

LABORATORY 9 MAGNETISM III: FARADAY'S LAW, LENZ'S LAW, INDUCTION

Objectives

- to observe that a changing magnetic field can give rise to a current
- to be able to explain the concept of magnetic flux
- to be able to explain the concept of emf
- to be able to determine by measurement or calculation the emf of a changing magnetic flux
- to be able to determine the magnitude and direction of a current set up by a changing magnetic field (Lenz's Law)

Overview: In this lab, we will explore Faraday's Law and Lenz's law.

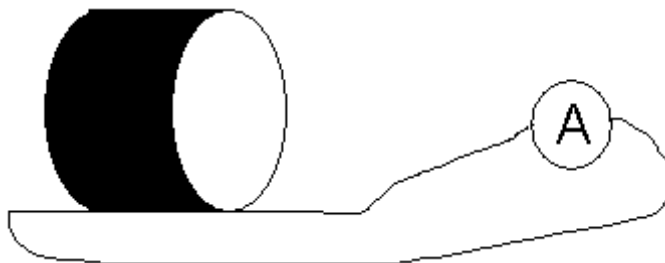
Equipment:

- 1 cow magnet
- 1 solenoid
- 1 small compass
- 1 analog ammeter

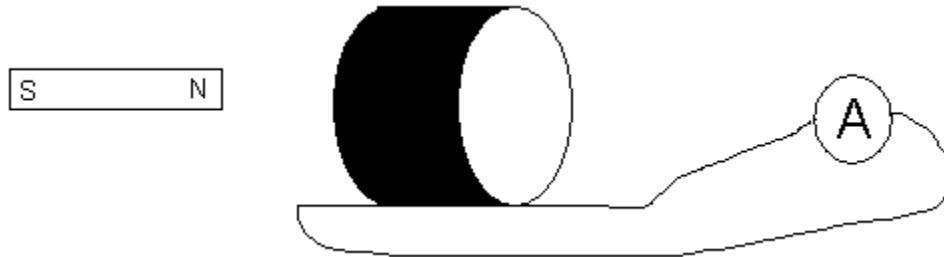
Exploration 1: Lenz's Law

Exploraton 1.1 Take the pre-test for this lab.

Exploration 1.2 Connect the solenoid to an analog ammeter, as shown in the diagram below.



a. Determine which end of the cow magnet is north. Take a cow magnet and move it back and forth near the solenoid. Observe the ammeter while the magnet is moving.



Put the north pole toward the loop. Then put the south pole toward the loop. Does the ammeter record a current? Which direction does the ammeter needle move when the north pole moves towards the magnet? Which direction does it move when the north pole moves away from the magnet? South pole towards? South pole away? Record your observations below.

b. Hold the magnet still near the loops of wire. Does the ammeter record a current? Record your observations.

c. Repeat part a. This time determine the direction of flow of positive charge through the solenoid based on the ammeter reading for each case:

- north pole moves toward the solenoid
- north pole moves away from the solenoid
- south pole moves toward the solenoid
- south pole moves away from the solenoid

For each case, determine if positive charge flows clockwise or counter-clockwise, when you look end on from the side the magnet is on. Record your data in the table below.

	Record if current flow is clockwise or counterclockwise from end on view
north pole moves toward the solenoid	
north pole moves away from the solenoid	
south pole moves toward the solenoid	
south pole moves away from the solenoid	

Ask your TA, if you are unsure of the direction positive charge flows through the circuit.

d. There is no battery in the circuit. Yet, charges are moving through the wire. There must be a force doing work on the charges. Further experiments show that the charges are moving because they are in an electric field. The changing magnetic field is creating an electric field. The work done per unit charge by the electric force is called the emf. If more work is done per unit charge, the current is larger. The emf and the current are related by $\text{emf} = IR$.

The rate at which charges move through the wire seems to depend on the motion of the magnet. Further experiments reveal that the amount of current in the wire depends on:

- the time rate of change of magnetic flux
- the number of loops (turns) in the wire

The magnetic flux is defined the same way as the electric flux, but in terms of the magnetic field and the area, instead of the electric field and the area:

$$\Phi = BA\cos\theta$$

The equation for the emf for a wire with N turns is:

$$E = -N \frac{\Delta\Phi}{\Delta t}$$

where N is the number of turns in the wire, $\frac{\Delta\Phi}{\Delta t}$ is the time rate of change of magnetic flux. This equation is called Faraday's Law.

