# Magnetic Torque Proposal

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## I. Outline

The goal of our experiment is to explore the effects of magnetic dipoles. We will use a Teachspin "Magnetic Torque" instrument to view phenomena resulting from torque or force induced by the magnetic dipole. These interactions include static torque resulting from balance of magnetic and gravitational torque, harmonic oscillation, precessional motion, and magnetic resonance. For the static torque, harmonic oscillation, and precessional motion experiments will be used to measure the magnetic dipole moment provided magnet. These measurements can be compared to measurement of the moment determined by observing the strength of the magnetic field, given by the following equation.

$$B = \frac{\mu_0 \mu}{2z^3} \tag{1}$$

Our experiment will demonstrate important properties of magnetic dipoles which occur both in classical and atomic physics.

## II. Background

Magnetic dipole moment is a key concept in electricity and magnetism, and important in both classical and quantum systems. Static torque occurs when the net torque on a object is zero. In our case, we will be balancing magnetic and gravitational torque, and this is given by equation (2).

$$\mu \times B = r \times mg \tag{2}$$

Our experimental set up is also able to act as a harmonic oscillator. The period of this oscillation be be calculated by solving a differential equation, resulting in the following equation.

$$T^2 = \frac{4\pi I}{\mu B} \tag{3}$$

The precessional frequency of a spinning dipole given by the following equation, where L is the angular momentum of the dipole.

$$\Omega_p = \frac{\mu B}{\mid L \mid} \tag{4}$$

Magnetic resonance is a key concept in atomic physics, and is able to be used for spectroscopy and medical imaging. Using a spinning magnetic field around a dipole, we should be able to observe the flipping of the dipole resulting from discretized absorption of energy. This can be considered a classical example of NMR spectroscopy.

## III. Procedure

The "Magnetic Torque" device that is able to produce a uniform magnetic field, using Helmholtz coils. On the top of the deice is an air bearing centered over the coils. This is designed to produce a low friction environment for a cue ball, containing a magnetic disk. The device also includes a strobe light and frequency counter.

Our experiment is divided into four separate subsections. The first subsection involves a static force equilibrium between the the magnetic torque an gravitational force. By inserting a rod with an adjustable weight and directly controlling the strength of the magnetic field, we will be able to observe the relationship seen in equation (2). We will test ten different magnetic field strengths and find the corresponding gravitational torque that allows the device to stay in equilibrium. The next subsection is observing the harmonic motion of the dipole in the magnetic field. By inducing small displacements on the dipole, we expect the device to start oscillating as per equation (3). Again, using ten different magnetic fields we will acquire the appropriate statistics. Third, we will induce an orbital precession on the dipole. The frequency of the precession will be adjusted using the magnetic field, see equation (4). The angular momentum can be calculated using classical physics. We will measure the period of the precession with ten field strengths. Here we will need to use the strobe light to accurately determine the orbital precession period. In our final subsection, we will directly measure the magnetic field surrounding the dipole using a hall effect probe. The magnetic field on the axis perpendicular to the "surface" of the dipole should decrease by $1/z^3$ seen in equation (1).

## IV. Analysis

The analysis for these experiments are fairly straightforward. For each of the four subsections we will attempt to fit the corresponding equation to the ten (or more) data points. From these fits we will be able to calculate an experimental value for the magnetic moment of the dipole, $\mu$. We can then compare the calculated magnetic moments between each of the different methods and see identify the most accurate mode.

## V. Results

The magnetic moment measured in each of these experiments, should be consistent with each other, when accounting for systematic errors of each technique. Our experiment will demonstrate magnetic phenomena with a classical object, which will provide insight into dipole effects in the microscopic system. Using the experimental setup, we can qualitatively observe the classical analog to nuclear magnetic resonance (NMR). We will induce a spinning magnetic field around the dipole and observe the resonances and flipping actions. In summary, the methods which we employ in this experiment are used everyday to calculate the magnetic moments of both classical and quantum systems.