Electronics Engineers' Handbook

Donald G. Fink, Editor-in-Chief

ELECTRONICS ENGINEERS' HANDBOOK

DONALD G. FINK, Editor-in-Chief

Executive Director and General Manager, Institute of Electrical and Electronics Engineers (Ret.);
Formerly Vice President—Research, Philco Corporation,
President of the Institute of Radio Engineers,
Editor of the Proceedings of the IRE;
Member, National Academy of Engineering;
Fellow of the Institute of Electrical and Electronics Engineers;
Fellow of the Institution of Electrical Engineers (London);
Eminent Member, Eta Kappa Nu

ALEXANDER A. McKENZIE, Assistant Editor

Contributing Editor, IEEE Spectrum,
Formerly Senior Editor, Electronics,
Editorial Manager, McGraw-Hill Book Company,
Member of the Technical Staff, M.I.T. Radiation Laboratory;
Senior Member, Institute of Electrical and Electronics Engineers

First Edition

McGRAW-HILL BOOK COMPANY

New York St. Louis San Francisco Auckland Düsseldorf
Johannesburg Kuala Lumpur London Mexico Montreal
New Delhi Panama Paris São Paulo
Singapore Sydney Tokyo Toronto

Library of Congress Cataloging in Publication Data

Fink, Donald G
Electronics engineers' handbook.

1. Electronics—Handbooks, manuals, etc. I. Title.
TK7825.F56 621.381'02'02 74-32456
ISBN 0-07-020980-4

1234567890 QBQB 784321098765

The editors for this book at McGraw-Hill were Harold B. Crawford, Robert E. Curtis, and Robert Braine, and the production supervisor was Stephen J. Boldish. It was set in Times Roman by Rocappi/Lehigh, Inc.

It was printed and bound by Quinn & Boden Company, Inc.

CONTRIBUTORS

Byron S. Anderson, Communications Consultant, formerly Chief, Information Acquisition Technical Area, United States Army Electronics Command (Sec. 22)

Howard P. Apple, Assistant Professor of Biomedical Engineering, Case Western Reserve University (Sec. 26)

Richard Babbitt, United States Army Electronics Command (Sec. 7)

Henry Ball, Research and Engineering, RCA Corporation (Sec. 20)

David K. Barton, Consulting Scientist, Missile Systems Division, Raytheon Co. (Sec. 25)

Ilan A. Blech, Associate Professor, Department of Materials Engineering, Technion-Israel Institute of Technology, Haifa (Sec. 6)

W. Calder, Chairman, Corporate Products Safety Committee, The Foxboro Company (Sec. 24)

Robert A. Castrignano, EVR Technology Department, CBS Laboratories (Sec. 20)

Joseph L. Chovan, Senior Engineer, Electronics Laboratory, General Electric Company (Sec. 14)

Wils L. Cooley, Assistant Professor of Electrical Engineering, West Virginia University (Sec. 3)

Munsey E. Crost, United States Army Electronics Command (Sec. 7, 11)

William F. Croswell, Head, Antenna Research Section, Langley Research Center, National Aeronautics & Space Administration (Sec. 18)

N. A. Diakides, United States Army Electronics Command (Sec. 11)

Milton Dishal, Senior Scientist, International Telephone and Telegraph Corporation Laboratories (Sec. 12)

Sam Di Vita, United States Army Electronics Command (Sec. 7)

Sven H. Dodington, Assistant Technical Director, International Telephone and Telegraph Corporation (Sec. 25)

C. Nelson Dorny, Associate Professor, Moore School of Electrical Engineering, University of Pennsylvania (Sec. 5)

Beverly Dudley, Consultant, formerly Staff Member, Institute for Defense Analyses (Sec. 1)

P. D. Dunn, Professor of Engineering Science, Department of Engineering and Cybernetics, The University of Reading, England (Sec. 27)

Myron D. Egtvedt, Senior Engineer, Electronics Laboratory, General Electric Company (Sec. 14)

Stanley L. Ehrlich, Consulting Engineer, Submarine Signal Division, Raytheon Company (Sec. 25)

J. C. Engel, Westinghouse Research Laboratories (Sec. 15)

C. H. Evans, Research Laboratories, Eastman Kodak Company (Sec. 20)

David G. Falconer, Research Physicist, Stanford Research Institute (Sec. 20)

George K. Farney, Varian Associates (Sec. 9)

Kenneth A. Fegley, Professor, Moore School of Electrical Engineering, University of Pennsylvania (Sec. 5)

