Name________________________________ Date ________________ Section ____________

LAB 8: SOURCES OF MAGNETIC FIELDS

Purpose

The purpose of this lab is to gain an understanding for magnetic fields, to see how electric currents produce magnetic fields, and to measure the geomagnetic field using Helmholtz coils and a dip needle.

Theory

Just as electric fields are "generated" by electric charges, magnetic fields are generated by moving charges. The law of Biot and Savart describes the magnetic field generated by a given electric current:

$$B(r) = \frac{\mu_0}{4\pi}\int \frac{(\vec{r}_s - \vec{r})\times I\ ds}{\left|\vec{r}_s - \vec{r}\right|^3}, \qquad \mathbf{1}$$

where I is the electric current, $\vec{r}$ is the position of the point of interest, $\overrightarrow{r_s}$ is the position of the wire element, and μ_0 is a constant called the "permeability of free space" and has a value of $4\pi \times 10^{-7}$ Tm/A. If the current is the same everywhere in the circuit, then (1) can be rewritten as

$$\vec{B}(r) = I\vec{\gamma}, \qquad \mathbf{2}$$

where $\vec{\gamma}$ is a quantity which is dependent upon **r** and upon the wire geometry, but independent of I. $\vec{\gamma}$ could probably be called the "B-field generation coefficient." In this lab, we will determine $\vec{\gamma}$ both experimentally and theoretically for a Helmholtz coil and for a solenoid.

Recall that we can use Ampere's Law to compute the magnetic field inside a solenoid:

$$B_{sol} = \mu_0 n I \qquad (3)$$

where *n* is the number of turns per meter and *I* is the current flowing through the solenoid.

Computing the integral (1) for a pair of Helmholtz coils gives:

$$B = \left(\frac{8}{5\sqrt{5}}\right)\frac{\mu_0 N I}{a} \qquad (4)$$

where *N* is the number of turns in one coil, *I* is the current flowing through that coil, and *a* is both the radius of each coil as well as the distance between the two coils.

A small compass (a magnetic dipole) can serve as a "test magnet" for studying magnetic fields. In electrostatics, a test charge is used to help determine the direction that the electric field points in. In magnetism, a compass can be used to determine magnetic field, **B**. The direction to which the "north" end of the needle of the compass points is taken as the direction of **B** at that point. A compass moved carefully along the direction in which it points will ideally trace out a magnetic field line.

As with an electric field, one can get a feeling for the relative strength of a magnetic field by comparing the spacing of the field lines. By tracing two lines from one region to where they are close together to another region where they are farther apart, it can be determined that **B** is weaker in the latter region. Conversely, following the same two lines to a region where they are closer together, it can be concluded that the **B**-field is stronger in that region.

Equipment

- Part I: Large gauge wire connected to the "+" and "-"terminals of a large current (low voltage) power supply, compass, iron filings (with platform on which to sprinkle them).
- Part II: Two bar magnets, iron filings (with wood platforms and cardboard), compass, coil, and lab power supply (even numbered binding posts set at 2.5 V).
- Part III (1 station): Dip needle. (5 stations): Helmholtz coils tri-output power supply with a current-limiting (2.2 kΩ) resistor, digital ammeter, small wooden block, and compass.
- Part IV (1 and 2): Spare set of Helmholtz coils, solenoid, and ruler.

Procedure

Part I: Long Straight Wire

The direction of a **B**-field will be shown for that of a vertically oriented current-carrying wire in two ways:

1. **Compass** – This is the most direct way to determine the direction of **B**. One end of the compass needle points in the same direction as **B**. Note that your compass polarity should be rechecked frequently, because the needle can become remagnetized when exposed to a strong magnetic field. The main disadvantage of a compass for mapping out **B**-field lines is that it only shows the direction of **B** at a single location at a time.

2. **Iron filings** – Magnetic fields induce magnetism in soft iron. Hence, the individual iron splinters line up like little compasses enabling us to visualize the **B**-field lines directly. The main disadvantage of this method is that one cannot discern which direction the field lines are pointing.

<u>**Task**</u>: Sketch the **B**-field lines for a wire carrying electric current. Have the wire (and, thus, the current) pointing out of the paper:

Part II: Mapping B-Field Lines

You will sketch a representation of the magnetic field lines for a few configurations of bar magnets and for a coil with current running through it. You will identify north poles and south poles: the arrows you draw on field lines should point in the same direction that the north end of a compass needle would point.

1. **Bar Magnet**
   (a) **Sketch the magnetic fields lines around a bar magnet**. Use the compass to determine the directions of the magnetic field and the polarity of the magnet. Use iron filings to show the overall shape of the field lines. To do this most effectively, rest the magnet (flat) on top of the wooden frame and place the cardboard on top of the magnet. Sprinkle a *very small amount* of iron filings on top and tap the cardboard gently with your fingers to align the filings.

