Magnetic Fields: Right Hand Rules

Magnetic forces on wires, electron beams, coils; direction of magnetic field in a coil

January 14, 2014

Print *Your Name*

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Print *Your Partners' Names*

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Instructions

Before the lab, read all 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; **N** and **S** taped over with masking tape; ends randomly re-labeled **A** and **B**)
- Suspension Loop as in Figure 2. (Bare 22 gauge wire suspended by two lengths of 30 gauge wire. Short lengths of insulated 22 gauge wire connected to the 30 gauge wire for making the connection to the battery. Wire-to-wire connections are soldered.)
- Banana plug wires; two, one red and one black (Radio Shack 270-375C)
- Alligator clips (one pair) that can plug onto banana wire plugs
- e/m apparatus with power supplies (one setup as a demonstration)
- Large coil of wire
- Magnetic compass
- D-cell (1.5 V) in D-cell holder

0. Introduction

Electromagnetism is one of the most interesting and intriguing areas of physics to study. Certain kinds of objects are able to exert forces over distance for some reason. Charged rods attract or repel depending on their composition and the material they were rubbed with; magnets attract or repel depending on which poles are brought near to each other. A magnet will always attract a ferrous metal (steel, iron, etc) but has no effect on metals like aluminum or copper; or do they? You will investigate electromagnetic interactions using simple materials like batteries, wires, magnets, and more complex devices like a galvanometer. You will even build a simple motor. Once you understand how this motor works, you will, in principle, understand how all electric motors work.

The following sections in this Introduction cover the concepts and rules you need to complete the activities of this lab on magnetism. There are no formulae. In these lab activities you will be concerned with the directions of currents, magnetic fields, and magnetic forces but not with the magnitudes of the currents, fields, or forces.

The summary here is complete but very terse. For more expansive explanations with examples and diagrams, refer to the general physics text citations given in each section below.

0.1 *The nature of electric current*

Text	*Reference*
James Walker, 4th edition	Section 21.1
Randall Knight, 2nd 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).

0.2 *The nature of magnetic fields*

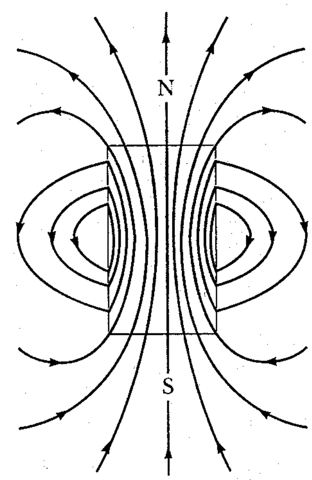
- The lines of the magnetic field always form closed loops.

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

Text	*Reference*
James Walker, 4th edition	Section 22.1
Randall Knight, 2nd edition	Section 33.2

- Permanent magnets always have two poles, called **N** and **S** for *N*orth and *S*outh.
- 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 or near the **N** pole, re-enter the permanent magnet at or near the **S** pole, and continue through the permanent magnet back to the **N** pole. See the diagram to the right.)



0.4 *Compass conventions*

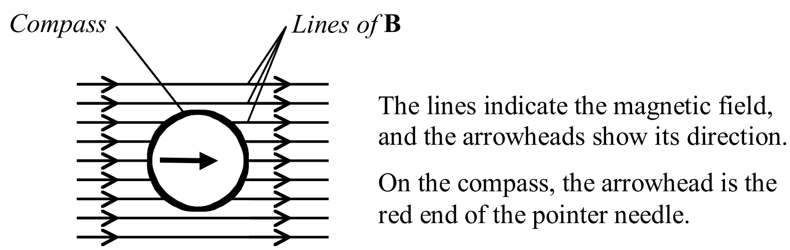


Figure 1 How to use a compass to determine the direction of a magnetic field

- 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 1 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.

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

Text	*Reference*
James Walker, 4th edition	Section 22.2
Randall Knight, 2nd 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.

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

Text	*Reference*
James Walker, 4th edition	Section 22.6 page 780 and figure 22-20
Randall Knight, 2nd 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.

