American Institute of Physics Handbook

Third Edition

Section Editors

BRUCE H. BILLINGS, Ph.D.
Commissioner, Joint Commission on Rural Reconstruction
Taipei, Taiwan

D. F. BLEIL, Ph.D.
Associate Technical Director and Head, Research
U.S. Naval Ordnance Laboratory

RICHARD K. COOK, Ph.D.
Special Assistant for Sound Programs, Office of Deputy Director
The National Bureau of Standards

H. M. CROSSWHITE, Ph.D.
Adjunct Professor of Spectroscopy, Physics Department
The Johns Hopkins University

H. P. R. FREDERIKSE, Ph.D.
Chief, Solid State Physics Section
The National Bureau of Standards

R. BRUCE LINDSAY, Ph.D.
Professor of Physics, Emeritus, Brown University

J. B. MARION, Ph.D.
Professor of Physics, Department of Physics and Astronomy
University of Maryland

MARK W. ZEMANSKY, Ph.D.
Professor of Physics
The City College of the City University of New York

Coordinating Editor

Dwight E. Gray, Ph.D.
American Institute of Physics

McGraw-Hill Book Company

New York St. Louis San Francisco Düsseldorf Johannesburg
Kuala Lumpur London Mexico Montreal New Delhi
Panama Rio de Janeiro Singapore Sydney Toronto

OTHER McGRAW-HILL HANDBOOKS OF INTEREST

American Society of Mechanical Engineers · ASME Handbooks:
Engineering Tables
Metals Engineering—Design
Metals Engineering—Processes
Metals Properties
Baumeister and Marks · Standard Handbook for Mechanical Engineers
Berry, Bollay, and Beers · Handbook of Meteorology
Blatz · Radiation Hygiene Handbook
Brady · Materials Handbook
Burington · Handbook of Mathematical Tables and Formulas
Burington and May · Handbook of Probability and Statistics with Tables
Callender · Time-Saver Standards
Chow · Handbook of Applied Hydrology
Condon and Odishaw · Handbook of Physics
Considine · Process Instruments and Controls Handbook
Considine and Ross · Handbook of Applied Instrumentation
Etherington · Nuclear Engineering Handbook
Fink and Carroll · Standard Handbook for Electrical Engineers
Flügge · Handbook of Engineering Mechanics
Grant · Hackh's Chemical Dictionary
Hamsher · Communication System Engineering Handbook
Harris and Crede · Shock and Vibration Handbook
Henney · Radio Engineering Handbook
Hicks · Standard Handbook of Engineering Calculations
Hunter · Handbook of Semiconductor Electronics
Huskey and Korn · Computer Handbook
Ireson · Reliability Handbook
Juran · Quality Control Handbook
Kaelble · Handbook of X-rays
Kallen · Handbook of Instrumentation and Controls
King and Brater · Handbook of Hydraulics
Klerer and Korn · Digital Computer User's Handbook
Koelle · Handbook of Astronautical Engineering
Korn and Korn · Mathematical Handbook for Scientists and Engineers
Landee, Davis, and Albrecht · Electronic Designers' Handbook
Lange · Handbook of Chemistry
Machol · System Engineering Handbook
Mantell · Engineering Materials Handbook
Markus · Electronics and Nucleonics Dictionary
Meites · Handbook of Analytical Chemistry
Merritt · Standard Handbook for Civil Engineers
Perry · Engineering Manual
Perry, Chilton, and Kirkpatrick · Chemical Engineers' Handbook
Richey · Agricultural Engineers' Handbook
Rothbart · Mechanical Design and Systems Handbook
Streeter · Handbook of Fluid Dynamics
Terman · Radio Engineers' Handbook
Touloukian · Retrieval Guide to Thermophysical Properties Research Literature
Truxal · Control Engineers' Handbook
Urquhart · Civil Engineering Handbook
Wolman · Handbook of Clinical Psychology

Section 1

MATHEMATICS BIBLIOGRAPHY; SI UNITS

CONTENTS

The third edition of the AIP Handbook, like the second, presents a bibliography of mathematical references in lieu of an assortment of actual mathematical tables. Selection of such tables necessarily would have been arbitrary; they would have been bound to duplicate many tables already easily available to most physicists; and, most important, including them would have necessitated the omission of significant physics material. The basic pattern of the third-edition bibliography is described at the beginning of Sec. 1a. For reasons outlined in the first paragraph of Sec. 1b, it was believed neither practicable nor desirable to attempt exclusive use of the International System of Units in this edition of the Handbook. Section 1b outlines the background of SI Units, and presents a portion of a National Bureau of Standards bulletin on their interpretation.