Joseph Feinstein. Varian Associates (Sec. 9)

C. S. Fox. United States Army Electronics Command (Sec. 11)

R. E. Franseen. United States Army Electronics Command (Sec. 11)

Donald A. Fredenberg. Principal Engineer, Submarine Signal Division, Raytheon Company (Sec. 25)

Richard W. French. ELEMEK, Incorporated (Sec. 13)

E. Gaddy. Goddard Space Flight Center (Sec. 11)

Rodger L. Gamblin. Area Manager, Chemical Products Development, Office Products Division, IBM Corporation (Sec. 23)

Glenn B. Gawler. Senior Engineer, Barker Manufacturing Company (Sec. 14)

E. A. Gerber. Consultant, United States Army Electronics Command (Sec. 7)

Robert A. Gerhold. United States Army Electronics Command (Sec. 7)

Joseph M. Giannotto. United States Army Electronics Command (Sec. 7)

Charles H. Gibbs. Assistant Clinical Professor and Senior Research Associate, School of Dentistry and Engineering Design Center, Case Western Reserve University (Sec. 26)

S. B. Gibson. United States Army Electronics Command (Sec. 11)

Emanuel Gikow. Late United States Army Electronics Command (Sec. 7)

L. F. Gillespie. United States Army Electronics Command (Sec. 11)

B. Goldberg. Formerly United States Army Electronics Command (Sec. 11)

Thomas S. Gore, Jr., United States Army Electronics Command (Sec. 7)

R. D. Graft. United States Army Electronics Command (Sec. 11)

Alan B. Grebene. Vice-President Engineering, Exar Integrated Systems, Incorporated (Sec. 8)

W. A. Gutierrez. United States Army Electronics Command (Sec. 11)

Gunter K. Guttwein. United States Army Electronics Command (Sec. 7)

L. Gyugyi. Westinghouse Research Laboratories (Sec. 15)

Edward B. Hakim. United States Army Electronics Command (Sec. 7)

P. D. Hansen. Senior Technical Consultant, The Foxboro Company (Sec. 24)

G. Burton Harrold. Senior Engineer, Electronics Laboratory, General Electric Company (Sec. 13)

Jack H. Heimann. Principal Engineer, Submarine Signal Division, Raytheon Company (Sec. 25)

T. M. Heinrich. Westinghouse Research Laboratories (Sec. 15)

William P. Heising. Systems Development Division, IBM Corporation (Sec. 23)

Joseph P. Hesler. Consulting Engineer, Electronics Laboratory, General Electric Company (Sec. [illegible])

Gerhard E. Hoernes. Systems Products Division, IBM Corporation (Sec. 23)

D. J. Horowitz. United States Army Electronics Command (Sec. 11)

William [illegible] Hughes. Professor and Head of the School of Electrical Engineering, Oklahoma State University (Sec. 20)

G. M. Janney. Hughes Aircraft Company (Sec. 11)

Paul G. A. Jespers. Professor of Electrical Engineering, Institut d'Electricité, Catholic University of Louvain, Belgium (Sec. 16)

C. A. Johnson. United States Army Electronics Command (Sec. 11)

Earle D. Jones. Manager Electronics and Optics Group, Stanford Research Institute (Sec. 20)

Peter G. Katona. Associate Professor of Biomedical and Electrical Engineering, Case Western Reserve University (Sec. 26)

Chang S. Kim. Consulting Engineer, Electronics Laboratory, General Electric Company (Sec. 13)

Raymond S. Kiraly. Director of Engineering, Department of Artificial Organs, Research Division, Cleveland Clinic Foundation (Sec. 26)