0.7 *Uniform magnetic fields make charged particles move in circles*

Text	*Reference*
James Walker, 4th edition	Section 22.3
Randall Knight, 2nd edition	Section 33.7

- A charged particle moving perpendicular to a uniform magnetic field – and subject to no forces other than the magnetic force – will have uniform circular motion.
- The magnetic force will always be directed towards the center of the particle's circular trajectory and will keep the particle moving in a circle. Therefore the magnetic field is what supplies the particle's centripetal acceleration.
- If R is the radius of the circle, q the particle's charge, m its mass, and v its velocity, Newton's Second Law, $\Sigma F_x = ma_x$ becomes $qvB = mv^2/R$, because qvB is the magnetic force, and mv^2/R is mass times the centripetal acceleration.
- Solving $qvB = mv^2/R$ for R gives $R = mv/qB$, the radius of the circle in terms of particle mass, velocity, charge and the magnetic field strength.

Please, No magnets near the computer monitor!

Magnets cause permanently distorted displays in computer monitors.

Thanks.

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 answers have been answered satisfactorily.

2. Activity #2: Lab instructor presents the e/m apparatus to each group

As each group of lab partners completes their review of the pre-lab questions, the instructor shows the group the e/m apparatus. The purpose is to ensure that everybody knows what they are seeing when the look at the e/m apparatus.

- Outer coils produce a magnetic field parallel to the floor
- High-quality vacuum inside the glass bulb
- Electron gun (hot cathode boils electrons out of the wire, accelerating potential)
- Electrons move in a circle due to the magnetic field
- Electron trajectory is visible because the low pressure gas inside the tube glows due to electron impacts with gas molecules

3. Activity #3: Force on a current carrying wire.

Equipment: Bar magnet (Alnico preferred; **N** and **S** taped over with masking tape; ends randomly re-labeled **A** and **B**)
Suspension Loop as in Figure 2. (Bare 22 gauge wire suspended by two lengths of 30 gauge wire. Short lengths of insulated 22 gauge wire connected to the 30 gauge wire for making the connection to the battery. Wire-to-wire connections are soldered.)
D-cell in a D-cell holder
Alligator clips (one pair)

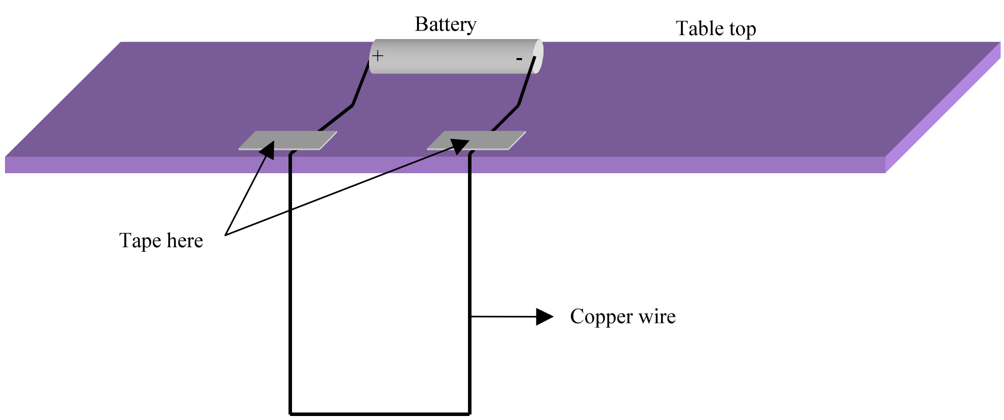


Figure 2 The Suspension Loop when connected to the battery

Do not connect the Suspension Loop to the battery at this time.

The lab instructors do not take off points for wrong answers to the questions in Activity #3.

Q 1 If the Suspension Loop were connected to the battery and the N pole of a vertical bar magnet were placed directly below the short horizontal wire at the bottom of the loop, which way would the Suspension Loop deflect? Toward the table or away from the table? Explain

your answer using Right Hand Rule #1 (the rule which gives the direction of the magnetic force on a moving positive charge).

Q 2 The same question as the previous question, but this time the S pole of a vertical bar magnet is directly below the Suspension Loop.

