Magnetic Field on a Current Loop's Axis

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Introduction

In this lesson students will find that a current-carrying loop can be regarded as a dipole, as it generates a magnetic field for points on its axis. Students use PocketLab Voyager and Phyphox software to compare experiment and theory for the magnetic field on the axis of a current loop. A similar experiment not making use of Phyphox can be found by clicking this link. An experiment making use of a magnet, instead of a current loop, can be found by clicking this link.

There are many ways that you can make a current loop. The author used a plastic ribbon spool approximately 3" in diameter and 3/4" wide, and then wrapped 10 turns of insulated wire around the spool. The ends of the wire were connected to a DC power supply that supplied constant current for the current loop. Figure 1 shows Voyager with its magnetometer centered on the axis of the spool. Voyager's magnetic sensor is located almost directly below the letter Z on the circuit board inside Voyager. It is important to keep the magnetic sensor on the loop axis while it is moved to known distances from the center of the loop. Voyager is attached to the end of a balsa stick that can be kept parallel to the axis of the current loop.

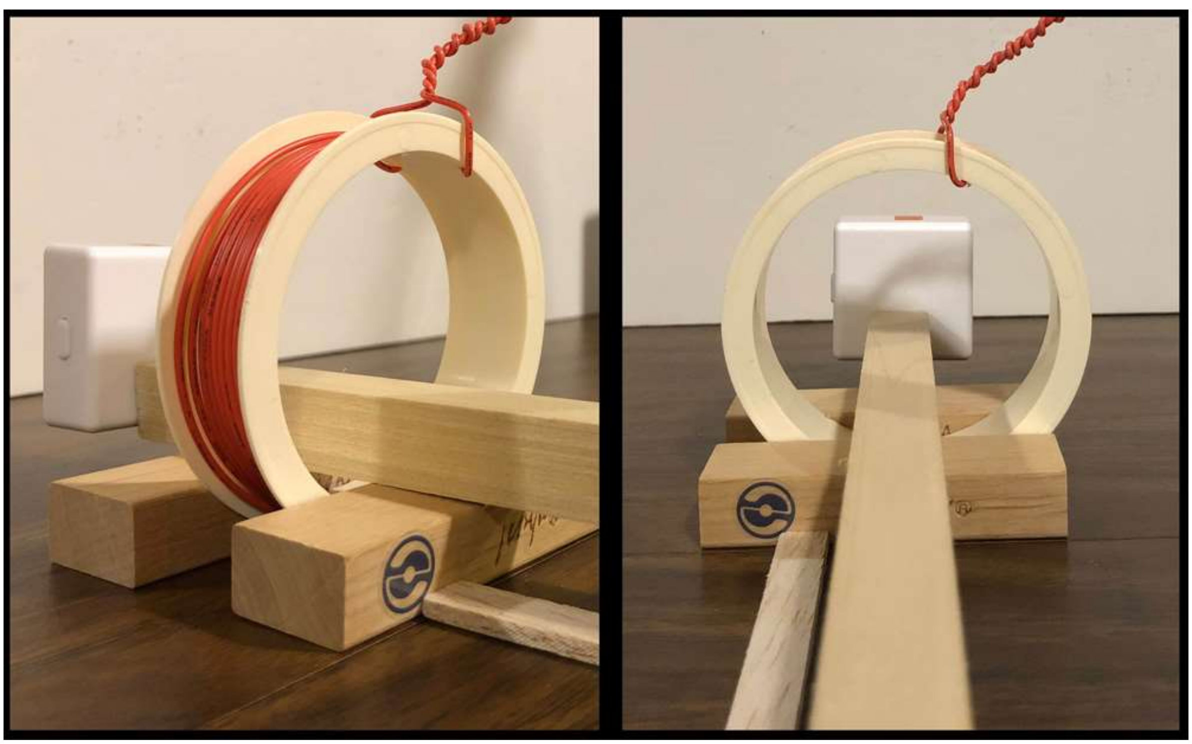
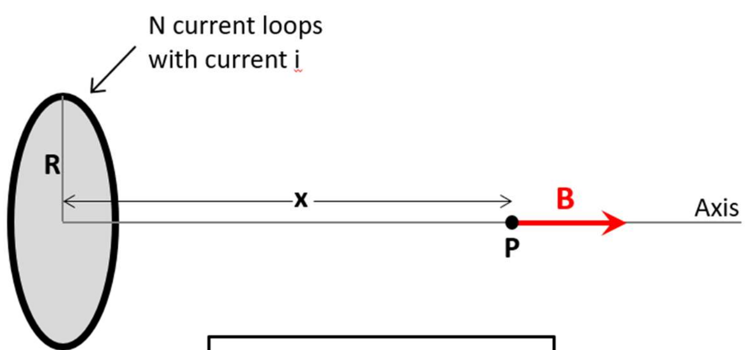


