Name: ________________________ Partner(s): ________________________

Investigation #12 ________________________

MAGNETISM & ELECTROMAGNETIC INDUCTION

In this investigation, you will become familiar with the behavior of magnets and magnetic forces. You will explore magnetic fields, and construct a simple magnetic compass and electromagnet. The concept of *electromagnetic induction* is investigated as you apply these ideas to examine generators and motors as a culminating activity.

You may notice there is very little background information provided in the activities that follow. This is by design. For this investigation, you are essentially going to be recording observations and then looking for patterns in the observed phenomena in order to explain what causes electromagnetic induction.

CAUTION: Magnets can cause complications with individuals who wear a pacemaker. Inform your instructor immediately if you wear a pacemaker. Furthermore, magnets can erase computer disks, credit cards, video and cassette tapes and damage color monitors. Do not bring magnets near these items.

Part I
Magnets

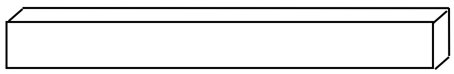
Your group will need the following materials/equipment for this part:

- Several different magnets (bar, disk, horseshoe, etc.)
- 1 "magnaprobe"
- 1 compass
- 1 low-friction turntable
- 1 small sealed plastic case with iron filings
- 1 tray with small magnetic objects (paper clips, staples, BBs, etc.)

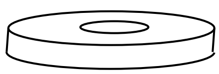
Procedure

1. Working with your partner(s) and using the materials provided, go ahead and freely explore the behavior of the magnets with each other and with the various materials. You are not limited to just the materials provided. Feel free to test items around the room. However, DO NOT bring the magnets near computer drives and monitors!
2. In particular, be sure to examine how the different metals respond to magnets.
3. One at a time, place different magnets in a tray of small magnetic objects. Carefully lift the magnet above the tray. You should notice some attraction of the objects to the magnet. For each type of magnet, note where the attraction of the objects seems to be the strongest. These regions are the *poles* of the magnet.
4. Place different magnets on the low-friction turntable. Observe how different parts of each magnet respond to other magnets brought nearby.
5. Move the "magnaprobe" around the different magnets to determine where the magnetic force is stronger and where the magnetic force is weaker.

Questions: How do the bar magnets behave when two ends are brought near each other? Is the behavior different when one bar is turned around? What if both bars are turned around? Sketch where the poles of the bar magnets are located.



Questions: How do the disk magnets behave when brought near each other? In what ways (if any) is the behavior of the disk magnets different from that of the bar magnets? ? Sketch where the poles of the disk magnets are located.



Questions: Did the magnets attract to any of the metals listed below? If so, which ones?

Metal tested	Aluminum	Brass	Copper	Iron	Lead	Zinc
Attracts to a magnet?						

Other metals tested?

Additional Observations: In the space below, list any other observations that you notice regarding the behavior of magnets and how they interact with other materials and the compass. (You may wish to consult the **Homework Questions** at the end of this investigation for ideas of what to be noting.)

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** ______

Part II
Making a Compass

Hold the compass from **Part I** flat in your hand so that the needle can turn freely. Try to situate yourself so that other magnets are far away and do not affect the compass needle. Note which part of the room the painted end of the needle is pointing.

Questions: Do the painted ends of all the compasses in the room point in that same direction? If so, why? If not, why not?

Your group will need the following materials/equipment for this part:

- 2 flat (disk) magnets with holes
- 2 pieces of wire (about 15-20 cm each)
- 1 cup (metal or ceramic preferred—plastic OK)
- 1 soda straw
- 1 straight pin

Using these materials, you will construct a simple compass. (Your instructor may have a finished example of the compass that you are about to construct. If so, take a look at it.)

Procedure

1. First, bend both of the wires in half around a pencil. Remove the pencil.
2. Insert the free ends of one of the wires into one of the magnets so that the ends stick out about 2-3 cm as shown in Fig. 1 below. Repeat this with the other wire and magnet.
3. With one of the magnets, fold the free ends of the wire around the magnet in opposite directions. Then fold the looped end of the wire over the magnet perpendicular to the way you folded the free ends as shown in Fig. 1. Repeat this with the other magnet.

