Lab 5. Magnetism

PART I: INTRODUCTION TO MAGNETS

This week we will begin work with magnets and the forces that they produce. By now you are an expert on setting up circuits, and we will look at the interaction between magnetic fields and flowing current. The goals of this lab are to see how magnetism is created by and acts on electrical currents, to learn two ways to use the right-hand rule in magnetism, and to see some real-world examples of magnetism.

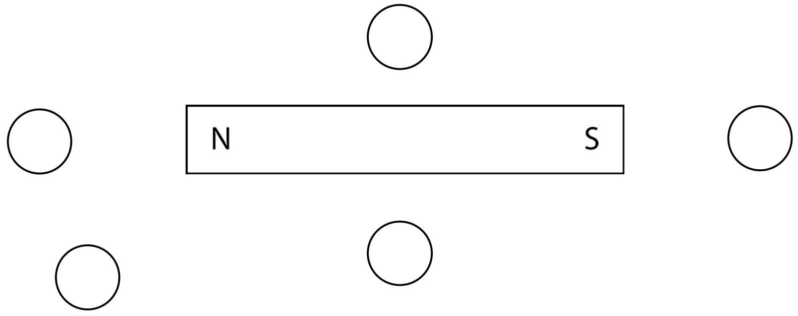
Magnetic fields are caused by moving charges – sometimes by charges moving on the atomic level (electrons moving around atomic nuclei, for example), and sometimes moving on a macroscopic scale, such as through the wires in an ordinary circuit. Similarly to how electric fields are both *produced by* and *act on* charged particles, magnetic fields are both *produced by* and *act on* **moving** charges. The unit of measurement of magnetic field is the **Tesla** (the earth's magnetic field is about 0.00005 Tesla, and a refrigerator magnet creates a field of about 0.01 Tesla).

1 Tesla = 1 T = 1 N / (A*m)

In this lab you will be using bar magnets as the source of the magnetic field. The bar magnets each have two poles (North and South), but they are not labeled. Once you determine which end of the magnet is North and which is South, be sure to keep track of it! IMPORTANT: The convention for magnetic field lines is that they point **away** from a magnetic "North" pole, and **towards** a magnetic "South" pole (analogous to how electric field lines point away from positive charges and towards negative charges).

Predict what the magnetic field structure would be around this bar magnet. Draw in 10 or so magnetic field lines.

Predict which way a compass would point in the field of this magnet. In each of the circles, draw an arrow in the direction that a compass should point.



Using the compass, measure the direction of the field lines near the tips of your bar magnet. NOTE that the colored compass tip points **along** the magnetic field direction. Does the general shape match your prediction? Can you determine which end of your magnet is North and which is South?

The iron core of the earth acts like a giant bar magnet. Given that the compass needle (which points towards the geographic north), points along the magnetic field lines, draw in the magnetic field lines surrounding the earth. Once you have done this, label the magnetic poles of the giant magnet in the earth.

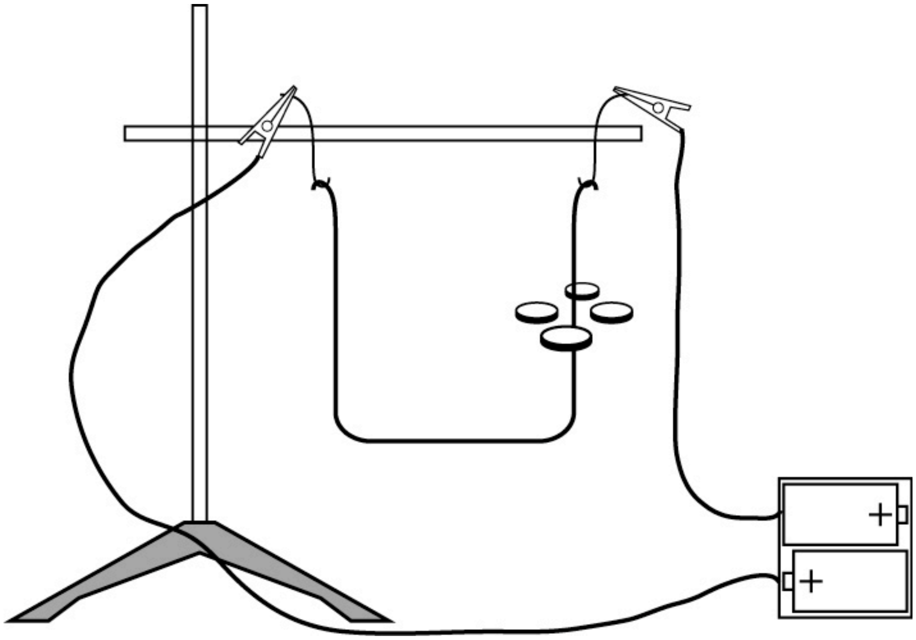
PART II: MAGNETIC FIELD PRODUCED BY A CURRENT