Section 2

MECHANICS

R. BRUCE LINDSAY, Editor

Brown University

CONTENTS

Contents

Contributors

J. R. Anderson, Ph.D., *University of Maryland.* Solid State Physics (9d)
Gordon Atkinson, Ph.D., *University of Maryland.* Electricity and Magnetism (5g)
Fred Ayres, Ph.D., *Reed College.* Mechanics (2n)
H. W. Babcock, Ph.D., *Hale Observatories.* Electricity and Magnetism (5i)
Julius Babiskin, Ph.D., *U.S. Naval Research Laboratory.* Solid State Physics (9d)
Stanley Ballard, Ph.D., *University of Florida.* Optics (6b, 6c)
Philip Baumeister, Ph.D., *University of Rochester.* Optics (6i)
J. A. Bearden, Ph.D., *The Johns Hopkins University.* Atomic and Molecular Physics (7f)
E. C. Beaty, Ph.D., *The National Bureau of Standards, Boulder.* Electricity and Magnetism (5e)
L. I. Beaubien, Ph.D., *U.S. Naval Research Laboratory.* Mechanics (2e)
Leo L. Beranek, Ph.D., *Bolt Beranek and Newman Inc.* Acoustics (3a, 3b, 3d, 3p)
Robert T. Beyer, Ph.D., *Brown University.* Acoustics (3o)
Hans Bichsel, Ph.D., *University of Washington.* Nuclear Physics (8d)
Bruce H. Billings, Ph.D., *Joint Commission on Rural Reconstruction, Taipei, Taiwan.* Optics (6c, 6f, 6h, 6l, 6o)
David T. Blackstock, Ph.D., *University of Texas.* Acoustics (3n)
E. Boldt, Ph.D., *NASA—Goddard Space Flight Center.* Electricity and Magnetism (5i)
R. M. Bozorth, Ph.D., *U.S. Naval Ordnance Laboratory.* Electricity and Magnetism (5f)
Willem Brouwer, Ph.D., *Diffraction Ltd. Inc.* Optics (6d)
James S. Browder, Ph.D., *University of Florida.* Optics (6b, 6c)
R. M. Burley, A.B., *Baird-Atomic, Inc.* Optics (6p)
Constance Carter, M.S., *Library of Congress.* Mathematics Bibliography; SI Units (1a, 1b)
Gregg E. Childs, Ph.D., *The National Bureau of Standards, Boulder.* Heat (4g)
R. J. Collins, Ph.D., *University of Minnesota.* Optics (6s)
W. R. Cook, Jr., M.A., *Gould, Inc.* Optics (6m)
H. M. Crosswhite, Ph.D., *The Johns Hopkins University.* Atomic and Molecular Physics (7a, 7b, 7c, 7d, 7e)
Evan A. Davis, Ph.D., *Westinghouse Research Laboratory.* Mechanics (2f)
R. DiPippo, Ph.D., *Southeastern Massachusetts University.* Mechanics (2r)
E. S. Domalski, Ph.D., *The National Bureau of Standards.* Heat (4j)
J. D. H. Donnay, Ph.D., *The Johns Hopkins University.* Solid State Physics (9a)
Thomas B. Douglas, Ph.D., *The National Bureau of Standards.* Heat (4e)
J. F. Ebersole, Ph.D., *University of Florida.* Optics (6b, 6c)
Phillip Eisenberg, Ph.D., *Hydronautics, Inc.* Mechanics (2o)
Eugene Epstein, Ph.D., *Aerospace Corporation.* Optics (6q)
John Evans, Ph.D., *Air Force Cambridge Research Laboratories.* Optics (6i)
Robley D. Evans, Ph.D., *Massachusetts Institute of Technology.* Nuclear Physics (8e)