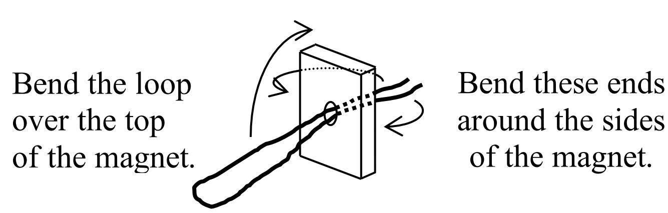
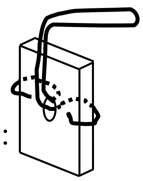


Fig. 1: Folding the wire around the magnet.

4. When completed properly, the two magnets should be able to stick to each other with the looped parts of the wire facing in opposite directions as shown in Fig. 2 on the next page. If this is not the case, remove the wire from one of the magnets, reinsert it in the other direction, and repeat Step 3. Consult your instructor if you are having difficulties.

When finished, magnet and wire should look like this:



When both wires are wrapped properly, the magnets should attract when held as shown:

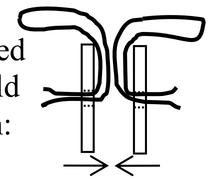


Fig. 2: Magnets with wires correctly wrapped

5. Insert the looped part of the wire of each magnet into opposite ends of the straw.
6. Balance the straw on your finger to locate the center-of-gravity of the straw-magnet system. Once found, carefully insert the straight pin through the straw (Don't poke yourself!) so that the point sticks out about 0.5 cm from the bottom of the straw.
7. Balance the straw on the cup. If using a plastic cup, DO NOT poke the pin into the cup. Small adjustments may be necessary. (Recall the torque investigation with the meter stick and hanging masses.) If the straw tips toward one end, push in or pull out the wire loops slightly until balance is achieved. If the straw tips to the side, rotate the wires in the straw slightly until balance is achieved. When finished your compass should balance horizontally as shown in Fig. 3 below.

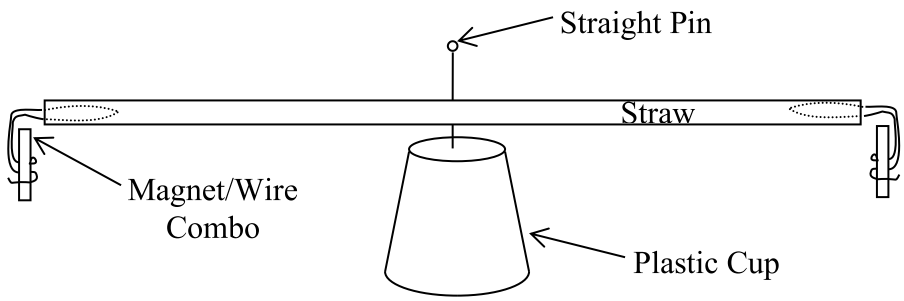


Fig. 3: Constructed and properly balanced compass.

Questions: Once balanced and steady, how does the alignment of your newly constructed compass compare with the one you used earlier? If you orient your compass in various positions and let it go, what does it do?

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** ______

Part III
Magnetic Induction

In this part, you will use a galvanometer (a sensitive current-measuring device) to explore how electromagnetic induction occurs. This will be done by inserting and removing a magnet from a wire coil.

Your group will need the following materials/equipment for this part:

- 1 wire coil or solenoid
- 1 galvanometer
- 2 connecting wires ("banana" leads and "alligator" clips)

Procedure

1. Connect the coil to the galvanometer by wiring one side of the coil to one of the galvanometer posts and the other side of the coil to the other galvanometer post as shown in Fig 4 below.

