Lab 12
Faraday's Law and Lens's Law

Learning Goals:

- to measure the potential difference induced in a coil of wire by dropping magnets through the center of the coil.
- to study the effect of the direction of the moving magnetic field and the effect of the change in intensity and rate of change of intensity of the magnetic field
- to use the magnetic field in a current carrying solenoid to generate a voltage pulse in a detector solenoid.
- to use the Voltage Sensor and *the GLX interface* to measure the induced potential and to record and display the voltage, time and area data in graphical form.

Apparatus:

Qty	Instrument	Instrumental Error	Instrumental Resolution
1	GLX	± 1%	.00001 volt.sec
1	Voltage Sensor	± 0.020 volts	± 0.005 volts
1	AC/DC Electronics Lab		
4	Disk Magnets		
1	Magnetic compass		
1	Hollow wound solenoid		
2	plastic guide tubes		

Theory:

When electricity is passed through a conducting wire, a magnetic field can be detected near the wire. Micheal Faraday was one of the first scientists to reverse the process. The essence of his work is decribed in the following statement: *A changing magntic field in the presence of a conductor induces a voltage in the conductor*. Lenz expressed the direction of this voltage as a counter voltage established by a changing flux--which change opposes the change in flux initiated by the moving magnet.

Flux is a concept used to describe how well a field (electric, magnetic, or any other) lines up with a given area. For an example of flux, imagine a fan blowing air in a fixed direction. The movement of the air particles can be represented by arrows pointing in the direction of their motion. If someone held a piece of paper facing the fan, they would feel the air blowing strongly against the paper. This is analogous to a strong flux, since the arrows for the air line up with the area of the paper. If the paper is turned so that the thin edge is lined up with the arrows, the paper feels almost no push at all from the air. This is like a zero flux, since the arrows are perpendicular to, and do not line up with, the area of the paper.

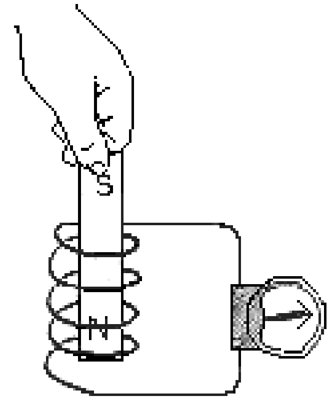
The arrows in the example are similar to the field lines for magnetic fields, and the area of the paper is similar to the area of a loop of wire (or several loops of wire). If a magnetic field lines up with the area of a loop of wire, there is a large magnetic flux. If the magnetic field is perpendicular to the loop, no magnetic flux is present. In general, the descriptions of flux above can also be described by the following equation:

$$\Phi_m = \mathbf{B} \cdot \mathbf{A} = \mathbf{BA} \cos \theta \qquad \textbf{(1)}$$

where

Φ_m ≡ "magnetic flux"
B ≡ "magnetic field"
A ≡ "area of wire loop"
θ ≡ "angle between B and A"

When a magnet is passed through a coil there is a changing magnetic flux through the coil that induces an Electromotive Force (EMF) in the coil. According to Faraday's Law of Induction: $\boldsymbol{\mathcal{E}} = -N\dfrac{\Delta\phi}{\Delta t}$



where $\boldsymbol{\varepsilon}$ is the induced EMF, N is the number of turns of wire in the detection coil, and $\dfrac{\Delta\phi}{\Delta t}$ is the time rate of change of the flux through the coil. In this activity, a plot of the EMF versus time is made and the area under the curve is found by integration. This area represents the flux since: $\boldsymbol{\mathcal{E}}\Delta t = -N\Delta\phi$.

