Experiment 18: Earth's Magnetic Field

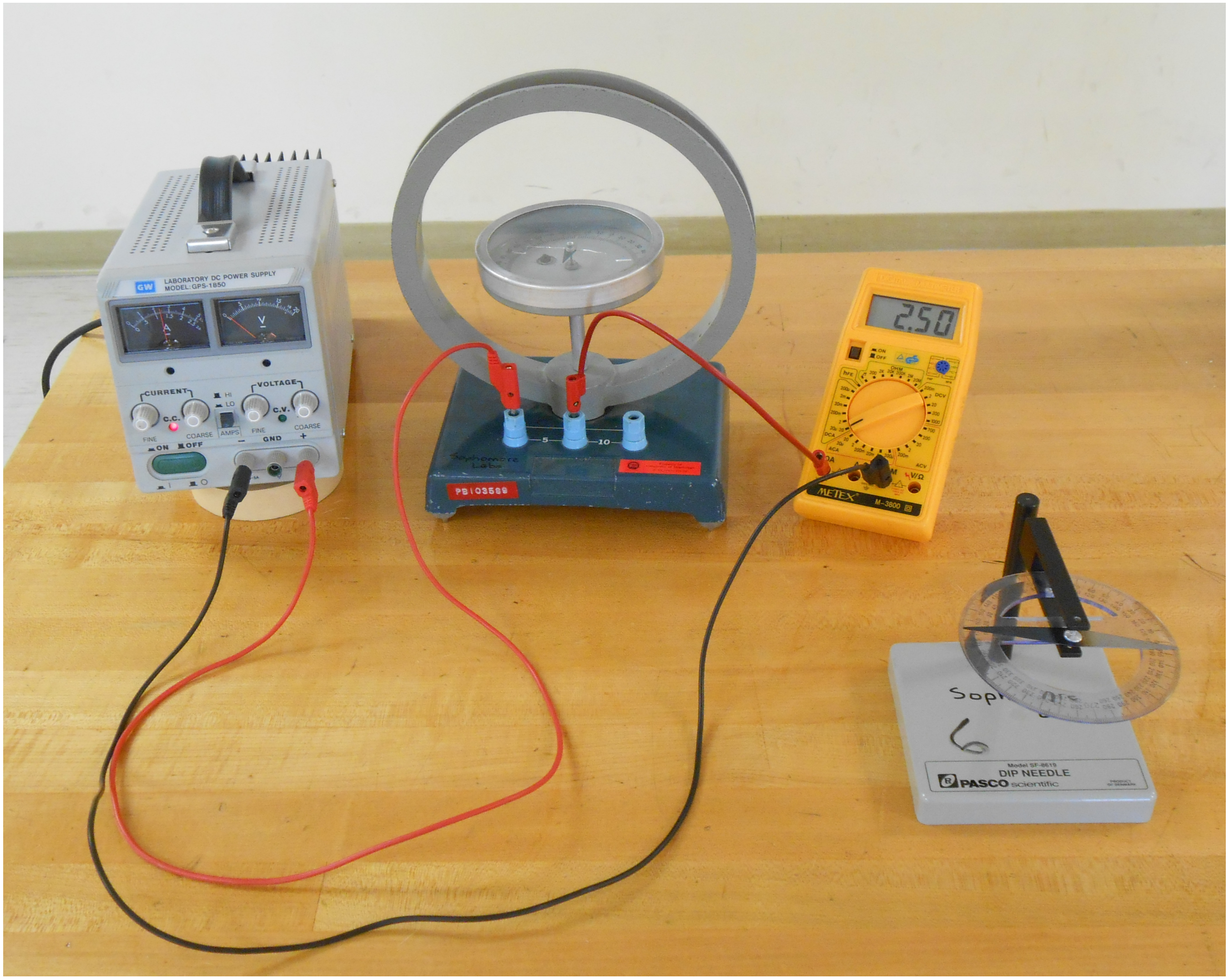

Figure 18.1: Earth's Magnetic Field - Note that each of the 3 elements of the circuit are connected in series. Note the large power supply: large power supply → large current. Use the 20A jack and scale of the ammeter.

