

Magnetic Fields: Magnetic Flux and Lenz's Law

Currents induced in coils by magnets and by other coils

January 14, 2014

Print Your Name

Print Your Partners' Names

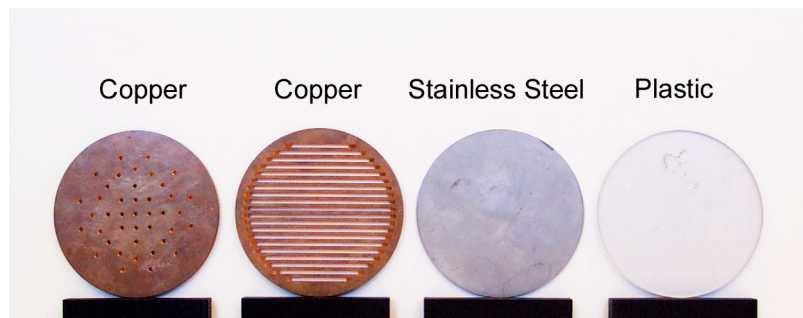
Instructions

Before the lab, read sections 0.1 - 0.3 of the *Introduction*. In addition, review all the other sections of the *Introduction* and the warning at the beginning of Activity #1. Then answer the Pre-Lab questions on the last page of this handout. Be prepared to discuss the Pre-Lab questions in lab as Activity #1.

You will return this handout to the instructor at the end of the lab period.

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Comprehensive Equipment List

- Bar magnet (alnico preferred)
- A large coil
- Galvanometer ($\pm 50 \mu\text{A}$)
- Compass
- Small coil, fits inside large coil
- D-cell battery in a D-cell holder
- Banana plug leads, red & black
- Alligator clips, red & black



- Large magnet (see picture)
- Disks (copper, stainless steel, plastic; see picture, above)
- World's Simplest Motor (Cenco CP33678-00 or Arbor Scientific P8-8300; includes motor stand, magnet*, and 1.24 meters (124 cm) of enamel-coated 22-gauge copper wire)
 - * Label the magnet poles N and S.
- D-cell in battery holder for World's Simplest Motor
The Motor Stand is used throughout this lab as a D-cell holder.
- Pre-built motor coil, but with both ends completely stripped of insulation
- Knife blade or sandpaper, to remove insulating enamel as appropriate
Inexpensive box cutters with razor blades work well.
- One good motor coil, to be shared by the whole lab as an example

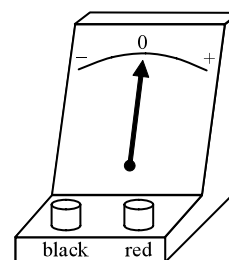
0. Introduction

Sections 0.1 through 0.3 in this *Introduction* describe **galvanometers**, **magnetic flux**, and **Lenz's Law**. The remaining sections are identical to the sections in the *Introduction* for the lab on Right Hand Rules. Those sections are repeated in this handout for reference, since both Right Hand Rules are used extensively in applying Lenz's Law.

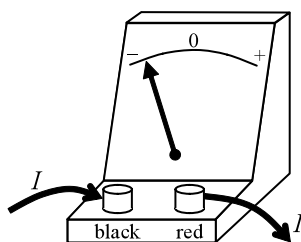
To distinguish the sections copied from the Right Hand Rule lab, they are printed in a smaller font.

0.1 The galvanometer

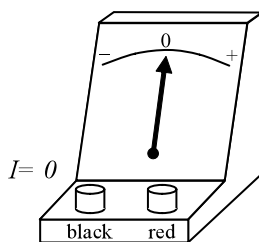
A galvanometer is a fairly sensitive device for determining the direction in which current flows in a circuit. When you connect a galvanometer in series in an electrical circuit, any current in the circuit flows through the galvanometer. A deflection of the galvanometer meter needle to the right indicates current is flowing into the galvanometer's red terminal and out of the galvanometer's black terminal. Deflection of the needle to the left indicates current is flowing in the opposite direction, into the black terminal and out of the red terminal. If there is no deflection, no (or very little) current is flowing through the galvanometer. See Figure 1.



