Name: ___________________________________

Partner(s): ________________________________

1118 section: _______

Desk # _____________

Date: ______________

Electromagnets and Magnetic Forces

(All questions that you need to answer are in italics. Answer them all!)

Problem 1: The Magnetic Field of an Electromagnet

Purpose

To study the directions of the magnetic field of an electromagnet (the solenoid).

Introduction and Theory

In class you learned how a current-carrying wire creates a magnetic field surrounding the wire. This phenomenon can be used to create an electromagnet. The most common type of electromagnet is the solenoid.

A solenoid is made by taking a very long wire and wrapping it tightly around a tube with many turns. When a current passes through the wire, a uniform magnetic field is present inside the solenoid, and a magnetic field similar to a permanent bar magnet is present outside the solenoid.

The direction of the magnetic field of the solenoid is determined by the way the wire is wound and the direction of the current. We can use the Right Hand Rule (RHR) for the solenoid to decide the direction of the magnetic field. (See the Appendix A, last page, for details on the RHR.) As with a bar magnet, the magnetic field lines point out of the north pole of the solenoid, as shown in Figure 1.

The magnitude of the magnetic field depends on the geometry and the number of turns in the solenoid, and the size of the current in the solenoid. One way to increase the strength of the magnetic field is to insert an iron core inside the solenoid, like the screw in Figure 1c.

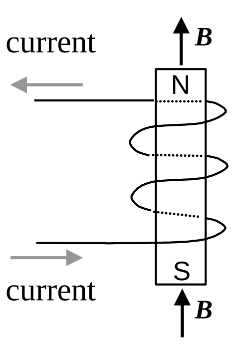


Figure 1a: Current in this direction yields a north pole at the top.

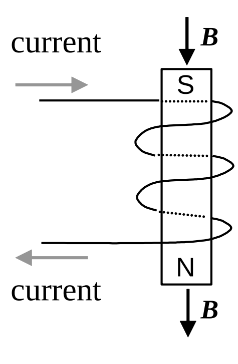


Figure 1b: Current in this direction yields a south pole at the top.

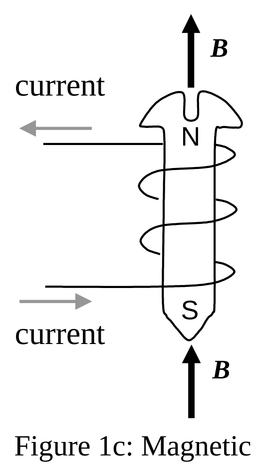


Figure 1c: Magnetic field is stronger with an iron core in the solenoid.

Electromagnets are easy to build and can provide fairly strong magnetic fields. More importantly, it is easy to change the direction and the strength of the magnetic field by changing the current.

Apparatus
Solenoid, a magnetic field probe (Magnaprobe), a bar magnet, two batteries, wire leads

Procedure/Questions

1. Connect the two ends of the solenoid to the battery as shown in Figure 2. *Mark the direction of the conventional current I at point* *.
2. Use the RHR to predict the direction of the magnetic field and *mark the predicted direction of the magnetic field at the 5 little circles with short arrows*.

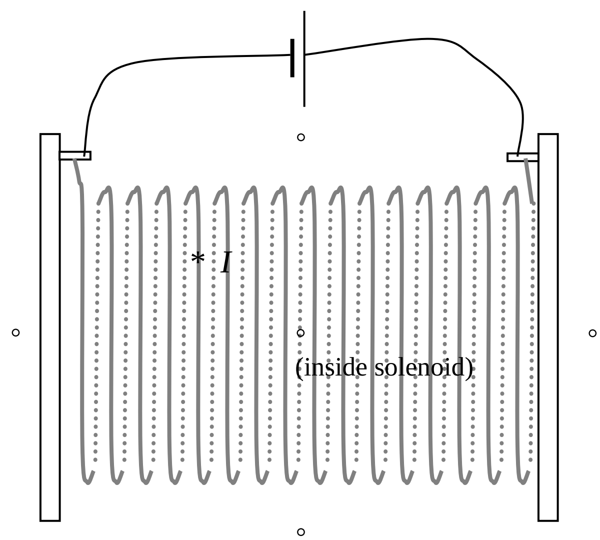


Figure 2

3. Check your predictions with the Magnaprobe. The red end of the Magnaprobe points in the direction of the magnetic field.

