

Revised Edition

AN INTRODUCTION TO ELECTRICAL ENGINEERING MATERIALS



**Dr. C.S. INDULKAR
Dr. S. THIRUVENGADAM**

S. CHAND

AN INTRODUCTION TO ELECTRICAL ENGINEERING MATERIALS

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

Dr. C.S. INDULKAR

*B. Tech (Hons) (IIT Kharagpur), M.Sc. Tech. (Manchester), Ph.D. (Manchester)
Life Senior Member IEEE, F.I.E. (India)
Associate of the Manchester College of Science & Technology
Former Professor & Head, Electrical Engineering Department (IIT Delhi)*

Dr. S. THIRUVENGADAM

*Ph.D. (IIT Delhi)
Former Professor & Head, Electrical Engineering Department
National Institute of Technology, Calicut*



S. CHAND & COMPANY PVT. LTD.

(AN ISO 9001 : 2008 COMPANY)

RAM NAGAR, NEW DELHI-110055



S. CHAND & COMPANY PVT. LTD.

(An ISO 9001 : 2008 Company)

Head Office: 7361, RAM NAGAR, NEW DELHI - 110 055

Phone: 23672080-81-82, 9899107446, 9911310888 Fax: 91-11-23677446

Shop at: schandgroup.com; e-mail: info@schandgroup.com

Branches :

AHMEDABAD	: 1st Floor, Heritage, Near Gujarat Vidhyapeeth, Ashram Road, Ahmedabad - 380 014, Ph: 27541965, 27542369, ahmedabad@schandgroup.com
BENGALURU	: No. 6, Ahuja Chambers, 1st Cross, Kumara Krupa Road, Bengaluru - 560 001, Ph: 22268048, 22354008, bangalore@schandgroup.com
BHOPAL	: Bajaj Tower, Plot No. 243, Lala Lajpat Rai Colony, Raisen Road, Bhopal - 462 011, Ph: 4274723, bhopal@schandgroup.com
CHANDIGARH	: S.C.O. 2419-20, First Floor, Sector - 22-C (Near Aroma Hotel), Chandigarh - 160 022, Ph: 2725443, 2725446, chandigarh@schandgroup.com
CHENNAI	: No. 1, Whites Road, Near Clock Tower, Royapettah, Chennai 600014, chennai@schandgroup.com
COIMBATORE	: 1790, Trichy Road, LGB Colony, Ramanathapuram, Coimbatore - 6410045, Ph: 0422-2323620, 4217136 coimbatore@schandgroup.com (Marketing Office)
CUTTACK	: 1st Floor, Bhartia Tower, Badambadi, Cuttack - 753 009, Ph: 2332580; 2332581, cuttack@schandgroup.com
DEHRADUN	: 1st Floor, 20, New Road, Near Dwarka Store, Dehradun - 248 001, Ph: 2711101, 2710861, dehradun@schandgroup.com
GUWAHATI	: Pan Bazar, Guwahati - 781 001, Ph: 2738811, 2735640 guwahati@schandgroup.com
HYDERABAD	: Padma Plaza, H.No. 3-4-630, Opp. Ratna College, Narayanaguda, Hyderabad - 500 029, Ph: 24651135, 24744815, hyderabad@schandgroup.com
JAIPUR	: 1st Floor, Nand Plaza, Hawa Sadak, Ajmer Road, Jaipur - 302 006, Ph: 2219175, 2219176, jaipur@schandgroup.com
JALANDHAR	: Mai Hiran Gate, Jalandhar - 144 008, Ph: 2401630, 5000630, jalandhar@schandgroup.com
KOCHI	: Kachapilly Square, Mullassery Canal Road, Ernakulam, Kochi - 682 011, Ph: 2378207, cochin@schandgroup.com
KOLKATA	: 285/J, Bipin Bihari Ganguli Street, Kolkata - 700 012, Ph: 22367459, 22373914, kolkata@schandgroup.com
LUCKNOW	: Mahabeer Market, 25 Gwynne Road, Aminabad, Lucknow - 226 018, Ph: 2626801, 2284815, lucknow@schandgroup.com
MUMBAI	: Blackie House, 103/5, Walchand Hirachand Marg, Opp. G.P.O., Mumbai - 400 001, Ph: 22690881, 22610885, mumbai@schandgroup.com
NAGPUR	: Karnal Bag, Model Mill Chowk, Umrer Road, Nagpur - 440 032, Ph: 2723901, 2777666, nagpur@schandgroup.com
PATNA	: 104, Citicentre Ashok, Govind Mitra Road, Patna - 800 004, Ph: 2300489, 2302100, patna@schandgroup.com
PUNE	: 291/1, Ganesh Gayatri Complex, 1st Floor, Somwarpeth, Near Jain Mandir, Pune - 411 011, Ph: 64017298, pune@schandgroup.com (Marketing Office)
RAIPUR	: Kailash Residency, Plot No. 4B, Bottle House Road, Shankar Nagar, Raipur - 492 007, Ph: 09981200834, raipur@schandgroup.com (Marketing Office)
RANCHI	: Flat No. 104, Sri Draupadi Smriti Apartments, East of Jaipal Singh Stadium, Neel Ratan Street, Upper Bazar, Ranchi - 834 001, Ph: 2208761, ranchi@schandgroup.com (Marketing Office)
SILIGURI	: 122, Raja Ram Mohan Roy Road, East Vivekanandapally, P.O., Siliguri -734001, Dist., Jalpaiguri, (W.B.) Ph. 0353-2520750 (Marketing Office)
VISAKHAPATNAM	: Plot No. 7, 1st Floor, Allipuram Extension, Opp. Radhakrishna Towers, Seethammadhara North Extn., Visakhapatnam - 530 013, (M) 09347580841, visakhapatnam@schandgroup.com (Marketing Office)