Given a magnet that is free to rotate in an external magnetic field, which way will it line itself up? Draw your answer below (i.e. draw the field lines, and draw the final position of the magnet with the poles labeled).

The situation that you drew is exactly how a compass works – namely, a compass is just a freely-rotating little magnet which aligns itself with any external fields.

As mentioned above, magnetic fields are also produced by moving current. The direction of the magnetic field around a current-carrying wire can be determined by the **right-hand rule**. Namely, if you point your thumb in the direction of the current, your fingers will curl in the direction of the magnetic field lines which surround the current.

At your table, you should have the pieces to construct a "trapeze" setup similar to the picture below. **NOTE: After you are done with each measurement, disconnect the battery!** The trapeze should be set up to swing freely – be careful that there is no pressure on the joints that will keep it from moving. On the figure, draw the direction of the current.



Using the figure above, predict and draw the direction of the magnetic field lines in the vicinity of the upward-leg of the trapeze. The four disks in the picture are supposed to represent little compasses -- draw in the compass needles for the four compasses.

Connect the circuit and use your compass to check your prediction – were you correct? If not, why not?

PART III: FORCE ON A CURRENT IN A MAGNETIC FIELD

As mentioned in part I, magnetic fields produce a force on any moving charge. This can be observed in the lab by moving charges through a wire (i.e. with an electrical current). The force on a current-carrying wire in a magnetic field is given by

$$\vec{F} = I\vec{L} \times \vec{B}$$

where $\vec{F}$ is the force on the wire, I is the current, $\vec{L}$ is the length, and $\vec{B}$ is the magnetic field. Notice that $\vec{F}$, $\vec{L}$, and $\vec{B}$ are all **vectors**, and the "×" sign indicates a specific kind of vector multiplication called the **cross product**.

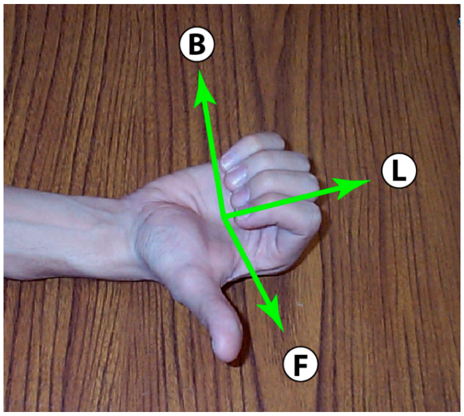
To figure out just the **magnitude** of the force, you can use the formula

$$\left|\vec{F}\right| = ILB\sin(\theta)$$

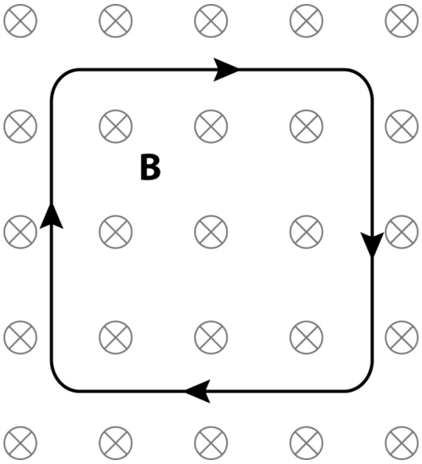
where θ is the angle between the current / length direction and the magnetic field direction. For example, if the current is perpendicular to the magnetic field, $\theta=90°$ and $\sin(\theta)=1$, so the magnitude of the force just equals ILB. Notice that if the current is doubled, the force is doubled. Notice also that if the magnetic field strength is doubled, the force is doubled. Notice also that if the length of wire is doubled, the force is doubled. In other words, the force has a **linear dependence** on each of the variables I, L, and B.

