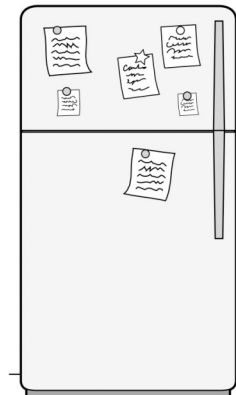
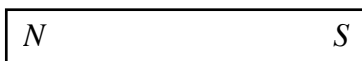


In this lab, you will focus on the concepts of magnetism and magnetic fields and the interaction between flowing charges (electric current) and magnetic fields. You will find this material in Chapter 19 of Serway and Faughn. It is a good idea to read all of the steps in each part before you start.



Pre-Lab Questions

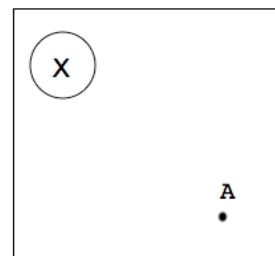
1. For the permanent magnet shown below, draw its magnetic field lines.



What happens to the North and South poles if you break the magnet in half? Label the appropriate North and South ends for each half. What if you break each piece in half again? And again and again, until you get to what the Greek Atomists called 'the indivisible', or 'the atom'? Can each 'atom' act as a magnet? Use an arrow \rightarrow to represent the magnetic dipole pair $S-N$. Sketch the atomic dipoles inside of your original, unbroken magnet.

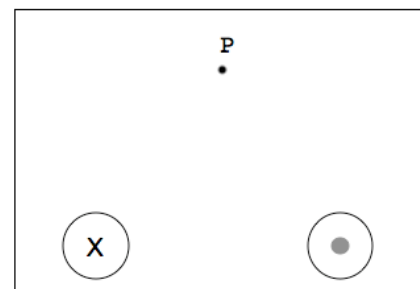
2. For ferromagnetic materials, such as iron or steel, explain the difference on an atomic level between a momentary attraction and a more permanent magnetized state. (An example of a momentary attraction is getting a bit of iron to “stick” to a permanent magnet, with the iron bit then returning to a non-magnetic state when the permanent magnet is removed. An example of a permanent magnetized state is when a permanent magnet has been used to magnetize some iron, such that even when the original magnet is removed, the iron still acts a magnet with other metals. You can find more details in section 19.10 of the text)
3. The diagram shows the cross section of a wire carrying conventional positive current towards us out of the plane of the paper. (You may ignore the earth’s magnetic field)

- a) By means of an arrow on the diagram, show the direction in which a compass would point if placed at location A and describe the rule you use to remember this effect.
- b) Show the direction in which the compass would point at two other points of your own choosing.



4. Two wires lie perpendicular to the plane of the paper, and equal electric currents pass through the paper in the directions shown. Point P is equidistant from the two wires.

- a) Construct a vector diagram showing the direction of the resultant magnetic field at point P. Explain your reasoning.
- b) If the currents in both wires were directed out of the plane of the page, show the field at point P.



5. Write “I checked my grades online”. (Please, actually check them on webct.ucsd.edu. And if you have some problems then it would be better to solve them with your TAs during the last lab instead of emailing them during the finals week.)

Experiment A: Interactions between Magnets

- Take two bar magnets, and bring them towards each other slowly. Do they exert a force on each other? Which parts (ends, middle) exert or feel forces from which other parts?
- Attach the magnets to the wheeled carts so they repel each other. Put the carts close together then release them from rest. What happens? Is the force on cart 1 equal and opposite to the force on cart 2?
- The carts start with no kinetic energy, but they gain KE when released. Where does the KE come from?
- Can magnets interact without touching?
- How does one magnet know the other one is there?

Experiment B: Interactions between magnets and compasses

NOTE: Do not allow the compass to get close to a strong magnet as this will magnetize them and destroy their accuracy!!

Whenever a magnet is allowed to rotate freely, and without another magnet nearby, one end will always end up pointing (approximately) towards the geographical North pole of the Earth. By mutual agreement, scientists **define** this end of the magnet as the **North pole** of the magnet. The opposite end of the magnet, by definition, is called the **South pole**.

