International Journal of Pure and Applied Physics.
ISSN 0973-1776 Volume 22, Number 1 (2026), pp. 19-26

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An Experimental Study of Magnetic Charges in Magnetic Materials at Room Temperatures

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Abstract

Experiments investigating magnetic charges in ferromagnetic materials were conducted at room temperature. A new mapping technique was developed to visualize the magnetic field lines of magnetized dipoles with improved spatial resolution. The resulting field distributions were analyzed and compared with their electrical counterparts.

The experimental observations reveal several similarities between magnetic and electric charge behavior. In particular, the magnetic field lines were found to be perpendicular to the sample surface near its boundaries, indicating the accumulation of effective magnetic charges. This behavior closely resembles the redistribution of electric charges in a conductor, where charges migrate to the surface and produce perpendicular electric field components.

The results provide strong experimental evidence supporting the effective description of magnetic dipoles in terms of magnetic charges. Furthermore, the findings suggest that Gauss's theorem can be applied analogously to magnetic charges within magnetized materials. Based on the observed behavior, it is proposed that Maxwell's equations may be extended to include magnetic charge terms in order to consistently describe the experimental phenomena presented in this work.

Key words: electric and magnetic charges, Gauss theorem, magnetic monopoles.

1. INTRODUCTION

Most physics textbooks assume that magnetic monopoles (single magnetic charges) do not exist; therefore, magnetic field lines are treated as continuous, with no sources or sinks. However, recent experiments indicate that this assumption may not be correct [1]. Dirac [2] proposed that magnetic monopoles could exist and that a quantization condition should relate electric and magnetic charges. The purpose of this paper is to present direct experimental evidence for the existence of magnetic charges and to show that magnetic field lines closely resemble the electric field lines produced by electric charges.

Faraday [3] introduced the concept of electric field lines in the nineteenth century, and they remain a powerful tool for visualizing electric field patterns. If magnetic field lines can be mapped with similar clarity, they would provide an equally useful visualization of magnetic field structures. With the development of new field-mapping techniques, it is now possible to obtain highly detailed magnetic field line patterns suitable for comparison with their electric counterparts.

2. **THEORY**

Electric field lines originate on positive charges and terminate on negative charges, and the number of lines is proportional to the magnitude of the charge. For conductors, the net charge resides only on the surface, and the electric field is perpendicular to that surface. It is therefore natural to investigate whether comparable features can be measured in magnetic materials.

Gauss's theorem for electric fields is known to be mathematically equivalent to Coulomb's law for electric charges [4], and magnetic charges are expected to obey an analogous relationship. Consequently, one would expect Gauss's theorem to apply to magnetic systems as well.

By analogy with the electric case [4], Gauss's law for magnetism in the presence of magnetic charges can be written as

$$\oint B \times dA = \mu_0 q_m$$

where the net magnetic flux through a closed surface equals the net magnetic charge q_m enclosed by that surface. Here, μ_0 is the permeability of free space. The experimental results presented in this paper will be interpreted using this relation.

3. EXPERIMENTAL DETAILS

3.1 Materials Used

When selecting materials suitable for studying magnetic charges, researchers often use magnetic systems such as spin ice, cobalt nanoparticles, or spinor Bose–Einstein condensates [6, 7, 8]. Most of these experiments must be performed at very low temperatures and require theoretical models to interpret the results.

In this work, we chose ferromagnetic materials such as iron and nickel for several reasons:

- The samples are easy to obtain.
- The behavior of magnetic charges in these materials is similar to the behavior of electrons in an electrical conductor.
- This similarity makes it easier to compare magnetic properties with their electrical counterparts.

3.2 Experimental Procedure

Two iron samples were used in this experiment: a small plate (7 × 7 cm^2, 0.43 mm thick) and a hexagonal wrench (10 cm long, 4 cm in diameter). Each sample was magnetized using a small permanent magnet (approximately 1 kG field strength, 5 cm in diameter, 5 mm thick) placed on top of the sample for several minutes.

After magnetization, the magnetic field of each sample was measured using a Gauss meter and a compass before proceeding to the next step described in Section 3.3.

3.3 Method Used for Mapping

To visualize the magnetic field lines, an experimental setup was developed using an iron plate and a wrench as the magnetic samples. After magnetization, the sample was placed on top of a sealed plastic bag (such as a Ziplock bag) containing a few drops of low-viscosity oil (e.g., vegetable oil or any similar thin oil) mixed with fine iron (Fe) powder.

The thin oil allows the iron particles to move freely and align along the magnetic field lines generated by the sample. The sealed bag prevents contamination and ensures uniform distribution of the particles. The entire setup was recorded from above using a camera or video device to capture high-resolution images of the field patterns.

