Measuring the magnetization of a permanent magnet

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The effect of an external magnetic field ***B*** on magnetic materials is a subject of immense importance. The simplest and oldest manifestation of such effects is the behavior of the magnetic compass. Magnetization ***M*** plays a key role in studying the response of magnetic materials to ***B***. In this paper, an experimental technique for the determination of ***M*** of a permanent magnet will be presented. The proposed method discusses the effect of ***B*** (produced by a pair of Helmholtz coils) on a permanent magnet, suspended by two strings and allowed to oscillate under the influence of the torque that the magnetic field exerts on the magnet. The arrangement used Newton's second law for rotational motion to measure ***M*** via graphical analysis.

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I. INTRODUCTION

Magnetism has been intriguing mankind for centuries now. A magnet's ability to influence magnetic materials, from a distance, mesmerized numerous inquisitive minds of the past. The magnetic compass, used across all continents, is such a device, acting under the influence of Earth's magnetic field.[1] With the advancement of science, particularly after the discovery of the atomic model, magnetism at the microscopic scale came to the fore. Hans-Christian Oersted's discovery of a current-carrying wire producing a magnetic field added a whole new dimension, leading to the advent of a technological revolution in the field of electromagnetism.[2] With the exploration of newer magnetic materials, exhibiting paramagnetism, ferromagnetism, and diamagnetism, it became essential to develop techniques to measure magnetization in these. While many experimental methods have been proposed, along with the existence of high tech equipment for research, a basic design requirement for educational purposes has eluded us so far.[3,4] In this paper, we present an experimental technique to determine the magnetization of a permanent magnet using readily available lab instruments namely as a pair of Helmholtz coils, an ammeter, a power supply, and a stopwatch. While this technique is applicable for both introductory physics (calculus and algebra based) and undergraduate Physics/Engineering majors, the extent of exploration rests with the instructor. As a quick in-class demo, an introductory class can observe the effect of an external magnetic field on the oscillation period of a permanent magnet without determining any value of magnetization. In an advanced lab setting, students can explore numerical values of magnetization of the four types of permanent magnets, viz., neodymium iron boron (NdFeB), samarium cobalt (SmCo), alnico, and ceramic or ferrite magnets.

II. THEORY

A. Magnetic moment

It is well known that in a wire loop with area A, in which a current i is flowing, we define a vector known as the "magnetic moment" (symbol $\vec{\mu}$), perpendicular to the plane of the loop.[1,5–7] The magnitude μ is given by the following equation:

$$\mu = iA. \tag{1}$$

If we place this loop in a uniform magnetic field $\vec{B}$ at an angle θ with $\vec{\mu}$, as shown in Fig. 1(a), we have a torque acting on the loop whose magnitude τ is given by the following equation:

$$\tau = \mu B \sin\theta. \tag{2}$$

If the loop is allowed to move, it will rotate under the action of the torque in such a way that $\vec{\mu}$ becomes parallel with the magnetic field $\vec{B}$, as shown in Fig. 1(b). Indeed, in the configuration of Fig. 1(b), we have that $\theta = 0$ for which Eq. (2) shows that $\tau = 0$ and all movement stops. Thus, the magnetic moment is defined so that the torque exerted on a current carrying loop, when placed in an external magnetic field, is proportional to μ.[8]

B. Magnetization

For our experimental discussion, we consider a cylindrical permanent magnet (composed of iron atoms) of radius R and height l, as shown in Fig. 2. In each atom, its electrons move around the nucleus on orbits similar to that shown in Fig. 1. Thus, each iron atom behaves like a microscopic loop with magnetic moment $\vec{\mu}_{Fe}$. In iron and other ferromagnetic materials, all the magnetic moment vectors are aligned and the net magnetic moment μ of the magnet is equal to $N\mu_{Fe}$, where N is the number of iron atoms in the magnet. The magnetization M of the magnet, with a volume V is defined as[5,9]

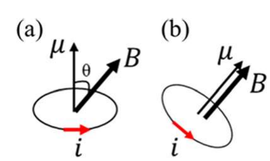

Fig. 1. (a) Magnetic moment of a current carrying loop at an angle θ with respect to $\vec{B}$ and (b) $\vec{\mu} \parallel \vec{B}$.