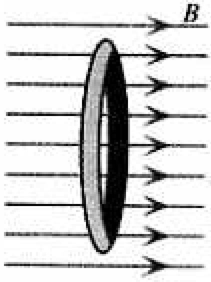
LENZ' LAW

In this tutorial, we will examine Lenz' Law, induction using a variety of situations to help you build a cohesive understanding of forces involved in producing induced currents. Please work through each of the following physical setups.

I. Induced currents

A. A copper wire loop is placed in a uniform magnetic field as shown. Determine whether there would be a current through the wire of the loop in each case below. ***Explain your answer in terms of magnetic forces exerted on the charges in the wire of the loop.***



- The loop is stationary.

No current. ($\vec{v}=0$)

- The loop is moving to the right.

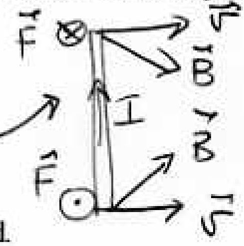
No current ($\vec{v} \parallel \vec{B}$)

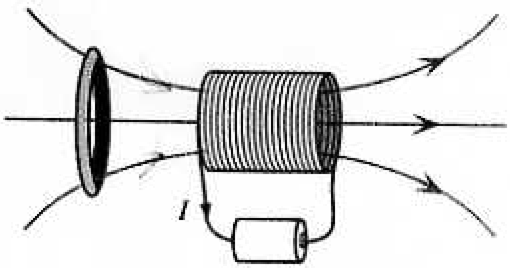
- The loop is moving to the left.

No current ($\vec{v} \parallel \vec{B}$)

B. Suppose that the loop is now placed in the magnetic field of a solenoid as shown.

1. Determine whether there would be a current through the wire of the loop in each case below. If so, give the direction of the current. *Important, try to explain any current in terms of magnetic forces exerted on the charges in the wire of the loop.*





- The loop is stationary.

No current ($\vec{v}=0$)

- The loop is moving toward the solenoid.

ⓐ Current up along front.

- The loop is moving away from the solenoid.

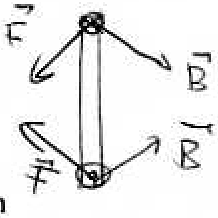
ⓑ Current down along front

2. For each case in which there is an induced current, determine:

- the direction of the *magnetic moment* of the loop. *(Hint:* Find the direction of the magnetic field at the center of the loop due to the induced current in the loop. The magnetic moment is a vector that points in this same direction.)

ⓐ $\xleftarrow{\vec{\mu}}$ ⓑ $\longrightarrow \vec{\mu}$

Case ⓐ



- whether the loop is *attracted toward* or *repelled from* the solenoid

ⓐ repelled (see figure →) ⓑ attracted

- whether the force exerted on the loop tends to *increase* or to *decrease* the relative motion of the loop and solenoid.

