ICE#9 – Ampère’s and Faraday’s Laws

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These are the problems that you and a team of other 2-3 students will be asked to solve during the recitation session next week. We may add numerical values and more questions to these problems for the actual class team work. Print this form BEFORE coming to class. Get familiar with the problems proposed, think about a solving approach, and identify the methods and equations needed. Choose five problems from this form and sketch a symbolical solution for them. Attach pages if you need more space for writing. DO NOT actually solve the problems but only indicate in words or in a numbered list the order in which the equations will be put at work. This is the Approach. For each of the five problems you will choose, write a very short verbal Explanation. Bring your annotated pre-ICE to the recitation session and hand it to the recitation instructor for grading.

1. Hollow cylinder generates magnetic field:
   A conducting cylinder is oriented parallel to the z axis and carries a uniform current \( I \) in the negative z direction (into the page). This cylinder is hollow, however, with a cylindrical bore centered on the point \( Q \) shown in the figure. The radius of this bore is \( R_1 \), while the outer radius of the cylinder is \( R_2 \).

   a) Calculate the magnetic field at the point \( P \) on the y axis.

   b) Calculate the magnetic field at the point \( Q \) at the center of the hollow bore.

2. Infinite current sheets: Long, straight conductors with square cross section, each carrying current \( I \), are laid side-by-side to form an infinite current sheet with current directed out of the plane of the page (see the figure). A second infinite current sheet is a distance \( d \) below the first and is parallel to it. The second sheet carries current into the plane of the page. Each sheet has \( n \) conductors per unit length.

   a) Evaluate the magnetic field generated by these two current carrying sheets at the points \( P \), \( R \), and \( S \).

3. Loop Sliding in a Uniform Magnetic Field:
   A uniform magnetic field \( \vec{B} \) is set in the region \( 0 \leq x \leq L \), \( 0 \leq z \leq H \); the B-field extends indefinitely in the y-direction. There is no magnetic field outside that region. A rectangular loop of sides \( D \) and \( L \), made of a very thin wire with the total resistance \( R \), moves in the horizontal \( xz \)-plane at the constant velocity \( v \) in the +x direction, as shown in the figure. The rectangular loop starts moving at \( t=0 \) from \( x=-L \) until the leading edge \( ab \) reaches the final position \( x=3L \).

   a) When the leading edge \( ab \) moves uniformly from \( x=-L \) to \( x=3L \), derive symbolic expressions for the magnitude and polarity of the emf induced in each of the sides of the rectangular loop. How many cases do you need to consider? Clearly state the rule(s) employed for deciding the polarity of the emf in each side of the loop.
b) For each of these cases in part a), find the total induced emf and the induced current in this rectangular loop (both the magnitude and the direction) as functions of time. Clearly show on the diagram(s) the direction of the induced current. Use the labels “clockwise” or “counterclockwise” where appropriate.

4. Inflating Loop in a Uniform Magnetic Field
A circular metallic loop has the resistance \( R \) and lies in the horizontal plane on a flat table. A uniform magnetic field of amplitude \( B_0 \), pointing up, crosses that table. The loop begins to expand at the moment \( t=0 \) so its radius changes according to the equation below; the factor \( \beta \) is a known constant.

\[
r(t) = r_o (1 + \beta t)
\]

a) Evaluate the current in the inflating loop as a function of time.

5. Loop Rotating in a Uniform Magnetic Field:
Consider a rectangular loop of wire with width \( w \), height \( h \), and total resistance \( R \). The region of space occupied by the wire loop contains a uniform magnetic field \( B \) pointing out of the page. A motor attached to the loop keeps it rotating about the vertical axis with constant angular velocity \( \omega \). At time \( t = 0 \), the loop is parallel to the paper (as shown in the figure).

(a) Evaluate the magnetic flux \( \Phi_B \) through the loop as a function of time.
(b) Evaluate the induced EMF \( E \) through the loop as a function of time. Find the maximum value (amplitude) of the EMF, and write it on your plot.
(c) Evaluate the induced current \( I \) through the loop as a function of time. Find the maximum value (amplitude) of the current, and write it on your plot.

6. Search Coils and Credit Cards:
One practical way to measure magnetic field strength uses a small, closely wound coil called a search coil. The search coil has \( N \) turns, each of area \( A \), and a total resistance \( R \). It is initially held with its transverse plane perpendicular to a magnetic field of magnitude \( B \) pointing up, like in the figure. Then the search coil is quickly pulled completely out of the magnetic field in a time \( \Delta t \).

a) Derive an equation giving the total charge flowing through the search coil. Include only the known constants \( N \), \( A \), \( R \), \( B \), and \( \Delta t \).

b) In a credit card reader, shown in the second figure, the magnetic strip on the back of the credit card is rapidly swiped past a coil within the reader. Explain, using the same ideas that underlie the operation of a search coil, how the reader can decode the information stored in the pattern magnetization on the strip.
1. Hollow cylinder generates magnetic field

**Approach:**

*List the steps taken by you for finding the solution. Here, you are answering the questions WHAT? and HOW?*

**Explanation:**

*Explain why you chose this approach. Here, you are answering the questions WHY? and WHEN?*

2. Infinite current sheets

**Approach:**

*List the steps taken by you for finding the solution. Here, you are answering the questions WHAT? and HOW?*

**Explanation:**

*Explain why you chose this approach. Here, you are answering the questions WHY? and WHEN?*
3. Loop Sliding in a Uniform Magnetic Field

Approach:
List the steps taken by you for finding the solution. Here, you are answering the questions WHAT? and HOW?

Explanation:
Explain why you chose this approach. Here, you are answering the questions WHY? and WHEN?

4. Inflating Loop in a Uniform Magnetic Field

Approach:
List the steps taken by you for finding the solution. Here, you are answering the questions WHAT? and HOW?

Explanation:
Explain why you chose this approach. Here, you are answering the questions WHY? and WHEN?
5. Loop Rotating in a Uniform Magnetic Field

Approach:

List the steps taken by you for finding the solution. Here, you are answering the questions WHAT? and HOW?

Explanation:

Explain why you chose this approach. Here, you are answering the questions WHY? and WHEN?

6. Search Coils and Credit Cards

Approach:

List the steps taken by you for finding the solution. Here, you are answering the questions WHAT? and HOW?

Explanation:

Explain why you chose this approach. Here, you are answering the questions WHY? and WHEN?