

FARADAY INDUCTION

- **Conceptually** explore Faraday's and Lenz's Laws of Induction
- **Numerically** test Faraday's Law of Induction.

Equipment

Voltage logging hardware, such as the *IOLab* device

Bar magnets (2), these need not be very strong

Small coil (a few turns wound, *e.g.*, on a toilet paper roll), Larger coil (0.1 mH will do nicely), connecting wires

50-to-100-Ohm resistor

Meterstick, clear plexiglass tube; mechanical mounting hardware

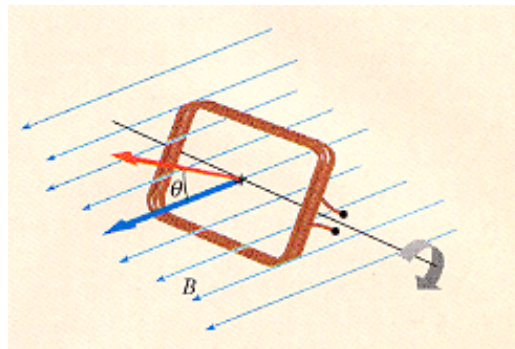


Figure 1

Theory:

Magnetic fields are created by **moving** charges. Magnetic field lines are continuous and consequently form closed paths in space. In our *sketches*, the magnetic field B at some point in space is proportional to the density of field lines. An earlier lab in this course aimed to introduce the notion of the magnetic **flux**, Φ . In Figure 1, the magnetic flux through the area of a wire loop is given by the product of B , which goes as the number of field lines per unit area, times the area A of the loop times the **cosine** of the angle between the field direction and the perpendicular to the plane of the loop.

$$\Phi = BA\cos\theta \quad (1)$$

From Equation (1) we see that the flux can change in several ways: (a) the magnetic field B at the location of the loop can change, (b) the area of the loop can change or (c) the angle between the loop and the field direction can change. As you'll see in this lab, when the magnetic flux **changes** through a loop of wire, then a voltage (oddly termed an *emf*) is induced in the loop of wire. This induced voltage is given by the equation shown below.

$$V_{induced} = -N \frac{d\Phi_{oneloop}}{dt} \quad (2)$$

where N is the number of turns or loops of wire in the coil of wire and the derivative shows the **rate of change** of the magnetic flux through any *one* of these loops. In this experiment you will try to create graphs of this induced voltage *versus* time, using your own experimentally measured data.

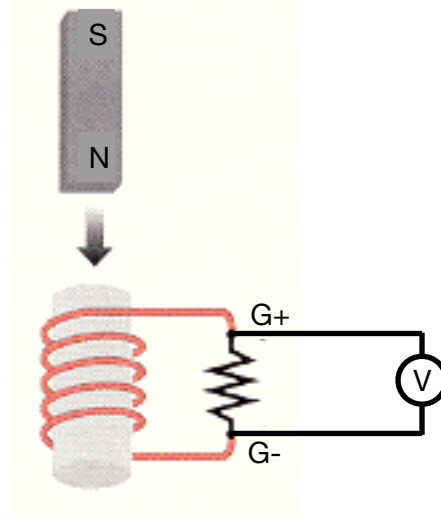


Figure 2

Examine various ways moving a magnet through a coil of wire (*e.g.*, by simply dropping the magnet, as in Figure 2, above), which will change the flux through the coil and, according to the prediction given by Equation 2, *induce* a voltage in the coil.

Direct integration of Equation (2) should allow **you** to **show** that the area under the graph of induced voltage *versus* time is equal to the total magnetic flux that has passed through the coil.

