# Lab 7. 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

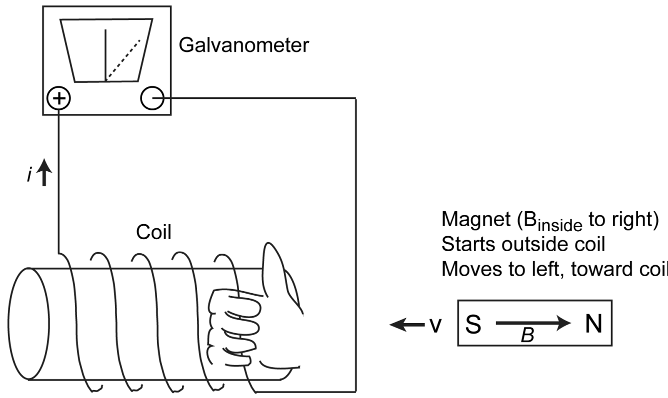
A major portion of the learning activity for this week's lab is precision of language. Students often write things like "the coil wants to..." in the course of this lab. This is false, no matter how you finish the sentence. The coil wants nothing. The coil can do nothing. Please be careful in your word choices as you describe what you expect and what you observe. Refer to physical principles and established laws/theories. Do not anthropomorphize your equipment.

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 the induction process. Lenz's Law is an abbreviated 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. Students often record results in this lab as "We moved the magnet this way, so the needle moved left" which is a useless recording, as you can swap your connections to the galvanometer and the needle will now deflect in the opposite direction.

Essentially the only way to record any observations in this lab is through careful use of diagrams supplemented with text. In prior labs this was ideal, but in this lab it is mandatory. Look at Figure 7.1 for an example. Refer to Lab 6: Current Balance writeup for the two options you may use for Right Hand Rules to include in your drawing.




As the magnet moves to the left and enters the coil, the magnetic field (pointing to the right) inside coil gets stronger.

By Lenz's Law, the magnetic field induced inside the coil must point in the opposite direction (to the left).

By the right-hand-rule, current must flow up on the front-side of the coil (inside the coil, fingers point to the left).

Current flowing up on the front side of the coil enters the (+) terminal of the galvanometer.

Galvanometer needle deflects to right.

Figure 7.1. One approach to drawing a single observation during this week. You may draw the RHR in other manners, but must include it in some style.

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. Your goal for the end of the laboratory is to be able to explain how the needle will react if you move the bar magnet from one end of the coil completely through the other end without stopping (explain prior to performing, and then perform to verify explanation accuracy).

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. You may still have your drawings from the Magnetic Fields lab previously which you can simply supplement with the internal field lines.

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. The current understanding of the source of magnetism is the motion of electrons. This explanation makes a magnetic monopole impossible to exist, so if one were ever discovered it would cause significant changes in fundamental physics, and thus all more complicated physics as well.

**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.**

# 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 drawings: pictures with words of explanation. Refer to Figure 7.1. Your depiction 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 depictions, 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 drawings 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.

Additionally, when you fail to set your prediction down in permanent form, so long as the observation makes sense to you as it happens, your mind will decide that whatever you believed before the experiment was correct. **Even when the observation is directly contrary to what you believed before the experiment.** By having a prediction written down in permanent form, you are

[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).

forced to acknowledge any flaw in your understanding, and can then work on learning the proper approach.

# 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

The manual will not remind you in each experiment to predict, then experiment. You are expected to do so for your own improvement/understanding. Always draw and explain precisely what you expect to see, then observe and look carefully for chances to prove your prediction wrong.

## 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 (Remember to predict first):

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.

Does the position of the bar magnet within the coil change your results at all? Not just direction of deflection, but even magnitude of deflection (how far from zero the indicator swings)? Test with the magnet sliding on the bottom, on each side, on the top, or going perfectly in the center.

