Magnetic Shielding: A Demonstration and Experimental Realization

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Abstract: ***Action of electric and magnetic fields and their interaction effects are the basis of operation of every electrical and electronic instrument. But such action fields could also cause serious problems to the functioning of those instruments if they act on them unnecessarily, to the extreme, failure of the system may also occur. To avoid such unpleasant consequences arising out of unwanted electromagnetic interferences, in recent days, many modern magnetic systems employ magnetic shielding for their safety and security. For the people of scientific pedagogy associated with magnetic systems, deep understanding of the concept of magnetic shielding not only increases their domain knowledge and also will strongly aid them for the effective implementation of protected new magnetic systems. Literature survey reveals that not many sources available for the demonstration of the concept of magnetic shielding coupled with an experiment. Hence, this work is attempted. The objective of this paper is to illustrate the concept of magnetic shielding by way of a simple demonstration and its experimental realization for the benefit of scientific pedagogy in teaching-learning process. In brief, magnetic shielding is a process of restraining the entry of magnetic flux lines from reaching a specific point or region. This is normally achieved by re-routing the magnetic flux, suitably establishing an alternate path for it as the stoppage of magnetic flux lines is limited by Maxwell's equation*** $\nabla \cdot \mathbf{B} = 0$ ***. This article describes a simple procedure to demonstrate magnetic shielding and its experimental realization. Inclusion of photographs of the experimental set-up used in our laboratory for the demonstration of magnetic shielding provides a better tool for teaching and learning process. This article is prepared with a view to effectively communicate the concept of magnetic shielding in an efficient way for the curious learners of magnetism. The article also helps scientific pedagogy to grasp the concept of magnetic shielding graphically.***

Keywords: Magnetic shielding, demonstration, experiment

1. Introduction

Interactive learning as well as teaching of fundamentals of physics and realization of their potential applications are often lacking in recent days due to non availability of enough illustrative demonstrations and experiments. Keeping this in mind this article is structured. The focus of this article is to provide a fundamental report on demonstration of magnetic shielding and its experimental realization with a view to improve the teaching and learning of physics interactively and effectively. Literature survey shows that there is not much information available for the study of magnetic shielding in experiment form. Hence this present work.

In general, the response of materials to a magnetic field greatly varies by their nature which depends on their internal structures and change in magnetization capabilities. Many modern magnetic systems employ magnetic shielding for its protection. Magnetic shielding is a process of obstructing the entry of a magnetic flux to a specific point or region [1], [2], [3], [4], [5], [6]. The objective of magnetic shielding is to protect field sensitive systems from unwanted interferences of external magnetic fields. For instance, typical applications requiring magnetic shielding include computer hard drives, mobile phones, conducting cables, hall effect devices, cathode ray tubes, medical imaging systems viz. magnetic resonance imaging (MRI) and CT scan, particle accelerators and instruments used to study sub atomic particles [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21]. This paper provides a simple method, procedure and experiment for the demonstration of magnetic shielding.

2. Instructions for Demonstration

Figure.1 shows the block diagram of illustration to demonstrate magnetic shielding phenomenon.

Step-1: Place the magnetometer on a wooden table free from disturbances and set the pointer to read (0-0) on both ends.
Step-2: Place a small bar magnet in line with the pointer in East – West direction at a distance D from magnetometer. Observe the deflection produced in the magnetometer.

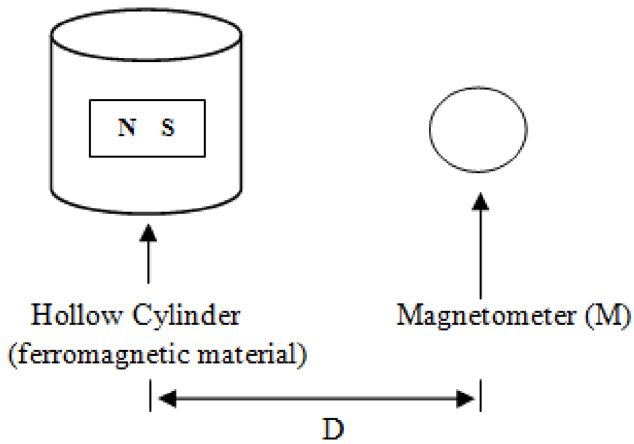

Figure 1: Block diagram of illustration

Step-3: Reduce the distance D slowly by moving the bar magnet towards the magnetometer and observe the change in deflection of the magnetic needle. This could be examined for the increasing value of D also. This shows that the magnetic needle is influenced by the bar magnet and the observed deflection in the magnetometer is according to its distance from the bar magnet.

