**Magnetic Fields**

# Notes:

1. ***This is a three-week long lab with multiple parts that you do face-to-face in the lab.***
2. A **full report** must be submitted. Check “E&M Handout 1 - Lab Overview.docx” for more details.
3. You might be able to do activities 1-3 in the first week, and 4-5 in the second, leaving you week 3 available to correct any mistakes or consult with your TA on your analysis.
4. You will submit a formal lab report on this experiment. Be sure to review the syllabus documents on how to write a lab report, including the grading rubric we will use.
5. Turning in your report:
	1. Collaborate with your partner(s) on data collection, analysis, and report.
	2. Turn in only one report but be sure it lists all partners as authors.
	3. Lab reports should be uploaded to Canvas in pdf format by the deadline in the course calendar.
6. Getting help:
	1. Your lab TA can answer questions by email or during their office hours listed in the syllabus.
	2. You can also ask advice from lab partner(s) and/or other students.

# Objectives of this lab:

In this experiment, you explore the magnetic field of a wire coil, essentially a simple electromagnet. You will measure how the field depends on the size of the coil, the current it carries, and other parameters. You will wind several coils yourself and measure the field in two different ways.

These are things you will do:

1. Using the magnetometer in a smartphone, you will investigate the magnetic field produced by a coil carrying electric current: a simple electromagnet.
2. You will study how the field depends on the current, position in the plane of the coil, and distance from the coil.
3. You will gather data and transfer to Excel for analysis.
4. You identify the errors that can occur in your experiment.
5. You will measure the value of *m0*, the permeability of free space.

# What you will learn:

Please review the learning goals for the semester in lab in the handout from the first week. In addition, this lab has several specific goals:

1. You will practice keeping lab notes in a paper notebook, computer file, or other format.
2. You will enhance the data analysis skills you learned previously, by applying them to real data.
3. You will learn to distinguish between two types of errors that occur in data: systematic errors and random errors.
4. You will enhance your understanding of how noise arises in data, and how to account for that noise when interpreting experimental results.
5. You will practice scientific communication skills by preparing graphs and writing a formal lab report.

## What goes in my lab notes, and what about my report?

The purpose of lab notes is to enable you or a colleague to reconstruct what was done and why.

* They don’t have to be neat, in complete sentences, etc., but they do have to be useful.
* In a case like this, they should include things like the number of loops in each coil, its size, the electric current, and the physical setup for the measurements. A picture of the whole setup is a good idea.
* It should include the actual data, and the equations you plan to use to analyze the data.
* If you store multiple files using a phone app or computer, record what filenames correspond to what conditions.

The purpose of a **report** is to explain what you learned and how you learned it. The sorts of things that belong here are

* A description of each step you did.
* Any graphs to show to your results.
* Explanations of how you determined any “derived” quantities used in your analysis
* Explanations of how you went about the data analysis, including the sources of experimental error.
* Your conclusions about any relevant and useful information you were able to extract from the data.

# Equipment:

* A smartphone with a magnetometer[[1]](#footnote-2) and the app “phyphox”
<https://phyphox.org/>
* A small nail (used to locate the magnetometer sensor in your phone).
* A wire coil wound on a cylinder, a block to elevate your phone to near the center of the coil, and a DC power supply to provide current.
* A ruler to measure location of the sensor with respect to the coil.
* A digital multimeter to measure electric current.

**Dos & Don’ts:**

* ***Do*** think about what data you need before you make a lot of measurements.
* ***Do*** use your imagination and have fun.
* ***Don’t*** damage your phone by dropping it, etc. It is pretty tough to damage it with magnetic fields, but don’t go overboard with a really strong magnet (none in this lab).

# BACKGROUND:

The magnetic field at the center of a flat, circular, current carrying, coil

The field of the coil is given by

 $B=\frac{μ\_{0}NI}{2R}$ (1)

Where *N* is the number of loops in the coil, *I* is the electric current in the coil, and *R* is the radius of the coil. The constant $μ\_{0}≈4π×10^{-7}$ m.kg/A2.s2 (or T.m/A) is “the permeability of free space.” The field is perpendicular to the coil as shown. This formula depends on a few assumptions, e.g., that the coil is a perfectly “flat” circle, that is, it has no thickness or radius of its own.



