A wire loop travels to the right at a constant velocity. Which plot best represents the induced current in the loop as it travels from left of the region of magnetic field, through the magnetic field, and then entirely out of the field on the right side.



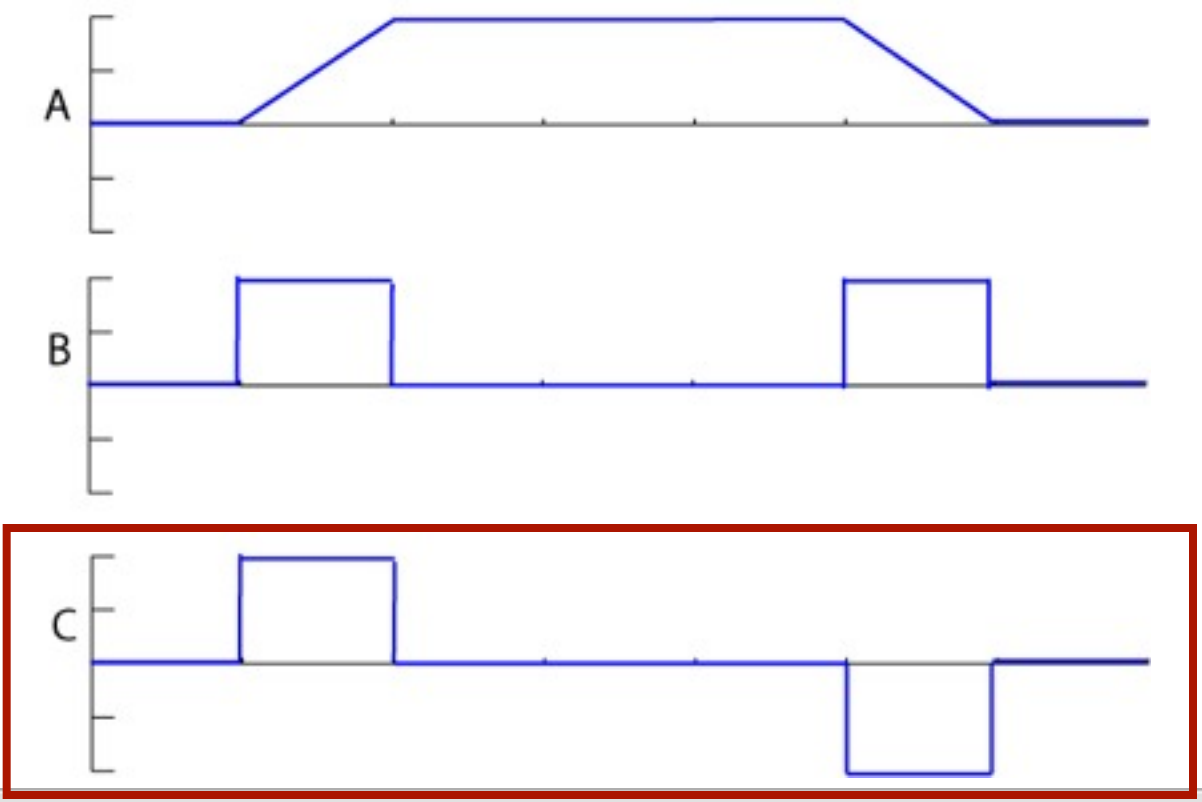


Only trailing side has charge separation

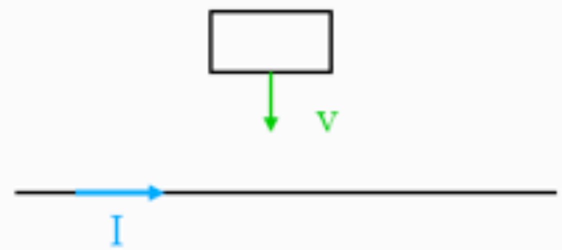
$emf = BLv$ (ccw current)

CheckPoint 11

A wire loop travels to the right at a constant velocity. Which plot best represents the induced current in the loop as it travels from left of the region of magnetic field, through the magnetic field, and then entirely out of the field on the right side.



6) A conducting rectangular loop moves with velocity v towards an infinite straight wire carrying current as shown.