If a 5 cm long wire carrying 2 amps is ***parallel*** to the magnetic field lines of a 0.1 Tesla field, what is the force on the wire? Make a sketch to go with your answer.

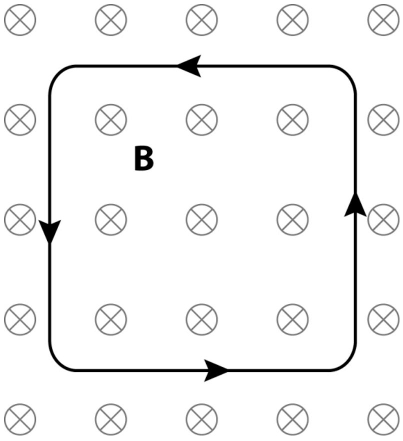
To figure out the **direction** of the vector that results from a cross-product, you need to use the **right-hand rule** (note that this is the *second* way we use the right-hand rule for magnetism). To use the right-hand rule, aim your fingers towards the first vector in the cross product ($\vec{L}$, which is taken to be the current direction) then curl your fingers in the direction of the second vector in the cross product ($\vec{B}$). Now extend your thumb, which will point in the direction of the cross-product ($\vec{F}$).



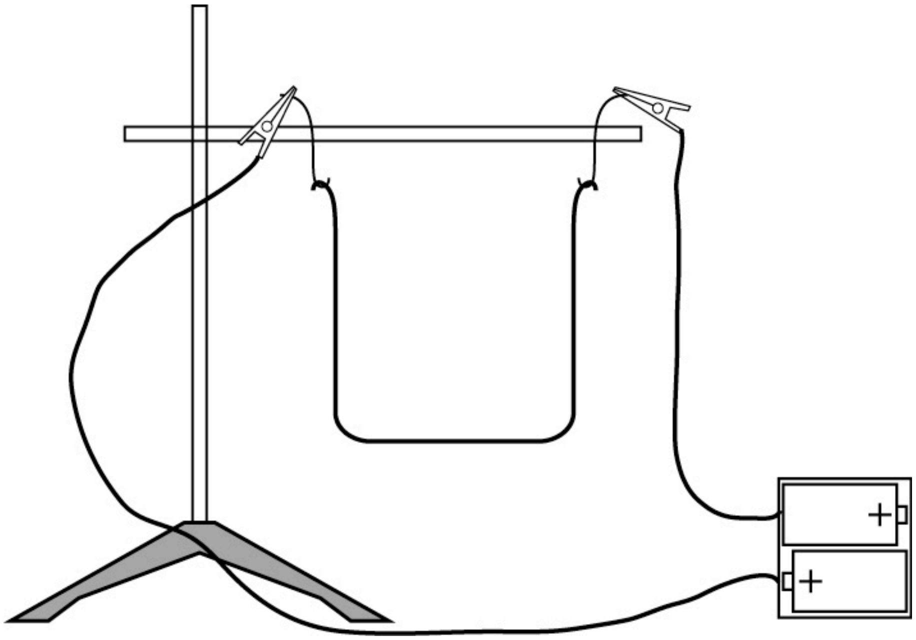
In the figure below, the magnetic field lines point into the page (as indicated by the little circle with the cross in it – that symbol is supposed to represent the view of an arrow shooting away from you). Current is running through the circuit as indicated by the arrows on the rectangular wire. On each side of the circuit, draw an arrow representing the direction of the force (use the right-hand-rule to figure out the direction). If this wire were flexible, what would happen to it?