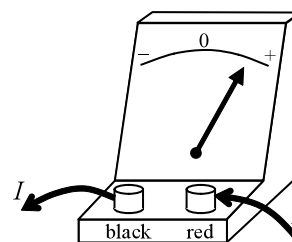
Galvanometer



Here, current flows into the **black** terminal and out of the **red** terminal.



When **no current** flows through the meter, the needle points to zero.



Here, current flows into the **red** terminal and out of the **black** terminal.

Figure 1 How the galvanometer needle responds to current flowing through the galvanometer

0.2 Magnetic Flux

Given a coil of wire in a constant magnetic field, and oriented so that the lines of the magnetic field are perpendicular to the face of the coil, the *magnetic flux* through the coil can be calculated using the following formula.

$$\Phi = BAN$$

B is the magnetic field strength, in teslas.
 A is the area of the face of the coil, in square meters.
 N is the number of loops of wire in the coil.
 Φ is the magnetic flux through the coil, in webers.

However, this formula is not important for the purposes of this lab.

What is important is the following.

You can think of magnetic flux Φ through a coil as being the number of lines of magnetic field that pass through the coil.

If the magnetic flux through a coil is increasing, that means the number of magnetic field lines that pass through the coil is increasing. If the magnetic flux through a coil is decreasing, that means the number of magnetic field lines that pass through the coil is decreasing.

Use this image of magnetic flux to help you visualize magnetic flux as if it were something that one could actually see.

You may find it useful to read about magnetic flux in your text before coming to lab.

<i>Text</i>	<i>Reference</i>
James Walker, 4 th edition	Section 23.2
Randall Knight, 2 nd edition	Section 34.3

0.3 Lenz's Law

Lenz's Law is part (c) of the following series of statements. (a) If a magnetic flux through a coil of wire changes, a current will flow in the coil. (This current is known as an *induced current*. The changing flux induces current to flow.) (b) The flowing current creates its own magnetic field, in addition to the magnetic field that is the source of the changing flux. (c) *The magnetic flux through the coil due to the new magnetic field opposes the **change** in the magnetic flux that is causing the current.*

To the above, add the following. (d) *A magnetic flux that does not change will not cause a current to flow in a coil.* In other words, no matter how strong a magnetic field is, it by itself will not cause current to flow in a coil. In addition to the magnetic field, something must change. For example, a changing magnetic field will make a current flow in a stationary coil even though an unchanging magnetic field will not.

Having said all that, it may be helpful to express Lenz's Law in terms of lines of magnetic field and to consider two special cases.

- ❖ Assume the lines of magnetic field passing through a coil of wire are **increasing** in number. Then new lines of magnetic field are created that pass through the coil in the direction **opposite** to the original magnetic field. The direction of the new lines of

magnetic field and Right Hand Rule #2 will tell you which way the current is flowing in the coil.

- ❖ Assume the lines of magnetic field passing through a coil of wire are **decreasing** in number. Then new lines of magnetic field are created that pass through the coil in the **same** direction as the original magnetic field. The direction of the new lines of magnetic field and Right Hand Rule #2 will tell you which way the current is flowing in the coil.

It will be helpful to read about Lenz's Law in your text.

<i>Text</i>	<i>Reference</i>
James Walker, 4 th edition	Section 23.4
Randall Knight, 2 nd edition	Section 34.4

0.4 *The nature of electric current*

<i>Text</i>	<i>Reference</i>
James Walker, 4 th edition	Section 21.1
Randall Knight, 2 nd edition	Section 31.1

- Electric current always flows in closed loops.
- The direction of electric current in a circuit connected to a battery is always from the plus terminal of a battery toward the negative terminal.
- You should think of electric current as positive charges moving from the plus terminal of a battery to the negative terminal (even though in wires current is really negative electrons moving from the negative terminal to the positive terminal).

0.5 *The nature of magnetic fields*

- The lines of the magnetic field always form closed loops.

0.6 *The nature of permanent magnets and their magnetic fields*

<i>Text</i>	<i>Reference</i>
James Walker, 4 th edition	Section 22.1
Randall Knight, 2 nd edition	Section 33.2 and page 1030

- Permanent magnets always have two poles, called **N** and **S** for *North* and *South*.
- Opposite magnetic poles attract, and like magnetic poles repel.
- The magnetic field lines in the space outside a permanent magnet always have a direction that points away from **N** poles and towards **S** poles. (Inside the permanent magnet, they point from **S** to **N**, thus completing continuous closed loops that leave the permanent magnet at the **N** pole, re-enter the permanent magnet at the **S** pole, and continue through the permanent magnet back to the **N** pole.)