$$\Phi = -\frac{1}{N} \int V_{induced} dt \quad (3)$$

Experimental Procedures

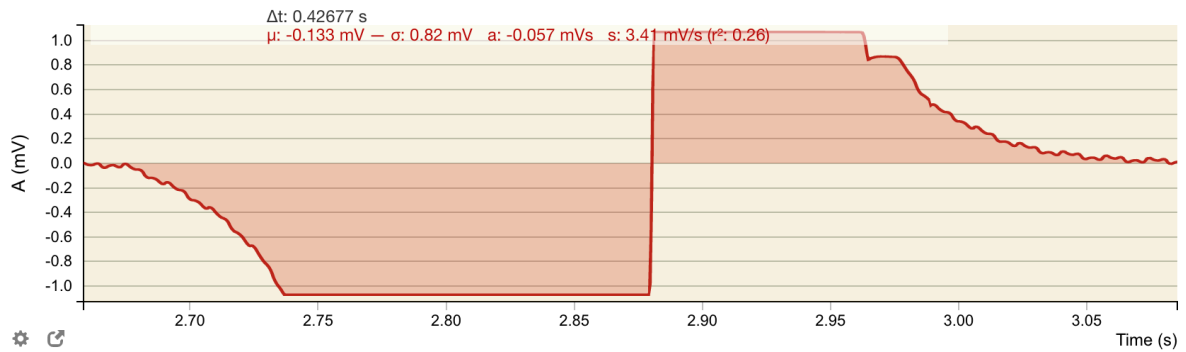
One approach to getting voltage measurements that nicely swing from NEGATIVE to POSITIVE (or vice versa) is to use the G+ and G- inputs on the IOLab device. These connectors feed a DC-coupled *differential* amplifier. You'll need to select the **High Gain** sensor in the IOLab application, in order for your measurements to be displayed and recorded.



[Use of these inputs amplifies your signal by a factor of 1400, before it is digitized (at 12-bit resolution). This means that you should **never apply a LARGE signal to these particular inputs**. (More on this, later on!)]

1. Using Figure 2 as a guide, set up your IOLab device to measure the voltage difference between G+ and G-, such that your results will be displayed as a graph of voltage-*versus*-time.
2. Connect the measurement leads from the IOLab device to a large coil.
3. Now experiment with moving the magnet into and out of the large coil. Try moving the magnet slowly and then more rapidly. Notice what happens to the induced voltage when you put the North Pole of the magnet into the coil first. Try it again with the South Pole going in first. **Carefully report your observations.**
4. Try the same experiments with a smaller coil. **Carefully report your observations and compare with those in the previous step.**

High Gain (4800 Hz)



[Data will be *truncated*, as indicated by the “flat-top” peaks shown above, if voltages exceed the allowed range of the IOLab’s differential inputs, which is only $\pm 1.17 \text{ mV}$.]

Data that exceeds the measurement limits of the inputs is said to be *saturated*. To change your signal size, you could try changing the coil that you use, the speed of the magnet, the strength of the magnet, the resistor across which you measure the voltage, **Do any of those factors *not* matter? Are there other factors that might?**

Example data that does *not* suffer from saturation is shown below:

Data sets

Fixed duration (s) :

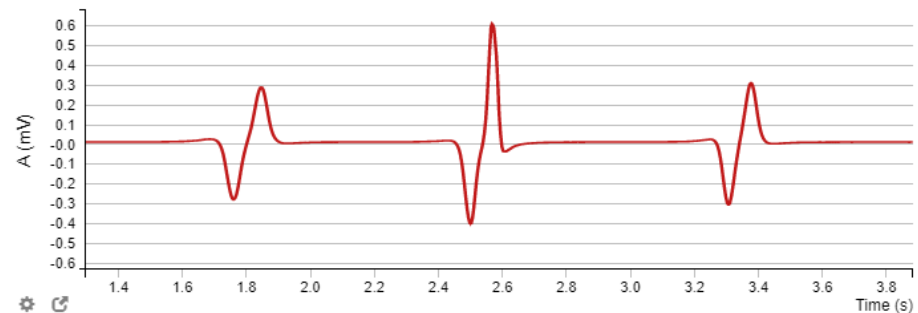
Run1 [\[Remove\]](#)

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Sensors (Remote 1)

- Accelerometer
- Analog 7
- Analog 8
- Analog 9
- Barometer
- Battery
- Digital
- Electrocardiogram (3)
- Electrocardiogram (9)
- Force
- Gyroscope
- High Gain (4800 Hz)
- Light

High Gain (4800 Hz)



[The maximum sampling rate for the IOLab’s High Gain sensor is 4800 Hz.]

