LAB 10
Magnetic Induction & RL Circuits

OBJECTIVES

1. Use Lenz's law to predict the direction of the induced current in a coil.
2. Understand the concept of eddy currents.
3. Observe the transient behavior of a series LR circuit.
4. Predict the behavior of an LR circuit.

EQUIPMENT

Capstone (Signal Generator & Voltage Sensors), power supply, bar and horseshoe magnets, decade resistor, 3400-turn solenoids, DMM, wires, hanging conducting rings, eddy current apparatus, and jumping ring apparatus.

THEORY

Faraday's and Lenz's Law
A changing magnetic flux through the coil induces an electromotive force (emf). According to Faraday's Law of Induction:

$$\varepsilon = -N\frac{d\phi_B}{dt}$$

where ε is the induced emf, ***N*** is the number of turns of wire in the coil, and $d\phi_B / dt$ is the rate of change of the magnetic flux through the coil. To find the direction of the induced emf, we use Lenz's Law, which states that the induced emf will produce a current whose magnetic field opposes the original change in flux that caused it.

RL Circuit
When a *DC* voltage is applied to an inductor and a resistor in series, a steady-state current will be established after a "long time" given by $i_0 = V_S / R_{total}$, where V_S is the source voltage and *R* is the *total* resistance in the circuit. It takes time to establish this steady-state current because the inductor creates a back-emf in response to the rise in current. The current will rise exponentially:

$$i = i_0\left(1 - e^{-t/\tau_L}\right)$$

where $\tau_L = L / R_{total}$ is the time constant and *L* is the inductance. The time constant is a measure of how long it takes the current to be established.

If, after the maximum current is established, the voltage source is turned off, the current will then decrease exponentially to zero:

$$i = i_0 e^{-t/\tau_L}$$

At any time, Kirchhoff's Loop Rule applies: The algebraic sum of all the voltages around the series circuit is zero. In other words, the voltage across the resistor plus the voltage across the inductor will add up to the source voltage.

PROCEDURE

Magnetic Induction – Lenz's Law

In this part of the lab, you will be exploring Lenz's law at different stations. At each station, first predict the direction of the induced current using Lenz's law and then do the experiment to test out your predictions.

Part 1A: Bar Magnet Moved Towards and Away from Coil

- Predict the direction of the induced current in the coil if the **N pole** of the bar magnet is moved **towards** the coil. Predict the direction of the induced current in the coil if the **S pole** of the bar magnet is moved **towards** the coil. *Record your predictions. After you have made your predictions, do the experiment and report on your results.*

- Predict the direction of the induced current in the coil if the **N pole** of the bar magnet is moved **away from** the coil. Predict the direction of the induced current in the coil if the **S pole** of the bar magnet is moved **away from** the coil. *Record your predictions. After you have made your predictions, do the experiment and report on your results.*

Part 1B: Bar Magnet Dropped through Three Coils

- Predict what a plot of V_L vs. time will look like when the N pole of the bar magnet is dropped through the three coils. *Make a sketch of your prediction.* After you have made your prediction, do the experiment. *Sketch a plot of V_L vs. time in your notes and then answer the following questions by looking at your data:*

  Why is the outgoing peak higher than the incoming peak?
  Why are the peaks opposite in direction?
  Why are the peaks (both ingoing and outgoing) from the 3 different coils different in magnitude?

Part 2A: Spinning Bar Magnet Near Coil

- *Predict how the current induced in the coil will change as the bar magnet is spun near the coil. Should the magnitude of the induced current change if the rate at which the bar magnet is spun is increased or decreased? Why or why not? After you have made your predictions, do the experiment and report on your results.*

Part 2B: Rotating Coil Near Stationary Bar Magnet

- *Predict the direction of current induced in the coil when the coil is rotated clockwise near the N pole of the bar magnet. Should the magnitude of the induced current change if the rate at which the coil is rotated is increased or decreased? Why or why not? After you have made your predictions, do the experiment and report on your results.*

- Repeat the above step, except change the direction in which you rotate the coil. Then, change which pole of the bar magnet is facing the coil. *Report on your results.*

Part 3: Running Current through One Coil in the Presence of Another Coil.