3.1 **When performing the following steps, try to have the suspension loop (see Figure 2) connected to the battery for as little time as possible. This is to keep the battery from running down too soon.**

3.2 Without using excess time, but still being careful, do the following.

3.2.1 Use alligator clips to clamp the Suspension Loop leads to the posts on the battery holder.

3.2.2 With your bar magnet oriented vertically and having the pole labeled **A** up, slowly bring the **A** pole up under the Suspension Loop and observe which way the Suspension Loop deflects.

Q 3 Which way did the Suspension Loop deflect? Toward the table or away from the table?

Q 4 Based on the answer to Q 3, is the* A *end of the bar magnet an N pole or a S pole?

3.2.3 Repeat 3.2.2 but with the **B** end of the bar magnet up.

3.2.4 Disconnect the Suspension Loop from the battery.

Q 5 Which way did the Suspension Loop deflect? Toward the table or away from the table?

Q 6 Based only on the answer to Q 5, is the* B *end of the bar magnet an N pole or a S pole?

3.3 Remove the masking tape from your bar magnet, and see if your identification of the polarity of the ends of the bar magnet were correct.

Q 7 Did you correctly identify the polarity of the ends of your bar magnet? (Yes or No)

3.4 If you did not correctly identify the polarity of the ends of your bar magnet, please consult with your lab instructor to determine what went wrong.

4.   Activity #4: Electron beam moving in a magnetic field

Equipment: e/m apparatus with power supplies (one setup as a demonstration shared by everyone in the lab)