0.7 Compass conventions

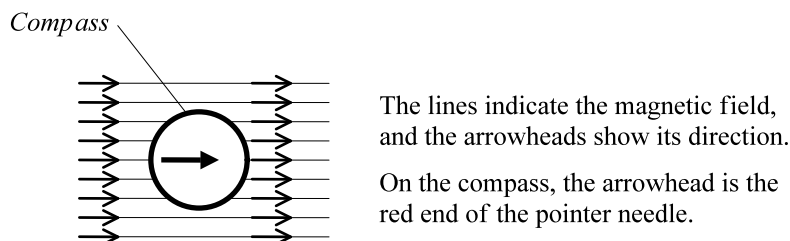


Figure 2 How to use a compass to determine the direction of a magnetic field

- Each compass used in this lab has a pointer needle. One end of the pointer needle is painted red, and the other is white.
- Figure 2 shows how to use a compass to determine the direction of a magnetic field. The red end of the pointer needle points in the direction of the magnetic field.

0.8 Right Hand Rule #1: Direction of magnetic forces on charges moving in magnetic fields

<i>Text</i>	<i>Reference</i>
James Walker, 4 th edition	Section 22.2
Randall Knight, 2 nd edition	Section 33.7

- If a charged particle in a magnetic field has velocity zero m/s, the magnetic field exerts zero force on the particle.
- If a charged particle with *positive* charge is moving in a magnetic field, the relation between the direction of the particle's velocity, the direction of the magnetic field, and the direction of the magnetic force on the particle is given by the Right Hand Rule. See the references for the statement of the Right Hand Rule.
- If a charged particle with *negative* charge is moving in a magnetic field, the magnetic force is in a direction opposite to the direction given by the Right Hand Rule.

0.9 Right Hand Rule #2: Direction of magnetic field around a current-carrying wire

<i>Text</i>	<i>Reference</i>
James Walker, 4 th edition	Section 22.6 page 780 and figure 22-20
Randall Knight, 2 nd edition	Section 33.2 figure 33.2

- A wire that carries an electric current has a magnetic field the lines of which loop around the wire in closed loops.
- If you seize the wire with your right hand in a fist and your thumb pointing in the direction the current is flowing, your fingers wrap around the wire in the direction of the magnetic field. This is Right Hand Rule #2.
- You can also use Right Hand Rule #2 to determine the direction of the magnetic field generated by a coil of wire. Grab the coil with your right hand in a fist (so that your fingers poke through the center of the coil) and with your thumb in the direction of the current. The direction of the magnetic field loops is the same as the direction your finger point.

1. Activity #1: Review Answers to Pre-lab questions

1.1 With your lab partners at your workstation, review your answers to the pre-lab questions. Your goal is for all of you to agree on the answers. Your instructor will be pleased to assist, if appropriate.

1.2 When you and your lab partners have agreed on all the answers to the pre-lab questions, have the lab instructor check your answers. The lab instructor will sign your lab handout when all questions have been answered satisfactorily.

**Please, No magnets near
the computer monitor!**

**Magnets cause
permanently distorted
displays in computer
monitors.**

Thanks.

Lab Instructor's Signature goes here

2. Activity #2: Lenz's Law demonstration / observations

With the large permanent magnet and the four disks, make the following observations. You will analyze your observations in a later activity.

2.1 Copper disk with round holes

2.1.1 Note the strength of the force with which the disk resists motion within the magnetic field. Circle one: **Strong Weak Zero**

2.1.2 Does the force depend on the orientation of the disk? Circle one: **Yes No**

2.2 Copper disk with long slits

2.2.1 Note the strength of the force with which the disk resists motion within the magnetic field. Circle one: **Strong Weak Zero**

2.2.2 Does the force depend on the orientation of the disk? Circle one: **Yes No**

2.3 Stainless steel disk: The force is (circle one) **Strong Weak Zero**

2.4 Plastic disk: The force is (circle one) **Strong Weak Zero**

3. Activity #3: The direction of an induced magnetic field

Equipment: A large coil
Galvanometer
Banana plug leads (one red, one black)

3.1 Connect the coil to the galvanometer as shown in Figure 3, with the red terminal on the galvanometer connected to the socket marked **S** and the black terminal on the galvanometer connected to the socket marked **F**.

