Lecture 32.

Faraday's law & Lenz's law: Practice

$$\mathcal{E} = \left| \frac{d\Phi_m}{dt} \right|$$

status quo
(opposes change)

Week 10: External current $\Rightarrow$ External magnetic field

$$d\vec{B}(t) = \frac{\mu_0}{4\pi}\frac{I(t)\,d\vec{l} \times \hat{r}}{r^2} \qquad B_{wire}(t) = \frac{\mu_0 I(t)}{2\pi r}, \text{ RHR}$$

Week 11:

Changing external current $\Rightarrow$ Changing external magnetic field

$\Downarrow$ Lenz's law

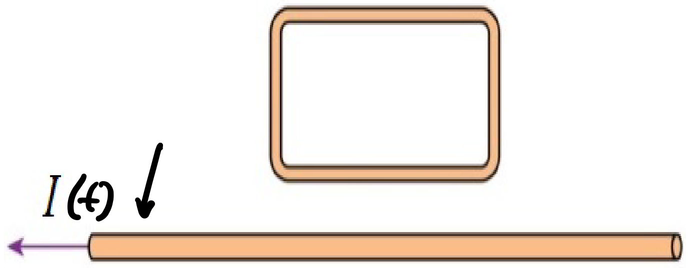
Induced magnetic field $\Leftarrow$ Induced current (need a loop)

Q: 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.



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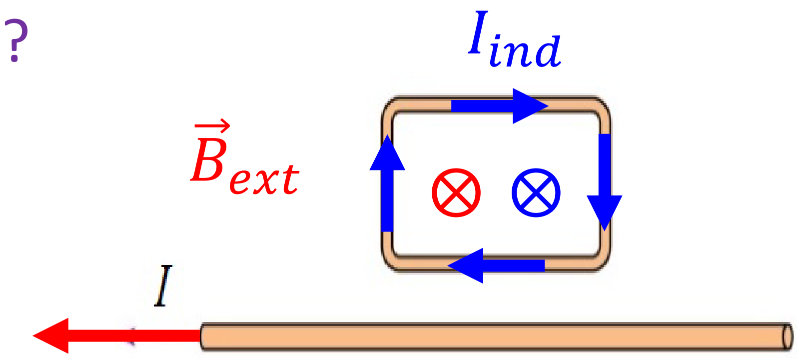


A. There is a clockwise induced current in the loop.

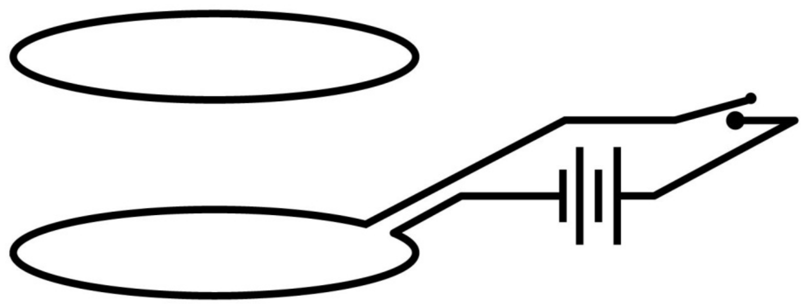
B. There is a counterclockwise induced current in the loop.

C. There is no induced current in the loop.

- External current: I_{ext} decreasing
- External B field at the location of the loop: $\vec{B}_{ext}$ $\otimes$ (RHR): decreasing
- Induced B field through the loop: $\vec{B}_{ind}$ $\otimes$ ("comes to rescue")
- Induced current: CW (RHR)

Q: Immediately after the switch is closed, the lower loop exerts _____ on the upper loop:

A. a torque
B. an upward force
C. a downward force
D. no force or torque
E. both force and torque



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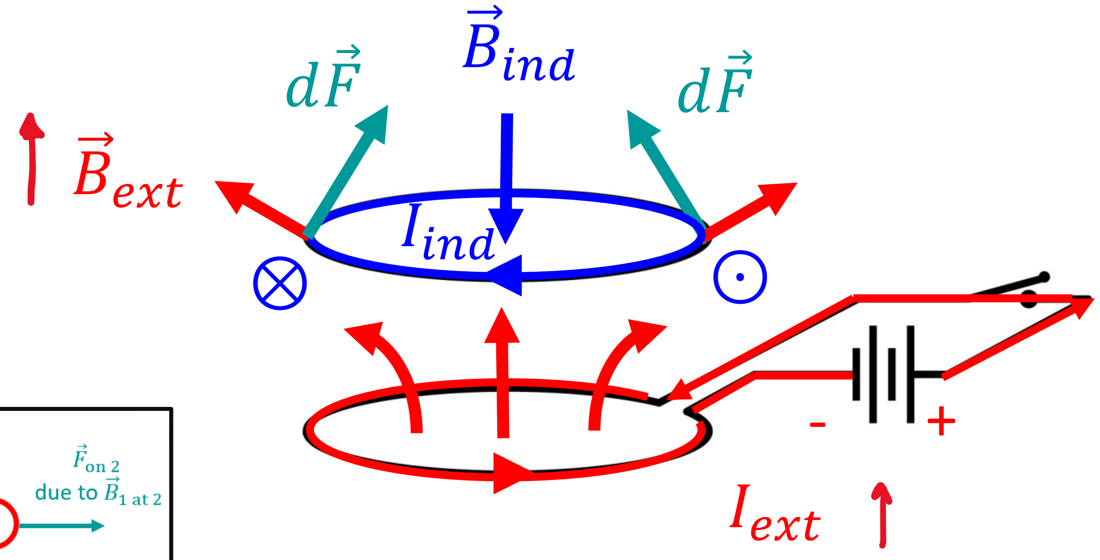
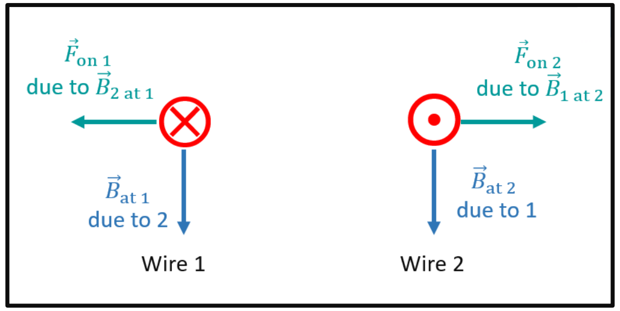




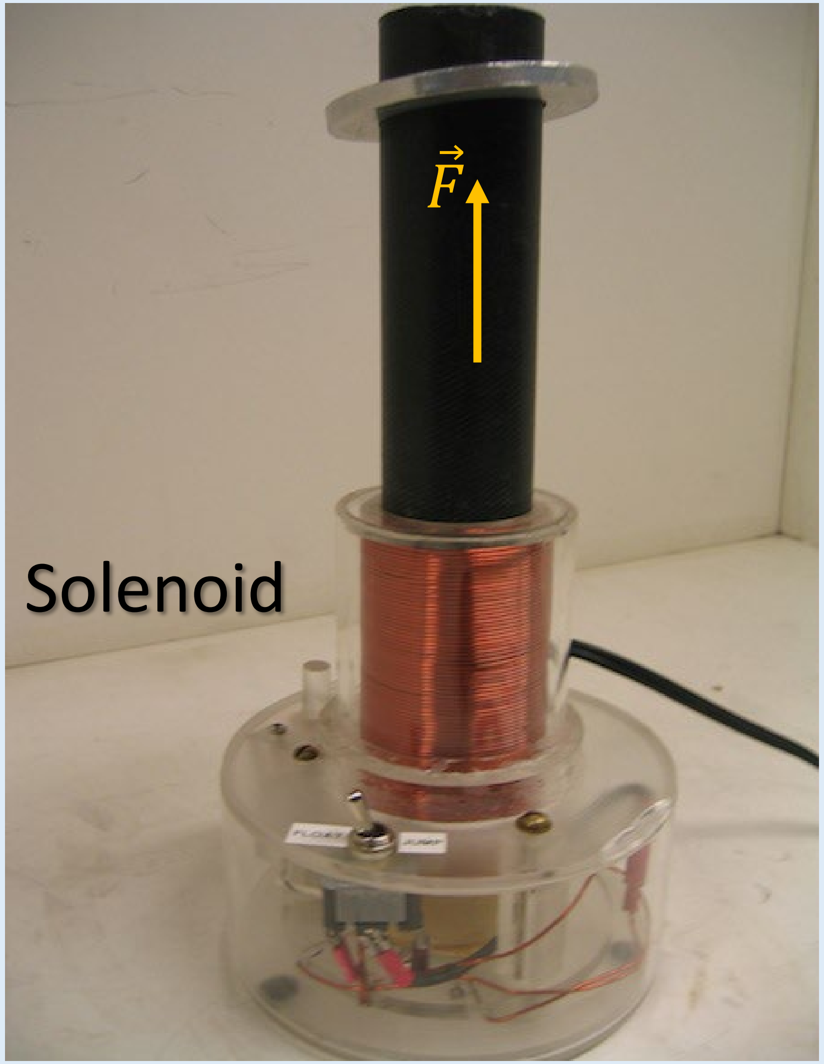
- External current:
- External B field at the location of the loop:
- Induced B field through the upper loop:
- Induced current:
- What do two unlike currents do, repel or attract?

…or just look at the force on the loop:

- Net upward component is apparent
- We also see that there is no torque

DEMO!

Jumping rings



https://www.youtube.com/watch?v=T9PflsLZqY8

Jumping Rings paper

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Jumping ring experiment: effect of temperature, non-magnetic material and applied current on the jump height

J. Taweepong, K. Thamaphat*, S. Limsuwan

Department of Physics, Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand

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Abstract

The jumping ring experiment is an outstanding demonstration of Faraday's laws of electromagnetic induction and also of Lenz's law. A conducting non-magnetic ring is placed over the extended vertical core of a solenoid. When ac power is applied to the solenoid, the ring is thrown off or held in a state of levitation. This phenomenon happens because the induced current in the ring flows in the direction to counter that of the solenoid current. Consequently, two magnetic fields repel each other, giving rise to the jump effect. The induced current is corresponding to the jump height of a ring. In this work, the jump heights of brass, copper and aluminium rings subjected to different parameters such as temperature, vertical length of ring and applied solenoid current were investigated.