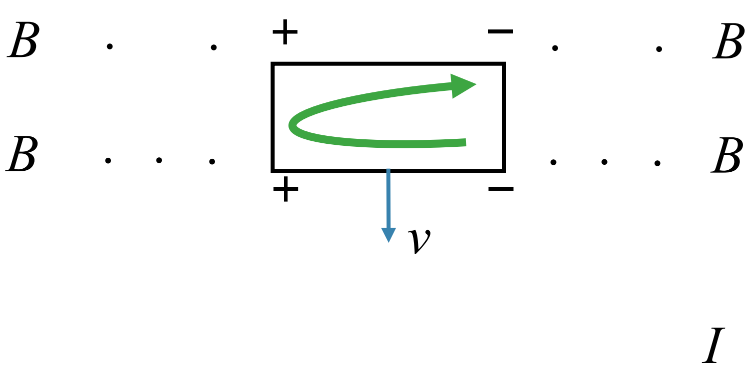


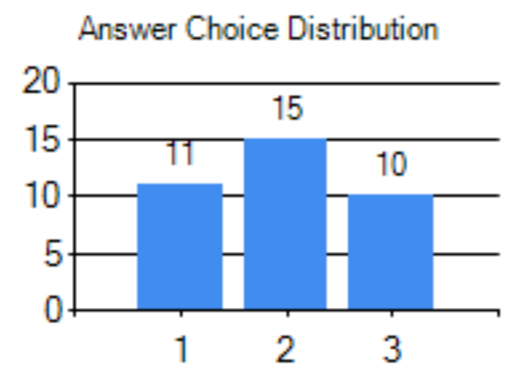
In what direction is the induced current in the loop?

A clockwise

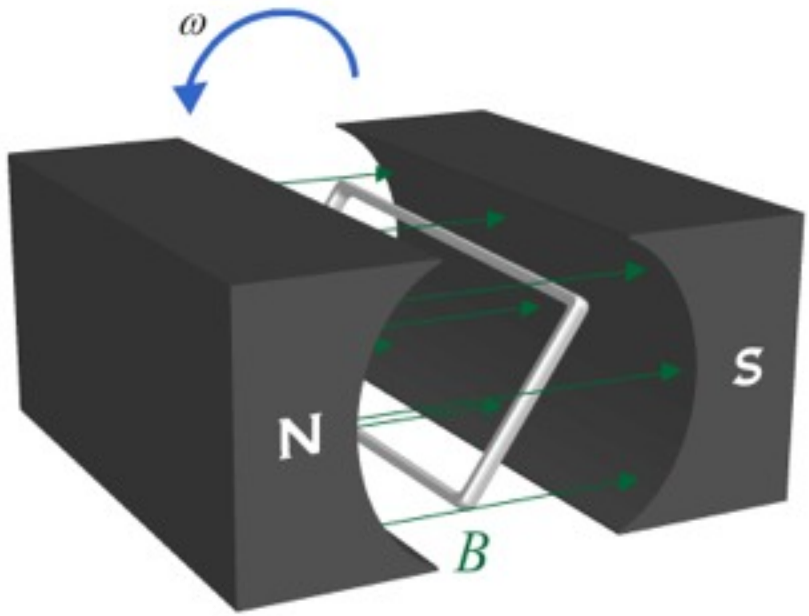
B counter-clockwise

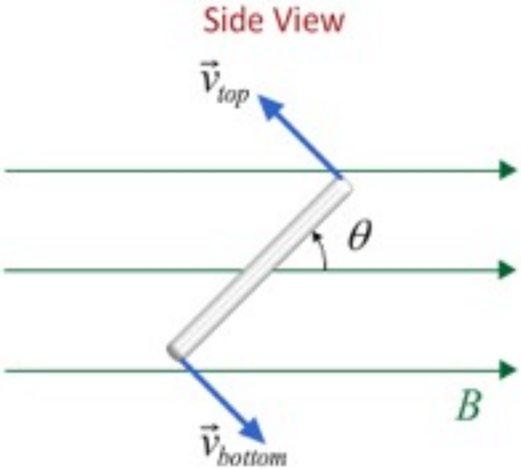
C there is no induced current in the loop





Generator: Changing Orientation





On which legs of the loop is charge separated?

