Measuring earth's magnetic field from the deflection of a compass needle*

Mohsina Asif, Kaneez Amna, Azeem Iqbal, Muhammad Umar Hassan and Muhammad Sabieh Anwar

LUMS Syed Babar Ali School of Science and Engineering

September 16, 2022
Version 2022-1

This experiment aims to find the horizontal component of earth's magnetic field. The experiment involves the investigation of the combined effect of the magnetic fields produced by the earth and a current carrying multi-turn coil. With the help of graphs, students are expected to study the relation of current through the coil and the magnetic field that it generates measured by the deflection of a compass needle.

Keywords
Magnetic field · Tangent galvanometer · Ampere's law · magnetic torque · Magnetic dipole moment

Essential pre-lab reading:

1. *Fundamentals of Physics*, 9'th edition, Halliday, Resnick and Walker, (Section 29–6).

2. *Conceptual Physics*, 10'th edition, Paul G Hewitt, (Chapter 24, page 469–470).

1 Experimental Objectives

After the completion of this experiment, you should be able to understand that,

1. a current produces a magnetic field,

2. how to determine the resultant of two vectors,

3. how to make graphs and fit data, and

4. how to linearize data and perform weighted fit of a straight line.

2 Introduction

The earth, just like many other planets, possesses a magnetic field whose shape resembles that of a bar magnet. The magnetic dipole is a fundamental entity in magnetostatics just like a point charge is in electrostatics. A bar magnet is an approximate magnetic dipole. The magnetic field lines of a bar magnet form a closed loop as shown in the accompanying figure. The magnetic dipole moment, by convention, is a vector pointing from the south to the north pole. We can find the direction of the field at any point in space around the magnet by taking the tangent at the field line at that particular point. A freely suspended magnet tries to align with the north. For example, the compass needle also aligns with earth's magnetic field and has been used for millenniums by explorers and seafarers for navigating the nooks and corners of the globe. This lab exercise is a simple undertaking in quantitatively estimating the magnitude of the horizontal component of the terrestrial field.

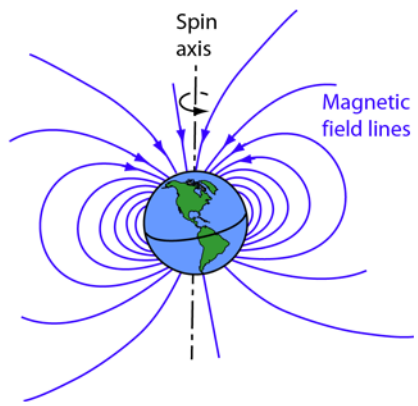

Figure 1: Conceptual illustration of earth's magnetic field. This image is taken from `http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/MagEarth.html`

.

Q 1. We know that motion of electric charges causes magnetism, but what is moving inside a permanent bar magnet?

3 The Experiment

Earth's magnetic field can be resolved into two components, horizontal and vertical, $\boldsymbol{B}_e = \boldsymbol{B}_h + \boldsymbol{B}_v$. In this experiment we will measure only the horizontal component, $\boldsymbol{B}_h$. The direction of $\boldsymbol{B}_h$ points towards the magnetic north pole of the earth and (in the absence of any external field) a magnetic compass tends to align itself in this direction.

The field $\boldsymbol{B}_h$ will be determined using the *deflection galvanometer* method, sometimes also called *tangent galvanometer* method. In this method, an external magnetic field $\boldsymbol{B}_{\text{coil}}$ is generated which makes an angle of 90° with $\boldsymbol{B}_h$. This field, labelled $\boldsymbol{B}_{\text{coil}}$, is produced by current flowing through a multi-turn coil whose axis is along the east-west direction. When this current is switched on, the resultant magnetic field $\boldsymbol{B}_{\text{resultant}}$ is the vector sum of $\boldsymbol{B}_h$ and