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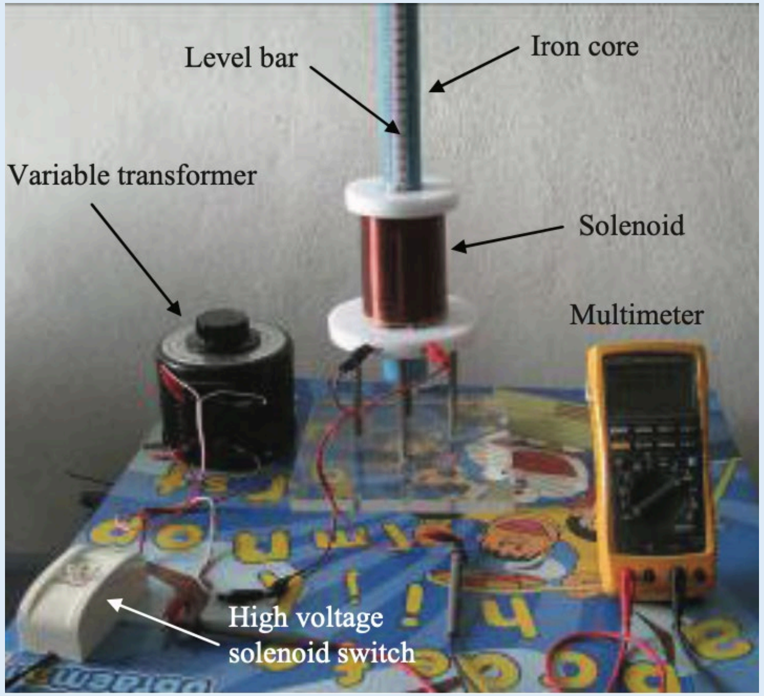
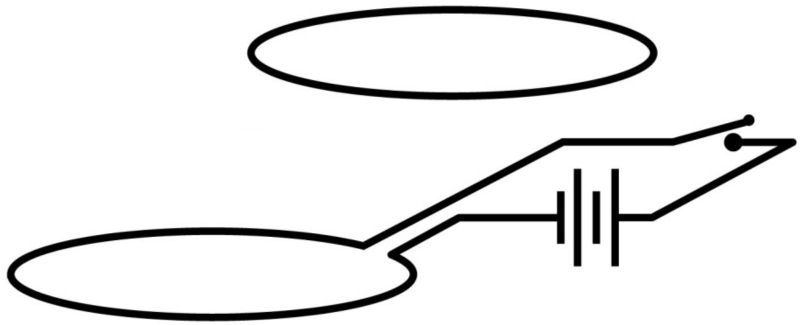


