Experiment 17: Earth's Magnetic Field

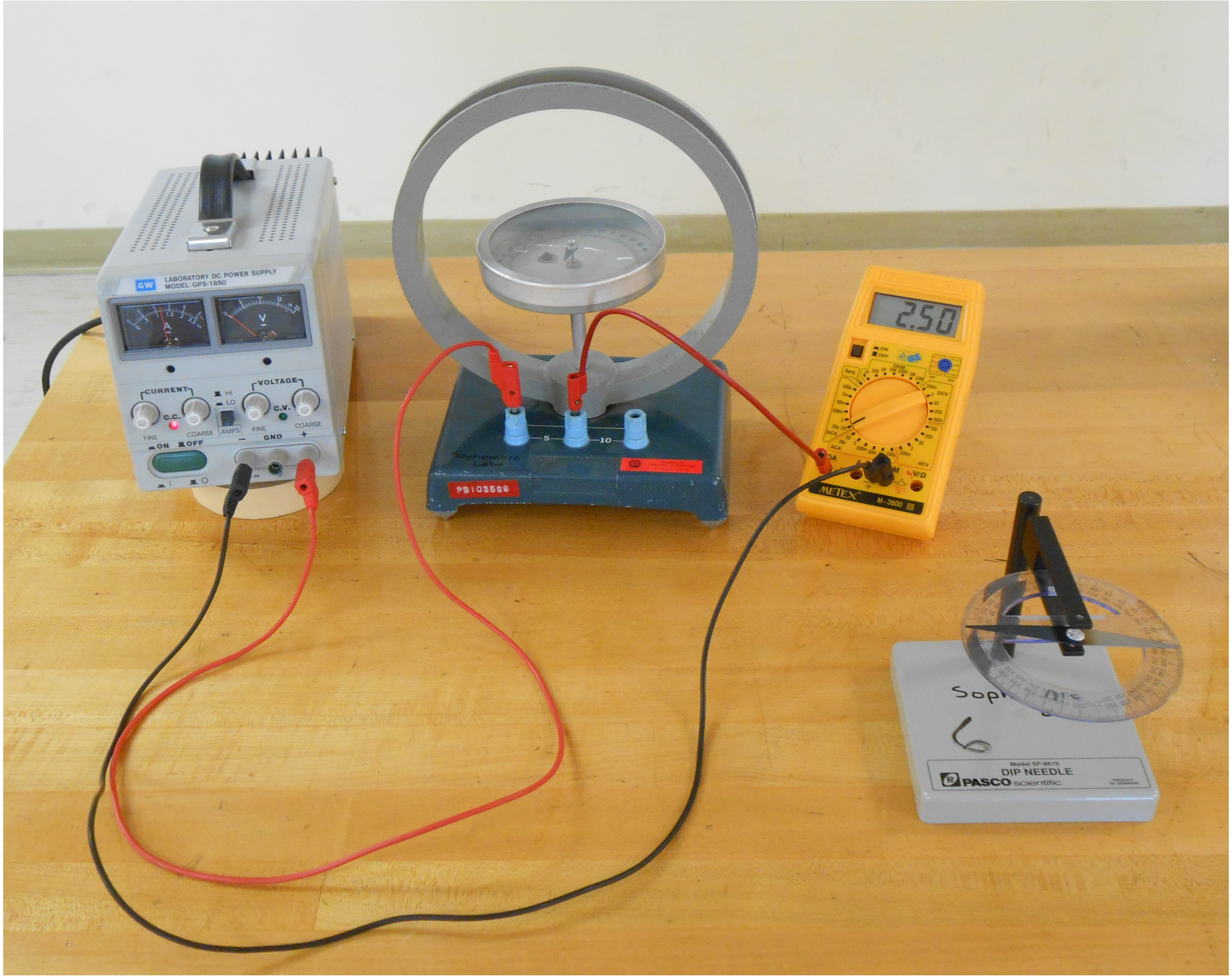

Figure 17.1: Earth's Magnetic Field - Note that each of the 3 elements of the circuit are connected in series. Note the large power supply: large power supply → large current. Use the 20A jack and scale of the ammeter.

