# FARADAY'S LAW OF INDUCTION

According to Faraday's Law a changing magnetic flux causes an induced emf in a coil of N turns given by

$$\mathbf{V} = -N \, d\Phi/dt,$$

where the magnetic flux $\Phi$ is related to the field **B** by an integral over area,

$$\Phi = \int \mathbf{B} \cdot d\mathbf{A}.$$

The significance of the minus sign is given by Lenz's Law. It says that the induced current in the loop will be in a direction that opposes the change that produces it. That is, the flux due to the field produced by the induced current will add vectorially to the applied field in such a way as to reduce the amount of flux change.

For several situations you will use the computer as both a signal generator and a digital storage oscilloscope for observing voltages induced by changing magnetic flux. There should be a two-wire lead connected to both the A and B analog channels of the computer interface.

## Computer Setup

- Double Click the "Data Studio" icon on the desktop.
- At the main menu select "Create Experiment".
- Scroll down in the "Sensors" window to "Voltage Sensor". Double Click on the voltage sensor **twice**. This should place voltage sensors in channel A and B (on your picture of the interface).
- Double Click on the channel-A voltage sensor, change the sampling rate to 200Hz, and click "OK". Repeat for the channel-B voltage sensor.
- In the bottom left window double click on "Graph", choose channel-A voltage, and click "OK". You should now see a graph of voltage vs. time for the channel-A voltage.

## Moving Magnet

Connect the Channel A wires to the larger of the two solenoid coils. You can use the stack of ceramic magnets to change the flux in this coil. Hold the stack above the hole through the coil. Press [Start] and then immediately stick the magnet into the coil and hold it there (then [Stop]). You'll probably need to hit the auto scale button () to get a good look at your trace. Then look at a new trace by pressing [Start] and then pulling the magnet from the coil (then [Stop]). Explain your observations in terms of Lenz's Law. Switch ends of the magnet and repeat the two traces.
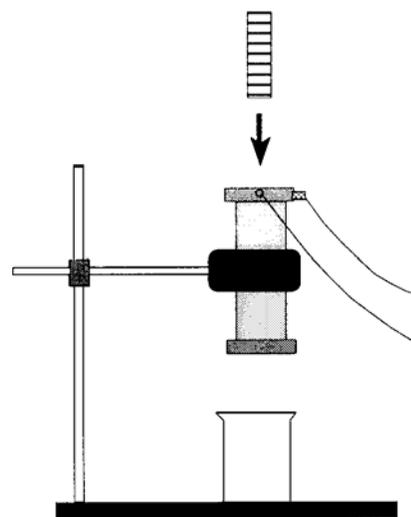
Next you are to drop the magnet through the coil while using the computer to monitor the coil voltage. How do you expect the trace to look? Mount the coil vertically by means of the stand and clamps. Place the padded can below the coil to catch the magnet. Hold the magnet vertically about one-half inch above the hole in the coil. Click on the "Experiment" tab at the top of your screen and choose "Delete All Data Runs". Click [Start] then drop the magnet through the coil (then [Stop]). Why are the two voltage pulses of different signs? Why is the second taller?

Now we'll consider flux changes by having the computer perform the integration

$$\int \mathbf{V}\, dt = -N \int (d\Phi/dt)\, dt = -N\, \Delta\Phi$$

How do you expect $\Delta\Phi_{in}$ for the magnet entering the coil to compare with $\Delta\Phi_{out}$ for the magnet leaving? What do you expect for $\Delta\Phi_{total}$ for the whole trip through the coil?
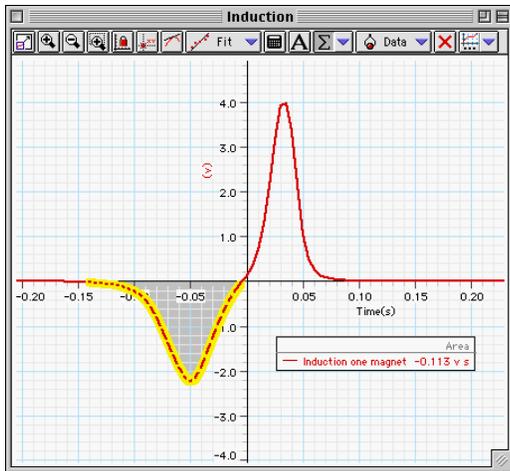


To perform the integration on your graph click on the arrow part of the sigma button (  ) and check "Area". Now click and drag your cursor across the first peak and take note of the area (the units are Vs). Repeat this for the second peak and also for the combined area. Record $N\, \Delta\Phi_{in}$, $N\, \Delta\Phi_{out}$, and $N\, \Delta\Phi_{total}$ .