© Copyright Reserved

All rights reserved. No part of this publication may be reproduced or copied in any material form (including photo copying or storing it in any medium in form of graphics, electronic or mechanical means and whether or not transient or incidental to some other use of this publication) without written permission of the copyright owner. Any breach of this will entail legal action and prosecution without further notice.

Jurisdiction : All disputes with respect to this publication shall be subject to the jurisdiction of the Courts, tribunals and forums of New Delhi, India only.

First Edition 1967

Subsequent Editions and Reprints 1977, 81, 84, 85, 87, 88, 90, 91, 92, 94, 96, 98, 99, 2000, 2001, 2004, 2006, 2007, 2008, 2009, 2010

Sixth Revised Edition 2011

Reprint 2013

ISBN : 81-219-0666-0

Code : 10B 059

PRINTED IN INDIA

By Rajendra Ravindra Printers Pvt. Ltd., 7361, Ram Nagar, New Delhi -110 055

and published by S. Chand & Company Pvt. Ltd., 7361, Ram Nagar, New Delhi -110 055.

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 mechanics, 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

Disclaimer : While the authors of this book have made every effort to avoid any mistake or omission and have used their skill, expertise and knowledge to the best of their capacity to provide accurate and updated information. The author and S. Chand does not give any representation or warranty with respect to the accuracy or completeness of the contents of this publication and are selling this publication on the condition and understanding that they shall not be made liable in any manner whatsoever. S.Chand and the author expressly disclaim all and any liability/responsibility to any person, whether a purchaser or reader of this publication or not, in respect of anything and everything forming part of the contents of this publication. S. Chand shall not be responsible for any errors, omissions or damages arising out of the use of the information contained in this publication. Further, the appearance of the personal name, location, place and incidence, if any; in the illustrations used herein is purely coincidental and work of imagination. Thus the same should in no manner be termed as defamatory to any individual.

