Digital Computer Laboratory
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SUBJECT: GROUP 63 SEMINAR ON MAGNETISM, I

To: Group 63 Staff

From: Arthur L. Loeb and Norman Menyuk

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In the majority of courses given on electromagnetic phenomena in various colleges and universities, a detailed study of ferromagnetism is usually left to be studied at the end of the term "if time permits." Since time usually does not permit the subject, as a formal classroom topic, has been relatively neglected.

As we shall see later, magnetic effects are due to electron spin characteristics which lead to ferromagnetism only in special cases. These special, but important cases, might be considered an "accident" of nature, comparable to the way the special properties of the carbon atom lead to the field of organic chemistry.

There are various ways of approaching the subject. In this seminar we will begin with a review of magnetic properties, introducing fundamental theories whenever necessary. This will be followed by a discussion of the theories, with quantitative applications to simple problems and semi-quantitative or qualitative extensions to real cases.

It is important that we begin with a study of the fundamental concepts in order that we know which phenomena are a consequence of the same basic properties, and which are independent.

DEFINITION OF SYMBOLS

The following are a group of symbols which will be used throughout the seminar:

a.) Magnetic

$\vec{H}$ Magnetic field intensity

$\vec{B}$ Magnetic flux density or magnetic induction

$\vec{I}$ Magnetization

Φ_M Magnetic flux

μ Permeability

χ Susceptibility

$\vec{M}$ Magnetic moment

b.) Electrical

$\vec{E}$	Electric field intensity
$\vec{D}$	Electric induction or displacement
$\vec{P}$	Polarization
ϵ	Permittivity
ρ	Electric charge density
$\vec{i}$	Current density
γ	Conductivity

Basic relationships

$$\vec{D} = \epsilon \vec{E} = \vec{E} + 4\pi\vec{P}$$
$$\vec{B} = \mu\vec{H} = \vec{H} + 4\pi\vec{I}$$

Assuming $\vec{E}$ parallel to $\vec{P}$ and $\vec{H}$ parallel to $\vec{I}$ then

$$\frac{D}{E} = 1 + \frac{4\pi P}{E} = \epsilon$$

$$\frac{B}{H} = 1 + \frac{4\pi I}{H} = 1 + 4\pi \chi \equiv \mu$$

$$\text{or} \quad \chi = \frac{I}{H}$$

The vector quantities $\vec{P}$ and $\vec{I}$ are associated with matter and are identically zero in vacuo. For a better understanding of these quantities, let us consider the relationship of $\vec{E}$, $\vec{D}$, and $\vec{P}$ in a dielectric at the microscopic level.

An electric field is, by definition, the force acting on a unit positive charge. Therefore, when an external field is applied in the region of a dielectric, a force is exerted on the individual particles of the material. This will tend to align these particles with their positive charge shifted somewhat in the direction of the field and their negative charge (electrons) in the opposite direction. The picture is then approximately as shown in Figure 1.

The induced charge, or polarization, is directly related to the polarization vector $\vec{P}$, which is in such a direction as to reduce the value of the electric field within the dielectric.

To show this mathematically, use is made of the boundary condition which states that the displacement vector component normal to a surface containing no free charges is continuous across the boundary.

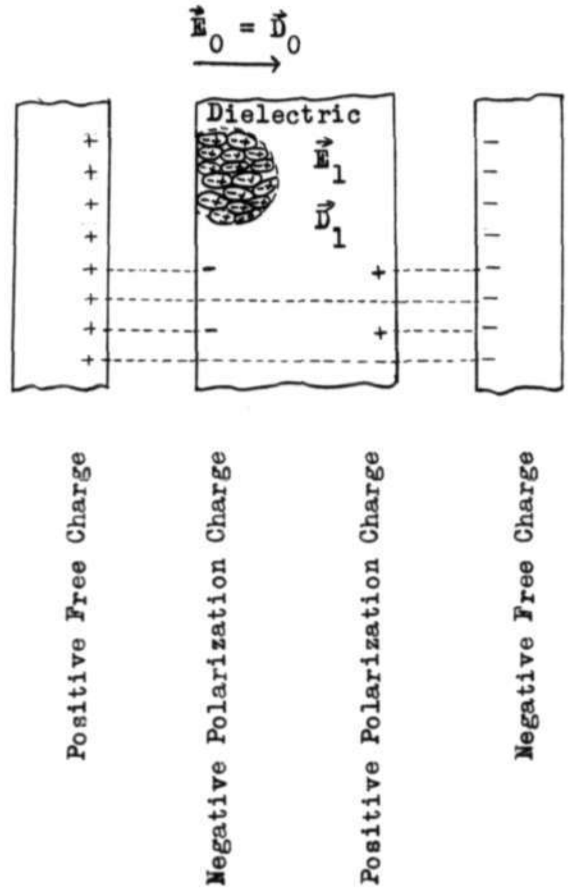

Figure 1

Thus in Figure 1,

$$\vec{D}_1 = \vec{D}_0$$

Further, since there can be no polarization in free space,

$$\vec{P}_0 = 0$$

Therefore

$$\vec{D}_0 = \vec{E}_0$$

and

$$\vec{D}_1 = \vec{D}_0 = \vec{E}_0 = \vec{E}_1 + 4\pi\vec{P}$$

and we see that $\vec{E}_1 < \vec{E}_0$ or the electric field within the dielectric is smaller than in the surrounding free space.

To see physically why the electric field is smaller inside the material we will use the discussion by Skilling.*

All non-conducting material contains positive and negative charges bound together. When material of this kind is in an electric field, the positive charges tend to move in the direction of the field and the negative charges the other way. However, since they are bound, they can only move as far as the elastic nature of the bond permits. Thus each particle is distorted, becoming positive on one side and negative on the other.

As shown in Figure 1, a block of dielectric material has been placed between a pair of charged plates which set up an electric field as shown. The elementary particles of the material are then strained by the electric field as shown in the inset, with their negative charge on the left and positive charge on the right. Because of this, the left-hand side of the dielectric surface is predominantly negative and the right-hand surface positive.

In this way, without any flow of free charge through the material, but merely as a result of polarization, the material has acquired the equivalent of a surface charge. This explains why the electric field strength is less in dielectric material than in free space; the surface charges of polarization partially shield the region within the material.

It should be noted that in anisotropic materials the vectors $\vec{D}$, $\vec{E}$ and $\vec{P}$ are not generally parallel to each other. In this case the permittivity ϵ is a tensor. Similarly for non-parallel $\vec{B}$, $\vec{H}$ and $\vec{I}$, μ represents a tensor. However, when the quantities are parallel, ϵ and μ are scalars. In the discussion to follow, ϵ and μ are always to be considered scalar quantities unless there is a specific statement to the contrary.

Signed ______________________
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ALL/NM:jk

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* Skilling, H. H., Fundamentals of Electric Waves, John Wiley and Sons, New York, 1948, p. 59.