EXPERIMENT 8: FARADAY'S LAW

In this experiment we will examine the validity of Faraday's Law in several experiments. We will also measure the acceleration of gravity by a crude experiment, in order to help us determine and understand the acceleration of a magnet falling in a copper tube.

ADVANCED STUDY ASSIGNMENT

1. Show that for a wire (or coil) that if the applied voltage to the wire is plotted vs time, then the area under the curve is proportional to the charge moving through the wire. (Hint: Consider the wire to have resistance R, and remember Ohm's law.)
2. Sketch a solenoid, and show a bar magnet with N end being pushed into the solenoid. Use Lenz' law to predict the direction of current in the solenoid.

BACKGROUND

Faraday's law states that the induced emf is equivalent to negative the change in magnetic flux, multiplied by N if there are more than one turn of wire. In a formula, we have $\varepsilon = - N\, d\Phi/dt$. The magnetic flux may change because of physical motion of a magnet, or of the coil through which the flux is measured, or because of a time-varying magnetic field in the presence of a coil. The effect of the induced emf may be measured by a galvanometer, a sensitive voltage sensor, or by a force effect from the induced current.

The direction of the induced current (or emf) may be found directly from the negative sign in Faraday's law, or from Lenz' law. Recall that Lenz' law states that the direction of any induced magnetic effect will always be such as to oppose the change which causes the induced effect.

PROCEDURE A

1. Turn on the black computer interface box, then turn on the computer.
2. Double click on the Data Studio icon. Select "Create an Experiment", then in the Sensor window, scroll down and highlight and double-click on Photogate icon (for digital channel one). Again double click on the Photogate icon, because we will be using two photocells.
3. Drag the icon for Table three times, onto "Velocity in Gate, Ch 1", then onto "Velocity in Gate, Ch 2" and finally onto "Velocity between any gates, Ch 2. You should see three tables, labeled 1, 2 and 3.
4. Measure the length of the metal cylinder, of the plastic cylinder containing the magnet, and the distance between the holes in the copper tube. Record all these lengths on Data Table A. In the Experiment Setup window, double click on the photogate icon connected to Digital Channel one, then select the constant tab on the screen which appears, and enter the length of the metal cylinder (in meters) as the flag length, and click OK.
5. Now double click on photogate two icon, and again select the constant tab, and enter the same length of the cylinder, and enter the distance between holes in the copper tube as the "photogate spacing", after highlighting that choice. Click OK.
6. Now take the copper tube provided and support it in a test tube clamp attached to a ring stand. Place the ring stand near the end of the table, with the copper tube placed so the top

hole is 10 to 20 cm above the table level, and the bottom hole the same distance below the table level.

7. If not already done, screw the aluminum rods into the black metal bases, and attach the photogates to the aluminum rods. Then plug one of the two photogates into digital channel one, and place it so the photocell beam goes through the higher of the two holes in the copper tube. Thus when an object falls through the copper tube it will break the light beam, and trigger the photogate. Plug the second photogate into digital channel two, and place it at the lower of the two holes in the copper tube. (To accomplish this, you need to reverse the stand holding photogate two, with the photogate hanging below the table level, and stack the stand holding photogate one on top of it. Adjust the two photogates so the (infrared) light beams go through the holes. This is done by assuring that the beam is unblocked while going through the hole. You can tell the beam is unblocked because a red light emitting diode (LED) comes on when the beam is blocked. When you think you have the photogates adjusted properly, drop the plastic cylinder containing the magnet, and you should see the photogates' LEDs blink as the magnet passes through the copper tube.
8. We will drop two cylinders through the copper tube, and record the cylinders' velocities as calculated by the computer, using the lengths we recorded. You may get additional, non-significant readings (usually very small compared to the other readings) on Table three. Ignore those readings on the data table. One cylinder is metallic, and another cylinder is plastic, containing a small powerful magnet, similar to the one used in class for a qualitative demonstration of this same effect. The plastic cylinder should be made opaque (non-transparent) either by wrapping with tape or inserting material in the empty portion of the plastic tube. The purpose of the plastic tube is to protect the magnet and give a longer length to measure.
9. Experiment with the metallic cylinder to see how the equipment works. Be sure to catch the cylinder as it falls out of the copper tube. You may find it helps to adjust the photogates so one end or the other of the photogate is close to the copper tube, rather than the copper tube being exactly in the middle of the gate. Try different arrangements, and use whatever arrangement gives fewer erroneous readings.
10. Now drop the metallic (non-magnetic) cylinder through the copper tube, four times, and record the velocities in Data Table A. Note the pattern of the velocities recorded in photogate 1, photogate 2, and between photogates 1 & 2. Calculate the acceleration of the metal cylinder by using v of photogate 1 as initial velocity, v of photogate 2 as final velocity, and the distance between the holes. One of the 5 equations of kinematics will give you the acceleration. Enter the calculated acceleration on the data table.
11. Next, delete all data in the Experiment Window, and enter the length of the magnet after double clicking on the 2 photogate icons, as above. You do not need to change the photogate spacing entry. Then drop the plastic cylinder with the magnet through the copper tube five times. Try dropping with magnet down and with magnet up, to see if there is any difference. Again calculate the acceleration and record in Data Table A. Comment on the acceleration.