Moving away from the center of the coil but staying in its axis.

In this case, the magnetic field decreases according to

 $B=\frac{μ\_{0}NI}{2}\frac{R^{2}}{\left(R^{2}+z^{2}\right)^{3/2}}$ (2)

where *z* is the distance from the center of the coil. Notice that if you set $z=0$ in equation (2), you get equation (1) back, so these are completely consistent.

 

Moving away from the center of the coil, but staying in the plane, is another matter. The field a radius *r* from the center has a different magnitude and direction that at the center, but there is no simple formula. It can only be approximated using computational methods. The one thing you can count on is symmetry. The field should only depend on radius, not on the angle in the *x-y* plane.

# ACTIVITY 1: Find the magnetometer in your phone

The magnet fields you will measure depend strongly on position, and the magnetometer in your phone is quite small, just a few millimeters across. This means you need to figure out where inside your phone the magnetometer is located. The simplest way to do this is to use the magnetic field near the tip of a nail, a key, a screwdriver or any other pointy steel object. Start by opening the phyphox app and choose the magnetometer function. Put the phone on the table, start the app recording data, and move the nail provided around the phone while looking at the display. Find the spot where the effect of the nail is strongest.

Be sure to document the details in your report.**ACTIVITY 2: The magnetic field environment**

Notice that even with the nail far away, the magnetic field isn’t zero. The Earth has a magnetic field, so does all the steel in the building, so do the steel legs of the lab tables. For this activity you should explore the field in your experimental area.

* What is the strongest field you can find?
* What is the weakest?
* What is the magnitude and direction of the Earth’s field? (you may have to go outside to get this!)
* Make a map of the field over a few square feet on top of your lab table.

# ACTIVITY 3: Measuring $μ\_{0}$

Next, you will use the magnetometer to measure the field of a coil vs. current and analyze your result to measure $μ\_{0}$, the permeability of free space.

1. Arrange the provided coil and phone so that you can run current from the DC power supply to the coil while the magnetometer in the phone is as close as possible to the center of the coil.
2. Measure the radius of the coil, and check the number of turns (it is indicated on the coil).
3. Measure the magnetic field as a function of the current you apply. As usual, it is up to you to choose a range of values for the current.
4. Note: is the magnetic field zero when the current is zero? Probably not. This is a systematic error you can account for by measuring and subtracting the background field. Be sure not to move the phone after measuring the background, since you found in activity 2 that the field can change a lot vs location!
5. Based on equation (1), you can find a way to fit a line to the field vs. current plot and get a value for $μ\_{0}$.
6. Be sure to explain your calculations and compare your result to the value given above in your report.

# ACTIVITY 4: Exploring the field of the coil, part 1.

1. Measure field vs. distance from the center of the coil along the axis and
2. As in activity 3, remember that it is essential to subtract the background field. It is far better to keep the phone stationary and move the coil.
3. In your report, include a graph of your data vs. z.
4. You want to compare your results to equation (2) but excel doesn’t fit that function. Never fear! You now have the skills to make a column that calculates that function on your own, if you make the prefactor ($μ\_{0}NIR^{2}/2$) one parameter (call it “*a*”) and the constant term in the denominator ($R^{2}$) a second parameter (“*b*”) you can vary them “by hand” to get a best fit.

# ACTIVITY 5: Exploring the field of the coil, part 2.

1. Measure field vs. distance from the center of the coil in the plane of the field, that is, vs. radius.
2. Graph your results in your report.
3. As noted in the background, there is no simple formula for $\vec{B}(r)$, but you can still describe its behavior. Does the field get bigger or smaller with radius? Does the field tilt in towards the *z*-axis or away from it? Is it the same inside and outside the loop?

As always, be sure to write it up your methods, analysis, and findings carefully in your report. A future student should be able to understand what you did and what your findings were!

1. Pretty much all smartphones will work. If you can play a game that involves tilting the phone, your phone has one. [↑](#footnote-ref-2)