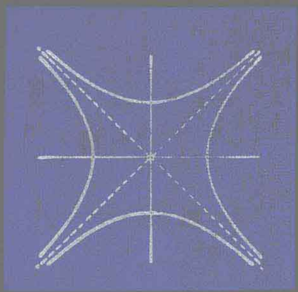
FUNDAMENTALS OF PHYSICS

HALLIDAY
RESNICK

EXTENDED
THIRD
EDITION



FUNDAMENTALS OF PHYSICS

Third Edition Extended

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PREFACE

This third (1988) edition of *Fundamentals of Physics* is a major revision of both the second (1981) edition of that text and of its revised printing (1986). Although we have retained the basic framework of these earlier versions, we have virtually rewritten the entire book. Users of the earlier editions can appreciate the changes better if we list them in some detail.

(a) In the words of one reviewer, "you have succeeded in maintaining the overall level throughout but have substantially lowered the learning threshold." Many new techniques have been used to achieve this. For example, many hints on problem solving are sprinkled throughout the early chapters, each one focusing on a chronic student hang-up. (A complete list of these Hints appears on page x). A larger set of worked examples—now called Sample Problems to reflect their consistent focus—is included to provide problem-solving models for all aspects of each chapter; several are put in extended question and answer format to reveal directly the pathways followed by experienced problem solvers. There are more but shorter sections per chapter for easier digestion of the material, and more use of subheads is made within sections for greater clarity and emphasis. In the body of the text, relationships are typically displayed and discussed before they are formally derived, a more inductive procedure that we think will prove effective. Often these formal derivations appear in separate sections or subsections. And, we have greatly expanded the set of confidence-building exercises for homework while increasing the number of problems as well.

(b) Greater clarity has been achieved in many ways. A more student-oriented style is employed than before and a two-column format has been adopted for easier reading. Chapter-head photographs are now included along with captions that make a valid attention-grabbing point about the contents of each chapter. Opening sections discuss the relevance of the topics to be treated in each chapter in order to motivate students from the start. Throughout the chapter, photographs and diagrams are featured in greater numbers, with self-contained captions, to reinforce the text material. In each chapter there are examples that deal with practical and applied situations. Chapters conclude with a detailed Review and Summary section for student reference and study.

(c) The sets of chapter-ending questions, exercises, and problems are by far the largest and most varied of any introductory physics text. We have edited the highly praised sets of the earlier edition to achieve even greater clarity and interest and have added a substantial number of new applied and conceptual ones. A more generous use of figures and photographs serves better to illustrate the questions, exercises, and problems than before.

The thought questions have always been a special feature of our books. They are used as sources of classroom discussion and for clarification of homework concepts. There are nearly 30 per chapter. Their total

number, now over 1400 in the entire book, is greater than before and they relate even more to everyday phenomena, serve to arouse curiosity and interest, and stress conceptual aspects of physics.

Exercises typically involve one step or formula or represent a single application and are used for building student confidence. They now constitute about 45 percent of the exercise-problem sets. In preparing the new set of problems, we have been careful not to discard the many tried and true problems that have survived the test of the classroom for many years. Long-time users of our text will not find their favorites missing. Of the substantial number of new problems, many fit the "real world" category of student interest and these and the others serve different pedagogic objectives as well. Amongst the problems are a small number of advanced ones, as well, identified by stars* next to their number. A typical chapter has about 31 exercises and 37 problems, the total number of exercises and problems in the entire book being about 3400.

By labeling exercises "**E**" and problems "**P**" and organizing them in order of difficulty for each section of the chapter, we have simplified the selection process for teachers from the voluminous material now made available. The variation of level and the breadth of scope have been enlarged. Hence, teachers can vary the content emphasis and the level of difficulty to suit their tastes and the preparation of the student body while still having a very adequate supply for many years of instruction. Indeed, the book is now somewhat longer principally because of all the self-study and learning features that are now included.

(d) Our treatment of modern physics has been enhanced. There are two entirely new modern physics chapters, one on Relativity and the other on Quarks, Leptons and the Big Bang. And, in rewriting the earlier chapters, we have sought to pave the way more effectively than in previous editions for the systematic study of modern physics presented in the later chapters. We have done this in three ways. (i) In appropriate places we have called attention — by specific example — to the impact of relativistic and quantum ideas on our daily lives. (ii) We have stressed those concepts (conservation principles, symmetry arguments, reference frames, role of aesthetics, similarity of methods, use of models, field concepts, wave concepts, etc.) that are common to both classical and modern physics. (iii) Finally, we have included a number of short optional sections in which selected relativistic and quantum ideas are presented in ways that lay the foundation for the detailed and systematic treatments of relativity, atomic, nuclear, solid state, and particle physics given in later chapters.

(e) To emphasize the relevance of what physicists do, and further motivate the student, we include, within the chapters, numerous applications of physics in engineering, technology, medicine, and familiar everyday phenomena. In addition, we feature 21 separate, self-contained essays, written by distinguished scientists and distributed at appropriate locations in the text, on the application of physics to special topics of student interest such as sports, toys, amusement parks, medicine, lasers, holography, space, superconductivity, concert-hall acoustics, and many more. (See the Table of Contents.)

(f) In the interests of simplification and of greater clarity for students, certain rearrangements of material have been made. For example, motion in one dimension is now treated before vectors. A better balance of the material on rotational motion in mechanics is achieved over two chapters by presenting the simpler concepts in kinematics and dynamics first, and then the more difficult concepts, enabling the instructors to more easily choose the depth desired. Similarly, formerly-scattered material — such as on the Doppler effect or on special relativity — has been drawn together in one place for greater conceptual unity. Material on elasticity, now somewhat longer, fits more naturally into the chapter on equilibrium. There are, of course, many other smaller rearrangements too numerous to mention here.