Figure 1

Current Loop Axis Magnetic Field Theory

Figure 2 shows a diagram and the equation for the magnetic field B on the axis of a current loop. Derivation of this equation requires knowledge of the Biot-Savart Law, calculus and trigonometry. But in this lesson, we are interested only in comparing experimental results from Voyager's magnetometer to the theoretical equation in Figure 2. If desired, AP and college students can also consider derivation of the equation. The author's setup used a current of i = 5.1 amp, R = 0.0361 m, and a loop with 10 turns of wire.

Magnetic Field on the Axis of a Current Loop



$$B = \frac{N\mu_0 i R^2}{2(R^2 + x^2)^{3/2}}$$

Magnetic permeability of a vacuum:
$\mu_0 = 4\pi \times 10^{-7}$ H/m (henries per meter)

Figure 2

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 *CurrentLoop.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, similar to that in Figure 3.

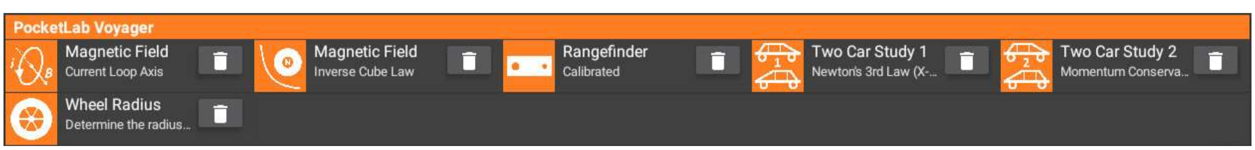


Figure 3

Performing the Experiment

The first screen that you will see after selecting the *Magnetic Field—Inverse Cube Law* 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 two-minute YouTube video clarifies the entire process that was just described.

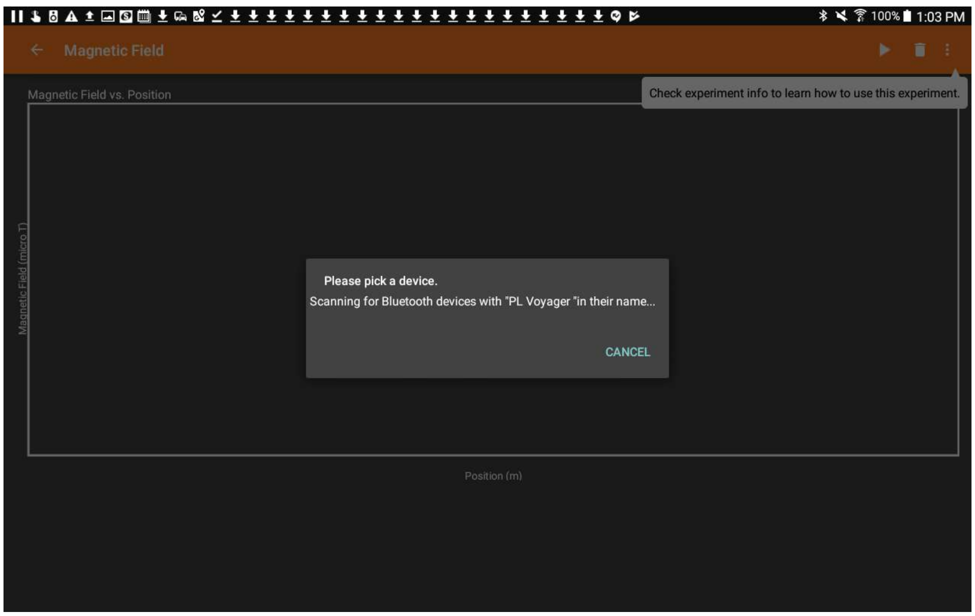


Figure 4

Figure 5 shows what the graph may look similar to once data collection is complete.

