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Experiment 15
Faraday's Law and Lenz's Law

Objective

In this experiment, we are going to study various aspects of Faraday's and Len's Laws.

Equipment

- Harrison 6200B DC Power Supply.
- Galvanometer.
- Tap switch.
- Two coils of wire.
- Permanent magnets.
- Rheostat.
- Iron cores.

Theory

Faraday's law, in simplest terms, says that a changing magnetic flux induces an emf. Mathematically,

$$\mathcal{E} = -\frac{\Delta\phi}{\Delta t}.$$

The magnetic flux ϕ is the product of the cross-sectional area of the loop A and the perpendicular component of the magnetic field $B_\perp$. The flux may change because the magnetic field itself is changing (for example, a permanent magnet in motion toward or away from a loop will lead to a change in the magnetic flux through the loop, because the magnetic field depends on the separation). If the area of the loop changes, the magnetic flux can change. If the loop is rotated, the perpendicular component of the magnetic field can change. Faraday's Law tells us that if the magnetic flux through a closed, conducting loop changes for whatever reason, an emf will be induced around the loop, leading to a current flow.

Lenz's Law is even simpler! Lenz's law tells us the direction of the induced current. In reality, the minus sign in Faraday's Law *is* Lenz's Law. In practice, Lenz's Law tells us that the induced current will flow in such a direction that the **induced** magnetic field opposes the change in the external magnetic flux. If the external magnetic field is increasing in one direction, the induced magnetic field will point in the opposite direction to the external magnetic field; if the external magnetic field is decreasing in one direction, the induced magnetic field will point in the **same** direction as the external magnetic field. In either case, *the induced magnetic field attempts to maintain the original magnetic flux.*

Procedure

Perform step **1** first; the remainder of the steps may be performed in any order as the equipment becomes available. Each step will have a separate station in lab. Carefully read all instructions and sketch circuits, currents and magnetic fields as requested. **These sketches are your data for this experiment.** It is important that you make clear and complete sketches. “Rough sketch” means that you don’t have to be artistic; you may, for example, draw a multi-turn loop of wire as a single loop of wire. It does not mean you can be sloppy.

1. In order to determine the direction of induced current flow, you must first determine the direction of the galvanometer needle deflection corresponding to a known current direction. Connect the circuit shown in Figure 1. You know that current flows from positive to negative potential; record the direction of current flow through the galvanometer and the corresponding direction of needle deflection. You will need this information throughout the lab, so please be certain that you understand this before moving on.

