FUNDAMENTAL FORCES OF NATURE (CERN)

TEACHER GUIDE

Investigating Electromagnetism

GRADES: 8–12 **STANDARDS ALIGNMENT**

This lab can be an enrichment activity for advanced Physical Science students or a scaffolded introductory activity for AP Physics students. This activity should be at grade-level for Honors/Standard Physics as written.

OVERVIEW: After viewing the **Fundamental Forces of Nature (CERN) Lesson Video** found on the **Lesson webpage**, students will explore some of these forces: magnetism, electricity, and how one can generate the other. Discussion will explore the value of science with no practical applications..

TIME REQUIRED: Two to three class periods (100-150 minutes)

NOTE

If your class has recently implemented a ***Searching*** Lesson, you can skip the video introduction and begin the video at minute 03:45.

SUGGESTED LESSON FLOW:

Day 1:

1. As a class, students view the 16-minute video found on the **Lesson webpage**.
2. Students should read the short **Lesson Introduction** document before they begin the activity.
3. Begin the **Fundamental Forces of Nature (CERN) Lesson Student Worksheet**. Station rotation is suggested to help students move through the three activities efficiently.

Day 2:

1. Finish the Fundamental Forces of Nature Lesson (CERN) Student Worksheet.
2. Review observations as a whole class.
3. Quiet time for reflection and for students to individually jot down their thoughts on each of the questions in the "Conclude and Reflect" section of their student worksheets.
4. Review the **Establishing Group Norms for Discussion** as a class (the **Bok Center for Teaching and Learning** has some helpful resources).
5. Classroom discussion of the reflection questions.

If time allows or at home:

Students compose a written reflection following the instructions at the end of their Student Worksheet.

SET-UP: Students should ideally be placed in groups of 2-4 to rotate around stations. Teachers may set up each activity ahead of time (See Step 1 in “Before You Start”). Instructions are included for set-up of each station in the “Procedure” section of each activity if students are setting up the activities themselves. Students should be advised to skip past set-up steps if the activities are prepared ahead of time. Each station for each activity will require the materials listed below.

Activity 1: MAGNETIC FIELD LINES

- **Clear plastic sheet protector**
  This activity can be completed without the sheet protector (students can sprinkle filings on paper), but pre-filling sheet protectors with iron filings will prevent students from inhaling or ingesting the filings accidentally and make for quick and easy clean-up.
- **Iron filings**
  You can find inexpensive canisters of iron filings at educational lab supply stores.
- **Tape**
- **Sheet of plain white paper**
- **2 bar magnets**
  These bar magnets should be strong, with clearly labeled north and south poles on each end. If the same magnets are being used for Activity 3, they should be long (5-6 inches) and should be purchased from a scientific supply store to produce the best results.
- **Directional Compass**
  These can also be purchased cheaply at educational lab supply stores.

Activity 2: STATIC ELECTRICITY

- **Latex balloon**
- **Tissue paper (cut into a few small pieces)**
  Any lightweight paper will do. You can also supply other objects that will react to the static electricity in the balloon. Have students use the balloon to separate salt from pepper or roll empty aluminum soda cans across the table.

Activity 3: ELECTROMAGNETIC INDUCTION

- **PVC pipe (1-1.5” diameter, 1 foot length)**
  The PVC pipe should be just wide enough to slide the magnet through without resistance. Using a longer pipe allows students to experiment with more coils.
- **Insulated copper wire (magnet wire)**
  Enameled copper wire will work best for this activity. A metal file may be used to remove the insulation from the ends of the wire attached to the galvanometer.
- **Galvanometer**
  A regular multimeter/ammeter will not work for this activity. The current generated in this activity is on the scale of a few microamperes. Galvanometers can be purchased cheaply at educational lab supply stores or online.
- **Pencil**
  Any long, non-magnetic object will do as a control.
- **Bar magnet**
  This magnet should be strong. Large (5-6") steel or alnico bar magnets will produce the best result. These can be purchased at educational lab supply stores.

SAFETY PRECAUTIONS:

1. Take care to keep iron filings contained. They can cause injury if they get in the eyes, mouth, or nose. It is advised to wear safety goggles and a mask while working with uncontained iron filings.
2. Handle magnets and wire carefully to avoid pinching or piercing the skin.

BEFORE YOU START:

1. If using station rotation, set up the stations ahead of time according to the set-up steps in the procedures.
    a. Activity 1: Steps 1 and 2
    b. Activity 2: Step 1
    c. Activity 3: Steps 1 through 4
2. To keep student groups small, you may need several stations for each activity.