CONTENTS

1. Structure of the Atom	1—66
1.1 Introduction	
1.2 Electron groups	
1.3 Mechanical model of the atom	
1.4 The wave nature of light	
1.5 The dual nature of matter	
1.6 Probability and the wave function	
1.7 The electron wave in one dimension	
1.8 The electron wave in two dimensions	
1.9 The electron wave in three dimensions	
1.10 The wave function and the four quantum numbers	
1.11 The Pauli exclusion principle	
1.12 The quantization of energy and multi-electron states	
1.13 The electronic charge distribution in multi-electron states	
1.14 Periodic Law	
1.15 Summary of the behaviour of electrons in atoms	
1.16 The arrangement of atoms in materials	
1.17 Crystallinity	
1.18 Anisotropy	
1.19 Fractional volume packing	
1.20 Crystal dimensions	
1.21 Miller indices, crystal directions and planes	
1.22 Interplaner separation	
1.23 Bragg's Law and X-ray diffraction	
Problems	
Self-assessment questions	
2. Conductivity of Metals (Part I)	67—79
2.1 Introduction	
2.2 Factors affecting the resistivity of electrical materials	
2.3 The electron gas model of a metal	
2.4 Motion of an electron in an electric field	
2.5 Equation of motion of an electron	
2.6 The current carried by electrons	
2.7 Mobility	
2.8 Energy levels of a molecule	
2.9 Fermi-Dirac distribution	
2.10 Summary	
Problems	
Self-assessment questions	

3	Conductivity of Metals (Part II)	80—104
3.1	Emission of electrons from metals	
3.2	Thermionic emission	
3.3	Photo-electric emission	
3.4	Field emission	
3.5	Secondary emission	
3.6	Contact Potential	
3.7	Effect of temperature on electrical conductivity of metals	
3.8	Superconductivity	
3.9	Electrical conducting materials	
3.10	Thermal properties	
3.11	Thermal conductivity of metals	
3.12	Specific heat of metals	
3.13	Contributions of electrons to the heat capacity of metals	
3.14	Thermoelectric effects	
3.15	Operation of thermo-couple	
3.16	Application of thermo-dynamics to a thermo-couple	
	Problems	
	Self-assessment questions	
4.	Dielectric Properties (Part I: Static Fields)	105—119
4.1	Introduction	
4.2	Effect of a dielectric on the behaviour of a capacitor	
4.3	Polarisation	
4.4	The dielectric constant of monoatomic gases	
4.5	Other polarisation mechanisms	
4.6	The internal field in solids and liquids	
4.7	The polarisability catastrophe	
	Problems	
	Self-assessment questions	
5.	Dielectric Properties (Part II: Alternating Fields)	120—148
5.1	Introduction	
5.2	Frequency dependence of electronic polarisability	
5.3	Frequency dependence of permittivity	
5.4	Frequency dependence of ionic polarisability	
5.5	Dielectric losses	
5.6	Significance of the loss tangent	
5.7	Dipolar relaxation	
5.8	Frequency and temperature dependence of the dielectric constant of polar dielectrics	
5.9	Dielectric properties of polymeric systems	
5.10	Ionic conductivity in insulators	
5.11	Insulating materials	
5.12	Ferroelectricity	
5.13	Piezoelectricity	
	Problems	
	Self-assessment questions	

6. Magnetic Properties of Materials	149—171
6.1 Introduction	
6.2 Classification of magnetic materials	
6.3 The origin of permanent magnetic dipoles	
6.4 Diamagnetism	
6.5 Paramagnetism	
6.6 Ferromagnetism	
6.7 The origin of ferromagnetism	
6.8 Ferromagnetic domains	
6.9 The magnetisation curve	
6.10 The hysteresis loop	
6.11 Magnetostriction	
6.12 Factors affecting permeability and hysteresis loss	
6.13 Common magnetic materials	
6.14 Anti-ferromagnetism	
6.15 Ferrimagnetism	
6.16 Magnetic Resonance	
Problems	
Self-assessment questions	
7. Semi-conductors	172—202
7.1 Semi-conductors	
7.2 Energy bands in solids	
7.3 Conductors, semiconductors, and insulators	
7.4 Types of semi-conductors	
7.5 Intrinsic semi-conductors	
7.6 Impurity type semi-conductor	
7.7 Interaction of a semi-conductor with time-dependent field	
7.8 Diffusion	
7.9 The Einstein relation	
7.10 Hall effect	
7.11 Thermal conductivity of semi-conductors	
7.12 Electrical conductivity of doped materials	
7.13 Materials for fabrication of semi-conductor devices	
Problems	
Self-assessment questions	
8. Junction Rectifiers and Transistors	203—226
8.1 Metal semi-conductor contacts	
8.2 p - n junction	
8.3 The barrier capacitance	
8.4 Breakdown phenomena in the barrier layer	
8.5 Junction diodes	
8.6 The junction transistor	
8.7 Thermistors and Varistors	
8.8 Semi-conductor materials	
8.9 Silicon controlled rectifier	
Problems	
Self-assessment questions	

