Science Lab: Helmholtz Coils Magnetic Field

Richard Born
Associate Professor Emeritus
Northern Illinois University

Helmholtz Coils

In this lesson students will find that these coils come in pairs with the same number of turns of wire on each of the two coils. In "true Helmholtz" configuration: (1) the coils are wired in series with identical currents in the same direction in each coil, and (2) the coils are placed a distance apart that is equal to the radius of each coil. When in this configuration, they produce a very uniform magnetic field that is directed along their common central axis. One of the most common uses for such coils in science education is in determining the charge to mass ratio of electrons, accomplished by immersing an electron tube in the central region of the coils and measuring the resultant curvature of the electron beam.

Helmholtz coils are also used for a variety of other applications including, but not limited to:

- canceling out the earth’s magnetic field, allowing experiments on magnetic substances in an environment that is free of magnetic fields.
- the production of magnetic fields for determining the effectiveness of magnetic shielding on electronic equipment.
- the calibration of magnetometers and Hall probe calibration.
- bio-magnetic studies, such as the effect of magnetic fields on seed germination and growth rates.
- Magnetic Resonance Imaging (MRI).

Because of the wide applicability and use of Helmholtz coils, science labs with these coils would be quite instructive. While Helmholtz coils can cost hundreds to thousands of dollars, it is possible in this maker world we now live in to easily and expensively construct them in just a couple of hours. The pair of coils can then be used to investigate how the induced magnetic field is affected by their spacing.

The Science Lab Setup

Figure 1 shows the experiment setup for this science lab. The Helmholtz coils were constructed from two 12" outside-diameter Styrofoam wreaths. White duct tape was wrapped around the outside of the wreaths to provide a less slippery surface for the wire. The tape was also used at four locations around the wreath to keep the wire from slipping off. The wire used was 14-gauge solid insulated wire, with 10 turns of wire on each wreath. Small 2x4 wood blocks were taped to the side of the wreaths to keep them upright on the table-top and provide a bit more stability. A pair of binding posts (not shown in Figure 1) was mounted to each 2x4 and the two ends of the wrapped wire were connected to the binding posts. The two coils were connected in series to a power supply and were aligned so that their central axes coincide. Since 14-gauge wire was used, a current of about 10 A could be used with only small heating of the wire. PocketLab Voyager was mounted to the end of a 2' dowel rod, with the center of the dowel rod in line with the letter Z on the orange side of Voyager. (The letter Z is very close to the location of the magnetometer on Voyager's internal circuit board.) The other end of the dowel rod is attached to a clamp on a ring stand. The dowel rod is visually aligned with the axis of the Helmholtz coils. A basswood stick taped to the table allows moving the ring stand smoothly while keeping the dowel rod aligned with the coil axis. A vertical white cardboard behind the Helmholtz coils serves as the origin for positions recorded by Voyager's rangefinder. Voyager is connected via BLE (Bluetooth Low Energy) to a Samsung Android tablet running Phyphox software. A graph of magnetic strength vs. position is created in real-time as Voyager is moved away from the white cardboard. The graph shown in Figure 1 was produced when the coils were spaced a distance apart that is equal to the coil radius, i.e., "true Helmholtz" configuration. As can be seen in the graph, this resulted in the production of a very uniform magnetic field in the region between the two coils.

