Revised Edition

AN INTRODUCTION TO ELECTRICAL ENGINEERING MATERIALS

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S. CHAND

AN INTRODUCTION TO ELECTRICAL ENGINEERING MATERIALS

(For the students of B.E./ B. Tech.)

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FOREWORD

It gives me great pleasure to write a foreword to this volume, which I hope will be the first of many to be prepared by the staff of the Electrical Engineering Department of the Indian Institute of Technology, Delhi. The aim of the Indian Institutes of Technology, to provide forward-looking courses for students who will make their careers in Indian industry, requires that text books suitable for such students should be readily available. The differences in back-ground and eventual requirements of these students make it highly desirable that text books should be prepared by staff in the Indian Institutes. Mr. Indulkar has spent a considerable time collecting the material for this volume, and has now been teaching this material to the under-graduates of the B.Tech. course of a number of years. He is therefore fully aware of the special needs of the group of students for whom he is writing.

The origin of this book dates from the period when I.I.T. Delhi, was a constituent college of Delhi University. The university Committee of Courses in Electrical Engineering accepted a proposal that Electrical materials should form a major part of the studies of Electrical Engineering undergraduates. It soon became obvious, however, that no textbook immediately available covered the content of the proposed syllabus. Mr. Indulkar very readily accepted my suggestion that he should prepare such a book, and I hope that it will reach the wide audience of students which it deserves.

JOHN BROWN, D.Sc. (*Engg.*) *M.I.E.E.*
Professor of Electrical Engineering,
University College, London.

PREFACE TO THE SIXTH EDITION

In sixth edition, a new chapter on "Semiconductor Fabrication Technology and Miscellaneous Semiconductor Devices" has been included. Additional self-assessment questions with answers and additional worked examples.

In this edition new pictures and problems has been added at the end of the book for the benefit of the students. The new sixth edition is published in a bigger size than the previous editions. The authors are thankful to S.chand Editorial Department for bringing out the new edition of the book with a larger size and a new layout.

AUTHORS

PREFACE TO THE FIRST EDITION

The Electrical Age has opened new problems to all connected with modern electrical industry, making a thorough working knowledge of the fundamental principles of the science of materials necessary. The increasing importance of this science has led to a number of new devices used in present day electrical engineering. As such the subject of electrical materials is occupying an important place in all electrical engineering undergraduate courses.

This book is an outgrowth of a course given by Prof. John Brown of the University College, London to the undergraduate students of the Indian Institute of Technology, Delhi. The main purpose with which this book was written was to present the students of electrical engineering with a single book containing a description of the syllabus known as "*Electrical Materials*". This book offers a first general introduction to the subject being mainly descriptive in nature and provides a guiding framework from which the reader may assess probable properties of electrical materials. Stress is laid on the basic physical processes responsible for the properties in materials. Since undergraduates have insufficient acquaintance with wave mechanies, quantum-mechanical concepts have been omitted. A number of tables have been included to give the student a feeling for the order of magnitude of the quantities which enter into the discussion. The author hopes that the inclusion of many illustrations and much descriptive matter will make the book interesting. The topics covered include conducting, dielectric, magnetic and semiconducting materials. As a necessary background for an electrical materials course, the book includes one chapter on "*The structure of the atom*". The complex permittivity problems is discussed in the chapter on "*Dielectric materials*". The chapter on "*Semi-conductors*" contains mostly a qualitative discussion of such materials, and covers the band theory. The chapter on "*Junction rectifiers and transistors*" gives the proof of the junction capacitance. A chapter on "*The measurement of electrical and magnetic properties*" is included. The discussion in this chapter is intended to present simple methods and techniques appropriate to various measurements on materials. The chapter on "*Conduction in liquids*" gives a general idea of electrochemistry and corrosion effects.

The book includes enough materials for a 3-hours per week course of one semester duration. Many practice problems are available at the end of nearly all chapters.

In collecting information on the subject many books on materials and solid state physics have been consulted. However, major portions of the book have been prepared from lecture notes. Hence it is possible that published material will sometimes have been used without proper acknowledgement. I regret any such inadvertences. A list of references which have been extensively consulted is given at the end of the book.

Thanks are due to those who have helped me to complete this book, and I must particularly mention Prof. John Brown who very patiently but with great enthusiasm, has gone over the major portion of the manuscript and has offered many valuable suggestions.

The author will welcome any suggestions for the improvement and notification of errors.

February, 1967
New Delhi.

AUTHORS

CONTENTS

Chapter

1

STRUCTURE OF THE ATOM

1.1 INTRODUCTION

The physical and chemical, properties of the atom indicates that each atom consists of a positively charged particle—the nucleus—and negatively charged particles—the electrons—the number of which in a neutral atom is equal to the atomic number of the given elements in the Periodic Table.

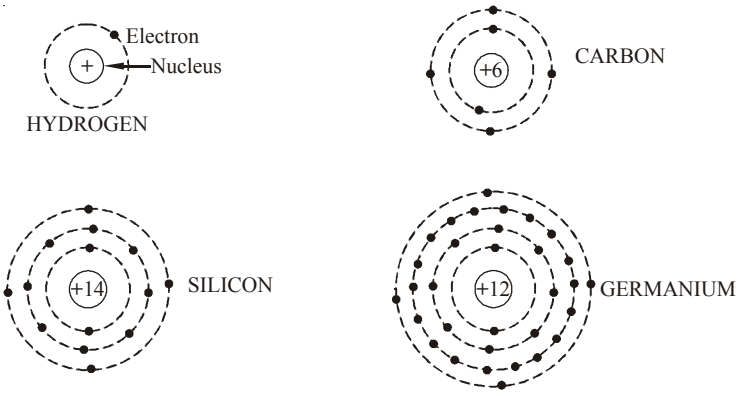

Fig. 1.1 *Hydrogen, carbon, silicon and germanium atoms.*

It is possible to remove one or more electrons from a neutral atom, the result being a positive ion. The energy necessary for ionisation may be imparted to the atom by the impact of an electron or it may be absorbed by the atom in the form of quantum of light (photon). The bombarding electrons acquire energy due to the presence of an electric field and therefore this energy called the ionisation potential is expressed in electron-volts. The inert gases have a large value and the alkaline metals have a small value for the ionisation potentials. The ionisation potentials for certain atoms are 13.5(H); 13.5 (O); 5.1 (Na).

