Electricity and Magnetism

UNIVERSITY PHYSICS SERIES

ELECTRICITY
AND
MAGNETISM

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ELECTRICITY AND MAGNETISM

University Physics Series

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WALTER C. MICHELS, PH.D.

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Dedicated to
Lucy Hayner Kurrelmeyer
and
Mildred L. Mais

PREFACE

This book is intended as a college text at the sophomore or junior level, for students who have had the equivalent of a year of calculus, a year of introductory physics, and a semester of intermediate mechanics. We believe that the selection of topics is appropriate for students intending to specialize in any branch of science or engineering. The emphasis is on the fundamental phenomena and on the principles which have been deduced from them. A certain amount of space has been devoted to the more important applications.

Most of the equations are written in such a way that they are valid in any system of units, provided that appropriate numerical values are assigned to the constant ε_0 appearing in Coulomb's law and to the constant μ_0 appearing in Ampère's law. We have used the rationalized MKSA system of units almost exclusively. A set of conversion factors to other units, and a table showing the dimensions of all the more commonly used electrical and magnetic quantities, are given in Appendix 5.

The first chapter contains a brief review of the basic experimental facts, and is followed by several chapters dealing with dc circuits. We have found this arrangement of material to be superior pedagogically to the historical approach beginning with electrostatics, for two reasons. First, students are in general more familiar with circuits and with the concepts involved, so that they acquire some much-needed confidence. Second, the laboratory work, which normally begins with dc measurements, proceeds much more smoothly with this introduction.

If it is desired to begin with electrostatics, the text assignments can begin with Chapter 5, where all the necessary definitions are given, leaving the first four chapters as reading assignments for laboratory work.

The course in electricity and magnetism is usually one of the most difficult in the undergraduate physics sequence, even for superior students. We have therefore made the presentation very detailed at the start, at the risk of repeating material covered in the introductory course. Students with good preparation can absorb this part of the book very rapidly. In later chapters the pace is gradually stepped up. Vector analysis is used sparingly at the start, and then increasingly as the

work progresses. All the necessary definitions and formulas of vector analysis are collected in Appendix 3.

It has been our experience that even the superior student has difficulty with the large number of new concepts appearing in this subject. We have therefore followed the rule of introducing a new concept only when it is really needed, that is, when the failure to introduce it would result in awkward formulas or extensive circumlocution. For example, as long as we are dealing with fields in vacuum, the vectors **E** and **B** are sufficient; the vectors **D** and **H** are not even mentioned until we come to phenomena in material media.

The book may be used for a course of either one or two semesters. At Brooklyn College, in a course of one semester with four class hours per week plus laboratory, we aim to cover the content of Chapters 1 through 14 and 17, either in the lectures or in the laboratory. Chapters 15, 16, and 18 provide reference material for later courses in electronics and advanced laboratory work in atomic physics.

Problems have been constructed with several objectives in view. Some are intended to promote familiarity with the most important results, and with the orders of magnitude of physical quantities occurring in typical processes and situations. These usually involve numerical substitution into formulas. Some involve derivations not given in detail in the text. Still others involve application of principles to new situations. They are intended to test comprehension of the principles and of the limitations under which they apply.

For the legion of students who still have difficulty with arithmetic, a special feature will be Appendix 2, "Mental Arithmetic, When and How."

We have given frequent references to the literature, especially where the content touches on recent developments. These can be used as the starting point for independent study projects.

We wish to express our gratitude to Professor Walter C. Michels, who as Editor of the University Series in Physics, offered initial encouragement and much helpful advice on scope and content during several revisions of the text. We would also like to acknowledge the helpful cooperation of the staff of D. Van Nostrand Co.

B. KURRELMEYER
WALTER H. MAIS

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Chapter 1

BASIC FACTS, LAWS, AND DEFINITIONS

Introduction

In this chapter we give a brief review of the basic experimental facts of electricity and magnetism. The definitions of electrical quantities and units are given in terms of these facts. The definitions are the link between operations of measurement and the operations of mathematical character which form the foundations of electromagnetic theory.

1.1 Charging by Contact

Phenomena that are typically electrical are observable through mechanical, thermal, chemical, or optical effects which appear when matter is brought into certain definite conditions by special procedures. One very simple electrical phenomenon, charging by contact, is detected by mechanical means. Two bodies A and B, of different materials, when brought into close contact and then separated, will be found to exert forces on each other. The forces are attractions, are many times larger than the force of gravitation between the two bodies, and act over considerable distances.

Let us prepare two identical specimens of material A, labeled A_1 and A_2, and also two specimens B_1 and B_2. Suppose A_1 is first brought into contact with B_1, while A_2 is brought into contact with B_2. Then the two A s will be found to repel each other, and the two B s will also repel each other, while either A will attract either B. We can now try specimens of the material A of different shapes and sizes, and we can try other pairs of materials. The results of all these experiments can be described by a single statement: The materials that attract the original A will repel the original B, and vice versa.

These and other similar experiments are interpreted to mean that any kind of matter contains particles of two kinds, which are normally present in such numbers that they counteract or *neutralize* each other as far as externally observable effects are concerned. All these particles are said to carry electrical charges. Our picture of charging by contact is that a certain number of particles of the one kind move from A to B, leaving behind an equivalent number of the other kind in excess on A. In agreement with this view is the fact that if A and B, after being