- Place a compass at different places on the lab bench when all the other magnets are kept far away (at the front or back table).
- Mark with tape and an arrow the direction to magnetic North inside the lab room. (Be sure to remove the tape when you finish the lab). Add small labels to S, E and W.
- Use the bar magnet to investigate the field of influence of the magnet on a compass.
- Does the effect of the magnet on the compass depend on distance?
- Does it depend on which pole of magnet is used?
- Label the poles of your bar magnet as N or S using tape. Please be sure to remove the tape at the end of the lab.
- Place the bar magnet at the center of a sheet of white paper. Trace the outline of the magnet onto the paper and label the poles. Use the compass to record the direction of the magnetic field of the bar magnet.
- Connect “magnetic field lines” and put arrows on them. Remember the field lines show the direction of the force on a “N pole”.

Experiment C: What kinds of materials are attracted to magnets?

- Before you make any tests, record your predictions for the interaction between the materials provided (they include wood, glass, copper, a PVC pipe that can be charged with wool, and a spoon) and the magnet. Discuss your predictions with your lab group.
- If these materials are not themselves magnets can they be repelled from magnets?
- Try the objects provided and any other items you find of interest. Record your observations in a table. Are any objects repelled?

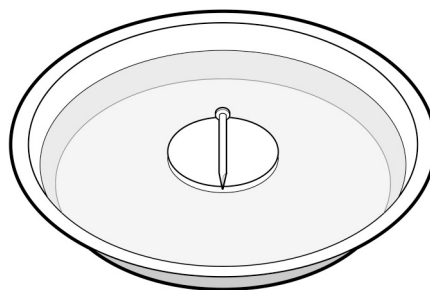
Scientists call materials that are attracted to a magnet *ferromagnetic materials*. Magnets are also made of ferromagnetic materials. Iron is the most common ferromagnetic material, and objects that include iron in them (like steel) are ferromagnetic. (Nickel and cobalt are also examples of ferromagnetic materials.) For the remainder of this activity, you will use iron (or steel) nails to explore some important properties of the magnetic interaction.

Experiment D: What happens when a nail is rubbed with a magnet?

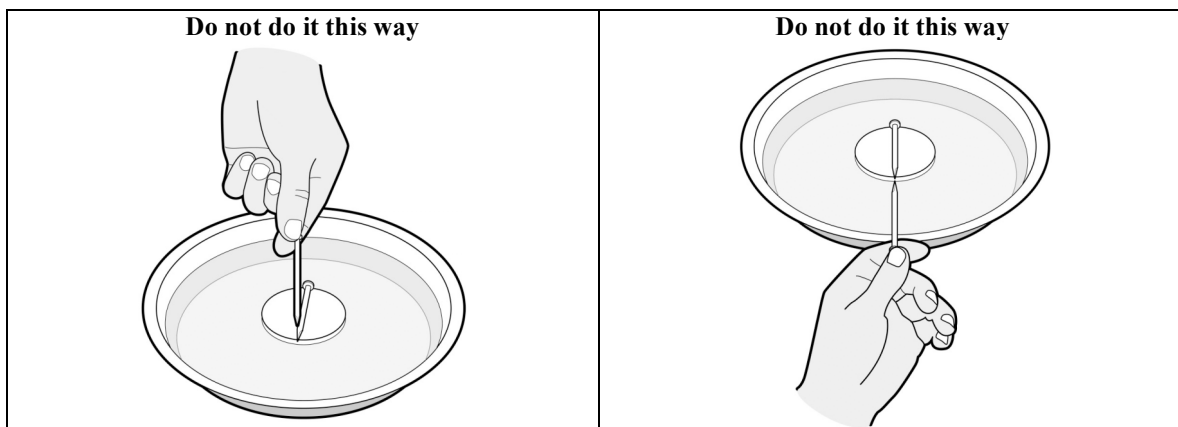
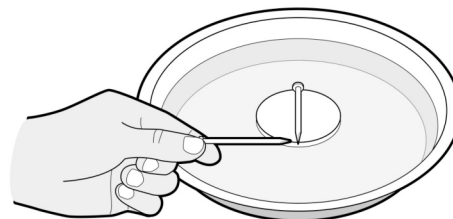
Your group will need a magnet, three nails, a small styrofoam float, an aluminum pie tin, a beaker to carry water and some water from the tap. In this experiment you will distinguish between two types of nails: those that are rubbed with a magnet (called *rubbed*), and those that are not rubbed with a magnet (called *unrubbed*).