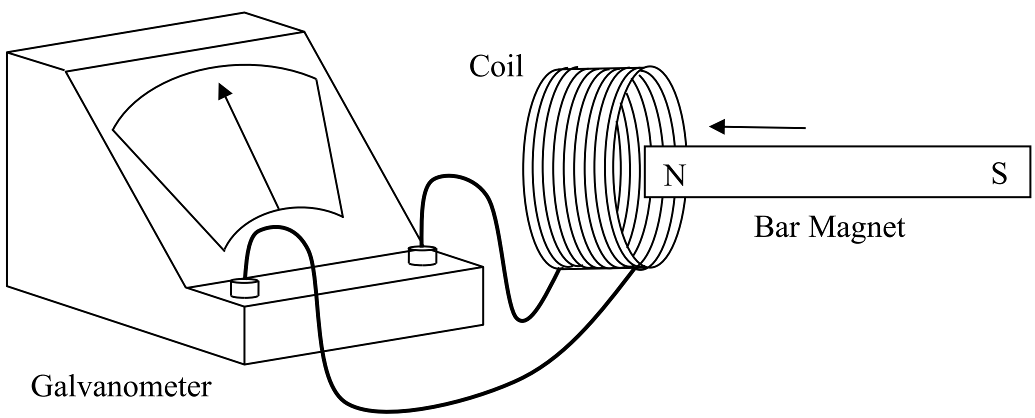


Fig. 4: Connecting the coil to the galvanometer.

2. Slowly move the "North" pole of a bar magnet in the coil until the center of the magnet is in the center of the coil. Observe what happens to the galvanometer and record your observation by placing a check in the appropriate space below.

   ______ The galvanometer needle deflects to the left.

   ______ The galvanometer needle does not deflect at all.

   ______ The galvanometer needle deflects to the right.

Question: If deflection occurred while the magnet was inserted, what was the magnitude of the deflection (in arbitrary "galvanometer" units)?

Record the magnitude of deflection: ______ Arbitrary Units

3. Now, slowly remove the magnet by backing it out toward the same side that you inserted it. Try to pull the magnet out with the same speed that you inserted it.

______ The galvanometer needle deflects to the left.

______ The galvanometer needle does not deflect at all.

______ The galvanometer needle deflects to the right.

Question: If deflection occurred while the magnet was removed, what was the magnitude of the deflection (in arbitrary "galvanometer" units)?

Record the magnitude of deflection: ______ Arb. Units

4. Move the N-pole of the magnet into the coil (as in Step 2), only faster this time. Note the deflection of the galvanometer. Remove the magnet by backing it out toward the same side that you inserted it with the same fast speed. Record your observations by circling the appropriate response:

Insertion: Meter deflects to the (left / right)

Meter deflection is (more than / the same as / less than) that in Step 2.

Removal: Meter deflects to the (left / right)

Meter deflection is (more than / the same as / less than) that in Step 3.

5. Repeat Step 2 by slowly inserting the N-pole of the magnet into the coil from the other side. Try to move at the same speed as you did in Step 2. Note the deflection of the galvanometer. Remove the magnet by backing it out toward the side that you inserted it. Note the behavior of the galvanometer.

Questions: In what ways (if any) was the behavior of the galvanometer in Step 5 (insertion of N-pole into the other side) the same as in Steps 2 and 3? In what ways was the behavior different?

Similarities:

Differences:

6. Repeat Steps 2-5, with the magnetic poles reversed. (That is, insert the "South" pole of the magnet into the coil slowly, quickly, from the other side, etc.) Note how the galvanometer behaves in each case.

Questions: When using the S-pole, in what ways (if any) was the behavior of the galvanometer the same as in Steps 2-5? In what ways was the behavior different?

Similarities:

Differences:

Questions: Does the galvanometer show any deflection when the magnet is stationary? What must be happening in order to get a deflection on the galvanometer?