4. *Are the magnetic fields at the little circles consistent with your predictions?*
Yes *No*

5. *Does the magnetic field appear to be continuous as you move the probe around?*
Yes *No*

6. *If the magnetic field appears to be continuous, join the field vectors (arrows) with continuous lines on Figure 2.*

7. *Compare the magnetic field outside the solenoid with the field of a bar magnet. Are they similar?*
Yes *No*

When you are finished with your observations, disconnect the circuit – don't drain the battery.

Problem 2: The Strength of the Magnetic Field of a Solenoid with an Iron or Steel Core

Purpose
To compare the strength of the magnetic field of the solenoid with and without a steel core.

Apparatus
Large steel nail, straw, ~ 120 cm enamel insulated wire, two batteries, wire leads, coins and paper clips.

Procedure/Questions

1. Insert the large steel nail through the straw, and wrap the wire around the straw to make a solenoid. It should be about 2 to 3 cm in length and 1 to 2 layers in thickness. Remove the nail.

2. Run a current through your solenoid with the batteries, and try to pick up a dime (or a paper clip) from the desktop with one end of the solenoid. *Can you do it?*

   Yes *No*

3. Now insert the large steel nail back. Try to pick up a dime (or a paper clip) with the nail head. *Can you pick them up individually?*

   Yes *No*

4. From the above tests, we can conclude that the magnetic field at the end of the solenoid is __________ (*weaker, stronger*) with the nail (iron or steel core) inserted in the solenoid.

5. Try to pick up coins of different sizes and materials. You may notice differences between different coins. *Give two reasons why this could be true.*

When you are finished with your observations, disconnect the circuit – don't drain the battery.

Problem 3: Building a Speaker

Purpose

To build a simple working speaker consisting of an electromagnet and a vibrating membrane.

Introduction and Theory

A speaker's job is to turn an electrical signal or current from your phone or MP3 player into mechanical vibrations at frequencies you can hear. In this problem, you are going to build a simple speaker. Keep in mind that all a speaker has to do is to vibrate at the correct sound frequencies. It doesn't matter if it is your voice box vibrating or a piece of plastic vibrating. If the frequencies are the same, you'll hear the same sound. We're going to use magnetic forces to set a plastic membrane vibrating.

A speaker works like this: we take a surface that is free to vibrate (the lid of a plastic container) and attach a magnet to it (Figure 3). If we bring a magnetic north pole near the bottom of the lid, the magnets will attract and the lid will be pulled down (Figure 3a). If we bring a south pole near the bottom of the lid there will be repulsion and the lid will be pushed up (Figure 3b). By switching the north and south poles of the magnet very quickly, we can get the lid to vibrate up and down.

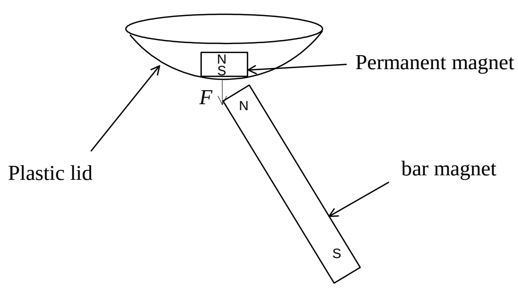


Figure 3a: Magnetic attraction.

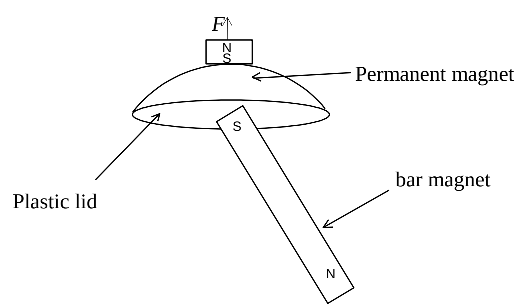


Figure 3b: Magnetic repulsion.