The direction the current flows through the loop is such that the current in the loop will set up a magnetic field to oppose the change in flux through the loop. This is called Lenz's Law. Is this consistent with your data?

If the north pole of the magnet is moving toward the loop, the flux, which is essentially the number of field lines through the loop, is increasing. The current through the loop will set up a magnetic field in the opposite direction to the magnetic field produced by the north pole of the magnet in order to decrease the flux (the number of field lines) through the loop.

If the north pole of the magnet is moving away from the loop, the flux (number of field line through the loop) is decreasing. The current through the loop would set up a magnetic field in the same direction as the magnetic field produced by the north pole of the magnet in order to increase the flux (the number of field lines through the loop).

e. Use Lenz's Law to determine the direction that current flows through the loop when the south pole of the magnet moves toward the loop and when the south pole of the magnet is moved away from the loop.

Discuss your answers to part e with the TA.

Equipment:

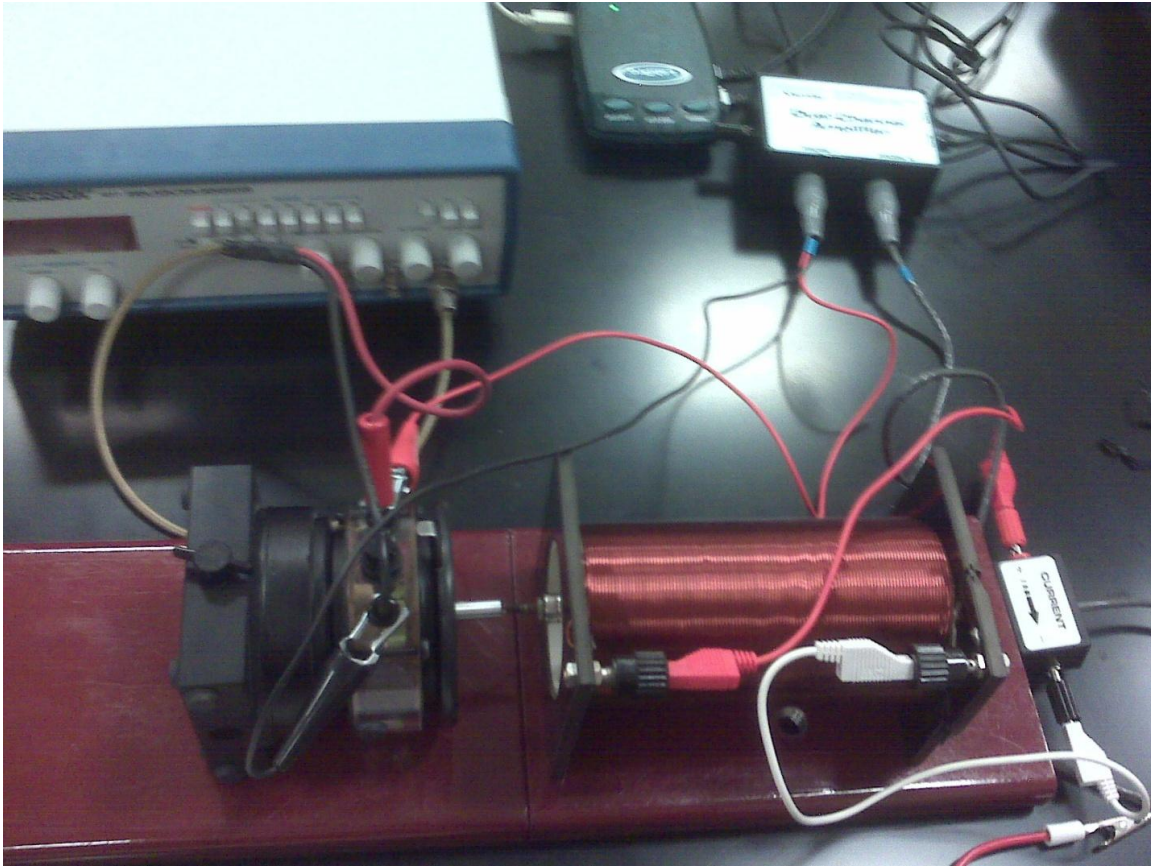
- 1 oscillator
- 1 function generator
- 5 neodymium magnets
- 1 solenoid
- 1 Vernier Magnetic Field Sensor
- 1 Vernier Current probe
- 1 Vernier computer interface
- 1 Vernier computer software
- 1 multimeter

Investigation 1: Using Faraday's Law to determine the magnetic field of a magnet

Investigation 1.1 Relationship between current and change in magnetic field strength

In this Investigation, we will oscillate a magnet near a solenoid and observe the current through the solenoid. We will use the data to calculate the emf in two ways.