Compared to the conventional dry iron filings method described in standard textbooks [4], this oil-suspension technique provides improved spatial resolution and clearer visualization of magnetic field lines.

4. EXPERIMENTAL RESULTS AND DISCUSSION

The results obtained from two magnetized samples are presented below, along with their corresponding magnetic field line distributions.

Figure 1 illustrates the magnetic field distribution for the iron plate sample. The field lines are observed to be perpendicular to the surface near the edges of the plate in this two-dimensional configuration. This behavior occurs because magnetic charges tend to accumulate at the boundaries of the sample. This phenomenon is analogous to the behavior of electric charges in an electrical conductor, where charge accumulation at the surface.

In Figure 2, the images demonstrate that the field lines emerge from the north pole and terminate at the south pole, clearly revealing the dipolar structure of the magnetic field. The pattern is identical to that of an electric dipole, as illustrated in standard physics textbooks [3][4]. The observed patterns confirm that the magnetic dipole can be modeled as two magnetic poles (north and south) separated by a finite distance. Although magnetic monopoles have not been experimentally observed in nature, the dipole behavior can be theoretically described as a pair of equal and opposite magnetic charges.

In Figure 3, Gaussian surfaces S_1, S_2, and S_3 are constructed for the dipole in Figure 2. For example, S1 encloses the entire sample, while the magnetic poles (N) and (S) are enclosed individually by S_2 and S_3, respectively. The magnetic flux entering or leaving each surface depends solely on the magnetic charge enclosed by that surface, exactly as in the corresponding electric case (see Figure 24-6 on p. 548 of [4]). This represents a natural extension of Gauss's theorem from electric to magnetic systems.

Furthermore, the constant μ_0 should be replaced by μ_r, since the medium is not a vacuum. This modification is also analogous to the electric form of Gauss's law in dielectric media (p. 604, section 26-8 of [4]).

The magnetic flux can be measured with a Gauss meter, and the resulting magnetic charges can be compared with measurements obtained from a magnetometer or a magnetoscope [1].

Overall, the oil-suspension method proved to be effective for high-resolution mapping of magnetic field lines and provided clearer visualization compared to traditional techniques.

It is important to distinguish between magnetic monopoles (MMs) and magnetic charges (MCs). Magnetic charges are mobile within magnetic materials, behaving in a manner analogous to electrons in a metal. Magnetic monopoles, in contrast, are magnetic poles formed by a localized collection of magnetic charges. They are essentially point-like structures and do not move significantly, much like electric poles.

Attempts to observe monopoles using particle accelerators—similar to most high-energy experiments conducted so far—would require extremely high energies that may exceed current technological capabilities. Magnetic charges, however, are much lighter and can be driven by magnetic fields. For this reason, it may be possible to detect them in accelerator experiments in the near future.

5. CONCLUSIONS

5.1 The experimental results clearly demonstrate that Gauss's law must incorporate magnetic charges in order to account for the phenomena observed.

5.2. The data indicate that magnetic charges migrate toward the surface of the sample and generate magnetic field lines perpendicular to that surface—behavior closely analogous to the motion of electrons in a conductor. These observations provide compelling evidence for the presence of isolated magnetic charges and magnetic poles (i.e., magnetic monopoles, though not of the Dirac type) within magnetic materials.

5.3 Dirac noted in [2] that the large ratio between electric and magnetic charges, approximately 137/2, might explain why such similarities had not been experimentally identified in his time. Our findings, however, show that these similarities are sufficiently pronounced to be detected with modern instrumentation. This suggests that Maxwell's equations should be extended to include magnetic charges, thereby restoring symmetry between electricity and magnetism.

5.4 The observed mobility of magnetic charges suggests that they could potentially serve as carriers of information, functioning analogously to electrons. This possibility opens the door to significant technological applications.

5.5 Further investigations employing complementary techniques—such as ultrasound, neutron diffraction, optical scattering, and muon decay—will be essential for advancing our understanding of the properties of magnetic monopoles and magnetic charges in magnetic materials.

ACKNOWLEDGEMENTS

The valuable discussions with Professors Thomas Hsieh and C.M. Fou are highly appreciated. I receive no funding for this work.