- Predict the direction of the current induced in one coil when current is suddenly "switched on" in a second nearby coil. *After you have made your prediction, do the experiment and report on your results.*

- Predict the direction of the current induced in one coil when current is suddenly "switched off" in a second nearby coil. *After you have made your prediction, do the experiment and report on your results.*

- Experiment and answer the following questions:

  How does the current induced in the first coil change if you increase or decrease the voltage supplied the second coil?

  Is there an induced current in the first coil when the current in the second coil has reached a steady-state value? Why or why not?

Part 4A: Induced Currents – Moving a Stationary Ring

- Using the concept of induced currents, see if you can make the hanging solid ring swing without touching it. *Report on your procedure.*

- *Predict whether or not you can use the same procedure to make the second ring (with a gap in it) swing.* After you have made your prediction, do the experiment. *Did the same procedure work? Why or why not?*

Part 4B: Induced Currents – Jumping Ring Apparatus

The "Jumping Ring Apparatus" sends an alternating current through the coil of wire on the ring stand. This alternating current will then produce a changing magnetic flux through a conducting ring placed on the stand. This changing magnetic flux will then induce a current through the ring that will cause it to jump.

- *Explain why the current induced in the ring causes it to jump.*

- *Experiment with the different conducting rings. Explain why some rings jump higher than others and why some rings do not jump at all.*

Part 4C: Eddy Currents – Magnetic Braking

The aluminum plates may be pulled through the strong B field in the small gap. The flux is rapidly changing in the aluminum plates, and this causes an induced emf, which produces circulating "eddy currents" in the metal. These currents oppose the change that produced them, so they resist the motion of the plate.

Eddy currents are much stronger in the solid plate than the slotted one. Why?

Also try the magnetic pendulum. Eddy currents are produced to resist the motion. This is the principle of magnetic braking.

Part 5: Microphones

A **microphone** is like a tiny generator: It makes an electrical signal when sound waves move a magnet near a coil (or a coil relative to a magnet). When you wiggle the membrane with the magnet on it, you produce pulses of current that mimic your motion. The amplifier strengthens this current and sends it to the **speaker**.

- *What does the speaker do when it receives the current? Describe and explain what you observed*.

- The **speaker** also uses a coil of wire and a magnet. *Draw a simple sketch of these.*

We also have a smaller microphone model that really works. There is a powerful magnet stuck inside the coils of wire. When you talk, the rubber membrane vibrates and the washer moves in an out of the coil. Try singing a song and see how well it reproduces your voice.

Part 6: RL Circuit

Use the Output port of Capstone to provide a low-frequency positive 5.0 V-square wave voltage for a circuit consisting of an inductor and a resistor in series. Use Capstone to record and display the voltages across the inductor and the resistor as a function of time. Use the graph display of the voltages to investigate the behavior of the LR circuit.

(a) **First** predict what the voltage across the inductor and the voltage across the resistor (as a function of time) will look like when it is connected to a 5.0 V-positive square wave. Make two predictions. One for then the square wave is at 5.0 V (current rising) and one when the square wave voltage is at 0 V (current decaying). *Sketch your predictions.*

(b) Construct the series RL circuit connected across the Capstone output. For the resistor, use the decade resistor set to 100 Ω. Set the Signal Generator to produce a 5 V "positive square wave" with a frequency of 20 Hz. Connect two Voltage Sensors to Channels A & B to record the voltage across the resistor and the voltage across the inductor. Turn on the power supply and plot the V_R and V_L on the same graph as the output of Capstone (the 5V positive square wave).

(c) *In your lab notes, make a sketch of V_R and V_L vs. time for both the current rising phase and the current decaying phase. How do the results match with your predictions? Explain in detail any discrepancies.*

(d) From your plots of V_R and V_L vs. time, calculate the internal resistance of the inductor (show all calculations). Then compare your calculation to the actual internal resistance (measure with a DMM) using a % difference.

(e) Predict how the plots of V_R and V_L vs. time will change if you increase the resistance of the decade resistor to 500 Ω. After you have made your prediction, run the experiment. In your lab notes, make a sketch of V_R and V_L vs. time for both the current rising phase and the current decaying phase.