An electromagnet's poles are at its ends, so we position one end close to the lid's permanent magnet. We then connect the electromagnet to a transistor radio that outputs a current that changes direction at the sound frequencies. This changing current will cause the electromagnet to switch the north and south poles at the sound frequencies, thus physically vibrating the plastic lid at those frequencies, and we will hear the sound (Figure 3c).

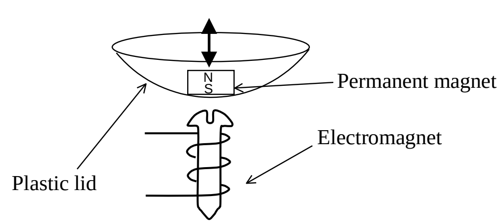


Figure 3c: The lid vibrates as a speaker.

Apparatus
~2.5m of thin wire, a steel screw, plastic container with lid, permanent rare-earth magnet, battery, a steel nail, tape, radio or other sound source.

Assembly and Procedure

Solenoid: Wrap the wire around the screw many times. (The more turns per unit length a solenoid has, the stronger the magnetic field.) Try keeping all the turns together near the head of the screw – leave at least 2 cm of the screw bare of wire at its pointy end. Also leave about 10-15 cm of wire not wound around the screw at each end (see Figure 4). Strip the insulation for about 1 cm at both ends. This solenoid with the screw core is your electromagnet.

Test your magnet: Connect the battery to the ends of the wire and bring the head of the screw in contact with your steel nail. Slowly try to lift the nail with your magnet. If you can lift one end of the nail a reasonable distance off the table, then you have a good magnet. If not, you will either need to increase the number of turns on your solenoid or you'll need to make the turns closer together.

Speaker assembly: Thread the screw into the hole in the bottom of the plastic container so that the head is a few millimeters below the top rim of the container. Now place the lid on the container and make sure there is some space (a few millimeters) between the lid and the head of the screw.

Tape the permanent magnet to the outside of the container lid at its centre. Put the speaker together.

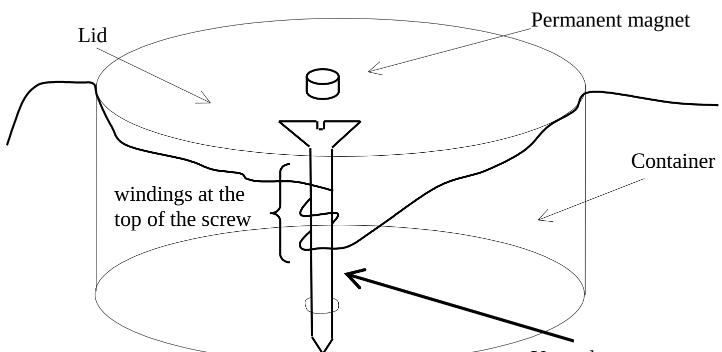


Figure 4: The final product. Connecting the wires to a radio should produce a sound.

Test your speaker: If you hear a clicking noise when you connect the wires coming out of your speaker to the battery, your speaker is probably working. If not, the distance between the permanent magnet and your solenoid may be too large or too small. Adjust the screw position, if necessary.

Final Tests: Once you're confident that you have a working model, take it to the instructor's table for a final test. If your speaker works well, have your instructor or lab demonstrator sign here.

Instructor initial: ___________________________

Discussions

1. *What force causes the plastic lid to vibrate? Name the two objects that are interacting.*

2. *How does the force change directions?*

3. *Why can't you see the plastic lid vibrating but you can hear it? Is there another way to prove that the lid is vibrating? Use senses other than vision and hearing.*

When you are done, disassemble your speaker, unwind the wire, and neatly re-pack the kit.

Problem 4: World's Simplest Motor*

Purpose
To observe and understand the operation of a basic motor.

Introduction and Theory
A motor works using a fixed permanent magnet with a current-carrying solenoid. The forces interact to make the solenoid rotate.

