Basic Electromagnetism and Materials

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Foreword by Arthur J. Epstein

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Foreword

Electromagnetism has been studied and applied to science and technology for the past century. It is mature field with a well developed theory and a myriad of applications. Understanding of electromagnetism at a deep level is important for core understanding of physics and engineering fields and is an asset in related fields of chemistry and biology. The passing of the knowledge of electromagnetism and the skills in application of electromagnetic theory is usually done in university classrooms.

Despite the well developed literature and existing texts there is a need for a volume that can introduce electromagnetism to students in the early mid portion of their university training, typically in their second or third year. This requires bringing together many pieces of mathematics and physics knowledge and having the students understand how to integrate this information and apply the information and concepts to problems.

André Moliton has written a very clear account of electromagnetic radiation generation, and its propagation in free space and various dielectric and conducting media of limited and also infinite dimensions. Absorption and reflection of radiation is also described. The book begins by reminding the reader in an approachable way of the mathematics necessary to understand and apply electromagnetic theory. Thus chapter one refreshes the reader's knowledge of operators and gradients in an understandable and concise manner. The figures, summaries of important formulas, and schematic illustrations throughout the text are very useful aids to the reader. Coulomb's law describing the force between two charges separated by a distance r and the concept of electric field produced at a distance from a charge are introduced. The scalar potential, Gauss's theorem, and Poisson's equation are introduced using figures that provide clarity to the concepts. The application of these concepts for a number of different geometries, dimensionalities and conditions is particularly useful in cementing the reader's understanding. Similarly in chapter one, Ohm's law, Drude model, and drift velocity of charges are clearly introduced. Ohm's law and its limits at high frequency are described. The author's comments provide a useful perspective for the reader.

The introduction of magnetostatics and the relationships between current flow, magnetic fields, and vector potential, and Ampère's theorem are also introduced in chapter one. Again the figures, summaries of important formulas, and author's comments are particularly helpful. The questions and detailed answers are useful for retaining and deepening understanding of the knowledge gained.

Chapter two provides a useful and practical introduction to dielectrics. The roles of dipolar charges, discontinuities, space charges, and free charges as well as homo- and hetero-charges are illustrated in Figure 2.2. The applications of the formulas introduced in chapter one and the corresponding problems and solutions complete this chapter. Similarly magnetic properties of materials are introduced in chapter three. Dielectric and magnetic materials are introduced in Figure 3. The properties of magnetic dielectric materials are described in Figure 4 together with a number of useful figures, summaries, problems, and solutions.

Maxwell's equations together with oscillating electromagnetic fields propagating in materials of limited dimensions are introduced and described in chapters five through seven. Propagation of oscillating electromagnetic waves in plasmas, and dielectric, magnetic, and metallic materials is described in chapter eight. The problems and solutions at the end of each chapter will be particularly helpful.

The generation of electromagnetic radiation by dipole antennae is described in chapter nine, with emphasis on electric dipole emission. Absorption and emission of radiation from materials follow in chapters ten and eleven. Chapter twelve concludes with propagation of electromagnetic radiation in confined dimensions such as coaxial cables and rectangular waveguides.

In sum, I recommend this book for those interested in the field of electromagnetic radiation and its interaction with matter. The presentation of mathematical derivations combined with comments, figures, descriptions, problems, and solutions results in a refreshing approach to a difficult subject. Both students and researchers will find this book useful and enlightening.

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Preface

This volume deals with the course work and problems that are common to basic electromagnetism teaching at the second- and third-year university level. The subjects covered will be of use to students who will go on to study the physical sciences, including materials science, chemistry, electronics and applied electronics, automated technologies, and engineering.

Throughout the book full use has been made of constructive exercises and problems, designed to reassure the student of the reliability of the results. Above all, we have tried to demystify the physical origins of electromagnetism such as polarization charges and displacement and Amperian currents ("equivalent" to magnetization).

In concrete terms, the volume starts with a chapter recalling the basics of electromagnetism in a vacuum, so as to give all students the same high level at the start of the course. The formalism of the operators used in vectorial analysis is immediately broached and applied so as to help all students be well familiarized with this tool.

The definitions and basic theories of electrostatics and magnetostatics then are established. Gauss's and Ampère's theories permit the calculation—by a simple route—of the electric and magnetic fields in a material. The calculations for charges due to polarization and Amperian currents caused by magnetization are detailed, with attention paid to their physical origins, and the polarization and magnetization intensity vectors, respectively.

A chapter is dedicated to the description of dielectric and magnetic media such as insulators, electrets, piezoelectrets, ferroelectrics, diamagnets, paramagnets, ferromagnets, antiferromagnets, and ferrimagnets.

Oscillating environments are then described. As is the tradition, slowly oscillating systems—which approximate to quasistationary states—are distinguished from higher-frequency systems. The physical origin of displacement currents are detailed and the Maxwell equations for media are established. The general properties of electromagnetic waves are presented following a study of their propagation in a vacuum. Particular attention has been paid to two different types of notation—used by dielectricians and opticians—to describe what in effect is the same wave. The properties of waves propagating in infinitely large materials are then described along with the description of a general method allowing determination of dynamic polarization in a material that disperses and absorbs the waves. The Poynting vector and its use in determining the energy of an electromagnetic wave is then detailed, followed by the behavior of waves in the more widely encountered materials such as dielectrics, plasmas, metals, and uncharged magnetic materials.

The following two chapters are dedicated to the analysis of electromagnetic field sources. An initial development of the equations used to describe dipole radiation in a vacuum is made. The interaction of radiation with electrons in a material is detailed in terms of the processes of diffusion, notably Rayleigh diffusion, and absorption. From this the diffusion of radiation by charged particles is used to explain the different colors of the sky at midday and sunset. Rutherford diffusion along with the various origins of radiation also are presented. The theory for absorption is derived using a semiquantic approximation based on the quantification of a material but not the applied electromagnetic field. This part, which is rather outside a normal first-degree course, can be left out on a first reading by undergraduate students (even given its importance in materials science). It ends with an introduction to spectroscopy based on absorption phenomena of electromagnetic waves, which also is presented in a more classic format in a forthcoming volume entitled *Applied Electromagnetism and Materials*.

The last two chapters look at the propagation of waves in media of limited dimensions. The study of reflection and refraction of waves at interfaces between materials is dominated by the optical point of view. Fresnel's relations are established in detail along with classic applications such as frustrated total internal reflection and the Malus law. Reflection by an absorbing medium, in particular metallic reflections, is treated along with studies of reflection at magnetic layers and in antiradar structures. Guided propagation is introduced with an example of a coaxial structure; then, along with total reflection, both metallic wave guides and optical guides are studied. The use of limiting conditions allows the equations of propagation of electromagnetic waves to be elaborated. Modal solutions are presented for a symmetrical guide. The problem of signal attenuation, i.e., signal losses, is related finally to a material's infrared and optical spectral characteristics.

I would like to offer my special thanks to the translator of this text, Dr. Roger C. Hiorns. Dr. Hiorns is following post-doctorial studies into the synthesis of polymers for electroluminescent and photovoltaic applications at the Laboratoire de Physico-Chimie des Polymères (Université de Pau et des Pays de l'Adour, France).

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