Richard C. Kirby, Director, International Radio Consultative Committee, Geneva, Switzerland (Sec. 18)
Joseph H. Kirshner, United States Army Electronics Command (Sec. 7)
Myron W. Klein, Associate Director for Research and Development, Night Vision Laboratory, United States Army Electronics Command (Sec. 11)
W. Klein, United States Army Electronics Command (Sec. 11)
Wen H. Ko, Director, Engineering Design Center, Professor of Electrical Engineering, Professor of Biomedical Engineering, Case Western Reserve University (Sec. 26)
Granino A. Korn, Professor of Electrical Engineering, The University of Arizona (Sec. 2)
Theresa M. Korn, Tucson, Arizona (Sec. 2)
Samuel M. Korzekwa, Senior Engineer, Electronics Laboratory, General Electric Company (Sec. 13)
Henry N. Kozanowski, Commercial Electronic Systems Division, RCA Corporation (Sec. 20)
Ezra S. Krendel, Professor, Wharton School, University of Pennsylvania (Sec. 5)
Joseph A. Kuzneski, Senior Engineer, Submarine Signal Division, Raytheon Company (Sec. 25)
J. L. Lee, Manager, Program Management Services, The Foxboro Company (Sec. 24)
David Linden, United States Army Electronics Command (Sec. 7)
Harold W. Lord, Consulting Engineer (Sec. 13)
John W. Lunden, Senior Engineer, Electronics Laboratory, General Electric Company (Sec. 13)
Gregory J. Malinkowski, United States Army Electronics Command (Sec. 7)
P. R. Manzo, United States Army Electronics Command (Sec. 11)
Daniel W. Martin, Research Director, Engineering Research Department, D. H. Baldwin Company (Sec. 19)
Robert J. McFadyen, Consulting Engineer, Electronics Laboratory, General Electric Company (Sec. 13)
C. A. McKay, Corporate Director of Research Development and Engineering, The Foxboro Company (Sec. 24)
Floro Miraldi, Professor of Engineering, Case Western Reserve University (Sec. 26)
J. Thomas Mortimer, Associate Professor of Biomedical Engineering, Case Western Reserve University (Sec. 26)
J. W. Motto, Westinghouse Research Laboratories (Sec. 15)
Conrad E. Nelson, Senior Consulting Engineer, Heavy Military Electronic Systems, General Electric Company (Sec. 13)
Richard B. Nelson, Varian Associates (Sec. 9)
Michael R. Neuman, Associate Professor of Biomedical Engineering, Case Western Reserve University (Sec. 26)
W. E. Newell, Westinghouse Research Laboratories (Sec. 15)
Harry N. Norton, Member, Technical Staff, Jet Propulsion Laboratory, California Institute of Technology (Sec. 10)
Yukihiko Nosé, Department Head, Research Division, Department of Artificial Organs, Cleveland Clinic Foundation (Sec. 26)
R. M. Oates, Westinghouse Research Laboratories (Sec. 15)
Norman W. Parker, Staff Scientific Adviser, Motorola Incorporated (Sec. 20, 21)
B. R. Pelley, Westinghouse Research Laboratories (Sec. 15)
George F. Pfeifer, Senior Engineer, Electronics Laboratory, General Electric Company (Sec. 14)
P. F. Pittman, Westinghouse Research Laboratories (Sec. 15)
Robert Plonsey, Professor Biomedical Engineering, Case Western Reserve University (Sec. 26)

H. K. Pollehn, United States Army Electronics Command (Sec. 11)
Noble R. Powell, Consulting Engineer, Electronics Laboratory, General Electric Company (Sec. 14)
J. R. Predham, United States Army Electronics Command (Sec. 11)
Donald A. Priest, Varian Associates (Sec. 9)
E. G. Ramberg, RCA Laboratories, RCA Corporation (Sec. 20)
I. Reingold, United States Army Electronics Command (Sec. 7, 11)
Frederick M. Remley, Jr., Television Center, University of Michigan (Sec. 20)
Keith Y. Reynolds, International Video Corporation (Sec. 20)
D. A. Richardson, Development Project Engineer, The Foxboro Company (Sec. 24)
S. P. Rodak, United States Army Electronics Command (Sec. 11)
G. A. Rosica, Manager of Electronic Development and Engineering, The Foxboro Company (Sec. 24)
L. E. Scharmann, United States Army Electronics Command (Sec. 7)
E. J. Sharp, United States Army Electronics Command (Sec. 11)
R. R. Shurtz II, United States Army Electronics Command (Sec. 11)
Paul Skitzki, Technical Consultant, Submarine Signal Division, Raytheon Company (Sec. 25)
Jack Spergel, Late United States Army Electronics Command (Sec. 7)
Hans H. Stellrecht, Signetics Corporation (Sec. 8)
Joseph L. Stern, Vice President and Director of Engineering, Goldmark Communications Corporation (Sec. 21)
George W. Taylor, United States Army Electronics Command (Sec. 7)
Stephen W. Tehon, Consulting Engineer, Electronics Laboratory, General Electric Company (Sec. 13)
John B. Thomas, Professor of Electrical Engineering, Princeton University (Sec. 4)
Francis T. Thompson, Director, Electronics and Electromagnetics Research, Research Laboratories, Westinghouse Electric Corporation (Sec. 17)
Howard W. Town, Video Systems Division, Ampex Corporation (Sec. 20)
Harold R. Ward, Principal Engineer, Missile Systems Division, Raytheon Company (Sec. 25)
Gunter K. Wessel, Professor, Physics Department, Syracuse University (Sec. 13)
Everard M. Williams, Late George Westinghouse Professor of Engineering, Carnegie-Mellon University (Sec. 3)
R. A. Williamson, Jr., Senior Research Engineer, The Foxboro Company (Sec. 24)
R. S. Wiseman, Director, Research, Development and Engineering, and Director of Laboratories, United States Army Electronics Command (Sec. 11)

