ARBOR SCIENTIFIC

Faraday's Law and Lenz's Law Demo Sets

98-8500 & 98-8600

INSTRUCTIONAL GUIDE

Contents

Faraday's Law and Lenz's Law Base Demo Set
- Base Plate
- Guide Tube
- Copper Collar
- 2 Banana Plugs
- Impact Pillow

Faraday's Law and Lenz's Law Complete Demo Set
- Base Demo Kit
- 5 A Max Air Core Solenoid
- Giant Neodymium Magnet with red sticker to indicate the north pole

Recommended for Activity:
- Ring Stand (66-4220)
- Burette Clamps (66-8002)

Introduction

Electromagnetism has always been one of the more challenging subjects to grasp in the course of a physics curriculum, but its uses include a wide range from seemingly mundane things like an electric toothbrush to incredible technological innovations like the Apollo missions' guidance computer, which had a physical electromagnetic memory module.

However, this highly applicable branch of physics is often taught abstractly with hand rules and equations alone. The Faraday's Law and Lenz's Law Demo Kit aims to bridge the gap between the descriptive fundamental equations and real-world application. With the pedagogy outlined here, students connect the concepts they've learned to their direct application.

Background

Michael Faraday in 1831 discovered that when a magnetic field changes state, it induces an electrical current. Faraday's early experiments were done with a wire and iron ring, and it was found that the wire acquired an electromotive force (EMF) as it was deformed. This is known as Faraday's Law of Induction.

Emil Lenz took this discovery a step further and described the "flux through the circuit." He determined the direction of the *induced* EMF and current resulting from the electromagnetic induction that Faraday observed.

The interrelatedness of these discoveries gives a clear path for the evolution of electrodynamics and lays the ground work for some of the most significant technological advancements in history.

Demonstration

Part 1

Hold up the copper collar. Ask if the copper is magnetic. Hold the tube next to the magnet to show that copper is NOT magnetic! Place the copper collar over the plastic tube. Place a small piece of tape on one end of the magnet (if not using the magnet included in the Complete Demo Set) and announce that this is the North pole. Place the impact pillow at the bottom of the tube to catch the magnet.

Warning! Neodymium magnets are quite brittle and small shards may fly off at high speed if dropped onto a hard surface.

Drop the magnet through the tube. Students will be AMAZED that the magnet nearly stops inside of the copper collar. Repeat the drop. Where did the energy go? Ask students to suggest a possible hypothesis for this strange result. Ask several students to share their hypotheses.

The correct answer can be determined by working backwards. Yes, there is a temporary upward force. This upward force must be a magnetic force. As the magnet reaches the copper tube, it must have caused something to happen to the copper tube.

Announce that a moving magnet near a coil causes a push on the electrons. As the electrons flow though the copper tube, it creates a magnet field in and around the tube. Most of the kinetic energy of the falling magnet was transformed into electrical energy. This transformation from mechanical energy is named Faraday's Law. This same effect, called electromagnetic induction, is the operating principle of all electric generators, motors, and loudspeakers. These clever devices work as low voltage motors or generators**.**

Ask students to predict what might happen if the opposite end of the magnet is dropped. Ask if they have ever heard of the concept of "Conservation of Energy." Suggest that some of the energy might be stored in the copper tube. Perhaps some of this "stored" energy could be recovered. Maybe this time, that the falling magnet might speed up as it enters the copper tube. Drop the magnet with the South pole down.

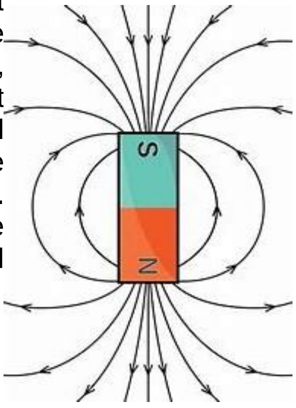
The magnet still slows down inside the copper tube. Ask, "What happened?" Ask for a possible explanation. Take several suggestions, but do NOT provide the answer.

