Physics 202 Lab 6: Measuring The Earth's Magnetic Field
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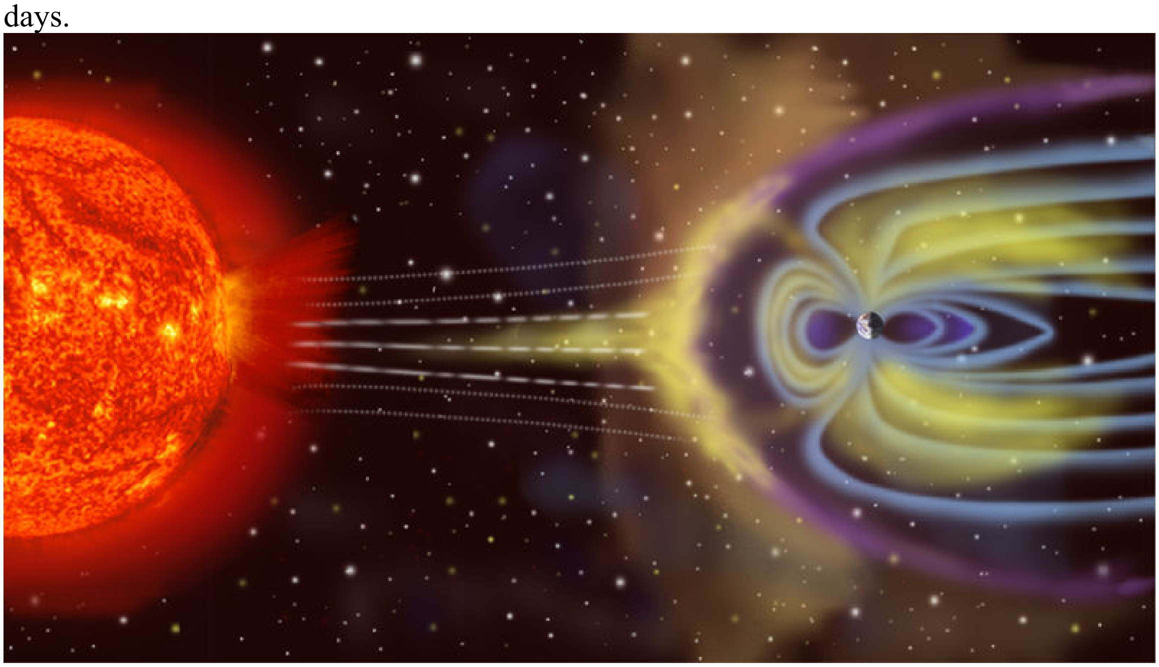
Theoretical Discussion

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 existence of geologically large convection patterns of molten core material which arrange themselves in vast current loops. 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). Contrary to popular belief, a sudden reversal or diminution of the field would not result in widespread and immediate death and destruction on Earth. A sudden reversal of the field might cause possibly fatal confusion to certain migratory animals whose “sense” of north and south depends upon the absolute orientation of the field. A sudden diminution of the field would have more serious consequences for humans, although the effects would likely be felt over a time scale of months and years rather than hours and days.



The Earth’s magnetosphere deflecting high-energy charged particles from the sun

The Earth’s magnetic field in fact plays an important role in deflecting high-energy charged particles streaming outward from the sun. Depending on the extent to which the field strength was reduced, this could result in the Earth’s surface being bathed in high-energy radiation, which would certainly not be good for most forms of advanced life.

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 1. 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 local angle between the field direction and the earth's surface is called the *dip angle*. The dip angle in Wilmington, NC is about $\phi_{dip} = 58^\circ$. If we call the component of the magnetic field parallel to the earth's surface B_H (H is for horizontal) and the component perpendicular to the earth's surface B_V (V is for vertical), then the trigonometric relationship between them is

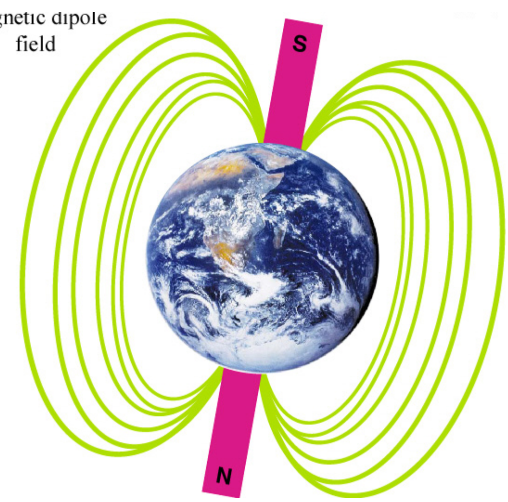
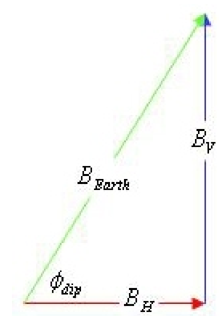