The setup consists of a function generator hooked to an oscillator. Five neodymium magnets are attached to the oscillator. The neodymium magnets will be placed just inside a solenoid placed next to the oscillator, as in the picture below.



The function generator will be used to drive the oscillator back and forth. The driving wave function used will be a sine wave.

The oscillating magnets will cause a change in the magnetic field through the solenoid, changing the magnetic flux through the solenoid. We will use a magnetic Field Sensor to record the change in magnetic field as a function of time.

The changing magnetic field will produce an emf. The emf will produce a current through the solenoid. We will measure the current through the solenoid using a current probe.

The emf can be calculated two ways:

- (1)
- (2) —

The current probe should be connected to the ends of the solenoid and to the computer interface. The Magnetic Field sensor should also be connected to the computer interface.

Make sure the magnetic field probe is set on the highest setting.

Open the computer interface program. On the Experiment drag down menu, set the sample time to 5seconds and the sample rate to 20 samples per second. Before taking data, you will need to zero the input. Use the zero button to zero both sensors.

Set the function generator to produce sine waves. Turn on the function generator and set the frequency to between 40-45 Hz.

Hold the magnetic field Sensor inside the solenoid and hit “Collect” to collect data.

Two graphs should appear on the screen – one of current vs. time and the other of magnetic field vs. time.

a. Write down Faraday’s Law and use it to analyze the relationship between the graphs of magnetic field vs. time and current through the solenoid vs. time. How should they be related, based on Faraday’s Law and how are they related graphically? Discuss.

Discuss the relationship between the magnetic field vs. time and current through the solenoid vs. time with your TA before you continue.

b. Measure the resistance of the solenoid wire. Record the resistance below.

Investigation 1.2 Calculation of the emf

a. Determine the change in magnetic field at three points on the magnetic field curve. Choose a point at the top or bottom of the curves, a point of greatest slope and a third point. Use the software to determine the change in B as a function of time for each of the three points. Record the data in the table at the end of this section.

b. Calculate the emf for each of the three points. Show your work below and record the results in the table at the end of this section.

c. Record the value of the current at each of the points in the table at the end of the section.

d. Calculate the emf for each of the three points using $\text{emf} = IR$. Record the results in the table below.

Location	$\Delta B/\Delta t$	—	I	
Top of curve				
Point of greatest slope				
Intermediate slope				

Do the two calculations of the emf agree or not? Explain.

Equipment:

- 1 Induction wand
- 1 Variable Gap Lab Magnet
- 1 Large Rod stand
- 145cm Long Steel Rod
- 1 Multi Clamp
- 1 Pasco Voltage Sensor
- 1 Pasco Magnetic Field Sensor
- 1 Pasco Rotary Motion Sensor
- 1 mass Balance
- 1 Meter Stick
- 1 Science Workshop 500 Interface
- 1 Data Studio Software

Investigation 2: More work with Faraday's Law**Investigation 2.1**

In the setup at your table, a rigid pendulum with a coil at its end swings through a horseshoe magnet. An emf is induced in the coil, as the magnet swings through the approximately constant magnetic field between the poles of the magnet. The setup is shown in the picture below.

- a. Explain why there is an emf in the coil as it passes through the magnetic field.

b. What do you expect a graph of emf vs. time to look like? Sketch your prediction of a graph of emf vs. time in the space below. Explain why you drew the graph the way you did.

c. Write out Faraday's Law in symbols in terms of the magnetic field, B , and the area, A . Is the field changing as the coil passes between the poles of the magnet? Is the area changing as the coil passes through the poles of the magnet? Explain.

d. What would you need to measure, in order to calculate the emf as the coil passes between the poles of the magnet?

e. If you were in the frame of reference of the coil, is the field changing as the coil passes between the poles of the magnet? Is the area changing as the coil passes through the poles of the magnet? What would you need to measure, in order to calculate the emf as the coil passes between the poles of the magnet?