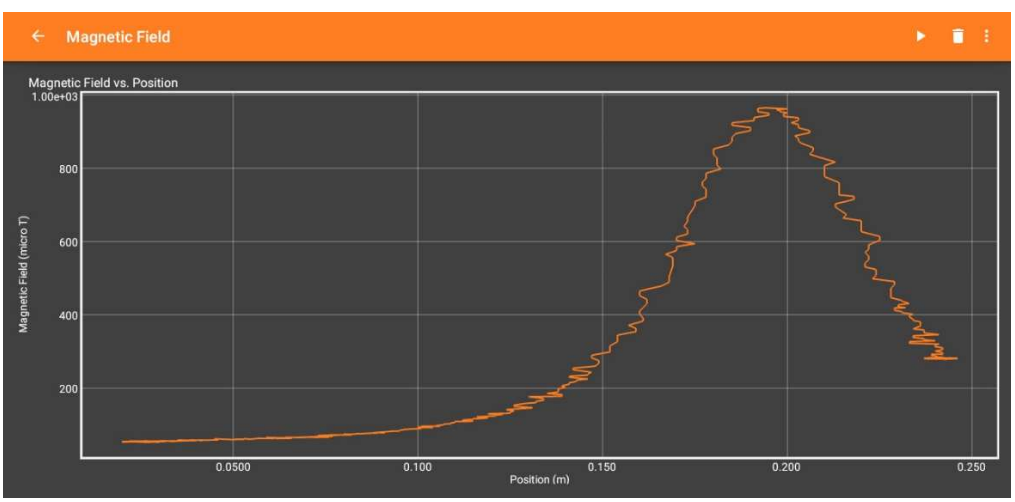


Figure 5

In order 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 6.

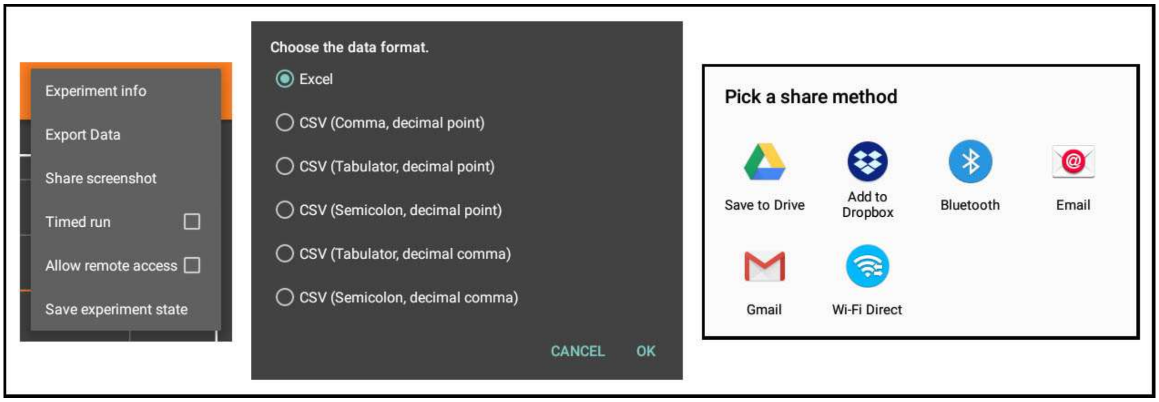


Figure 6

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 center of the loop, but 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 7 shows what the raw data looks like for the author's zeroing.

