PHYSNET

MISN-0-510

MAGNETIC PROPERTIES OF MATTER

Electricity and Magnetism

Project PHYSNET Physics Bldg. Michigan State University East Lansing, MI

MAGNETIC PROPERTIES OF MATTER

by

R. Young

Title: **Magnetic Properties of Matter**

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Length: 2 hr; 9 pages

Input Skills:

1. Vocabulary: magnetic induction, Biot's law, magnetic dipole, vector potential (MISN-0-509).
2. Express the magnetic vector potential in terms of the magnetic dipole moment (MISN-0-509).
3. Express the magnetic induction in terms of a vector potential (MISN-0-509).

Output Skills (Knowledge):

K1. Vocabulary: magnetization, volume and surface magnetization current density, volume and surface pole density, magnetic intensity, magnetic susceptibility and permeability, relative permeability, diamagnetism, paramagnetism, ferromagnetism, magnetic saturation, hysteresis, hysteresis loop, remanence, coercivity.

K2. State the two basic field equations for magnetostatics in the case where magnetic materials are present, both in integral and differential form.

Output Skills (Rule Application):

R1. Given the magnetization in a medium determine the magnetic current densities, the magnetic pole density, and the surface density of magnetic pole strength.

Output Skills (Problem Solving):

S1. Given the magnetization of a specified object, determine the magnetic induction, vector potential and scalar potential for arbitrary regions of space.

External Resources (Required):

1. J. Reitz, F. Milford and R. Christy, *Foundations of Electromagnetic Theory*, 4th Edition, Addison-Wesley (1993).

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New authors, reviewers and field testers are welcome.

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1. Introduction

The purpose of this unit is to present a theoretical structure for dealing with the magnetic effects of matter. We will derive relations such as those below.

If $\vec{J}(\vec{r})$ is the current density due to "true" current which consists of charge transport and $\vec{J}_M(\vec{r})$ is the current density due to "atomic" currents which cause no charge transport, then the vector potential can be written as:

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi}\int_V \frac{\vec{J}(\vec{r}\prime)\,dV'}{|\vec{r}-\vec{r}\prime|} + \frac{\mu_0}{4\pi}\int_V \frac{\vec{J_M}(\vec{r}\prime)\,dV'}{|\vec{r}-\vec{r}\prime|}\,.$$

The current density $\vec{J}_M(\vec{r})$ describes the magnetic properties of matter in the magnetostatic case.

2. Procedures

1. Read Chapter 9, Sec. 9-1 to 9-6 . This is a rather technical and important chapter. It would benefit you if you copied down some of the figures and drew some additional figures of your own. It also wouldn't hurt if you actually went through the details of some of the derivations, e.g. like the derivation resulting in equations 9-19 and 9-19a.

2. Write down or underline in the text the first ten vocabulary terms in Output Skill K1.

3. The final eight vocabulary terms in K1 are slightly more difficult to extract from the text. The relevant material is in Sec. 9-6 so you must read this section very carefully. A brief definition of each of the items is listed below. Write down the definitions so you are sure that you know them.

   a. *Diamagnetism* - $X_m < 0$ and $|X_m| \ll 1$ so that the magnetic induction is slightly weakened by the presence of the material.

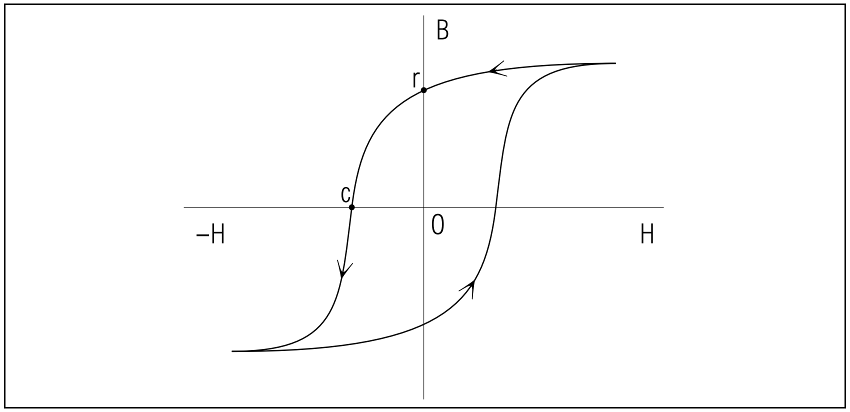

Figure 1. .

   b. *Paramagnetism* - $X_m > 0$ and $|X_m| \ll 1$ so that the magnetic induction is slightly strengthened by the presence of the material.

   c. *Ferromagnetism* - When ferromagnetic material is present, it is possible that the condition $X_x \gg 1$ can occur. It is also possible that $\vec{m} \neq \vec{0}$ even when no external magnetic intensity $\vec{H}$ is present. That is, permanent magnetization is possible.

   d. *Magnetic saturation* - This term applies to ferromagnetic material and the fact that the magnetization M reaches a maximum value in the material.

   e. *Hysteresis* - This term applies to ferromagnetic material and the fact that magnetic induction B depends on the magnetic intensity H at a given point in time as well as the past magnetic history of the sample. This phenomena is expressed by the "hysteresis loop" in a plot of B versus H.

   f. *Hysteresis loop* - The hysteresis loop is the curve traced out in the B - H plane by increasing H to a maximum strength in one direction and then in the other direction. A typical hysteresis loop is shown in Fig. 1.

   g. *Remanence* - The magnetic induction present in a ferromagnetic material after the magnetic intensity has been reduced to zero. The ferromagnetic material is then a permanent magnet.

   h. *Coercivity* - The strength of the magnetic intensity which is needed to reduce the magnetic induction to zero is a permanent magnet. The negative sign for H simply means that the externally applied magnetic intensity H must be in the opposite direction to the magnetic induction of the permanent magnet.

4. Write down or underline in the text the formulas called for in Output Skill K2. Be prepared to write them down from memory when asked on the Unit test.

5. Solve the following problems:

Problem	Type
9-1	Magnetic current densities given $\vec{M}$
9-2	Magnetic current densities given $\vec{M}$
9-7	Scalar potential & magnetic induction given $\vec{M}$
9-8	Magnetic pole and current densities given $\vec{M}$

Acknowledgments

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