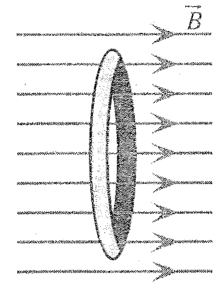
I. Induced currents

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.

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



- The loop is stationary.

  No, $v=0$

- The loop is moving to the right.

  No, $\vec{v} \parallel \vec{B}$ $\theta = 0$

- The loop is moving to the left.

  No, $\vec{v} \parallel \vec{B}$ $\theta = 180°$

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. Explain in terms of magnetic forces exerted on the charges in the wire of the loop.

   - The loop is stationary.

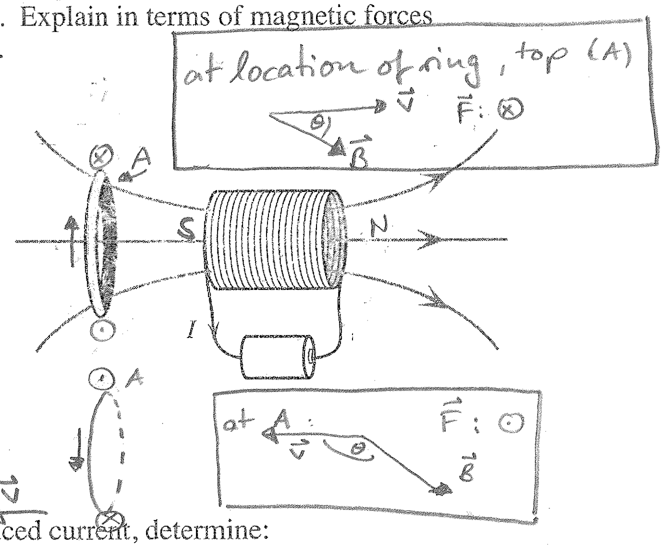
     No, $v=0$

   - The loop is moving toward the solenoid.

     $I \neq 0$, current is up in front

   - The loop is moving away from the solenoid.

     $I \neq 0$, current is down in front.



2. For each case above 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.)

     $\vec{\mu} = AI$, from S → N inside loop

     $\vec{v}$ → N I S so ← $\vec{\mu}$

     $\vec{v}$ ← S I N so → $\vec{\mu}$

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

     $\vec{v}$ → repelled

     ← attracted

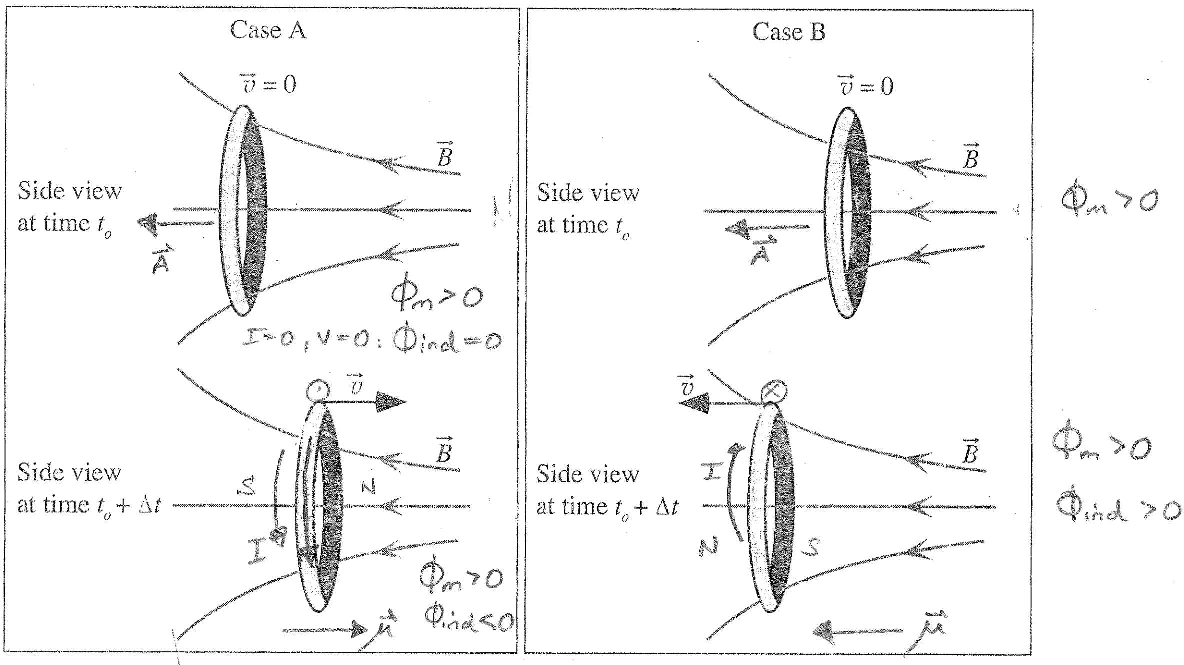
   - whether the force exerted on the loop tends to *increase* or to *decrease* the relative motion of the loop and solenoid.

     in both cases the force tends to decrease the motion, i.e. opposes the change.

Key

C. In each of the diagrams below, the position of a loop is shown at two times, t_o and $t_o + \Delta t$. 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 instants), and
- the sign of the induced flux (at both instants).