Note: Keep the magnets far away from the nails. Once you rub a nail, it is no longer “unrubbed.” Please do not rub the nails until you are asked to do so.

D1. Use the beaker to pour some water into the aluminum pie pan. Lay an **unrubbed** nail on a small, flat piece of Styrofoam and float it in the water. This will give a very sensitive test arrangement. Check that your aluminum pan is not sitting over a piece of metal under the table, and that there are no large metallic objects nearby. Try to keep it away from the edges of the pan.

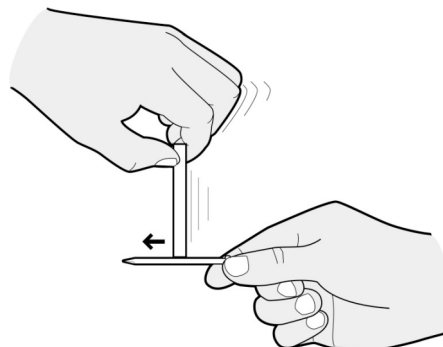


D2. We first want you to investigate whether an unrubbed nail can affect another unrubbed nail. To determine this, take a second unrubbed nail, hold it horizontally, and bring its tip **close to** (but not touching) the floating nail. See picture to the right showing that the held nail should be at right angles to the floating nail. Always test held and floating nails this way. Do not bring the held nail from above (picture below to the left), nor bring it parallel to the floating nail (see picture below to the right).



- What, if anything, happens to the floating nail when the held unrubbed nail is brought nearby?

D3. Make a **rubbed** nail as follows. Place one end (use the N pole) of the bar magnet over one end (start at the head end) of an unrubbed nail and rub in **one direction only (head to tip) to the other end**. Then lift the magnet away from the nail and repeat the process a few times, always rubbing in the **same** direction.



D4. Now we will investigate the interactions between a **rubbed** and an **unrubbed** nail.

- Using the same procedure as described in step D2, bring the tip of a held **rubbed** nail near the tip of the **floating unrubbed** nail. What, if anything, happens to the tip of the floating unrubbed nail?
- Bring the tip of the held rubbed nail near the head of the floating unrubbed nail. What, if anything, happens to the head of the floating nail?
- Turn the held **rubbed** nail around and bring its head near the tip and head of the floating nail.
- Summarize what happens, if anything, to the tip and head of the floating **unrubbed** nail.

D5. Lay the rubbed nail aside for a moment. *Imagine* that you removed the floating nail, rubbed it with the magnet in the same way you rubbed the other nail, then floated it again. You would then have two rubbed nails—one held and one floating. (Don't do it yet!)

- Predict what you think will happen if you were to bring the tip of the held **rubbed** nail near the tip of the floating **rubbed** nail.
- Predict what you think would happen if you were to bring the tip of the held **rubbed** nail near the head of the floating **rubbed** nail?

D6. Now remove the floating nail, rub it with the magnet the same way as in D3, and replace it on the floater. Then test your predictions.

- What actually happens when you bring the tip of the held rubbed nail near the tip of the floating rubbed nail?
- What actually happens when you bring the tip of the held rubbed nail near the head of the floating rubbed nail?
- What happens when you bring the head of the held rubbed nail near the tip and head of the floating rubbed nail?

D7. The direction of magnetization of the nail:

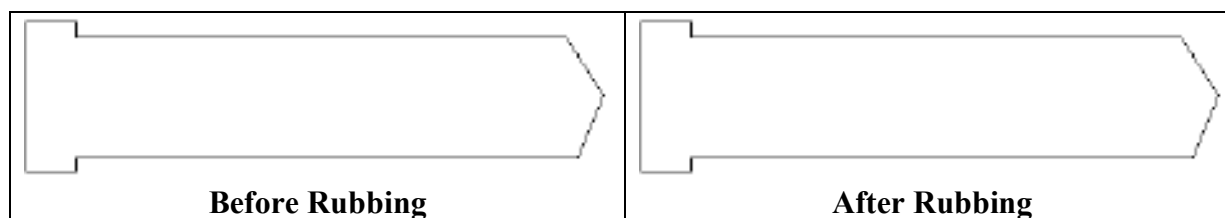
- Establish and record which end (head or tip) of the two rubbed nails is the N pole.
- Describe at least two ways to magnetize a nail in the **opposite** sense.
- Try one of your techniques on a third nail and test the result.