Apparently, the temporary magnet field is ALWAYS in the opposite direction of the magnet. This observation is called **Lenz's Law**.

Wouldn't it be nice to see what is actually happening inside of the copper tube? Hold up the coil and announce that the wires are also copper. We will use now use this coil to understand what is happening!

Part 2

The wire in the coil is longer and thinner, but we can connect the ends of the coil to different types of devices to better "see" what is happening. Attach the coil to the base plate by slotting the ends of the solenoid into the cutouts and securing it in place with the hook-and-loop strap. Announce that diodes are devices that will allow electrical flow in one direction, but block flow in the opposite direction. Use the banana plugs to connect the coil to the inputs on the base plate. Adjust the tube so that the magnet will fall 30 cm before it reaches the top of the coil. Dim the lights and drop the magnet. Students will see the LED flash. Repeat the drop to make sure that everyone can see the flash. Announce, "Yes, now we can be certain that the falling magnet pushed (or pulled) electrons in one direction around the coil. This voltage produced the electrical flow that caused the LED to flash."



SHOW the diagram of the bar magnet with the magnetic field lines.

Part 3

Now close the switch on the circuit board and announce that the green LED will only light if the current flows in the opposite direction. Make sure that the tube is positioned above the bean bag and then drop the magnet. Students will be surprised that both of the LEDs flash, but with a slight time delay. Repeat this drop, asking students to determine which color flashes first.

Questions:

- Why is there a delay in between the flashes?

Apparently, the direction of the flow reverses so a possible hypothesis is that entering the coil and leaving the coil reverses the electrical flow.

Part 4

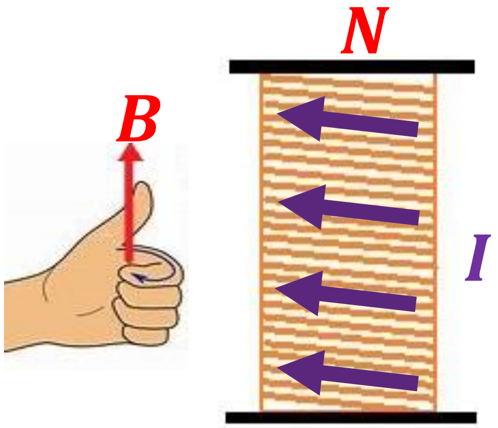
Questions:

- **"**Suppose that we repeat the experiment, but this time reverse the poles on the magnet before we drop it. What might happen? Why?"
- Ask for a few hypotheses. Be sure to ask for the explanation!

Hopefully most students will correctly predict that the LEDs will flash in the opposite order!

Drop the magnet with the opposite pole down and students understanding will be reinforced.

SHOW the diagram of the left-hand rule.

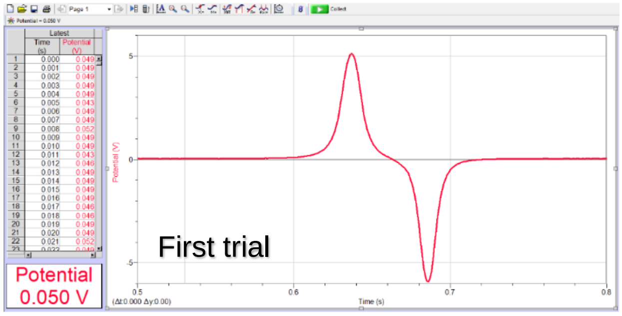


The diagram shows the direction when the N pole is facing downward. To slow the magnet, the top end of the coil will act like a N pole. When the South pole of the magnet faces downward, then the top end of the coil will act like a S pole requiring that the thumb of the left-hand points downward and the electron flow is reversed.

Part 5

Ask, "Wouldn't it be nice to actually 'see' what is happening inside the wires? Electrons are too small to see with our eyes, but we can measure the push on the electrons (voltage). Connect voltage probes to the ends of the coil and set up your datalogging software. A good starting point is to set the collection rate at 1,000 times per second and the time interval of 1.0 second. Display the graph of voltage vs. time on a large display. Press the **START** Collection and then drop the magnet as soon as you see the graph begin.

