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

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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. Furthermore, magnetic fields measured at different distances will provide insight to the distance dependence of the magnetic field.

Keywords
Magnetic field · Tangent galvanometer · Hall effect · 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. the Hall effect can be used to measure the magnetic field,
3. determine the resultant of two vectors, and
4. how to make graphs and fit data.

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.

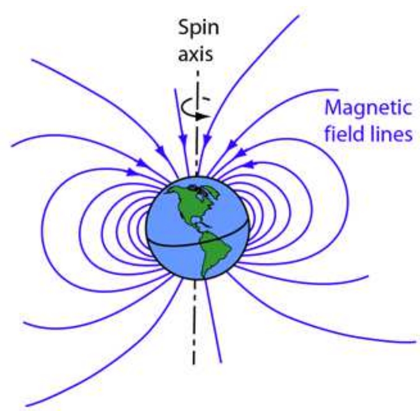

Figure 1: Conceptual illustration of earth's magnetic field. This image is taken from `http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/MagEarth.html`

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

2.1 The Hall Effect and Hall sensors

The Hall effect was discovered by Dr. Edwin Hall in 1879 while he was a Ph.D. student. When a current-carrying conductor is placed inside a perpendicular magnetic field, a voltage will be generated perpendicular to both the current and the magnetic field. This principle is known as the Hall effect. The Hall voltage, V_H is proportional to the magnetic field B and current, I,

$$V_H = CBI$$

where C is a constant of proportionality. The phenomenon of Hall effect is illustrated in Figure 2. Measurement of V_H can therefore provide a measure of the field B. This effect is exploited in Hall sensors. You will use one such sensor to measure B.

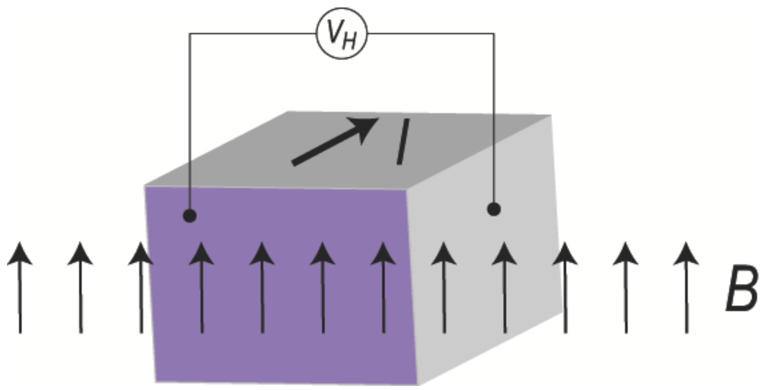

Figure 2: The development of a Hall voltage (V_H) through a sensor immersed in a magnetic field B through which a current I flows. The directions of the current, field and Hall voltage are perpendicular to one another.

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For the provided Hall effect sensor and amplifier combination, the magnetic field B (in Gauss) can be inferred from the voltage from the relationship,

$$B = \frac{(V_H - V_{\text{offset}})}{k} \tag{1}$$

where V_H is the measured output voltage from the amplifier (in volts), from the Hall sensor, V_{offset} is the offset voltage at zero field (also measured in volts) and $k = 0.0412 \times 10^{-3}$ V/G. The calibration factor k has been calculated independently using a more accurate Gaussmeter. See Appendix A for details. The Gauss is a small unit of magnetic field, 1 G$= 10^{-4}$ T.

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 a magnetic compass tends to align itself in this direction.

Measurement of the $\boldsymbol{B}_h$ will be done by 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 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. The overall orientation of the experiment is depicted in Figure 3 while a photograph of the various components is shown in Figure 4.

The current through the coil is supplied from the dc power supply. When this current is zero, the Hall detector may give some offset voltage, V_{offset} in Equation (1). Try nulling this voltage using a screw driver which is inserted into the labeled opening on the top cover of the Hall amplifier box. Slowly rotate the screw driver, and in the process, rotate the variable resistor. Try getting as close to null as possible and mention the offset voltage in the Equation (1).

