



# Magnetic Fields & Electric Motors

## Physics Lab XI

### Objective

The magnetic fields experiment allows students the opportunity to observe magnetic field patterns produced between two or more magnets for various arrangements of north and south poles. Students will construct electric motors, and through qualitative analysis students will observe the response of a current carrying loop in the presence of a magnetic field.

### Equipment List

#### Magnetic Fields

4 Bar magnets wrapped in plastic, iron filing, paper clamps, plexiglas plate.

#### Electric Motors

1 'D' size battery, 1.5 meter length magnetic wire, two button magnets, paperclips, rubber bands, compass, sandpaper, wire cutter.

### Theoretical Background

#### Magnetic Fields

The discovery of magnetism cannot be accredited to a single individual or a particular time period. However the unique properties of magnets including an encompassing theory of electromagnetism was developed by several scientists, philosophers and laymen studying the phenomenon independently or in some cases cooperatively throughout the course of several centuries.

The Greeks through an inquisitive analysis discovered that a magnetized metal such as iron or lodestone is attracted to another piece of iron, and this attraction magnetizes the new piece of iron. The new magnetized piece of iron would then be attracted to other pieces of iron, similarly magnetizing each new piece. But certain questions still

remained: Would magnetized metals always point to other magnetized metals? And more importantly, what causes magnetism?

The Chinese may have been the first to acknowledge the directional properties of magnets. The location of burial grounds were mapped out with the use of a flat tabature ordained with certain grid markings. In the center of the table sat a spoon made of lodestone. Upon taking the apparatus to the burial grounds the spoon would point to an area of land considered to be favorable for the deceased. The compass, associated with the Han Dynasty (200 B.C.E to 200 C.E.) was later adopted by the Western World for navigation.<sup>1</sup>

During the Renaissance Period William Gilbert published “De Magnete” (On the Magnet), a work which summarized the current understanding of magnetism. The text was hailed as a noteworthy commentary of the subject by scientists such as Newton, Galileo and Kepler. The work contained Gilbert’s own experiments with magnets. A most notable experiment is one in which he placed a piece of lodestone on a flat surface, and around this were placed several small compasses. Placing more compasses around the sample allowed him to map the magnetic field pattern of the lodestone. He concluded that the lodestone not only contains a magnetic field strength, but also the field points in a direction indicated by each compass; the magnetic field is a vector quantity with magnitude and direction.<sup>2</sup>

Further experiments were performed demonstrating the two distinct poles of a magnet; namely the magnetic north and south poles. These poles exhibit forces on each other; like poles repel each other while unlike poles attract each other. Unlike electric charges which are classified as separable positive charges and separable negative charges, a single north or a single south pole, has yet to be discovered. Furthermore, a magnet divided in half contains two halves each with a north and south pole. The same result is obtained upon further divisions of the magnet. Many scientists staunchly dismiss the existence of the magnetic monopole.

Students participating in this lab experiment can imagine themselves as the scientists who first discovered magnetism. Students may wish to consider a few thought experiments during the exercise: Where does a magnet’s field originate? What is the resulting magnetic field when two or more magnets are near each other? Is it possible for a single bar magnet to have two or more sets of poles and how would they interact with each other? Is it possible to isolate a single pole of a magnet? and so on. A few of these questions and many others remain unanswered.

## Electric Motors

In general the rotation or the torque on a loop of wire placed within an external magnetic field is defined as the cross-product of the coil’s magnetic dipole with the applied magnetic field

$$\vec{\tau} = \vec{\mu} \times \vec{B} \quad (1)$$

for the torque  $\vec{\tau}$ , the magnetic dipole moment  $\vec{\mu}$  and the magnetic field  $\vec{B}$ . The magnetic dipole moment is an intrinsic property of the wire loop for which a constant flow of

<sup>1</sup>reference: “A History of Classical Physics: From Antiquity to the Quantum,” J.D. Bernal

<sup>2</sup>reference: “A History of Classical Physics: From Antiquity to the Quantum,” J.D. Bernal

current  $I$  is distributed evenly through  $N$  loops of wire encircling an area  $A$

$$\mu = NIA \quad (2)$$

for which a power source such as a dry cell delivers direct current through the coil. (Methods of utilizing power sources to deliver alternating current through wire loops are introduced in an experiment devoted to Faraday's Law of Induction.) The direction of the magnetic dipole is determined by the right-hand rule. For a loop wire in which a current flows, the fingers of the right hand wrap around the loop in the direction of the current and the thumb points in the direction of the magnetic dipole (see figure ??). A noteworthy result of this application is  $\vec{\mu}$  always points perpendicular to the plane of the loop.

