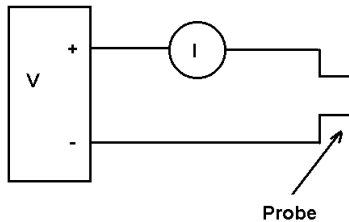


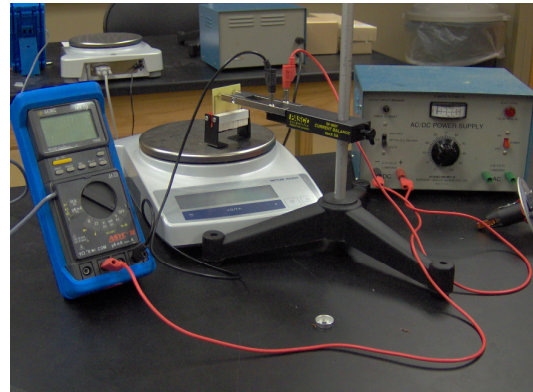
## The Current Balance

In the first part of this lab, you are to verify certain aspects of the force of interaction between a current and a magnetic field. We have a fixed magnetic field and we will, in the first experiment, run a known current through a wire in order to determine the force on the wire. By reversing the current direction, the force will appear in the opposite direction. The easiest way to reverse your current is to change the leads on your power supply.

The circuit diagram for this experiment is quite simple as shown below.



### Part I



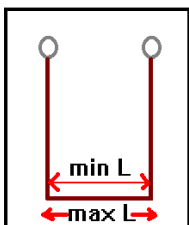
If we assume a constant magnetic field, then a current in a magnetic field will experience a force

$$F = ILB$$

where  $I$  is the current through the wire,  $L$  is the length of wire exposed to the magnetic field and  $B$  is the magnetic field. **This also assumes that the magnetic field is at right angles to the current.**

On your electronic scales, choose the force readings to be provided directly in kg (I should already have the scales set to do this). We do not have direct access to the value of magnetic field but your measurements will provide us with this measurement and, in fact, you will make a fairly good measurement of the magnetic field in Tesla.

The first part of the lab is fully computerized with regard to data acquisition. You should use the 10A DC scale of the MX55 and you additionally should choose the 10 M $\Omega$  input impedance. When you log into the computer, I have noticed that the system will work better if you have both the pb602-s and the MX55 initially off. It seems that the electronic scales try to talk to the computer when the computer boots and this confuses the both of them.



The procedure is fairly straight forward for the first part of the experiment. You have 6 circuits of varying lengths (notice that two have the length doubled on the back). You will need to measure the inner and outer lengths of the portion of the circuit which will be in the magnetic field and perpendicular to the magnetic field. The difference in these measurements will be a source of uncertainty in your magnetic field measurement. You'll want to record these values in the table

below. If your circuit is doubled, you might want to make a special notation about this. The spreadsheets already know which circuits are doubled.

Circuit	L Max [mm]	L Min [mm]
sf40		
sf37		
sf39		
sf38		
sf41		
sf42		

You should vary your current from 0 to 5A in steps of 0.25 A. You will need to run the program “current balance without spinner” to acquire the data. I recommend naming the files something simple like, for example, “sf40-1” for your first trial on circuit sf40 (you might discard this and run it again). You will take data by pressing the space bar. however, when you increase the current, do so slowly and give the balance several seconds to settle down. Failure to do this will result in degradation of your data results.

**Do not exceed 5A in this experiment (you might use a current of say 5.1 but don’t go higher).** You won’t need to exactly have, for example 4.00 A ... if you have 4.05 A, that would be an acceptable data point. You’ll also notice that the power supplies have some trouble to maintain a current of 5 A. You should align your circuit so that a positive current results in a positive force. At least once, during today’s lab I do want you to confirm that a negative current then causes a negative force and also that if you reverse the direction of the magnet, what was a positive force will become a negative force.

**Here is a check off for you: make sure you do these confirmations.**

Confirmation 1: \_\_\_\_\_

Confirmation 2: \_\_\_\_\_

**Note: Make sure you tare the scales at zero current to insure that you will see these results. You will also want to make sure the scales are leveled by rotating the legs on the bottom until the bubble on the scale is correctly centered.**

**I want you to make measurements for each of the circuits provided.** You will probably want to practice a few runs before you begin to take data for analysis. Make sure you feel comfortable with changing the current in small increments and waiting long enough for things to settle before commanding the computer to take the data point.

After you complete this portion of the experiment you will paste your data into the excel spreadsheet which I have prepared to help with your lab today. It has several unique features. In particular, you are going to be using an excel function called “solver” to fit your data. I’ll probably need to show you how to run the solver and I have also placed an animation on the lab webpage which indicates some of the steps needed to run it. Sometimes if you are using a new excel program, you may need to click on <tools> <Add-Ins> <Solver Add in> in order for this to appear in your menu. Thanks go to Kurt Grafton for this and other information about the solver.