Q: Asymmetric rings

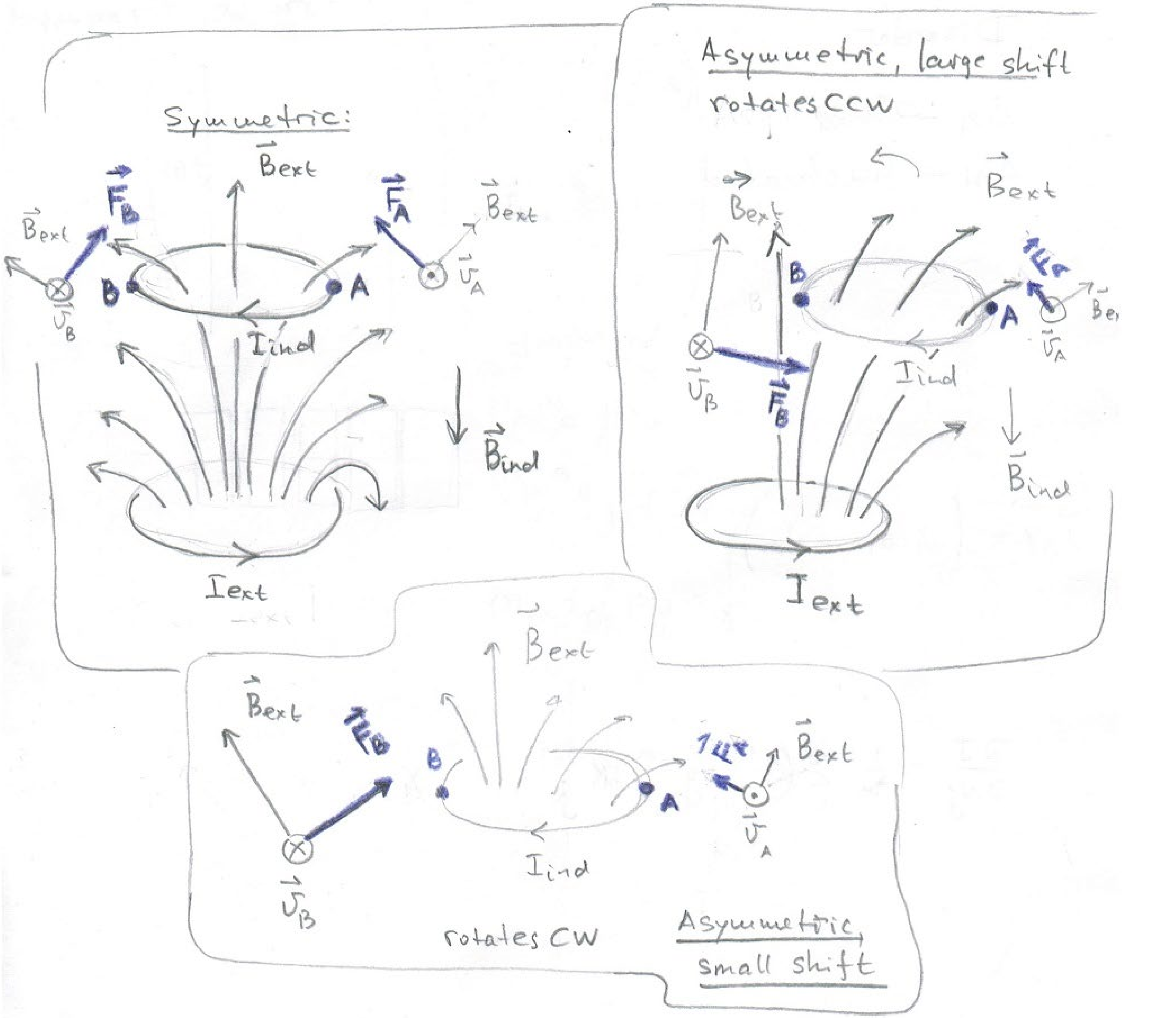
Immediately after the switch is closed, the lower loop exerts _____ on the upper loop.

A. a torque
B. an upward force
C. a downward force
D. no force or torque
E. both force and torque



The answer depends on the magnitude of the shift from the symmetry axis!

Extra, f.y.i.



Calculating the induced emf and induced current:

$B = B(t)$ $A = A(t)$

$\theta = \theta(t)$

(1)
$$\varepsilon = \left|\frac{d\Phi_m}{dt}\right| = \left|\frac{d}{dt}(BA\cos\theta)\right| = \left|\frac{dB}{dt}A\cos\theta + B\frac{dA}{dt}\cos\theta + BA\frac{d\cos\theta}{dt}\right|$$

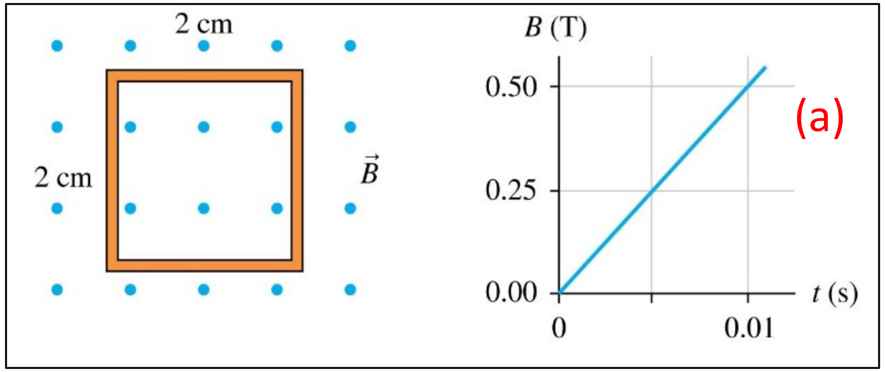
(a) Magnitude of the field changes

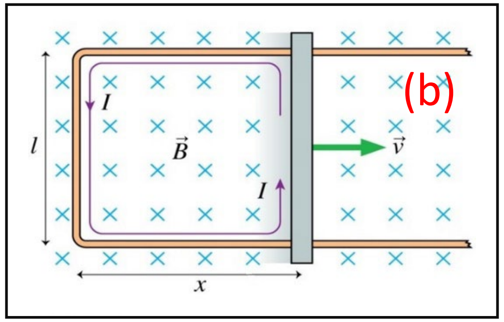
(b) Area of the loop changes

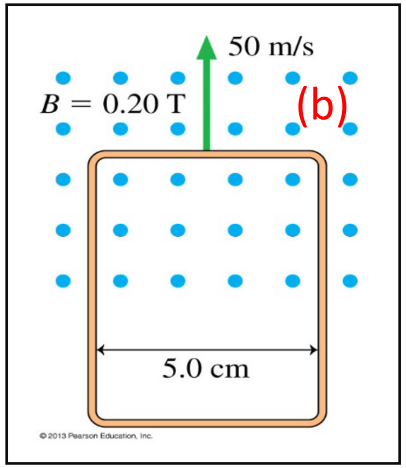
(c) Mutual orientation of the loop and the field changes

