INTERACTION OF A MAGNETIC MOMENT WITH A MAGNETIC FIELD

INTRODUCTION

A dipole magnetic moment $\vec{\mu}$, such as that of a permanent magnet, will experience a torque when placed in a magnetic field $\vec{\mathbf{B}}$. The torque $\vec{\tau}$ is given by

$$\vec{\tau} = \vec{\mu} \times \vec{\mathbf{B}} \qquad (1)$$

This torque tends to align the moment along the magnetic field, just as a compass needle tries to line up with the earth's field. If θ is the angle between $\vec{\mu}$ and $\vec{\mathbf{B}}$ the magnitude of the torque is

$$\tau = \mu B \sin\theta \approx \mu B \theta \qquad (2)$$

The latter equality holds for small values of θ (to within 1% for $\theta < 15^o$).

QUESTIONS

Here are some things to think about before you go on. This experiment involves some rather complicated mathematical expressions, and it is important to know ahead of time, in a simple way, what you are going to do.

1. What kind of motion do you expect will result if a dipole is placed in a magnetic field, pushed aside a little, and released? Consider, for example, what a compass needle will do if it is frictionless.

2. How will the motion change, qualitatively, if the magnetic field is increased in strength (i.e., will the motion be faster, slower, or unchanged)?

3. How would you expect this motion to depend on the moment of inertia I of this dipole?

INTRODUCTION, CONTINUED

Did you figure out that this dipole will oscillate, just like a pendulum or a mass on a spring? This is true because the restoring torque is proportional to the angular displacement. Therefore, a magnet suspended in a magnetic field and disturbed from equilibrium will undergo simple harmonic motion with period

$$T = 2\pi \sqrt{\frac{I}{\mu B}} \qquad (3)$$

Here *I* is the moment of inertia of the permanent magnet about its center of mass.

This experiment will explore the interaction of a small permanent magnet with a combination of the earth's field and the field produced by a coil of wire of radius R and with N turns of wire. The field of such a coil along its axis is given by

$$B_{COIL} = \frac{\mu_o Ni}{2}\frac{R\sin\phi}{r^2} = \frac{\mu_o Ni}{2}\frac{R^2}{\left(R^2 + x^2\right)^{\frac{3}{2}}} = [\text{for } x=0] = \mu_0 N i / 2R \qquad (4)$$

where x is the distance along the axis from the coil plane and r and ϕ are defined in Figure 1.

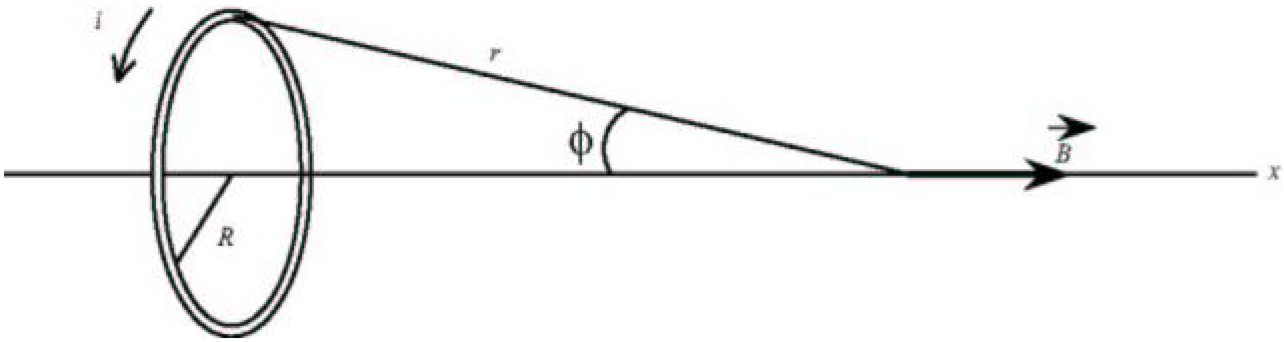

Figure 1

The apparatus to be used is drawn in Figure 2.