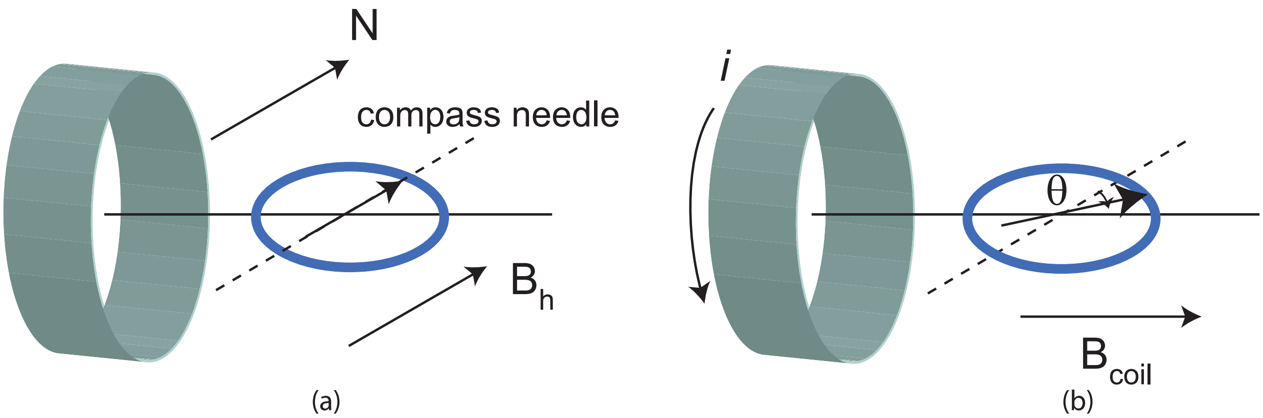

Figure 2: Deflection of compass as a result of two magnetic fields; figure (a) shows our experimental configuration. The compass needle points in the NS direction in the absence of current in the coil while (b) shows the resultant of two magnetic fields ($\boldsymbol{B}_{\text{coil}}$ and $\boldsymbol{B}_h$) when the current i has some non-zero value. The angle θ is the needle's deflection from the original.

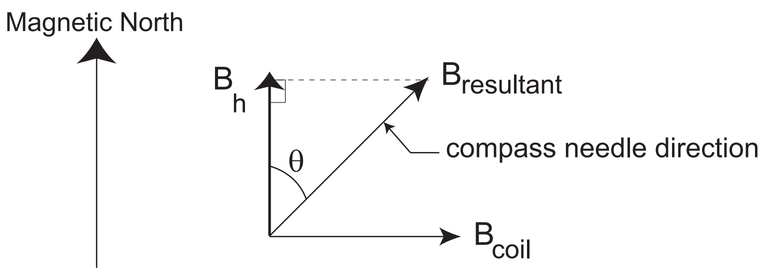

Figure 3: The relation between the compass needle deflection θ, $\boldsymbol{B}_{\text{coil}}$, and $\boldsymbol{B}_h$.

$\boldsymbol{B}_{\text{coil}}$, as shown in Figure 3. The compass needle aligns with the direction of $\boldsymbol{B}_{\text{resultant}}$. The $\boldsymbol{B}_{\text{coil}}$, as also shown in Figure 3, is related to $\boldsymbol{B}_h$ by the following equation 1.

$$\boldsymbol{B}_{\text{coil}} = \boldsymbol{B}_{\text{h}} \tan\theta \tag{1}$$

The field $\boldsymbol{B}_{\text{coil}}$ being generated by the current carrying coil can be inferred from the measured current using the relation,

$$\boldsymbol{B}_{\text{coil}} = kI. \tag{2}$$

This equation follows from the Ampere law which states that for a particular distance away from the center of the coil, the generated field is directly proportional to the magnitude of the current. The gain constant k (measured in Gauss/Ampere) has been pre-calculated by us and is provided with each setup. Using k, $\boldsymbol{B}_{\text{coil}}$ can be found for different readings of current I.

The overall orientation of the experiment is depicted in Figure 2 while a photograph of the various components is shown in Figure 4.

