

Lenz Law:
Verifying the Lenz Law by Measuring the
Electric Current Flowing through a Coil
Created by an External Magnetic Field
(*Teacher's Guide*)

OVERVIEW

Students will make a copper coil by coiling up a copper wire in their hands. They will then move a magnet several times relative to the coil to prove the Faraday and Lenz Laws.

****WARNING**** MOVE ALL ELECTRONIC DEVICES AWAY FROM THE MAGNET TO PREVENT THEM FROM BEING ADVERSELY AFFECTED BY THE MAGNETIC FIELD.

MATERIALS NEEDED

Ward's DataHub
USB Communication Cable*
Red and Black banana to banana connector cables
Ten meters of 1 mm copper wire
A neodymium magnet with at least 4000 gauss rating

* – *The USB connector cable is not needed if you are using a Bluetooth enabled device.*

NUMBER OF USES

This demonstration can be performed repeatedly.

FRAMEWORK FOR K-12 SCIENCE EDUCATION © 2012

* The Dimension 1 practices listed below are called out as **bold** words throughout the activity.

Dimension 1 Science and Engineering Practices	✓	Asking questions (for science) and defining problems (for engineering)	✓	Use mathematics and computational thinking
	✓	Developing and using models	✓	Constructing explanations (for science) and designing solutions (for engineering)
	✓	Planning and carrying out investigations	✓	Engaging in argument from evidence
	✓	Analyzing and interpreting data	✓	Obtaining, evaluating, and communicating information

Dimension 2 Cross Cutting Concepts	✓	Patterns	✓	Energy and matter: Flows, cycles, and conservation
	✓	Cause and effect: Mechanism and explanation	✓	Structure and function
	✓	Scale, proportion, and quantity		Stability and change
	✓	Systems and system models		

Dimension 3 Core Concepts	Discipline		Core Idea Focus	
	Physical Science		PS4: Waves and Their Applications in Technologies for Information Transfer	
			PS4.B: Electromagnetic Radiation	

NGSS Standards	Middle School Standards Covered		High School Standards Covered	
	MS.PS-WER: Waves and Electromagnetic Radiation		HS.PS-ER: Electromagnetic Radiation	

NATIONAL SCIENCE EDUCATION STANDARDS © 2002

Content Standards (K-12)			
✓	Systems, order, and organization	✓	Evolution and equilibrium
✓	Evidence, models, and explanation	✓	Form and Function
✓	Constancy, change, and measurement		

Physical Science Standards Middle School		Physical Science Standards High School	
✓	Properties and Changes of Properties in Matter	✓	Structure of Atoms
✓	Motion and Forces	✓	Structure and Properties of Matter
✓	Transfer of Energy		Chemical Reactions
		✓	Motion and Forces
			Conservation of Energy and Increase in Disorder
			Interactions of Energy and Matter

✓ Indicates Standards Covered in Activity

LEARNING OBJECTIVES

Core Objectives (National Standards):

- Develop the ability to refine ill-defined questions and direct to phenomena that can be described, explained, or predicted through scientific means.
- Develop the ability to observe, measure accurately, identify and control variables.
- Decide what evidence can be used to support or refute a hypothesis.
- Gather, store, retrieve, and analyze data.
- Become confident at communicating methods, instructions, observations, and results with others.

Activity Objectives:

The purpose of this activity is to study the relationship between an electric current inside a conductor and an external magnetic field. The electric current will be measured by the Ward's DataHub electric current sensor.

Time Requirement:

45–60 minutes

VOCABULARY

Conductor: A material that an electric current can pass through easily.

Electric Charge: A physical property of matter which causes it to experience a force when near other electrically charged matter. Electric charge comes in two types, positive and negative.

Electric Current: A flow of electricity through a conductor.

Electric Field: A region around a charged particle or object within which a force would be exerted on other charged particles or objects.

Electricity: Producing energy through charged particles.

Electron: A small particle that carries one unit of negative energy.

Electromagnet: A metal core that creates a very strong magnet after a current passes through wire that is coiled around it.

Electromotive Force: A difference in potential that tends to give rise to an electric current.

Faraday's Law: A law stating that when the magnetic flux linking a circuit changes, an electromotive force is induced in the circuit proportional to the rate of change of the flux linkage.

Force: Power that's active.

Insulator: A material that an electric current cannot pass through easily.

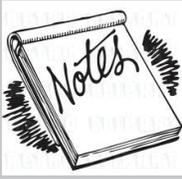
Lenz Law: Common way of understanding how electromagnetic circuits must always obey Newton's Third Law.

