# Electromagnetic Induction

Structured

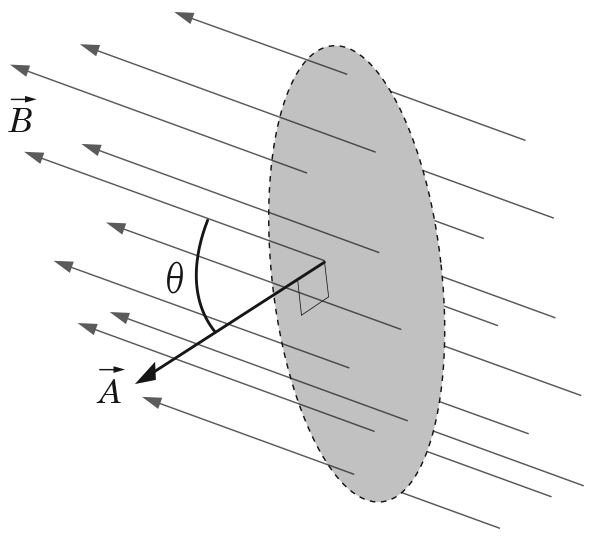
Driving Question | Objective

How is the emf induced in a wire coil affected by the total area of the coil and the rate of change of magnetic flux through the coil? Investigate how the number of loops in a coil, and the rate of change of magnetic flux through the coil affect the coil’s maximum induced emf voltage.

Materials and Equipment

|  |  |
| --- | --- |
| * Data collection system | * Magnet wire or enameled wire, fine gauge, 80 cm |
| * PASCO Wireless Voltage Sensor1 | * Strong magnet, cylindrical, 13 mm dia × 5 mm (4) |
| * 4-mm banana plug patch cord with | * Clear rigid plastic tubing, 3/4" inner-diameter, 30 cm |
| alligator clip1 (2) | * No-bounce pad, or similar padding |
|  | * Sandpaper |
|  | * Tape |

|  |
| --- |
| 1[www.pasco.com/ap41](http://www.pasco.com/ap41) |
|  |
| PASCO Wireless Voltage Sensor |

Background

Magnetic flux ΦB is a measure of the amount of magnetic field that passes through a given surface area. It is often referred to as a measure of relative magnetic field strength and can be demonstrated in a diagram as the density of magnetic field lines that pass through a given surface area.

If a uniform magnetic field  passes through a flat uniform surface, the equation for magnetic flux can be written:



 (1)

where is the vector representing the magnitude and direction of the magnetic field at the surface,  is the normal vector to the surface with area A through which the magnetic field passes, and θ is the angle between the two vectors. For magnetic field lines that pass perpendicularly through the surface, Equation 1 can be simplified to:

 (2)

When the magnetic flux through a coil of wire changes ∆ΦB, an electromotive force (emf) is induced within the coil. This emf, in turn, generates current flow in the wire and a measurable emf   
voltage .

In this lab activity, you will explore how the total area of a coil and the rate of change of magnetic flux ∆ΦB/∆t through a coil affects the maximum induced emf voltage  in the coil, and then use your data to establish a mathematical relationship between the three variables.

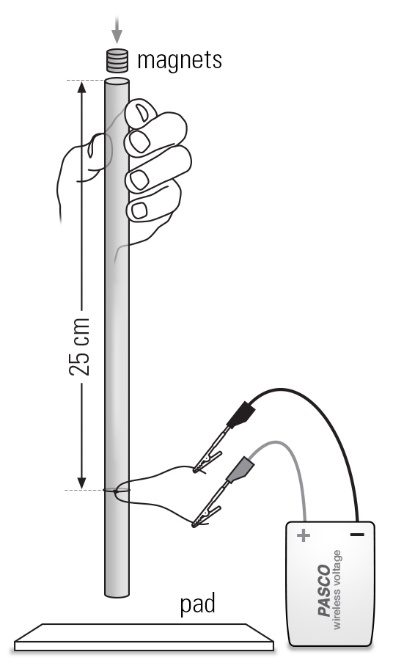
Relevant Equations

 (2)

Procedure

Part 1 – Total Area of a Coil (Number of Loops) and Maximum emf

Set Up

1. Obtain a piece of magnet wire about 80 cm long, and then use sandpaper to remove the insulation coating the ends. The ends should be shiny after completing this step.