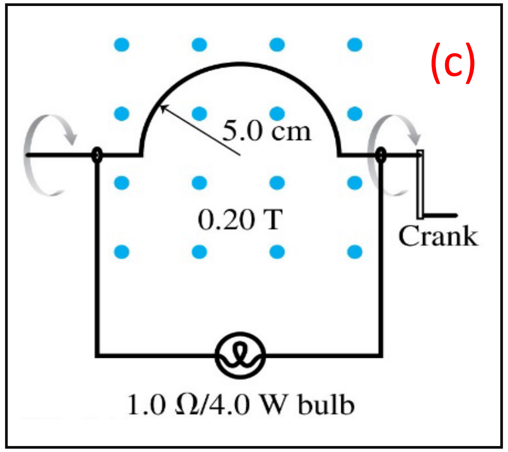
(2) Ohm's law:

$$I_{induced} = \frac{\varepsilon}{R}$$



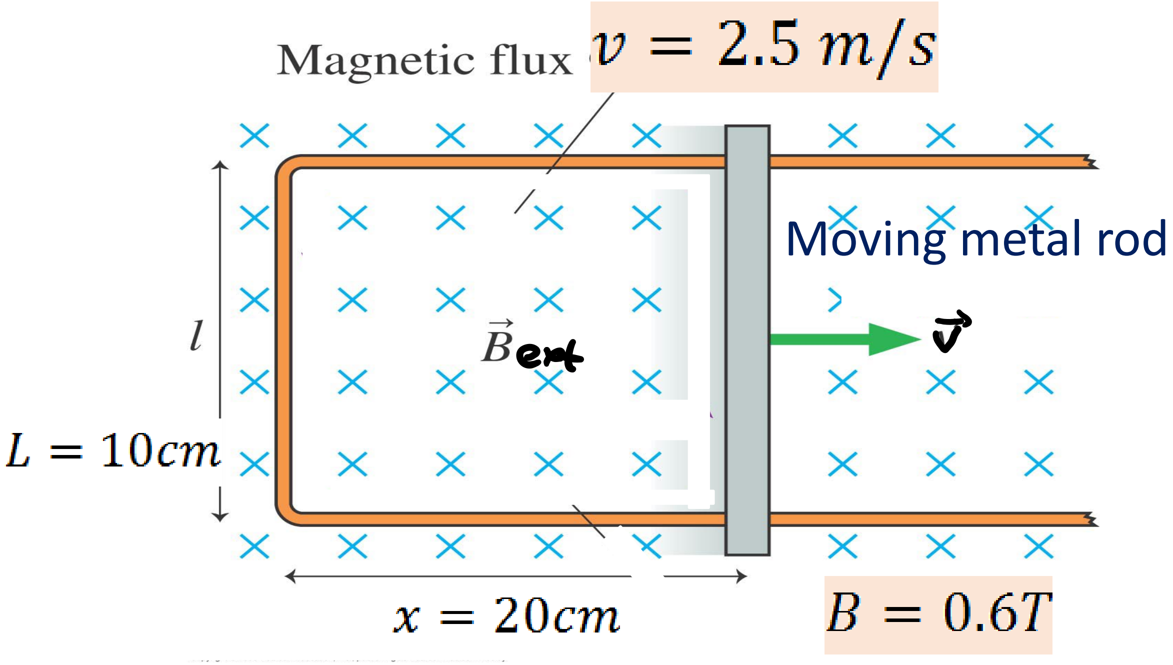






Q: You pull a metal rod to the right at a constant speed of 2.5 m/s. The metal rod, which has an electrical resistance R = 0.3 Ω, is free to move on a U-shaped conductor.

What is the magnitude and direction of the induced electrical current?



A. 0.1 A, CW

B. 0.5 A, CW

C. 0.1 A, CCW

D. 0.5 A, CCW

E. 0 A

Q: You pull a metal rod to the right at a constant speed of 2.5 m/s. The metal rod, which has an electrical resistance R = 0.3 Ω, is free to move on a U-shaped conductor. What is the magnitude and direction of the induced electrical current?

- Direction: A increases $\Rightarrow$ $\Phi_m \otimes$ increases $\Rightarrow$ $B_{ind} \odot \Rightarrow I_{ind}$ CCW