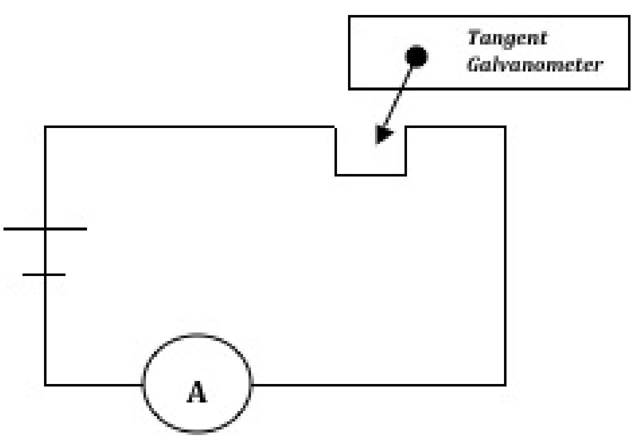

Figure 18.2: Earth's B-Field Schematic

EQUIPMENT
Tangent Galvanometer
Ammeter (20A jack, 20A DCA)
Dip Needle
Large Power Supply
(2) 12" Wire Leads
(2) 36" Wire Leads

Advance Reading

Text: Magnetic field, vectors, right-hand rule for a wire loop, resistivity.

Objective

The objective of this lab is to measure the magnitude of Earth's magnetic field in the lab.

Theory

The magnetic field of Earth resembles the field of a bar magnet. All magnetic field lines form a closed loop: a field line originates at the north pole of a magnet, enters the south pole, then moves through the magnet itself back to the north pole. Although we usually think of this field as two-dimensional (north, south, east, west), remember that it is, in fact, a three-dimensional vector field.

The horizontal component of the magnetic field of Earth is typically measured using a compass. The needle of a compass is a small magnet, which aligns with an external magnetic field. Recall that opposite poles attract, and like poles repel. Thus, the north pole of the compass needle points to the south magnetic pole of Earth, which is sometimes close to the geographic north pole.

We will measure the horizontal component of Earth's magnetic field, $\vec{\mathbf{B}}_{\mathbf{e}}$, then use this information to determine the magnitude of the total magnetic field of Earth, $\vec{\mathbf{B}}_{\mathbf{t}}$.

Determining the magnitude of an unknown magnetic field can be accomplished by creating an additional, known magnetic field, then analyzing the net field. The magnetic fields will add (vector math) to a net magnetic field (resultant vector).

$$\vec{\mathbf{B}}_{\mathbf{net}} = \vec{\mathbf{B}}_{\mathbf{known}} + \vec{\mathbf{B}}_{\mathbf{unknown}} \tag{18.1}$$

The known magnetic field, $\vec{\mathbf{B}}_{\mathbf{galv}}$, will be produced by use of a *tangent galvanometer*. A tangent galvanometer is constructed of wire loops with current flowing through the loops. The current produces a magnetic field. The magnitude of this magnetic field depends on the current, the number of loops, and the radius of each loop:

$$B_{galv} = \frac{\mu_0 I N}{2r} \tag{18.2}$$

where $\mu_0 = 4\pi \times 10^-7$ Tm/A is the permeability constant, I is the current, N is the number of loops, and r is the radius of the loop.

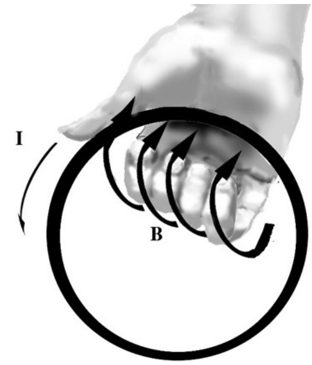

Figure 18.3

The direction of the magnetic field of a current carrying wire is given by the right-hand rule. When the thumb of the right hand points in the direction of the current (positive current; conventional current), the fingers will curl around the wire in the direction of the magnetic field. Refer to Fig. 18.3.

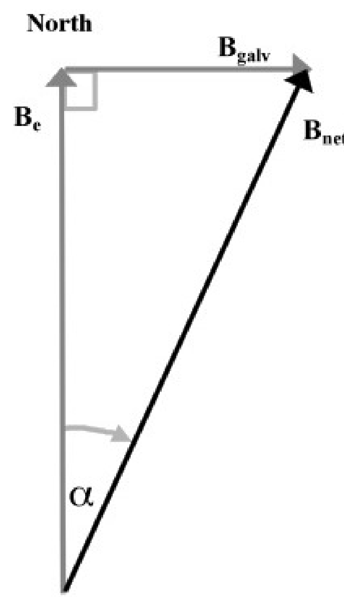

Figure 18.4

The coil of the tangent galvanometer is first aligned with the direction of an unknown field, B_e, or north. The compass inside the tangent galvanometer allows accurate alignment. Once current begins flowing, the two magnetic fields will add (vector addition) to yield a resultant magnetic field. The compass needle then rotates to align with the net field. The deflection angle α is the number of degrees the compass needle moves. α is measured, and B_e is calculated from:

$$\frac{B_{galv}}{B_e} = \tan\alpha \tag{18.3}$$

A typical compass is constrained to 2 dimensions and rotates to point to Earth's magnetic south pole, which is (approximately) geographic north. Earth's magnetic field, however, is a 3 dimensional phenomenon. It has components that point into and out of the earth, not just along the surface. We need to measure at our location the direction of the total magnetic field of Earth (the angle θ).

