MAGNETIC FIELDS AND INDUCED EMF

Purpose:

To investigate the EMF created by a varying magnetic field in a coil.

Equipment:

Rotating rod from centripetal force lab, magnet, coils, PASCO interface and computer, voltage sensor, vernier magnetic field sensor.

Background:

Electromotive Forces (EMF) convert one form of energy to others which we consume daily. We recognize the devices that supply power as batteries, photo-voltaic cells, thermocouples, and generators.

All EMFs can produce a potential difference between two points, commonly called terminals. The high potential terminal is denoted with a + sign, and the low potential terminal is denoted with a - sign. When the terminals are connected to a circuit the potential difference causes any free charges within the circuit to move, thereby doing work on the charges. We measure the work an EMF can perform in volts, work per unit charge. The important property of the EMF is that it can produce a potential everywhere in the circuit and can produce a current.

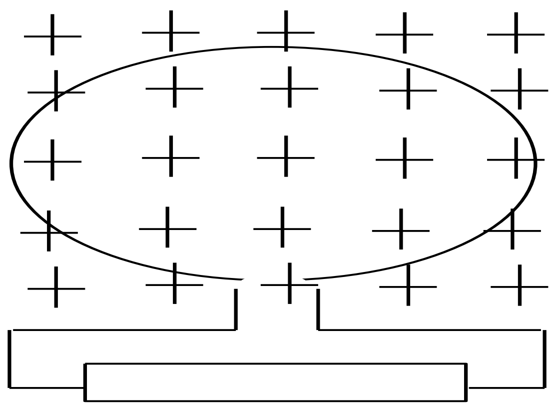

Figure 1. A loop of wire in a magnetic field that is directed into the page. Changes in the size of the loop, orientation of the loop, or magnetic field strength will produce an EMF in the circuit while those changes are occurring.

We know that EMF 's can be created by chemical means from our everyday use of batteries. And, as we know, batteries have limitations on the length of time the potential difference can be maintained and the size of the potential difference. Magnetic fields and conductors can produce EMF's of varying strengths. Consider a loop that is connected to a circuit component, like that of figure 1, and is centered in a magnetic field. Changes in dimension of the loop will cause a current to be produced. Likewise, if the magnitude of the magnetic field should change and the size of the loop is constant, a current will also be produced.

In either case, the charges in the conductor feel the presence of the magnetic field. When the loop changes size or the magnetic field changes strength, the flux through the loop changes. It is this change in flux that induces the EMF in the loop. Remember that flux is defined as the number of field lines that pass through a cross sectional area. If the area changes or the magnetic field changes in time then the flux through the loop has changed. The change in flux produces an EMF which is given by

$$\varepsilon = -\frac{\Delta\phi}{\Delta t} \qquad \text{Eq.1.)}$$

Here ε is the EMF, $\Delta\phi$ represents the change in flux, and Δt represents the time in which it changes.

In the case where the loop changes size over time the equation for the EMF is

$$\varepsilon = -B\frac{\Delta A}{\Delta t} \qquad \text{Eq. 2)}$$

Where B is the magnitude of the magnetic field and $\Delta A/\Delta t$ represents the change in area of the loop per change in time.

If the magnitude of the magnetic field changes over time then the equation for the EMF can be written as

$$\varepsilon = -N\pi r^2\frac{\Delta B}{\Delta t} \qquad \text{Eq. 3.)}$$

Here ${}^{\Delta B}/_{\Delta t}$ represents the change in the magnetic field over time, and πr^2 represents the cross sectional area of the loop. We may have a situation where there is more then 1 loop in the time varying magnetic field. N represents the number of loops of cross sectional area πr^2. Close analysis of equation 3 indicates that there are two ways to increase the induced EMF in the loop. One way is to increase the number of loops, N. The other is to increase the rate of change of the magnetic field, ${}^{\Delta B}/_{\Delta t}$.

In this experiment we will attach a magnet to spinning rod. A coil will be fixed beside the rod and the magnet will pass by the coil. The moving magnet and the fixed coil will produce an EMF in the terminals of the coil. We will see how the rate of change of the magnetic field, ${}^{\Delta B}/_{\Delta t,}$ and the number of loops in the coil affects the EMF produced.

Set-up:

In this experiment we will control the rate of change of the magnetic field by the speed of the rotating rod. The period of rotation of the magnet can be measured directly from the computer data. The circumference of motion, with this period then gives the velocity of the magnet. The voltage probes from the interface box's channel B will pick-up the voltage that is induced by the moving magnet in the coil when the magnet passes by the coil. Another clamp holds the magnetic field probe behind the coil so that the total magnetic field can also be monitored. This can be plugged into channel A.

Figure 2 illustrates the equipment set-up. Run the datastudio program using the activity induction2.ds. After you take data, determine the derivative of the magnetic field and plot it on the voltage graph. Here is how you do this. The graph of the derivative should appear, super imposed over the induced emf graph. If they are not exactly matching then adjust the sign and magnitude of the multiplying factor in front of the derivative to make them match. Click on the Y4 function on the datalist to change the multiplying factor.