Magnet: An object made out of material such as iron that have magnetic properties.

Magnetic Field: Space around a magnet where a magnet acts.

Magnetic Flux: A measure of the strength of a magnetic field over a given area.

Magnetic Pole: Ends of a magnet.



Teacher Notes

INTRODUCTION

Magnetic fields and electric current are closely related. We can use an electric current flowing inside a motor coil to rotate the motor and convert electricity into a mechanical rotation; while on the other hand in a generator we rotate a coil inside a magnetic field to create electricity and produce current that will flow from the generator coil.

TRY THIS!

Carefully cut a beverage can approximately 5 cm from the base to obtain a small metal container. Place it on a deep plate full of water. Fix a big magnet to the end of a rope. Spin the magnet over the center of the can without touching the sides... What happens to the can?



- **What do you think the magnets on the inside of headphones or loudspeakers are for? Explain.**
- **In what situations have you used magnets or experienced with magnetism?**

Carry out the experiment activity with your class so that at the end students will be able to answer the following question:

- **Can we induce an electric current using a magnet?**



DID YOU KNOW?

Before technology, electromagnetism was only experienced in the form of lightning. This is electromagnetic radiation in the form of light.

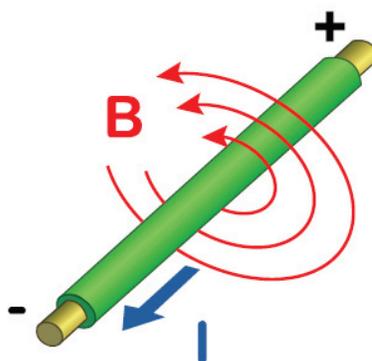


BACKGROUND

In physics, electric current is a flow of charge through a given point of space, in a specific time period. The point of space is determined by an arbitrary reference point. Historically, electric current was first studied by investigating how electric charge transfers between two objects. The objects were charged using friction or induction methods.

In 1800 the Italian, Alessandro Volta built the first electric battery. The Dane, Christian Oested, used Volta's battery when he discovered by accident in 1820, that there is a relationship between electric current and magnetism. He observed how the needle in a compass moved when it was close to a conductor cable where electricity was passing through.

The accident moved him to write that "all electric current or flow of charge causes a magnetic field around the path of the conductor, whose magnitude is inversely proportional to the distance between the observer and the electric current." Furthermore, the effect of a magnetic field can be amplified and transmitted through a ferromagnetic material (a material that can turn into a magnet if it is exposed to a magnetic field). Some examples of ferromagnetic elements are iron (Fe), cobalt (Co) and nickel (Ni).



The expression for a magnetic field B caused by an electric current is:

$$B = \frac{I}{2\pi \cdot r} \mu_0$$

Where:

B = magnetic field

r = radial distance to the observer

I = electric current

μ = magnetic permeability in free space



DID YOU KNOW?

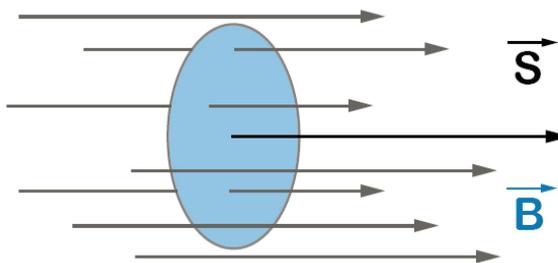
Man has long since used magnetism for navigation. A device called a compass relies on the fact that a magnetic object aligns itself with the Earth's magnetic field.



Starting from previous discoveries, in 1831 the Englishman, Michael Faraday made a new discovery. He found out that in the same way that changes in motion cause an electric field, a variation in the magnetic field also induces a force on the free charges inside the conductor. This force is called electromotive force or EMF, and drives the electric current to pass through the conductor. Therefore, electric current may be induced by the movement of a magnet in a certain time period.

Two years later, the German, Heinrich Lenz proved that "electromotive force gives rise to a flow of charges whose magnetic field opposes its original cause, i.e., it opposes the original change in magnetic flux." This may be expressed in Faraday's Law of Induction:

$$\varepsilon = -\frac{dB}{dt}$$



Where:

- ε = electromotive force (EMF)
- t = time
- B = magnitude of the magnetic field
- S = area of the surface where the magnetic flux passes through (defined by the conductor wire)

Faraday's Law means that the electromotive force (ε) is proportional to the change in magnetic flux in a given time period. The change of magnetic flux opposes the direction of the original magnetic field.

Now students are encouraged to raise a hypothesis which must be tested with an experiment. Students may find it helpful to formulate their hypothesis as an answer to the following question.