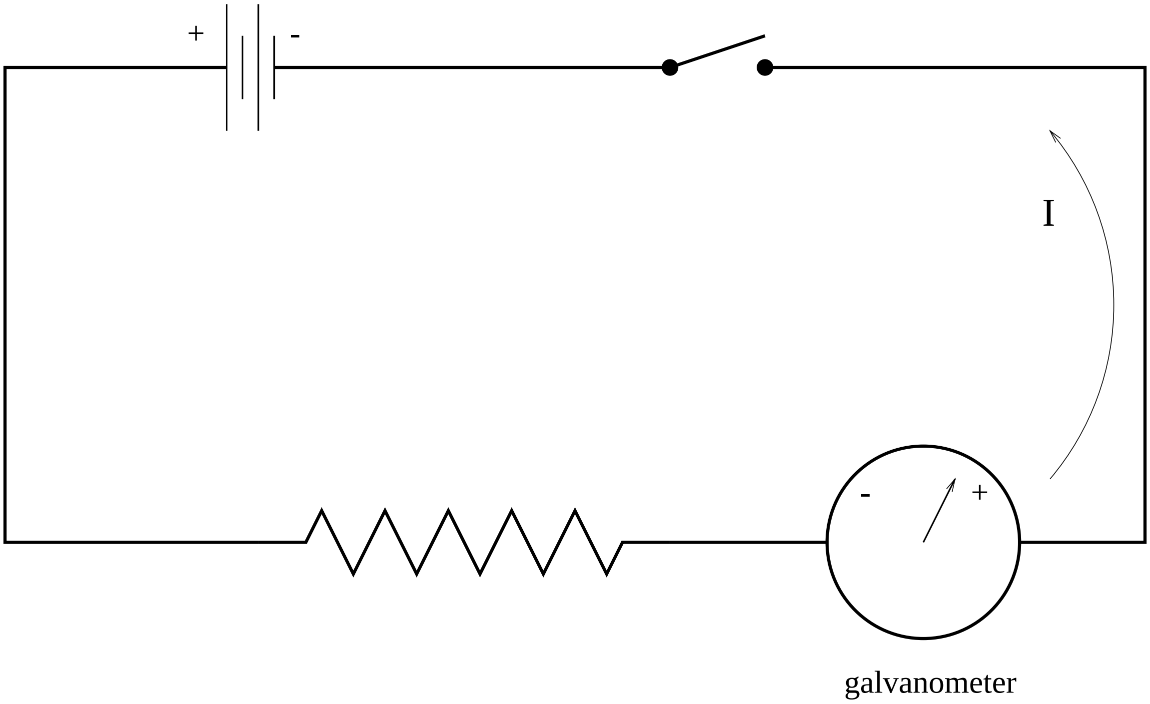

FIGURE 1

2. A large permanent magnet will be mounted on a ring-stand. Use a compass to determine which pole is North and which is South (remember that the North end of the compass needle points toward the South pole of the magnet!). Connect a single wire across the terminals of your galvanometer. Move the wire quickly into the space between the poles of the magnet and record the deflection of the galvanometer needle. Move the wire quickly out of the space between the poles of the magnet and record the deflection of the galvanometer needle. For your analysis, sketch roughly both cases, indicating the direction of current flow and the direction of the external magnetic field on your sketches. Use the right hand rule to determine the direction of the magnetic field due to this current, and add this to your sketch (you may want to use different colors of ink for $\boldsymbol{I}$, $\boldsymbol{B}_{ext}$, and $\boldsymbol{B}_{ind}$). Are the directions consistent with the predictions of Lenz's Law?

3. Connect the coil and galvanometer as shown in Figure 2 below. Sketch roughly your circuit, paying close attention to the way the coil is wound. Hold the magnet stationary near the coil; record the deflection of the galvanometer needle. Move the North pole of the magnet toward the coil; record the deflection of the galvanometer needle. Move the North pole of the magnet away from the coil; record the deflection of the galvanometer needle. In your analysis, roughly sketch the situation in each case: redraw your circuit and indicate the direction of current flow (if any), and the direction of the external magnetic field. Explain the direction of current flow in terms of Faraday's and Lenz's Laws, remembering that the magnetic field lines point away from the North pole of a magnet. How does the magnitude of the galvanometer needle deflection depend on the speed at which you move the magnet? What happens to the direction of the needle deflection when you turn the magnet around (swapping North and South poles)? Try it!

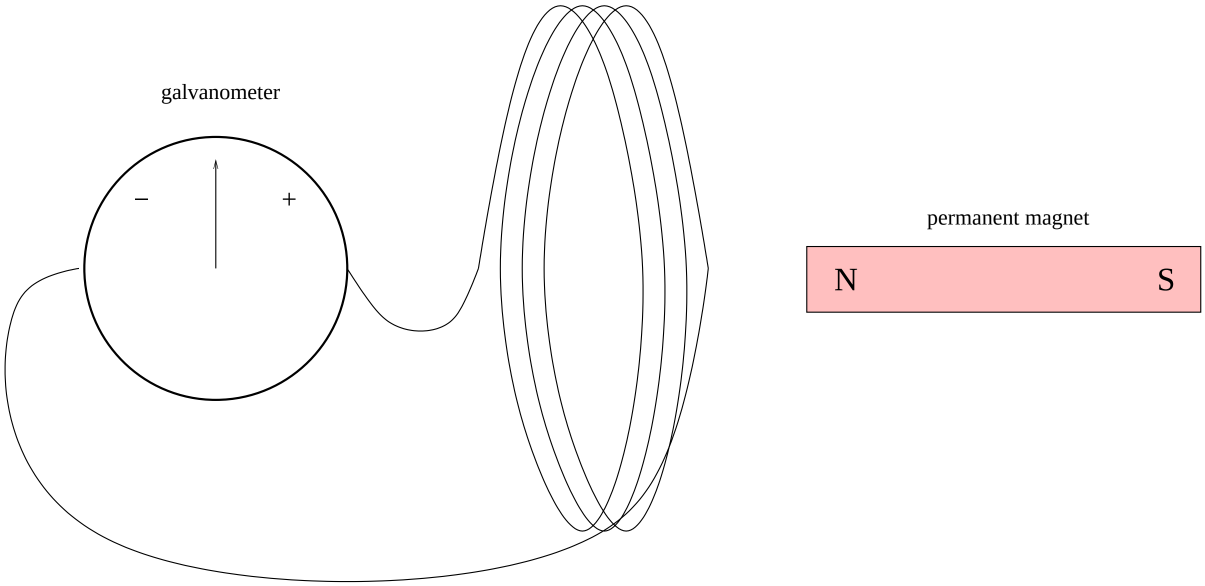

FIGURE 2

4. Connect the second coil to the power supply and rheostat as shown in Figure 3. Adjust the resistance of the rheostat to zero. Record the direction of current flow in the coil and the direction of the magnetic field lines produced by this coil. Roughly sketch this setup. Close the switch and record the magnitude and direction of the needle deflection; open the switch and record the magnitude and direction of the needle deflection. Insert the straight iron core into both coils and repeat. Make two sketches, one for closing the switch, and one for opening the switch. Indicate the directions of current flow and magnetic fields for both coils. How does the iron core affect the magnitude of the deflections? What does this indicate to you?

