

NAME _____
Station Number _____

LAB PARTNERS _____

Electromagnetic Induction: Faraday's Law and Lenz's Law

Experiment 9

INTRODUCTION

A changing magnetic field can produce a potential difference, often called an *emf*, across a coil of wire. If the coil is part of a closed circuit, a current is induced in the circuit. The changing magnetic field can be produced by relative motion between a coil and a permanent magnet or by changing the current in one coil that is placed near another coil. Effects of these kinds are known as electromagnetic induction and can be described by Faraday's law and Lenz's law. Motors, generators, and transformers are a few of the many common devices whose operation is explained by the laws of electromagnetic induction. In this experiment, a coil passes through a magnetic field, causing a change in the magnetic flux in the coil. The induced *emf* in the coil and the effect of the induced current on the coil's motion are studied.

THEORY

Faraday's law of induction states that the magnitude of the induced *emf* is related to the change in magnetic flux according to

$$|emf| = N \left| \frac{\Delta\Phi}{\Delta t} \right| = N \left| \frac{\Phi_f - \Phi_i}{t_f - t_i} \right|, \quad (1)$$

where Φ is the magnetic flux, N is the number of turns in the coil, t is the time, and f and i mean final and initial, respectively. The magnetic flux for a constant magnetic field B is given by

$$\Phi = B A \cos \theta, \quad (2)$$

where A is the area of the loop through which the field lines pass, and θ is the angle between the magnetic field and the line normal to the plane of the loop.

In this experiment, a coil at the end of a pendulum will swing through a region of space with magnetic field. As the coil enters this region, the magnetic flux, Φ , through the coil increases and an *emf* is induced according to Eq. (1). The *emf* induced in the coil causes a current that produces a magnetic field to oppose the change in flux, this is Lenz's Law. The orientation of the induced magnetic field will be opposite to the orientation of the field between the magnets producing a repulsive magnetic force that slows down the pendulum.

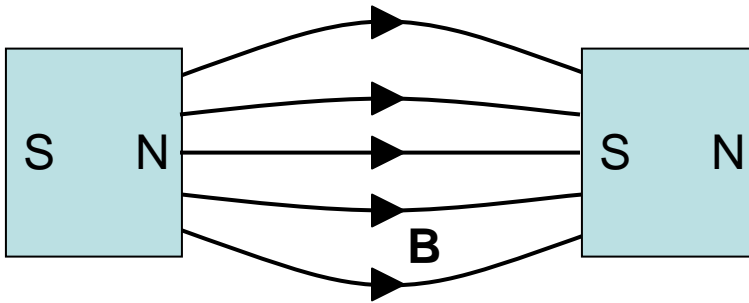


Figure 1

During the experiment, the coil will be connected in the circuit shown in Figure 2. When the switch connecting points **a** and **b** is closed, the current created by the induced *emf* has a relatively small resistance in its path. However, when the circuit is open there is a much larger resistance in the path of the current. From Ohm's law it follows that the magnitude of the current for the second configuration will be much smaller. If the current is small enough the pendulum will not be slowed down by a magnetic force.

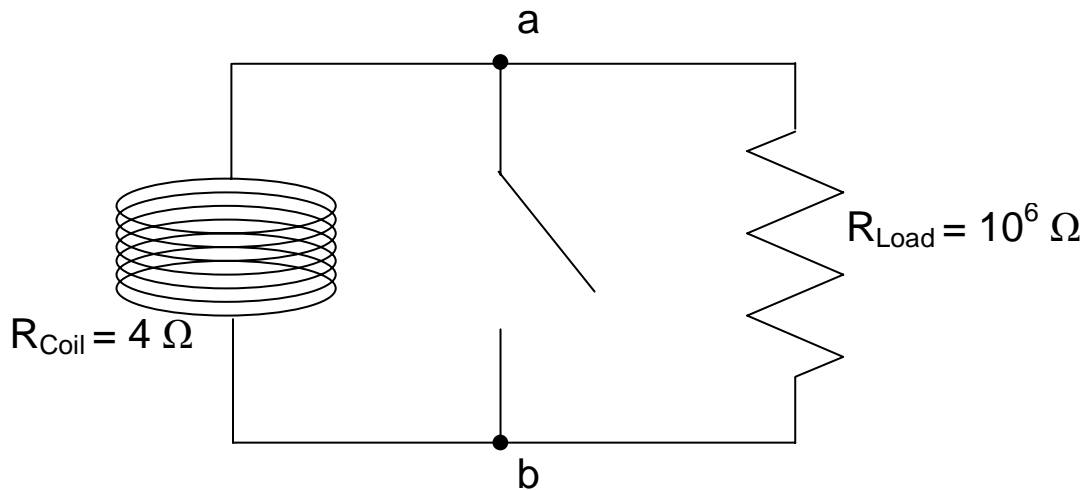


Figure 2

EXPERIMENT NO. 7

WARNING: The magnets used in this experiment have a very strong magnetic field. Keep electronic devices, credit cards, watches, etc. away from the magnets.

1. Open the Scope activity in the 1122 Folder.
2. Before taking data for use in calculations, a few qualitative experiments will help you understand the basic ideas contained in Faraday's law and Lenz's law.