9. Measurement of Electrical and Magnetic Properties	227—243
9.1 Introduction	
9.2 Conductivity measurement	
9.3 Dielectric measurement	
9.4 Magnetic measurement	
9.5 Measurement of semi-conductor parameters	
Problems	
Self-assessment questions	
10. Conduction of Liquids	244—256
10.1 Classification of conductors	
10.2 Electrolytic conduction	
10.3 Faraday's Law of electrolysis	
10.4 Electrons in electrolysis	
10.5 Experimental evidence for the dissociation theory	
10.6 Equivalent conductivity	
10.7 Ionic velocities	
10.8 Chemical cells and concentration cells	
10.9 Irreversible and reversible cells	
10.10 Practical Cell	
10.11 Electrolytic deposition	
10.12 Uses of electrolytic depositions	
10.13 Corrosion of metals	
10.14 Nature of Corrosion	
10.15 The origin and characteristics of corrosion currents	
10.16 Corrosive action of electric currents	
Problems	
11. Optical Properties of Solids	257—262
11.1 Photo-emission	
11.2 Photo-emissive materials and types of photo-cathodes	
11.3 Definition of terms	
11.4 Silver-oxygen Caesium cathode	
11.5 Antimony-Caesium Cathode (Cs_3Sb)	
11.6 Bismuth-silver-Oxygen Caesium cathode	
11.7 Multi-alkali photocathodes	
11.8 Electroluminescence	
11.9 Electroluminescent panels	
11.10 Junction-diode photoemitters	
11.11 Gallium arsenide	
11.12 Gallium phosphide	
11.13 Injection lasers	
11.14 Other materials	
Problems	
Self-assessment questions	
12. Materials for Electronic Components	263—281
12.1 Introduction	
12.2 Resistors	
12.3 Capacitors	

12.4 Inductors	
12.5 Relays	
Problems	
Self-assessment questions	
13. Mechanical Properties	282—292
13.1 Introduction	
13.2 The stress/strain relationship	
13.3 Plastic behaviour	
13.4 Block slip theory	
13.5 Hardening	
13.6 Ductility	
13.7 Cold working, recrystallization and annealing	
13.8 Creep and fatigue	
Problems	
Self-Assessment Questions	
14. Semiconductor Technology and Miscellaneous Semiconductor Devices	293—328
14.1 Fabrication Technology	
14.2 Grown junction	
14.3 Alloyed junction process	
14.4 Diffused junction technique	
14.5 Epitaxial diffused junction diode	
14.6 Fabrication of junction transistors	
14.7 Field-effect devices	
14.8 JFET	
14.9 Drain and Transfer characteristics of JFET	
14.10 IGFET	
14.11 Other field-effect devices	
14.12 Gunn diode	
14.13 Light-emitting diode (LED)	
14.14 LASER	
14.15 IMPATT diode (Impact Avalanche Transit Time Diode)	
14.16 Integrated Circuits	
Problems	
Additional Self-Assessment Questions with Answers	329—335
Additional Worked Examples	336—352
Appendix A NANOMATERIALS	353—357
Appendix B METALLIC GLASSES	358—360
Appendix C SOLAR/PHOTOVOLTAIC CELL	361—372
Appendix D FUEL CELLS/BIOFUELS	373—375
Index	376—379

STRUCTURE OF THE ATOM

1.1 INTRODUCTION

The physical and chemical properties of the atom indicate 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.