Repeat these measurements for a magnet dropped from much higher above the coil. Place the plastic tube against the top of the coil to assist you in this drop. How do the sizes of the induced voltages and flux changes in this case compare to those for the first drop? Use Faraday's Law in explaining the similarities and differences. Be sure to clear your data runs again before proceeding.

## MOVING-COIL MEASUREMENT OF THE FIELD

Attach Channel A to the small coil at the end of the white plastic pipe. Double-click on voltage sensor and change the sensitivity to high. If you place the coil between the poles of the large magnet with the coil axis perpendicular to the pole faces, to the extent that the field is uniform, the flux through the coil should have magnitude



$$\left| \Phi \right| = \left| \int \mathbf{B} \cdot d\mathbf{A} \right| = BA,$$
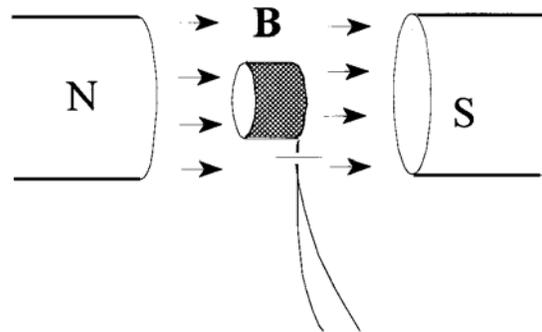
where A is the circular area enclosed by the coil. If the field direction or the coil were flipped 180˚, $\Phi$ would be the same size but would change sign. Place the coil in the field, click [Start], and then pull the coil out. The field changes from **B** to zero and the flux changes from BA to zero. Therefore, the magnitude of the field should be related to the integral of the coil voltage by

$$NBA = \left| \int V\, dt \right| .$$

Use these ideas to obtain B. You'll once again want to make use of the area function of your graph (for the integral). Make sure that the integral (the area) is in volt-seconds to get the field in tesla. Convert your result to gauss. (1 tesla = 10,000 gauss)  Make the measurement several times using differing speeds of removal of the coil from the magnet.

Next start your graph with the coil in the field, as before; then spin the pipe smoothly about its axis one half turn to flip the coil 180° without removing it from the field (wait again before hitting [Stop]). Explain the resulting trace. How could you use this graph to get the field? Again, delete all data runs before you proceed.

## TRANSFORMER

Place the smaller solenoid inside the larger one; reconnect channel A to the outer coil and channel B to the inner coil. Connect a set of wires from the back of the channel B wires at the inner coil to the signal generator (OUTPUT) on the interface. Get rid of your graph by clicking the "X" at the top right corner of your graph; then OK (this should now give you picture of your interface). Double Click on "OUTPUT" in the Signal Generator window. Set the voltage to 0.100 volts and the frequency to 60Hz. You will use an oscilloscope to observe your transformer. Double Click on "Scope" in the display window at the bottom left and choose "Voltage, ChA". In the data window click and drag "Voltage, ChB (V)" into your scope. You should now have a scope that will display both channel A and B voltage on the y-axis. Click [Start] and observe the voltages from channels A and B. Use the "V/div" and "ms/div" to get a good picture of your waves (be sure that your V/div is the same for both channels). Click [Stop]. What is the source of the signal coming from the outer core (channel A)? Use Faraday's Law in your answer to this question. What is the ratio of the two peak voltages? Would you call this a step-up or step-down transformer? Insert the iron rod into the hole in the coils. How does this "iron core" affect the ratio of the two signals? Now, what is the ratio of the two peak voltages? What must the rod have done to the size of the magnetic field inside the inner coil? Keep in mind that it is the changing flux that gives the induced voltage. Do you see why most practical transformers have iron cores?



To Channel A

Core

Connect one set of wires from the inner core to Channel B and another to the signal generator (OUTPUT).

To Channel B