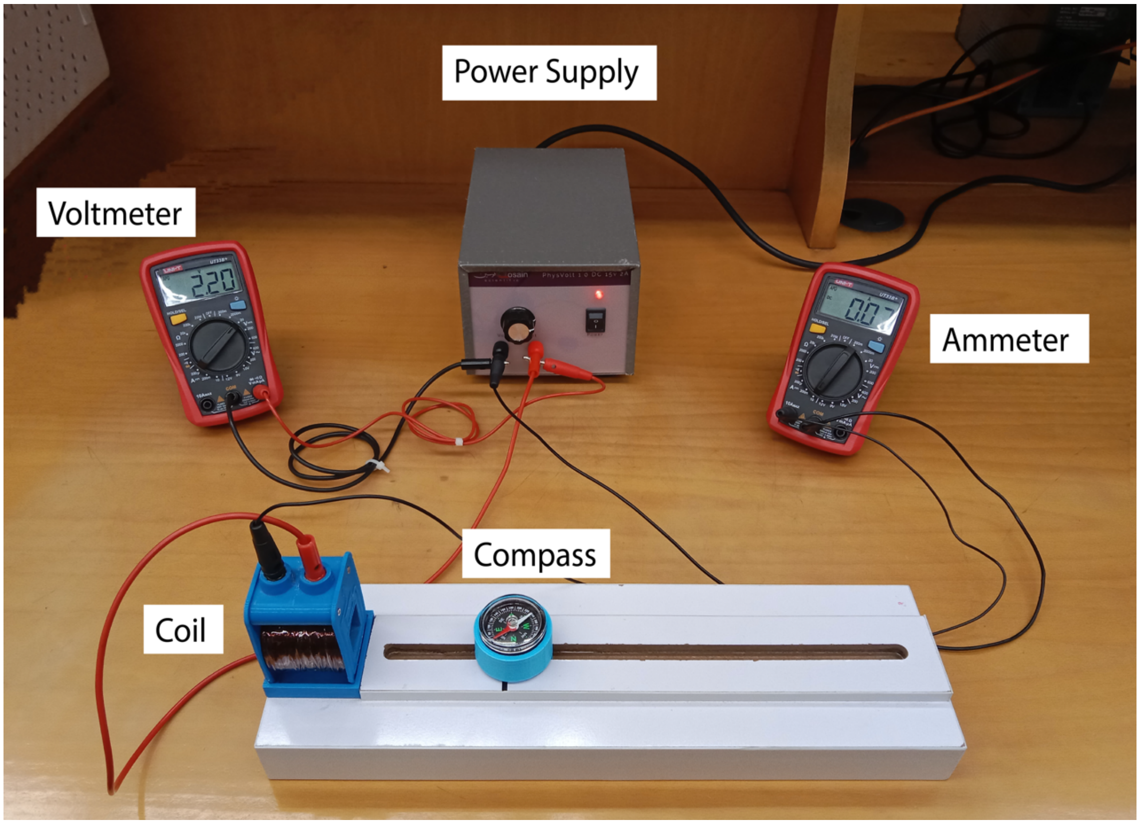

Figure 4: Experimental arrangement: A DC power supply provides current and voltage to the multi-turn coil that are measured by a voltmeter and ammeter, A magnetic compass is placed on top of a wooden-board that has a central groove. The compass is placed at a distance at which the calibration gain k is known.

3.1 Experimental procedure

Before beginning the experiment, remove all ferrous materials and other possible sources of magnetic fields from the immediate vicinity of the apparatus.

1. The compass is positioned on the board such that, when the power supply is off, the needle pointing in the N-S direction is perpendicular to the central coil axis. This signifies the direction of the magnetic north and $\boldsymbol{B}_{\mathrm{h}}$ (as shown in Figure 2).
2. Ensure that the center of the compass is aligned with the marked position on the board, i.e., at the distance for which the the calibration gain k is provided by us.
3. Make all connections as shown in Figure 4.
4. Switch on the power supply.
5. Vary the voltage from 0 to 15 V and record the angle of deflection of the compass needle along with the corresponding current values.

6. Using the provided value of calibration gain k, calculate $\boldsymbol{B}_{\text{coil}}$ for each of these current values.

Use the *tangent galvanometer* law given in Equation (1) to calculate the horizontal component of earth's magnetic field.

Q 2. From the data acquired, make appropriate tables, use the data to find the best estimate of the earth's magnetic field (horizontal component only). What is your uncertainty in this measurement?

Q 3. Devise a method to find the *effective radius* of the multi-turn coil used in this experiment.

Q 4. How can you find the vertical component of the Earth's magnetic field?

Q 5. A current-carrying wire is placed in the north-south orientation. What direction does the compass needle point when a compass needle is placed below or above the wire?

Q 6. Plot deflection versus tangent of deflection. Comment how data can be linearized to find the best estimates of physically useful properties according to scale of the quantity.

Q 7. Identify the range where uncertainties in the data are most prominent.

Q 8. In what region do you think the compass needle deflection is most sensitive to changes in the applied field of the current carrying coil.