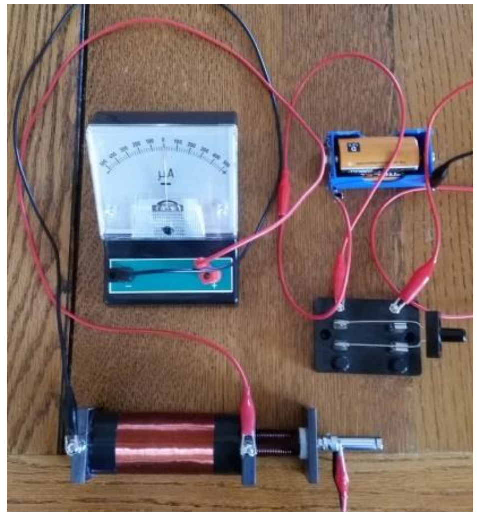
Physics 196 Lab 10: Electromagnetic Induction

Equipment:

Current Galvanometer (+/- 500 μA), Air Core Solenoid (Science Source), Large Bar Magnets (2), Battery Holder with 1.5 V D Cell Battery, SPST Switch, Nested Solenoid Assembly (Inductance, Vernier), Function Generator (PASCO), Power Cord for Function Generator, Banana-Alligator Leads, Alligator-Alligator Leads.

Layouts:



Experiment 1: Magnets in Solenoid (Qualitative). Experiment 2: Solenoid in Solenoid (Qualitative)

Experiment 3: Solenoid in Solenoid (Quantitative with Function Generator)

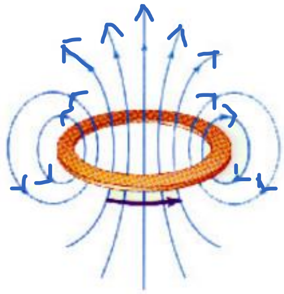
Summary:

Students will use a Sensitive Current Galvanometer to investigate Electromagnetic Induction. Faraday's Law tells us that an EMF is induced in a closed loop of wire by a changing magnetic flux. In MKS units, for a solenoid with N turns,

$$\varepsilon = -\frac{Nd\phi_B}{dt}$$

In Experiment 1 students will observe current in a large solenoid (due to induced EMF) as permanent magnets are inserted and removed from the interior of the solenoid with different rates, directions, and orientations. They will also compare the direction of the induced current to what they would expect from Lenz's Law. In experiment 2 students will use a battery and a switch to create a changing magnetic flux with a small solenoid and observe the induced current in a larger solenoid which surrounds the small solenoid. In experiment 3, students will use a function generator with the nested solenoids to make quantitative measurements to verify that the induced EMF is indeed directly proportional to the time rate of change of the magnetic flux.

Prelab:



The magnetic field lines through a current loop look something like what is shown in the diagram at left. Imagine putting a second wire loop just inside the one shown, and calculating the magnetic flux through that loop:

$$\emptyset_B = \oint \vec{B} \cdot d\vec{A}$$

For 1A of current in the outer loop we could designate this flux as ϕ_{B1A}, and then the total flux for an arbitrary current I would be $\phi_B = \phi_{B1A}$ I. Thus, a changing current in the outer loop would lead to a changing flux through the inner loop which would lead to an induced EMF in the inner loop according to Faraday's Law. This induced EMF would drive a current in the inner loop, and that current would create a magnetic field in a direction which would minimize (oppose) the changing magnetic flux from the outer loop (Lenz's Law). Draw two diagrams in your lab notebook. Each should have an outer current loop with a counterclockwise current (bold arrow) and magnetic field lines (lighter arrows) as shown in the diagram. Draw an inner wire loop on both diagrams. For one diagram, sketch a graph showing the current increasing linearly as a function of time (I vs. t, line with positive slope) and for the other diagram, sketch a graph showing the current decreasing linearly as a function of time. Then the induced EMF in the inner loop, with positive being in the counterclockwise direction, should be given by Faraday's law as

$$\varepsilon = -\frac{d\emptyset_B}{dt} = -\emptyset_{B1A}\frac{dI}{dt}$$

Draw the direction of the induced EMF in the inner loop in each diagram, and thus the direction of the induced current. Use the right hand rule to calculate and show the direction of the magnetic field produced by this induced current on each diagram. Convince yourself that this induced magnetic field is in the opposite direction from the change in the primary magnetic flux. (That is, convince yourself that Lenz's Law is consistent with Faraday's Law).

