Lab 8. Electromagnetic Induction

Goals

- To understand what it means to have magnetic flux through a loop or coil in a circuit.
- To understand and apply Lenz's law and the right hand rule for magnetic fields produced by currents to correctly predict the direction of currents produced by changing magnetic fields.
- To explain the steps in the induction process precisely through words and pictures for several different cases.

Introduction

Magnetic flux can be thought of as the number of magnetic field lines passing through a given area. According to Faraday's Law a change of the magnetic flux through an area bounded by closed circuit induces a voltage that drives the flow of current around the circuit. This is simply the induction process. Lenz's Law is an abbreviated, text version of Faraday's Law that gives the direction of the emf (potential change) as one moves around the circuit loop:

The polarity of the induced emf (or voltage) is such that it tends to produce a current that will create a magnetic flux to oppose the change in magnetic flux which is causing the emf.

In this experiment you are supplied with a coil of wire, a bar magnet, and a sensitive ammeter—also called a galvanometer. Remember that the ammeter reads a positive value of current when the current enters the positive (+) input terminal and leaves through the negative (–) or common terminal.

Move the bar magnet in to, out of, or through the coil of wire. Using the galvanometer, you can demonstrate that an electrical current flows when you do this.

Remember that, by convention, the magnetic field lines external to a bar magnet go from the N pole to the S pole. Since magnetic field lines are continuous, that is, they do not start or end anywhere, the field lines inside the bar magnet must necessarily go from the S pole to the N pole. All the field lines outside the magnet must be squeezed together as they pass through inside, going the opposite direction. If this is confusing, draw a simple diagram of a bar magnet, and add field lines to your drawing both inside and outside the magnet, indicating the directions of the fields with arrows.

Just a reminder that electric and magnetic fields differ significantly in this regard. Electric fields do begin and end somewhere, namely on electric charges. At this point scientists have yet to discover a single magnetic “charge” existing by itself, with magnetic field lines emanating from it radially analogous to the electric field of a point electric charge.

Be sure to check the pole designation of your bar magnet with a compass using the Earth’s magnetic field as a reference before beginning this experiment. Bar magnets can be remagnetized in strange ways by bringing them close to another magnet, so this check is important. It is not hard to do!

Prediction

Imagine pushing the bar magnet N-pole first into the right-hand end of the wire coil. Predict which way the galvanometer needle will deflect based on your knowledge of the magnetic fields of bar magnets, the magnetic fields due to currents in wires, the configuration of the wire windings of the coil, the right-hand rule, and the connection of the ammeter. Illustrate your method of prediction with a series of simple, annotated cartoons: pictures with words of explanation. Your TA will have some important suggestions for making simple, accurate drawings, particularly of the coil itself. Your cartoons must clearly show:

- The position of the ammeter and coil in your circuit. Clearly label the positive terminal of the ammeter.
- How the direction of the current (clockwise or counterclockwise) around the solenoid is related to the direction of its flow (from left-to-right or from right-to-left) along the coil.
- The initial position of the magnet relative to the coil and the direction of magnet motion. Clearly label the N and S poles of the magnet.
- The dominant direction of the magnetic field of the magnet at points inside the coil.

In notes below these cartoons, draw arrows and additional annotated sketches to show:

- The direction of increasing magnetic field inside the coil.
- The direction of the induced magnetic field required by Lenz’s Law. Refer to Lenz’s Law in this step.
- The direction of current in the coil required to produce this induced magnetic field. Specify both direction (left-to-right) and sense (clockwise or counterclockwise).
- You will need the right-hand rule. Draw a simple right hand. The direction of the current at the positive terminal of the ammeter. Clearly indicate the direction of the initial motion of the needle.

The required cartoons and notes will occupy most of a page in your lab notebook.

The process of prediction is important for two reasons. First, prediction is the true test of whether we understand a phenomenon. When we know the answer ahead of time, we often settle for a partial explanation with missing or incorrect steps. Second, we remember what we observe better if we make a prediction before observing it.[1] This is true whether our prediction is correct or incorrect. In the end, prediction is much better test of understanding than explanation.

Experiment

Now perform the experiment. Did the ammeter deflect in the predicted direction? Do not erase or throw away your cartoons in any case. Go over them carefully and identify any mistakes. Make a note in the margin near the mistaken text or drawings, then redraw or rewrite the mistaken material below your original prediction or on a subsequent page. **This is the only acceptable way of correcting lab notes when an error has been made.**

Predictions and experiments for other geometries

Magnet starting at rest in coil with N pole to right—move to right

Position the bar magnet inside the wire coil with the N pole on the right and S pole on the left. Predict the direction of the current when you pull the magnet out the right-hand end of the coil—drawing another set of annotated cartoons. Then do the experiment and draw corrected cartoons as required. Make sure that your explanation above is consistent with your explanation here.

Magnet starting left of the coil with S pole to right—move into coil

Push the bar magnet S-pole first into the left-hand end of the coil. Predict/observe.

Magnet starting at rest in coil with N pole to right—move to left

Starting with the bar magnet at rest inside the wire coil, with the N pole on the right and S pole on the left, pull the magnet out the left-hand end of the coil. Predict/observe.

What does it take to induce a current in an ammeter?

Perform additional experiments to answer the following questions:

What effect does varying the speed with which you insert or remove the magnet from the coil have? Explain your observations using Faraday's Law.

Under what conditions does a current flow in response to a magnetic field? For instance, how about when the magnet is at rest in the coil? Explain.

Can you cause a current to flow in the coil by moving the bar magnet along the outside of the the coil rather than inside the coil? If so, are certain orientations of the magnet more effective than others for inducing this current? Observe and explain.

[1] Kelly Miller, Nathaniel Lasry, Kelvin Chu, and Eric Mazur, "Role of physics lecture demonstrations in conceptual learning," Phys. Rev. ST Phys. Educ. Res. **9**, 020113 (2013).

Summary

Be as precise as possible in presenting your experimental results. Don't make such broad sweeping statements that they are meaningless. State all your conclusions clearly in a summary (maybe even a table) at the end of the report.

Before you leave the lab please:
    Straighten up your lab station.
    Report any problems or suggest improvements to your TA.