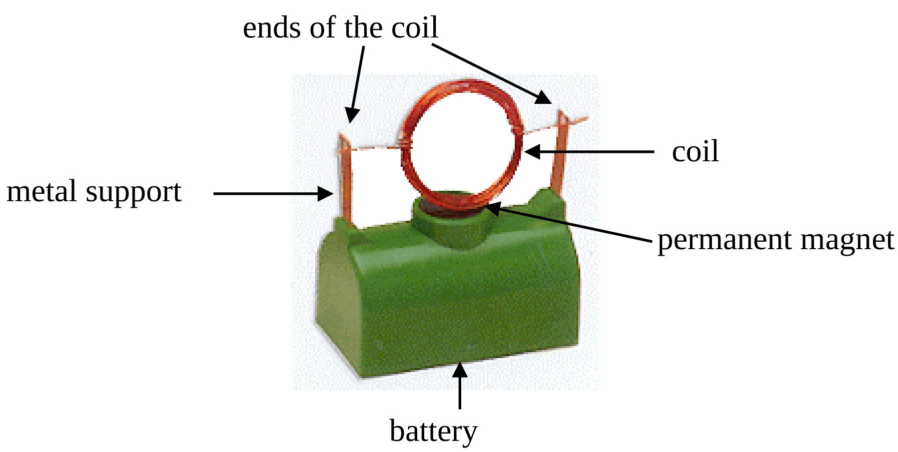


Figure 5: the world simplest motor

* This section was adapted from: http://www.scitoys.com/scitoys/scitoys/electro/electro.html#motor.

The coil in Figure 5 is free to rotate about a horizontal axle made up by the two ends of the coil. With the battery installed, the coil rotates continuously. This rotation, in principle, can lift a mass, turn a fan or a drill, or drive an electric car. Our coil, however, can't do much more than turn itself.

To see why the coil can rotate continuously, we simplify the coil to one single loop of wire, with current, I, coming out of the page on the bottom of the loop and into the page on the top of the loop, as shown in Figure 6a.