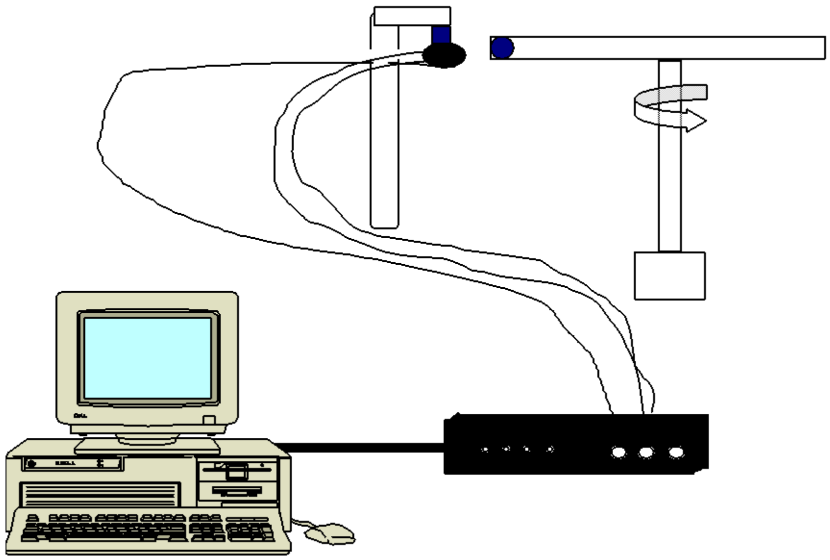

Figure 2. The voltage probe will sense the EMF created by the magnet moving by the coil and the computer will display this signal. The magnetic field sensor will sense the magnetic field through the coil.

Part 1:

SINGLE DATA RUN

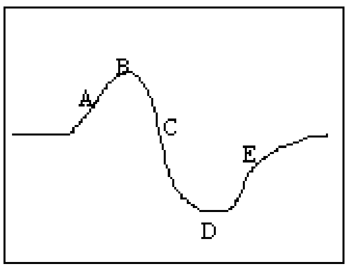

Figure 3. The electric potential graph given above is similar to the one you will find in part 1. Your data screen also includes the total magnetic field (B) and the derivative of the total magnetic field. Use this figure as a map for your discussion of what is happening to the magnetic field and induced EMF at each of the lettered times.

Spin the magnet on the rod so that it quickly passes the coil-sensor bundle.

Make the derivative graph as described above.

Zoom in on a single peak in the magnetic field and lock the EMF graph into the same time axis (little magnifying glass and box off the peak, then click on the lock).

Make a printout of your computer screen with the B field, EMF and derivative of the B field traces on it.

Draw lines vertically on your printout from the starting positions marked on figure 3 of the voltage above, to the magnetic field curve. On your printout, you should now be able to see how the magnetic and induced EMF quantities match up.

Do four more runs in which you fit the derivative by adjusting the multiplicative factor each time. Write down the five values of the multiplicative factor.

Extra questions:

Why are the maximum and minimum electric potentials produced at positions B and D?
What is happening to the Magnetic field in locations B and D?
Why is the electric potential zero in position C?
What is happening to the Magnetic field in location C?
Why does the derivative of the B field match up with the EMF?
Find out the number of turns of the coil (probably 2000) and multiply it by the area of the coil ($N\pi r^2$) . Calculate an average and standard deviation for the multiplicative factors you found before. Does the error range of multiplicative factors include the expected value $N\pi r^2$? These two calculations of the number of turns may be different by as much as 50%, why?

Part 2:

Make a single data run in this part of the lab. Spin the arm with as large a rotation rate as possible safely. Begin taking data and do not stop the data taking until the spin comes to a stop. To fill in the data table use only the peaks which show a constant maximum B Field. Write the values of the maximum B field for the last 10 spins and put it in a column next to the value of the measured peak to trough signal from the coil.

We would like to investigate the relationship between the rate of change of the magnetic flux and the EMF produced in the coil. With the above set-up, the rate of change of the magnetic flux is controlled by the speed of the turning rod. The peak to peak voltage difference on the computer screen will determine the effect of the speed on the EMF. Find out the time it takes to make a rotation by measuring from peak to consecutive peak on the magnetic field graph. Each time determines the speed magnet by dividing circumference over time. Table 1 is a typical data table. From the data table make a graph of peak to trough EMF versus velocity.

Example table:

Rotation	Time of rotation	Velocity $= 2\pi R/T$	Peak to Trough Voltage	Maximum B field
1	T_1	V_1	ε_1	B_1
2	T_2	V_2	ε_2	B_2
3	T_3	V_3	ε_3	B_3
4	T_4	V_4	ε_4	B_4
5	T_5	V_5	ε_5	B_5
6	T_6	V_6	ε_6	B_6

Table 1 lists the velocity of the glider and the induced EMF on the coil with the maximum B field from the Hall probe.

Extra questions:

What is happening to the Maximum value of the B field with increasing velocity of the magnet?

How is it that the Maximum value of the B field does not change but the electric potential keeps getting larger? Doesn't the coil need more B field to make more electric potential?

Questions:

1.) Were your two estimates of the number of turns close to one another?

2.) Explain the shape of the induced EMF curve in part 1).

3.) How does the speed of the glider affect the rate of change of the magnetic field and the induced EMF?

4.) How does the number of loops affect the EMF produced?

Problems:

1.) A loop of radius 20 cm is placed in an external magnetic field of strength 0.20 T such that the plane of the coil is perpendicular to the field. The coil is pulled out of the field in a time of 0.3 s. Find the average induced EMF during this time interval.

2.) A 500-turn circular loop coil 15.0 cm in diameter is initially aligned so that its axis is parallel to the Earth's magnetic field. In 2.77 ms the coil is flipped so that its axis is perpendicular to the Earth's magnetic field. If a voltage of 0.166 V is induced in the coil, what is the value of the Earth's magnetic field?