

Lab Exercise #7: MAGNETIC INDUCTION, TRANSFORMERS, AND ALTERNATING CURRENT

OBJECTIVES

- Describe how a bar magnet moving in a coil induces an electromotive force.
- Explain qualitatively the effects of Lenz's law
- Explain how to use transformers to step-up or step-down voltages.
- Explain how resistors, capacitors, and inductors behave in an AC circuit.

EQUIPMENT

- Lenz's Law Apparatus
- Function Generator
- Coil set + iron cores
- 10 Ω Resistor
- 330 μ F Capacitor
- Wires
- Current Probe and 2 Voltage Probes
- Bar Magnet

PART ONE: MAGNETIC INDUCTION

In this part of the lab you will observe how a moving bar magnet induces an electromotive force into a coil.

PREPARATION

According to Faraday's law of induction, an electromotive force (*emf*) and thus, a current are induced in a closed current loop (e.g. a ring) if the magnetic flux (Φ_B) passing through the loop changes. For a magnetic field that is perpendicular to the plane of the circuit loop, the magnetic flux is:

$$\Phi_B = BA \quad (1)$$

where B is the absolute value of the magnetic field and A is the area the circuit encloses. For a changing magnetic flux in a coil with N loops, Faraday's law states that:

$$\varepsilon = -N \frac{\Delta\Phi_B}{\Delta t} \quad (2)$$

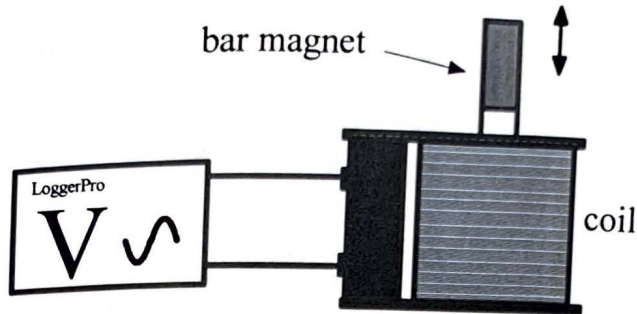
Where ε is the induced *emf*, and Φ_B is the magnetic flux through each loop of the coil.

PROCEDURE

1. If using the Dual Channel amplifier, make sure that the voltage probe is plugged into "Probe 1" of the Dual Channel amplifier. Otherwise, connect the differential voltage probe into channel 1 of the LabPro jack. Open LoggerPro. We need to tell the computer what type of experiment to do: Choose Open in the File menu. Open the PSU folder and then double-click on the Magnetic Induction file. LoggerPro should open to a voltage vs. time graph.
2. Zero your Voltage Probe
3. Connect the two leads of the Voltage Probe to the plugs on the 200-loop coil. (You do not need to pay any attention to the polarity of the leads in this part of the experiment.)

4. Push "Collect" and move a bar magnet back and forth inside the coil and observe the voltage vs. time graph.

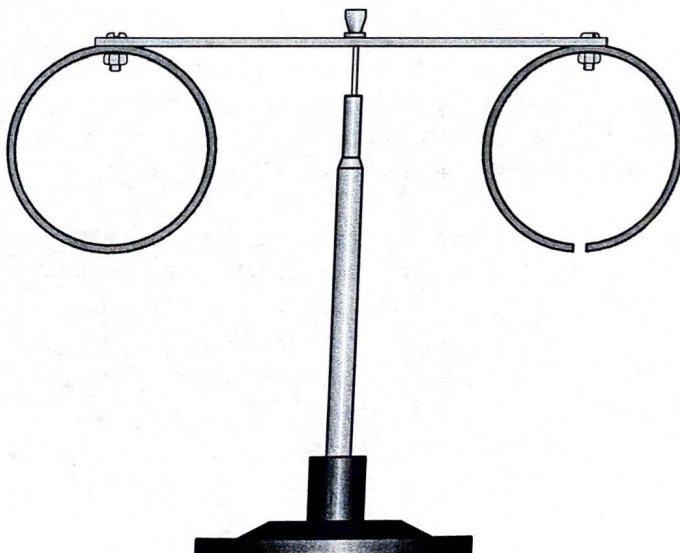
Figure 1. Magnetic induction



- Q1: What do you observe as you move the magnet into and out of the coil?
 - Q2: What do you observe when you increase and decrease the frequency of the oscillation of the magnet (the frequency with which you move the magnet into and out of the coil)?
 - Q3: Explain your observations in terms of Faraday's Law of induction.
5. Repeat the above procedure with the 800-loop coil
- Q4: How does the voltage graph change when you increase the number of loops from 200 to 800? Explain in terms of Faraday's Law of induction.