   (b) Sketch the field lines for two bar magnets arranged in a line with two S-poles close to each other (not touching).

   (c) Repeat the previous step for a N- and S-pole close to each other.

2. **Coil of Wire**

You may use the iron filings for any of the following investigations. Be sure to cover the coil of wire with the wooden frame and the slotted piece of cardboard.

(a) Connect the coil to the "A" terminals of the lab-power supply. **Determine the magnetic field lines around the coil and sketch these lines.** Be sure to indicate the direction of the magnetic field and the polarity of the magnetic dipole which is induced by the electric current.

(b) What happens to the field lines around the coil when the current is turned off?

(c) What happens to the magnetic field of the coil if the current's polarity is reversed?

Put the filings back in the container when you're done.

Get your instructor's initials before proceeding.

Part III: Geomagnetic Field

1. Dip Needle

In this part, you will measure the geomagnetic "inclination" or the magnetic "dip", which is the angle θ between $\mathbf{B}_{\mathbf{geo}}$ and the horizon. You will use a "dip needle", which you must first attach to its stand using the banana-plug connection. Each lab partner must perform the following three steps on his/her own:

(a) Rotate the needle (at its banana-plug connection to the stand) so that the plastic angular scale is in the horizontal plane. (Note that this now looks and acts like a regular compass needle).

(b) After it has equilibrated (so that the needle points towards Northward), rotate the needle's stand so that the needle is aligned with the banana-plug support. Rotate the dip needle at its banana-plug connection until the plastic scale is in the vertical plane (at which time the needle's rotation-axis points east-west).

(c) After it has equilibrated (so that the needle is pointing steadily in the direction of **B**), measure the angle θ that **B** points below the horizon.

(d) Before you leave, randomize the orientation of the stand so that subsequent student groups must redo this measurement.

(e) Take θ to be the mean of your group's measurements. Record your value for θ:

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2. Helmholtz Coils

In order to measure the horizontal component of the geomagnetic field $\mathbf{B}_{\mathbf{geo}}$, you will use a pair of Helmholtz coils to generate a magnetic-field $\mathbf{B}_{\mathbf{helm}}$ perpendicular to the Earth's magnetic field. (Note that the total magnetic field $\mathbf{B}_{\mathbf{tot}}$ will simply be the vector sum of $\mathbf{B}_{\mathbf{geo}}$ and $\mathbf{B}_{\mathbf{helm}}$.)

Be sure that the coils are in series and that the current passes through each coil in such a way as to get the same direction of $\mathbf{B}_{\mathbf{helm}}$ from each coil. You can test this latter condition experimentally by slowly bringing a compass towards the center of each coil, thereby determining its particular **B**-field. Align the coils so that their axis points east-west and make sure that the compass is located precisely at the coils centers. Wooden blocks can be used for elevating the compass.

(a) Turn on the power supply and ensure that the "A-Volts" dial is fully counter-clockwise.

(b) Switch the DMM to the "40 mA" setting

(c) Take several measurements of the current required to deflect the compass needle so its N-pole points NE (or NW) (45° to the east/west). When this occurs, $\mathbf{B}_{\mathbf{helm}}$ is equal to the horizontal component of B_{geo}.

Record your value for I_1: ________________________

(d) Change the polarity of the current by reversing the leads coming from the power supply and connected to the Helmholz coils. Perform the measurement a second time, this time the compass needle will point in the other direction 45°.

Record your value for I_2: ________________________________

(e) The average (I_{avg}) of the absolute values of your measurements is your best estimate of the current that produces a magnetic-field magnitude $\mathbf{B}_{\mathbf{helm}}$ equal to the horizontal component of $\mathbf{B}_{\mathbf{geo}}$.
Compute I_{avg} . ________________________

3. Use the B-field generation constant γ=0.0042 T/A for the Helmholtz coils results from last week's lab (Magnetic Forces) and your I_{avg} to calculate the magnitude of the horizontal component of $\mathbf{B}_{\mathbf{geo}}$.

Get your instructor's initials before proceeding.

QUESTIONS (Part IV)

1. **Helmholtz coils** – Compare the value for γ with that which you would expect theoretically, based on the coils' geometry. Each coil has 320 turns. **Show your work**.

2. Solenoid – Use results from last week's activity (Lab 9) to determine γ for the center of the solenoid. Repeat the previous task, except that the solenoid has 540 turns. (Assume that the solenoid's length-to-width ratio is infinite.) **Show your work**.

3. The current that generates the magnetic field lines associated with the coil studied in Part II-2 is obvious. What do you suppose constitutes the constant current that generates the lines associated with the bar magnet studied in Part II-1?

4. Determine the generally accepted (**vector**) value of B_{geo} (sometimes referred to as the geomagnetic "intensity") at our location here in Newport News. You may use the internet for this value. Be sure to report the source of your information.