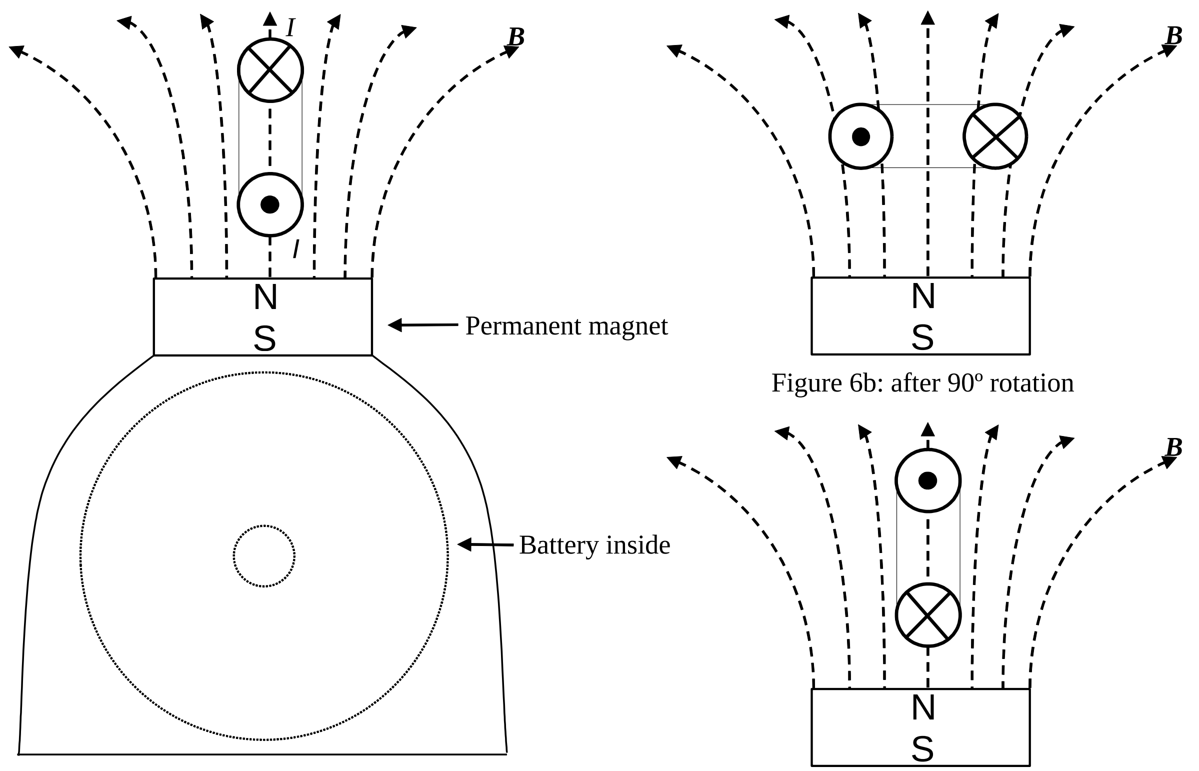


Figure 6a: current into page at top

Figure 6c: after 180º rotation

Figure 6: End view of the motor

Use the RHR for the magnetic force on a current-carrying wire to answer following questions:

1. *Draw the direction of the magnetic force on the top current in Figure 6a using an arrow.*

2. *Draw the direction of the magnetic force on the bottom current in Figure 6a using an arrow.*

3. *What is the direction of the torque, or the direction that the coil wants to turn in Figure 6a?*
   clockwise *counter clockwise*

4. *Draw the forces after the loop rotates 90º (Figure 6b). Is there a torque on the loop now?*
   Yes *No*

5. *Draw the forces after the loop rotates 180º (Figure 6c). Is there a torque on the loop now?*
   Yes *No*

   If yes, which way will this torque try to turn the loop? *clockwise* *counter clockwise*

We see that once the loop rotates 180º, the torque changes direction, and this will slow down the rotation. We can remove this unwanted torque by turning off the current. This is done by keeping the insulation on one side of the wire ends, as shown in Figure 7. As the coil turns, it will receive torque for one half of the cycle and no torque for the other half of the cycle, and will turn continuously in the same direction. If all the insulation were removed, the coil would receive clockwise torque for one half of the cycle and counter clockwise torque for the other half of the cycle and thus would not turn continuously.

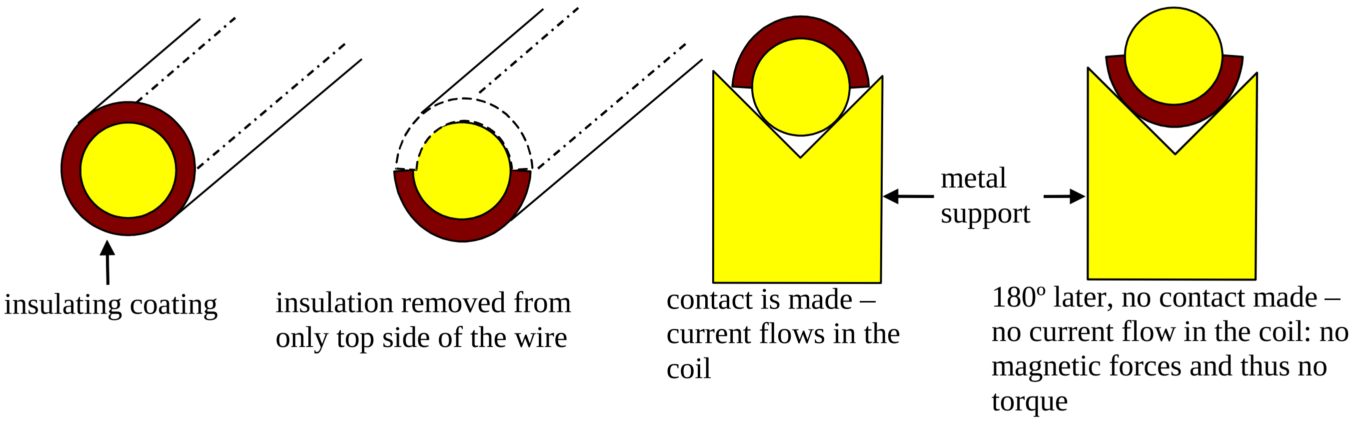


Figure 7: Cross sectional view of the wire end as it contacts the metal support – how the current gets into the coil

Apparatus

Battery holder, permanent magnet, two metal supports, a pre-made coil, D-cell battery.

Procedures

Get a pre-made coil from the instructor. Half side of the two ends of the coil loop are scraped (as shown in Figure 7).