Lab:

In your lab notebook, please include a description and labelled diagram of each experiment, a data table, graphs as appropriate, and a discussion of the results including comparisons between data and expected results and a conclusion. Start your lab by taping in the first page of this write-up, as usual.

Experiment 1, Current induced in a solenoid by moving permanent magnets: Connect leads from the large solenoid to the current galvanometer. Insert the N pole of a bar magnet into the solenoid from the right and observe the deflection of the galvanometer needle. Adjust the leads (if necessary) so that a positive current is observed during the time that the N pole is entering the solenoid. Make a table with the following entries, and record the observed maximum currents (including sign) as combinations of bar magnets are inserted into and removed from the solenoid from different directions, with different orientations, and at different rates:

	Insert slowly	Remove slowly	Insert medium speed	Remove medium speed	Insert quickly	Remove quickly	Insert really quickly	Remove really quickly
N pole from right								
S pole from right								
N pole from left								
S pole from left								
2 N poles aligned from right								
2 S poles aligned from right								
2 opposed magnets from right								

Discuss your observations with your lab partner in the context of Faraday's Law. Comment in your lab notebook about what you learned. Carefully observe the direction that the current must be flowing in the solenoid wires when the current galvanometer shows a positive current (positive current flows through the galvanometer from its red connector to its black connector). Then figure out the direction of the induced magnetic field for this positive current. Verify that it is consistent with Lenz's law for the case where the flux through the solenoid is increasing to the left as the North end of the magnet is being inserted from the right.

Experiment 2, Current induced in a solenoid by a changing electromagnet: Connect the outer solenoid in the nested pair to the current galvanometer. Connect the inner solenoid to the 1.5 V battery through the Single Pull Single Throw (SPST) switch, with the switch in the open position. Insert the inner solenoid about half way into the outer solenoid, and insert the steel cylinder about half way into the inner solenoid. Close the switch and write down your observations (for instance, what does the observed current do as a function of time). When you open the switch what do you observe? Now compare your observations when you close the switch with the inner solenoid inserted different amounts into the other solenoid, and the steel cylinder inserted different amounts into the inner solenoid. (The steel bar increases the strength of the magnetic field at its ends, and thus increases the flux through the outer solenoid). Discuss your observations with your lab partner, and write a discussion in your lab notebook relating your observations back to Faraday's Law. (That is, the induced current in the outer solenoid should be proportional to the change in the magnetic flux through it, and flipping the switch causes a change in current through the inner solenoid, which changes its magnetic field).

Now leave the inner solenoid connected to the battery, insert the steel cylinder all the way, and move the inner solenoid in and out of the outer solenoid at different speeds (similar to what you did with permanent magnets in Experiment 1). Discuss your observations, and compare them to what you observed with the permanent magnets. Finally, leave the inner solenoid powered and inserted all the way into the outer solenoid, and move the steel cylinder in and out of the inner solenoid. What does this tell you about how the steel cylinder changes the magnetic flux through the outer solenoid?

Experiment 3, Direct proportionality of induced current to time rate of change of magnetic flux: Leave the current galvanometer connected to the outer solenoid of the nested pair. Remove the battery and switch from the inner solenoid, and instead connect the inner solenoid to the function generator. Before turning on the function generator, completely remove the inner solenoid from the outer solenoid. (Too large of an induced current could damage the galvanometer). Adjust the function generator so that it has a triangle wave output (equal ramps up and down), it has a frequency of 0.5 Hz, and a peak voltage output of 0.1V. Insert the inner solenoid fully into the outer solenoid, and push the steel cylinder all the way into the inner solenoid. You should now observe the measured current oscillating between a fairly fixed positive value, and an equal negative value. (The meter may overshoot, so wait for it to settle on a value).

3A: In a table, record the peak value of the measured current (after settling) versus the function generator voltage output as the voltage is varied from 0.1V to 0.5V in 0.1V increments. Graph this data. Does it agree with Faraday's Law?

3B: Leave the function generator output peak voltage at 0.5V. In a table, record the peak value of the measured current (after settling) versus the function generator triangle wave frequency as the frequency is varied from 0.1Hz to 0.5Hz in 0.1Hz increments. Graph this data. Does it agree with Faraday's Law?

Discuss your results in your lab notebook in terms of the rate of change of magnetic flux through the outer solenoid. The rate of change of the flux depends on the rate of change of current to the inner solenoid, and this in turn depends both on the change in voltage, and the frequency at which the voltage is changed. Why?