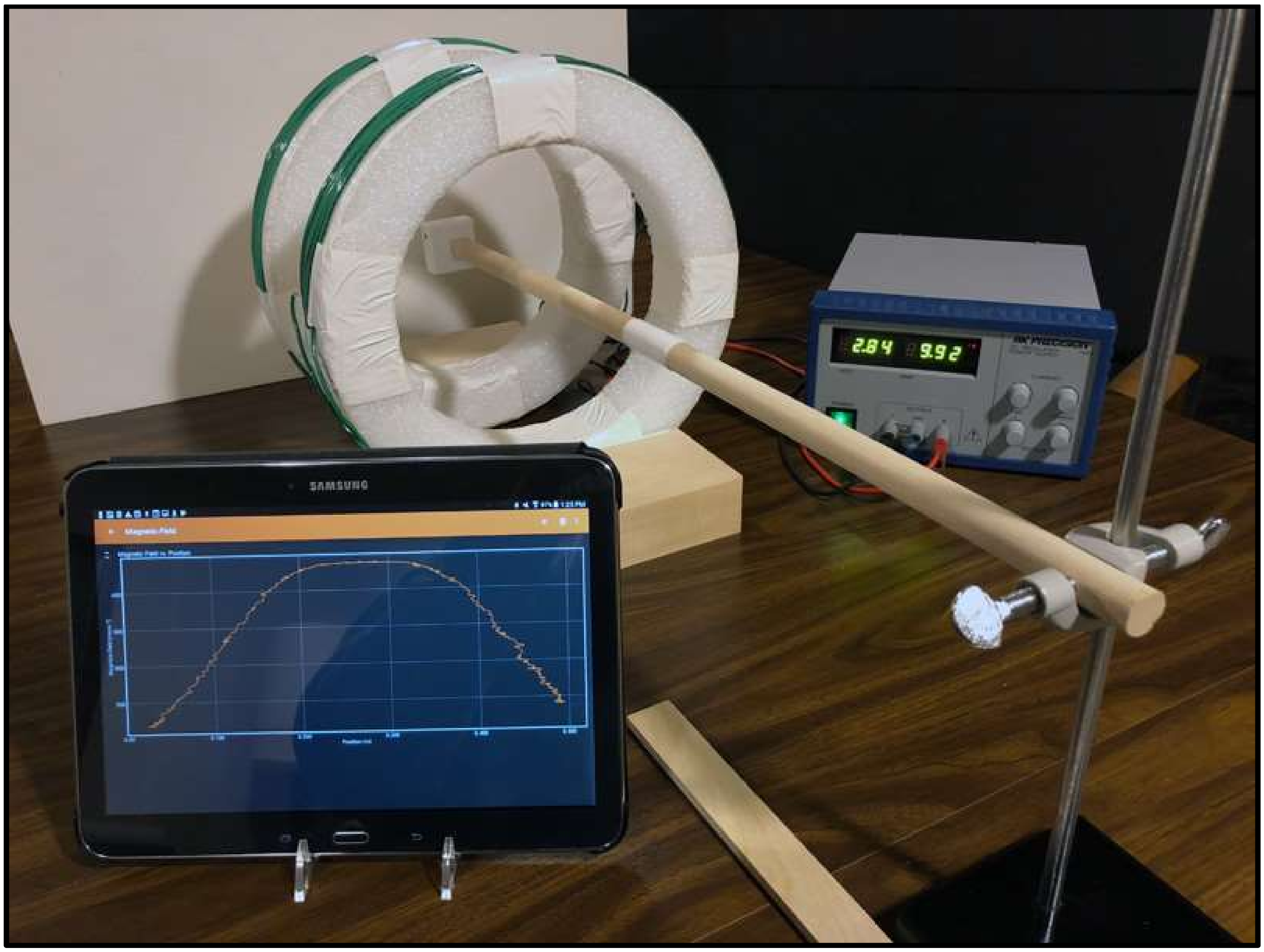

Figure 1

Phyphox Software

Phyphox (***phy***sical ***pho***ne e***x***periments) is a free app developed at the 2nd Institute of Physics of the RWTH Aachen University in Germany. The author of this lesson has been working with a pre-release Android version of this app that supports BLE (Bluetooth Low Energy) technology to transfer data from multiple Voyagers to the Phyphox app. It is important to understand that this capability of Phyphox may not be available to the public until the July 2018 anticipated beta release.

The experiment of this lesson is in a file named *HelmholtzCoils.phyphox* and will be made available from the author when the Phyphox beta is released. This file can then be opened in Phyphox and will appear in the *PocketLab Voyager* category of the main screen, like that in Figure 2.

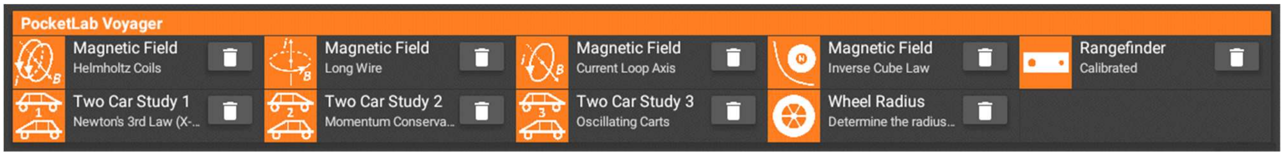

Figure 2

Performing the Experiment

The first screen that you will see after selecting the *Magnetic Field—Helmholtz Coils* experiment from the main menu is shown in Figure 3. The graph axes indicate that a graph of Magnetic Field vs Position will be created when data collection begins. A message in the center of the screen tells you that it is scanning for a Bluetooth device with the name "PL Voyager" and asks you to pick a device. At this point you should turn Voyager on. "PL Voyager" will appear in the message. Click on "PL Voyager" and a message will tell you that Bluetooth is connecting to the device. When the connection is complete, you can start data collection whenever you are ready with the pulsating triangle in the upper right corner of the screen. A 2½-minute YouTube video clarifies the entire process that was just described.