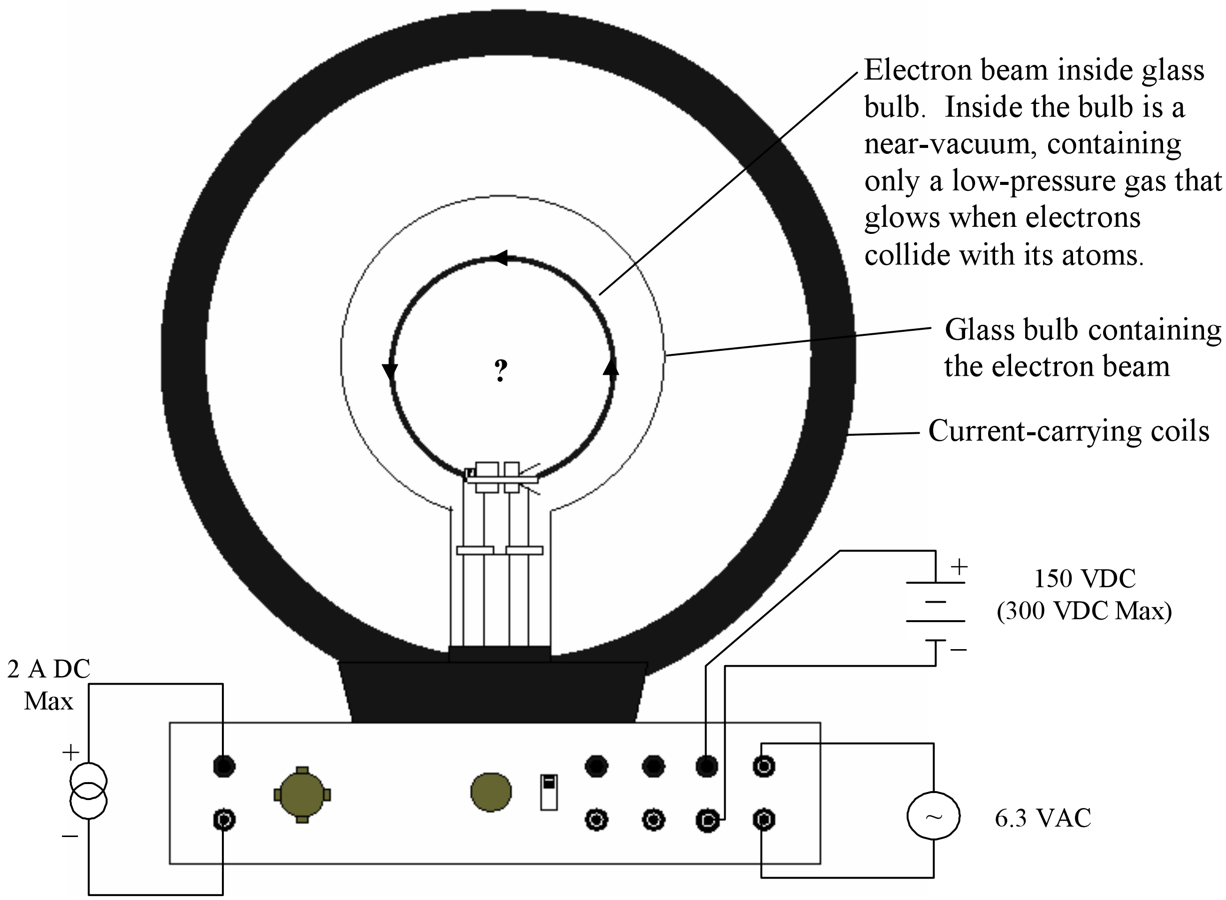


Figure 3 Electron beam moving in the magnetic field produced by current-carrying coils of wire

4.1 Note the electron beam in a magnetic field prominently displayed in the lab. The direction in which the electrons are moving is as indicated in Figure 3.

Q 8 The beam is composed of electrons, and the electrons are moving counterclockwise in uniform circular motion. Which direction in the beam does electric current flow? Clockwise or counterclockwise? Explain.

Q 9 At the center of the electrons' orbit (where the ? is in Figure 3), which direction does the magnetic field created by the moving electrons point? With respect to Figure 3, choose from (1) up, (2) left, (3) right, (4) down, (5) into the paper, or (6) out of the paper. Explain your answer using Right Hand Rule #2.

Q 10 From the direction in which the electrons move, determine the direction of the magnetic field created by the coils. With respect to Figure 3, choose from (1) up, (2) left, (3) right, (4) down, (5) into the paper, or (6) out of the paper. Explain your answer using the Right Hand Rule #1. Method: You need to begin by identifying the direction of the force that the magnetic field created by the coils exerts on the electrons in the beam. From the direction of the magnetic force on the electrons and their velocity, you can determine the direction of the coil's magnetic field.

5. Activity #5: Predicting the magnetic field around a coil of wire

Equipment: Large coil of wire
D-cell battery in D-cell holder
Magnetic compass
Banana plug wires; two, one red and one black
Alligator clips (one pair) that can plug onto banana wire plugs

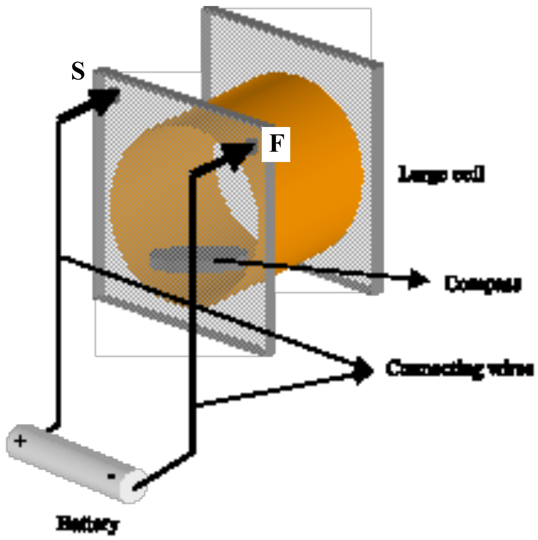


Figure 4 A compass inside a coil connected to a battery

Do not connect the coil to the battery at this time.

The lab instructors do not take points off for wrong answers to the questions in Activity #5.

5.1 Carefully inspect your coil to determine which way the wire in the coil is wound. If you are not sure, ask your lab instructor to assist you.

Q 11 For someone looking at your coil face-on, like Figure 4, and if the battery were connected as in Figure 4, would the current flow clockwise or counterclockwise?

Q 12 If your coil were connected to the battery as in Figure 4, which way would the magnetic field inside the coil point (for a person looking at the coil face-on)? Out of the paper and toward you? Or into the paper and away from you? Use the Right Hand Rule to explain your answer.

Q 13 With the compass inside the coil, which way would the needle of the compass point, if the coil were connected to the battery as in Figure 4? With respect to Figure 4, out of the paper toward you, or into the paper away from you? Explain your answer in terms of the way a compass needle responds to a magnetic field.

Q 14 With the compass outside the coil and on top of it, which way would the compass needle point (still pretending the coil is connected to the battery as in Figure 4)? With respect to Figure 4, out of the paper toward you, or into the paper away from you? Explain your answer in terms of the way a compass needle responds to a magnetic field.