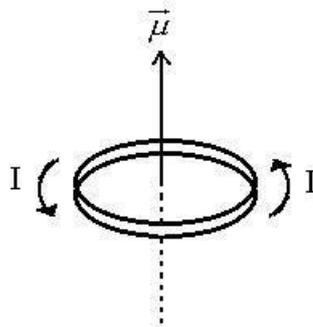


Figure 1: Determination of the magnetic dipole of a current-carrying loop with  $N$  turns.

In the presence of an external magnetic field the loop of wire experiences a torque. The rotation of the coil is either clockwise or counterclockwise. Recall that clockwise rotation indicates a negative torque while counterclockwise rotation give positive torque. Figure ?? shows the coil in the presence of an external magnetic field. The right-hand rule is used to determine the coil's rotation. The outstretched fingers of the right hand point in the direction of the magnetic dipole, while the thumb points in the direction of the magnetic field. The curl of the fingers about the thumb gives the direction of torque about the coil. Here the torque is positive since the rotation is counterclockwise. Notice that if the magnetic field points to the left the coil would rotate clockwise and experience a negative torque.

The coil experiences no torque when the magnetic dipole is parallel to the magnetic field. The motion of the coil is then governed by the current flow from the battery. It will be necessary to scrape insulation away from the wire during the experiment. This is done so as to provide an efficient flow of current through the wire to maintain rotation.

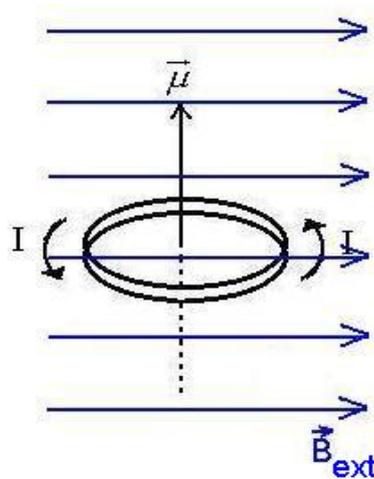


Figure 2: Magnetic dipole and external field.

## Procedure and Data Analysis

### Magnetic Fields

In this set of experiments, students will examine the nature of magnetic field patterns produced by bar magnets. Students will predict magnetic field patterns between two or more bar magnets of varying bar magnet arrangements.

#### Experiment 1: B-field of Simple Bar Magnet

1. Clamp a sheet of paper to the plexiglas plate. Place one plastic wrapped bar magnet underneath the plate. **Never remove the bar magnet from the plastic wrapping!!!**
2. Sprinkle iron filings onto the paper. Observe the arrangement formed by the filings due to the magnetic field (B-field) produced by the single bar magnet. Sketch this field pattern on the data table for Experiment 1.

#### Experiment 2a: B-fields between Two Magnets of Opposite Poles

1. Remove the plexiglas plate from the bar magnet used Experiment 1. Carefully funnel the iron filings back into the salt shaker. **Never remove the bar magnet from the plastic wrapping!!!**
2. Replace the sheet of paper to the plexiglas plate and place two magnets under the plate. These magnets should be arranged so that their opposite poles face each other. Consult with you lab instructor if necessary.
3. Sprinkle iron filing onto the paper. Observe the pattern formed by the filings due to the magnetic field of two magnets with opposite poles facing each other. Sketch this B-field pattern on the data table for Experiment 2a.

### Experiment 2b: B-fields between Two Magnets of Similar Poles

1. Remove the plexiglas plate from the bar magnets used in Experiment 2a. Carefully funnel the iron filings back into the salt shaker. **Never remove the bar magnets from the plastic wrapping!!!**
2. If necessary, clamp a new sheet of paper to the plexiglas plate.
3. Rearrange the bar magnets used in Experiment 2a so that the same poles face each other. Place the plexiglas plate atop the bar magnets and sprinkle iron filing on the paper. Observe the pattern formed by the filings due to the magnetic field of two magnets with same poles facing each other. Sketch this B-field pattern on the data table for Experiment 2b.