- Read through the produces below, for safely dropping a magnet through a coil, and (without saturation) measuring the induced voltages:
 1. ***Magnets are brittle***, so be sure to arrange for a soft landing! (*e.g.*, set things up so that the magnet will fall into a **padded box** when dropped through the coil.
 2. If dropping the magnet from a height, plastic pipe may be used to help *guide* it through the coil. For example, you might adjust the height of the tube so that the bottom end of the magnet starts out at a distance of 1.0 m above the top of the coil.
 3. Start collecting data and drop a magnet ***North Pole first*** through the tube and the coil. You should be able to get a graph of voltage versus time like that shown in the (unsaturated) sample data. (You may want to try a few configurations until you get a graph you are happy with.) Enter the graph into your lab notebook.
 4. Find the **area under each voltage peak** and record the values on the graph.
 5. Now drop the magnet through the coil but send the ***South Pole first***. Note the differences from the previous graph.
 6. Adjust the height of the top of the tube so that you can drop the bottom of the magnet from a significantly different distance (*e.g.*, 25 cm above the top of the coil). Find the area under each voltage peak and record that on the graph.
 7. Tape two magnets together with ***like poles together*** and get the graph as you drop it through the coil from some ***specified*** height. Find the area under each voltage peak and record that on the graph.
 8. Now tape the two magnets together so that ***opposite poles are together*** at each end. Again drop this combination through the coil from some ***specified*** height. Find the area under each voltage peak and record that on the graph.

Analysis - Part A

1. How did the max value of the induced voltage depend on the speed of the magnet through the coil? Explain your results using Faraday's Law.
2. How did the polarity of the induced voltage depend on which end of the magnet was thrust into the large coil and the direction of motion of the magnet in the coil? Explain your results using the right-hand rule and Faraday's Law.
3. Compare results for a small coil with those for a large coil and explain carefully.

Analysis - Part B

1. Carefully compare the *maximum values* of the voltage induced by the falling magnet that was dropped from heights of 1.0 m and 0.25 m. Are they different and if so why? See if you can explain theoretically and analytically why the heights of the peaks for the two drop heights have the ratio that you observed.
2. Compare the *areas* for the first and second peaks for each drop of the magnet and compare the areas for the 1.0 m drop with that of the 0.25 m drop. Carefully discuss your results and try to explain what you observed. What numerical relationship would you expect between these two areas?
3. Examine the data you obtained for the two magnets *taped together end-to-end* (same Poles together; opposite Poles together). Compare the maximum peak heights *and* the area under the peaks with the results discussed in steps 1 and 2 above. See if you can explain what you observed.

Question

In Part B explain carefully why the induced voltage has one peak upward and one downward. As you noticed, these voltage peaks are not the same magnitude, but the area under each peak is nearly the same. Which peak has a larger magnitude, the earlier or later one? Explain why. What do the *areas* represent and *why* should they be nearly equal?

Initiative Options

Determine the *time* between the two peaks in the induced voltage data obtained for the two drop heights in Part B of the experiment. See if you can use basic kinematics to calculate what the time between the peaks *should be* and compare.

Note that, in previous labs, you made voltage measurements with the IOLab device's analog inputs operating in *single-ended* measurement mode, where all voltages were measured relative to ground. The range on those measurements was **limited to positive voltages alone**, from 0 to 3.3 Volts, and so we say that those analog channels are *unipolar*. While the High-Gain Differential Amplifier allows inputs to nicely swing between positive and negative values, the allowed input range for these *bipolar* measurements is quite limited (to $\pm 1.17 \text{ mV}$). *Some* students have been able to perform bipolar differential measurements over a wider range of positive and negative voltages by measuring between the A1 and A2 inputs on the IOLab device. The fact that this does *not* work with every IOLab device suggests that there may be differences in the firmware. Will it work with your device?

More information about the *quirks* of the IOLab device inputs, including options *other than* these, are described at the link below:

<http://prod-cat-files.macmillan.cloud/MediaResources/instructorcatalog/college/digital/iolab/iOLab-analog-v2.pdf>