PROCEDURE B

12. For this part, disconnect the photogates, virtually and physically, and connect the voltage sensor to analog channel 1. In Experimental Setup window, highlight & double-click on voltage sensor. Double-click on the voltage sensor icon below Analog Channel 1 and change

the sensitivity level to high (by using the arrow to the right of the sensitivity box) then click ok.

13. Plug the two banana plugs of the voltage sensor into the two terminals on either side of the coil on the RLC board provided. This connects the voltage sensor to the coil to measure any induced emf in the coil. Drag the icon for the graph onto the voltage sensor icon.
14. Using the magnet in the plastic cylinder, slowly pass the magnet through the coil, after clicking on Start to start collecting data. Click stop immediately after passing the magnet through the coil. Maximize the graph window, and use the magnify button at top left to enlarge the graph, until you can see it moving above and below the axis. Sketch the shape of the V vs t graph on your Data Table B. Use the Statistics button (looks like Σ) to display the statistics options. Check the area option. This function will calculate the area under (or above) the curve. Draw a box for the portion of the V vs time curve above the axis. The program should calculate the area for that region, which ASA 1 shows is proportional to the charge moved by the changing flux. Record this number in Data Table B (with + or – sign.).
15. Now draw a box around the other portion of the graph, below the axis, and again record the result, with the sign.

PROCEDURE C

16. Now you should replace the coil in the RLC circuit board with a solenoid, and connect the terminals of the solenoid to the voltage sensor. Now push the N pole of a bar magnet into the solenoid (part way), and then pull it out. Push the S pole in, and then pull it out. Record the sign of the induced emf in Data Table C. Draw a sketch for the N pole being pushed into the solenoid, and show the current induced in the coil. Does it match the direction of the induced emf shown on the graph on the computer monitor?

QUESTIONS

1. In procedure A, how close was the acceleration of the metal to 9.80 m/s^2? Give the numbers and a percent difference. Explain why you think this difference may occur.
2. Did the acceleration vary for the plastic cylinder with the magnet in the upper or lower position when dropped? Taking the magnitude of the error in question 1, what can you conclude about the acceleration of the magnet falling in the copper tube? Was there any acceleration, within the possible range of error?
3. In procedure B, how does the amount of charge moving in the two directions compare as the magnet moves completely through the coil? What would you expect for this situation, and why (consider also the result shown in procedure C).
4. Comment on the sign of the induced emf in procedure C, particularly with the reversal of in and out, and N for S.

DATA TABLE A

$L_{cylinder}$ ________________ L_{magnet} ____________________

Distance between holes ____________________

METAL CYLINDER		MAGNET IN PLASTIC	
v in gate 1	v in gate 2	v in gate 1	v in gate 2

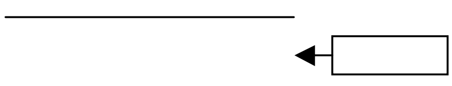
Calculated a ___________________ Calculated a ________________

DATA TABLE B

area above axis, just before or after magnet goes through coil ________

area below axis, just before or after magnet goes through coil ________

DATA TABLE C



	Sign of V
N in	
N out	
S in	
S out	