Lab 9. 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.

[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).

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.

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.

Grading Rubric

	No Effort	Progressing	Expectation	Exemplary
AA Is able to extract the information from representation correctly Labs: 1-12	No visible attempt is made to extract information from the experimental setup.	Information that is extracted contains errors such as labeling quantities incorrectly, mixing up initial and final states, choosing a wrong system, etc. Physical quantities have no subscripts (when those are needed).	Most of the information is extracted correctly, but not all of the information. For example physical quantities are represented with numbers and there are no units. Or directions are missing. Subscripts for physical quantities are either missing or inconsistent.	All necessary information has been extracted correctly, and written in a comprehensible way. Objects, systems, physical quantities, initial and final states, etc. are identified correctly and units are correct. Physical quantities have consistent and informative subscripts.
AB Is able to construct new representations from previous representations Labs: 1-12	No attempt is made to construct a different representation.	Representations are attempted, but omits or uses incorrect information (i.e. labels, variables) or the representation does not agree with the information used.	Representations are constructed with all given (or understood) information and contain no major flaws.	Representations are constructed with all given (or understood) information and offer deeper insight due to choices made in how to represent the information.
AC Is able to evaluate the consistency of different representations and modify them when necessary Labs: 3-5, 7-9, 11, 12	No representation is made to evaluate the consistency.	At least one representation is made but there are major discrepancies between the constructed representation and the given experimental setup. There is no attempt to explain consistency.	Representations created agree with each other but may have slight discrepancies with the given experimental representation. Or there is inadequate explanation of the consistency.	All representations, both created and given, are in agreement with each other and the explanations of the consistency are provided.
AD Is able to use representations to solve problems Labs: 3-5, 8, 9, 11, 12	No attempt is made to solve the problem.	The problem is solved correctly but no representations other than math were used.	The problem is solved correctly but there are only two representations: math and words explaining the solution.	The problem is solved correctly with at least three different representations (sketch, physics representation and math or sketch, words and math, or some other combination)
AF Sketch Labs: 1-3, 5, 7-9	No representation 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. Subscripts are missing or inconsistent. Majority of key items are drawn.	Sketch contains all key items with correct labeling of all physical quantities have consistent subscripts; axes are drawn and labeled correctly.

	No Effort	Progressing	Expectation	Exemplary
BA Is able to identify the phenomenon to be investigated Labs: 1, 2, 4, 6, 7, 9, 11, 12	No phenomenon is mentioned.	The description of the phenomenon to be investigated is confusing, or it is not the phenomena of interest.	The description of the phenomenon is vague or incomplete but can be understood in broader context.	The phenomenon to be investigated is clearly stated.
BE Is able to describe what is observed concisely, both in words and by means of a picture of the experimental setup. Labs: 1, 2, 4, 6, 7, 9, 11, 12	No description is mentioned.	A description is incomplete. No labeled sketch is present. Or, observations are adjusted to fit expectations.	A description is complete, but mixed up with explanations or pattern. OR The sketch is present but relies upon description to understand.	Clearly describes what happens in the experiments both verbally and with a sketch. Provides other representations when necessary (tables and graphs).
BF Is able to identify the shortcomings in an experiment and suggest improvements Labs: 1, 2, 4, 6, 7, 9, 11, 12	No attempt is made to identify any shortcomings of the experimental.	The shortcomings are described vaguely and no suggestions for improvements are made.	Not all aspects of the design are considered in terms of shortcomings or improvements, but some have been 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.
BG Is able to identify a pattern in the data Labs: 1, 2, 4, 6, 7, 9, 11	No attempt is made to search for a pattern	The pattern described is irrelevant or inconsistent with the data.	The pattern has minor errors or omissions. OR Terms labelled as proportional lack clarity- is the proportionality linear, quadratic, etc.	The patterns represents the relevant trend in the data. When possible, the trend is described in words.
BI Is able to devise an explanation for an observed pattern Labs: 1, 2, 4, 6, 7, 9, 11	No attempt is made to explain the observed pattern.	An explanation is vague, not testable, or contradicts the pattern.	An explanation contradicts previous knowledge or the reasoning is flawed.	A reasonable explanation is made. It is testable and it explains the observed pattern.
GD Is able to record and represent data in a meaningful way Labs: 1, 2, 4-12	Data are either absent or incomprehensible.	Some important data are absent or incomprehensible. They are not organized in tables or the tables are not labeled properly.	All important data are present, but recorded in a way that requires some effort to comprehend. The tables are labeled but labels are confusing.	All important data are present, organized, and recorded clearly. The tables are labeled and placed in a logical order.

	No Effort	Progressing	Expectation	Exemplary
GE Is able to analyze data appropriately Labs: 1, 2, 4-12	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed or inappropriate.	The analysis is appropriate but it contains minor errors or omissions.	The analysis is appropriate, complete, and correct.
SA Is able to identify an optimally relevant special-case for analysis Labs: 2, 3, 9, 10	No attempt is made to identify a relevant special case	An attempt is made, but the identified special case is either irrelevant or ill-defined	A relevant special case is identified, but it is not an optimal special case (i.e., there are other special cases which give a stronger, more clear-cut analysis of the solution)	A optimally relevant special case is identified and clearly stated

EXIT TICKET:

- ☐ Quit any software you have been using.
- ☐ Straighten up your lab station. Put all equipment where it was at start of lab.
- ☐ Report any problems or suggest improvements to your TA.
- ☐ Have TA validate Exit Ticket Complete.