To determine field declination, θ, we will use a *dip needle*. A dip needle (Fig. 18.5 and Fig. 18.6) is a compass that rotates. It measures both horizontal and vertical angles.

First, arrange the dip needle in a horizontal position, compass needle and bracket aligned, pointing north (normal compass). Refer to Fig. 18.5, below, for clarification. The needle should align with 270°.

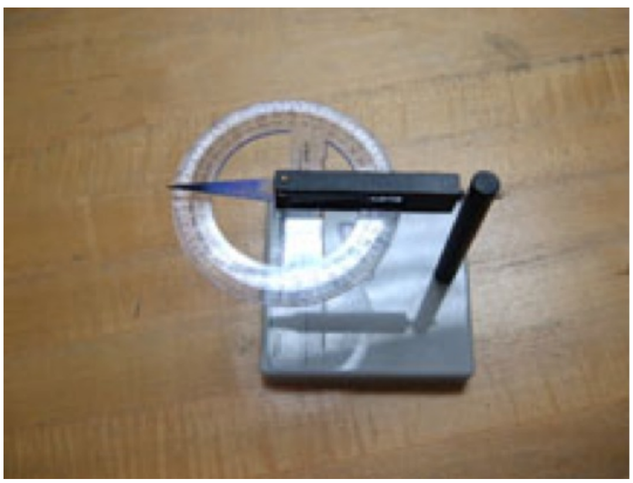

Figure 18.5: Dip Needle: Horizontal Orientation

Now rotate the compass 90° (Fig. 18.6) to a vertical position. The needle rotates to a new angle; the difference between the initial angle and the final angle is the angle θ.

From Fig. 18.6, we see that the dip needle points in the direction of Earth's total magnetic field at our location.

Figure 18.6: Dip Needle: Vertical Orientation

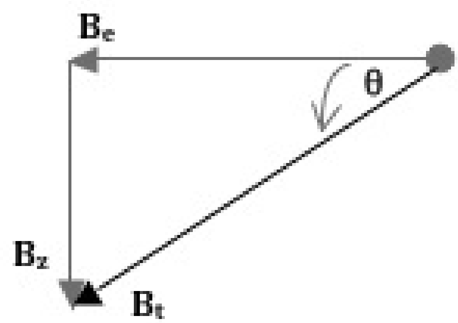

Figure 18.7

By determining the magnitude of the horizontal component of Earth's magnetic field, B_e, using α, and measuring the direction of Earth's total magnetic field, B_t, using θ, the magnitude of B_t can be determined. (Refer to Fig. 18.7.)

Name: ____

1. What physical phenomenon does the relationship $B_{galv} = \frac{\mu_0 i N}{2r}$ describe? (10 pts)

2. Explain the right-hand rule for current. (10 pts)

3. Consider Fig. 18.4. Determine the following in terms of B's (B_e, B_{galv}, and B_{net}). (10 pts)

   $\sin\theta =$

   $\cos\theta =$

   $\tan\theta =$

4. Consider Fig. 18.7. Determine the following in terms of B's (B_e, B_z, and B_t). (10 pts)

   $\sin\alpha =$

   $\cos\alpha =$

   $\tan\alpha =$

5. Given B_e of 45×10^{-6} T and a dip angle of $55°$, calculate B_z. See Fig. 18.7. (30 pts)

6. Consider the top-view diagram of the tangent galvanometer, Fig. 18.11. Given the galvanometer's alignment with North, as shown, indicate the direction that current flows through the top of the wire loops. (30 pts)

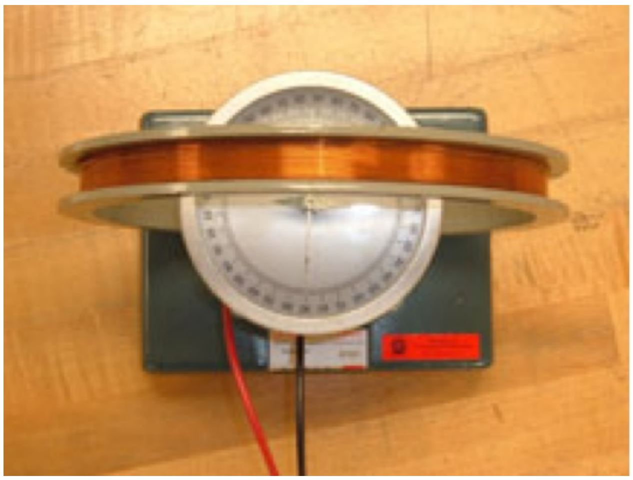

Figure 18.8: Top View - Wire loops encircle compass.