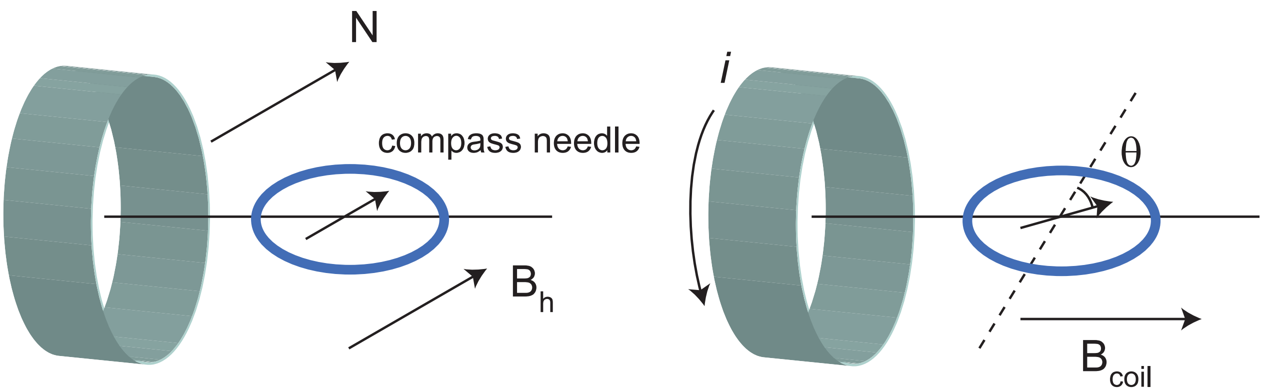

Figure 3: Deflection of compass as a result of two magnetic fields (a) Shows our experimental configuration: the compass needle points in the NS direction in the absence of current in the coil. (b) Shows the resultant of two magnetic fields ($\boldsymbol{B}_{\text{coil}}$ and $\boldsymbol{B}_h$) when the current i has some non-zero value. The angle θ is the needle's deflection from the original.

