Magnetic Torque

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This lab consisted of three separate experiments, each measuring magnetic moment using magnetic torque. All three were performed using the same prefabricated device on the same magnetic dipole. The first compared a known gravitational torque to an unknown magnetic torque in a stationary state to isolate the dipole moment. The second used only magnetic torque, but in a pendulous state to measure the dipole again. Finally, the dipole was measured after the addition of an angular spin momentum to the system. The three measurements were then compared and a close agreement was found rendering the experiments a success.

1. INTRODUCTION

This set of experiments is somewhat unique in that it presents a very macroscopic demonstration of primarily intangible phenomenon. The fundamental equation at work throughout is that of magnetic torque (τ)

$$\tau = \mu \times B, \tag{1}$$

which will be manipulated repeatedly to isolate μ (the magnetic dipole moment) from B (the external magnetic field) and other forces.

2. EXPERIMENTAL SETUP

FIG. 1: 'Magnetic Torque' by TEACHSPIN

The device used in this experiment was the 'TEACHSPIN *Magnetic Torque*' device (see Fig. 1). This device consists of an air-fed low-friction bearing situated within a Helmholtz coil.

In the bearing fits a modified cue ball with a magnetized disk at its center and a handle oriented along the disk's magnetic moment. When the Helmholtz coil is activated it produces a uniform magnetic field and the ball is allowed to rotate freely within the bearing.

A lightweight rod can also be placed into the handle of the ball and a small mass moved along the rod's length to produce a variable gravitational torque on the ball (see Fig. 2). Additionally, there is a small white dot painted onto the handle which (when used in tandem with a strobe light mounted to the device) can be used to measure the axial spin of the ball.

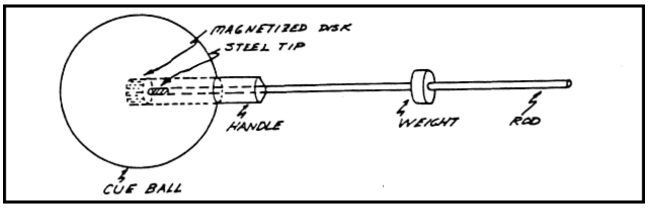

FIG. 2: Cue Ball with Handle and Rod

Power and air are supplied to the device via the control panel which regulates each system. Along with independent on/off switches for each component, the panel also allows for variation in the magnitude (current) and direction (up or down) of the magnetic field generated by the coils and the rate at which the strobe light flashes.

3. EXPERIMENT ONE

For the first experiment, the magnetic moment of the disk was measured using gravitational torque. By utilizing the mass and rod, a gravitational torque was applied to the ball given by

$$\tau_g = rmg\ sin(\theta), \tag{2}$$

where τ_g is the torque due to gravity, r is the distance along the rod that the mass is set, m is the mass of the mass, g is acceleration due to gravity, and θ is the angle of the rod off of the horizontal.

By turning on the coils, a magnetic torque was also applied to the ball apposing the torque due to gravity. The magnitude of the magnetic torque is given by

$$\tau_m = \mu B\ sin(\theta), \tag{3}$$

where τ_m is the magnetic torque, μ is the dipole moment of the ball's interior disk, B is the generated magnetic field and θ is again the angle of the rod off horizontal.

Once the mass and rod were measured and set, the field and bearing were turned on and the ball was loosely held with the rod horizontal to the ground. The current to the coils was then adjusted until the magnetic torque equaled the gravitational torque and the rod no longer fell or rose when released. Since the gravitational and magnetic torque were equal (as well as the angle of the rod) the magnetic moment could be represented as

$$rmg = \mu B. \tag{4}$$

By readjusting the mass's position and repeating the process, multiple data point points were taken. The points were then plotted and graphed to find the slope i.e. μ (see Fig. 3).

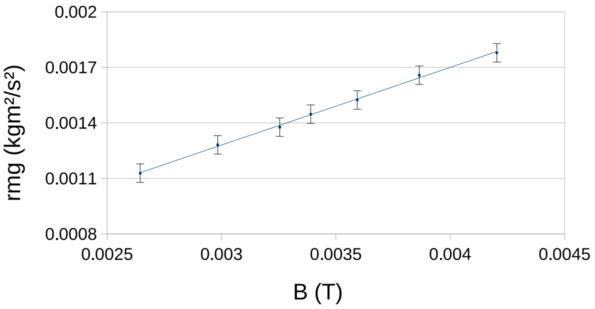

FIG. 3: $\mu = 0.42 \pm 0.01\ Am^2$

4. EXPERIMENT TWO

In the second experiment, harmonic motion caused by magnetic torque was used to again find the dipole of the magnetic disk. With the rod removed and the coils turned on, the ball was placed on the bearing with the handle pointed upward. It was then tilted slightly to the side and released which caused it to oscillate about the perpendicular. The period of oscillation was then timed and recorded along with the current for the magnetic field. To increase accuracy, the timer ran for 20 periods and the time was then was divided to find the average. The relation between the period and magnetic field is given by

$$T^2 = \frac{4\pi^2 I}{\mu B}, \tag{5}$$

where T is the period, μ is the magnetic dipole moment, B is the magnetic field and I is the inertia of the ball (calculated using the ball's mass and diameter).