The atomic structure of certain elements is capable of accommodating extra electrons thus forming negative ions like the H and O^- ions. The energy released in the process is called electron affinity and is also expressed in electron volts. The values of electron affinity for certain atoms are; 0.71 (H); 3.78 (Cl); 1.48 (O); 2.07 (S). The halogen atoms have the greatest electron affinity.

1.2 ELECTRON GROUPS

As the electrons are removed from the neutral atom, the charge of the remaining part of the atom (the atomic core) increases with a consequent increase in the attraction between the electrons and the atomic core. This results in an increase of energy which is required to remove further electrons.

Thus the minimum energy required to remove the first electrons from an atom is lower than that required to remove the second and subsequent electrons removed from the atom is not continuous, but exhibits sharp discontinuities, showing that the electrons in an atom are distributed in discrete energy groups or layers characterized by different binding strength of the electrons.

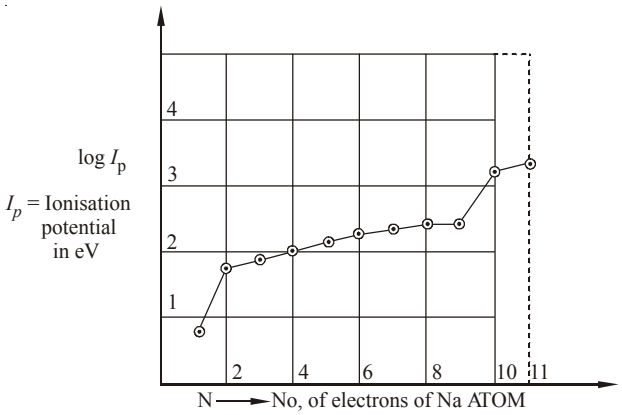

Fig. 1.2 *Ionisation potentials of the Na atoms*

The curve in Fig. 1.2 shows that the ionisation potential of sodium and its ions has two discontinuities, the first in the transition from the atom Na (N = 1) to the ion or Na^+ (N = 2) and the second in the transition from the ion Na^{+8} (N = 9) to the ion Na^{+9} (N = 10). It is seen from the curve that the first electron in the sodium atom is very weakly bound to the atom and the last two are more firmly bound. The remaining eight electrons are appreciably less firmly bound than the last two. Consequently, the 11 electrons of sodium are distributed into 3 groups : A two electrons group of firmly bound electrons, an eight-electron group and a group containing the loosely bound electrons. The latter must clearly lie in the outermost orbits whereas the 2 firmly bound electrons which require greatest energy for their removal must lie in an orbit closest to the nucleus.

1.3 MECHANICAL MODEL OF THE ATOM

The problem of getting a true picture of the atom has been considered since the discovery of the Periodic Law. The experiments of Rutherford led to the discovery of the atomic nucleus which served as a starting point for the construction of a modern theory of the atom. Rutherford postulated a planetary model of the atom in which electrons revolve about a heavy nucleus. This planetary theory of the atom served as the basis for Bohr's theory of the hydrogen atom. The theory immediately encountered difficulties that could not be surmounted by classical physics alone. One of the stumbling blocks was that an electrons revolving about a nucleus and, consequently, experiencing acceleration, should according to classical electrodynamics, be continually radiating energy and should ultimately and inevitably fall into the nucleus.

The only way to surmount this difficult was to give up classical electrodynamics and to consider it inapplicable to processes occurring inside the atom. Reasoning from this fact, Bohr postulated the existence of stable electron orbits in the atom, and suggested that orbital motion was not attended by the radiation of energy. In order to retain the stability of the orbit, Bohr suggested a quantum condition of the motion of the electron.

1.3.1 The Thomson model of the Atom

In the late nineteenth century, J.J. Thomson identified one of the basic constituents of matter namely the electron. Thomson found that, if certain materials were heated, they gave off some unique

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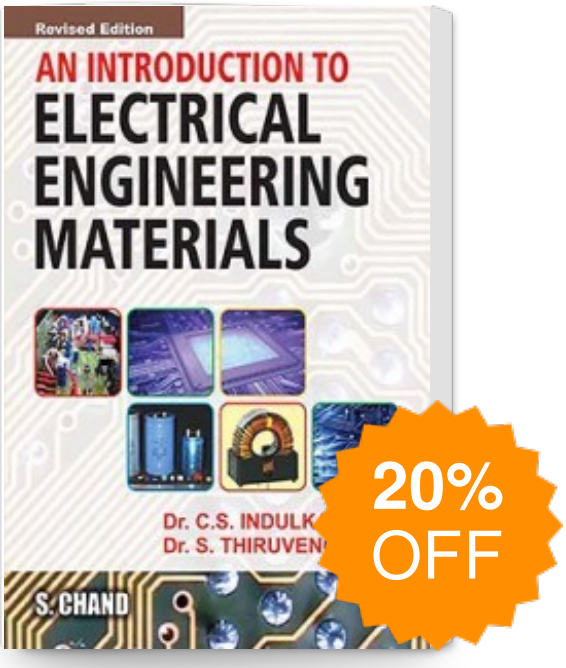

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