3.2 Answer the following questions, but do not do any experiments at this time.

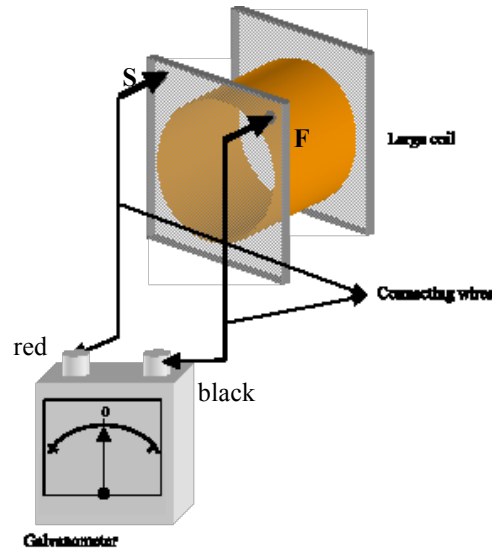


Figure 3 A galvanometer connected to the large coil of wire

Q 1 Would the act of quickly thrusting the N pole of a bar magnet into the coil through the opening that is toward you cause the coil to respond by creating its own magnetic field? (Yes or No?) If Yes, which direction would the new magnetic field point? (Toward you or away from you?) Explain.

Q 2 Would the act of steadily holding the N pole of a bar magnet inside the coil cause the coil to respond by creating its own magnetic field? (Yes or No?) If Yes, which direction would the new magnetic field point? (Toward you or away from you?) Explain.

Q 3 Would the act of quickly withdrawing the N pole of a bar magnet from inside the coil through the opening that is toward you cause the coil to respond by creating its own magnetic field? (Yes or No?) If Yes, which direction would the new magnetic field point? (Toward you or away from you?) Explain.

4. Activity #4: The direction of an induced electric current

The lab instructors do not take points off for wrong answers to the questions in sections 4.2 and 4.3. However, section 4.4 is graded.

4.1 Inspect the large coil carefully to determine the direction the coils wind around the center. You will need to know this in order to answer the questions in this activity.

4.2 Answer the following questions, but do not do any experiments at this time. Wait to do experiments until explicitly directed to do so.

***Q 4** If the N pole of a bar magnet is quickly thrust into the opening of the large coil that faces you, how will the galvanometer deflect while the magnet is moving into the coil? (a) Positive deflection, because current flows into the red terminal of the galvanometer and out of the black terminal. (b) Negative deflection, because current flows into the black terminal of the galvanometer and out of the red terminal? (c) No deflection, because no current flows through the galvanometer. Explain your choice.*

***Q 5** If the N pole of a bar magnet is held motionless inside the large coil, how will the galvanometer deflect? (a) Positive deflection, because current flows into the red terminal of the galvanometer and out of the black terminal. (b) Negative deflection, because current flows into the black terminal of the galvanometer and out of the red terminal? (c) No deflection, because no current flows through the galvanometer. Explain your choice.*

***Q 6** If the N pole of the bar magnet is quickly withdrawn from the coil, how will the galvanometer deflect as the magnet moves out of the coil? (a) Positive deflection, because current flows into the red terminal of the galvanometer and out of the black terminal. (b) Negative deflection, because current flows into the black terminal of the galvanometer and out of the red terminal? (c) No deflection, because no current flows through the galvanometer. Explain your choice.*

4.3 Do the following.

4.3.1 Quickly insert the north pole of your bar magnet into the coil opening facing you (as in Figure 3), and record the deflection of the galvanometer here. _____

4.3.2 Hold the bar magnet steady inside the coil, and record the galvanometer deflection here. _____

4.3.3 Quickly pull the bar magnet out of the coil, and record the galvanometer deflection here. _____

Q 7 Were your answers to the preceding three questions (Q 4, Q 5, Q 6) correct? (Yes or No?)