Under Displays, double click Scope. Select Voltage as your Data Source and click OK.

Maximize the scope window. At the bottom of the window, click the left arrow until the display shows 200 ms/div. At the right of the window, click the down arrow until the display shows 0.1 V/div.

Make sure that only the voltage sensor is connected to the top of the pendulum. Click Start to activate the display. Swing the pendulum in between the magnets and look at the Scope's display. If the voltage becomes too large, you are swinging the pendulum too fast.

Slowly swing the pendulum in and out of the magnetic field region from one side of the magnets to the other. Repeat several times.

- a) How is the sign of the induced *emf* related to the motion of the pendulum?

Repeat the procedure, swinging the pendulum faster this time. Explain the observations.

- b) With the pendulum in its lower position between the two magnets, make it oscillate with very small amplitude (the pendulum should not leave the magnetic field). Write down your observations.

c) Move the pendulum as you did in part b), this time the small oscillations will take place at border of the magnetic field region.

Compare your observations with what you saw in part b). Explain why there is a difference in the magnitude of the *emf*.

3. Close the application window and open the Lenz's Law experiment in the 1122 folder.

In this part of the experiment, we want to record voltage data as the pendulum swings in and out of the magnetic field. Since we are using a relatively low frequency to record the data, the pendulum must move with a slow speed.

Displace the pendulum from its equilibrium position just enough to remove it from the magnetic field region. Release the pendulum and record data as it oscillates once, then stop recording. The voltage vs. time graph should show two smooth peaks. If the peaks are sharp the pendulum was moving too fast and you must repeat this step using smaller amplitude of oscillation.

Print your graph.

4. Record the voltage at each peak.

$V_+ =$ _____

$V_- =$ _____

Why do these peaks have opposite signs?

The coil has a resistance of 4 ohms and it is connected to a load with resistance of 10^6 ohms, as show in Figure 2. Calculate the peak current, I_+ and I_- for V_+ and V_- . Show your calculations.

$I_+ =$ _____

$I_- =$ _____

5. We now will look at how the amplitude of oscillations decays with time. First remove the magnet from the pendulum's path. Set the pendulum into oscillations, use large amplitude so you can record at least 30 seconds of data.

Look at the graph of angular position vs. time, and you should see that the amplitude decays with time. The decay in the amplitude is due to friction on the system.

6. Put the magnet back in its original place and repeat the previous step, record at least 30 seconds of data. Again look at the graph of angular position vs. time and note how it decays with time.

Does the addition of the magnetic field change the pendulum's motion?

7. Under the Load section of **Table 1**, record the time and angular position of at least five maxima from the data obtained in Step 6. **DO NOT** use consecutive maxima, instead once you choose your first maxima, skip two maxima to choose your next one.

8. Connect a short circuit between the terminals of the voltage sensor (ask your TA how).

Let the pendulum oscillate only once through the magnetic field, as you did in Step 3, print your graph and record the voltage at both peaks.

$V_+ =$ _____

$V_- =$ _____

9. By putting the short circuit you simply closed the switch between points **a** and **b** in Figure 2. Notice that the current takes a different path this time.

Calculate the peak current through the circuit for both cases. Show your calculations.

$I_+ =$ _____

$I_- =$ _____

10. Set the pendulum into oscillations using a large displacement from the equilibrium position and record data until it stops.

Record the time and angular position of five maxima in **Table 1**. Do not skip any maxima this time.

Why the pendulum does come to rest sooner this time? Explain.

Table 1

Load		No Load	
Time	Angular Position	Time	Angular Position

11. On the Data window click on Load and drag it to Table on the Displays window. You should see a blank table with two columns, Time and Angle. Type the Load data from **Table 1**.

12. The amplitude of oscillations decays exponentially according to

$$A = A_0 e^{-(Bt)} + C,$$

where A_0 is the initial amplitude of the oscillations, C is the angular position of the pendulum at $t = 0$, and B is the damping constant. This constant determines how fast the amplitude of the oscillations decays.

On the Data window click on Load and drag it to Graph on the Displays window to plot the data.

On the graph window click on Fit and select User-Define Fit. Double click on the User-Defined Fit box that appeared on the graph, you should see the Curve Fit window now. On the Curve Fit window, delete x in the space provided at the upper right side of the window, type $a*exp(-b*x) + c$ and click Accept.

Record the value of the damping constant in **Table 2**.

13. Repeat Steps 11 and 12 and obtain the damping constant for the No Load case.

Table 2

Damping Constant	
Load	No Load

14. How is the damping constant related to the decay of the oscillations?

3. Suppose a student recorded the following data during Step 10 of this experiment,

A	6.2 deg	4.7 deg	3.2 deg	2.4 deg	1.8 deg
Time	2 s	4 s	6 s	8 s	10 s

The student was careful to start taking data when the angular position of the pendulum was zero. Unfortunately he does not have a computer available to fit the data as we did in Step 12, but he knows that the amplitude of oscillations decays exponentially according to $A = A_0 e^{-(Bt)} + C$. Use the data obtained by the student to plot a straight line graph of the appropriate variables, and use it to find values for the parameters A_0 and B .