

# Induction

## Worksheet Format

### Equipment Needed

Coil, Induction (400)	Leads, Banana (2)
Compass	Magnet, Cow
Galvanometer, Analog	Stopwatch
Electric Generator, Genecon Hand	Voltmeter, Analog

### Introduction

In this lab we will investigate the process of electromagnetic induction. The idea of induction is one of the most important in physics. First, conceptually it is through induction that we find the connection between the magnetic and the electric fields. A changing magnetic field produces an electric field, and as we will learn later in the semester a changing electric field produces a magnetic field. These ideas unify the electric and magnetic field into a single field that we call the electromagnetic field. Second, induction is vital to the propagation of radiation. It is the fact that a changing magnetic field causes an electric field and a changing electric field causes a magnetic field that allows electromagnetic energy to propagate across the 'vacuum' of space and among other things make life on Earth possible. Third, induction is the process used in the generation of electricity, and thus is vital to our modern technology.

The magnetic flux through an area  $A$  is defined as

$$\Phi_B = BA$$

where

$B$  = the average magnetic field across the area.

The great discovery made by the English physicist Michael Faraday (and independently by the American physicist Joseph Henry) in the 1830's is that

whenever the magnetic flux changes in time for whatever reason, a voltage is induced. This important observation is summarized in Faraday's Law

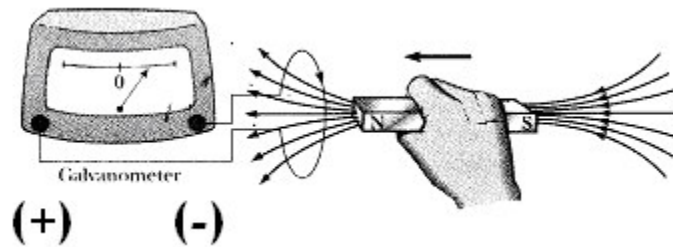
$$E = - \frac{\Delta \Phi_B}{\Delta t}$$

where

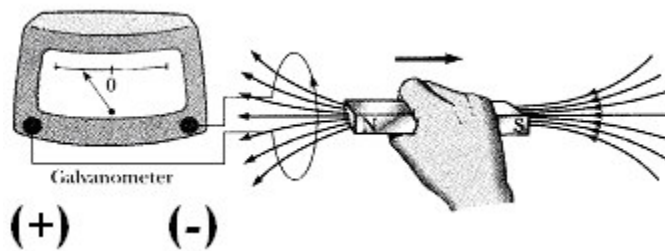
$E$  = the potential or EMF which is induced.

The minus sign in Faraday's Law has great significance and is actually given the name of Lenz's Law. The significance of the minus sign is that the EMF resulting from the changing magnetic flux, which we will refer to as the induced EMF, always tries to counteract the change in the magnetic flux. To understand this, consider Figure 1 shown below. When the north pole of the magnet heads toward the loop of wire, the magnetic flux increases. The induced EMF produces a current in the loop that produces a magnetic field opposite in direction to the increasing magnetic flux. When the magnet heads away from the loop of wire, the magnetic flux decreases. The induced EMF produces a current in the loop that produces a magnetic field opposite in direction to the decreasing magnetic flux. The magnetic flux through the loop is decreasing and consequently the induced EMF produces a current that tries to increase the magnetic field through the loop.

**Figure 1** Schematic of Procedure for determining Lenz's Law



**Figure 2**



**Note:** The positive terminal in the picture is on the left. The positive terminal on your galvanometer may or may not be marked. (Many of them are on the right.) The flux through an area can change for several reasons. First if you keep the magnetic field constant, the flux can be changed by changing the area of the loop. This is approximately the procedure used in an electric generator. Similarly the area can be kept constant and the magnetic field can be varied. This can be accomplished by using either an AC magnet or else by moving a DC magnet through the field coils. The total rate of change of flux can then be written as

$$\frac{\Delta\Phi_B}{\Delta t} = A \frac{\Delta B}{\Delta t} + B \frac{\Delta A}{\Delta t}.$$

In the first part of this lab we will examine Lenz's Law by moving a magnet through a constant area, and in the second part of the lab, we will partially investigate Faraday's Law by turning a loop through a constant magnetic field.

## Part 1—Lenz's Law

### Procedure

In Part 1 of this procedure we will make some simple qualitative observations to verify Lenz's Law. Use the compass to identify the North Pole of the magnet. With the terminals facing you, determine the direction (i.e. clockwise or counter-clockwise) that current will flow in the coil when the terminal on the left is used as the positive terminal. Identify which is the positive and which is the negative terminal of the galvanometer. Rapidly insert the North Pole of the bar magnet into the center of the choke coil while observing the deflection of the galvanometer. Make sure that you know which way a positive current will flow through out your circuit.

Connect the choke coil to the galvanometer such that a current flowing clockwise around the coil runs into the positive terminal of the galvanometer. Rapidly insert the North Pole of the bar magnet into the center of the choke coil while observing the deflection of the galvanometer.

