

Magnetic Induction

Object: To measure the electromotive force (emf) induced in a coil by a magnet dropping through the center of a coil. To construct and test transformers.

Apparatus: Voltage Sensor, coils, magnets, soft iron core, patch cords, PASCO Interface, power amplifier, computer, and Data Studio Software

FOREWORD

Part I. Induced emf

When a magnet is passed through a coil, there is a changing magnetic flux through the coil which induces an electromotive force (EMF) in the coil. According to Faraday's law of induction:

$$(1) \quad \mathcal{E} = -N \frac{\Delta\Phi}{\Delta t}$$

where \mathcal{E} = the induced emf, N is the number of turns of wire in the coil, $\frac{\Delta\phi}{\Delta t}$ is the rate of change of flux through the coil, and the minus sign reminds us that the induced emf is such that it opposes what created it.

In the first part of this experiment, a plot of the emf vs. time is made and the area under the curve is found by integration. This area represents the flux since:

$$(2) \quad \mathcal{E}\Delta t = -N\Delta\phi$$

Part II. Transformers

A transformer can be used to increase or decrease AC voltages. An AC voltage is applied to the **primary** coil of a transformer, which is surrounded by the **secondary** coil but is not electrically connected to it. The primary coil produces a changing magnetic flux through the secondary coil, which will induce an AC voltage in the secondary coil. If the number of turns of wire in the secondary coil is *more* than the number of turns in the primary coil, the voltage induced in the secondary coil will be more than the voltage in the primary coil. This is called a step-up transformer. If the number of turns in the secondary coil is *less* than the number of turns in the primary coil, the voltage will be reduced. This is called a step-down transformer.

If the rate of change in flux through both coils is the same, we may write:

$$(3) \quad -\frac{d\phi}{dt} = \frac{\mathcal{E}_s}{N_s} = \frac{\mathcal{E}_p}{N_p}$$

From this we write:

$$(4) \quad \frac{\mathcal{E}_s}{\mathcal{E}_p} = \frac{N_s}{N_p}$$


Equation (4) tells us that the theory (based on the fact that both coils feel the same changing flux) predicts that the ratio of the voltage induced in the secondary coil to the voltage applied to the primary coil is the same as the ratio of the number of turns in the secondary coil to the number of turns in the primary coil. In this part of the experiment you will see that it is difficult to have all of the changing flux from the primary coil felt by the secondary coil. You will also see that a core made of a ferrous material such as iron can drastically change the amount of magnetic flux created by the primary coil that influences the secondary coil.

PROCEDURE

Part I. Measuring Induced EMF


In this activity, the Voltage Sensor measures the voltage (EMF) induced in a coil by a magnet as the magnet falls through the coil. The Data Studio program records and displays the induced voltage versus time and integrates the area under the curve of the voltage versus time plot to determine the magnetic flux.

Initial Equipment and Software Set-up

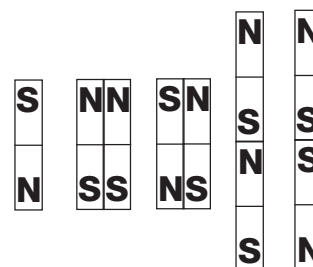
1. Start Data Studio, and select *Create Experiment*.
2. Connect the voltage sensor to the computer via an analog port on the PASCO interface.
3. Inform the software which analog port you plugged the voltage sensor into by selecting the voltage sensor icon and dragging it to the appropriate analog port.
4. Double click on the voltage sensor icon that is connected to the interface. Change the *sample rate* to 200Hz, and click **OK**.
5. Remove the inner coil and the iron core from the large coil. Mount the large coil vertically with the provided clamp and stand. The square base of the coil should rest on top of the upper prong of the clamp. Please be careful not to tighten the clamp too tight. Rotate the clamp so that it is as close to vertical as possible.
6. Connect the voltage sensor to the coil terminals.
7. Create a graph of the Voltage of the Coil vs. time.
8. Double click somewhere within the body of the actual graph, or click on the **Graph Settings** button  located on the graph toolbar to open the Graph Settings window. Select the layout tab, and under Group Measurements select the *Do Not Group* option. Select **OK**.

Data Collection

1. Prepare to drop the magnet through the coil from a height of approximately 5cm above the coil. To facilitate hitting the hole, you may wish to make a tube from a piece of paper.
2. Press the start button.
3. Drop the magnet through the coil with the north pole up. The magnets are fragile and prone to breaking if not handled properly. Either catch the magnet or drop it on to a soft surface.
4. Press the stop button.


5. Click the **autoscale**  button located on the graph tool bar.

6. Now you will drop magnets through the coil in the following configurations. You may have to use tape to assemble a couple of these configurations.



7. Press the start button before each drop, and then press the stop button. A graph will be generated each time. These graphs will only be used to make sure that data is being collected.


8. After all of the magnet configurations have been dropped, you should have six data runs.

9. Click on each graph one at a time, and click the **autoscale**  button located on the graph tool bar.

10. Print these graphs.

11. Presently the six plots are linked together on one piece of graph paper. In order to obtain information from them it will be convenient to have each plot on a different piece of graph paper. To do this, without deleting the Data Runs, delete the graphs. Now create six separate graphs by dragging the graph icon to each Data Run.