Repeat the drop and ask for students to share their observation. (The graph has both a positive peak and a negative peak.) The time between peaks is approximately __________ seconds. The second peak is slightly taller—the magnet is still speeding up inside the coil—the gravity force is slightly more that the upward magnetic force from the coil



	Latest	
	Time (s)	Potential (V)
1	0.000	0.049
2	0.001	0.049
3	0.002	0.049
4	0.003	0.049
5	0.004	0.049
6	0.005	0.043
7	0.006	0.049
8	0.007	0.049
9	0.008	0.052
10	0.009	0.049
11	0.010	0.049
12	0.011	0.043
13	0.012	0.046
14	0.013	0.049
15	0.014	0.049
16	0.015	0.049
17	0.016	0.049
18	0.017	0.046
19	0.018	0.046
20	0.019	0.049
21	0.020	0.049
22	0.021	0.052
23	0.022	0.049

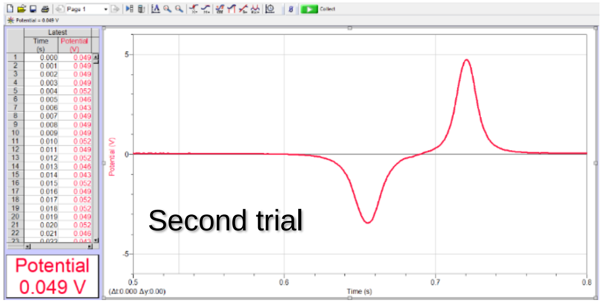
Potential
0.050 V

Part 6

Announce, “To check your understanding, we will repeat the drop, but with 2 changes. We will drop the magnet from lower height and with the opposite pole downward. Make a sketch to predict the new graph of voltage vs. time. Explain how will be similar and how it will be different.”

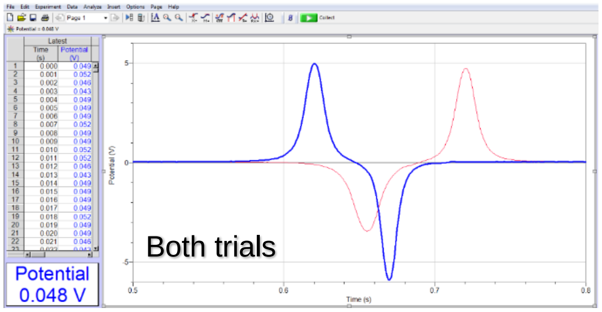
Allow students time to draw and compare graphs with their neighbors.

Next, drop the opposite pole down from a height of 15 cm. Conduct a brief discussion to review the results.



	Latest	
	Time (s)	Potential (V)
1	0.000	0.049
2	0.001	0.049
3	0.002	0.049
4	0.003	0.049
5	0.004	0.052
6	0.005	0.046
7	0.006	0.043
8	0.007	0.049
9	0.008	0.049
10	0.009	0.049
11	0.010	0.052
12	0.011	0.049
13	0.012	0.052
14	0.013	0.046
15	0.014	0.043
16	0.015	0.052
17	0.016	0.049
18	0.017	0.052
19	0.018	0.052
20	0.019	0.049
21	0.020	0.052
22	0.021	0.046

Potential
0.049 V



	Latest	
	Time (s)	Potential (V)
1	0.000	0.049
2	0.001	0.052
3	0.002	0.046
4	0.003	0.043
5	0.004	0.049
6	0.005	0.049
7	0.006	0.049
8	0.007	0.052
9	0.008	0.049
10	0.009	0.049
11	0.010	0.052
12	0.011	0.052
13	0.012	0.046
14	0.013	0.043
15	0.014	0.049
16	0.015	0.049
17	0.016	0.049
18	0.017	0.049
19	0.018	0.052
20	0.019	0.049
21	0.020	0.049
22	0.021	0.046