- Magnitude:

$$\varepsilon = \frac{d(AB\cos 0^0)}{dt} = B\frac{dA(t)}{dt} = B\frac{d(xL)}{dt}$$

$$= BL\frac{dx}{dt} = BLv$$

$$\varepsilon = 0.15\ V$$

$$I = \frac{\varepsilon}{R} = 0.5\ A$$

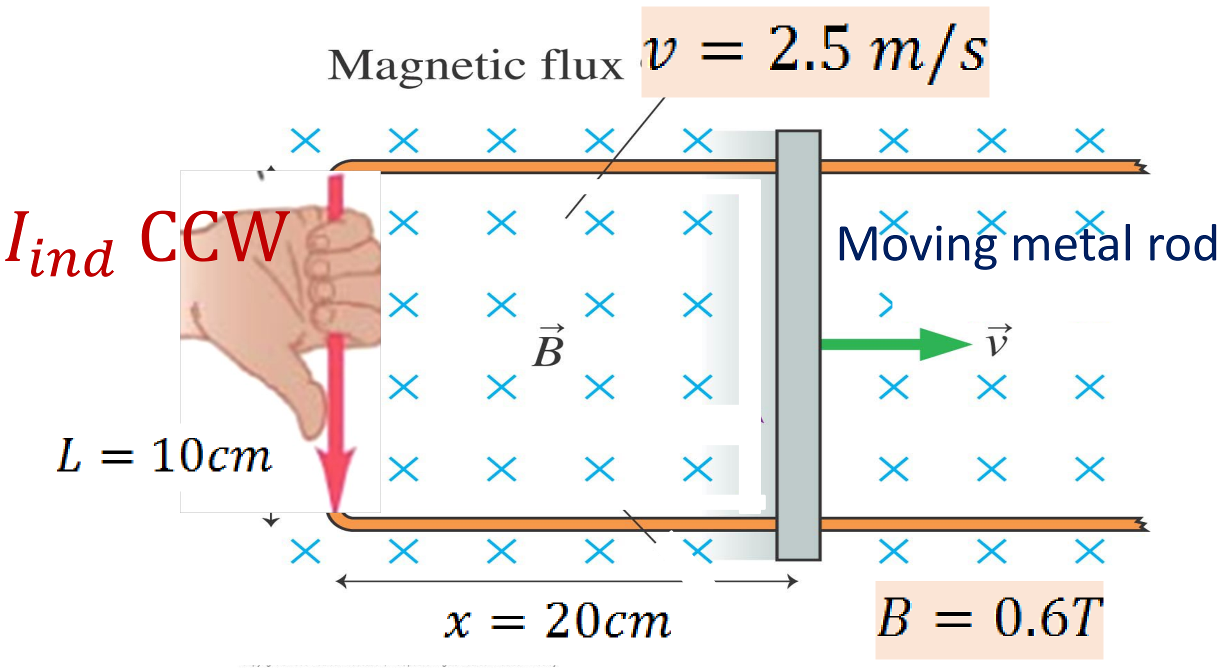
A. 0.1 A, CW

B. 0.5 A, CW

C. 0.1 A, CCW

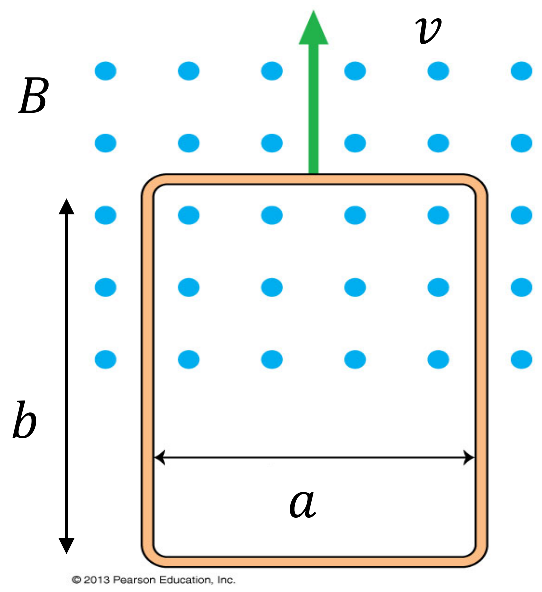
D. 0.5 A, CCW

E. 0 A



Q: The loop in the figure is being pushed into the 0.20 T magnetic field at 50 m/s. The resistance of the loop is 0.10 Ω.

What is the magnitude of the current in the loop?



A. $I = \frac{Bab}{R}$

B. $I = \frac{Bav}{R}$

C. $I = \frac{Bbv}{R}$

D. $I = \frac{Babv}{R}$

E. $I = 0$

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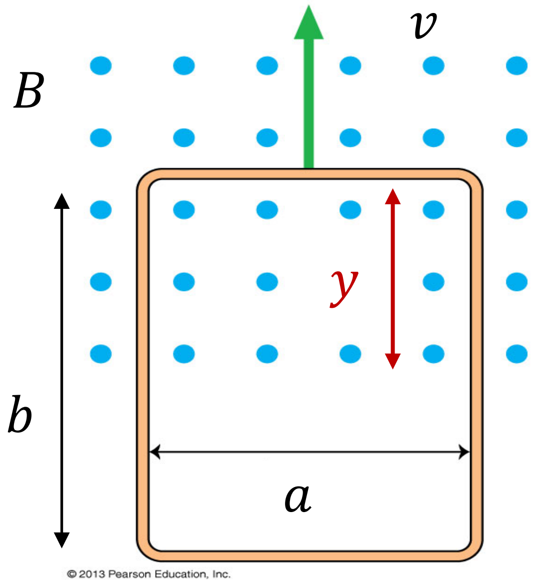