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."*

Disagree: it does not in case B : $\vec{B}$: ← ; $\vec{B}_{ind}$: ← } "same" direction

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

Disagree: again, in case B: $\Phi_m > 0$, $\Phi_{ind} > 0$ } same sign

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

Agree: Case A: $\Delta\Phi_m > 0$ b/c $\vec{B}$ is stronger at $t_o + \Delta t$, $\Phi_{ind} < 0$

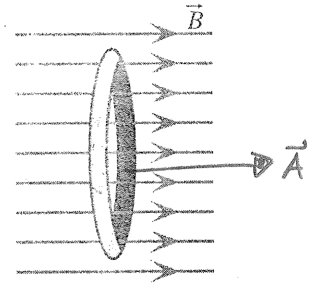
Case B: $\Delta\Phi_m < 0$ b/c $\vec{B}$ is weaker at $t_o + \Delta t$, $\Phi_{ind} > 0$

⇨ Before continuing, check your answers to parts C and D with a tutorial instructor.

Key

II. Lenz' law

A. The diagram at right shows a stationary 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:

   - if you were to use the idea that there is a magnetic force exerted on a charge moving in a magnetic field? Explain your reasoning.

     No. Charge isn't moving!

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

     Yes: Let $\vec{A}$ to the right. Then $\Phi_m > 0$ and decreases as $\vec{B}$ decreases, so $\Delta\Phi_m < 0$. Therefore, $\Phi_{ind} > 0$, requiring $\vec{\mu} \rightarrow$, or current down in front of loop.

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.

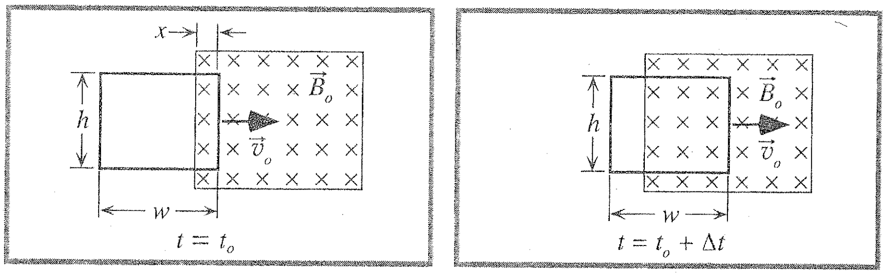
   I down in front, since $\Phi_{ind} > 0$ has opposite sign of $\Delta\Phi_m$

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. In other 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. There is 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.

Key

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, $t = t_o$ and $t = t_o + \Delta t$.

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

   a. at $t = t_o$?

   b. at $t = t_o + \Delta t$?

   Case 1: Let $\vec{A} \otimes$ — $\Phi_m > 0$; $\Phi_m > 0$ and larger.

   Case 2: Let $\vec{A} \odot$ — $\Phi_m < 0$; $\Phi_m < 0$ and more negative

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

   Case 1: $\vec{A} \otimes$ $\Delta\Phi_m > 0$ — Case 2: $\vec{A} \odot$ $\Delta\Phi_m < 0$

3. Use Lenz' law to determine whether the flux due to the induced current in the loop is *positive, negative,* or *zero.*

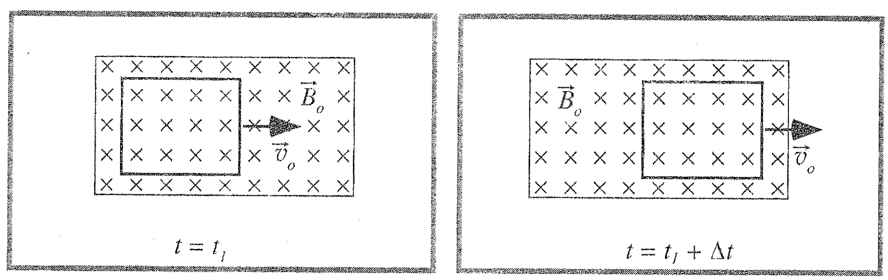
   Case 1 $\vec{A} \otimes$: $\Phi_{ind} < 0$ — Case 2: $\vec{A} \odot$: $\Phi_{ind} > 0$

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

   Case 1 $\vec{A} \otimes$: $\vec{B}_{ind} \odot$ so I is ccw — Case 2 : $\vec{A} \odot$ so $\vec{B}_{ind} \odot$ so I is ccw

   ↑ direction of I and $\vec{B}_{ind}$ does NOT depend on your choice of $\vec{A}$

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



1. Use Lenz' law to determine whether the flux due to the current induced in the loop is *positive, negative,* or *zero.* Explain.

   $\Delta\Phi_m = 0$ so $\Phi_{ind} = 0$ and $\vec{B}_{ind} = 0$

2. Describe the current in the loop during this time interval.

   Since $\vec{B}_{ind} = 0$ the current induced is 0.

3. Consider the following student dialogue:

   Student 1: *"The sign of the flux is the same as it was in part C. So the current here will also be counter-clockwise."* Disagree: what matters is the CHANGE in flux

   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."* Disagree: the force on a positive charge on the trailing edge is ALSO up. Potential at top ends is the same, i.e. no current will flow.

   Do you agree with either student? Explain.