The Laws of Faraday and Lenz
Spring 2017

Introduction

This experiment is designed to help you envision the phenomenon of electromagnetic induction. Faraday’s Law states that an emf (\(E\)) is induced when the magnetic flux (\(\Phi\)) changes through a coil of wire: 
\[E = \frac{1}{\mu_0 c} \frac{d\Phi}{dt}\]  
Lenz’s Law states that the direction of the induced current in a wire coil always opposes the change in magnetic flux through the coil that induced the current. Your lab report will consist of a series of sketches showing the arrangement of components, direction of induced current flow, and direction of magnetic flux, for several configurations of coils and magnets.

Experiment

1. Connect a 100 k\(\Omega\) resistor in series with the galvanometer to allow a small current to pass through the meter, as shown in the circuit diagram (\textit{You’ll Destroy the Galvanometer If You Omit or Incorrectly Connect The Resistor!}). The galvanometer in your circuit diagram should show the direction the needle points and the direction of current through the meter. Reverse the direction of the current through the meter to confirm your observation.

2. Using a permanent magnet to induce current:
   a. Use a known compass to determine the polarity of your bar magnet (recall that \(\vec{B}\) leaves the north pole, and enters the south, as shown at right). Check with your instructor that you have the correct polarity.
   b. Connect the larger (detector) coil to the galvanometer using two short wires; the orientation of the coil does not matter.
   c. Each person will complete a series of diagrams on a worksheet (handed out in lab) where you will draw the wire wrapped around the detector coil (it is very important that you draw your coils carefully), the direction the galvanometer needle points, the induced current, and the induced \(B_{in}\) through the coil due to (i) inserting and (ii) withdrawing a north and a south pole, from each end of the coil (a total of eight figures). Your observations for each figure should agree with your expectations using the right-hand rule! If your observations and the right-hand rule don’t agree, you may have misidentified the polarity of your magnet.
   d. After completing the eight figures, write a summary of your observations where you generalize what happens during the two situations observed: (1) when a pole is inserted into the coil, and (2) when a pole is removed from the coil. You only need to discuss the induced flux through the detector coil and the direction of \(\vec{B}\) in each situation: if the flux through the coil is increasing, are the directions of \(\vec{B}\) (from the bar magnet) and \(B_{in}\) (in the detector coil) the same or opposite? How about when the flux through the coil is decreasing?
   e. Describe what happens when the magnet is moved toward and away from the coil quickly, and what happens when it is moved slowly. Explain your observations in terms of Faraday’s Law:
\[E = -\left(\frac{1}{c} \frac{d\Phi}{dt}\right)\]
3. Using an electromagnet to induce a current:
   a. Connect the small (source) coil and a knife switch to the DC power source (connect the wire from the + terminal of the power supply to the terminal of the coil marked with a dot). When the switch is later closed, current will flow through the source coil as shown at right.
   b. Use the right-hand rule to predict which electromagnetic pole will be at each end of the small coil when a current passes through it. Connect the small coil to the power source, and verify with a known compass that your prediction is correct.
   c. Now insert the small source coil completely inside the left side of the large detector coil, as shown at right (the sketch shows the source coil partially inserted into the detector coil). Again on the worksheet you will complete four sketches of the detector coil to show the observed direction of the induced current (and $\bar{B}_{out}$) in the detector coil i) the instant the switch is closed (current turned on); ii) the switch stays closed (steady current); iii) the instant the switch is opened (current turned off); and iv) the switch stays open (current off). You only need to experiment with one side of the detector coil.

   Note: Don’t leave the knife switch closed for too long. The source coil will get very hot!

4. Now, answer this question: Why are your observations the same when the current through the source coil is steady and when it is completely off? If you can answer this, then you truly understand the theory!

5. Think again about the pattern of flux change and direction of $\bar{B}$ and $\bar{B}_{out}$ for these two coils. Describe the similarities (or differences) with what you found for the detector coil and bar magnet.

6. Replace the galvanometer with an older galvanometer and quickly close & open the switch. Place a bolt inside the inner coil and try it again. What happens to the galvanometer’s response?

7. Did I Understand This? At the front of the lab, you will find a coil and several magnets with tape covering the ends. Your instructor will ask you to determine the polarity for one of these unknown magnets without the aid of a compass. You will have to explain your reasoning as you are performing the experiment. In order for you to determine the polarity of the unknown magnet, you will follow the same series of steps as you did when inducing a current with a permanent magnet:

   - Move the magnet in or out from the left or right side (only one motion is required)
   - Note the direction the galvanometer needle points
   - Determine the direction of the induced current from the galvanometer reading
   - Follow the direction of the induced current around the coil
   - Use the right-hand rule to determine the polarity of the coil’s induced magnetic field
   - Finally, infer the polarity of the bar magnet from the direction of the induced magnetic field, and the motion of the permanent magnet

   ✓ You must successfully complete this “Exit Quiz” to finish this experiment! Note that the coil used for the exit quiz will not necessarily be connected in the same manner as the one you used, so you will not pass by simply memorizing your pictures!

Discussion:

- State Faraday’s and Lenz’s laws, and explain how your observations are consistent with these laws.
- Be sure to attach the worksheet to your lab report!