### Experiment 3a: B-fields between Parallel Bar Magnets

1. Remove the plexiglas plate from the bar magnets used in Experiment 2b. Carefully funnel the iron filings back into the salt shaker. **Never remove the bar magnets from the plastic wrapping!!!**
2. Replace the sheet of paper to the plexiglas plate and place two magnets under the plate. These magnets should be arranged so that they are parallel to each other. Their poles should be on opposite ends of each other such that the top magnet's poles are aligned south to north and the bottom magnet's poles are aligned north to south. Consult with you lab instructor if necessary.
3. Make a prediction. On the data sheet for Experiment 3a predict the field lines resulting from these magnets by sketching the field pattern.
4. Reasoning. Briefly discuss the reason behind your predicted field pattern.
5. Perform the experiment. Sprinkle iron filing on the paper. Observe the pattern formed by the filings due to the magnetic field produced between the two parallel magnets. Sketch this B-field pattern on the data table for Experiment 3a.
6. Re-evaluation. Make a statement about the experiment that either confirms your prediction or negates your prediction. If your prediction was correct the experimental results should agree with your prediction. If your prediction was incorrect discuss possible reasons for the disagreement.

### Experiment 3b: B-fields between Parallel Bar Magnets

1. Remove the plexiglas plate from the bar magnets used in Experiment 3a. Carefully funnel the iron filings back into the salt shaker. **Never remove the bar magnets from the plastic wrapping!!!**
2. Replace the sheet of paper to the plexiglas plate and rearrange the two magnets under the plate. These magnets are still parallel to each other, yet their poles are now arranged so that the top magnet's poles are aligned south to north and the bottom magnet's poles are also aligned south to north. Consult with you lab instructor if necessary.

3. Make a prediction. On the data sheet for Experiment 3b predict the field lines resulting from these magnets by sketching the field pattern.
4. Reasoning. Briefly discuss the reason behind your predicted field pattern.
5. Perform the experiment. Sprinkle iron filing on the paper. Observe the pattern formed by the filings due to the magnetic field produced between the two parallel magnets. Sketch this B-field pattern on the data table for Experiment 3b.
6. Re-evaluation. Make a statement about the experiment that either confirms your prediction or negates your prediction. If your prediction was correct the experimental results should agree with your prediction. If your prediction was incorrect discuss possible reasons for the disagreement.

#### **Experiment 4: B-fields between Several Magnets**

1. Remove the plexiglas plate from the bar magnets used in Experiment 3b. Carefully funnel the iron filings back into the salt shaker. If necessary, clamp a new sheet of paper to the plexiglas plate. **Never remove the bar magnets from the plastic wrapping!!!**
2. Each group member will analyze one of the magnet configurations given on the Magnet Configurations sheet for Experiment 5. Group members will analyze their chosen configuration through the science by inquiry method: 1) Make a prediction by sketching field lines; 2) State a reason supporting the prediction; 3) Perform the experiment and sketch the result; 4) If necessary re-evaluate the prediction.

## Electric Motors

In this set of experiments, students will examine the torque produced by a magnetic field through a current carrying loop of wire.

### Constructing an Electric Motor

There is enough material at your lab station for each member to build an electric motor. After constructing your electric motor, begin the lab exercise with Experiment 1a.

1. Wrap 7 turns of wire around the battery. The newly created ring of wire is a small field coil. The procedures henceforth refer to this ring as the coil.
2. Remove the battery and twist 10 to 15 turns of the remaining wire through the coil to secure the 7 turns. Be sure to have at least 3 cm of the remaining wire on both sides of the coil. These remaining wire ends are the conducting leads of the coil.
3. Remove all insulation from one conducting lead. Scrape only the top half of the insulation from the other conducting lead.
4. Unfold two large paper clips. The unfolded paper clips should connect to the battery as shown figure ?? below.