- **What will happen inside a copper coil if you move a magnet relative to the coil?**

CONNECTING THE WARD'S DATAHUB TO A COMPUTER

If you are using a Bluetooth communication device:

Right-click on the Bluetooth icon in the lower right corner of the screen and select the Ward's DataHub you are using. The icon will change from gray to blue, as shown at right, indicating that the Ward's DataHub and the computer are now connected via Bluetooth.



If you are using a USB communication device:

In order to use USB communication, connect the Ward's DataHub and the computer with the USB cable supplied. Click on the USB icon at the lower right corner of the screen. This icon will change from gray to blue, as shown at right, indicating that the Ward's DataHub is connected to the computer via USB.



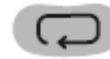
USING THE WARD'S DATAHUB



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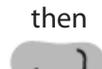
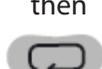
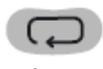


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To collect measurements with the Ward's DataHub, it must first be configured as follows:

1. Turn on the Ward's DataHub by pressing the On/Off/Esc key.		8. Press the On/Off/Esc key to return to the setup menu.	
2. Go to setup by using the Scroll key; then select Setup by pressing the Select key.	 then 	9. Press the Scroll key to highlight the Number of Samples and then press the Select Key.	 then 
3. Select the Set Sensors option by pressing the Select key.		10. Press the Scroll key until "10,000" is highlighted, then press the Select key.	 then 
4. If any sensor(s) appear on the screen, press the key representing that sensor to deactivate it. Once you have a blank window, press the Current Sensor key Twice .	 x 2	11. Press the On/Off/Esc key three times to return to the main operating screen.	 x 3
5. Press the On/Off/Esc key once to return to the setup menu.		12. Press the Select key to start measuring. (You are collecting data when there is an icon of a Runner in the upper left hand corner of the screen.)	
6. Press the Scroll key to highlight the Sampling Rate and then press the Select Key	 then 	13. Once you have finished measuring, stop the Ward's DataHub by pressing the Select key, followed by the Scroll key.	 then 
7. Press the Scroll key until "100/sec" is highlighted, then press the Select key.	 then 		



DID YOU KNOW?

Some objects found naturally on the Earth's surface are magnetic. Magnetite is the most magnetic of all the naturally occurring minerals on Earth. This was referred to as lodestone as early as 500 B.C., and was used for primitive compasses.



ACTIVITY

1. Take the copper wire and coil it around your hand, leaving about 10 cm of wire at both ends free. Make sure the wire doesn't unwind by fixing it with masking tape.
2. Connect the banana to banana cable to the Ward's DataHub and to the ends of the copper wire as shown in the figure below.
3. In the software, click the RUN icon and observe the graph built on the screen.
4. Start measuring, move the magnet two times inside and outside the coil. For the first time, do it slowly, moving the magnet more quickly on the second time.



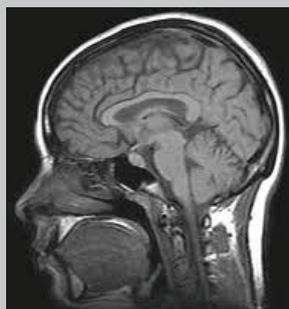
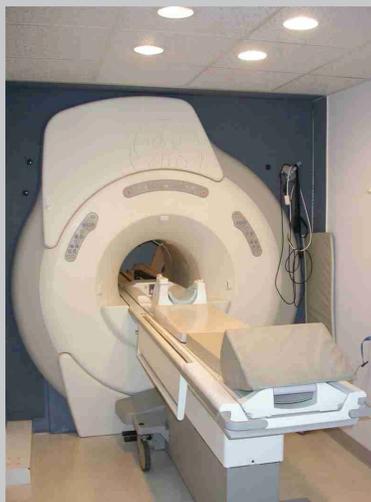
5. Stop measuring.



DID YOU KNOW?

Magnetic Resonance Imaging (MRI) machines let doctors look deep inside a person's body. This is done by putting a person inside the core of a giant magnet and probing them with radio waves.

These waves cause the molecules within the body to vibrate; different molecules vibrate at different rates. This allows a doctor to clearly see the different parts of a person's body.