6. Activity #6: Tracing the field of a magnet and of a coil with a compass

6.1 Without using excess time (to avoid discharging the battery), but still being careful, do the following.

6.1.1 Use banana plug wires, with an alligator clip plugged onto one end, to connect the positive terminal of the battery to the socket marked "S" on the coil.

6.1.2 Similarly, connect the negative terminal of the battery to the socket marked "F" on the coil.

6.2 Use your compass to trace the magnetic field of the coil as follows:

6.2.1 Put the compass inside the coil, and observe the direction in which the compass needle points.

6.2.2 Put the compass outside the coil but near to the ends of the coil (the end toward you and the end away from you), and observe the direction in which the compass needle points in both cases.

6.2.3 Hold the compass above and to the sides of the coil, and again observe the direction in which the compass needle points.

Q 15 With a diagram, describe the field of the coil, as determined by using the compass.

Q 16 Were your answers to questions Q 13 and Q 14 correct? (If they were not, please consult with your lab instructor to determine what went wrong.)

6.3 Reverse the polarity of the battery, and again trace the field of the coil with your compass.

6.4 Disconnect the coil from the battery.

Q 17 Briefly describe how the magnetic field of the coil changed when the battery was reversed.

6.5 Use your compass to trace the magnetic field of your bar magnet. Do this by:

> 6.5.1 Put the compass at the ends of the bar magnet, and observe the direction in which the compass needle points in both cases.
>
> 6.5.2 Hold the compass above and to the sides of the bar magnet, and again observe the direction in which the compass needle points.

Q 18 With a diagram, describe the field of the bar magnet, as determined by using the compass.

Q 19 Compare the magnetic fields of a coil and a bar magnet.

7. When you are done ...

Turn in this handout, with all questions answered.

Pre-Lab Questions

Print *Your Name*

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Read the *Introduction* to this handout and the warning at the beginning of Activity #1. Then 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. Why must magnets be kept away from the computer monitors?

2. A wire is connected to a battery. Which way does the current flow in the wire?

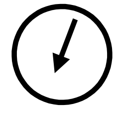
3. What are the conventional names for the poles of a magnet?

4. A permanent magnet has two poles. If you break a permanent magnet into two pieces, how many poles are there?

5. What is the rule that governs attraction and repulsion of magnets?

6. Draw a bar magnet, showing the direction of the magnetic field around and inside the magnet.

7. The diagram to the right shows a compass with its needle responding to a magnetic field. Add to the diagram the magnetic field lines, showing their direction with small arrowheads.



8. You are standing on the equator of the Earth when a positive charge flies past you moving from East to West. The Earth's magnetic field causes a magnetic force on the charge. Use Right Hand Rule #1 to determine the direction of the magnetic force on the particle. Choose from East, West, North, South, Up toward the sky, and Down toward the center of the Earth.

9. If you have not done so already, explain how you obtained your answer to the previous question.

10. You are standing on the equator of the Earth, facing North, and a long, straight, horizontal wire is suspended about 2 meters in front of you at shoulder height and runs East-West. It carries a current which flows from East to West. The same positively charged particle as in the earlier question flies past you at shoulder height (exactly the same height as the wire), traveling from East to West (parallel to the wire), about 1 meter in front of you.

    (a) The charged particle is moving through a magnetic field due to the current in the wire. Use Right Hand Rule #2 to determine the direction of this magnetic field. Choose from East, West, North, South, Up toward the sky, and Down toward the center of the Earth.

    (b) Use Right Hand Rule #1 to determine the force on the charged particle due to the current in the wire. Choose from East, West, North, South, Up toward the sky, and Down toward the center of the Earth.

11. If you have not done so already, explain how you obtained your answer to part (a) of the previous question.

12. Charged particles in a uniform magnetic field move in circular orbits. What causes the centripetal acceleration? (Recall that the centripetal acceleration is the acceleration that an object has when it moves at constant speed in a circle.)

13. Positive particles move in a circle in the direction shown in the diagram. What is the direction of the magnetic field? Choose from (i) perpendicular up out of this page or (ii) perpendicular down into this page. Explain.