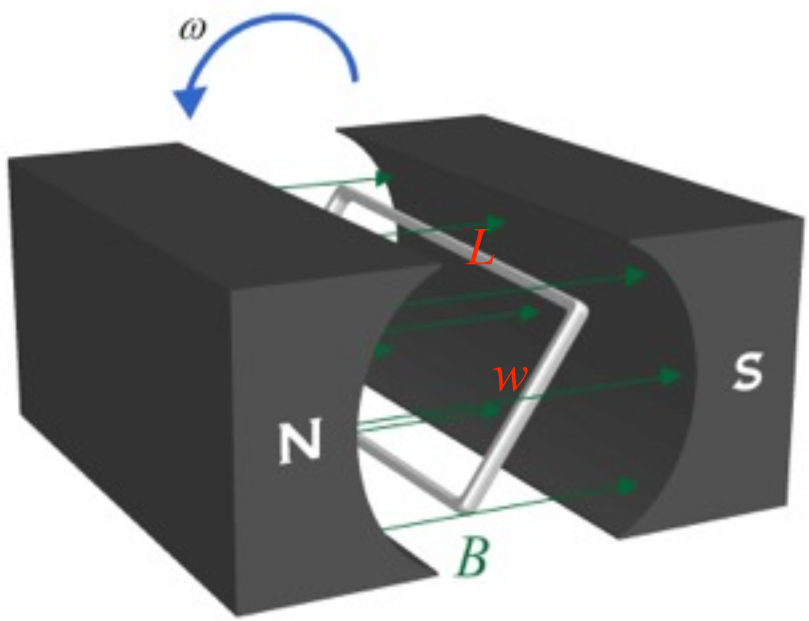
A) Top and Bottom legs only
B) Front and Back legs only
C) All legs
D) None of the legs

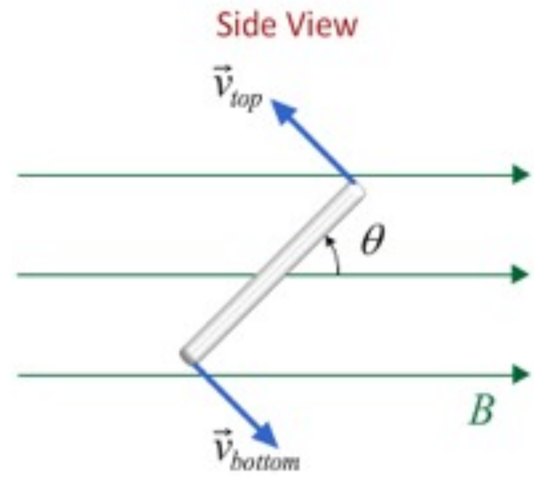
$\vec{v} \times \vec{B}$

Parallel to top and bottom legs

Perpendicular to front and back legs

Generator: Changing Orientation





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)

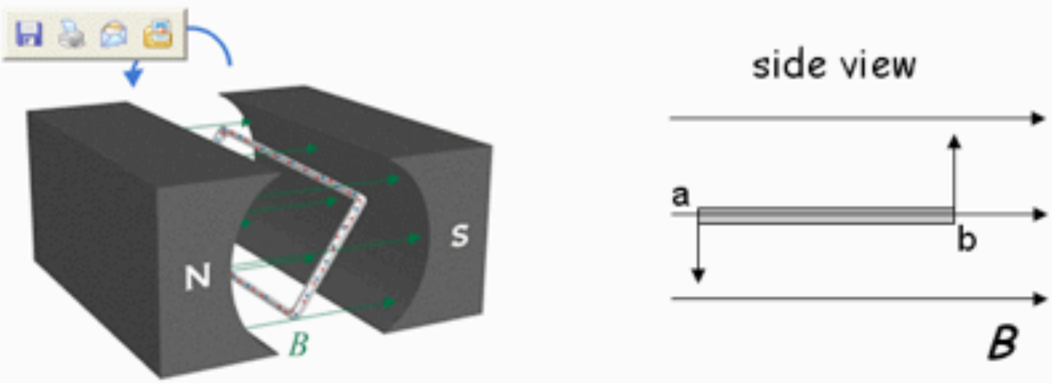
Be careful
w is not ω!