PREFACE TO THE FIRST EDITION

This new Handbook is the first to be devoted to the field of electronics engineering at large. Earlier important handbooks, notably those of Terman and of Henney, treated the field primarily from the point of view of the first important application in the field—radio engineering. Segments of the electronics field are treated exhaustively in excellent current handbooks, the majority of which appear in the bibliographies of this volume. But—surprisingly in view of the pervasive influence of electronics in so many areas of human endeavor—no one has heretofore attempted to bring together in one volume the essential principles, data, and design information on the components, circuits, equipment, and systems of electronics engineering as a whole. The present work is intended to fill the evident need for such a comprehensive single volume. Assembling its contents has proved to be a major undertaking, involving material contributed by 128 experts in their individual fields.

The present Handbook is a companion volume to the *Standard Handbook for Electrical Engineers*, the tenth edition of which was planned and edited by the undersigned. This "Electrical Handbook" is devoted primarily to the techniques of electrical power engineering, that is, the generation, transmission, distribution and utilization of electricity in macroscopic ("heavy current") forms. The many applications of electronics to the electrical power field are covered extensively in that volume. But, as I wrote in the Preface to the Tenth Edition, "to provide comprehensive design data on electronics circuits, systems and equipment would require another volume of equal size." This new "Electronics Handbook" is that volume and it is indeed of equal size: 2150 pages, one million words of text, 340 tables, 2000 illustrations, and 2500 bibliographic entries.

Aside from the different focus of subject matter, the aim of the Electronics Handbook is the same as that of its sister Electrical Handbook: to contain in a single volume all pertinent data within its scope, to be accurate and comprehensive in technical treatment, to be used in engineering practice (as well as in study in preparation for practice), and to be oriented toward application rather than theory. Sections on basic principles are included, but the predominant thrust is the practical use of those principles in engineering practice.

The Handbook is organized in four major divisions: *Principles Employed in Electronics Engineering*, Sections 1-5 inclusive; *Components, Devices and Assemblies*, Sections 6-11; *Circuits and Functions*, Sections 12-18; and *Systems and Applications*, Sections 19-27. The reader's attention is directed particularly to Section 6, *Properties of Materials*, prepared by Professor Blech of the Israel Institute of Technology. Contained in this 138-page section is, to the editor's knowledge, the most comprehensive compilation of data on materials used in electronics ever to appear in print.

While great care has been exercised in proofreading by the contributors and editors to check and recheck the data presented, it is inevitable that, in a first edition of a work of this size, some errors remain. The editor will appreciate these being brought to his attention.

The substantial effort made by all the contributors, not only to cover their special fields comprehensively, but to present their work in the most compact fashion consistent with informed and ready use, is gratefully acknowledged. I wish to thank particularly Assistant Editor Alexander A. McKenzie for the care with which he has guided the contributors in the final stages of editing and for his aid in the production of the book.

Donald G. Fink
Editor-in-Chief

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BASIC PHENOMENA OF ELECTRONICS

BY

B. DUDLEY Consultant, formerly Staff Member, Institute for Defense Analyses, Editor Technology Review, Massachusetts Institute of Technology; Senior Member, IEEE

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SECTION 1

BASIC PHENOMENA OF ELECTRONICS

ELECTRONIC PROPERTIES AND STRUCTURE OF MATTER

1. Elementary Particles. The charged elementary particles of principal interest in electronics are the electron and the proton, designated e^- and p^+, respectively. The hydrogen atom, for example, consists of one electron and one proton. The mass, charge, and charge-to-mass ratios of these particles are as follows (where C stands for coulomb and kg for kilogram):

Mass at rest, of electron	9.1096×10^{-31} kg
Of proton	1.6726×10^{-27} kg
Charge of electron	-1.6022×10^{-19} C
Of proton	$+1.6022 \times 10^{-19}$ C
Charge-to-mass ratio, for electron	1.7588×10^{11} C/kg
For proton	9.5791×10^{7} C/kg

The elementary particles whose existence has been experimentally verified or postulated on theoretical grounds are listed in Table 1-1.