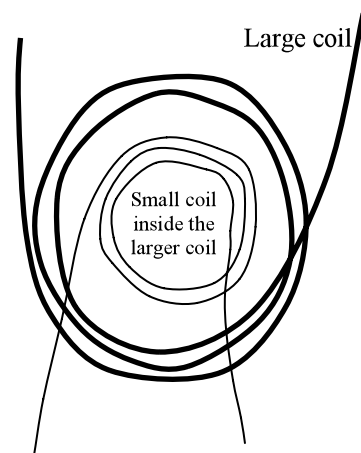
4.4 If your answer to the preceding question (Q 7) was *No*, have your lab instructor go over Q 4, Q 5, and Q 6 with you.

Q 8 What do you think would happen if you repeated 4.3.1 - 4.3.3 above using an *S* pole instead of an *N* pole?

Q 9 After answering Q 8, repeat 4.3.1 - 4.3.3 using an *S* pole instead of an *N* pole, and record whether your answer to Q 8 was right or not. If your answer was not right, please consult with your lab instructor to determine what went wrong.

5. Activity #5: Mutual induction between two coils

Equipment: A large coil
A small coil, able to fit inside the large coil
D-cell battery in a D-cell holder
Galvanometer
Compass
Banana plug leads (one red, one black)
Alligator clips (one red, one black)



5.1 Disconnect the galvanometer from the large coil.

5.2 Place the small coil inside the large coil so that the axes of the coils are parallel.

5.3 Answer the following questions. Do not do any experiments unless explicitly directed to.

Q 10 *If you were to connect the battery to the small coil so that the current would flow clockwise around the small coil, which direction would the magnetic field through the center of the small coil point? Toward you or away from you? Explain.*

5.4 At this time, connect the battery to the small coil so that the current flows clockwise around its coils. Use alligator clips to secure the coil's leads to the D-cell holder.

5.5 Check the direction of the magnetic field produced by the small coil with the compass.

Q 11 *Was your answer to the previous question correct? (Y or N?) If it was not, give here a correct explanation for the direction of the magnetic field from the small coil.*

Q 12 *Would a steady clockwise current in the small coil cause a steady current in the large coil? (Yes or No?) Explain.*

5.6 Re-connect the galvanometer to the large coil, and observe whether or not a current is flowing.

Q 13 *Was your answer to the previous question (Q 12) correct? (Y or N?) If it was not, give here a correct explanation for the effect on the big coil of a steady current in the small coil.*

5.7 Disconnect:

5.7.1 The galvanometer from the large coil

5.7.2 The battery from the small coil

5.8 Continue by answering the following questions. Do not do any experiments unless explicitly directed to.

Q 14 At the moment the small coil is connected to the battery, the large coil begins to create a magnetic field. This happens because, at the moment the small coil connects to the battery, the current in the small coil begins to increase from zero to some large value. Use the changing magnetic field inside the central region of the small coil to determine the direction of the magnetic field the larger coil creates in its central region? Toward you or away from you? Explain.

Q 15 What would be the deflection of the galvanometer, if it were connected to the large coil as shown in Figure 3? (Positive, because current is flowing into the red terminal and out of the black terminal, or negative because current is flowing into the black terminal and out of the red terminal?) Explain.

5.9 Re-connect the galvanometer to the large coil.

5.10 Watch the galvanometer needle as you connect the battery to the small coil.

Q 16 Was your answer to the previous question (Q 15) correct? (Y or N?) If it was not, give here a correct explanation for the direction the current flowed through the galvanometer.

6. Activity #6: Build and analyze a simple DC electric motor

To answer the questions in this activity, sometimes you need the ***Right Hand Rule for a force*** or the ***Right Hand Rule for the direction of a magnetic field*** (the previous lab), and sometimes you need ***Lenz's Law*** (this lab).

6.1 If you were to compare the magnetic field lines of a current carrying coil with those of a permanent magnet you would observe that they are quite similar. See Figure 4. Hence in many situations you can view the magnetic field of a current carrying coil as being that of a permanent magnet. This analogy will come in handy in determining how the electric motor of this activity works.