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A_{eff}

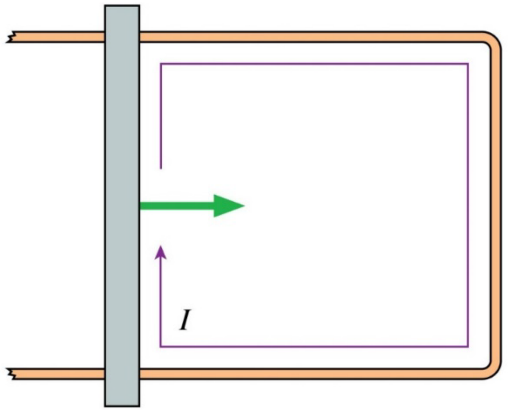
$$\varepsilon = \frac{d(AB\cos 0^0)}{dt}$$

with A being the effective area of the loop exposed to the field!

$$A_{eff}(t) = ya = y(t)a$$

$$\varepsilon = B\frac{dA}{dt} = B\frac{d(ya)}{dt} = Ba\frac{dy}{dt} = Bav \qquad I = \frac{\varepsilon}{R}$$

Q: An induced current flows clockwise as the metal bar is pushed to the right. The external magnetic field points



A. Up.
B. Down.
C. Into the page.
D. Out of the page.
E. There is no external magnetic field.

Q: An induced current flows clockwise as the metal bar is pushed to the right. The external magnetic field points

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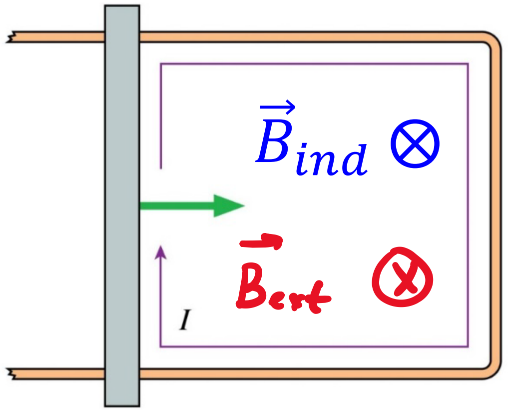
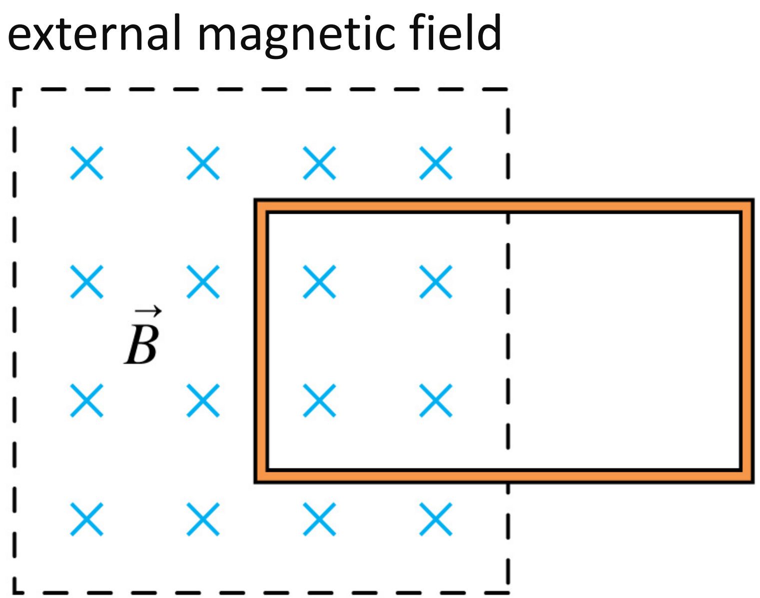


- Induced current? CW => $\vec{B}_{ind}$ ⊗
- External flux does what? A decreasing => Φ_{ext} decreasing
- Induced flux does what? "comes to rescue" => $\Phi_{ind} \uparrow\uparrow \Phi_{ext}$

Since $\vec{B}_{ind}$ is into the page and parallel to $\vec{B}_{ext}$, we conclude that the external magnetic field points into the page.

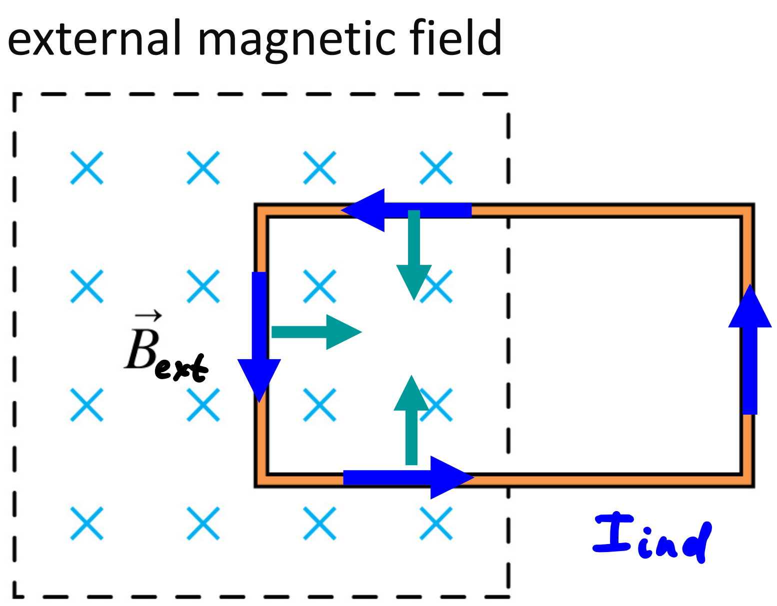
A conducting loop is halfway inside a uniform B field. Suppose B is increased rapidly. What happens to the loop?