The loops or coils of wire mentioned above, when spun into a tight coil, is called a *solenoid*. Solenoids are used in several different ways in modern devices, most notably as electromagnets. Also mentioned above, the circular area of the solenoid face may feel a flux due to some external magnetic field. However, something interesting happens in the solenoid when the magnetic flux changes. If the solenoid, or coil of wire, is in the presence of a changing magnetic field (therefore, a changing magnetic flux), a voltage is induced between the ends of the coil. This induced voltage is also called the electromotive force, or EMF, and is given the symbol "epsilon" **ε**. The equation which relates the change in magnetic flux to the induced EMF is called *Faraday's Law*:

$$\textbf{(2)} \qquad \boldsymbol{\varepsilon = -N\, \Delta\Phi_m/\Delta t}$$

where

$\boldsymbol{\varepsilon} \equiv$ "induced EMF"
$\mathbf{N} \equiv$ "number of loops in solenoid"
$\Delta\boldsymbol{\Phi}_\mathbf{m} \equiv$ "change in magnetic flux"
$\Delta\mathbf{t} \equiv$ "change in time"

When the **North** pole of a permanent magnet enters a coil of wire, because of the shape of its magnetic field, flux increases though the area of the coil and a positive voltage is induced in the coil of wire. When the **South** pole of the permanent magnet exits the coil of wire, because of the shape of the magnetic field, flux decreases through the area of the coil and a negative voltage is induced in the coil. When the **South** pole of a permanent magnet enters a coil of wire, because of the shape of its magnetic field, flux increases though the area of the coil and a negative voltage is induced in the coil of wire. When the **North** pole of the permanent magnet exits the coil of wire, because of the shape of the magnetic field, flux decreases through the area of the coil and a positive voltage is induced in the coil.

When current flows through a coil of wire, a magnetic field is established in the coil such that the north pole of this field is in the direction of the thumb of the right hand when the fingers are in the direction of the flow of positive charge through the coil of wire. This phenomenon is described by the Biot-Savart Law.

When current changes in a coil of wire, a magnetic field is established in the coil with a polarity opposite to the polarity of the magnetic field which started the flow of current in the coil. The change in magnetic flux in the coil is opposed by the coil in such a way that an increase in current in the coil is opposed or in such a way that a decrease in current in the coil is opposed. This phenomenon is described by the Lenz Law.

The negative sign in equation **(2)** is called *Lens's Law*. It means that the induced EMF opposes the change in flux. In your lab, you will be dropping magnets through a solenoid and measuring the voltage across the coiled wires to verify equation **(2)**. As the magnet falls, the magnetic field lines emanating from its surface get stronger (from the perspective of the wire) as the magnet approaches the coil. This changing magnetic field creates a changing flux, and induces a measurable EMF in the coil. As the magnet passes through the coil and exits the other end, the magnetic field gets weaker as the magnet moves further away, inducing another (and possible opposite) EMF. You will measure the induced EMF for different magnet configurations and analyze the graphs of these induced EMFs with respect to time by finding the areas under the voltage curves.

NOTE: During this experiment, keep the magnet away from the computer and from computer disks.

Prelab:

Figure A at the right shows a permanent magnet, with its South pole at the bottom, entering the top of a coil of wire. The wires from the coil are connected to an oscilloscope to indicate the voltage vs. time response of the coil. Eventually the North pole of the magnet will exit through the bottom of the coil.

Figure A

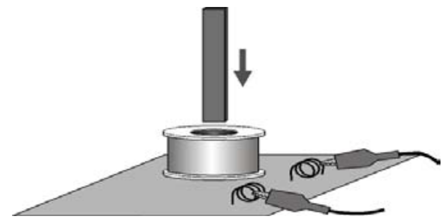
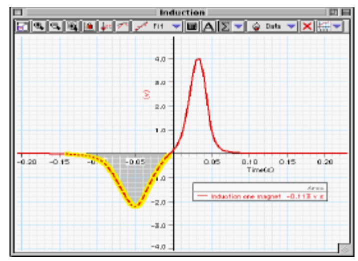


Figure B at the right is a voltage response which is negative first and positive second. It is produced as a result of the motion of the magnet described for figure A above. The width of the negative pulse represents the time when the North pole of the magnet was passing through the coil. The width of the positive pulse represents the time when the south pole of the magnet was passing through the coil. Because the magnet was moving faster with time as it falls through the coil with gravity, the second width is smaller than the first width. Because the magnet was moving faster with time as it falls through the coil with gravity, the second voltage has a larger magnitude than the first voltage. The area of both pulses should be equal because an equal amount of flux was cut by the coil for each magnet pole.