Step-4: Now, for an arbitrary distance D of the magnet, slowly insert a hollow ferromagnetic cylinder to house the bar magnet, observing the deflection of the magnetic needle. It could be seen that the deflection existed in the magnetometer in the absence of ferromagnetic cylinder drops to zero – which is the result of **'magnetic shielding'** phenomenon.
Step-5: Now, pressing and holding the bar magnet down using a non-magnetic rod inserted through the ferromagnetic cylinder, lift the cylinder vertically up slowly. It could be seen that the magnetic needle resumes its deflection due to the disappearance of magnetic shielding. If the cylinder is now lowered down, magnetic shielding is restored due to flux confinement and hence the deflection of the needle ceases.
Step-6: Now, move the entire cylinder along with the housed magnet near to or away from the magnetometer. It could be observed that the magnetometer needle is unaffected by such an operation and by the bar magnet housed inside the ferromagnetic cylinder – which reveals that there is no magnetic flux leakage out of the cylinder.
Step-7: Even if the cylinder with housed magnet is now moved around the magnetometer for 360^o, either clockwise or anti-clockwise directions, it is seen that the magnetometer needle is unaffected by such operation and pointer points remain undisturbed.

Note:

The aforesaid steps (4-7) could be repeated many a times and the phenomenon of magnetic shielding could be better demonstrated.

The above steps could also be carried out using a hollow PVC cylinder and its response to the magnetic field in comparison to ferromagnetic cylinder may also be explained on the basis of experimental observations - to realize the response of various materials to magnetic field and their role on technology development. Further, to project the distribution of magnetic flux of the bar magnet with and without ferromagnetic cylinder, the section of mapping of magnetic flux is introduced. This section helps learners to understand the concept of flux confinement within in the walls of ferromagnetic cylinder.

3. Photographs of Set Up Used

The photographs of set up used in our laboratory to demonstrate the phenomenon of magnetic shielding are shown in Figure.2, and in Figure.3.

Figure 2: Magnet placed near a magnetometer

Figure 3: Magnet housed in a ferromagnetic cylinder (iron)

4. Mapping of the Magnetic Flux (of the bar magnet)

Figure.4. illustrates the mapping of magnetic flux lines of the bar magnet when it is housed inside the ferromagnetic cylinder. This diagram shows that the entire flux lines of the magnet, particularly in horizontal direction, are confined within the cylinder. This is because the walls of the ferromagnetic cylinder prevents flux penetration due its high permeability and confines the magnetic flux by itself. Hence, though inside the cylinder, the flux distribution is unaffected, when the flux lines emanating from the north pole of bar magnet touch the ferromagnetic walls, they are unable to escape from the cylinder as all flux lines falling on the walls are confined in the walls of the cylinder, which act like a trap and through which they reach the other pole of bar magnet.

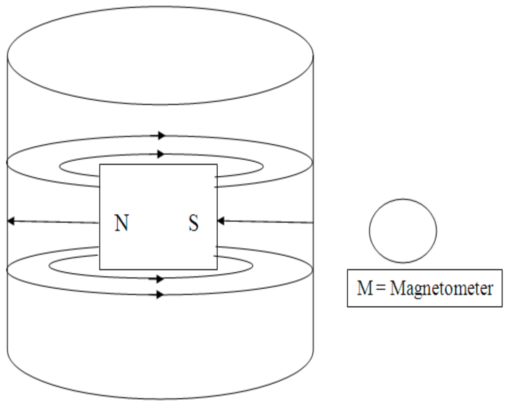

Figure 4: Magnetic flux configuration of the bar magnet with ferromagnetic cylinder
(Flux is affected by the cylinder and confined)

The configuration of magnetic flux lines seen from top view of the ferromagnetic cylinder is illustrated in Figure.5.