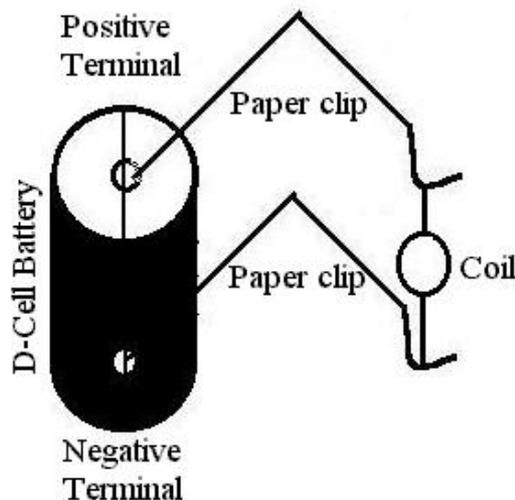


Figure 3: Electric Motor Diagram

5. Clamp the smaller part of the paper clip to the terminals of the battery using a rubber band.
6. Stick two button magnets on the side of the battery.

7. The coil now fits in the cradle formed by the paper clips. Lock the conducting leads into the cradle by bending the paper clip ends into small eyelets.
8. A digital picture of a constructed electric motor is shown below. The coil should start to turn on its own. Consult with your lab instructor if necessary.

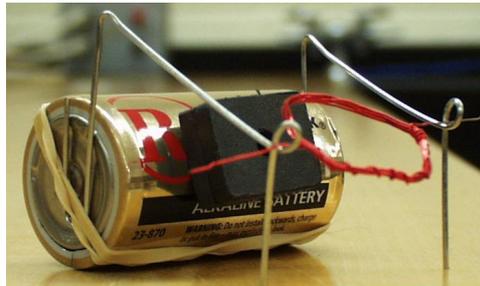


Figure 4: The Completed Electric Motor

### Experiment 1a: Rotation of Coil

1. Remove the coil from the circuit.
2. Use the compass to determine the pole of the magnet facing the coil. Hint: If the north pole of the compass points to the magnet, the magnet's south pole faces the coil, and vice versa.
3. Make a prediction. Use the right-hand-rule to determine the coil's direction of rotation due to the influence of the chosen magnetic pole. Hint # 1: In a continuous circuit, current flows from the positive terminal of the battery, through the coil and returns to the negative terminal of the battery. Hint # 2: The magnet's north pole is a *source* of magnetic field lines while its south pole is a *sink* of magnetic field lines. Hint #3: The magnetic dipole moment is always directed perpendicular to the plane of the coil. Record your prediction on the data table for Experiment 1.
4. Reasoning. Briefly discuss the reason behind your prediction for the rotation of the coil in the space provided on the data table.
5. Perform the experiment. Re-connect the coil to the circuit. Observe its direction of rotation. Record the result on the data table.
6. Re-evaluation. Make a statement about the experiment that either confirms your prediction or negates your prediction. If your prediction was correct the experimental results should agree with your prediction. If your prediction was incorrect discuss possible reasons for the disagreement.

## Experiment 1b: Rotation of Coil

1. Remove the coil from the circuit.
2. Turn the magnets over. The other pole of the magnet now faces the coil. Use the compass to determine the pole of the magnet facing the coil. The pole should be opposite the one chosen for Experiment 1a.
3. Make a prediction. Use the right-hand-rule to determine the coil's direction of rotation due to the influence of the chosen magnetic pole. Hint # 1: In a continuous circuit, current flows from the positive terminal of the battery, through the coil and returns to the negative terminal of the battery. Hint # 2: The magnet's north pole is a *source* of magnetic field lines while its south pole is a *sink* of magnetic field lines. Hint # 3: The magnetic dipole moment is always directed perpendicular to the plane of the coil. Record your prediction on the data table for Experiment 1.
4. Reasoning. Briefly discuss the reason behind your prediction for the rotation of the coil in the space provided on the data table.
5. Perform the experiment. Re-connect the coil to the circuit. Observe its direction of rotation. Record the result on the data table.
6. Re-evaluation. Make a statement about the experiment that either confirms your prediction or negates your prediction. If your prediction was correct the experimental results should agree with your prediction. If your prediction was incorrect discuss possible reasons for the disagreement.