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FIGURES AND CAPTIONS

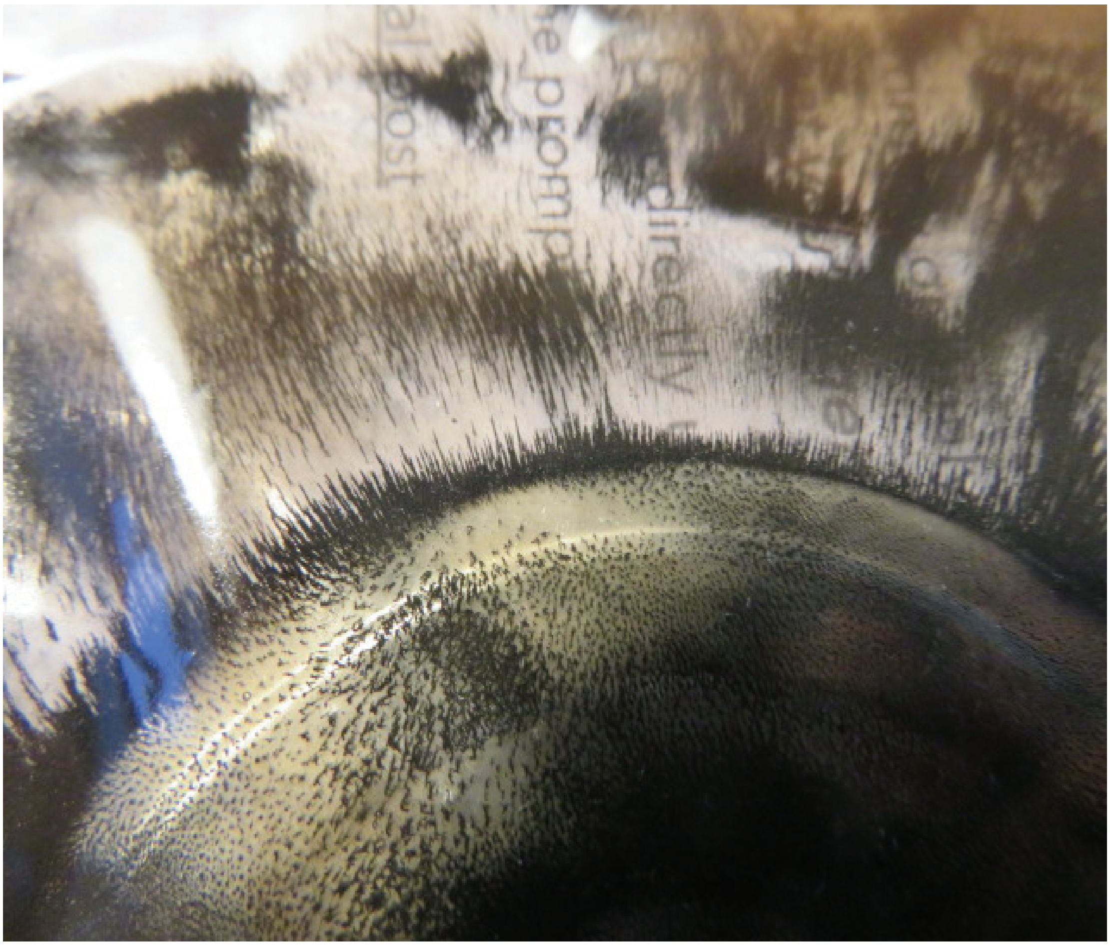

FIGURE 1. The magnetic field lines of an iron can food cover. The diameter of this circle disk is 5cm and the thickness is 0.43mm.