RESULTS AND ANALYSIS

1. Connect the Ward's DataHub to the computer using the Bluetooth wireless communication channel or USB connector.
2. In the top menu, click on the  button and select the  button.
3. Select the last experiment on the list.
4. Observe the graph displayed on the screen.
5. Identify the section of the graph where variations in the electric current were recorded. Once you have them, press  to select the two points on the graph representing the beginning and the end of the current pulses section.
6. Press  and then press OK. The graph was trimmed to show only the "interesting section" of the current pulses.
7. Fit the scale to observe the variations in electric current displayed. To do this, register the maximum and minimum values using the  button, and enter rounded values in the "Set Range" window by right-clicking on the y-axis on the chart.
8. Press and write notes on the graph specifying when the magnet was inside and outside the wire coil.
 - **How do the results relate to your initial hypothesis? Explain.**
 - **How would you explain the variations in electric current?**
 - **What differences did you find between the electric current when the magnet was moving inside the coil and the electric current when the magnet was moving outside the coil?**
 - **When did you observe a larger current pulse - when the magnet was moving slowly or when it was moving faster? Explain.**



DID YOU KNOW?

Have you ever pulled a hat off of your head and had your hair stand on end? Well that is electricity. Specifically static electricity. Rubbing two things together, such as your hair and the hat, can cause electrons to move from one atom to another. The atom that gets the extra electron has a negative charge, and the atom that has one less electron has a positive charge.

When the charges are separated in such a manner it is called static electricity. In the case of your hat and hair, electrons move from your hair to the hat. Now each of your hairs has a positive charge and thus are repelling each other.



The graph below should be similar to the one the students came up with.



CONCLUSIONS AND ASSESSMENTS

1. How does the magnetic field inside the coil relate to the current recorded in the coil? **Explain.**

Students should identify that the electric current is proportional to the CHANGE in the magnetic field. Thus when the magnet is moving fast in and out of the coil the graph registers a higher pulse compared to a slow magnet movement. When the magnet doesn't move, even when it is inside the coil creating a high magnetic field, there will be no electric current.

2. What does the negative and positive sign of the electric current mean? **Argue** your answer with evidence from the experiment.

Students should point out that the sign represents the electrons' direction of flow and is independent of the current's magnitude.

3. How is the sign of the current inside the copper wire related to the magnetic field of the magnet? **Explain.**

Students should explain that according to the Lenz Law the electric current in the coil is opposite to the magnetic field creating it. Thus from the above recorded graph, students can clearly observe that when we insert the magnet into the coil, increasing the magnetic field, the current will be negative. Similarly, when the magnet is pulled out of the coil (magnetic field is decreased) the current will be positive.

ACTIVITIES FOR FURTHER APPLICATION

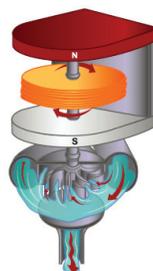
The aim of this section is for students to extrapolate the acquired knowledge during this lesson through its application in different contexts and situations. Furthermore, it is intended that students question and present possible explanations to the experimentally observed phenomena.

1. How would you explain the phenomenon observed during the first activity called **“TRY THIS”**?

Students should infer that the motion of the beverage can is caused because of the action of a magnetic field on the fixed charges of the metal. Therefore the metal will move in an opposite direction than the current induced by the magnetic flux.

2. How could you use the Faraday and Lenz Law to produce energy in a hydroelectric power plant? If you are not familiar with the process, investigate it.

Students should point out that the Faraday and Lenz Law may be used in a hydroelectric power plant to produce energy because the movement of a magnet inside a copper coil (dynamo) induces electric current. Water that falls on sails produces a circular movement of the magnet.



3. Could you build an electromagnet with a copper wire, a battery and a piece of iron? Try it using the materials of the experiment.

Students should deduce that if they coil the copper wire around a piece of iron and connect the wire to a power supply, a magnetic field will appear. Since iron is a ferromagnetic material, the magnetic field will amplify and reach a high magnitude, depending on the electric current that passes through the conductor.

4. How do you think the orientation of a compass would be affected if you exposed it to an electromagnet? Prove your theory with the electromagnet you built for the previous question.

Students should point out that the compass orientates according to the north pole of the natural magnetic field on our planet. If we expose the compass to a magnetic field other than the one of Earth, its orientation will change. We can prove this by coiling a copper wire around a piece of iron and connecting the end to a battery. Next we place the compass in front of the electromagnet and try connecting and disconnecting the wire to the battery. The orientation of the needle inside the compass will change depending on if it is orientated by the magnetic field of the planet or by the magnetic field of the electromagnet.

5. What will happen to the direction of the needle if you switch the cables connected to the battery?

Students should point out that the direction of the needle's movement will change due to the change in the battery's polarity which then causes a change in the direction of the electric flow.

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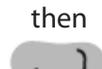
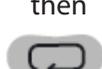
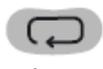


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5. Stop measuring.

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