In both cases, tends to decrease the relative motion

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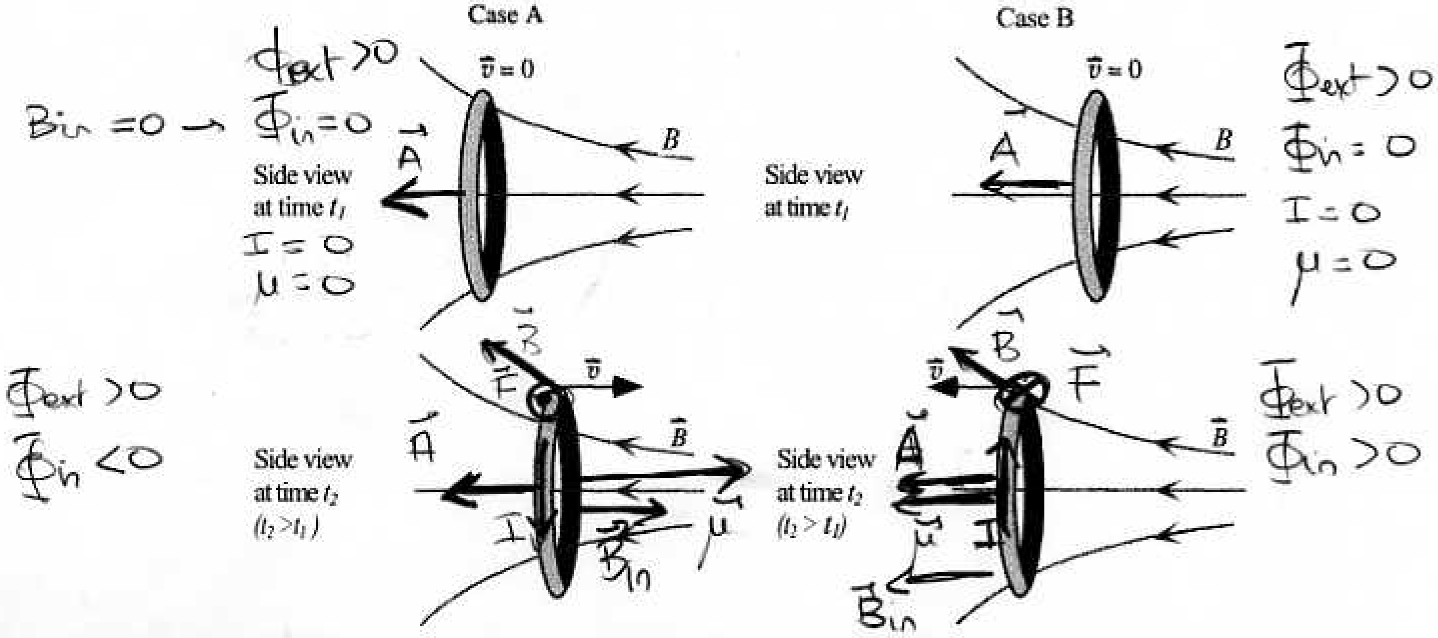
C. In each of the diagrams below, the position of a loop is shown at two times, t_1 and t_2 $(t_1 < t_2)$. Note the B-field setup is different than the previous diagrams. For each case, the loop starts from rest in each case and is displaced to the right in Case A and to the left in Case B. On the diagrams indicate:

- the direction of the induced current through the wire of the loop,
- the magnetic moment of the loop,
- an area vector for each loop,
- the sign of the flux due to the external magnetic field (at both times t_1 and t_2), and
- the sign of the induced flux (at both times t_1 and t_2).



D. State whether you agree or disagree with each of the students below. If you agree, explain why. If you disagree, cite a specific case for which the student's statement does not give the correct answer. *(Hint:* Consider cases A and B above.)

Student 1: *"The magnetic field due to the loop always opposes the external magnetic field."*

Wrong : see case B at $t = t_2$

Student 2: *"The flux due to the loop always has the opposite sign as the flux, due to the external magnetic field."*

Wrong : see case B at $t = t_2$

Student 3: *"The flux due to the loop always opposes the change In the flux due to the external magnetic field."*

Correct.

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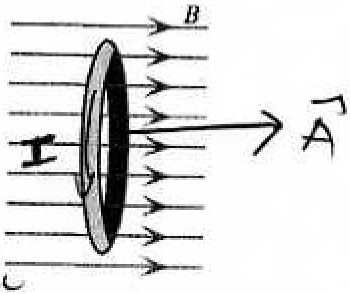
Before continuing, check your answer with a tutorial instructor.

II. Lenz' law

A. The diagram at right shows a copper wire loop in a uniform magnetic field. The magnitude of the field is *decreasing* with time.



1. Would you predict that there would be a current through the loop?: Yes

   - ***Important, try to explain any current in terms of magnetic forces exerted on the charges in the wire of the loop. If this is not possible then state why.*** Explain your reasoning.

     Cannot be explained with magnetic forces alone, since $\vec{F}=0$

   - If you were to use the reasoning of the student in part D of section I with whom you agreed? Explain.

