EXPERIMENT 15
THE TANGENT GALVANOMETER

I. THEORY

The purpose of this experiment is to measure the horizontal and vertical components of the earth's magnetic field. We will accomplish this by using a tangent galvanometer, an instrument which preceded the modern ammeter. The tangent galvanometer was originally designed to measure an unknown current by comparing the magnetic field produced by that current with the earth's magnetic field. Using an ammeter together with a tangent galvanometer, we can compute the earth's magnetic field.

The magnetic field at the center of a coil of N circular turns, each of radius R and carrying a current I, has a magnitude

$$B_c = \frac{\mu_0 NI}{2R}$$

in which μ_o is the permeability of free space.

Let such a coil be oriented in the vertical plane, with its central axis normal to the horizontal component B_{Ex} of the earth's magnetic field B_E. Refer to the diagram in section IV. B_E must then lie in the plane of the coil. When a current exists in the coil, the resultant magnetic field at the center of the coil is the vector sum of B_c and B_E.

$$\vec{B} = \vec{B}_c + \vec{B}_E$$

Since $\vec{B}_c$ lies entirely in the horizontal plane, the horizontal component of B is the vector sum of $\vec{B}_c$ and the horizontal component of $\vec{B}_e$.

$$\vec{B}_x = \vec{B}_c + \vec{B}_{Ex}$$

Let θ be the angle between $\vec{B}_{Ex}$ and $\vec{B}_x$. From the diagram, we see that

$$B_c = B_{Ex} \tan \theta$$

We see from this equation that a graph of the magnetic field strength of the coils, B_c, versus $\tan \theta$ should yield a straight line with slope B_{Ex}. Also, the graph must go through the origin, since θ is zero when B_c is zero. Because the graph must go through the origin, the usual Least Squares equation for slope is not the most accurate one to use. We will instead use the Modified Least Squares formula which gives the slope of the best fit line constrained to pass through the origin.

In this experiment we will also measure the dip angle ϕ, defined as the angle between B_E and the horizontal plane. Then, having obtained the horizontal component of the earth's

field from the slope of the graph described above, and having measured the dip angle, we can find the vertical component of the earth's field, and the magnitude of the field itself, by simple trigonometry.

The tangent galvanometer consists of a horizontal test compass mounted at the center of a vertical coil. The compass, in turn, consists of a non-magnetic pointer attached to a small magnetized disk. With no current in the coil, the apparatus is oriented so that the compass reads zero. The North and South poles of the magnetized disk will then lie in the plane of the coil, with the North pole pointing toward B_{Ex}. After current is turned on, the North pole will rotate through an angle θ and point toward B_x. The pointer, which originally read zero, will now read θ.

II. LABORATORY PROCEDURE

CAUTION: Do not tilt the tangent galvanometer excessively, as the glass plate may fall out and break.

1. Place the tangent galvanometer on an inverted wooden box to raise it above the ferrous metal of the laboratory table. Remove all ferrous metal (such as certain mechanical pencils) from the immediate vicinity of the tangent galvanometer. Turn the thumbscrew to free the pointer, but do not raise the pointer so high that it pushes against the glass plate. Orient the instrument so that the pointer reads zero. If the pointer is bent, each end should be equally close to zero.

2. Place the circular level on top of the glass plate. Level the tangent galvanometer by rotating one or more feet. Remove the level some distance from the instrument. If necessary, rotate the box to re-zero the pointer.

3. Refer to the circuit diagram in section IV. Set the VOLTAGE and CURRENT control knobs on the triple-output power supply to zero (full counter-clockwise position). Use a banana plug lead to connect the positive terminal of the ammeter to the positive terminal of the power supply (red banana jack). Connect the negative terminal of the ammeter (0.1-A range) to a clip on the wiring board. Connect the 50 turn binding post of the tangent galvanometer to the same wiring board clip. Connect the common binding post of the tangent galvanometer (the post with no number next to it) to another clip of the wiring board. Connect one fixed terminal of the 50 Ω resistor to the same clip. Use a banana plug lead to connect the other fixed terminal of the 50 Ω resistor to the negative terminal of the power supply (black banana jack). Set the ammeter (with its internal magnet) some distance from the tangent galvanometer.

