Physics 102 Lab 6: Measuring the Earth's magnetic field

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Theoretical Discussion

It was once thought (not so long ago) that the earth's magnetic field was permanently aligned along the earth's rotation axis. It was believed that this field was essentially the same as that of a bar magnet aligned along this axis and that it was due to a charged metallic core in the center of the earth that rotated along with it.

It is now believed that the earth's magnetic field in fact derives from the existance of geologically large convection patterns of molten core material which arrange themselves in vast current loops. (See Figure 1). The magnetic field thus generated is neither aligned along the Earth's axis of rotation, nor is it temporally stable. The south magnetic pole is presently near Hudson's Bay, Canada, about 20° south of the North Geographic pole. The North Magnetic pole is near Australia. As the convection currents that create the field shift in time, the fields shift with them. The North and South poles interchange every few hundred thousand years. It is not certain whether this pole flip is gradual or sudden (on a geological time scale).[1]

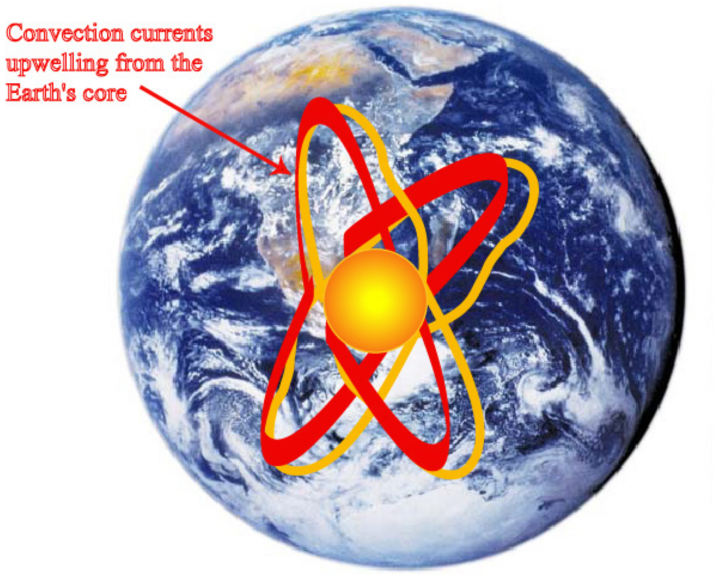

FIG. 1: Geologic origin of the Earth's magnetic field

The earth's magnetic field is close to being a *dipole field*, meaning that the magnetic field lines flow from one pole to the other, as shown in Figure 2. The arrangement of magnetic field lines is the same as the arrangement of electric field lines you observed in Lab 2, where you mapped an electric dipole field. Near the magnetic poles, the field lines are nearly perpendicular to the earth's surface. As you move away from the poles, they become increasingly parallel to the surface. The angle between the field direction and the earth's surface is called the *dip angle*. The dip angle in Wilmington, NC is about $\phi_{\text{dip}} = 58°$. If we call the component of the magnetic field parallel to the earth's surface B_H (for B-horizontal) and the component perpendicular to the earth's surface B_V (for B-vertical), then the trigonometric relationship between them is

$$B_V = B_H \tan\phi_{dip} = B_H \tan 58°$$

The magnitude of the earth's magnetic field is given by

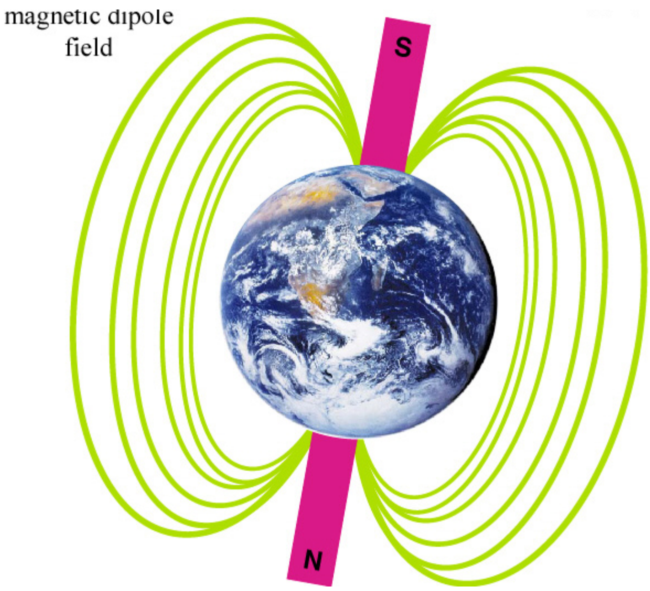

FIG. 2: The shape and orientation of the Earth's magnetic field

$$B_{Earth} = \frac{B_H}{\cos\phi_{dip}} = \frac{B_H}{\cos 58°}$$

A vector diagram of the earth's magnetic field is shown in figure 3A.