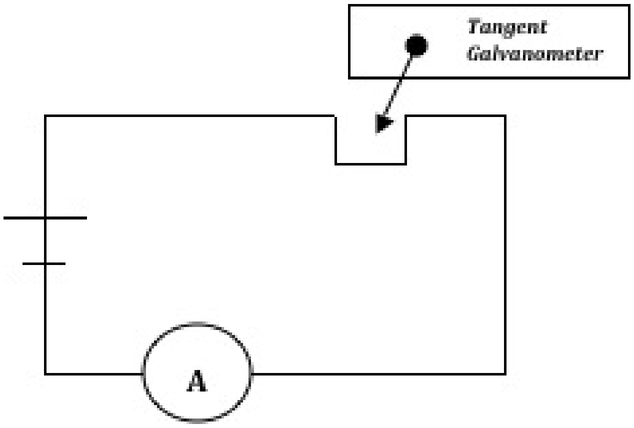

Figure 17.2: Earth's B-Field Schematic

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).

$$\vec{\mathbf{B}}_{\mathbf{net}} = \vec{\mathbf{B}}_{\mathbf{known}} + \vec{\mathbf{B}}_{\mathbf{unknown}} \tag{17.1}$$

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:

$$B_{galv} = \frac{\mu_0 I N}{2r} \tag{17.2}$$

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.

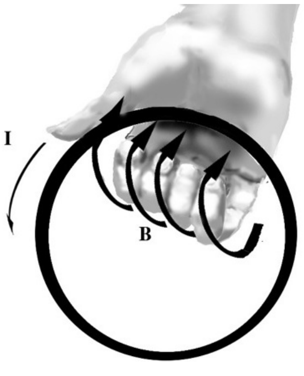

Figure 17.3

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. 17.3.

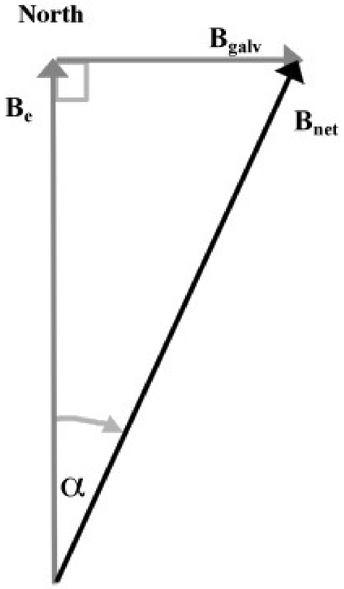

Figure 17.4

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:

$$\frac{B_{galv}}{B_e} = \tan\alpha \tag{17.3}$$

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. 17.5 and Fig. 17.6) 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. 17.5, below, for clarification. The needle should align with 270°.

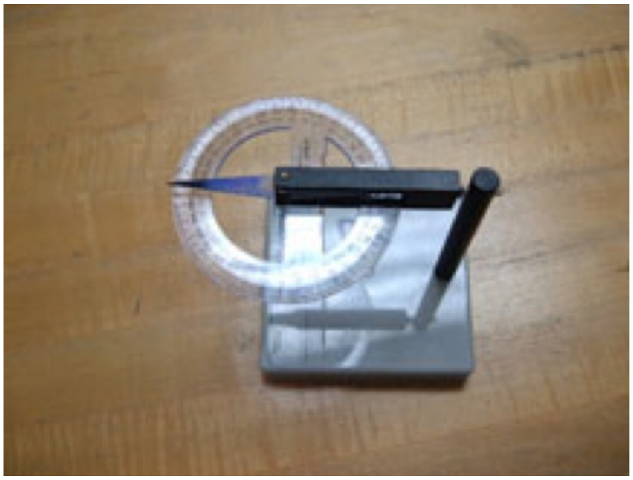

Figure 17.5: Dip Needle: Horizontal Orientation

Now rotate the compass 90° (Fig. 17.6) 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. 17.6, we see that the dip needle points in the direction of Earth's total magnetic field at our location.

Figure 17.6: Dip Needle: Vertical Orientation

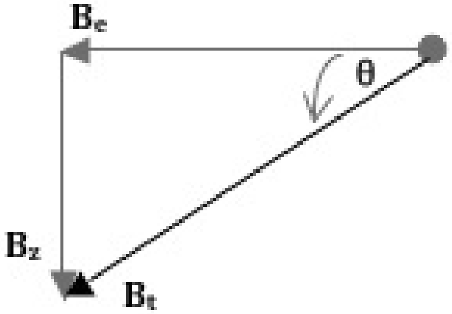

Figure 17.7

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. 17.7.)