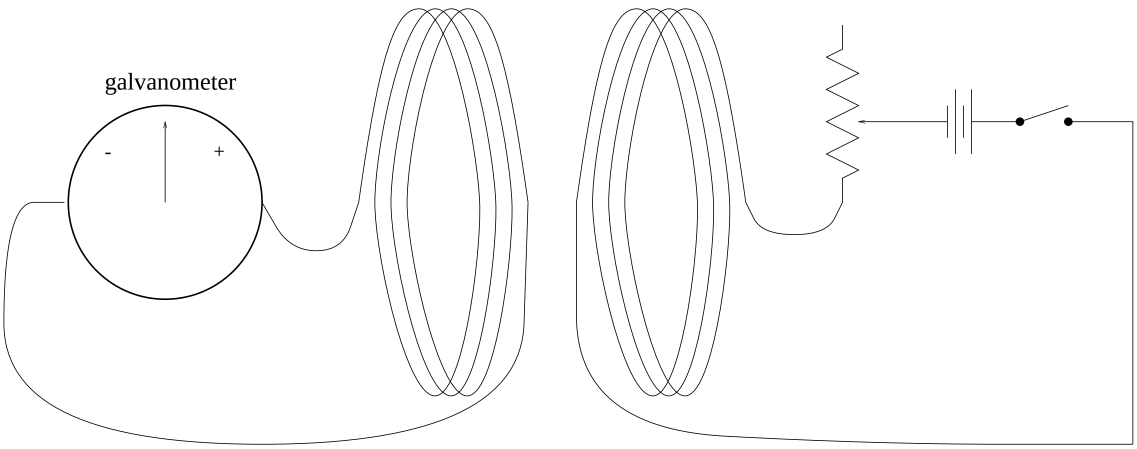

FIGURE 3

5. Set up the circuit as in Figure 3, without the iron core. Close the switch and wait for the needle to return to zero. Move the coils apart quickly and record the deflection. Move the coils together quickly and record the deflection. Sketch both cases, indicating the directions of current flow and magnetic field due to each coil. Is the direction of the induced magnetic fields consistent with Lenz's Law? Does it matter which coil you move (or even if you move both coils simultaneously)?

6. Set up the circuit as in Figure 3, without the iron core. Close the switch and wait for the needle to return to zero. Move the rheostat quickly to the position of maximum resistance; record the deflection. Return the slider to its original position and record the deflection. Sketch both cases, indicating the directions of current flow and magnetic field due to each coil. Is the direction of the induced magnetic field lines consistent with Lenz's Law? Remember that increasing the resistance in a series circuit decreases the current flow.

7. Set the two coils in positions as indicated in Figure 4 (without the U-shaped iron core). Close the switch and record the needle deflection. Insert the iron core, close the switch and record the needle deflection. What does this indicate to you about the path of the magnetic flux with and without the iron core?

8. Study the jumping ring apparatus; record any observations you may make. Try to come up with an explanation for this phenomenon (HINT: The ring with the slit cut in it won't jump. Why?)

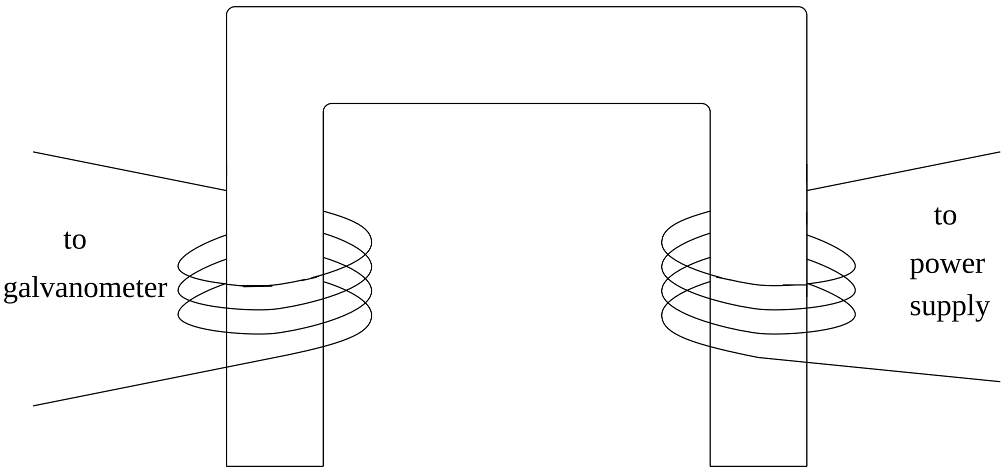

FIGURE 4

9. Using a bar magnet and the copper pipe provided in the lab, confirm that the copper is not attracted to the bar magnet. Then, hold the copper pipe vertically and drop the bar magnet through the pipe (have your lab partner catch the magnet underneath the pipe). Observe whether the motion of the magnet is slowed because of the pipe. For comparison, you can drop another metal object such as a penny outside the pipe at the same time as the bar magnet. Then, answer the following questions:

Q9A. Use Faraday's Law to explain your observations.

Q9B. Explain your observations in terms of energy conservation. (Concepts to consider: kinetic energy, gravitational potential energy, energy dissipation in a current-carrying conductor).