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

Changing Orientation

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

CheckPoint 9

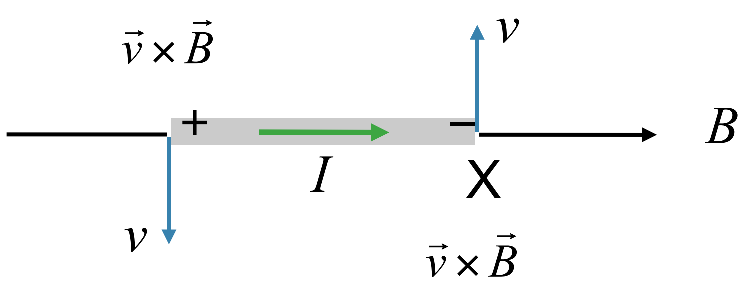


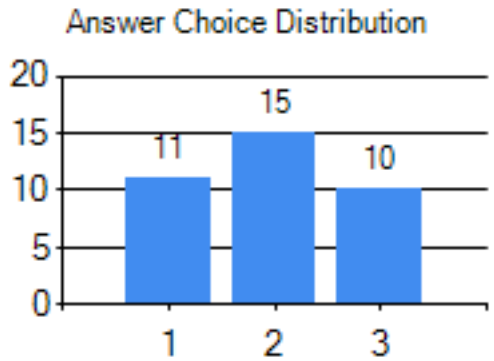
The side view of the loop is shown at a particular time during the rotation. At this time, what is the direction of the induced (positive) current in segment *ab*?

A from *b* to *a*

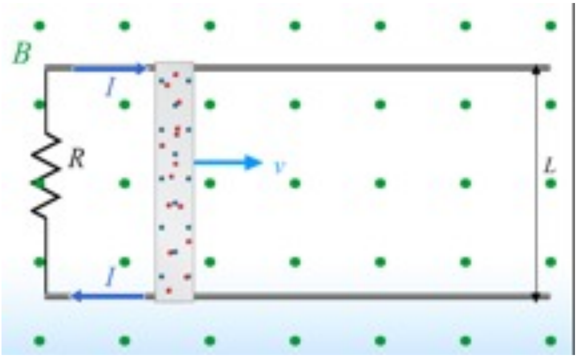
B from *a* to *b*

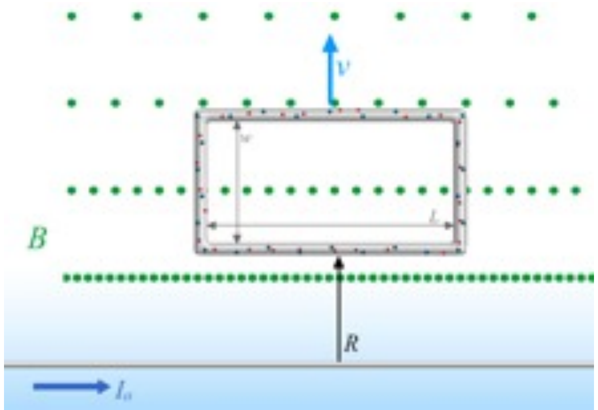
C there is no induced current in the loop at this time

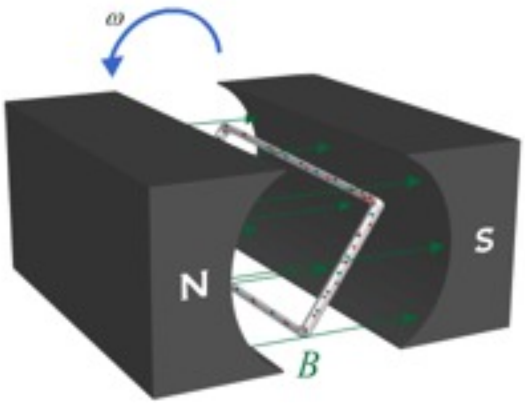




Putting it Together







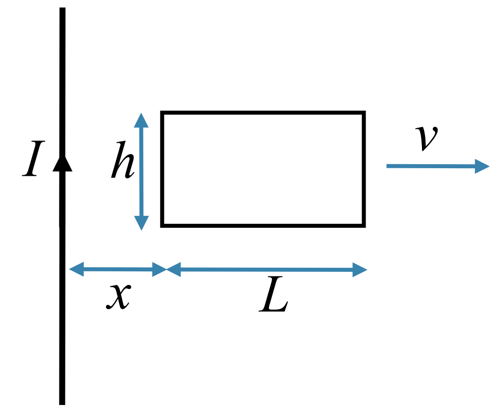
$$\Phi \equiv \vec{B} \cdot \vec{A}$$

Faraday's Law $\quad \varepsilon = -\dfrac{d\Phi}{dt}$

We will study this law in detail next time !