PART TWO: LENZ'S LAW

Figure 2. Lenz's apparatus



PREPARATION

In the previous part of the experiment you could observe how a changing magnetic flux causes an induced *emf* into a coil. Lenz law states that this *emf* leads to an induced current that causes a magnetic field opposing the original flux change. Now you will observe the force caused by the original and the induced magnetic fields.

PROCEDURE

The experiment should be conducted in an environment free of strong air currents or vibrations. Handle the device carefully. Excess force on the beam or rings can cause them to deform.

Place the balance beam on the support stand. Do not discard the plastic tube that protects the pivot pin. Tap one of the rings to check if the beam can rotate freely. Check that the height difference between the rings is less than 2 mm.

1. Wait until the beam stops moving. Insert the bar magnet (north pole first) repeatedly through the closed ring without touching it.
 - **Q5:** Briefly describe what you observe. Explain your observation in terms of Lenz's law.
2. Repeat step 1 but this time insert the south pole of the bar magnet first.
 - **Q6:** Briefly describe what you observe. Explain your observation in terms of Lenz's law.
3. Repeat step 1 with the open ring.
 - **Q7:** Briefly describe what you observe. Explain your observation.
4. Replace the plastic tube that protects the pivot pin.

PART THREE: TRANSFORMERS

In this part of the experiment you will find out how the arrangement of the coils, iron cores and the number of loops of the coils changes the output (or secondary) voltage in a transformer.

PREPARATION

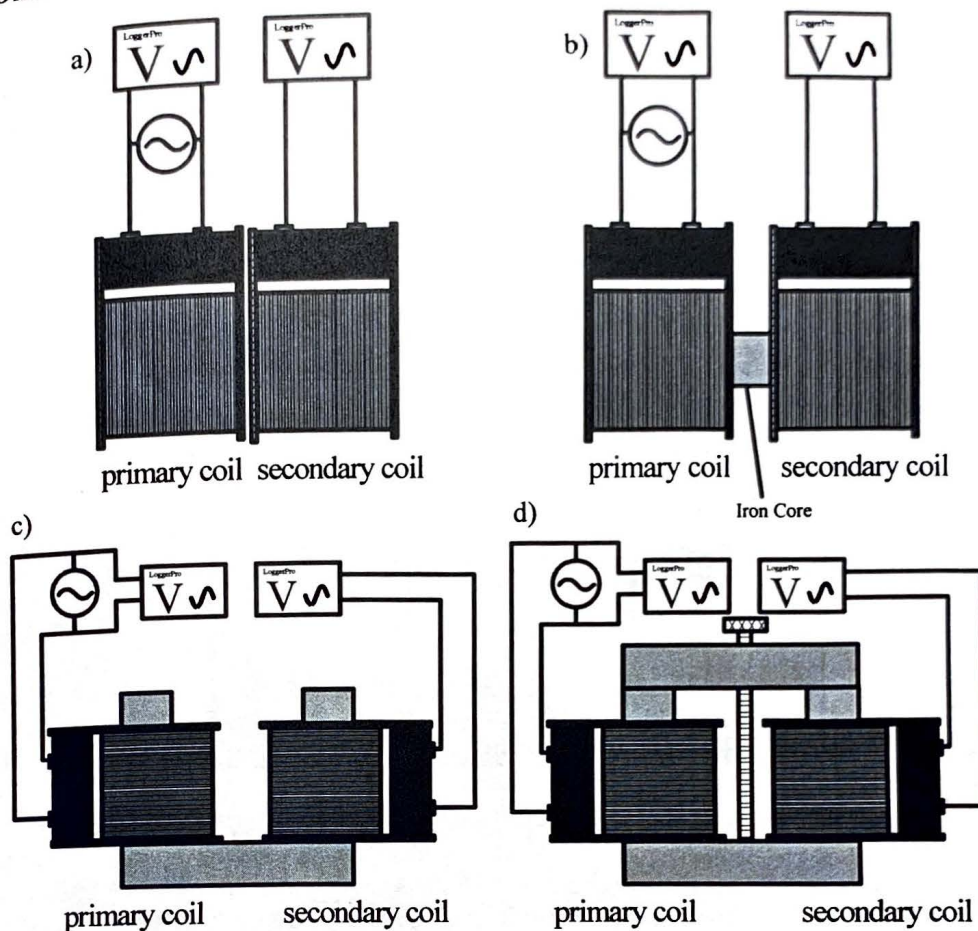
An electric transformer is a device that changes the magnitude of the voltage and current of alternating current (AC) with little power loss. Actual transformers minimize the loss due to the internal resistance of the coils, eddy currents, and hysteresis effects and are often more than 90% efficient. However, you should not expect that the transformers we make today will reach those efficiency levels.