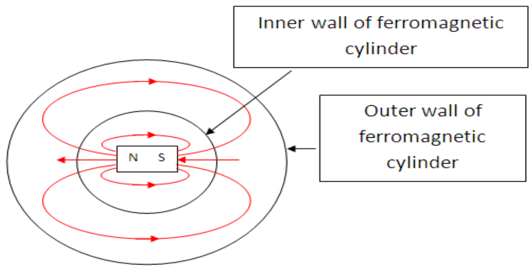

Figure 5: Cross-sectional view of the flux configuration for ferromagnetic cylinder

Figure.6. illustrates the mapping of magnetic flux lines of bar magnet when it is housed inside the non-ferromagnetic cylinder. Non-ferromagnetic materials do not affect the flux of the bar magnet much and hence the flux penetrates through the walls of the cylinder without any hindrance.

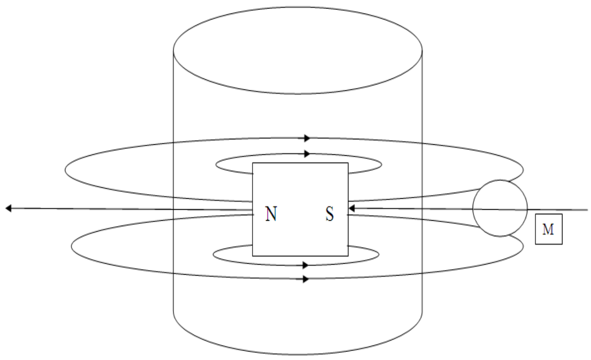

Figure 6: Magnetic flux configuration of the bar magnet with non-ferromagnetic cylinder
(Flux is unaffected by the cylinder)

The configuration of magnetic flux lines seen from top view of non-ferromagnetic cylinder is illustrated in Figure.7.

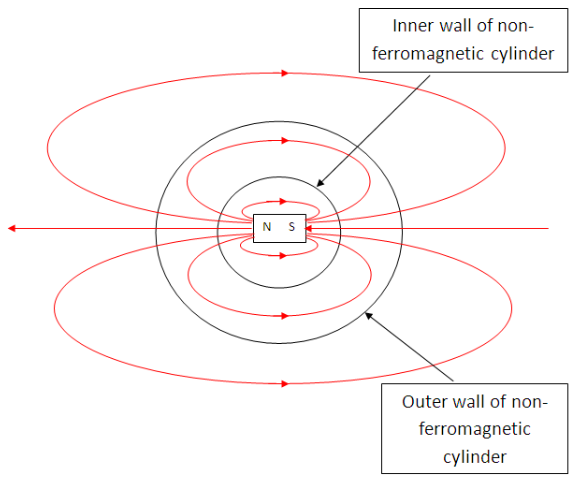

Figure 7: Cross-sectional view of the flux configuration for non-ferromagnetic cylinder

The flux mapping of unhoused magnet is similar to that of a housed magnet in non-ferromagnetic cylinder. If the housing material is non-ferromagnetic such as PVC, the path of flux lines is unaffected. In figure.8, the bar magnet is housed inside a PVC tube, which demonstrates this effect.

Figure 8: Magnet housed in a PVC cylinder

To re-route magnetic flux, diamagnetic materials could also be used, but the mapping of magnetic flux would be different in such cases.

5. Experiment

Aim: Study of magnetic shielding using deflection magnetometer.

Apparatus required: A small bar magnet, deflection magnetometer and a hollow ferromagnetic material (iron or steel).

Formula

Magnetic field strength, F = H tan θ Am^{-1}
Where, F = Magnetic field strength of the bar magnet at the point of magnetometer needle
H = Horizontal component of Earth's magnetic field and
θ = Deflection in the magnetometer

6. Procedure

Diagram: Experimental set-up is shown in Figure.9.