Summarize your observations for Experiment D by answering these questions.

- What happens when the tip or head of an **unrubbed** nail is brought near the tip or head of another **unrubbed** nail?
- What happens when the tip or head of a **rubbed** nail is brought near the tip or head of an **unrubbed** nail?
- Make a table to show this information more clearly
- Based on your observations, would you claim that a rubbed nail behaves like a magnet or like a ferromagnetic material that is not itself a magnet? What is your evidence?

Experiment E: Models for magnetism

E1. What do you think is happening **INSIDE** the nail when it is rubbed with a magnet? Copy a figure like this into your notebook and show as much detail as you can about your ideas.



- From your model predict what will happen if you cut a rubbed nail in half and put one half on the floater then bring an uncut rubbed nail close to the floating piece. Record your prediction.
- Do the experiment and record your observations.
- What other tests could you do to check your model?

E2. Make a **physical model**. Use the test tube half-full of iron filings, shake it up and hold it horizontally with the iron filings spread uniformly along the tube.

- Stroke the test tube slowly several times with a bar magnet's N pole, starting at the stopper and finishing at the tip (rounded end). Watch what happens to the iron filings.
- Float the rubbed nail again, bring the test tube close, rounded end to nail tip, then to nail head. Is the test tube like a rubbed or an unrubbed nail?
- Shake test tube and test it with the floating nail again, has it changed? Why?
- If you hammered on a magnetized nail would you be able to change its properties? Try it. What happens inside the hammered nail? An alternate procedure is to drop the nail to the floor many times. The nail has a hard landing. Both the hammering and the sudden acceleration tend to randomize magnetic domains.

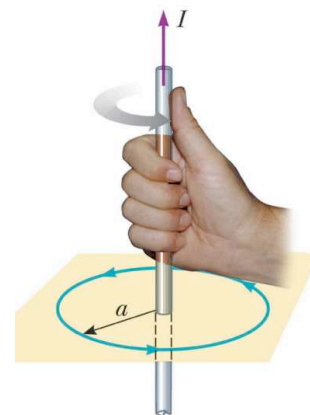
PLEASE discard all magnetized nails into the box on the front table.

Experiment F: Magnetic Effects of an Electric Current in a Straight Wire

The purpose of this experiment is to investigate the nature of the magnetic field generated by an electric current flowing in a straight wire. Before you start please be sure all magnets are at the far end of your bench. To get an effect measurable with a compass, we would like to be able to provide a large current through the straight wire to be able to make magnetic fields larger than the earth's field. However, practical considerations restrict the current to about 5A. To overcome this we have five wires running parallel to each other, each carrying about 5A. This is equivalent of a single wire carrying 25A. This setup also has a platform where you can place a sheet of paper and a compass. You can mark the angle of the compass needle on the paper.

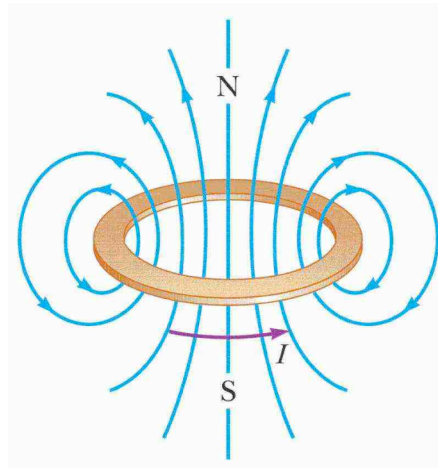
Before you connect the loops of wire to the power supply, set the current limit of the supply to its maximum value (turn up both coarse and fine knobs), and set the voltage to 2.5 V. Then switch the supply to read current, and turn the power supply off. Cut a sheet of paper to fit around the wire and rest on the platform to record the direction of the magnetic field. Set up the circuit so that the "conventional" current is flowing upwards. Review chapter 19 section 19.7 if you need to review magnetic fields of straight wires.