Figure B



#1 Each photos represents the face of an oscilloscope where the vertical axis is the voltage across the coil cutting the magnetic field of a magnet and the y-axis is the time when the magnet is passing through the coil of wire. Identify as North or South the polarity of the magnet entering the coil for each of the following figures. Also indicate if the magnet is speeding up or slowing down.

Figure C

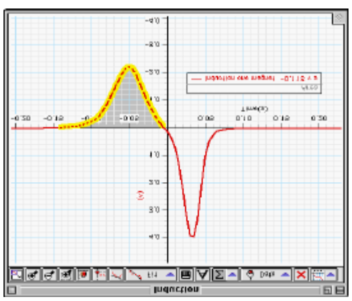


Figure D

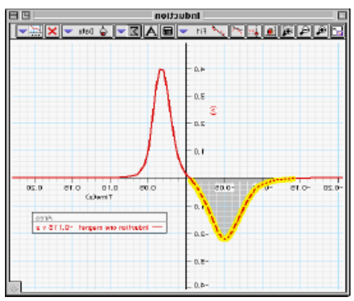
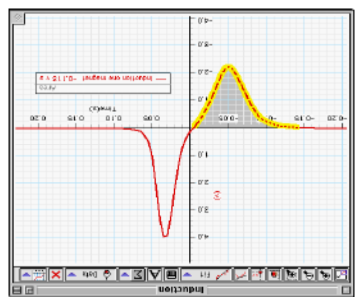


Figure E



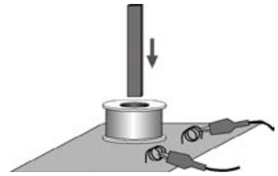
__________, __________. __________, __________. __________, __________.

#2 In figure B, the voltage response pictured is a result of a a battery connected to a coil of wire through a switch, when the switch is first closed quickly, then opened slowly. The magnetic flux from the current passing through the coil first increases, then decreases. Identify for each of the other figures if the switch is first closed quickly or first opened slowly. Also indicate if the battery connection was reversed from figure A.

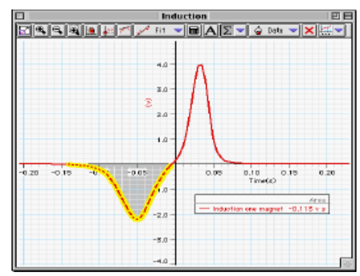
Figure C: ___________________, Figure D: ________________, Figure E: ________________.

Procedure:

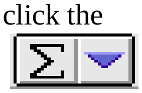
1. Connect the Voltage Sensor to the GLX and the GLX to the computer.
2. Open the *DataStudio* file: "create and experiment". Set the sample rate at 5,000 per second. Set the voltage resolution to 0.0001 volts.
3. Use the graph display of DataStudio to produce a Voltage versus Time graph.
4. Put alligator clips on the ends of the Voltage Sensor leads and attach the clips across the detector coil.



5. *Use a compass to detect the south pole of the magnet (the colored end of the compass needle points toward a south pole).* Let two magnets stick together so that their poles are SNSN. Be sure that the two magnets SNSN, when dropped through the coil, can fall freely. Hold the magnets so that the **South end** is about 2 cm above the coil and **enters the coil first**. Record in the data table the distance the South pole is above the coil.
6. Click 'Start' in *DataStudio*. Let the magnets drop South pole first through the coil. Click "stop".
7. Examine the graph of the voltage versus time. A graph with a negative pulse followed by a positive pulse should be displayed. If the positive pulse occurs first, either the magnets were dropped North pole first or the polarity of the voltage clips need be reversed. If necessary, make the correction and repeat procedure 6.



8. Rescale the Graph display to fit the data if necessary. In the Graph display, use the cursor to select a rectangle around the first peak of the voltage plot. Set up the Graph to show the area in the selected area of the curve of voltage versus time. In *DataStudio*, click the