Assemble and run the motor: Place the D-cell battery into the holder (at the bottom). With your Magnaprobe, find the North pole of the magnet, and place it into the holder with the North side up. Put the coil on the supports, as shown in Figure 5. Give the coil a "kick start" to overcome friction. It should start spinning, and continue to spin on its own.

If the coil will not continue to rotate, check all connections. **Check that the coil of wire is nice and flat, and balanced.** Once your motor can turn continuously, ask the instructor or the lab demonstrator to sign below.

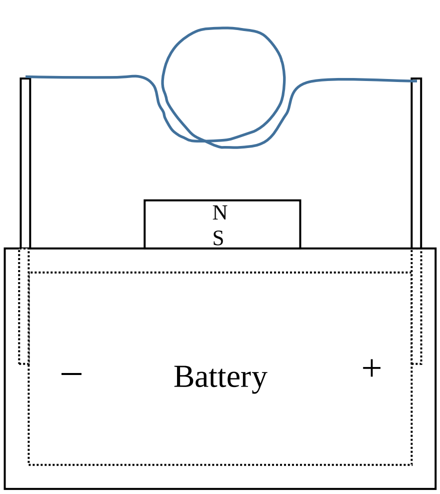
Instructor initial: ___________________________

Discussion

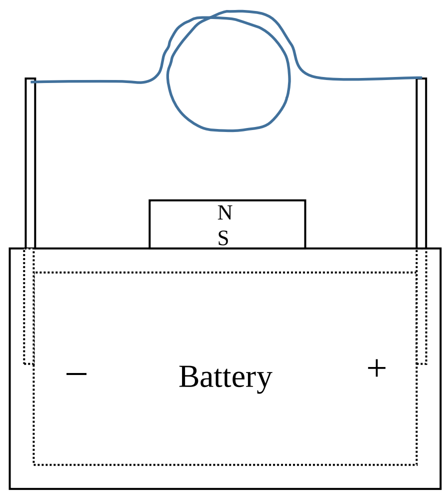
1. *Would the motor work if you removed none of the insulation around the wire? Why*?

2. *Would the motor work if you removed all the insulation around the wire at the ends? Why*?

3. Use the RHR to predict in which way the coil will rotate in the two pictures below. *Draw (1) the direction of current in the coils (only when there is a current), (2) the direction of the magnetic field above the magnet.*



while the stripped side is facing down



while the stripped side is facing up

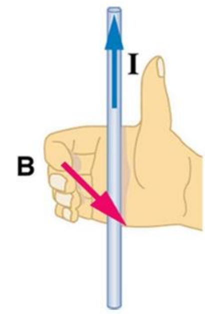
How should the coil shown above rotate?

Top into page *Bottom into page*

Appendix: The Right Hand Rule (RHR)

The Right Hand Rule has different forms. Those related to this lab are listed below:

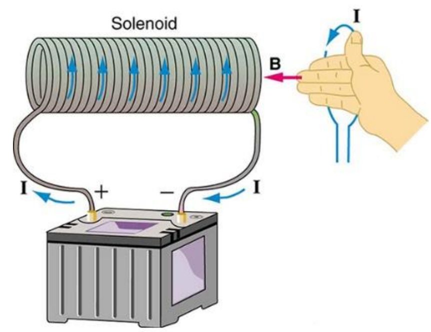
1. The direction of the magnetic field of a current-carrying straight wire: when the thumb points in the direction of the conventional current, the fingers wrapped around the wire point in the direction of the magnetic field.



2. The direction of the magnetic field due to a solenoid (or current loop):

   2a. When the fingers curl in the direction of the conventional current in the coil, the thumb points in the direction of the magnetic field inside the solenoid.

   2b. Point the thumb in the direction of the current. The fingers now point in the direction of the magnetic field inside the solenoid (See figure to the right).



3. The direction of the magnetic force on a current-carrying wire in external magnetic field (there are two forms that yield the same result):

   3a. Point your fingers in the direction of the conventional current, then curl the fingers toward the external magnetic field. The thumb points in the direction of the magnetic force on the wire.

   3b. When the fingers point in the direction of the external magnetic field and the thumb points in the direction of the conventional current, the palm faces in the direction of the magnetic force on the wire**.** (See figure to the right).