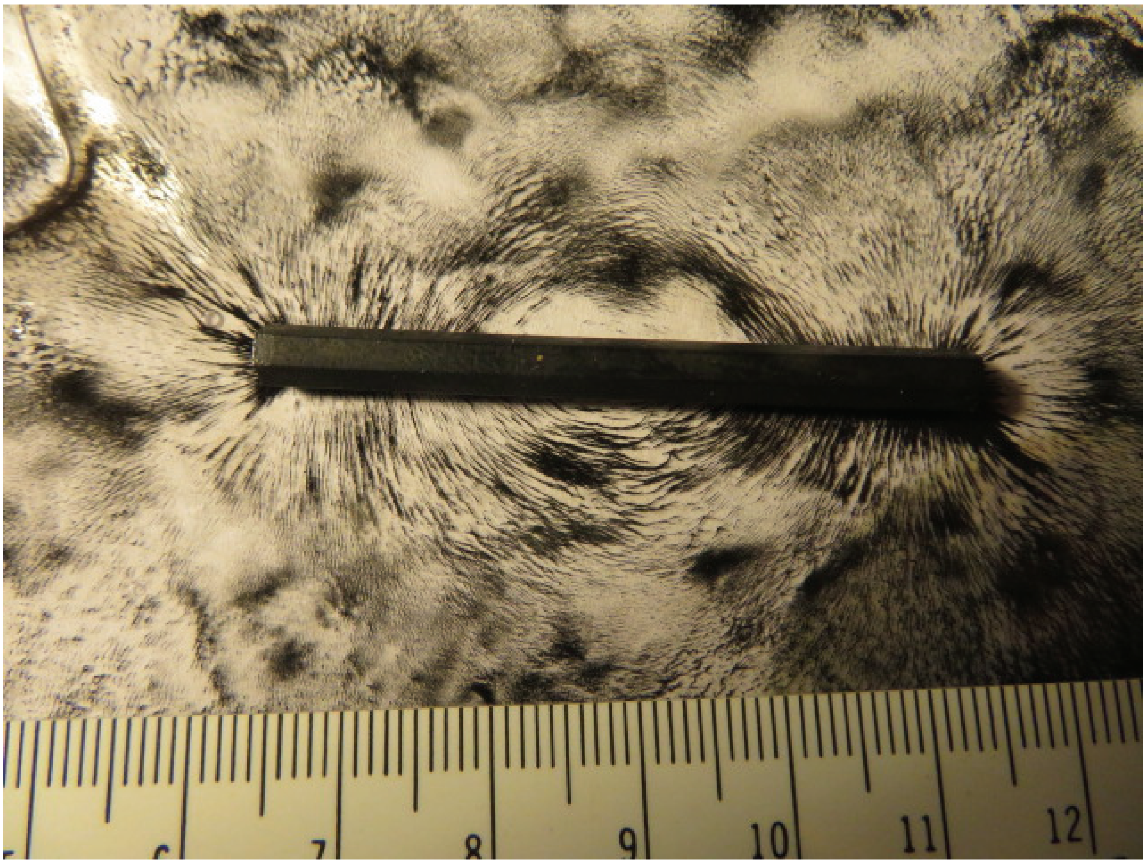

Figure 2. The magnetic field lines of an iron hexagonal shape wrench, about 5 cm long and 5mm in width. It shows the two magnetic poles, one at each end.

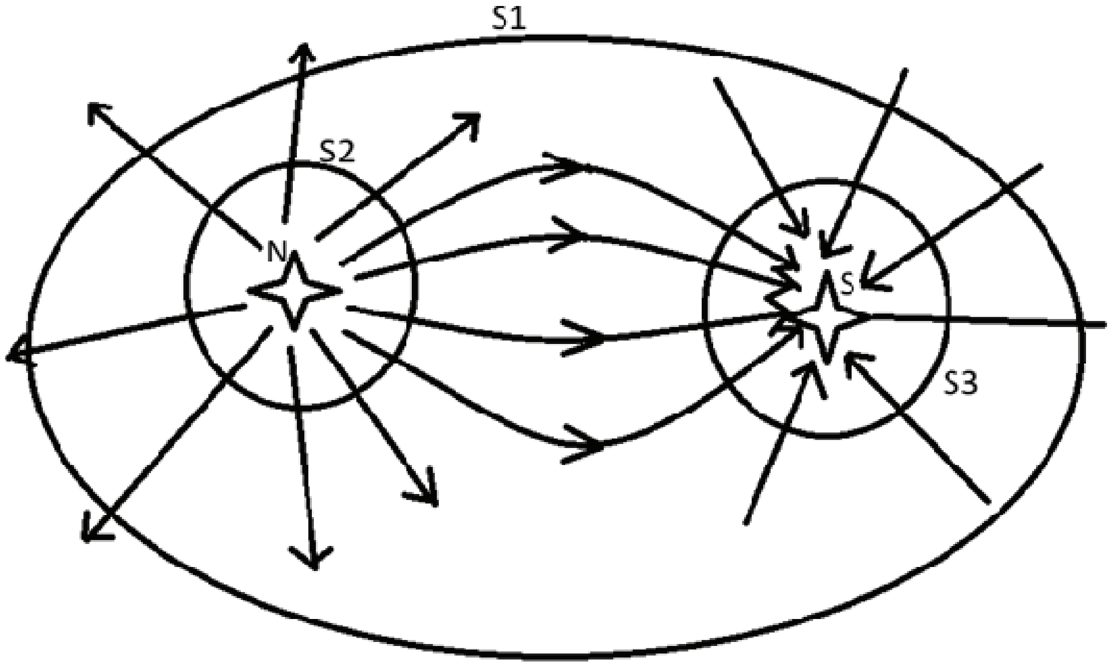

Figure 3. The Gaussian surfaces of the magnetic dipole of Figure 2.