

Experiment 10

Magnetic Fields and Induction

Please print 1 copy of REPORT page and bring a diskette to save your data.

Objective:

To study the special dependence of the magnetic field of a solenoid.

Apparatus:

Solenoid, magnetic field sensor, computer and interface, supporting posts and meter stick, power supply and resistor.

Theory:

When an electric charge is moving, it generates a magnetic field in the space. Since a current is a continuous flow of moving charges, it will generate a magnetic field around it. The magnetic field of a current element is given by Biot-Savart Law:

$$d\mathbf{B} = \mu_0 / (4\pi r^3) I d\mathbf{L} \times \mathbf{r} \quad (1)$$

Where I is the current; \mathbf{B} , \mathbf{L} and \mathbf{r} are, respectively, the magnetic field vector, the length vector of the current element and the displacement vector from the current element to the point of interest. The bold faced letters represent vectors. The constant $\mu_0 = 4\pi \times 10^{-7} \text{ N / A}^2$.

Experimentally, we can measure the magnetic field of a macroscopic current with finite size, instead of an infinitesimal current element. Eq.(1) is therefore of theoretical significance only. To obtain the magnetic field of a current of finite size, it is necessary to integrate Eq.(1) over the total length of the current, which is somewhat a tedious but straightforward process. Inside a solenoid, the magnetic field along the axis is given by

$$B = 0.5 \mu_0 n I [b / (b^2 + R^2)^{1/2} + a / (a^2 + R^2)^{1/2}] , \quad (2)$$

where R is the radius of the solenoid, n is the number of turns per unit length, a and b are the distances from the point of interest, which is the origin of the coordinates in Figure (1), to the ends of the solenoid. The direction of the magnetic field is along the X-axis.

The magnetic field of a solenoid is shown in Figure (1). Inside the solenoid, the magnetic field is nearly a constant. It starts to decrease dramatically towards the ends of the solenoid. It is sometimes called the "edge effect". The magnetic field quickly reduces to practically zero outside the solenoid. In the central part of the solenoid, if the solenoid is very long, namely, $a \gg R$ and $b \gg R$, Eq.(2) can be approximated by a much simpler formula:

$$B = \mu_0 n I \quad (3)$$

At the ends of the solenoid, when either a or b is zero,

$$B = 0.5 \mu_0 n I \quad (4)$$

The direction of the magnetic field along the axis of the solenoid is always parallel to the axis. Elsewhere, however, the direction of the magnetic field changes depending on the position. The magnetic field vector generally has three components, and it usually is obtained numerically with computer if the geometrical parameters of the solenoid are given. For a picture of the magnetic field lines, refer to your text book of general physics.

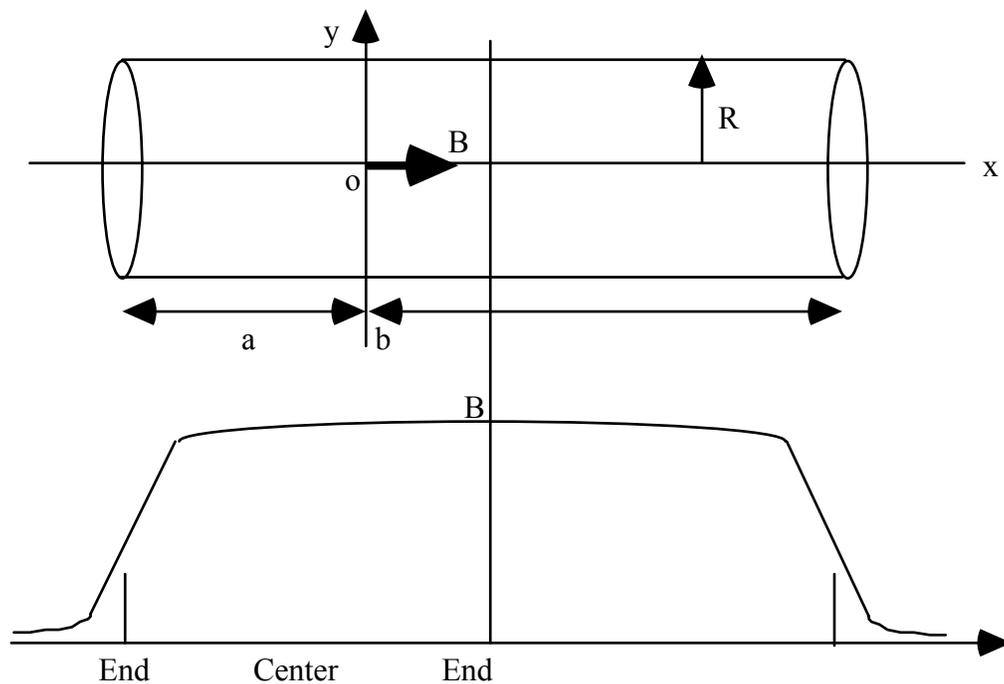


Figure 1. The magnetic field of a solenoid

Procedure

1. Set up the solenoid and the Gauss meter sensor as shown at the Fig. 2. Measure the inner and outer radii R_1 and R_2 . Enter the average radius into Eq.(2) for your theoretical calculations. Measure the length L of the solenoid. Record the total number of turns, N , which is written on the solenoid. Divide to total number of turns N by the total length of the solenoid to obtain n

$$n = N / L \quad (5)$$

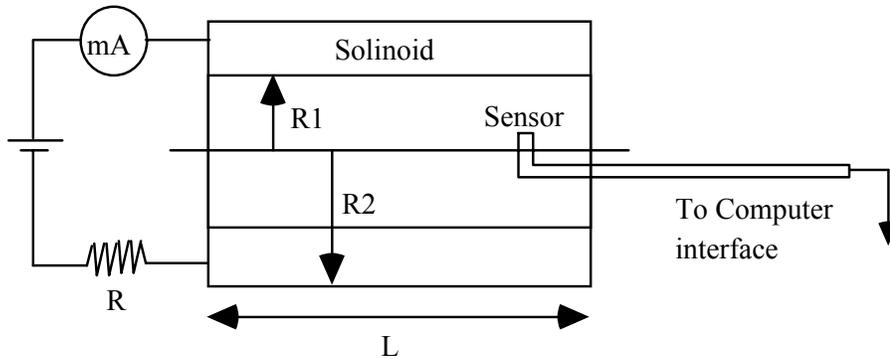


Figure 2. The experimental Set-up

2. Connect the solenoid to a DC power supply of 15 V. Divide this voltage by the total resistance of the solenoid and the resistor to obtain the current I through the solenoid. The resistance of the solenoid is also labeled on it.

Now you have all the information for your theoretical calculations.

3. Set up your semiconductor field sensor such that the tip, not the stem, of the sensor is centered at the axis of the solenoid. The stem of the sensor is but a glass sleeve of the electrical wire and therefore has no significance. The output of the sensor goes to the computer interface.

4. Turn on the computer and the interface, and open the software for data taking.

5. Measure the magnetic field along the axis of the solenoid. You need to measure the position of the sensor and manually enter into the computer to keep the data point. Starting from the center of the solenoid and map out the magnetic field along the axis. Save your data on a diskette.

DATA ANALYSIS

1. Calculate the theoretical curve (magnetic field vs. position) using Eq. (2).
2. Plot the experimentally measured magnetic field along the axis of the solenoid and the calculated field on the same graph.
3. How good is the agreement between theory and experiment?
4. What are the sources for discrepancies between theoretical and experimental results?

Reminder: Check you math, check the units, check your graph, do not forget to follow the format for your lab report (see syllabus).