# 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.

| | No Effort | Progressing | Expectation | Scientific |
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| **SL.A.a** Is able to analyze the experiment and recommend improvements<br>Labs: 1-3, 5, 7, 9, 11, 12 | No deliberately identified reflection on the efficacy of the experiment can be found in the report | Description of experimental procedure leaves it unclear what could be improved upon. | Some aspects of the experiment may not have been considered in terms of shortcomings or improvements, but some are identified and discussed. | All major shortcomings of the experiment are identified and reasonable suggestions for improvement are made. Justification is provided for certainty of no shortcomings in the rare case there are none. |
| **SL.B.b** Is able to explain patterns in data with physics principles<br>Labs: 1-3, 5, 7, 9-11 | No attempt is made to explain the patterns in data | An explanation for a pattern is vague, OR the explanation cannot be verified through testing, OR the explanation contradicts the actual pattern in the data. | An explanation is made which aligns with the pattern observed in the data, but the link to physics principles is flawed through reasoning or failure to understand the physics principles. | A reasonable explanation is made for the pattern in the data. The explanation is testable, and accounts for any significant deviations or poor fit. |
| **CT.A.a** Is able to compare recorded information and sketches with reality of experiment<br>Labs: 3, 4, 6-8 | No sketches present and no descriptive text to explain what was observed in experiment | Sketch or descriptive text is present to inform reader what was observed in the experiment, but there is no attempt to explain what details of the experiment are not accurately delivered through either representation. | Sketch and descriptive text are both present. The sketch and description supplement one another to attempt to make up for the failures of each to convey all observations from the experiment. There are minor inconsistencies between the two representations and the known reality of the experiment from the week, but no major details are absent. | Sketch and description address the shortcomings of one another to convey an accurate and detailed record of experimental observations adequate to permit a reader to place all data in context. |

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| **CT.B.a**<br>Is able to describe physics concepts underlying experiment<br>Labs: 1-3, 5, 7, 9-12 | No explicitly identified attempt to describe the physics concepts involved in the experiment using student's own words. | The description of the physics concepts underlying the experiment is confusing, or the physics concepts described are not pertinent to the experiment for this week. | The description of the physics concepts in play for the week is vague or incomplete, but can be understood in the broader context of the lab. | The physics concepts underlying the experiment are clearly stated. |
| **QR.B**<br>Is able to identify a pattern in the data graphically and mathematically<br>Labs: 1-3, 5, 7, 9-11 | No attempt is made to search for a pattern, graphs may be present but lack fit lines | The pattern described is irrelevant or inconsistent with the data. Graphs are present, but fit lines are inappropriate for the data presented. | The pattern has minor errors or omissions. OR Terms labelled as proportional lack clarity - is the proportionality linear, quadratic, etc. Graphs shown have appropriate fit lines, but no equations or analysis of fit quality | The patterns represent the relevant trend in the data. When possible, the trend is described in words. Graphs have appropriate fit lines with equations and discussion of any data significantly off fit. |
| **IL.A**<br>Is able to record data and observations from the experiment<br>Labs: 1-12 | "Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. " | "Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. " | Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference. | All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed. |
| **WC.A**<br>Is able to create a sketch of important experimental setups<br>Labs: 1, 2, 4-8 | No sketch is constructed. | Sketch is drawn, but it is incomplete with no physical quantities labeled, OR important information is missing, OR it contains wrong information, OR coordinate axes are missing. | Sketch has no incorrect information but has either a few missing labels of given quantities, or subscripts are missing/inconsistent. Majority of key items are drawn with indication of important measurements/locations. | Sketch contains all key items with correct labeling of all physical quantities and has consistent subscripts. Axes are drawn and labeled correctly. Further drawings are made where needed to indicate precise details not possible in the scale of initial sketch. |

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

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Lab 7 Electromagnetic Induction:

Name: ____________________ Lab Partner: ____________________

**EXIT TICKET:**

☐ Quit any software you have been using.
☐ Straighten up your lab station. Put all equipment where it was at start of lab.
☐ Required Level of Effort.
 ☐ Complete the pre-lab assignment ☐ Arrive on time
 ☐ Work well with your partner ☐ Complete the lab or run out of time

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