USEFUL BACKGROUND READINGS FOR HUMANITIES-BASED IDEAS:

- Chapter "**What Gets Them Started?**" in *The Shape of Wonder: How Scientists Think, Work, and Live*, by Alan Lightman and Martin Rees (New York: Pantheon Books, September 2025). [Discusses why scientists get interested in science as children]
- Chapter "**What Keeps Them Going?**" in *The Shape of Wonder: How Scientists Think, Work, and Live*, by Alan Lightman and Martin Rees (New York: Pantheon Books, September 2025). [Discusses the motivation of scientists]

TIPS, TROUBLESHOOTING, AND SUGGESTED ANSWERS

Worksheet Page 1

STUDENT WORKSHEET

FUNDAMENTAL FORCES OF NATURE (CERN)

Investigating Electromagnetism

INTRODUCTION

In the *Searching* series video clip you just watched as a class, Dr. Alan Lightman talks to scientists performing particle physics research at CERN, where they use some of the largest, most sophisticated technology in existence to probe the smallest, most fundamental structures of our universe. Today you will use common household objects to explore the effects of one of those forces: electromagnetism.

OBJECTIVE

In this lesson, you will perform three short activities demonstrating electromagnetic force, recording your findings in sketches and observational statements. After the lab, you'll reflect on your experimental process and explore the value of science with no practical application.

ACTIVITY 1: MAGNETIC FIELD LINES

MATERIALS

- Clear plastic sheet protector
- Iron filings
- Sheet of plain white paper
- Tape
- 2 bar magnets
- Directional compass

Instruct students to skip steps 1 and 2 if you have prepared the activity ahead of time.

PROCEDURE

1. Place the white paper on a work surface and lay one bar magnet flat on top of it, oriented vertically.
2. Sprinkle iron filings into the sheet protector and tape the top shut.
3. Lay the sheet protector on top of the magnet and gently shake the sheet protector to distribute the iron filings then tap the sides until the filings align in a pattern.
4. Record your observations.
   a. Sketch the pattern you see in the "Observe and Record" section below.
   b. Being careful not to touch the magnet, move the compass around the magnet, over the lines created by the iron filings. Determine which side of the magnet the compass points toward and label it North on your sketch. Label the other side South.
5. Experiment with different orientations. Turn the magnet on its side or stand it up on one end. Be sure to keep the sheet protector flat above the magnet.

Younger students may have trouble shaking the protector vigorously enough to distribute the iron filings but gently enough not to disturb the field lines once they become visible. A demonstration may be helpful.

Students, especially in lower grades, should be guided to understand that the compass needle is a magnetized material suspended on a pivot point. Allowed to pivot freely, one end will be attracted to the pole of a magnet and the other end repelled. Compasses used for navigation align with the Earth's magnetic field.

TIPS, TROUBLESHOOTING, AND SUGGESTED ANSWERS

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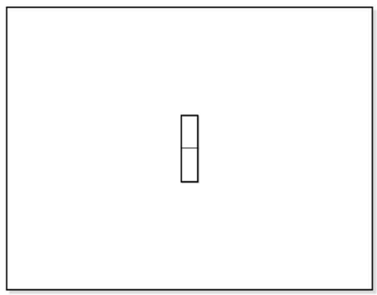
OBSERVE AND RECORD

One Bar Magnet



1. Describe the pattern the iron filings make around the magnet. These patterns are called **field lines**. Where do these field lines appear to be the strongest?

2. Why do you think the iron filings created patterns around the magnet?

TIPS, TROUBLESHOOTING, AND SUGGESTED ANSWERS

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STUDENT WORKSHEET

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Two Bar Magnets

Before you experiment, make a prediction about the orientation of the field lines for each scenario below. Sketch your predictions, then set up each scenario pictured and sketch the field lines you are able to observe from the iron filings.

	SCENARIO 1	SCENARIO 2
Prediction	N S N S	N S S N
Observation	N S N S	N S S N

3. Compare and contrast your prediction sketches to your observation sketches for each scenario. How well did you predict the pattern produced by the field lines?

Students should note how the magnetic field lines overlap when two magnets are placed near each other and comment on how well they predicted the shapes of the overlapping field lines. Students should be guided to the understanding that both magnets produce the magnetic field around them.

4. Compare and contrast the patterns produced by Scenario 1 to the patterns produced by Scenario 2. How are they the same? How are they different? Why?

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Students should be guided to notice that opposite poles attract and like poles repel based on the shapes of the field lines in the two scenarios. The iron filings show us the magnetic force caused by the magnetic field around the bar magnets. When two magnets are placed in proximity, like poles will generate a repulsive force and fewer iron filings will fall in those areas. Opposite poles will generate an attractive force and the field lines shown by the iron filings will appear denser. Behavior on the outside of the magnets remains much the same as the one magnet scenario. Students can once again move the directional compass around the two magnets in both scenarios as they make observations about the magnetic field.

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ACTIVITY 2: STATIC ELECTRICITY

MATERIALS

- Latex balloon
- Tissue paper (cut into a few small pieces)

PROCEDURE

1. Inflate and tie off the balloon, then rub it on your head for about 30 seconds.
2. Hold the balloon high over the pieces of tissue paper and slowly lower it towards them. Record your observations in the Observe and Record section below.

Wool clothing will also work!

OBSERVE AND RECORD

1. Describe what happened as you lowered the charged balloon over the tissue paper.

Students can be directed to experiment further with static electricity if time allows and record their observations here. Consider having students separate pepper from salt using the balloon, roll empty aluminum soda cans across the table by pulling the balloon away, or even move the charged balloon close to a stream of water and watch how it bends the stream.