2. Stack the magnets together, and then loosely wrap the wire once around the plastic tube and secure it with a twist. Slide the coil down the tube so it is 25 cm from the top. Use a piece of tape to hold the coil in place if needed.

NOTE: Make sure the magnet drops freely through the tube, past the coil. If not, make a looser coil or ensure the magnets are lined up well in the stack.

3. Connect the wireless voltage sensor to your data collection system, and then create a graph display of voltage versus time. Increase the sample rate to 1,000 Hz (1 kHz).

4. Connect the leads of the voltage sensor to the ends of the wire using the patch cords with alligator clips, and then zero the voltage measurement in your data collection system.

NOTE: Because you are measuring small voltages, always ensure   
the sensor is reading zero before collecting data throughout this lab.

Collect Data

5. Hold the tube vertically over the padding and hold the stack of magnets over the top of the tube. Begin recording data, and then drop the stack of magnets through the tube 4 times.

6. Stop recording data. Your graph should show 4 separate pairs of voltage spikes. Record the highest voltage reached in each pair in Table 1.

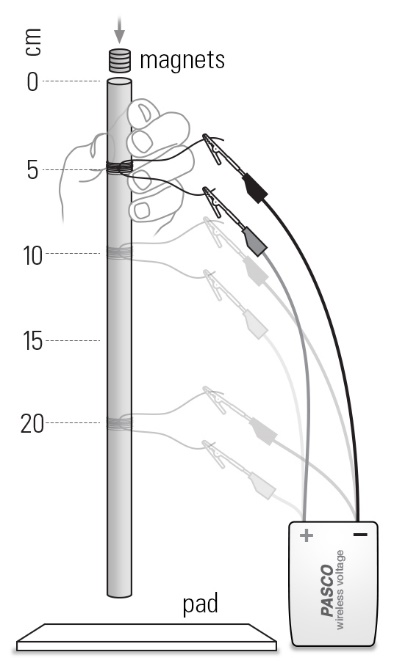
7. Untwist the coil and wrap it loosely one more time around. Your coil should now have two wraps, or twice the total area as the previous trial. Secure it again with a twist and a piece of tape if needed. Make certain the top of the coil is still 25 cm from the top of the tube.

8. Record data as you drop the magnet through the coil 4 more times. Record the four peak voltages for the 2-loop coil in Table 1.

9. Repeat the same data collection steps for 3, 4, and 5 loops in the coil.

Part 2 – Rate of Change of Magnetic Flux and Maximum emf

Set Up

10. Wrap the wire 3 more times around the tube so the coil has 8 loops. Slide the coil up the tube so the top of the coil is 5 cm below the top of the tube. Secure it with a small piece of tape if needed.

NOTE: Make sure the magnet drops freely through the tube, past the coil. If not, make a looser coil or ensure the magnets are lined up well in the stack.

Collect Data

11. Hold the tube vertically over the padding and hold the stack of magnets over the top of the tube. Begin recording data, and then drop the stack of magnets through the tube 4 times.

12. Stop recording data. Your graph should show 4 separate pairs of voltage spikes. Record the highest voltage reached in each pair in Table 2.

13. Repeat the same data collection steps with the coil 10 cm and 20 cm from the top of the tube. Record the four peak voltages for each position in Table 2.