     Φ_{ext} is changing so Φ_{in} will oppose that $\Rightarrow \vec{B}_{in} \neq 0 \Rightarrow I \neq 0$

2. It is *observed* that there is an induced current through the wire loop in this case. Use the appropriate reasoning above to find the direction of the current through the wire of the loop.

   $\Phi_{ext} > 0$ (see $\vec{A}$ in figure) is decreasing $\Rightarrow \Phi_{in} > 0$ $\Rightarrow \vec{B}$ points right $\Rightarrow I$ is down in front

To understand the interaction between the wire loops and solenoids in section I, we can use the idea that a force is exerted on a charged particle moving in a magnetic field. In each of those cases there was an induced current when there was relative motion between the solenoid and the wire loop. *The physical mechanism is that the current is caused by the magnetic force acting on the moving charges.*

In situations such as the one above, however, there is an induced current in the wire loop even though there is no relative motion between the wire loop and the solenoid. *The physical mechanism is that the current is caused by an induced E-field due to a changing B-field. The E-field exerts a force on the charges, causing the current.*

There is also a general rule called *Lenz' law* that we can use in *all* cases to predict the direction of the induced current.

B. Discuss the statement of Lenz' law in your textbook with your partners. Make sure you understand how it is related to the statement by the student with whom you agreed in part D of section I.

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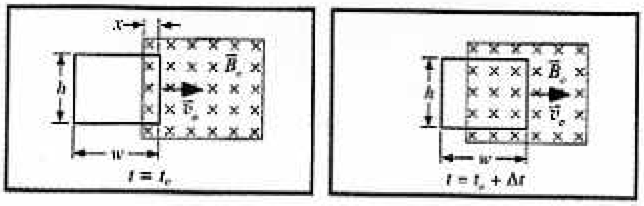
C. *A wire loop moves from a region with no magnetic field into a region with a uniform magnetic field pointing into the page.*



The loop is shown at two instants in time, $t = t_0$ and $t = t_o + \Delta t$.

let's take $\vec{A}$ ⊗

1. Is the magnetic flux through the loop due to the external field positive, negative, or zero:

   a) at $t = t_0$ Positive

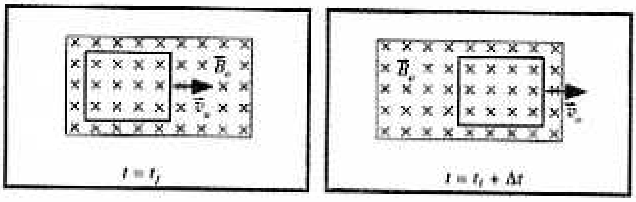
   b. at $t = t_0 + \Delta t$? Positive

2. Is the change in flux due to the external field in the interval Δt [✓ positive], negative, or zero?

3. Use Lenz' law to determine the sign of the flux due to the induced current in the loop. Negative

4. What is the direction of the current in the loop during this time interval? CCW

D. *At two later instants* at $t = t_1$ *and* at $t = t_1 + \Delta t$, *the loop is located as shown.*



1. Use Lenz' law to determine the sign of the flux due to the current induced in the loop. Explain.

$$\Phi_{t_1} = \Phi_{t_1+\Delta t} \Rightarrow \Delta\Phi_{ext} = 0 \Rightarrow \Phi_{in} = 0$$

(no current)

2. *Consider the following student dialogue:*

Student 1: "The sign of the flux from the induced current is the same as it was in part C. So the current here will also be counter-clockwise."

Student 2: "I agree. If I think about the force on a positive charge on the leading edge of the loop, It points towards the top of the page. That's consistent with a counter-clockwise current."

Do you agree with either student? Explain.

① Wrong: What matters is the sign of the change in flux.

③ Wrong: The force on a positive charge on the other edge points down, so the two forces oppose one another (+ charge accumulates on top edge of loop, but no current)

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