For each of your circuit measurements you will need to copy and paste your data into the spreadsheets. Notice in my spreadsheet page named sf40 that I identified a data point which was clearly in error in some way or another (I probably didn’t wait long enough for things to settle down). You should remove bad data points such as this completely

from your results. If you put the values from my bad data point into the cell provided, you will clearly see it is bad, and also notice that if you run the solver with this bad data point included, it will throw off the entire fit. It is my hope that you learn to identify bad data points in your data but note this: just because a data point does not agree with your theory, you are not permitted to throw it away: be particularly careful about this with data points occur near the extreme range of your measurements.

My abbreviations of the cells are SD (Deviations from fit) squared, and then  $\text{Sqr}[\text{StdDev}]$  is the square root of the standard deviations of the SD. This is what I'll be using for the error bars in measurement of the slope on the plots. It is also the function that the solver will be minimizing.

For each circuit, you will obtain a slope and an intercept. If you did properly tare the scale at zero current, then the intercept should be almost zero. Otherwise, it will not necessarily be zero.

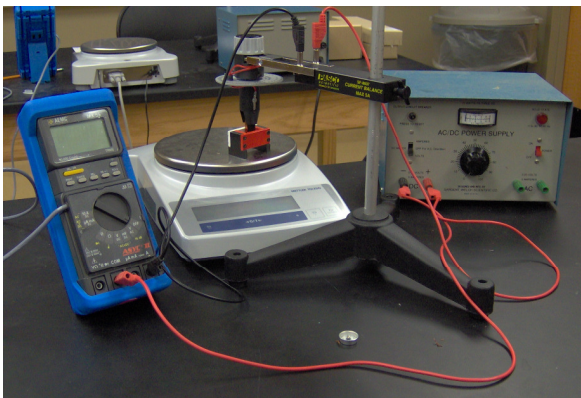
After you run the solver, you will obtain a slope and an intercept. If bad values result from a given run of the solver you may need to change the initial guesses in the bright green boxes and run the solver again.

After completing your measurements, enter your length measurements into the current analysis worksheet. The previously calculated slopes are already visible in this sheet. Then run your solver to give the best linear fits again. The slope of this final linear fit will be your magnetic field precisely measured. Here is the theory:

$$F = ILB$$

For each circuit measurement, you obtained values for  $LB$ . Now when you plot  $L$  vs  $F/I$  the result will be that the slope of this last graph is your magnetic field in Tesla. Typical values for this that I have measured in the past are of the order of about 0.1 T. You will, however, need to make sure you run the solver here also to provide the correct linear fit to your data.

## Part II



If a current is not at right angles to the magnetic field, an additional effect becomes important. The magnitude of the cross product holds the key to understanding this. In general, when currents are not perpendicular to a magnetic field, the force is given by:

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

If we look at the magnitude of this force, we have:

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

where  $\theta$  is the angle between the current and the magnetic field. In this part of the lab, you are going to verify this  $\sin(\theta)$  dependence. We have a special attachment which will help with this part of the lab. Place the current balance accessory kit into the current balance and change the magnets. Turn your accessory kit all the way to the extreme left (don't force it, however). Then align the red measurement line right over the last number mark. This will correspond to 110 degrees. You will make measurements here every 5

degrees, turning the scale from here with a clockwise twist. The current that you use here will be **2.0 A** although I have provided a small correction in the spreadsheet for currents that vary during the period of measurement. For this reason the acquisition program “current balance with spinner” will also be reading the current for this part of the experiment ... you have, if you did the first part of the experiment correctly, confirmed that the force is directly proportional to the current.

Note: When you initially set up this portion of the experiment, you should tare your scale at zero current and the placement must be such that the coils inside the magnet freely rotate without changing the scale reading (when zero current is applied). If you don't make sure of this, you will have significant error in your data.

Your acquisition program will need you to input the angles as you rotate them. I have set the program so that the first angle is recorded as zero and all other angles are relative to this initial angle. You will actually fit in the excel spreadsheet to obtain the angle of maximum force. It is also important to note that if the system is set up in other ways, the angle of maximum force may or may not correspond to 90 degrees. I recommend that you make a sketch of your system when it is at 90 degrees.

**Here is one final very important note: When you cross zero degrees, you should record the angles as negative angles. Otherwise your acquisition program will seem to duplicate data.**

When you run the solver on your spinner data, you will most likely succeed in showing that the sin dependence is correctly realized. **You will want to make sure that it is clear (while you are making measurements) that when the length of the bottom of the coil is at right angles to the magnetic field that the force is at a maximum and when it is parallel to the magnetic field, the force is at a minimum.** Other than observing the above features and showing that a sin curve does describe the data, there is no additional analysis needed for this portion of the lab. You should realize, however, that the “Amplitude” of the Force Vs Angle curve is given by  $IBL$  with  $I=2A$ , and  $L$  is the total length of wire in the field. Thus, in principle, we could make a measurement of the magnetic field by this method also if we had a good measurement for the wire length in the field. However, this is fairly redundant so we won't do this. The other fit parameter, the phase, tells you actually the offset from 90 degrees that is experienced. It is a fairly significant parameter also but I have asked you to notice the maximum in the force at right angles and the minimum at zero degrees so further interpretation here is not essential.

In your analysis you will want to show your understanding of the measurements that you have just done in addition to being able to present a complete analysis of the work.