The Laws of Faraday and Lenz
Spring 2024

Introduction

This experiment is designed to help you envision the phenomenon of electromagnetic induction. *Faraday's Law* states that an *Emf* ($\mathcal{E}$) is induced when the magnetic flux (Φ_B) changes through a coil of wire. *Lenz's Law* states that the direction of the induced current in a wire coil always *resists the change in magnetic flux* through the coil that induced the current. Your lab journal 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

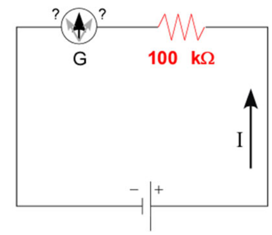

Figure 1: Galvanometer calibration.

1. Connect a 100 kΩ resistor in series with the galvanometer to allow a small current to pass through the meter, as shown in **Figure 1** (***YOU WILL DESTROY THE GALVANOMETER IF YOU OMIT OR INCORRECTLY CONNECT THE RESISTOR!***)

   Draw the galvanometer in your circuit diagram with the direction the needle points (left or right) 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:*

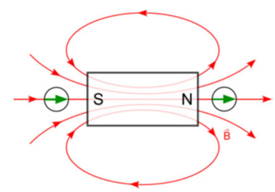

Figure 2: Direction of **B** in a bar magnet.

   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* (**Figure 2**). Check with your instructor that you have the correct polarity.

   b. Connect the larger coil to the galvanometer using two short wires; the orientation of the coil does not matter (**Figure 3**).

   c. *Try it!* Insert one side of the magnet into the right side of the coil, up to the coil's midpoint, and then withdraw the magnet. You should see that the needle moves to one side of the galvanometer while inserting the magnet and the other side when the magnet is removed. Using the other side of the magnet should move the needle in the opposite direction as you first observed.

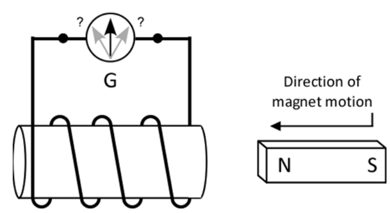

Figure 3: Inducing current with a bar magnet.

   d. Each person will complete a series of diagrams on a worksheet (handed out in lab) where you will draw the direction the galvanometer needle points, the *induced* current, and the *induced* $\vec{B}_{ind}$ 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 poles of your magnet.

   e. 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 $\vec{B}_{ind}$ (in the detector coil) the same or opposite? How about when the flux through the coil is *decreasing*?

   f. 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:

$$\mathcal{E} = -\left(\frac{1}{c}\frac{d\Phi_B}{dt}\right)$$

3. *Using an electromagnet to induce a current:*

   a. Connect the small coil and a knife switch to the *DC* power supply as shown in **Figure 4**, with the wire from the + terminal of the power supply connected to the terminal of the coil marked with a dot. When the switch is closed later, current will flow through the small coil as shown and you have created an *electromagnet*.

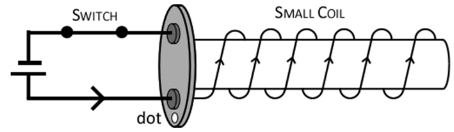

Figure 4: A small coil is connected to a power supply to create an electromagnet.

   b. Use the right-hand rule to predict the direction of $\vec{B}$ when a current passes through the coil. Close the switch and verify with a known compass that your prediction is correct.

   c. Now insert the small coil *completely inside* the left side of the large detector coil, as shown in **Figure 5** (the small coil is *partially* inserted into the detector coil in **Figure 5**). Again on the worksheet you will complete *four* sketches of the detector coil to show the observed direction of the induced current (and $\vec{B}_{ind}$) 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.

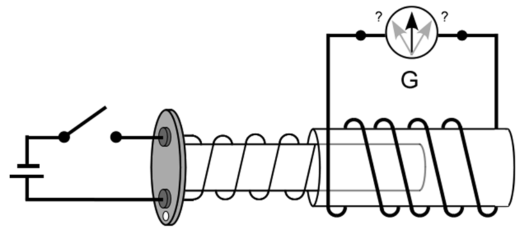

Figure 5: Small coil inserted into large coil.
Fully insert the small coil into the large coil.

NOTE: DON'T LEAVE THE KNIFE SWITCH CLOSED FOR TOO LONG. THE SMALL COIL WILL GET VERY HOT!

4. Now, answer this question: Why are your observations *the same* when the current through the small 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 $\vec{B}$ and $\vec{B}_{ind}$ for these two coils. Describe the similarities and differences with what you found for the detector coil and bar magnet.

6. *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. You will follow the same series of steps as you did when inducing a current with a permanent magnet to determine the polarity of the unknown 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 *in words* and explain how your observations are consistent with these laws. *Be sure to attach the worksheet to your lab journal!*