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** _______

Part IV
Magnetism from Electricity

Your group will need the following materials/equipment for this part:

- 1 lantern battery (6 volts)
- 1 minilamp with holder
- 1 contact switch (knife switch NOT recommended)
- 1 small compass and 1 magnaprobe
- 1 solenoid with steel bolt or rod
- 1 long piece of insulated wire (about 20 cm long)
- Paper clips, staples or small BBs
- Your constructed compass from **Part II**

Procedure

1. Start by hooking up a simple circuit so that the lamp will light when the switch is closed and go out when the switch is open. (This step is just an equipment check.)
2. With the switch now open, remove the lamp holder and replace it with the long wire.

CAUTION: You may already know from experience during the circuit investigation that a wire placed directly across the battery will cause the battery and wire to get hot if the switch is remained closed for more than a few seconds. Once you complete a given observation, open the switch immediately!

3. Place the small compass on top the wire and orient the wire so that it runs parallel to the stable direction of the compass. See Fig 5(a) below.

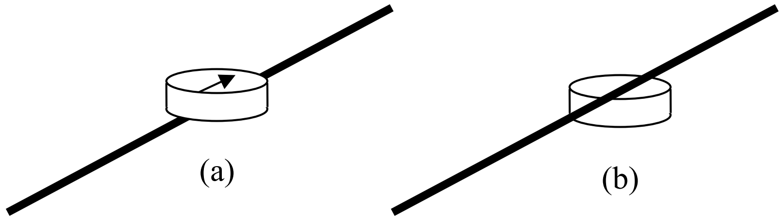


Fig. 5: (a) The commercial compass placed above the wire and (b) below the wire.

4. Close the switch. Observe the behavior of the compass. Wait a few seconds for the compass to settle down. Reopen the switch.
5. With the switch OPEN again, place the compass below the wire (again, with the wire parallel to the compass needle) and close the switch as shown in Fig 5(b). Note the behavior of the compass. Reopen the switch after the compass settles down.

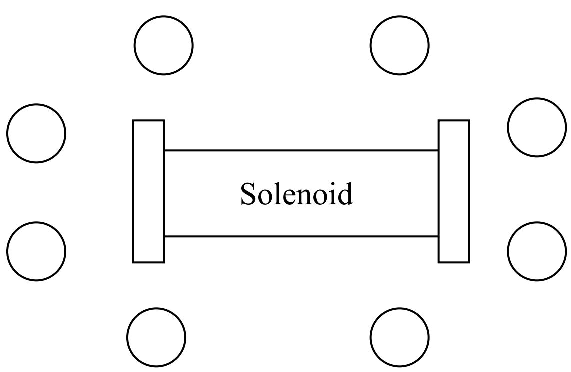
Questions: Describe how the compass behaved in each case. In what ways (if any) were the behaviors similar? In what ways (if any) were the behaviors different?

Similarities:

Differences:

6. Disconnect your wire (Be careful: it may be hot!) and with the switch open, connect the solenoid to the battery. Close the switch. Move the compass or "magnaprobe" around the solenoid. Check near the ends, the sides, and all around the coil. Note the behavior of the compass/magnaprobe. Reopen the switch.

Question: How does the behavior of the compass/magnaprobe around the coil compare to the behavior of the compass/magnaprobe around the bar magnet? Sketch the compass needle orientation in each of the circles around the solenoid



7. With the switch OPEN, insert a steel rod or bolt into the coil. Close the switch. Bring the small compass near the coil and again observe its behavior. Bring your constructed compass from **Part II** near the coil and observe its behavior. Reopen the switch. Test the strength of the magnetic force generated by observing how many paper clips, staples, or BBs the magnet can pick up.

Question: How does the strength of the magnetic force generated by the coil seem to compare to that of the straight wire? How can you check?

Question: What effect did inserting the steel bolt have on the strength of the magnetic force? How do you know?

Question: List at least three other ways in which you could increase the magnetic force created by your circuit.

1)

2)

3)

You just created an *electromagnet*. (That is, a magnet that runs on electricity.)

8. Check whether or not your electromagnet behaves in ways similar to the permanent magnets that you explored earlier. (Hint: Use the low-friction turntable with the other magnets.)