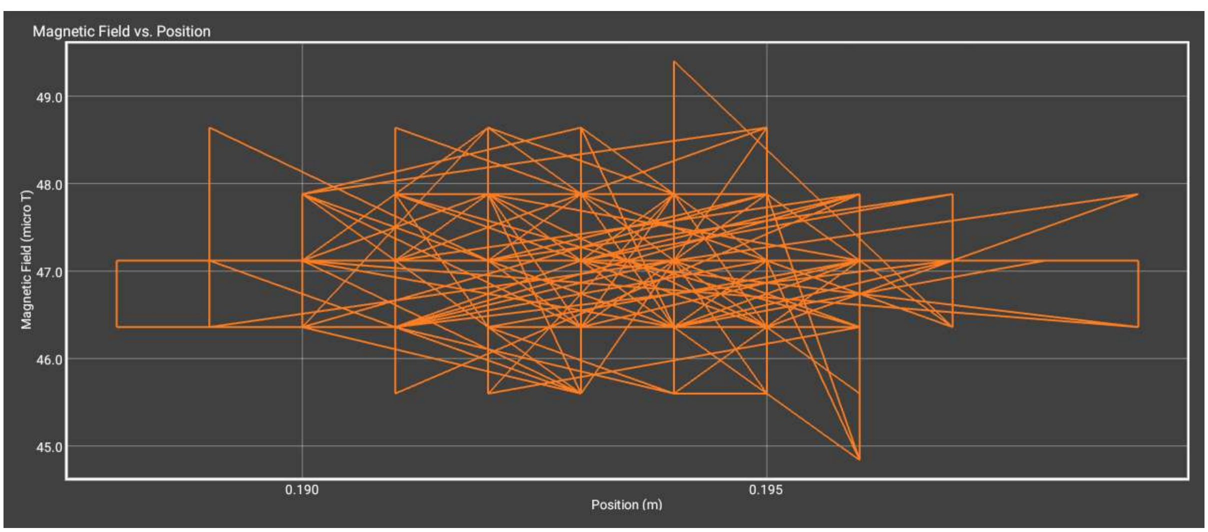


Figure 7

The visual average is about 47 micro-Tesla. Averaging the values in the exported Excel file showed the average to be 47.1 micro-Tesla.

2. With the current turned on and set to about 5-amp, magnetic field strength data was collected while moving Voyager from its initial position to the left of the current loop to a position to the right of the current loop. As shown earlier, Figure 5 displays a typical run. Positions are all measured from the white foam board. Positions need to be adjusted so that they are all measured from the center of the loop, assuming that you are interested in comparing your experimental results to the theory of Figure 2. With the peak magnetic field occurring at the center of the loop, Figure 5 tells us that we need to subtract about 0.195 m from each of the positions. As discussed in step 1, the magnetometer readings need to be adjusted as well. This is accomplished in our example by subtracting 47.1 micro Tesla from each magnetometer reading.

   Figure 8 shows the final graph of magnetic field along the axis vs. distance from the center of the current loop. The blue line shows experimental data while the red line shows the theory. Agreement between the two is good, providing convincing evidence in support of the theory.

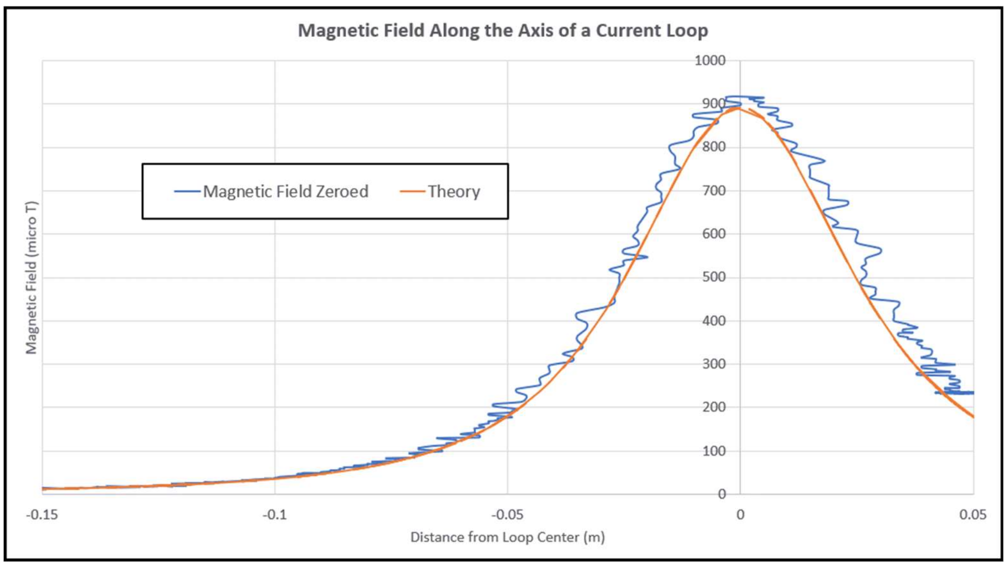


Figure 8