Analyzing the Data

1. Calculate the area of each peak of your first graph when the magnet was dropped through the coil with the north pole up. The area can be calculated using the **statistic tools** . Record the area of each peak on the Data Sheet.
2. Now answer all of the questions pertaining to Part I on the Data Sheet. After all of the questions have been answered, all graphs and Data Runs need to be deleted. You do not need to print each individual graph.

Part II. Step-up and Step-down Transformer

In the first part of this activity, you will put together a step-up transformer (number of turns in the secondary coil is greater than the number of turns in the primary coil). In the second part of this activity, you will use the same coils to put together a step-down transformer (number of turns in the secondary coil is less than the number of turns in the primary coil).




The power amplifier supplies the voltage to the primary coil in both transformer set-ups. The Voltage Sensor measures the induced emf (voltage) in the secondary coil. You will record the voltage in the secondary coil for two different configurations: one with an iron core inserted in the inner most coil, and one without an iron core inside the inner most coil.

The Data Studio program controls the voltage output of the power amplifier. It also collects and displays the voltages across both the primary and secondary coils. You will use the program to compare the voltage in the primary coil to the voltage of the secondary coil.

Equipment and Software Set-up for the Step-up transformer

1. Disconnect the voltage sensor from the large coil.
2. Remove the large coil from the clamp and stand.
3. Place the large coil in a horizontal position on the lab bench.
4. Insert the small coil into the larger coil.
5. Re-connect the voltage sensor to the large coil.
6. Connect the inner coil to the Power Amplifier using the red and black lead wires.
7. The voltage sensor should still be connected to an analog port.
8. Connect the Power Amplifier to the computer via an analog port on the PASCO interface. Plug the Power Amplifier into an AC outlet, and turn the power amplifier on.
9. Inform the software which analog port you plugged the Power Amplifier into by selecting the Power Amplifier icon and dragging it to the appropriate analog port.
10. A *Signal Generator* box should appear. The wave pattern should be a *Sine Wave* by default. Change the frequency to 60.0 Hz. Change the amplitude to 0.20V. The **Auto** button should already be selected. Minimize the *Signal Generator* box.
11. Tell the software that you wish to monitor the input voltage from the signal generator (which is the input to the primary coil) and the induced emf of the secondary coil with the oscilloscope. Locate the icon in the Displays section (the same section where the graph icon is located) that is labeled *Scope* and drag it to the *Output Voltage*. Now drag the *Voltage* icon from the voltage sensor to the oscilloscope display and drop it when the entire display is outlined by a dotted box.

Data Collection

1. Click the **Start** button.
2. Click in the Output Voltage control area of the oscilloscope and change the V/div to 0.05
3. Click the **trigger button**  located on the oscilloscope tool bar.
4. Use the **smart tool**  to determine the maximum Output voltage.
5. Click in the Voltage control area (this is the induced emf monitored by the voltage sensor), and adjust the V/div to an appropriate scale.
6. While the Voltage control area is active, click on the **smart tool** . Note that there should now be two **smart tool** cursers on the oscilloscope display. Each **smart tool** curser is connected to different scales so you must be careful to use the correct **smart tool** curser when measuring the maximum voltages.
7. Record the voltages on the Data Sheet.

8. Slide the iron core in to the inner most coil.
9. Repeat steps 4 through 8.
10. Click the **Stop** button.

Equipment and Software set-up for the Step-down Transformer

1. Remove the iron core from the inner most coil.
2. Maximize the *Signal Generator* box. Change the amplitude to 2.0 V, and minimize the *Signal Generator* box.
3. Disconnect the voltage sensor lead wires from the large coil.
4. Disconnect the power amplifier lead wires from the inner coil.
5. Connect the voltage sensor lead wires to the inner coil.
6. Connect the power amplifier lead wires to the large coil.

Data Collection

1. Click the **Start** button.
2. Click in the Output Voltage control area of the oscilloscope and change the V/div to 0.5
3. Use the appropriate **smart tool** to determine the maximum Output voltage.
4. Click in the Voltage control area that is monitoring the induced emf, and adjust the V/div to an appropriate scale.
5. Use the appropriate **smart tool** to determine the maximum emf voltage.
6. Record the voltages on the Data Sheet.
7. Slide the iron core in to the inner most coil.
8. Repeat steps 4 through 8.
9. Click the **Stop** button.

DATA AND CALCULATION SUMMARY

Part I.

One Magnet

Area of the first peak: _____ V•s Area of the second peak: _____ V•s

Comment on the incoming and outgoing flux:

Comment on the magnitude of the emf generated by the incoming and outgoing flux:

Comment on why the two peaks are in the opposite direction:

Compare Data Run #1 to Data Run #2:



Two Magnets

Compare Data Run #1 to Data Run #3. Consider the areas under the peaks.

N	NN
S	SS

Comment on Data Run #4:

SN
NS

Comment on Data Run #5. Why are there not four distinct peaks?

N
S
N
S

Comment on Data Run #6

N
S
S
N

DATA AND CALCULATION SUMMARY**Part II.****Step-Up Transformer**

	Primary Coil Voltage (V_p)	Secondary Coil Voltage (V_s)	Ratio V_p/V_s	Ratio N_p/N_s
Without Core				
With Core				

Step-Down Transformer

	Primary Coil Voltage (V_p)	Secondary Coil Voltage (V_s)	Ratio V_p/V_s	Ratio N_p/N_s
Without Core				
With Core				

Comment on the fact that the ratio of the voltages does not agree with the ratio of the turns when the iron core is not used.

Comment on why we used AC voltage in this laboratory activity versus DC voltage.