Experimental Procedure

Overview: The tangent galvanometer consists of a current coil with a compass mounted in its center. The magnetic field generated by the coil is given by the equation

$$B_{coil} = \frac{\mu_0 N I}{2R}$$

where I is the current in the coil, N is the number of turns in the current coil, R is the radius of the coil, and μ_0 is the magnetic permeability constant; Its value is

$$\mu_0 = 4\pi \times 10^{-7} \mathrm{T} \cdot \mathrm{m/A}$$

Figure 3B depicts the tangent galvanometer. The direction of the magnetic field generated by the current coil is given by the right-hand rule: Point the thumb of your right hand in the direction of the current. The fingers of your right hand will curl in the direction of the field. Looking at the coil from the side, if the current is clockwise, the field points into the plane of the coil. If it's counterclockwise, the field points out of the plane. In either case, the direction of the field is *perpendicular* to the plane of the coil. Figure 3C shows the geometry of the coil current and the field it produces.

The compass needle will always align itself along the direction of the horizontal components of the local magnetic field.[2] If no external local fields are present, the needle will align itself along the direction of the horizontal component of the Earth's magnetic field. If an external (horizontal) field is added, the needle will align itself along the direction of the combined field, which is the vector sum of the external field and the horizontal component of the Earth's magnetic field. Such an external field can be produced by the coil, so that

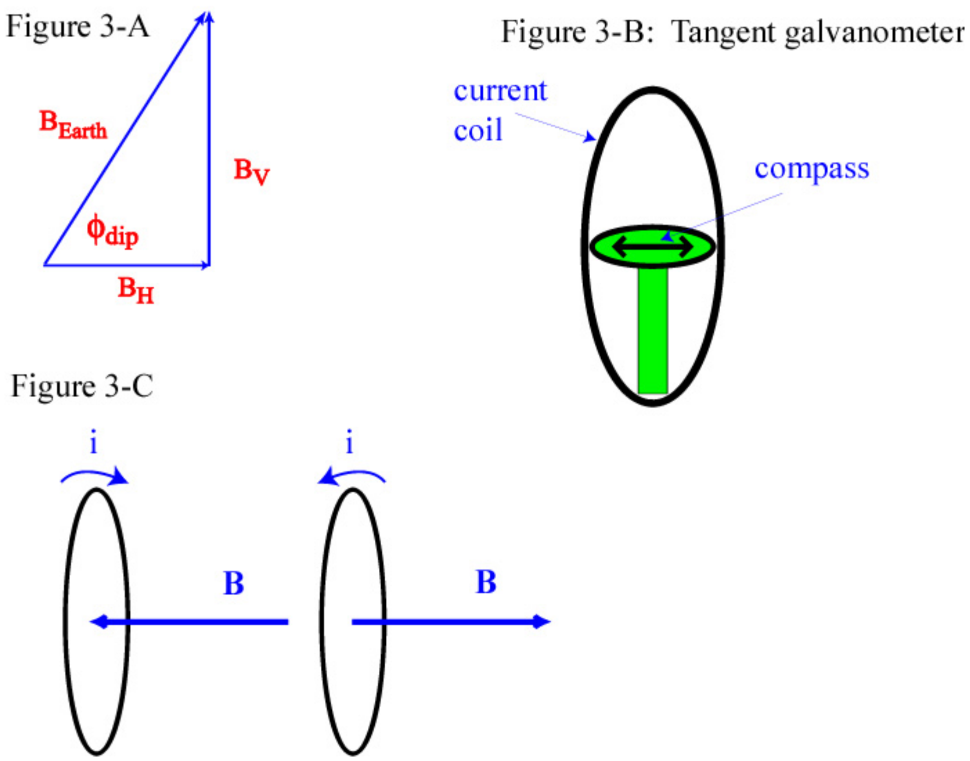

FIG. 3: Geometric and trigonometric relations involved in measuring the Earth's magnetic field

$$\vec{B_{tot}} = \vec{B_{coil}} + \vec{B_H}$$

Suppose that we align the coil along $\vec{B_H}$ by lining it up with the direction of the compass needle. If we then increase the current through the coil, we will create a field $\vec{B_{coil}}$ which is perpendicular to $\vec{B_H}$. The compass needle will deflect through an angle θ. The relationship between the magnitudes B_{coil} and B_H is then

$$B_{coil} = B_H \tan\theta$$

Figure 4 depicts the trigonometric relationships between B_{coil}, B_H, and B_{tot}.
Detailed Procedure:

1. Measure the inner and outer radii of the current coil. Take the average. This is R.
2. Orient the coil so that the coil's plane points along the N-S line, as indicated by the compass direction. The wire indicators should be aligned along the magnetic E-W line.
3. With the power supply off, connect the tangent galvanometer to the power supply in series with an ammeter. Use the 10-turn connection on the galvanometer. This means that $N = 10$.
4. For deflection angles near $\theta = 15°$, $30°$, $45°$, and $60°$, do the following:
   (a) Increase the current to produce a deflection of approximately θ with respect to the East indicator. Record the current i and the angle θ_1. Then record the angle with respect to the West indicator θ_2.

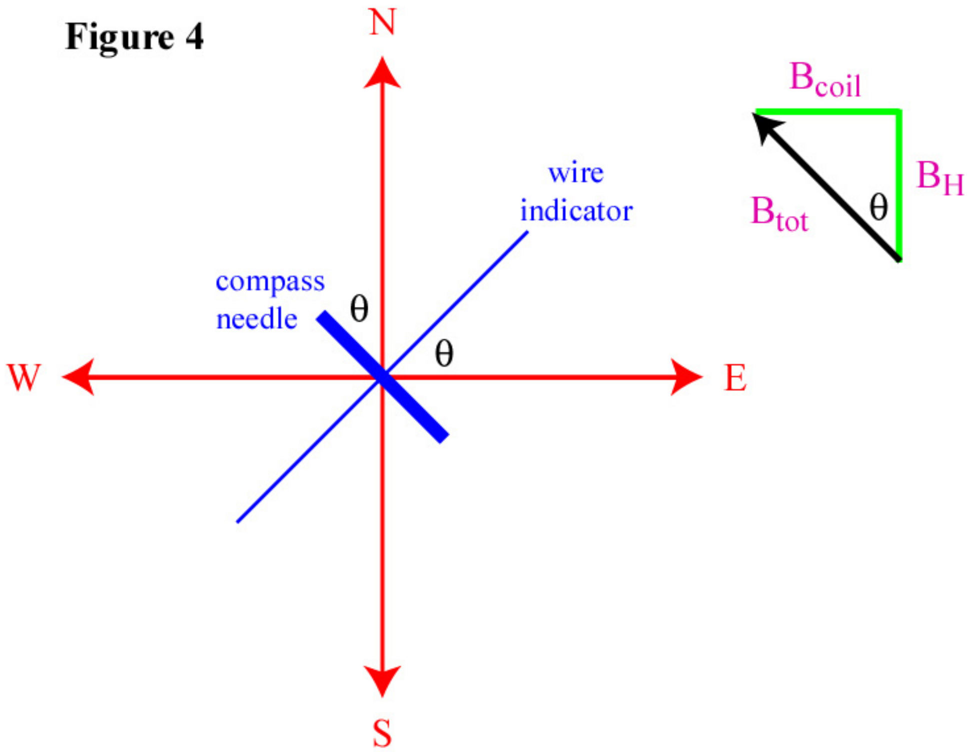

FIG. 4: Trigonometric relations between B_{coil}, B_H, and B_{tot}

(b) Without changing the current, reverse the direction of the current by reversing the leads into the coil. Record the angles θ_3 and θ_4 with respect to the East and West indicators respectively.

(c) θ_1, θ_2, θ_3, and θ_4 should be roughly equal. Take their average. Record the average value $\theta_{\rm avg}$

5. For each value of $\theta_{\rm avg}$, calculate B_{coil} and $\tan\theta_{\rm avg}$. Plot B_{coil} vs. $\tan\theta$ and determine B_H from a calculation of the slope of this line.

6. Determine B_{Earth} from your derived value of B_H.

7. Assuming that $B_{Earth}^{(nom)} = 5.0 \times 10^{-5}$ T, numerically compare this nominal value to your measured value by calculating a fractional discrepancy.

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[1] Note that while the Earth's magnetic field plays an important role in deflecting high-energy subatomic particles streaming from the sun, contrary to the ignorant assumptions of certain Hollywood movies, a sudden reversal or diminution of the field would not result in widespread and immediate death and destruction on Earth.

[2] It will not align itself along the vertical component because it is only free to rotate in the horizontal plane.