Data Analysis

Part 1 – Total Area of a Coil (Number of Loops) and Maximum emf

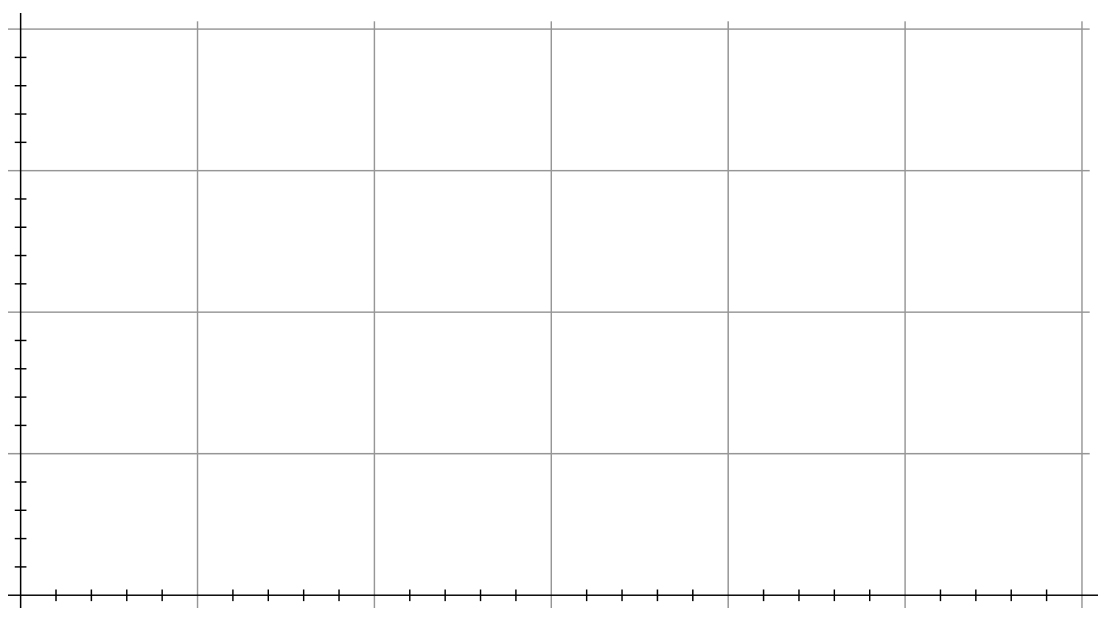
Table 1: Maximum induced emf voltage in a wire coil with varying number of loops.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Loops | Max emf Pair 1 (V) | Max emf Pair 2 (V) | Max emf Pair 3 (V) | Max emf Pair 4 (V) | Average Max emf (V) |
| 1 |  |  |  |  |  |
| 2 |  |  |  |  |  |
| 3 |  |  |  |  |  |
| 4 |  |  |  |  |  |
| 5 |  |  |  |  |  |

1. Calculate the average maximum emf for each coil. Record your results in Table 1.

2. Plot a graph of the average maximum emf voltage versus number of loops in the blank Graph 1 axes below. Be sure to label both axes with the correct scale and units.

Graph 1: Maximum emf voltage versus number of loops in a wire coil



* 3. Based on Graph 1, how is the number of loops related to the maximum induced emf in the coil (proportional, inverse, squared, et cetera)? Since the number of loops is directly proportional to the total area of the coil, how is the total area of the coil related to the maximum induced emf?

* 4. Using your Part 1 data as a guide, predict what the maximum emf voltage is for a coil with 8 loops, assuming you drop the same stack of magnets from the same height, 25 cm. Explain the reasoning for your prediction.

* 5. Check your prediction by making and testing a coil with 8 loops. Make sure you drop the same stack of magnets from the same 25-cm height, and average 4 drops for comparison.

|  |  |
| --- | --- |
| Average Max emf for an 8‑loop coil: |  |

* 6. Calculate the percent error of your prediction compared to the measured value for the 8-loop coil.

Part 2 – Rate of Change of Magnetic Flux and Maximum emf

Table 1: Maximum induced emf voltage in wire coil with varying drop height

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Drop Height  (cm) | Max emf Pair 1  (V) | Max emf Pair 2  (V) | Max emf Pair 3  (V) | Max emf Pair 4  (V) | Average Max emf (V) |
| 5 |  |  |  |  |  |
| 10 |  |  |  |  |  |
| 20 |  |  |  |  |  |

7. Calculate the average voltage of the 4 emf pairs for each drop height. Record your results in Table 2.

* 8. The magnet has an unchanging magnetic field: very strong near the magnet, and weak far from the magnet. How did the magnetic field through the coil change as the magnet fell toward it? How did the magnetic flux through the coil change as the magnet fell toward it?

* 9. The speed of the magnet through the coil increased with drop height. Did the rate of change of magnetic flux through the coil ∆ΦB/∆t increase or decrease as drop height increased? Explain your answer. Hint: the change in magnetic flux though the coil ∆ΦB was the same in every trial, regardless of the magnet’s speed.

* 10. Based on your data, how does the rate of change of magnetic flux through the coil affect the maximum emf induced in the coil?