Question: Does your electromagnet attract other magnets? Yes No

Question: Does it repel other magnets? Yes No

Question: Where are the poles of your electromagnet?

9. Repeat these observations with the polarity of the battery reversed.

Question: What similarities and differences did you observe upon reversing the polarity of the battery?

Similarities:

Differences:

Question: What is at least one advantage of an electromagnet over a permanent magnet?

Question: What is at least one advantage of a permanent magnet over an electromagnet?

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** _______

Part V
Motors and Generators

In this section, you will use your compass and electromagnet to familiarize yourself with the operation of a simple electric motor and generator.

Your group will need the following materials/equipment for this part:

- Your constructed compass from **Part II**
- Your electromagnet circuit from **Part IV**
- 1 bar magnet
- 1 low-friction turntable
- 1 wire coil or solenoid with steel bolt or rod

Procedure

1. With your constructed compass balanced and stationary, use the bar magnet to make your compass spin continuously in one direction at a fairly uniform rotational speed. The stipulation is that you cannot simply move your magnet in a circle around the compass. Rather, you must have your magnet approach and recede with coordinated timing. Note the pattern for how you move your magnet once you get your compass to spin at a steady rate.

Question: How do you have to move the permanent magnet in order to maintain a steady spin rate? Describe the timing of your approach and recession.

2. Set the bar magnet aside and place your electromagnet near one of the "poles" of your compass. Keep your electromagnet stationary and make your compass spin at a fairly uniform rate by repeatedly closing and opening the switch at appropriate times. Again, note pattern for how you have to operate the switch in order to get your compass to spin at a steady rate.

Question: How do you have to operate the contact switch in order to keep the compass spinning at a steady rate? Describe the timing of when you open and close the switch.

You are using electrical energy from the battery and converting it into mechanical energy to make the compass spin. Thus, you have essentially created a simple *electric motor*.

3. Disconnect the coil from the battery and reconnect the coil to the galvanometer. Spin your compass (by hand if you wish) and let it "coast." Bring of the coil near the spinning compass to allow the poles to pass right by one end of the coil. Observe the behavior of the galvanometer as the poles of the spinning compass pass by the face of the coil. Place the steel bolt into the coil and continue to observe the behavior of the galvanometer.

Questions: As the poles of your compass rotate past the coil, what behavior do you notice in the galvanometer readings? What is being "induced" in the coil? (Hint: What does the galvanometer measure?)

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** _______

Part VI
Designing a Motor

Although it may not be obvious, you essentially constructed a simple motor and a simple generator in **Part V**. In this part, you will design and construct a simple "hands free" motor coil in order to produce the fastest spin rate. You and your partner(s) need to come to consensus over the parameters that you will use. The choices include the thickness of the wire, the size of the coil and the number of turns. A couple of things to keep in mind: while a thicker wire allows more current, it will make the coil heavier. A thin wire is lighter, but does not allow as much current. More turns allows greater electromagnetic induction, but it also makes the coil heavier. You will have to decide what is most important.

Your group will need the following materials/equipment for this part:

- 1 computer with *LoggerPro*™ software installed
- 1 universal laboratory interface (ULI) box and appropriate cabling
- 1 photogate
- 1 D-cell battery and holder and strong disk magnet
- Varnish coated wire and 1 piece of sandpaper

Procedure

1. Below is a list of choices for the parameter that you will use. Circle your choices for each parameter that you think will produce the highest rotational speed.

A) Wire thickness:	Thin	Medium	Thick
B) Coil Diameter:	Small	Medium	Large
C) Number of windings:	4	6	8

Question: Justify the choices that you made.

2. Using the instructor's model as a guide, form a wire coil according to your choices from Step 1. To make a nice circular coil, wrap the wire around a cylinder having the diameter of your choice and then slide the cylinder out of the coil. Be sure to leave two straight ends about 2-3 cm long sticking out on opposite sides as shown in Fig. 6 on the next page.
3. Wrap the free ends of wire once or twice around the coil to keep it from unraveling. Try to keep the coil symmetric so that it will balance easily and stay in position when placed onto holder as shown in Fig. 7 on the next page.

