Faraday's Law of Induction - MBL

In this experiment you will investigate different aspects of Faraday's Law of Induction. A computer will be used to collect, display, and help you analyze the data.

I. Theory

Magnetic flux, Φ, is a measure of the number of magnetic field lines passing through an area. If the magnetic field vector **B** is not constant over the area, one must integrate (or sum up) over that area:

$$\Phi = \int_{area} \mathbf{B} \cdot d\mathbf{A} \quad or \quad \sum_{area} \mathbf{B} \cdot \Delta\mathbf{A} \tag{1}$$

Faraday's Law states that a change in magnetic flux can induce a voltage in a coil of wire. This is known as the induced emf.

$$V = -N\frac{d\Phi}{dt} \tag{2}$$

where $d\Phi/dt$ is the rate of change of the flux Φ and N is the number of turns in the coil.

The experiment consists of dropping a bar magnet through a coil of area A. Equation (2) can be written in terms of how the magnetic field through the coil changes over time, since A is constant:

$$V = -N\frac{d\Phi}{dt} = -NA\frac{dB_z}{dt} \tag{3}$$

The vertical component of the field, B_Z, at the coil will vary because the magnet is in motion.

$$\frac{dB_z}{dt} = \frac{dB_z}{dz}\frac{dz}{dt} = \frac{dB_z}{dz}v_z(t) \tag{4}$$

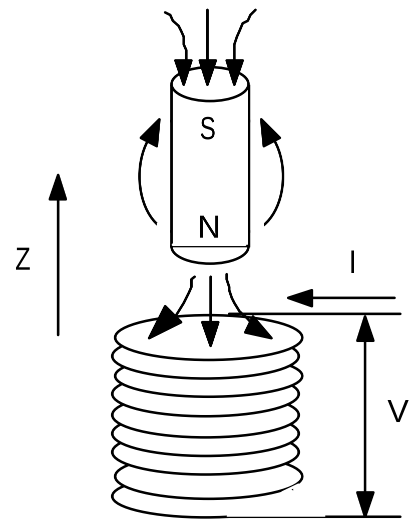
$$V = -NA\frac{dB_z}{dz}v_z(t) \tag{5}$$

You can vary the magnet's velocity by adjusting the height from which the magnet falls. You can vary the number of turns by selecting the various coil windings. These are the relationships that you will investigate with the measurements you make in this experiment.

From graphs of the induced emf vs. time, you will be able to measure the area under the curves, A_c .

$$A_c = \int_{t_1}^{t_2} V\,dt = \int_{\Phi_1}^{\Phi_2} -N\,d\Phi = -N\,(\Phi_2 - \Phi_1) \tag{6}$$

A diagram of the experimental apparatus:



By following the procedure below you can measure the relationship between the induced emf, the number of turns N, and the magnet's speed, given by Eq. (5) above. This is done by dropping a magnet from different heights through one coil and from the same height through different coils. The emf or voltage, V, induced by this procedure will last for no more than 0.2 s, which means that to study it quantitatively you will need a fast device to gather and store the voltage vs. time data. The computer will do this. The computer starts recording the data when the voltage reaches some trigger value. The digitized data are then stored for your analysis.

PROCEDURE

NOTE: The bar magnets have strong enough fields to destroy the magnetic memory of computer disks; **please keep the magnets away from any disks!**

Part I – Familiarizing yourself with the method.

1. Before recording any data, always zero the voltage sensor.

2. The computer is configured to start collecting data once the voltage exceeds a certain threshold, and to collect data for 0.15 seconds. You can change these settings if you wish by going to **Data Collection** in the **Setup** menu. You can modify the threshold voltage in **Triggering**, and the data rate and sampling time in **Sampling**.

3. The computer will display two graphs, one showing the induced voltage in the coil as a function of time, and the other showing the magnetic flux, multiplied by the number of turns, as a function of time.

Question 1 – Keeping in mind that the induced voltage is proportional to the **rate of change** of flux, explain why the two graphs look the way they do.

4. Tell the computer to collect data by hitting Collect , and drop the magnet down the tube through the coil, with the north pole of the magnet facing **down**. You should see two graphs and a table of the data. There are several parameters to measure off the voltage graph. Record each of these:

- The peak voltage of the first peak
- The peak voltage of the second peak
- The integral (area under the curve) of the first peak
- The integral (area under the curve) of the second peak

Peak values can be found easily by clicking-and-dragging to select a region of the graph, and then hitting the STAT button, . Integrals can be found in a similar way, selecting a particular peak and hitting the integral button, . Note that the best way to select the region on the graph to do the integral of is to select data in the table. This way you can be sure the region being integrated covers the entire peak, and does not include any part of the other peak.

Question 2 – How do the peak voltages of the two peaks compare? Is one always larger than the other? If so, what would explain this?

Question 3 – How do the areas under each peak compare? Should these areas be the same or should one be larger than the other? Explain.

3. After telling the computer to record more data, drop the magnet through the coil with the north pole of the magnet facing **up**.

Question 4 – Explain the difference between the curve you get with the north pole up and what you got before with the north pole down. There are at least two other ways to change the experimental setup to produce the same effect as reversing the magnet. Find two ways to do this.

Part II – Investigating the dependence on N, the number of turns in the coil.

1. You have a number of different coils available to you. Use these to determine how the induced voltage depends on N, the number of turns in the coil. Think carefully about what variables you should keep constant, and what numbers are relevant to record, before you start.

Question 5 – What does your data indicate about the dependence on N, the number of turns in the coil? How are the maximum and minimum voltages affected by N? How is the area under the curve affected by N? What is the expected dependence?

Part III – Investigating the dependence on v_z, the speed of the magnet through the coil.

1. Now investigate carefully how the induced voltage is affected by the speed of the magnet. Once again, think carefully about what numbers are relevant to record and what variables you should keep constant. In your lab report, briefly summarize the method you come up with to see whether or not the induced voltage depends on speed, and if so how it depends on speed.

Question 6 – How does the area under the curve for the peaks depend on the speed of the magnet? How do the maximum and minimum voltages depend on the speed of the magnet? Does your data agree with what is expected from the equations given in the Theory?

Part IV – Estimating the strength of the magnetic field of the bar magnet.

1. Choose the data from one representative trial to estimate the magnetic field of the bar magnet you've been using. Remembering that magnetic flux is the product of area and the component of the magnetic field passing perpendicularly through the area, use Equations (1) and (6) to calculate B, the magnetic field from the magnet. The factor of area in the flux should be the cross-sectional area of the magnet – this assumes that the magnetic field in the coil is confined to the magnet.

ADDITIONAL QUESTION

Question 7 – In Boston, the Earth's magnetic field has a strength of about 5.5×10^{-5} T. Would the Earth's magnetic field affect any of the measurements done in this experiment? Explain why or why not.