Example Problem

A rectangular loop $(h = 0.3\text{m}\ L = 1.2\text{ m})$ with total resistance of $5\ \Omega$ is moving away from a long straight wire carrying total current 8 amps. What is the induced current in the loop when it is a distance $x = 0.7$ m from the wire?



Conceptual Analysis:

Long straight current creates magnetic field in region of the loop.

Vertical sides develop *emf* due to motion through B field

Net *emf* produces current

Strategic Analysis:

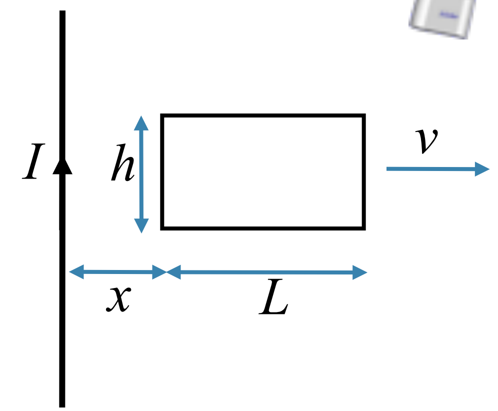
Calculate B field due to wire.

Calculate motional *emf* for each segment

Use net *emf* and Ohm's law to get current

Example Problem

A rectangular loop $(h = 0.3\text{m } L = 1.2\ m)$ with total resistance of $5\ \Omega$ is moving away from a long straight wire carrying total current 8 amps. What is the induced current in the loop when it is a distance $x = 0.7$ m from the wire?



What is the direction of the B field produced by the wire in the region of the loop?

A) Into the page

B) Out of the page

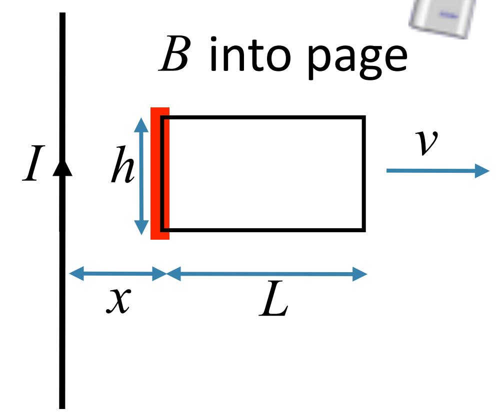
C) Left

D) Right

E) Up

Example Problem

A rectangular loop ($h = 0.3\text{m}$ $L = 1.2\ m$) with total resistance of $5\ \Omega$ is moving away from a long straight wire carrying total current 8 amps. What is the induced current in the loop when it is a distance $x = 0.7$ m from the wire?



What is the *emf* induced on the left segment?

A) Top is positive

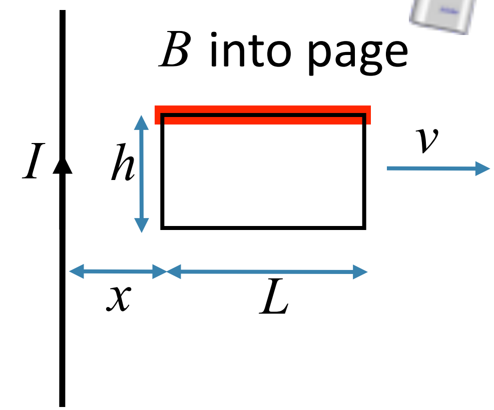
B) Top is negative

C) Zero

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

Example Problem

A rectangular loop $(h = 0.3\text{m}\ L = 1.2\ m)$ with total resistance of $5\ \Omega$ is moving away from a long straight wire carrying total current 8 amps. What is the induced current in the loop when it is a distance $x = 0.7$ m from the wire?



What is the *emf* induced on the top segment?