The ability to step-up or step-down the voltage is one of the great advantages of AC. A transformer is composed of two wire coils wrapped around an iron core. The primary coil carries the alternating current from the generator. This changing current induces an alternating magnetic field according to Ampere's Law in the iron core, which then induces an alternating current in the secondary coil according to Faraday's Law. For an ideal transformer (no losses) the voltage on the primary coil, V_p , and the voltage on the secondary coil, V_s , are related to the number of loops of the primary and secondary coil N_p , N_s by the transformer equation:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \quad (3)$$

PROCEDURE

Figure 3. Different transformer arrangements



1. Set the two 400 loop coils next to each other as shown in Figure 3a.
2. Connect a second voltage probe into the dual-channel amplifier or an additional voltage probe to channel two of the LabPro jack.
3. Open LoggerPro. We need to tell the computer what type of experiment to do: Choose Open in the File menu. Open the PSU folder and then double-click on the Transformers file. You should now see two voltage vs. time graphs.
4. Zero both Voltage Probes.
5. Connect one coil (we will call this the "primary" coil) to the Lo Ω and GND plug of the function generator. Wire Voltage Probe 1 parallel to the primary coil. Next, connect the leads of Voltage Probe 2 into the plugs of the other coil, the "secondary" coil. In this part of the experiment only the amplitude of the voltage will matter and you do not need to pay any attention to the polarity of the leads. Turn the function generator on and adjust the frequency to 60Hz (the frequency of outlets in the United States) by rotating the "adjust" button. Set the waveform to the sine wave setting.

6. Push collect. Adjust the Amplitude knob on the function generator until the voltage of the primary coil peaks at ± 2 V.
7. Push stop and find the peak for the secondary coil voltage (to find the peak voltage click on Analyze and select Examine, then move the vertical line to the peak of your voltage graph. You may also click on Analyze and Statistics to get maximums). Record this voltage into Table 1.
8. Insert the straight iron rod into both the coils as seen in Figure 3b. Repeat steps 6-7.
9. Now take the iron rod out from the two coils and put them on the U-shaped iron rod as in Figure 1c. Repeat steps 6-7.
10. Set the straight iron rod on top of the coil the U shaped iron rod as in Figure 3d. Repeat steps 6-7.

Table 1

$$N_p=400, N_s=400, V_p = 2V$$

Coil arrangement	V_s (volts)
without iron rod (Figure 1a)	0 V
with iron rod (Figure 1b)	0.79 V
with U-shaped iron rod (Figure 1c)	0.64 V
with U-shaped + straight iron rod. (Figure 1d)	1.43 V

➤ Q8: Would the transformers used in this lab exercise work with DC? Why?

➤ Q9: Which set up is the most efficient in transforming voltage? Why?

11. Using the set up that gives the highest secondary voltage, find the respective secondary voltages for the following combinations of coils N_p/N_s : 400/800, 400/200, 800/200, 800/400, 200/400, 200/800, 200/200, and 800/800. Follow the same procedure as before to find the secondary voltages and record them into Table 2. You can copy V_s for $N_p=400, N_s=400$ from Table 1 into Table 2

Table 2

N_p	N_s	V_p (volts)	V_s (volts)	$V_{ratio} = \frac{V_s}{V_p}$	$N_{ratio} = \frac{N_s}{N_p}$	$eff = \frac{V_{ratio}}{N_{ratio}}$
400	400	2 V	1.43	0.71	1	0.71
400	800	1.9 V	2.8 V	1.48	2	0.74
400	200	1.9 V	0.71 V	0.37	0.5	0.74
800	200	1.9 V	0.32 V	0.168	0.25	0.672
800	400	1.9 V	0.64	0.336	0.5	0.672
200	400	1.9 V	3.1 V	1.63	2	0.815
200	800	1.9 V	6.1 V	3.2	4	0.8
Average efficiency						0.735