Physics 121 Lab 9: Electromagnetic Induction

By Faraday's Law, a change in the magnetic flux through a coil of wire results in a current flowing in the wire. By Lenz's Law, the direction of this current is such that the magnetic field that it produces opposes *the change* in the external field. These relationships between changing fields and currents are known collectively as electromagnetic induction.

Activity 1: A Moving Magnet and a Coil

1. Lay the small coil flat on the table, connect it to the voltage probe, and connect the voltage probe to channel A in the Science Workshop Interface.
2. Open PASCO Capstone, select "Table & Graph." Click on "Hardware Setup" at the left, click on the image of the Channel A port, then scroll down and select "Voltage Sensor." Click the pushpin icon to the upper right of the window displaying the Science Workshop Interface box. In the graph window, click on the "<Select Measurement>" on the y-axis and select "voltage."
3. Insert a bar magnet, with the taped end down, into the hole at the center of the small coil.
4. Click "Record" and then quickly lift the bar magnet straight up and then click "Stop." The computer should display the emf induced in the small coil. Several trials may be required to get the correct timing between the start of data collection and the movement of the magnet. **Note and record *the sign* of the induced emf.**

   sign of emf: __________

5. **Prediction (before doing the experiment):** If you now quickly *lower* the magnet toward the coil, with the taped end still downward, what will be the sign of the emf and why?

   sign of emf: __________

   Why?

6. Test your prediction and record the sign of the induced emf. Does your result confirm or refute your prediction? Explain.

7. **Prediction:** What will be the sign of the induced emf if you perform the same pair of experiments with the untaped end downward and explain why?

   Moving magnet upward: ____________

   Moving magnet downward: ___________

   Why?

8. Perform the two experiments, lifting and lowering the magnet with the S-pole down. Record the sign of the induced emf in each case. Do they agree with your predictions? Why or why not?

   Moving magnet upward: _________

   Moving magnet downward: _________

   Why or why not:

9. Turn the small coil over and note the direction of the conventional current in the schematic. Check that the red connector in the voltage probe is connected to the coil at the higher voltage setting. Then, based on the signs of the emf's you observed, which end of the magnet, taped or untaped, is the N-pole? Explain your reasoning.

Activity 2: Two Coils and a Varying Current – Qualitative

1. Connect the low resistance output of the signal generator to the large coil (without the 1.2 k□. Resistor). Also connect the large coil to another voltage probe and connect that probe to Channel B in the Science Workshop Interface.
2. In Capstone, click on Hardware Setup, click on the Channel B image, and select "voltage sensor." Move the cursor to the graph window, and then on the bar that appears at the top, select the sixth icon from the right to "Add a new plot." Click on the "<Select Measurement>" on the new y-axis and select "Voltage, Ch B." Keep in mind for the following that the Ch. A voltage is in the small coil and Ch. B is in the large.
3. Turn on the generator and set the frequency to 20.0 Hz, the waveform to "sine," and the amplitude to a maximum.
4. At the bottom of the Capstone window, change the "frequency" setting to 500 Hz.
5. With the large coil laying flat on the table, place the small coil at its center so that the axes of the coils coincide. Be sure no magnets are near either coil.
6. Press 'Start' and then 'Stop' right away. Click on the "auto scale" button, the left-most icon at the top of the graph window. You should then see two sine curves displayed. The Ch. A curve is the induced emf in the small coil by the varying current in the large coil.
7. How do the amplitudes of the two curves compare? Comment, qualitatively.

8. Note that the induced emf is not in phase with the initial emf, i.e. they peak at different times. Comment on this *phase relationship* of the two curves. Does this make sense? Remember that Faraday's law says that the induced emf depends on *the rate of change of* the enclosed B field. Use this to explain the phase relationship of the two curves.

9. Tilt the small coil so that the plane of the coil is at 45° with respect to the plane of the large coil but keeping the coil at the center of the large coil. While holding the small coil in this position, collect data and note the amplitude of the induced. How does the relative amplitude of the induced emf in the small coil compared to what you saw in the previous experiment? Does this make sense? Explain.

10. Repeat for a rotation of 90° and explain the results.

11. Repeat for a rotation of 180° and explain the results.

12. Explain how the orientation of the secondary coil relative to the primary affects the response of the secondary to a varying current in the primary?

Activity 3: Two Coils and a Varying Current – Quantitative

1. Disconnect the large coil from the generator and the Pasco interface and measure its resistance using a DMM.

   R_{large} =

2. Replace the large coil in the circuit and position the small coil in the center of the large coil so that the axes of the two coils coincide.

3. Collect some data and measure the maximum of the voltage across the large coil and the maximum of the induced emf in the small coil.

   $(\text{Max } \Delta V)_{large}$ =

   $(\text{Max } \Delta V)_{small}$ =

4. Calculate the maximum current in the large coil, I_o.

   $(\text{Max } I)_{large}$ =

5. The expression for the magnetic field at the center of a circular loop with N turns is

$$B = \mu_o NI/2R,$$

   where R is the radius of the loop. Considering that the current in the large coil is $I = I_o \sin\omega t$ where I_o is the maximum current, $\omega = 2\pi f$ radians/s, and that the number of turns of wire in the large coil is $N_p = 200$, what is the magnetic field at the center of the large coil as a function of time?

   B(t) =

6. (a) What is the time derivative, dB/dt, as a function of time?

   (b) What is the maximum value of dB/dt?

7. Measure the diameter and calculate the area of the small coil, A.

d_{small} = A_{small} =

8. Faraday's law states that the induced emf in the small coil is given by

$$\varepsilon = -N_S \frac{d}{dt}\left[\int \vec{B} \cdot \hat{n} dA\right]$$

where N_s is the number of turns in the small coil and $\Phi_B = \int \vec{B} \cdot \hat{n}\, dA$ is the magnetic flux through the small coil. Calculate the maximum induced emf predicted by Faraday’s Law.

9. Quantitatively compare your measured value for the induced emf with that predicted by Faraday's law. Comment on the result.

10. In the calculations in Questions 7 and 8, above, you were instructed to use the area of the small coil. However, the B field you used (that due to the current in large coil) is non-zero throughout the area of the large coil. Why, then, should you use the area of the small coil in no. 8, instead of the area of the large coil?