## Experiment 2a: Rotation of Coil with Two Magnets

1. Remove the coil and magnets from the circuit.
2. Make a prediction. Use the right-hand-rule to determine the coil's direction of rotation for two magnets placed on opposite ends of the coil, both magnets have the same pole facing the coil. Hint: Review your observations and results from the Magnetic Fields exercise for field lines produced from two bar magnets with same-pole interactions.
3. Reasoning. Briefly discuss the reason behind your prediction for the coil's reaction to the given orientation of the magnets in the space provided on the data table.
4. Perform the experiment. Connect the coil to the circuit. Stick one magnet onto the battery and hold the other outside the circuit. Be sure both magnets face the coil with the same pole. You may require the assistance of a group member. Consult with your lab instructor if necessary.
5. Re-evaluation. Make a statement about the experiment that either confirms your prediction or negates your prediction. If your prediction was correct the experimental results should agree with your prediction. If your prediction was incorrect discuss possible reasons for the disagreement.

**Experiment 2b: Rotation of Coil with Two Magnets**

1. Remove the magnets and coil from the circuit.
2. Make a prediction. Use the right-hand-rule to determine the coil's direction of rotation for two magnets placed on opposite ends of the coil, one magnet's pole is opposite the other, both face the coil. Hint: Review your observations and results from the Magnetic Fields exercise for field lines produced from two bar magnets with opposite-pole interactions.
3. Reasoning. Briefly discuss the reason behind your prediction for the coil's reaction to the given orientation of the magnets in the space provided on the data table.
4. Perform the experiment. Connect the coil to the circuit. Stick one magnet onto the battery and hold the other outside the circuit. Be sure the magnets have opposite poles facing the coil. You may require the assistance of a group member. Consult with your lab instructor if necessary.
5. Re-evaluation. Make a statement about the experiment that either confirms your prediction or negates your prediction. If your prediction was correct the experimental results should agree with your prediction. If your prediction was incorrect discuss possible reasons for the disagreement.

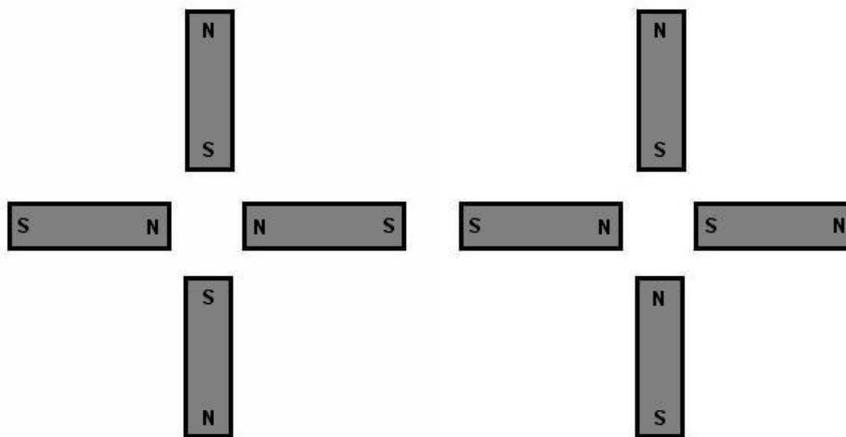
**Experiment 3: The Influence of Current in the Circuit**

1. Remove the coil from the circuit.
2. Make a prediction. Determine the direction of rotation of the coil if all the insulation is scraped from both ends of the coil's leads. Consult with your lab instructor if necessary.
3. Reasoning. Briefly discuss the reason behind your prediction for the coil's reaction to insulation-free leads in the space provided on the data table.
4. Perform the experiment. Stick both magnets together and place them on the battery. Completely scrape all insulation from the leads of the coil. Connect the coil to the circuit. Record your observation on the data table for Experiment 3.
5. Re-evaluation. Make a statement about the experiment that either confirms your prediction or negates your prediction. If your prediction was correct the experimental results should agree with your prediction. If your prediction was incorrect discuss possible reasons for the disagreement.

## Selected Questions

### Magnetic Fields

1. Is it possible to determine whether the a bar magnets are attracting or repelling one another by viewing the iron filings sketches? Discuss why or why not.
2. Based on your experiences with field line sketching, predict the field line patterns produced by the following bar magnet configurations. For each configuration briefly explain your sketches. Assume the left pattern does not interfere with the pattern on the right.



### Electric Motors

1. Explain the importance of scraping the insulation on only one side of the coil's leads.
2. Which combination of the magnets (same pole or opposite pole) facing the coil on opposite ends of the coil produced the best results for the motor? Review your observations from Experiment 2 and explain your answer through an analysis of the right hand rule.