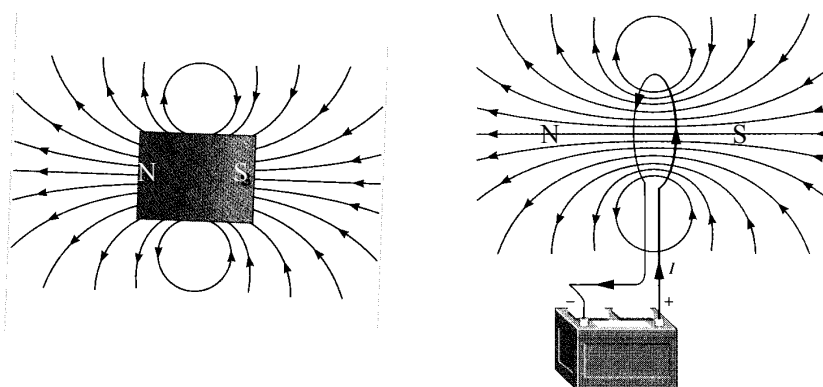


Figure 4 Diagram showing the similarities of the magnetic field near a permanent magnet (on the left) and a current carrying coil (on the right).

Q 17 Suppose a current is moving clockwise through the coil in Figure 5 (on page 13). What is the direction of the magnetic field that the current creates at the center of the coil? With respect to Figure 5, choose either: (1) out of the paper, or (2) into the paper. Explain your answer using the Right Hand Rule.

Q 18 [Use the RHR for the direction of a force on a current to answer this question.] Still referring to Figure 5, suppose the coil is supported by the posts and free to rotate, and a magnetic field pointing up (toward the top of the page) is turned on. What will the coil do? Will the top of the coil tip toward you and stop? Will the top of the coil tip away from you and stop? Will the top of the coil tip toward you and start to spin? Will the top of the coil tip away from you and start to spin? Explain your answer. (Hint: You may find it helpful to pretend the coil is a small bar magnet. See Figure 4.)

6.2 Inspect the battery inside the World's Simplest Motor and the direction of the coils on the pre-built in coil order to determine how to mount the coil on the motor so that the current flows through the coil clockwise.

6.3 Check the small disk magnet mounted in the World's Simplest Motor to determine whether the N pole of the magnet is up, so that the magnetic field from the magnet is directed upward. If it is not, reverse the magnet.

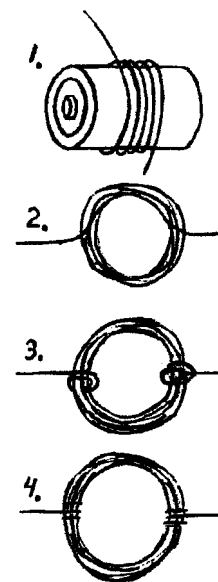
6.4 Mount the pre-built coil on the World's Simplest Motor with the current flowing clockwise and the magnetic field of the disk magnet directed upward. Observe what the coil does.

Q 19 Was your answer to Q 18 correct? If it was not, please consult with your lab instructor to determine what went wrong.

6.5 Construct a motor coil as follows. Refer to Figure 5.



Figure 5 Make this coil as a first step in building an electric motor. The posts show how the coil will be supported as it rotates.



6.5.1 Wrap the #22 enamel coated copper wire around your D cell to form a coil.

6.5.2 Wrap several turns around the coil to secure the leads. It is important that the coil leads be securely held in place and that the coil be well-balanced about its midline.

6.5.3 Trim the excess wire to leave about 1 cm.

6.5.4 Use sandpaper and/or a knife blade to remove all the insulation from **one** of the leads to the coil that you just made. **Do not remove insulation from the other lead yet.**

6.6 Now lay the coil flat on the table and remove the insulation from the **half** of the other lead that faces upward. When done, **exactly 180°** of the circumference should be bare, shiny copper (the side facing up) while the other 180° of the circumference should still be insulated (the side facing down toward the table).

6.7 Mount the coil on the supports connected to a battery. You may need to help the coil start spinning. Try both directions. Be gentle.

6.8 Show your motor to your lab instructor. S/he will initial your lab handout when the motor works correctly.

Instructor's initials go here: _____

Q 20 Explain why the coil spins. The way in which you removed the insulation from one half of one of the coil leads is the key. Thinking of the coil as a bar magnet (as in Figure 4) that can be turned on and off may be helpful.

Q 21 As the coil rotates in the magnetic field of the permanent magnet, there is an induced current in the coil in addition to the current created by the battery. Use Lenz's Law to determine the direction of the induced current as the coil rotates with battery current flowing. Is the induced current in the same direction as the battery current or in the opposite direction?