A) left is positive

B) left is negative

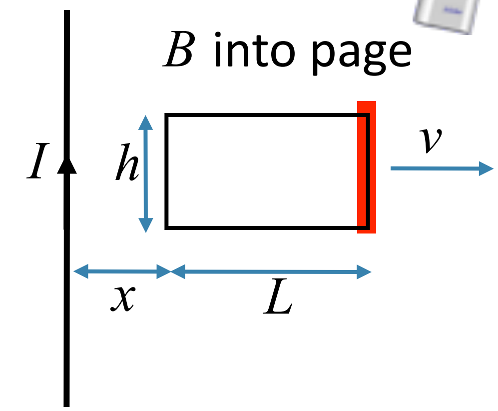
C) Zero

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

perpendicular to wire

Example Problem

A rectangular loop $(h = 0.3\text{m}\ L = 1.2\ m)$ with total resistance of $5\ \Omega$ is moving away from a long straight wire carrying total current 8 amps. What is the induced current in the loop when it is a distance $x = 0.7$ m from the wire?



What is the *emf* induced on the right segment?

A) left is positive

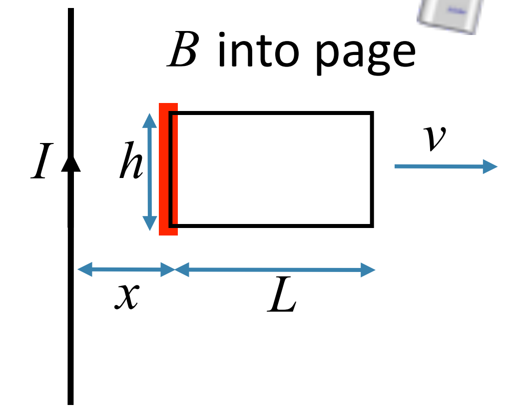
B) left is negative

C) Zero

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

Example Problem

A rectangular loop $(h = 0.3\text{m}\ L = 1.2\ m)$ with total resistance of $5\ \Omega$ is moving away from a long straight wire carrying total current 8 amps. What is the induced current in the loop when it is a distance $x = 0.7$ m from the wire?



Which expression represents the *emf* induced in the left wire?

A) $\varepsilon_{left} = \dfrac{\mu_o I}{2\pi x} Lv$

B) $\varepsilon_{left} = \dfrac{\mu_o I}{2\pi x} hv$

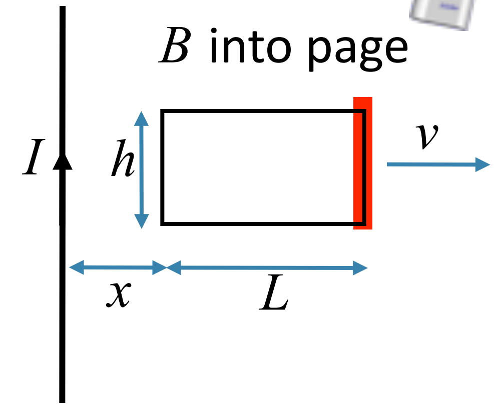
C) $\varepsilon_{left} = \dfrac{\mu_o I}{2\pi (L+x)} Lv$

$$qvB = qE \rightarrow E = vB \rightarrow \varepsilon = Eh = vBh$$

$$B = \frac{\mu_o I}{2\pi x} \rightarrow \varepsilon = \frac{\mu_o I}{2\pi x} hv$$

Example Problem

A rectangular loop ($h = 0.3\text{m}$ $L = 1.2\ m$) with total resistance of $5\ \Omega$ is moving away from a long straight wire carrying total current 8 amps. What is the induced current in the loop when it is a distance $x = 0.7$ m from the wire?



Which expression represents the *emf* induced in the right wire?