After collecting several data sets (by changing the coil current), the period squared (T^2) was plotted against the inverse magnetic field ($1/B$) and the slope was found to be $3.8{\times}10^{-3}$ ($\pm\ 2{\times}10^{-4}$) (see Fig. 4).

Then, the relation

$$\frac{4\pi^2 I}{\mu} = 3.8 \times 10^{-3}, \tag{6}$$

was used to find μ.

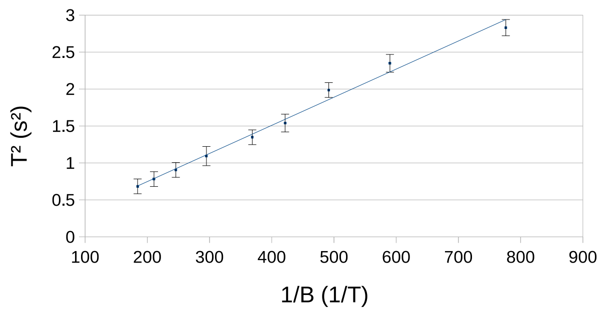

FIG. 4: Slope = $3.8{\times}10^{-3} \pm 2{\times}10^{-4}$

5. EXPERIMENT THREE

Lastly, for the third experiment the magnetic dipole moment of the disk was measured using processional motion and spin angular momentum. As in the previous experiment, the ball was oriented upward without the rod in place. With the magnetic field turned off and the strobe light turned on, the ball was tilted slightly and spun along its axis. As it spun, the small amount of friction present slowly reduced its angular velocity until its rotations per second matched the flashes per second of the strobe light. To the observer, this was signaled by the white dot on the handle of the ball transitioning from an apparent circle to a moving white dot to, finally, a stationary white dot.

At that moment, the Helmholtz coil was switched on and rapidly set to a predetermined current. This sent the ball rotating about the vertical axis and its procession was timed for the full circle. This process was repeated twice for every half amp increment between 1 amp and 4 amps, the times averaged and plotted according to

$$\Omega_P = \frac{\mu}{L} B, \tag{7}$$

where Ω_P is the processional angular velocity, μ is the dipole moment of the disk, B is the magnetic field and L is the spin angular momentum (see Fig. 4).

6. RESULTS AND DISCUSSION

After collecting and analyzing data from all three experiments, the magnetic dipole moment was found to be $0.42 \pm 0.01\ Am^2$, $0.43 \pm 0.02\ Am^2$, and $0.39 \pm 0.02\ Am^2$ for the first, second, and third experiments respectively. These numbers are acceptably close to one another, averaging 0.41 Am^2 (which also falls within each of their's error margin). Without a definitive reference it cannot be stated explicitly, however, due to the closeness of these values and their proximity to rough numbers provided by the manufacturer, it can be assumed that the dipole moment of the magnetic disk is approximately that which was calculated.

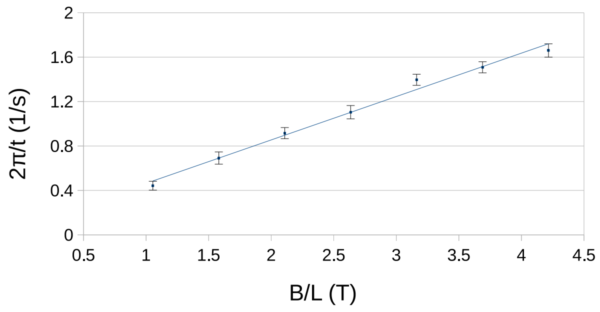

FIG. 5: $\mu = 0.39 \pm 0.02\ Am^2$

7. CONCLUSION

Overall, this series of experiments was successful. Although plagued with the usual difficulties of human measurement, the errors caused by reaction speed and visual inaccuracy were minimized enough to obtain satisfactory results.

[1] TEACHSPIN. "Magnetic Torque." *TeachSpin*, Tri-Main, Web. 26 April 2014.