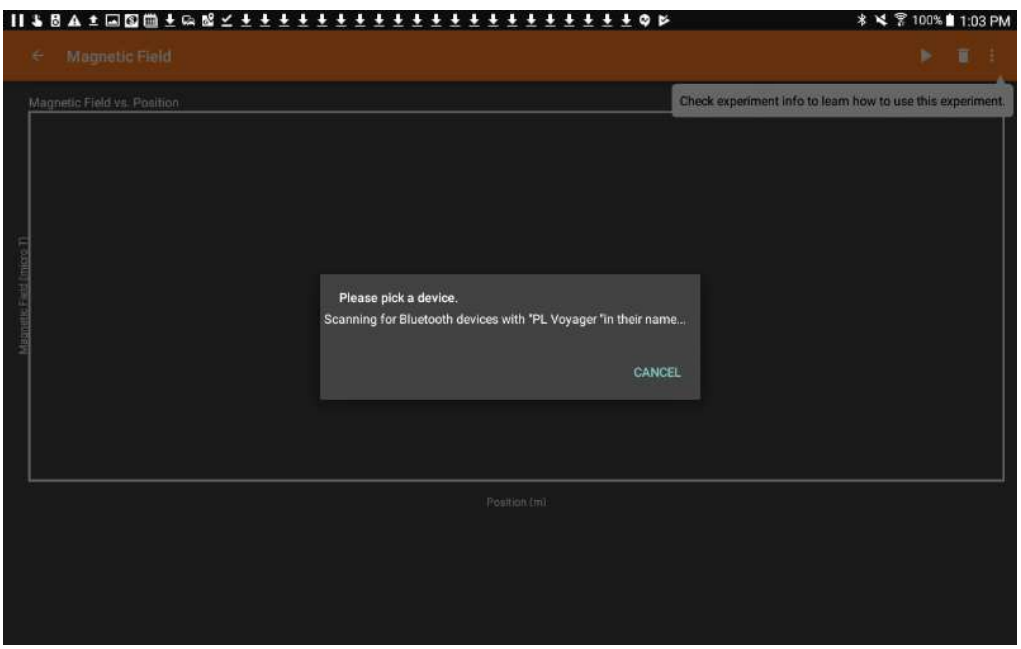

Figure 3

Start with Voyager near the white foamboard and then move Voyager along the axis of the Helmholtz coils away from the cardboard. The resultant Phyphox graph should look like that shown in Figure 1

To export the data, all you need to do is click the ellipsis in the upper right corner of the screen and select *Export Data* from the drop-down menu. You can then choose the desired data format (Excel, CSV) and pick a method for sharing the data (Google Drive, Dropbox, Email, etc.) See Figure 4.

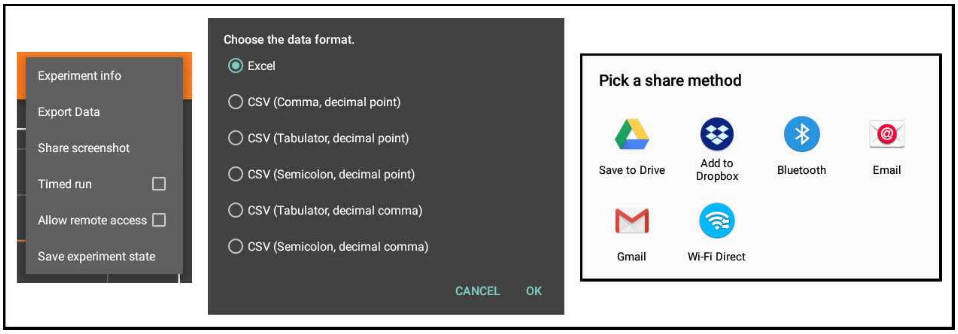

Figure 4

Procedures and Analysis

The author's approach to the analysis was to export the data from Phyphox into Excel. Two procedural steps are suggested:

1. Data was collected for several seconds with Voyager's magnetometer *at rest*, in the same orientation as it will be when collecting actual data, and with the *current turned off*. The purpose of this step is to compute the "zero" for magnetic field. This would allow for adjusting the magnetic field values in step 2 to compensate for the earth's background magnetic field. Figure 5 shows what the raw data looks like when zeroing. Since the zero visually appears to be about 47 micro T, then it would be necessary to subtract 47 micro T from each of the magnetometer values collected in the actual experiment.