A) $\varepsilon_{right} = \dfrac{\mu_o I}{2\pi(L+x)} hv$

B) $\varepsilon_{right} = \dfrac{\mu_o I}{2\pi x} hv$

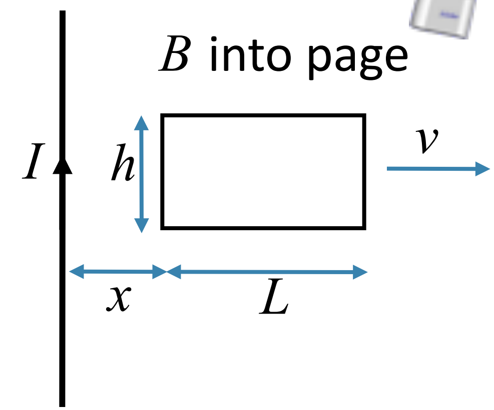
C) $\varepsilon_{right} = \dfrac{\mu_o I}{2\pi(h+x)} Lv$

$$qvB = qE \rightarrow E = vB \rightarrow \varepsilon = Eh = vBh$$

$$B = \frac{\mu_o I}{2\pi(L+x)} \rightarrow \varepsilon = \frac{\mu_o I}{2\pi(L+x)} hv$$

Example Problem

A rectangular loop ($h = 0.3\text{m}$ $L = 1.2\ m$) with total resistance of $5\ \Omega$ is moving away from a long straight wire carrying total current 8 amps. What is the induced current in the loop when it is a distance $x = 0.7\text{ m}$ from the wire?



Which expression represents the total *emf* in the loop?

A) $\varepsilon_{loop} = \dfrac{\mu_o I}{2\pi x} hv + \dfrac{\mu_o I}{2\pi (L+x)} hv$

B) $\varepsilon_{loop} = \dfrac{\mu_o I}{2\pi x} hv - \dfrac{\mu_o I}{2\pi (L+x)} hv$

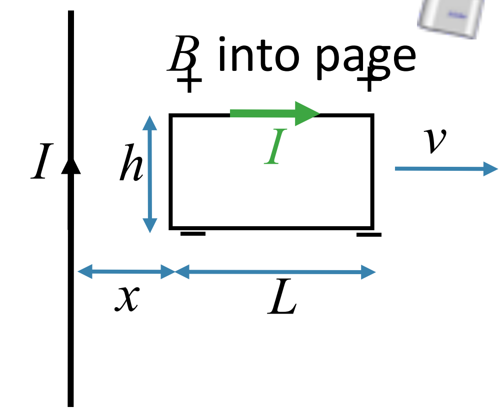
C) $\varepsilon_{loop} = 0$

$$I_{loop} = \frac{\varepsilon_{loop}}{R}$$

$$I_{loop} = \frac{\mu_o I}{2\pi R} hv\left(\frac{1}{x} - \frac{1}{L+x}\right)$$

Follow-Up

A rectangular loop $(h = 0.3\text{m}\ L = 1.2\text{ m})$ with total resistance of 5Ω is moving away from a long straight wire carrying total current 8 amps.



What is the direction of the induced current?

A) Clockwise

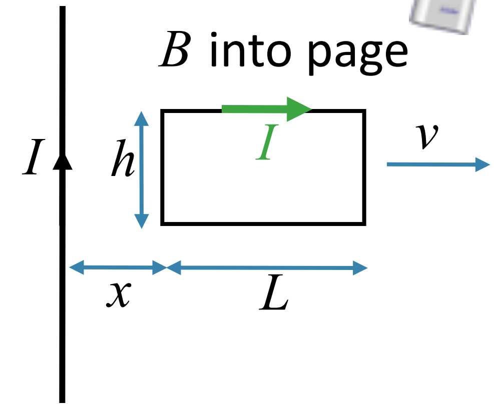
B) Counterclockwise

$\varepsilon_{left} > \varepsilon_{right}$

Clockwise current

Follow-Up

A rectangular loop (h = 0.3m L = 1.2 m) with total resistance of 5Ω is moving away from a long straight wire carrying total current 8 amps.



What is the direction of the force exerted by the magnetic field on the loop?

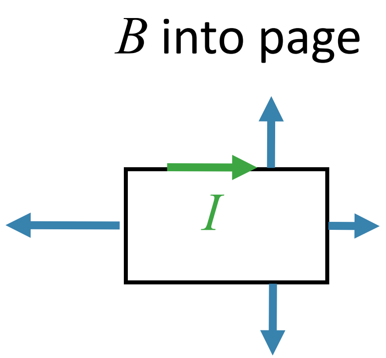
A) UP

B) DOWN

C) LEFT

D) RIGHT

E) $F = 0$



Total force from B
Points to the left !