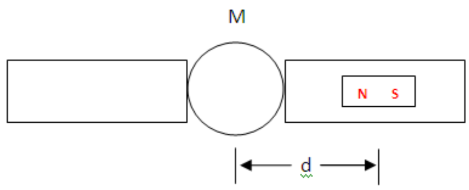

Figure 9: Experimental set-up

Table

Distance of magnet from magnet-ometer (d) cm	Deflection of magnetometer (deg)										F = H tan θ Am^{-1}	
	Unshielded magnet					Shielded magnet					Un-shielded magnet	Shielded magnet
	East		West		Mean Θ	East		West		Mean Θ		
	Θ_1	Θ_2	Θ_3	Θ_4		Θ_1	Θ_2	Θ_3	Θ_4			

Step -1: The deflection magnetometer is set in Tan-A position.
Step -2: Bar magnet is placed at different distances (d) from the magnetometer (M) in east and west directions (say, 10, 15, 20 and 25 cm) and the deflections observed in the magnetometer are recorded in the table.
Step -3: Hollow ferromagnetic material is inserted over the bar magnet and step -2 is repeated along with the tube. (The magnet is shielded when it is housed inside the tube of ferromagnetic material).
Step -4: The magnetic field strengths of the bar magnet at the point of magnetic needle for different distances from the magnetometer are calculated using the relation F=H tan θ Am^{-1}.
Step -5: Distance versus magnetic field strength (d-F) graphs are drawn for the unshielded as well as shielded magnets.

Model Graphs: Typical d vs. F graphs for unshielded and shielded magnets are shown in Figure.10 and Figure11.

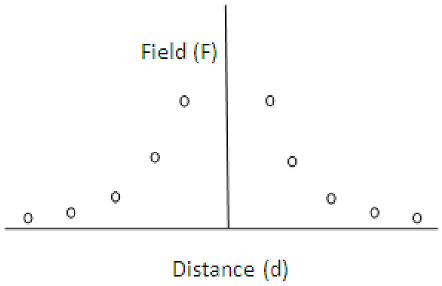

Figure 10: (d-F) graph for Unshielded Magnet

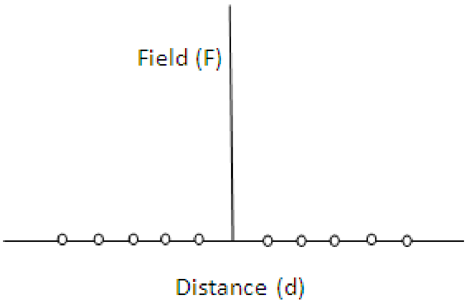

Figure 11: (d-F) graph for Shielded Magnet

7. Result

The magnetic field strength graphs for the shielded and unshielded bar magnet were drawn and the magnetic shielding phenomenon was studied

8. Conclusions

Interactive teaching-learning methods yield more bilateral efficiency. Particularly, this is very much required to understand science subjects. In this article a study of magnetic shielding was focused and the same was projected along with simple demonstrative instructions. Incorporation of the experiment and graphical analysis of magnetic shielding phenomenon help science pedagogy to have a deeper understanding about the concept of magnetic shielding. Photographs of experimental set up used in our laboratory make this article easier to understand about the magnetic shielding in teaching and learning environment. This article may also help teachers to project the concept of magnetic shielding phenomenon in an interactive way using the section mapping of the magnetic flux. This article will also aid enthusiastic students and researchers to develop new magnetic systems with enhanced protection through magnetic shielding. Future scope of this work may be extended on the research part for the identification and development of new/ alternate materials to perform effective magnetic shielding since recent days only selective materials such as permalloy and mu-metals are mainly used for magnetic shielding applications due to their high permeability and low magnetic reluctance properties. Research could also be focused on the development of new technologies for magnetic shielding to protect the magnetic field sensitive systems from the unwarranted interferences of very strong magnetic fields, which is also a challenge.

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