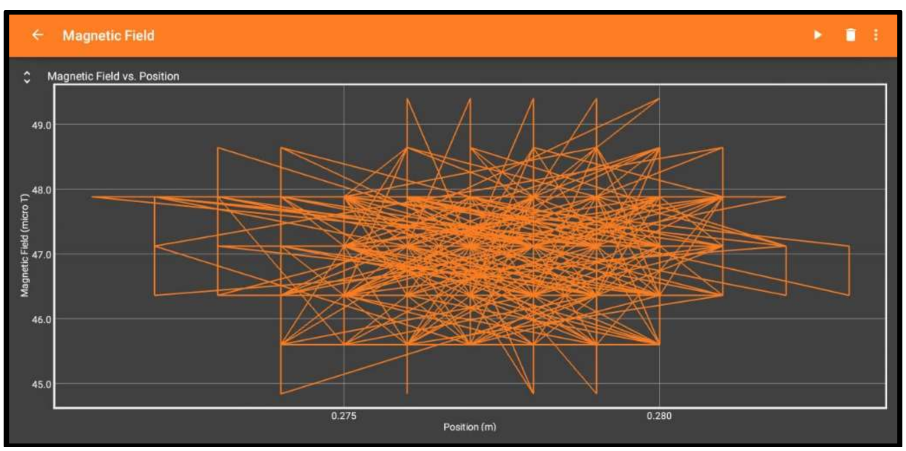

Figure 5

2. With the current turned on and set to about 10 A, magnetic field strength was collected while moving Voyager from its initial position near the white cardboard to a position about 0.5 m away from the cardboard. Three such runs are performed—one with the coil spacing too close

together, one with the spacing just right at “true Helmholtz” configuration, and one with the coil spacing too far apart. Figure 1 shows a typical Phyphox graph for “true Helmholtz” spacing.

Positions are all measured from the white cardboard but should be adjusted so that they are measured from a location at the center of the pair of coils. As mentioned in step 1, the magnetometer readings need to be adjusted as well. This is accomplished in our example by subtracting 47 micro Tesla from each magnetometer reading.

Figure 6 shows the final graphs of magnetic field strength vs. axial distance from the center of the coils. These graphs were constructed by exporting the data from Phyphox to Excel. In each of the graphs, the vertical colored lines indicate the position of the coils. For the case of “true Helmholtz” spacing, shown in green, the magnetic field strength is very even compared to “to close” and “too far”.

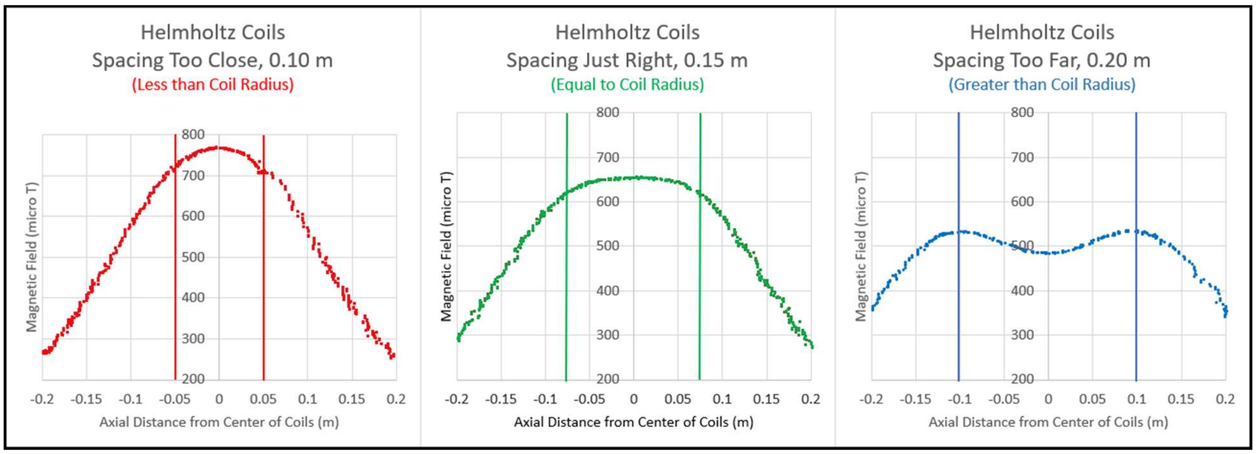

Figure 6

If you want your students to compare their experimental results to Helmholtz coils theory, go to this URL for a PocketLab experiment that discusses the theory in some depth:

https://www.thepocketlab.com/support/lesson/quantitative-study-helmholtz-coils