4. Turn the power supply on and rotate the CURRENT control knob to its far counter-clockwise position. While observing the ammeter, adjust the VOLTAGE control knob until that the tangent galvanometer reads 20°. If the ammeter reading fluctuates noticeably, tighten all connections. Record the current. Repeat for angles of 30°, 40° and 50°. Change the ammeter range, if necessary, to keep it on scale.

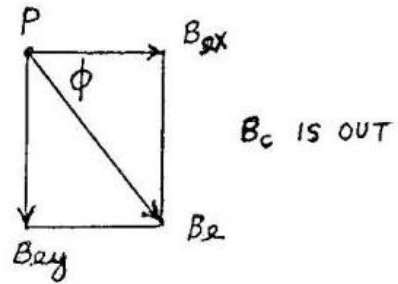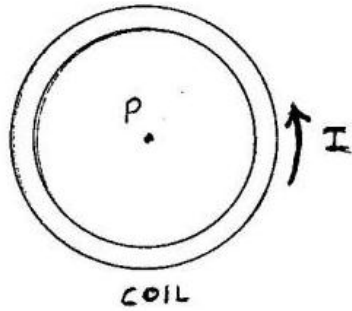5. Reverse the direction of the current through the coil (NOT THROUGH THE AMMETER) and repeat.

6. Change to the 5 turn binding post of the tangent galvanometer and the 1-A range of the ammeter. Replace the 50 Ω resistor by the 5 Ω resistor. Repeat steps 4 and 5.

7. Lock the pointer, but do not move the tangent galvanometer.

8. The dip compass reads correctly only if its (horizontal) axis of rotation is perpendicular to the horizontal component of the earth's magnetic field. To accomplish this, sight parallel to the coil of the tangent galvanometer at a fixed object on the other side of the room. Remove the tangent galvanometer from the box and replace it by the dip compass. Align the dip compass so that its protractor is parallel to the plane previously occupied by the coil, using your sighted reference point. Move the tangent galvanometer some distance away so that its magnetized disk does not affect the dip compass. Record the dip angle between the horizontal plane and the earth's magnetic field.

9. Use outside calipers and a meter stick to measure the outside diameter of the coil. Measure the actual windings, not the metal frame.

10. Measuring the inside diameter of the windings is a bit more difficult, because the compass is in the way. Also, we must compensate for the thickness of the metal frame. Measure and record the thickness of the metal which makes up the frame. Using the calipers as outside calipers, open them until they span the inside diameter of the metal frame. Place them on the meter stick; read and record the distance. Finally, add two metal thicknesses to the distance, to obtain the inside diameter of the windings.
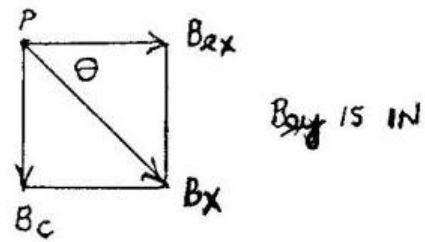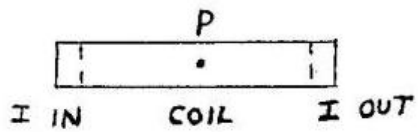

III. CALCULATIONS

1. Calculate the average coil radius.

2. Average each pair of currents, measured for the same number of turns and for the same angle of the pointer. Make a table containing the quantities: number of turns, angle, current, and magnetic field strength of the coils (in μT). Show the calculation of the magnetic field strength in one case.

3. Average the two values of the magnetic field strength of the coils for each angle. List the results in a table containing the quantities angle, tan θ, and magnetic field strength of the coils.

4. Plot a graph of magnetic field strength versus tan θ. Use a straightedge to draw the line that best-fits the data points and passes through the origin.

5. Use the Modified Least Squares formula to calculate the slope of your graph. The formula can be found in the Introduction of this Lab Manual.

6. What is the horizontal component, B_{Ex}, of the earth's magnetic field, in μT, at the location of the apparatus?

7. What is the vertical component of the earth's field at the same location?

8. What is the magnitude of the earth's resultant magnetic field at the same location?

IV. DIAGRAMS

Front View

P.

I

COIL

P

B_{2X}

ϕ

B_c IS OUT

B_{2y}

B_2

Top View

P

I IN   COIL   I OUT

P

B_{2X}

θ

B_{2y} IS IN

B_c

B_X

Circuit

AM

CLIP

CLIP

R

T.G.