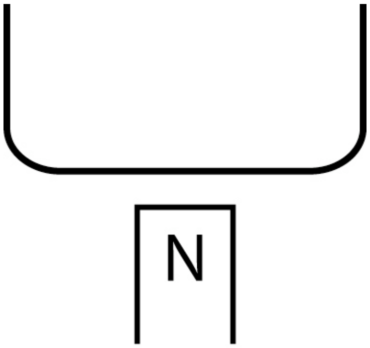
Repeat the previous problem with the figure below, which is similar except that the current is now going in the opposite direction. If this wire were flexible, what would happen to it?



On the figure below, draw the direction of the current.



The figure below is a zoom-in of the bottom of the trapeze as the end of the bar magnet is moved close to the trapeze. Re-draw the current direction, and now draw in the magnetic field lines from the bar magnet. Which way will the trapeze swing? (Will it swing at all?)



Hook up the circuit and try the experiment. Is your prediction correct? If not, why not?

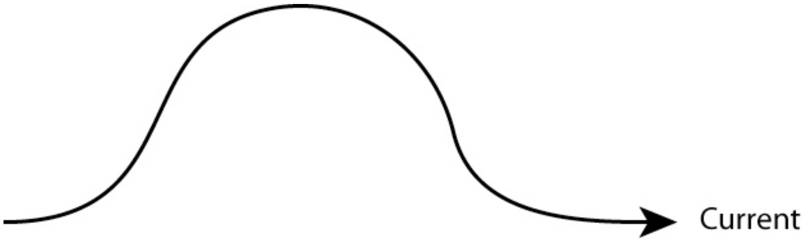
Predict what would happen if the other end of the magnet were used, then check your prediction – were you correct? If not, why not?

Predict what would happen if the battery was connected in the other direction, then check your prediction – were you correct? If not, why not?

PART IV: PUTTING IT ALL TOGETHER

Imagine you have a flexible wire with current running through it, bent into a kink as shown below. The current in each side of the kink will *produce* a magnetic field which *acts on* the current flowing through the other side.

Will these forces kink the wire up more or un-kink the wire?



POTENTIAL EXAM QUESTIONS:

1. Which of the following statements is true?

a) Two wires carrying parallel current are repelled from each other because the electrons in each wire repel the electrons in the other wire.

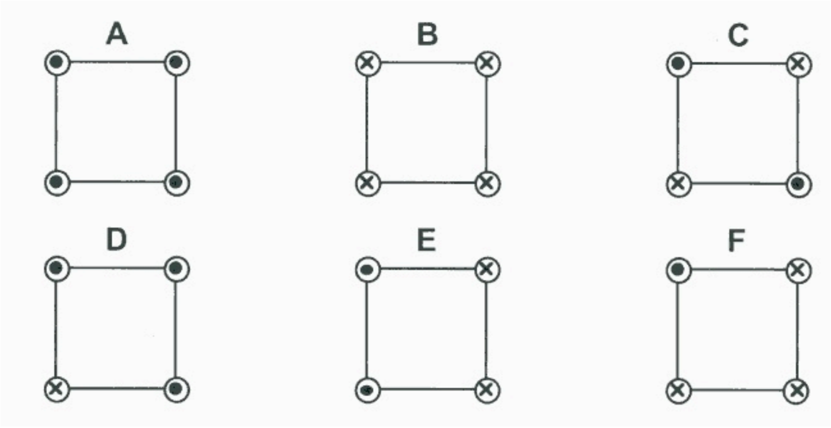
b) Two wires carrying parallel current are attracted to each other because the magnetic field produced by each wire attracts the current in the other wire.

c) Two wires carrying anti-parallel current are attracted to each other because the magnetic field produced by each wire attracts the current in the other wire.

d) Two wires carrying anti-parallel current exert no force on each other because their magnetic fields cancel.

e) Two wires carrying parallel current exert no force on each other because their magnetic fields cancel.

2. Shown below are six configurations of four current-carrying wires viewed "end on". Each circle with a dot represents current coming out of the page, and each circle with a cross represents current flowing into the page. Each wire carries the same amount of current. What is the order of **net magnetic field magnitude** at the center of each square?



a) A > D > C = E > F > B

b) A = B > D = F > C = E

c) D > F > E > C > A = B

d) E > D = F > A = B = C

e) C = E > D = F > A = B