7. Activity #7: Analyze the Lenz's Law observations from Activity #2

Use Lenz's Law to answer the following questions.

Q 22 Use Lenz's Law to explain the origin of the force you feel when moving the copper disk with small round holes through the magnetic field of the large magnet.

Q 23 Use Lenz's Law to explain why the magnetic force on the disk with long, thin slits depends on the orientation of the disk.

Q 24 Copper and stainless steel are both conductors. How can one explain the observation that the magnetic force on the stainless steel disk is much smaller than the magnetic force on the copper disk?

8. When you are done, ...

Turn in this handout, with all questions answered.

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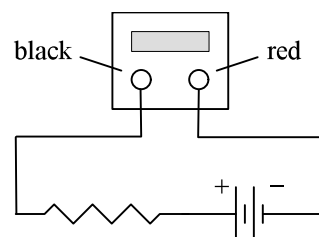
Pre-Lab Questions

Print Your Name

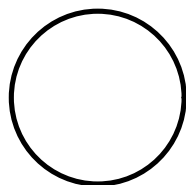
Read the *Introduction* to this handout, and answer the following questions before you come to General Physics Lab. Write your answers directly on this page. When you enter the lab, tear off this page and hand it in.

1. How does a galvanometer indicate the direction that electrical current flows through it?

2. In the circuit to the right, which direction is the galvanometer deflection? Plus or minus? Explain.



The diagram below shows a long straight wire and a circular loop of wire lying flat on a table beside each other. The long straight wire is connected to a power supply (not shown). The next six questions all relate to this diagram. In answering the questions, first use Right Hand Rule #2 on the long straight wire to determine the direction of the magnetic field through the circular loop, and then note whether the number of magnetic field lines through the circular loop is increasing, decreasing, or unchanging.



3. Assume that a *steady, unchanging* current is flowing in the long straight wire from *left to right*. Does this cause a current to flow in the circular loop and, if it does, will the flow be clockwise or counterclockwise? Explain.

4. Assume that a ***steady, unchanging*** current is flowing in the long straight wire from ***right to left***. Does this cause a current to flow in the circular loop and, if it does, will the flow be clockwise or counterclockwise? Explain.

5. Assume that a current is flowing in the long straight wire from ***left to right***, and that the current is ***increasing***. Does this cause a current to flow in the circular loop and, if it does, will the flow be clockwise or counterclockwise? Explain.

6. Assume that a current is flowing in the long straight wire from ***left to right***, and that the current is ***decreasing***. Does this cause a current to flow in the circular loop and, if it does, will the flow be clockwise or counterclockwise? Explain.

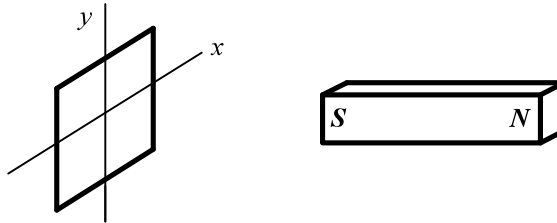
7. Assume that a current is flowing in the long straight wire from ***right to left***, and that the current is ***increasing***. Does this cause a current to flow in the circular loop and, if it does, will the flow be clockwise or counterclockwise? Explain.

8. Assume that a current is flowing in the long straight wire from ***right to left***, and that the current is ***decreasing***. Does this cause a current to flow in the circular loop and, if it does, will the flow be clockwise or counterclockwise? Explain.

The diagrams for questions 9 and 10 represent a bar magnet placed to the right of a rectangular loop of wire. The loop of wire is rigidly mounted (i.e., it cannot move) and it is perpendicular to the bar magnet.

9. The end of the bar magnet nearest the loop of wire is an S pole, and someone moves the magnet toward the loop, which makes the number of lines of magnetic field through the loop *increase*. As seen from the right does the current in the loop of wire flow clockwise or counterclockwise? Explain.

Question 9



10. The end of the bar magnet nearest the loop of wire is an N pole, and someone moves the magnet away from the loop, which makes the number of lines of magnetic field through the loop *decrease*. As seen from the right, does the current in the loop of wire flow clockwise or counterclockwise? Explain.

Question 10