2. Atomic Structure. The atoms of each element consist of a dense nucleus around which electrons travel in well-defined orbits, or shells. The total mass of the nucleons (protons and neutrons) is taken to be equal to the mass of the atom. The number of nuclear protons is equal to the *atomic number Z* of the element. The number of nucleons is equal to the *mass number A* of the atom, and $A - Z$ is the number of neutrons in the nucleus. Heavy atoms have more neutrons than protons; excess of neutrons over protons is important in determining the stability of atoms, i.e., their radioactive properties. Atoms having the same atomic number but different mass numbers have the same chemical properties but different atomic weights. They are called *isotopes* of the chemical element.

The diameter of the atomic nucleus is between 10^{-15} and 10^{-16} m, whereas the diameter of the outer orbiting electrons (taken to be the diameter of the atom) is of the order of 10^{-10} m.

The nucleus carries a positive charge equal to the atomic number Z of the element times $+1.6 \times 10^{-19}$C, the charge of a proton. In the normal (un-ionized) atom there are Z orbiting electrons, each with negative charge $e^- = -1.6 \times 10^{-19}$C. At distances large compared with the atomic radius, the atom shows no net electric charge.

The extranuclear (electronic) structure of the atom is characteristic of the element. The orbiting electrons are arranged in successive *shells*. In order of increasing distance from the nucleus these shells are designated K, L, M, N, O, P, and Q. The number of electrons each shell can contain is limited. The electrons of the inner shells of complex atoms are tightly bound to the nucleus, and their paths can be altered only by high-energy particles, such as gamma rays. In the more complex atoms, electrons of the outer shells are relatively loosely bound to the nucleus. The outer shells account for the chemical and electrical properties of the elements.

3. Electron Orbits, Shells, and Energy States. Each orbiting electron in an atom has energy which is uniquely characterized by four *quantum numbers*. According to Pauli's exclusion principle, the wave functions describing the electrons must differ by at least one quantum number in the complete set required for their description.

An electron within an atom may be specified in terms of (1) a *principal quantum number n*, (2) an *azimuthal quantum number l*, (3) a *spatial quantum number* m_l, and (4) a *spin quantum number* m_s *or s*. The principal quantum number n specifies the shell in which an electron is located and hence principally specifies the energy state of the electron. Electrons lodged in the K, L, M, N, O, P, and Q shells have principal quantum numbers $n = 1, 2, 3, 4, 5, 6,$ or 7, respectively.

Table 1-1. Elementary Particles

Family name	Name of particle	Symbol	Mass (e = 1.0)	Mass, MeV	Lifetime, s	Spin	Charge (e = -1.0)	Anti-particle
	Photon	γ	0	0	∞	1	0	γ
Electron	Electron	e^-	1	0.51098	∞	½	−1	e^+
	Electron neutrino	ν_e	0	0	∞	½	0	$\bar{\nu}_e$
Muon	Muon	μ^-	206.768	105.654	2.212×10^{6}	½	−1	μ^+
	Muon neutrino	ν_μ	...	0	∞	½	0	$\bar{\nu}_\mu$
Meson	Pion, positive	π^+	273.18	139.59	2.55×10^{8}	0	1	π^-
	Neutral	π^0	264.20	135.0	1.9×10^{16}	0	0	π^0
	Kaon, positive	K^+	966.6	493.9	1.22×10^{8}	0	1	$\bar{K}^+$
	Neutral	K^0	974.2	497.8	1.0×10^{10} 6.1×10^{8}	0	0	$\bar{K}^0$
Baryons	Nucleon, proton	p^+	1,836.12	938.213	∞	½	1	$\bar{p}^+$
	Nucleon, neutron	n^0	1,838.65	939.507	1.013×10^{3}	½	0	$\bar{\pi}^0$
	Lambda	Λ^0	2,182.8	1,115.36	2.51×10^{10}	½	0	$\bar{\Lambda}^0$
	Sigma, positive	Σ^+	2,327.7	1,189.40	8.1×10^{11}	½	1	$\bar{\Sigma}^+$
	Neutral	Σ^0	2,332	1,191.5	$\sim 10^{20}$	½	0	$\bar{\Sigma}^0$
	Negative	Σ	2,340.5	1,195.6	1.6×10^{10}	½	−1	$\bar{\Sigma}^-$
	Xi, neutral	Ξ^0	2,566	1,311	1.5×10^{10}	½	0	$\bar{\Xi}^0$
	Negative	Ξ	2,580	1,318	1.28×10^{10}	½	−1	$\bar{\Xi}^-$