Potential
0.048 V

Theory

Students should recognize that the voltage from half the dropping distance is less than the higher drop. In fact, the emf (voltage) is about 0.70 the value of the higher drop. Review with the students that when an object is dropped half of the distance, then the final velocity is 0.70 of the original velocity.

$$v^2 = 2gd \rightarrow v = \sqrt{2gd}$$

By comparing the peak values of the two drops, we can correctly conclude that the emf (voltage) is directly proportional to the velocity to the first power, or:

$$emf \propto v^1$$

It also seems reasonable that the emf should depend on the value of the magnetic field, B, or:

$$emf \propto B$$

Combining these proportional statements furnishes:

$$emf \propto B\,v$$

This equation is a different form of Faraday’s Law:

$$emf = {}^{d\Phi}/_{dt}$$

Faradays Law says that the emf is the rate of change of flux (per time). (Think of the magnetic field lines cutting through the wires. Whenever the **number of cutting lines changes**, the emf (voltage) is produced.):

$$emf = -N\,{}^{\Delta(BA)}/_{\Delta t}$$

Where emf = electromotive force, N = number of turns in the coil, Δ = change, B = magnetic field strength, A = cross section Area of coil, t = time interval.

English translation: As the magnet enters the coil, a Voltage (and current) is created in one direction causing the LED to flash. As the magnet leaves the coil, a Voltage (and current) is created in the opposite direction so that the other LED flashes. Note that the minus sign indicates that the magnetic field in the coil is ALWAYS in the OPPOSITE direction of the magnet. (Named Lenz’s Law)

Pose the question, “Why are there 2 voltage spikes – in opposite directions!?” (Show the drawing of the magnet and the coil. Assume that the N pole was facing downward. As the magnet approaches the top of the coil, then the top end of the coil must act like a N pole to push upward to slow the magnet. Now as the magnet reaches the bottom of the coil, the bottom of the coil must act like a N pole to pull upward on the S pole of the magnet. The polarity of the coil must be reversed to slow the magnet.)

Part 7 (Epilogue)

Announce, “The magnet field from the copper collar was MUCH GREATER than the field from the coil. Can anyone suggest a possible reason?”

Here are the key concepts in equation form: The same voltage was produced in the coil as the tube, but the **copper collar acted like a long fat wire so it had a very small resistance**. The small resistance of the tube resulted in a much larger electrical current ($I = V/r$) and therefor a much stronger magnetic field.

Write the equation as follows:

for coil: $$I = \frac{V}{\boldsymbol{r}}$$

for copper collar: $$\boldsymbol{I} = \frac{V}{r}$$

The magnetic field inside a coil is:

$$B = \frac{-N\,\mu_0\,I}{L}$$

where N = number of turns, μ_0 = permeability constant of air*, I = current, L = length of the coil.) *Note that if iron was placed inside a current carrying coil the magnetic field would be thousands of times greater! $\mu_{\text{iron}} >> \mu_0$ air

Our civilized society depends on our electric grid. Our local electric company does NOT drop magnets through copper collars, but they use the same principle. The electricity that we get from our wall outlets is produced by turbines. The turbines use a rotational motion between coils and very strong magnets to create the emf (voltage) that we enjoy to run our appliances.

Resources

Large-format versions of each diagram in this instructional guide can be found here under the “resources” tab:

https://www.arborsci.com/products/faradays-law-and-lenzs-law-complete-demo-set

Related Products

Electromagnetic Force Demonstrator (P6-2625) The Electromagnetic Force Demonstrator is a dynamic way of showing the interaction between magnetism and electricity. Watch how the aluminum pipe travels along the track in the direction the current is applied, reinforcing the interrelated concepts of Current, Magnetic fields and the Lorentz Force.

World’s Simplest Motor (P8-8300) By building and observing a motor that converts electrical energy into motion, students discover and explore first-hand several key properties of electricity and magnetism.

Lenz’s Law Apparatus (P8-8400) Experience the fundamental principle behind electric motors with this demonstration. Drop the strongly magnetized plug through the copper pipe, and induced currents cause it to fall very slowly.