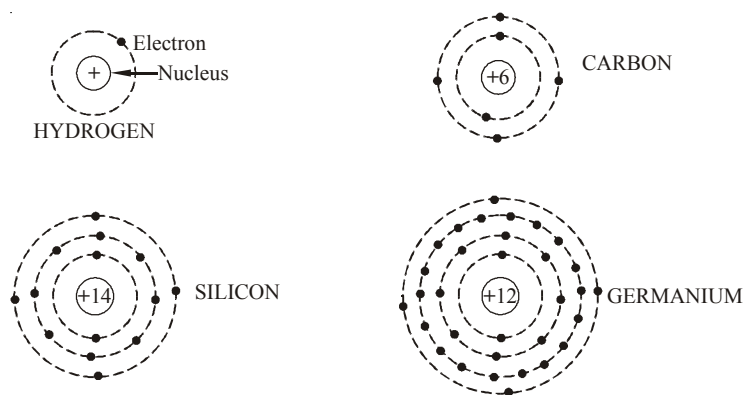


Fig. 1.1 Hydrogen, carbon, silicon and germanium atoms.

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.

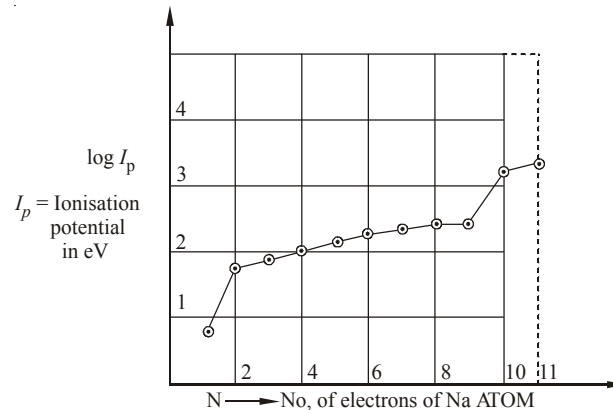


Fig. 1.2 Ionisation potentials of the Na atoms

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

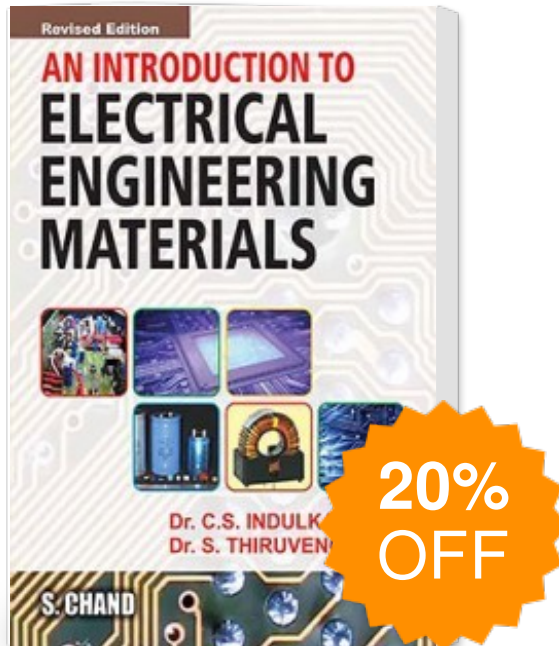
The problem of getting a true picture of the atom has been considered since the discovery of the Periodic Law. The experiments of Rutherford led to the discovery of the atomic nucleus which served as a starting point for the construction of a modern theory of the atom. Rutherford postulated a planetary 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

An Introduction to Electrical Engineering Materials



Publisher : SChand Publications ISBN : 9788121906661

Author : C S Indulkar

Type the URL : <http://www.kopykitab.com/product/10360>



Get this eBook