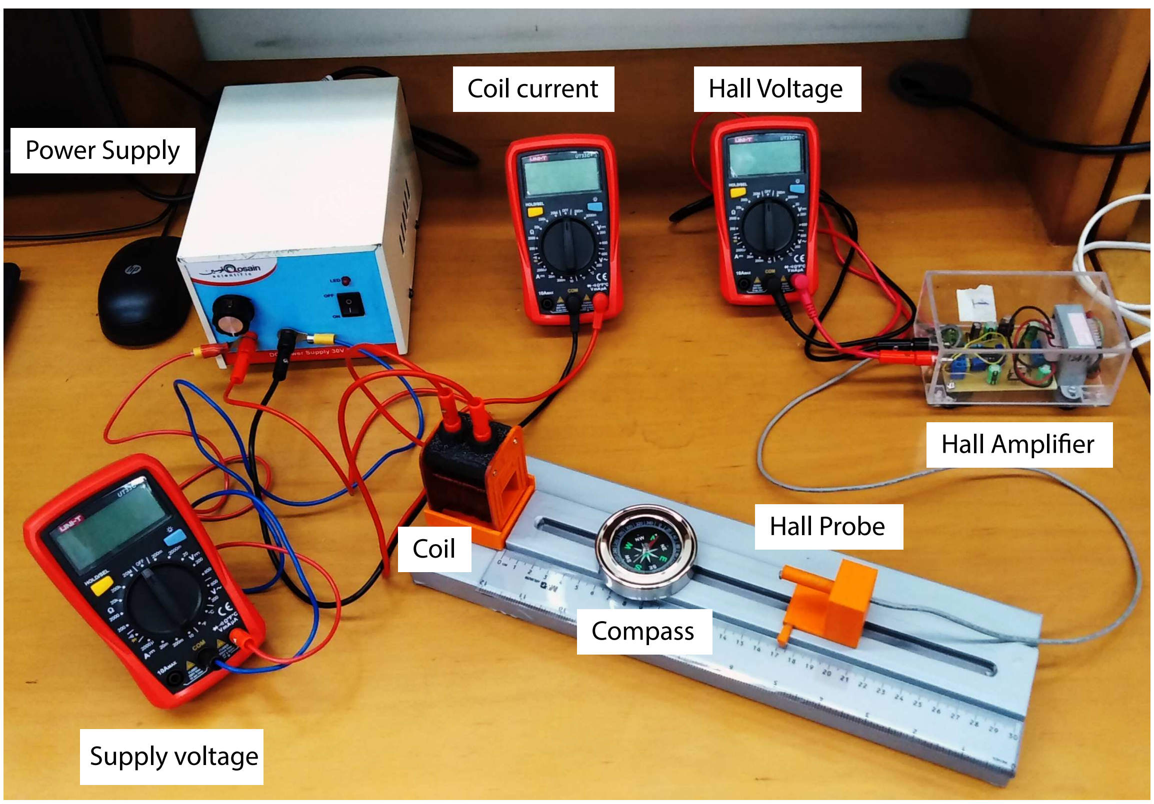

Figure 4: Experimental arrangement: A dc-power supply provides current and voltage to the multi-turn coil. A magnetic compass is placed on top of a wooden-board that has a central groove to mount a Hall probe. The probe is connected to a Hall voltage amplifier. A digital multimeter equipped with a voltmeter is then used for measuring the Hall voltage.

Place the compass to an optimum distance on the coil axis such that the resulting deflection from the magnetic field of the coil is large enough to cause a rotation of 90 ° in the compass needle when the power supply voltage spans from 0 to 15 V. Record the values of deflection of the compass against different values of current and voltage. Now at the same distance introduce a Hall probe using Equation (1), and measure the magnetic field produced from the coil, for identical current values.

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 you can 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?

A Appendix on Calibration of the Hall sensor

While preparing this experiment, we must calibrate the Hall sensor and the amplifier. For this purpose, placed the Hall sensor at a known distance, in our case, 4 cm from the edge of the coil and measured its amplified output voltage. In parallel, we also placed a Hall probe, connected to a Gaussmeter *(HIRST Magnetic Instruments, GM08)*. We varied the supplied voltage to the coil and measured the respective magnetic field strength in *Gauss* and Hall voltage in mV. We then plotted both the quantities and obtained the graph in Figure 5 which shows the respective calibration curve. The gradient of this graph is indeed the calibration factor k in Equation (1) and computed to be 0.0412 Volts/Gauss.

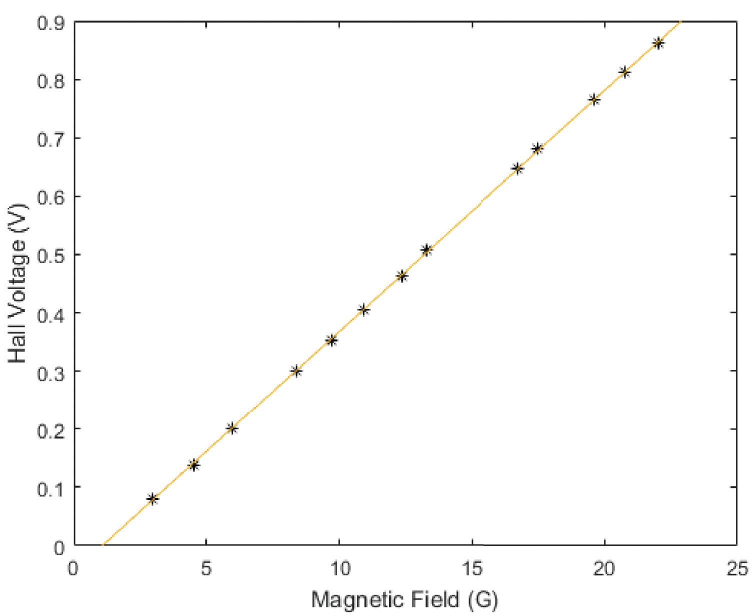

Figure 5: The calibration plot of the Hall voltage V_H versus the magnetic field strength B.