* 11. Ignoring air resistance and the little friction from the plastic tube, the magnet was a freely-falling object in each trial. If a freely-falling object is travelling twice as fast after it has fallen 40 m than after falling 10 m, what do you predict the maximum emf would be if you drop the magnet through the same coil from a height of 40 cm? Explain your answer.

12. What happened to the sign of the emf as the magnet moved toward and then away from the coil? How can you explain this?

Analysis Questions

* 1. In this experiment, what steps did you take to change the magnetic flux through the coil of wire?

* 2. Did the rate of magnetic flux change ∆ΦB/∆t affect the induced emf in the coil? If yes, how did it affect it?

* 3. Faraday's Law of Electromagnetic Induction is written:

 (3)

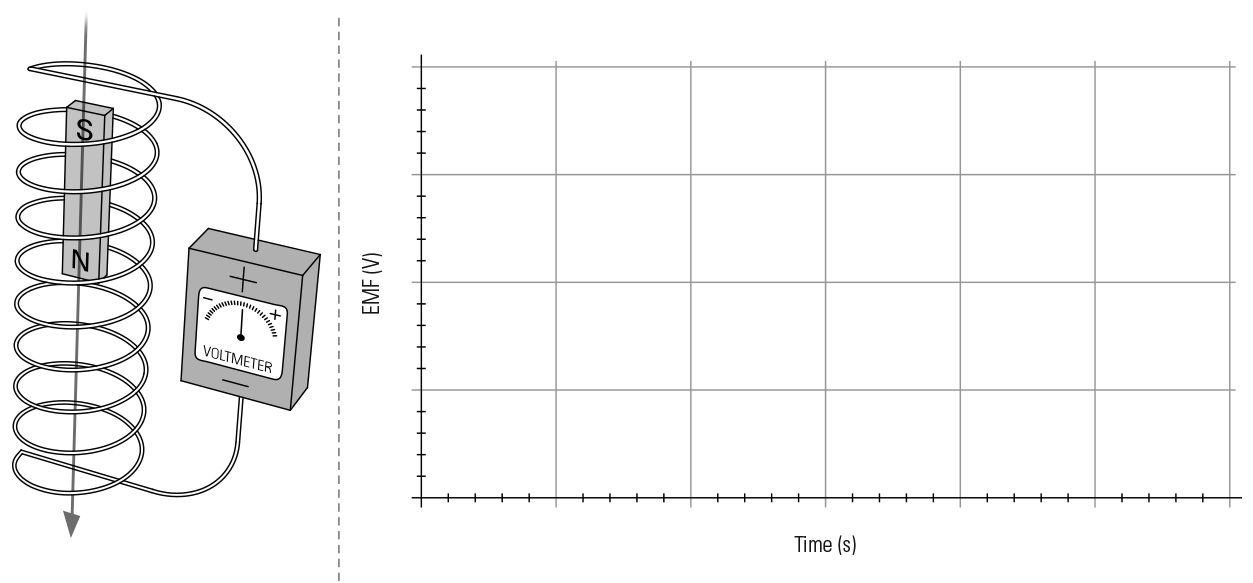
where N is the number of loops in the coil. How does your data support Faraday's Law?

* 4. How was the emf different when the magnetic flux through the coil was increasing versus when it was decreasing?

* 5. The negative sign in Faraday's Law is due to Lenz's Law, which states that the emf induced in a coil will generate current in the coil that produces a magnetic field opposing the change in flux. How does your data support Lenz's Law?

Synthesis Questions

* 1. A 4-cm long bar magnet is dropped from 2 cm above a coil of wire. If the falling bar magnet passes through the coil, north pole first (as in the diagram below), what would the graph of emf versus time look like? Sketch your answer in the blank graph axes below, starting from the time at which the magnet is dropped, and ending after the magnet has fallen out of the coil.



* 2. A maximum emf of 4 V is induced when a permanent bar magnet is dropped through a round coil of wire with 10 loops in it.

a. What would be the maximum emf voltage if the same magnet fell through the same coil, but in half the time? Explain your answer.

b. What would be the maximum emf voltage if the same magnet fell through the coil at the original speed, but the coil had had 30 loops instead of 10? Explain your answer.

c. What would be the maximum emf voltage if the same magnet fell through the original coil at the original speed, but you dropped the opposite end of the magnet through the coil first? Explain your answer.