2. What do you think happened when you rubbed the balloon on your head? Compare and contrast the way the balloon attracted objects with the magnet in the first activity. How might they be related?

Students should be guided to understand that static electricity arises from a charge imbalance. Electrons and protons are oppositely charged particles which, along with the neutron, make up the basic structure of an atom. When we rub the balloon on various materials like wool clothing or hair, we transfer electrons from the material to the surface of the balloon. The imbalance allows the balloon to attract objects with an opposite charge and repel objects with a like charge (similar to the magnets in the first activity). In the case of a neutrally charged object, like the lightweight tissue paper, moving the negatively charged balloon close repelled the like charges (electrons) to the other side of the object, leaving a positively charged surface that was attracted to the balloon.

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STUDENT WORKSHEET

FUNDAMENTAL FORCES OF NATURE (CERN)

ACTIVITY 3: ELECTROMAGNETIC INDUCTION

MATERIALS

- PVC pipe (1-1.5" diameter, 1 foot length)
- Insulated copper wire
- Galvanometer
- Pencil
- Bar magnet

Take a moment to explain how a galvanometer works before students begin the activity. For lower grades, a simple explanation that the galvanometer measures electric current (the flow of charged particles) is sufficient. For higher grades, students should be guided to understand that a galvanometer consists of a conducting coil which pivots within a magnetic field.

Any long, non-magnetic object will work as a control.

PROCEDURE

1. Strip the insulation from about 2 centimeters off one end of the wire.
2. Leaving a tail of about a foot, start wrapping the wire around the PVC pipe. Continue wrapping the wire in tight coils around the PVC pipe until you have around 100 coils.
3. Leaving another tail of about a foot, clip the end of the wire and remove the insulation from about 2 centimeters off this end of the wire.
4. Connect each end of the wire to the galvanometer, one end to the positive and the other to the negative.
5. Watching the galvanometer needle, pick up a pen or pencil and drop it through the pipe. Insert the pencil into the pipe quickly then pull it back out quickly. Record your observations below (Question 1).
6. Watching the galvanometer needle, drop the magnet through the pipe. Insert the bar magnet into the pipe quickly then pull it back out quickly. Watch the galvanometer needle. Record your observations below (Question 2).
7. Flip the magnet over and perform step 4 again. Watch the galvanometer needle. Record your observations below (Question 3).

The magnet must move quickly through the coils in order to generate a noticeable current. This can be achieved by dropping the magnet through or simply moving it in and out of the coil quickly by hand.

OBSERVE AND RECORD

1. Describe what happened as you moved the pencil into and out of the pipe. Did the galvanometer needle move?

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TIPS, TROUBLESHOOTING, AND SUGGESTED ANSWERS

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2. Describe what happened as you moved the magnet into and out of the pipe. Did the galvanometer needle move? Which way?

3. Describe what happened when you flipped the magnet over. Compared to your last trial, what was different about the way the needle moved on the galvanometer? What was similar?

Students should note which type of current (positive or negative) was generated by moving the magnet through the coils in one direction and that the opposite current was produced when the magnet was flipped. Have students look closely at the path of the current through the wire, to and from the positive and negative pegs on the galvanometer as they probe the relationship between the moving magnetic field and the generated electric current.

4. Why do you think the magnet was able to move the needle on the galvanometer but the pencil was not?

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STUDENT WORKSHEET

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5. Why do you think the behavior of the needle changed when you flipped the magnet?

Students should be guided, through close examination of the direction of the measured current and the movement of the magnet, that a changing magnetic field induces current in a conductor (the wire). Students in higher grades should make the connection to Faraday's Law, which states that the electromotive force around a closed path is equal to the negative of the time rate of change of the magnetic flux enclosed by the path[1].

CONCLUDE AND REFLECT

Using the questions below to guide your thoughts, reflect upon your experience during this lab. Jot down any thoughts in the space below and prepare to share your thoughts in a group discussion.

1. What have you learned about electromagnetic fields from these activities?
2. How is electricity connected to magnetism?
3. Electromagnetic forces, in the form of radio waves, are passing through our bodies all the time. Can you feel them?
4. Why do you think physicists are interested in finding the fundamental forces of nature?
5. These huge machines, like CERN, designed to understand the fundamental forces and particles of nature, cost billions of dollars, yet have few – if any – practical applications. Do you think our society can justify spending so much money on such machines?
6. What do you think is the motivation of the scientists who work at CERN?

The reflection section on this page is meant to encourage students to make connections between their experience with fundamental forces in the lab activities and the applications and implications of particle research currently being done at CERN. Students (and teachers!) may be uncomfortable with some of these questions or with sharing their thoughts on these questions aloud. Have a dedicated time set aside after students have completed the three activities to reflect quietly on these questions. Before you begin the classroom discussion, have the group set norms for discussion. See Establishing Group Norms for Discussion for ideas on norm-setting before group discussions. After the group discussion portion, if time allows, have students each choose one or two questions and produce a written reflection. Students can work on their reflections at home and submit them later.