Fig. 1: Shape and orientation of Earth's magnetic field

$$B_V = B_H \tan\phi_{dip} = B_H \tan 58^\circ$$

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

$$B_{Earth} = \frac{B_H}{\cos\phi_{dip}} = \frac{B_H}{\cos 58^\circ} \qquad \textbf{Eqn. 1}$$



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

$$B_{coil} = \frac{\mu_0 NI}{2R} \qquad \textbf{Eqn. 2}$$

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

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

Figure 2 shows a schematic diagram of the tangent galvanometer. The current through the coil generates a magnetic field oriented perpendicularly to the plane of the coil. 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 then curl in the direction of the field.

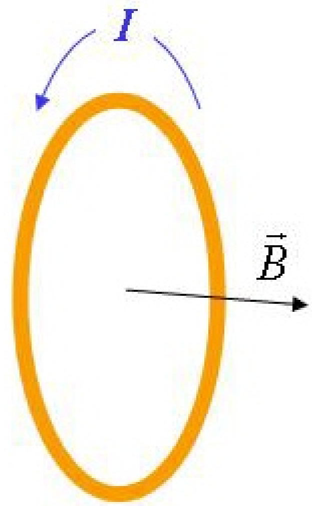


Fig. 2: Magnetic field of a tangent galvanometer

The compass needle will always align itself along the direction of the horizontal components of the local magnetic field[1]. 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 by the tangent galvanometer, 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. The total field is then the vector sum of the horizontal component of Earth's magnetic field, B_H, and the field due to the coil.

$$\vec{B}_{tot} = \vec{B}_H + \vec{B}_{coil}$$

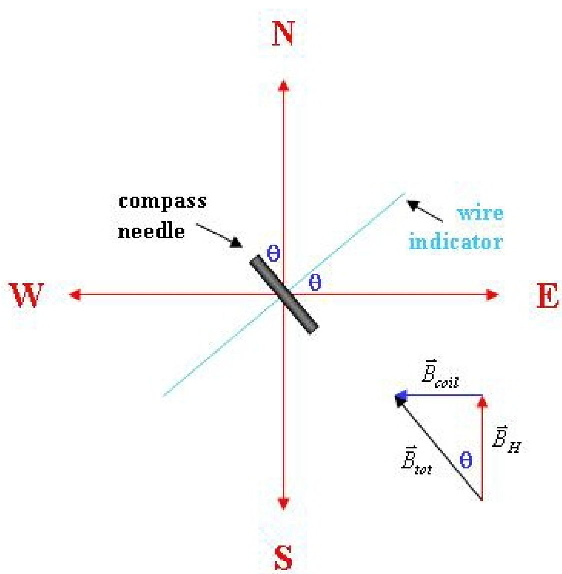


Fig. 3: Trigonometric relations between B_{coil} and B_H

Suppose that we align the coil along the direction of $\vec{B}_H$. We can do this by aligning the plane of the coil with the direction that the compass needle points when the coil current is turned off. Any field generated by the coil will then be perpendicular to $\vec{B}_H$.

If we now turn up the current through the coil, the compass needle will deflect through an angle θ. The relationship between the magnitudes of B_{coil} and B_H, as shown in Figure 3, is

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

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

DETAILED PROCEDURE

1. Measure the inner and outer radii of the current coil. Take the average of the two measurements. 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 $\theta_0 = 15°, 30°, 45°$, and $60°$, do the following:

    a. Adjust the current I to produce a deflection of approximately θ_0 with respect to the East wire indicator. Record the current I and the angle θ_E. Then record the angle with respect to the West wire indicator θ_W.

    b. θ_E and θ_W should be roughly equal. Take their average. Record the average value as θ_{avg}.

    c. For each value of θ_{avg}, calculate $\tan\theta_{avg}$ and use the current I in equation 2 to calculate B_{coil}.

5. Plot B_{coil} vs. $\tan\theta_{avg}$ and determine B_H from a calculation of the slope of the resulting line.

6. Use equation 1 and your derived value of B_H to calculate B_{Earth}.

7. Assuming that the nominal local value of Earth's magnetic field is $B_{Earth}^{(nom)} = 5.0 \times 10^{-5}$ T, numerically compare this nominal value to your measured value by calculating the fractional discrepancy between them.