A. The loop is pulled to the left, into the magnetic field.
B. The loop is pushed to the right, out of the magnetic field.
C. The loop is pushed upward, toward the top of the page.
D. The loop is pushed downward, toward the bottom of the page.
E. The tension is the wires increases but the loop does not move.

A conducting loop is halfway inside a uniform B field. Suppose B is increased rapidly. What happens to the loop?

- External flux? ⊗, increasing
- Induced flux? ⊙
- Induced current? CCW
- Magnetic forces?
- Net force on the loop? To the right



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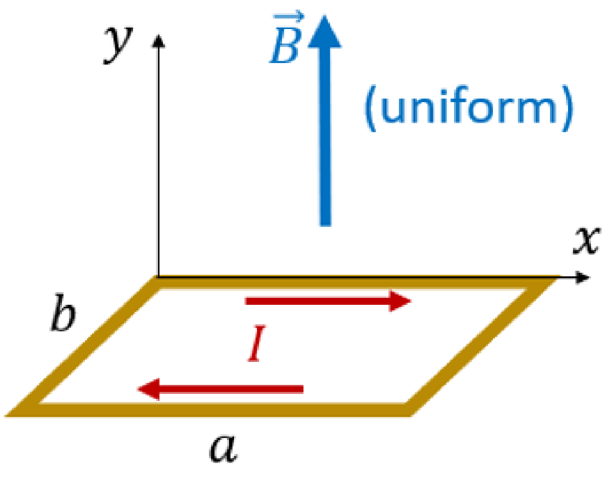
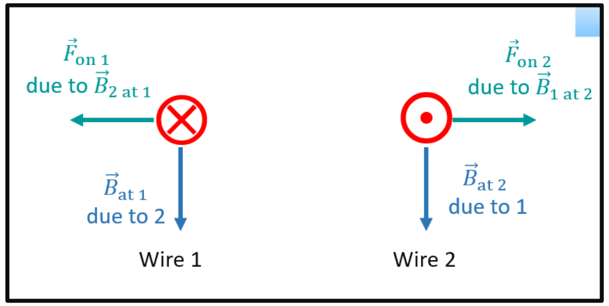
Magnetic forces exerted in uniform and non-uniform magnetic field

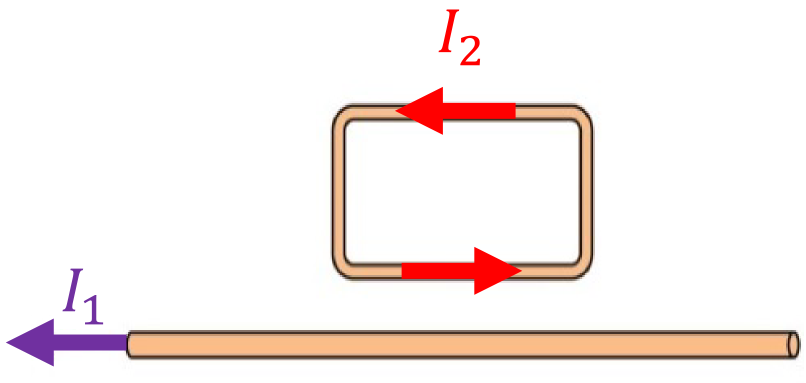


Week 10: find net force

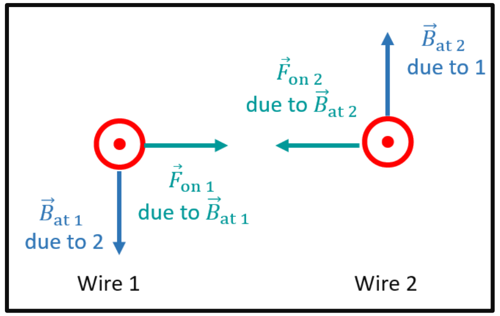
- We have a current I immersed in the external B field => use the equation of the magnetic force on a wire
- Here the magnetic field is uniform, and the forces acting on opposite sides of the loop are equal and opposite: e.g., $F_F = F_B = IaB$ => net force is zero



HW 10: find net force



- Why there is a force?
- How to calculate it?
- Did we do anything similar?



- Is the B-field at the location of the loop uniform or non-uniform??