Ernest Loewenstein, Ph.D., *Air Force Cambridge Research Laboratories.* Optics (6r)
Lewis G. Longsworth, Ph.D., *The Rockefeller University.* Mechanics (2p)
Walter Loveland, Ph.D., *Oregon State University.* Nuclear Physics (8g)
David MacAdam, Ph.D., *Eastman Kodak Company.* Optics (6a, 6j)
Nancy R. McClure, *Eastman Kodak Company.* Optics (6d)
T. R. McGuire, Ph.D., *IBM—Watson Research Center.* Electricity and Magnetism (5f)
John E. McKinney, Ph.D., *The National Bureau of Standards.* Mechanics (2l)
J. B. Marion, Ph.D., *University of Maryland.* Nuclear Physics (8a)
Robert S. Marvin, Ph.D., *The National Bureau of Standards.* Mechanics (2m)
W. P. Mason, Ph.D., *Columbia University.* Acoustics (3f, 3g); Solid State Physics (9a)
Frank Massa, M.S., *Dynamics Corporation of America.* Acoustics (3i)
W. J. Merz, Ph.D., *RCA Laboratories.* Solid State Physics (9f)
B. M. Miles, Ph.D., *The National Bureau of Standards.* Atomic and Molecular Physics (7i)
David Mintzner, Ph.D., *Northwestern University.* Mechanics (2a)
Karl Z. Morgan, Ph.D., *Oak Ridge National Laboratory.* Nuclear Physics (8i)
Edwin B. Newman, Ph.D., *Harvard University.* Acoustics (3k)
Wesley L. Nyborg, Ph.D., *University of Vermont.* Mechanics (2n, 2q)
Harry F. Olson, Ph.D., *RCA Laboratories.* Acoustics (3l, 3m)
Norman Pearlman, Ph.D., Purdue University. Heat (4e)
Karl B. Persson, Ph.D., *The National Bureau of Standards, Boulder.* Electricity and Magnetism (5e)
Harmon H. Plumb, Ph.D., *The National Bureau of Standards.* Heat (4a)
Robert L. Powell, Ph.D., *The National Bureau of Standards, Boulder.* Heat (4a, 4g)
Martin P. Reiser, Ph.D., *University of Maryland.* Nuclear Physics (8j)
B. W. Roberts, Ph.D., *General Electric Research and Development Center.* Solid State Physics (9g)
R. C. Roberts, Ph.D., *University of Maryland.* Mechanics (2s, 2t, 2u)
Arthur H. Rosenfeld, Ph.D., *University of California.* Nuclear Physics (8h)
Bruce D. Rothrock, B.S., *The National Bureau of Standards.* Heat (4f)
Hellmut H. Schmid, Ph.D., *National Oceanic & Atmospheric Administration.* Mechanics (2h)
R. H. Schumm, M.S., *The National Bureau of Standards.* Heat (4j)
Arthur F. Scott, Ph.D., *Reed College.* Mechanics (2n)
Philip A. Seeger, Ph.D., *Los Alamos Scientific Laboratory.* Nuclear Physics (8c)
J. M. H. Levelt Sengers, Ph.D., *The National Bureau of Standards.* Heat (4i)
J. C. Slater, Ph.D., *University of Florida.* Solid State Physics (9c)
Donald R. Smith, M.S., *Air Force Cambridge Research Laboratories.* Optics (6r)
W. R. Smythe, Ph.D., *California Institute of Technology.* Electricity and Magnetism (5a, 5b)
George A. Snow, Ph.D., *University of Maryland.* Nuclear Physics (8h)
Irene A. Stegun, M.S., *The National Bureau of Standards.* Mathematics Bibliography; SI Units (1a, 1b)
D. E. Stone, A.B., *Vertex Corporation.* Mechanics (2b, 2e)
Daniel R. Stull, Ph.D., *Dow Chemical Company.* Heat (4k)
Masahisa Sugiura, Ph.D., *NASA—Goddard Space Flight Center.* Electricity and Magnetism (5h, 5i)
James F. Swindells, A.B., *The National Bureau of Standards.* Heat (4a)
Paul Tamarkin, Ph.D., *RAND Corporation.* Mechanics (2a)
J. S. Thomsen, Ph.D., *The Johns Hopkins University.* Atomic and Molecular Physics (7f)

Index follows Section 9.

Preface

The *American Institute of Physics Handbook* has won wide acceptance among scientists and engineers. It is just such a degree of acceptance that has stimulated the issuance of this revised and updated third edition. This edition, like the previous two, continues the philosophy of supplying authoritative reference material—including tables of data, graphs, and bibliographies—selected and described with a minimum of narration by leaders in physical methods for research.

Among the entirely new sections in this edition are those on nonlinear optics, calibration energies for alpha particles and gamma rays, nonlinear acoustics, atomic mass formulas, particle accelerator principles, atomic transition probabilities, electric and magnetic fields in the earth's environment, and far infrared. Examples of topics in which especially extensive revisions have been made are: optical masers, various optical constants, virial coefficients, heats of combustion and formation, and superconductors. A number of sections were completely rewritten; these include radioastronomy, radiometry, various crystal properties, molecular constants and phase transitions. The mathematics section now consists of a special treatment of SI units and a bibliography that has been revised to include references to new methods, algorithms, and computer programs.

Publication of this Handbook was a mammoth undertaking that required the contributions and cooperation of many individuals and two organizations. Leading the individuals is Dr. Dwight E. Gray, who served as coordinating editor for this 1972 edition, as he also did for the 1957 and 1963 editions. Dr. Gray, who is a master of the pen and is well grounded in physics, was able to coordinate successfully the efforts of the eight section editors and the some 125 contributors. He did this work while also serving as the Washington Representative of the American Institute of Physics. Through his Washington office he was able

AMERICAN INSTITUTE OF PHYSICS HANDBOOK