1. Test your setup: turn the power supply on and verify that you get a current of about 5A. Do not leave the supply on for more than 10 seconds to avoid overheating. Note the current and the number of wires in your setup.
2. Using a compass observe and record the direction of the magnetic field at several points near the wire *when the current is zero*. Does this agree with the measurements you made in experiment B?
3. BEFORE you close the switch, predict what you expect to see when the current is not zero. Explain the figure on the right. Which way does the thumb point? Which way do the fingers point? Why is it useful?
4. Now close the switch, and record the magnetic field direction near the wires. Start with the compass north of the wires. Also note the field direction with the compass E, S, and W of the wires.
5. Is the direction and shape of the magnetic field you observe consistent with predictions made with the right hand rule?
6. Change the direction of the current through the straight wire. Is the magnetic field still consistent with the RH rule?
7. At what position relative to the wires is the magnetic field of the current is perpendicular to the earth's magnetic field? (Choose N, S, E, W). Set the compass at this position. Turn on the power supply and reduce the current in the wires until the compass settles at 45° to the NS direction of the earth's field. Measure the current.
8. Calculate the magnitude and direction of the magnetic field from the current at the compass position. (Remember there are five loops of wire.)
9. Show the vector diagram of the two magnetic fields and the resultant field. (Hint: you know the size and direction of the field from the wires, and the angles of the earth's field and the resultant field.) What is the earth's field from your measurements?

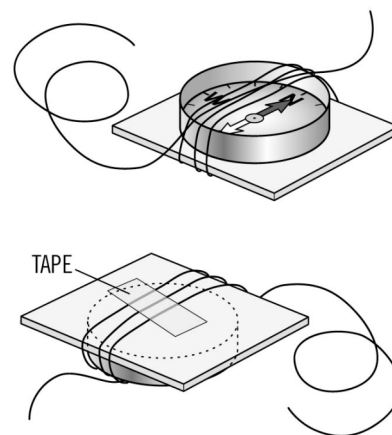


Experiment G: Magnetic field of current loops

If you bend a current carrying wire into a loop, the magnetic fields on the inside part of the curve reinforce each other giving a magnetic field shaped as shown. The direction of the current around the loop is linked to the direction of the magnetic field through the right hand rule.



G1. Use the piece of insulated wire and wrap it tightly around the compass so there are at least five wires directly over the top of the magnetic needle, **along the North-to-South line**. Leave at least 10 cm of wire extending from each end. The coils should be tightly bunched together. When several loops of wire are bunched together, this is called a *coil of wire*. Use a piece of tape on the back of the compass to hold the coil of wire in place.



G2. Lay the compass on the table so the compass needle points exactly North (at zero degrees). The wires of the coil should be directly over the compass needle.

G3. Connect the wires to the power supply set at 2.5 V and max current as for experiment E. To hold the compass steady on the bench top, tape the compass and the wire down as needed. Do not turn on the current for more than 10 seconds at a time to avoid overheating.

G4. Turn on the current. Watch the compass needle. It will swing dramatically for a while, then stabilize. Repeat the experiment, turning the current on and off several times.

- What happens to the compass needle when the current is ON? Record your observations.
- Besides the behavior of the compass needle, what other evidence is there that there is an electric current in the wires in the circuit when the switch is closed?
- Compare your observations to experiment F. In what direction is the magnetic field produced by the coil?

G5. Turn off the current. Disconnect the wires connected to the power supply, **reverse the connections**, and reconnect the wires so the wire that was originally connected to the positive terminal is now connected to the negative terminal, and the wire originally connected to the negative terminal is now connected to the positive terminal. Keep your eye on the compass needle and turn on the current.

- How does the behavior of the compass needle compare to its behavior in step G4? Record your new observations, and compare them with your observations in G4.
- Why do you think this happened?
- Use the right hand rule to explain the direction is the magnetic field of the coil given the direction of the current in the coil. Explain the geometry fully with diagrams. Show the direction of current flow, the coil and the magnetic field.
- The interaction between the magnetic compass needle and the electric current in the coil of wire is called an *electromagnetic interaction*. This type of interaction occurs whenever a magnet and a wire carrying an electric current are near each other.

BEFORE YOU LEAVE THE LAB: please remove all tape from tables, magnets, compasses etc. Place used tape in the trash and leave the lab as you would hope to find it.

Note: Some material for this lab is from the PET program lead by Prof Goldberg at SDSU. This program is funded by NSF and is designed to help teachers in training to understand physics concepts.