1. In this case, does the magnetic flux increase or decrease as the magnet enters the coil?
2. Consequently, what is the sign of the rate of change of the magnetic flux?
3. Determine and record the direction that the current flowed in the circuit.
4. In what direction would the magnetic field resulting from this induced current point?
5. Record your results.

Push the North Pole of the magnet through the other side of the coil.

6. Record the signs of the rate of change of the magnetic flux and the current for this case.
7. Determine the direction of the magnetic field resulting from this current.

Now insert the South Pole of the magnet through the front of the coil.

8. Record the signs of the rate of change of the magnetic flux and the current and determine the direction of the magnetic field resulting from the induced current.

Next make the same set of observations you have just made only place the South Pole of the bar magnet into the back of the coil.

9. Record the signs of the rate of change of the magnetic flux and the current and determine the direction of the magnetic field resulting from the induced current.
10. In each case, how does the direction of the induced magnetic field compare to the changing flux?
11. Explain how your results show Lenz's Law.

## Part 2—Faraday's Law

In Part 2 we will partially examine the proportionality between the induced EMF and the rate of change in the magnetic flux. We will make use of the Genecon. The Genecon turns, via a gear system, a coil in a magnetic field. Figure 3 shows a schematic of the geometry. The cross sectional area of the coil, through which the field lines cross, is a function of the angle between the coil and the field lines. When the angle is 90 degrees the cross sectional area is zero and it is the entire area of the coil when the angle is 0 degrees. Thus we can write the magnetic flux as

$$\Phi_B = AB \cos \theta .$$

If we turn the coil at a constant angular rate,  $\omega$ , then the angle is given by

$$\theta = \omega t ,$$

and thus the flux is given by

$$\Phi_B = AB \cos \omega t .$$

It can be shown, using calculus, that the rate of change of the magnetic flux and thus the average induced EMF is given by

$$E_{ave} = \frac{1}{2} \omega AB \quad \text{Equation 1}$$

In the Genecon the only variable on the right hand side of Equation 1 that we have access to is the rate at which the coil is turned. Thus, we will investigate the proportionality between the induced EMF and the rate of change of the magnetic flux by examining the proportionality between the induced EMF and the rate at which the crank is turned.

### **Procedure**

Begin by connecting the Genecon between the (+) terminal and the (-) terminal marked 15 V on the analog voltmeter. Turn the crank such that the meter reads a positive voltage. (Note: If this is an uncomfortable direction to turn the crank, simply reverse the connections between the Genecon and the voltmeter.) Our procedure will be to turn the crank such that we get a specified voltage and to determine the rate at which we are turning the crank. We will determine the rate

at which we turn the crank by simply timing ten turns. The frequency at which we turn the crank is then given by

$$f = 10/t$$

where

$t$  = the time required for 10 turns of the crank.

The rate at which we turn the crank is then given by

$$\omega = 2\pi f .$$

Turn the crank at a steady rate such that you get a voltage of 1 V on the meter.

12. Record the time it takes to complete ten turns of the crank.

13. Calculate the frequency,  $f = 10/t$ , and the angular frequency  $\omega = 2\pi f$ .

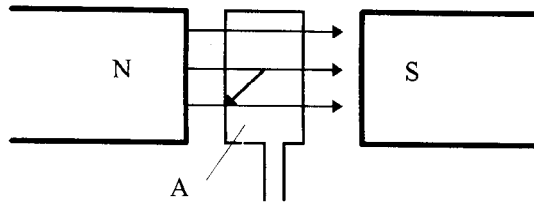
Increase the rate at which you turn the crank so that voltage reads 2 V and determine the rate at which you are turning the crank. Repeat your measurements three more times each time incrementing the voltage by 1 V. Record your measurements, including the first in the table below.

14.

**Table 1** Data for the Voltage as a function of the Frequency

Voltage, V (V)	Time for 10 turns, t (s)	Frequency, $f = 10/t$ (Hz)	Angular Frequency $\omega = 2\pi f (s^{-1})$

**Figure 3** Geometry of generator



### **Data Analysis**

15. For Part 2 of the lab, the data analysis is very straightforward. Using either Excel or Graphical Analysis for Windows, plot the induced EMF versus the angular frequency at which you turned the crank. Draw the best-fit line that goes through your data points and determine the slope of the line, including units. We need to make a slight adjustment to the result given by Equation 1. The rate at which we turn the crank is not the same as the rate at which the coil is turned because of the gearing within the Genecon. Thus we need to add the gear ratio to our result. We thus expect our model to be  $E_{avg} = \frac{1}{2} \lambda \omega AB$  where  $\lambda$  is the gear ratio. Our graph of  $E_{avg}$  vs.  $\omega$  should be a straight line with a slope  $m = \frac{1}{2} \lambda AB$ . Attach your graph to your worksheet. (Note: The gear ratio of the genecon is 48:1.)
16. Does this slope have a reasonable value? Explain your reasoning.

17. Explain in what way this graph demonstrates Faraday's Law?