Statistics menu button and select 'Area'.
9. Record the value of 'Area' for the left hand peak in the Data section in units of volts.sec. Also record the height of the peak in volts and the width of the peak Δt in seconds.
10. Repeat the process to find the area for the second peak. Record the value of 'Area' for the right hand peak and the value of the peak voltage with units and pulse width with units in the Data section in the notebook.
12. Label the graph with all pertinent detail then print the graph and tape it into the notebook.
13. Increase the distance of fall and record it in the data table. Click 'Start' in *DataStudio*. Let the magnets drop through the coil from this greater height. Click "stop". This graph indicates the effect of a different velocity which produces a different $\Delta\varphi/\Delta t$, thus a different induced EMF, ε.
14. Repeat procedures #6-#13 dropping two magnets NSNS with the North pole first.
15. Tape two disk magnets together so both south ends are together as NSSN . Record in the data table the distance of fall from the top of the coil. Click 'Start' in *DataStudio*. Let the magnets drop through the coil. Click "stop". Graph the effect of a different $\Delta\varphi$ which produces a different ε Δt, thus a different induced EMF, ε if Δt is constant.
16. Repeat procedures #8-#12.
17. Let four disk magnets stick together so that the south end of one is with the north end of the other NSNSNSNS. Select a high drop elevation and record it in the data table. Click 'Start' in *Data Studio*. Let the magnets drop through the coil north pole first. Click "stop". Graph the effect of a different $\Delta\varphi$ which produces a different ε Δt, thus a different induced EMF, ε if Δt is constant.
18. Repeat procedures #8-#12

Data A 1) (record in notebook)

South pole enters first	**South pole enters first**	**North pole enters first**	**North pole enters first**	**North pole enters first**
Number of magnets (2)	Number of magnets (2)	Number of magnets (2)	Number of magnets (2)	Number of magnets (4)
Magnets orientation SNSN	Magnets orientation SNSN	Magnets orientation NSNS	Magnets orientation NSSN	Magnets orientation NSNSNSNS
Entering pole: S	Entering pole: S	Entering pole: N	Entering pole: N	Entering pole: N
Drop elevation (low) cm	Drop elevation (high) cm	Drop elevation (high) cm	Drop elevation (high) cm	Drop elevation (high) cm
First pulse direction	First pulse direction	First pulse direction	First pulse direction	First pulse direction
First pulse width (sec)	First pulse width (sec)	First pulse width (sec)	First pulse width (sec)	First pulse width (sec)
Second pulse direction	Second pulse direction	Second pulse direction	Second pulse direction	Second pulse direction
Second pulse width (sec)	Second pulse width (sec)	Second pulse width (sec)	Second pulse width (sec)	Second pulse width (sec)
x	x	x	Third pulse direction	x
			Third pulse width (sec)	
First Pulse Area volt.sec	First Pulse Area volt.sec	First Pulse Area volt.sec	First Pulse Area volt.sec	First Pulse Area volt.sec
First Pulse Peak Voltage volt	First Pulse Peak Voltage volt	First Pulse Peak Voltage volt	First Pulse Peak Voltage volt	First Pulse Peak Voltage volt
Second Pulse Area volt.sec	Second Pulse Area volt.sec	Second Pulse Area volt.sec	Second Pulse Area volt.sec	Second Pulse Area volt.sec
Second Pulse Peak Voltage volt	Second Pulse Peak Voltage volt	Second Pulse Peak Voltage volt	Second Pulse Peak Voltage volt	Second Pulse Peak Voltage volt
x	x	x	Third Pulse Area volt.sec	x
x	x	x	Third Pulse Peak Voltage volt	x

A2) Graphs of Voltage versus Time for each trial. (tape in notebook)
A3) Detail if the incoming flux is equal to the outgoing flux for each trial. _____________.
A4) Explain why is the outgoing peak is higher than the incoming peak for each trial. ____.
A5) Explain why the peaks are opposite in direction for each trial. _______________.

Procedure continued:

19. Connect a dry cell in series with the push button switch and a solenoid.
20. Place the solenoid over the detector coil with a core passing through each coil and connect the coils together. Pulse the current through the solenoid using the push button switch.
21. Record the data with the voltage sensor and graphing software. Print the graph.
22. Use the graph and explain what the graph suggests about the interaction between the flux through each coil of wire when the switch is turned on, when the switch is turned off. Comment on the right hand rule noting the direction of the magnetic field, the change in flux and the direction of the induced voltage.
23. Attach the graph in the notebook with tape.

Data B (record in notebook)

Explanation of graph of procedure #19-#22. ____________________________________.