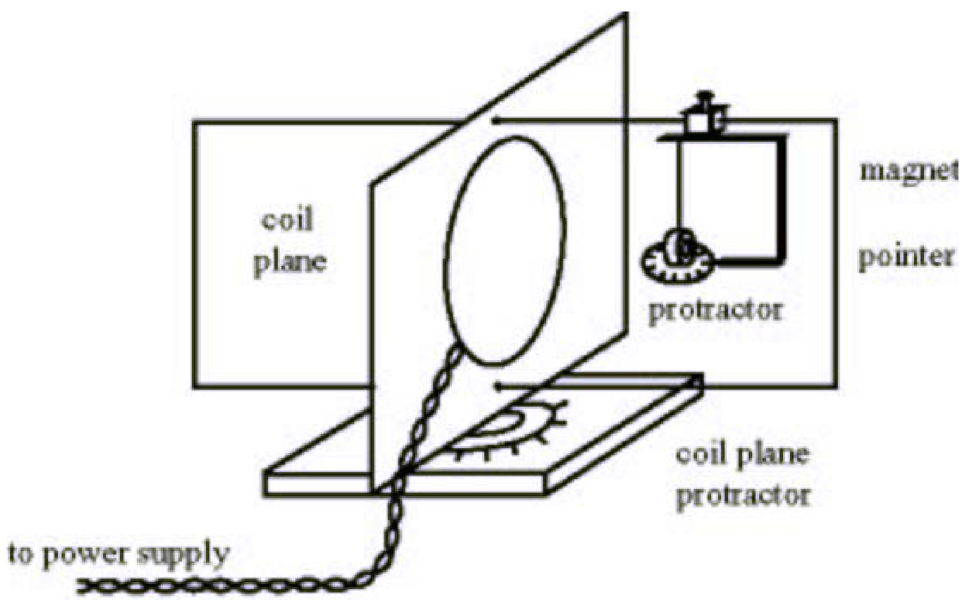

Figure 2

The position of the coil plane with respect to the earth's magnetic field is adjustable, and the angular position of the magnet can be determined by the protractor. The magnet position can also be adjusted along the coil axis (to vary x). Note that only the horizontal component of the earth's magnetic field, $B_{\mathbf{EARTH}}$, is effective in producing a torque on the magnet (why?). Hence, the total field to be used in Equations (1), (2), and (3) is

$$\mathbf{B} = \mathbf{B}_{\mathrm{COIL}} + \mathbf{B}_{\mathbf{EARTH}}. \qquad (5)$$

In this experiment, you will first of all align $\mathbf{B}_{\mathbf{COIL}}$ with $\mathbf{B}_{\mathbf{EARTH}}$ and measure the period of the magnet's oscillation as a function of i and x. This will allow determination of $B_{\mathbf{EARTH}}$ and verification of the functional form of Equation (4). You will next balance out the torque of the earth's field by means of the coil field to explore the vector properties of the field. Finally, you will determine the value of μ and I.

PROCEDURE

Part 1. First choose a spot in the room that is sufficiently isolated from magnetic materials. Do this by finding a location such that a compass points to the magnetic north.
Place the apparatus at this location and align the base and coil axis in a north-south direction.
Connect the coil to the power source. **Limit the current you send through the coil to about 1 ampere**.
Determine T as a function of current i between -1.0 and +1.0 amperes for about 10 values (negative current means B_{COIL} opposes B_{EARTH}).
Plot $1/T^2$ vs. current i.
You will want to use Excel for this and subsequent plots.
Your plot should look like Figure 3.

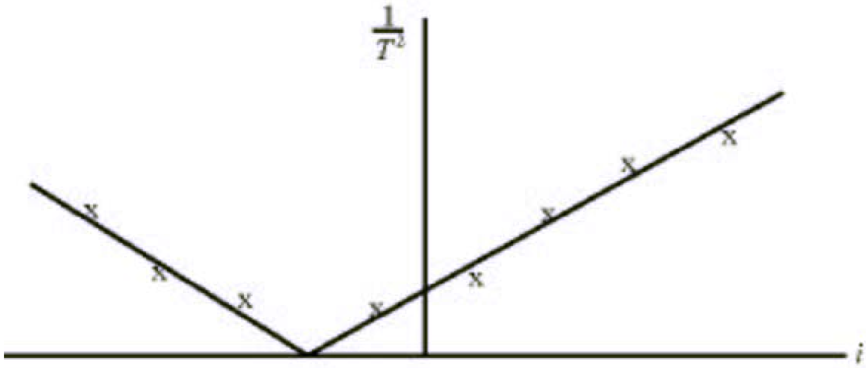

Figure 3

This plot should be described (according to Equations (3) and (4)) by

$$\frac{1}{T^2} = \frac{\mu}{4\pi^2 I} B = \frac{\mu\mu_o N}{8\pi^2 IR} \cdot i + \frac{\mu B_{\text{EARTH}}}{4\pi^2 I} \cdot$$

The current i_H, the intersection of the lines with the i axis, corresponds to infinite period, which means zero B field. Thus i_H can be interpreted as the current in the coil necessary to produce a coil field equal (and opposite) to B_{EARTH}, i.e.,

$$B_{EARTH} = B_{COIL} = \frac{N\mu_0 i_H}{2R} \qquad (6)$$

Determine B_{EARTH} from Equation (6) and determine the quantity μ /I from the slopes of your plot. You should determine uncertainties of B_{EARTH} from the uncertainties in the slopes of parts 1 and 2, and you should compare your value to the accepted value, namely 5×10^{-5}T.
Note -- In part 1, the two lines may not intersect the abscissa axis at the same point because of experimental error. You must then find some satisfactory procedure for assigning a value to i_H.

Part 2. We now wish to demonstrate the vector nature of **B**. Set the coil axis to some definite angle from the north – let us use 90°. Find a value of the coil current such that the magnet angle bisects the coil angle (in this example, the magnet would be made to point to 45°). The magnetic field of the coil will then equal B_{EARTH} (you should prove this to yourself). From the current in the coil, find B_{EARTH} from Equation (6).

Turn in:
Part1 - Excel graph + value of B_{EARTH}
Part2 - value of B_{EARTH}
Answers to questions on page 1.