Figure 18.9: Side View - Compass located inside wire loops.

Figure 18.10: Tangent Galvanometer

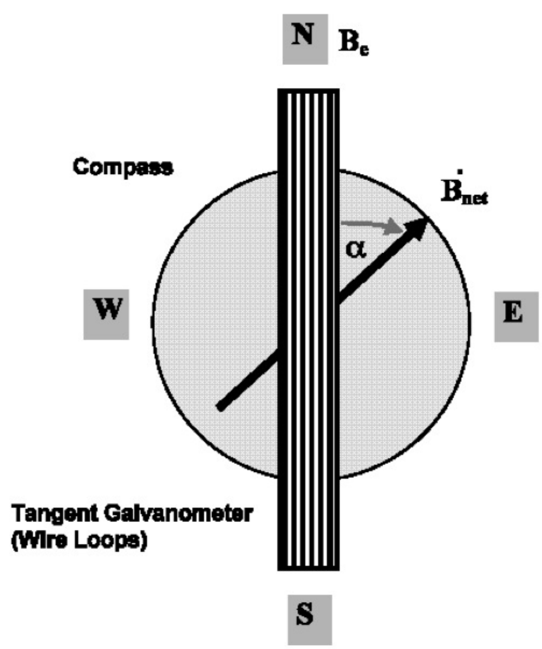

Figure 18.11: Compass Needle

PROCEDURE

PART 1: Horizontal Component

1. Connect the galvanometer ($N = 5$), ammeter (20A DCA), and power supply in series.
2. Align the galvanometer such that it creates a magnetic field perpendicular to that of Earth's field (the compass needle should be parallel to the wire loop). Do not move the galvanometer while taking data.
3. Turn on the power supply to flow current through the galvanometer. Adjust the current until the compass needle on the galvanometer reaches 30°, 40°, and 50°, recording the current required for each position in the data table provided.
4. Repeat this process for $N = 10$ and $N = 15$ (a total of nine trials).
5. Calculate the average horizontal field, B_e, for each of the nine trials using Eq. 18.2 and Eq. 18.3. The diameter of the coils is approximately 20 cm. [$\mu_0 = 4\pi \times 10^{-7}$ Tm/A]
6. Find the average value of B_e from your nine trials.

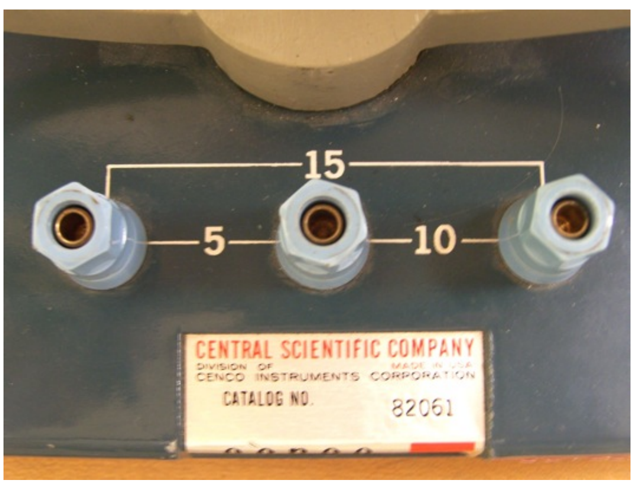

Figure 18.12: If leads are plugged into the left and middle jacks, $N = 5$, as indicated. If plugged into the right and middle jacks, $N = 10$. If plugged into the left and right jacks, $N = 15$.

PART 2: Field Declination

7. Use the dip needle to determine the direction of magnetic north. Align the dip needle's supporting arm with its compass needle (pointing north).
8. Roll the compass arm 90° until the bracket is vertical (and still pointing north/south).
9. Record the declination of Earth's magnetic field, the angle θ from the horizontal.
10. Use this declination to calculate the magnitude of the total magnetic field of the Earth, B_t, in the lab. Refer to Fig. 18.7.

QUESTIONS

1. Calculate the total resistance of 10 loops of copper wire of the galvanometer if the wire is 1 mm in diameter and the loops are 20 cm in diameter: $R = \rho L/A$. L is the length of the wire, A is the cross-sectional area of the wire, ρ is the resistivity of copper; look it up in your text, a CRC text, or online.
2. Compare your measured B_t from this experiment to a sample value of 43 μT. This is the magnitude of the magnetic field in Tucson, Arizona.