The azimuthal quantum number l specifies the angular orbital momentum of an electron in each orbital state in various subshells. Together with n, the value of l designates the eccentricity of an electron orbit; the smaller the value of l the greater the eccentricity of the orbits for any given shell. The magnitudes of l may be any integer from 0 to $n - 1$. Electrons whose values of l are 0, 1, 2, 3, 4, and 5, respectively, are referred to as the s, p, d, g, and f electrons. The number of electrons in a subshell is determined by restrictions on m_l and m_s imposed by Pauli's exclusion principle.

The spatial quantum number m_l specifies differently oriented orbits having the same general shape; it specifies the orientation of the magnetic field of the electron orbit. This quantity is the projection of l on the magnetic axis; it may have $\pm(2l - 1)$ integral values from $-l$ to $+l$ including 0.

The spin quantum number, m_s or s, specifies the direction of spin of an electron on its own axis. Corresponding to spin in opposite directions, the two spin quantum numbers are $+h/2$ and $-h/2$, where $h/2\pi$ is Planck's constant ($= 6.626 \times 10^{-34}$ joule · s).

In a normal atom, orbiting electrons are arranged in the set of allowed states having the lowest total energy. As the complexity of atoms increases from hydrogen to uranium (the latter having 92 protons, and 146 neutrons), the electrons fill the shells and subshells by taking those states having the lowest total energy. Sometimes the energy state of an inner shell is less than that of a state in the outermost shell, and this accounts for the fact that some shells may begin to be filled before inner shells are totally filled.

4. Chemical Valence. The chemical properties of the elements are determined by the electrons in the outermost shell (valence electrons). Atoms with completely filled outer shells (the rare gases: helium, argon, krypton, xenon, and radon) are chemically inert. They contain eight electrons in their outer shells.

Atoms with a single electron in the outer shell (lithium, sodium, potassium, rubidium, cesium, franconium, and hydrogen) can easily lose their outer electron. They then become positive ions with completely filled shells.

Atoms with seven outer-shell electrons (the halogens: fluorine, chlorine, bromine, iodine, and astatine) readily pick up an electron from other atoms and become negative ions; they form molecules by sharing electrons and are said to have ionic bonding. Atoms with other numbers of outer-shell electrons tend to unite with other atoms in such ways that each atom has eight outer-shell electrons. Partially filled inner shells have an important bearing on the magnetic properties of the elements.

5. Conduction Electrons. When electrons are in close proximity in crystalline solids, the presence of nearby atoms affects their behavior, and their energies are no longer uniquely determined. The single energy level of an electron in a free or isolated atom is thereby spread into a band, or range, of energy levels. Whether or not the band of allowed energies is completely filled with electrons determines its properties as an electric conductor or insulator.

The *conduction band* is a range of states in the free-energy spectrum of a solid in which electrons can move freely; i.e., the electrons must be capable of effecting transitions among energy states. The valence electrons in metals, for example, are not firmly attached to individual atoms but are free to travel within the crystal lattice. Such electrons are called *conduction electrons.* There is one such conduction electron per atom in silver, copper, gold, and the alkali metals, all of which are good conductors.

An insulator or dielectric is a material in which every energy level, or quantum state, is filled and the electrons are unable to effect the transitions among states required for electric conduction.

6. Chemical Bonds and Compound Formation. Chemical bonds occur when the total energy of an aggregate is less with atoms near each other than separated. The charges of the atom play an important role in bonding, especially electrons in the outer shells.

Electrostatic or *ionic bonds* result from attractive forces between positive and negative ions or between pairs of oppositely charged ions. *Covalent bonds* occur when atoms share two or more electrons; i.e., shared electrons are attracted simultaneously to two atoms, and the resulting energy stability produces the bond. *Metallic bonds* are those in which the attractive forces result from the exchange interaction of the electron gas with the ionic lattice. *Van der Waals bonds* occur when molecules are formed, giving each atom an outer shell of eight atoms, as in an inert gas.

7. Energy Conservation. In a system in which all types of energy can be determined