Investigation 2.2

If the pole plates are not on the ends of the horseshoe magnet, as in the picture below, put them on now.

Adjust the height of the coil so it is in the middle of the magnet. Align the wand from side-to-side so it will swing through the magnet without hitting it.

The Voltage Sensor should be plugged into Channel A of the ScienceWorkshop 500 interface. The Rotary Motion Sensor should be plugged into Channels 1 and the Magnetic Field Sensor should be plugged into Channel B.

a. Use the magnetic field Sensor to measure the strength of the magnetic field between the poles of the magnet. Record the value for the magnetic field strength in the space below.

Magnetic field strength_____

b. Determine the direction of the magnetic field between the poles of the magnet. Which pole is the north pole? Describe how you determined the direction of the magnetic field and record your results here.

Investigation 2.3

Plug the Voltage Sensor banana plugs into the banana jacks on the end of the coil wand. Drape the Voltage Sensor wires over the rods so the wires will not exert a torque on the coil as it swings. It helps to hold the wires up while recording data.

Open the DataStudio file called "Induced emf".

a. Click **START** and pull the coil wand back and let it swing through the magnet. Then click **STOP**. The emf vs. time graph will show on the screen. You may use the Magnifier Tool to enlarge the portion of the voltage vs. time graph where the coil passed through the magnet.

How does it compare to your prediction in **2.1.b**?

b. Discuss with your lab partners which part of the motion corresponds to which part of the graph. Discuss why the emf is positive, negative or zero at different points, as the coil passes through the magnetic field. Record your thoughts here.

Before you go on, discuss with your TA which part of the motion corresponds to which part of the graph.

Investigation 2.4

The emf is changing throughout the motion of the coil through the field. It is possible, however, to measure the average emf for each part of the motion of the coil. We can also measure the average rate of change of the area of the coil or the average rate of change of the magnetic field for each part of the motion (if we look at Faraday's Law from the frame of reference of the coil).

a. Use the mouse to highlight the first peak on the graph and find the average emf across the coil. Record the average emf and the relevant time interval in the space below.

average emf _____ time interval _____

b. Calculate the average change in area during the relevant time interval in part **a.** Explain your calculation and show your work.

c. Calculate the average emf from the average change in area. Show your calculation.

d. Compare the average emf as measured in part **a.** to that calculated in part **c.**

Investigation 2.5

It is also possible to calculate the average emf from the frame of reference of the coil.

a. Calculate the average change in magnetic field during the relevant time interval in part **2.4.a.** Explain your calculation and show your work.

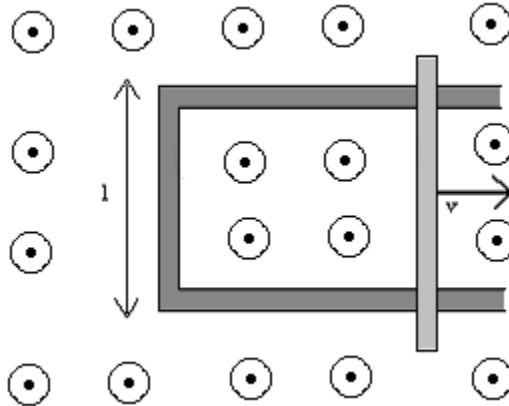
b. Calculate the average emf from the average change in area. Show your calculation.

c. Compare the average emf as measured in part **2.4.a.** to that calculated in part **b.** How do they compare?

Summary. Summarize what you have learned about Faraday's Law and Lenz's Law in your own words. Include in your summary a discussion about how to determine the direction of a current generated by a changing magnetic field, as well as a discussion of different ways to create a changing magnetic flux.

Laboratory Homework 9 Magnetism III

- 1) Consider a U-shaped metal rod with a metal rod touching it, which is free to slide (shown below). A magnetic field is out of the page everywhere, as in the diagram below.



If the rod is moving to the right at a velocity v ,

- a) would there be a current? Explain. If so, determine the direction of the current.
- b) would there be an emf? Explain. If so, calculate the emf in terms of the magnetic field, B , the velocity of the rod, v , and the length l . Show your work; do not just write down your result. Show your calculation.