4. With the sandpaper, sand the varnish coating completely off one of the straight ends from the end of the wire to the loop as in Fig. 6 below.
5. On the other end, sand the varnish off ONLY ONE SIDE of the wire from the end of the wire to the loop:

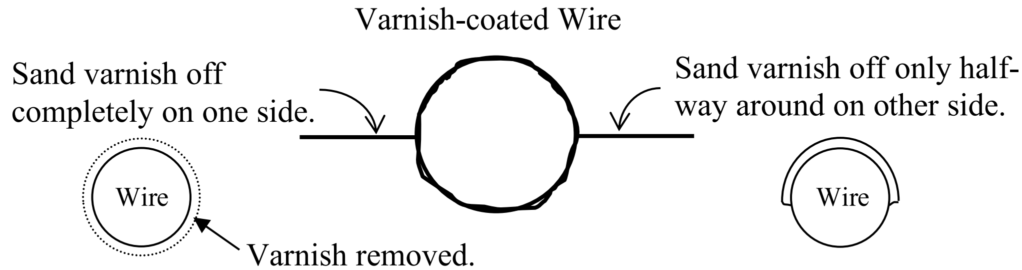


Fig. 6: Wire loop with the varnish properly sanded from the straight sections.

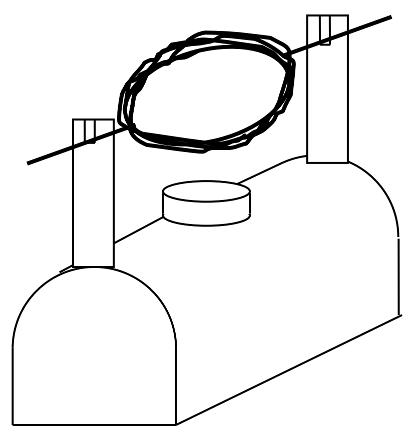


Fig. 7: The 'hands-free" motor. A D-cell battery is placed inside the plastic case and contacts the vertical metal strips in which the coil is to be placed. The disk magnet fits in a tray below the coil.

6. Place the disk magnet in the tray under the coil and blow on the coil to get it to spin. If the coil does not turn, try repositioning the coil, straightening the coils leads, etc.
7. Show your instructor your motor in operation. In the discussion questions you will be asked to explain how this simple motor works. (Hint: Use all of your observations from today's investigation along with information gleaned from your text in order to explain the operation of your motor.)
8. Open the file *DC-Motor* in the *Conceptual Physics* alias on the computer desktop. Once you have successfully opened the proper file, the computer will display a graph of "Frequency vs. Time." Note that the units for the frequency axis and time axis are Hertz and seconds, respectively. (You can change the range of the axes simply by clicking on the maximum or minimum value displayed on that axis, typing a new number, and pressing **Enter**.)

9. Get your coil spinning under the photogate so that the top of the coil intercepts the photogate beam as shown in Fig. 8. With the coil spinning in the photogate, click **Collect** and allow the computer to acquire data for a few seconds.

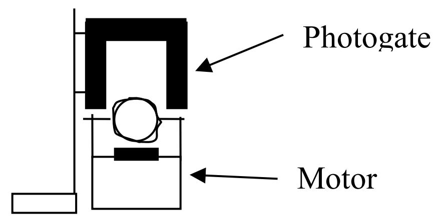


Fig. 8 Motor operation with photogate.

10. After the data collection, use the **Statistics** feature to determine the average frequency of the rotation during the data collection. Record this rotation frequency:

$$f_{ave} = \_\_\_\_\_\_\_\_ \text{Hz}$$

Question: What would happen to the spin direction if you reverse the polarity of the battery? Try it and see.

Question: What happens to the spin direction if you flip the permanent magnet? Try it and see.

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11. Return all materials back to the staging area. Do NOT throw away your wire coils.

Checkout: Consult with your instructor before exiting the lab. **Instructor's OK:** ______