Like the second edition, this edition is available in a single volume of 42 chapters, ending with relativity, and in an Extended Version of 49 chapters that contains in addition a development of quantum physics and its applications to atoms, solids, nuclei, and particles. The former is meant for introductory courses that treat modern quantum physics in a subsequent separate course or semester. There are also numerous optional sections throughout the text that are of an advanced, historical, general, or specialized nature.

Indeed, just as a textbook alone is not a course, so a course does not include the entire textbook. We have consciously made available much more material than any one course or instructor is expected to "cover." More can be "uncovered" by doing less. The process of physics and its essential unity can be revealed by judicious selective coverage of many fewer chapters than are contained here and by coverage of only portions of many included chapters. Rather than give numerous examples

of such coherent selections, we urge the instructor to be guided by his or her own interests and circumstances and to plan ahead so that some topics in modern physics are always included.

A textbook contains far more contributions to the elucidation of a subject than those made by the authors alone. As before, John Merrill (Brigham Young University) has been of special service for all aspects of this work, as has Edward Derringh (Wentworth Institute of Technology). Albert Bartlett (University of Colorado) has been of particular help with the essays and Benjamin Chi (SUNY Albany) with the figures and photographs. At John Wiley, publishers, we have been fortunate to receive strong coordination and support from Robert McConnin and Catherine Faduska, physics editors, with notable contributions from John Balbalis, Lucille Buonocore, Deborah Herbert, Karin Kincheloe, Safra Nimrod, and other members of the production team. We are grateful to all these persons.

Our external reviewers have been outstanding and we acknowledge here our debt to each member of that team, namely, Joseph Buschi (Manhattan College), Philip A. Casabella (Rensselaer Polytechnic Institute), Randall Caton (Christopher Newport College), Roger Clapp (University of South Florida), William P. Crummett (Montana College of Mineral Science and Technology), Robert Endorf (University of Cincinnati), F. Paul Esposito (University of Cincinnati), Andrew L. Gardner (Brigham Young University), John Gieniec (Central Missouri State University), Leonard Kleinman (University of Texas at Austin), Kenneth Krane (Oregon State University), Howard C. McAllister (University of Hawaii at Manoa), Manuel Schwartz (University of Louisville), John Spangler (St. Norbert College), Ross L. Spencer (Brigham Young University), Harold Stokes, (Brigham Young University), David Toot (Alfred University), and George U. Williams (University of Utah).

We thank all the essayists for their valuable contributions and cooperative spirit. Kathaleen Guyette has been superb in providing the wide range of secretarial services required.

We hope that the final product proves worthy of the effort and that this Third Edition of *Fundamentals of Physics* will contribute to the enhancement of physics education.

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January, 1988

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Charles P. Bean (Essay 14) is Institute Professor of Science at Rensselaer Polytechnic Institute. He received his Ph. D. in physics from the University of Illinois in 1952. For more than 33 years he was a research scientist in the General Electric Research Laboratory and its successor, the General Electric Research and Development Center. While there he made research contributions to the fields of ionic crystals, magnetism, superconductivity, and membrane biophysics. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. As an avocation he studies the physics of phenomena in nature.

PETER J. BRANCAZIO

Peter J. Brancazio (Essay 6) is a professor of physics at Brooklyn College, City University of New York. He received his Ph. D. in astrophysics from New York University in 1966. He is the author of two books: *The Nature of Physics* (Macmillan, 1975) and *Sport Science* (Simon & Schuster, 1984). His articles on the physics of baseball, football, and basketball have appeared in *Discover, Physics Today, New Scientist, The Physics Teacher,* and the *American Journal of Physics.* A lifelong athlete and sports fan, he is equally at home on the basketball court and in the classroom.

PATRICIA ELIZABETH CLADIS

Patricia Elizabeth Cladis (Essay 20) was born in Shanghai, China and grew up in Vancouver, British Columbia. She received her Ph. D. in physics from the University of Rochester with a thesis on the dc superconducting transformer. Before joining AT&T Bell Laboratories, she did postdoctoral research at the University of Paris, Orsay, France, where she first learned about liquid crystals and discovered "escape into the third dimension" and point defects in nematics. At Bell Labs she discovered the "reentrant nematic" phase. Currently she uses liquid crystals to study general problems in

nonlinear physics. She has published nearly 100 scientific papers and is on the editorial board of the journal *Liquid Crystals.*

ELSA GARMIRE

Elsa Garmire (Essay 19) is professor of electrical engineering and physics, and Director of the Center for Laser Studies at the University of Southern California. Garmire received the A. B. in physics from Harvard University in 1961 and the Ph. D. in physics from M. I. T. in 1965 for research in nonlinear optics under Nobel Prizewinner C. H. Townes. The author of over 120 papers with seven patents, she has been a researcher in quantum electronics and in linear and nonlinear optical devices for 25 years. She is a fellow of the Optical Society of America and of IEEE and has been on the board of both societies. She is associate editor of the journals *Optics Letters* and *Fiber and Integrated Optics,* and was U.S. delegate to the International Commission for Optics.

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Russell K. Hobbie (Essays 8 and 21) is a professor of physics at the University of Minnesota. He received his B. S. from M. I. T. and his Ph. D. from Harvard. His research interests include diagnostic radiology, magnetic resonance imaging, impedance cardiography, and computerized medical diagnosis. He is the author of *Intermediate Physics for Medicine and Biology,* published by Wiley, 1988.

TUNG H. JEONG

Tung H. Jeong (Essay 18) received his B. S. from Yale University in 1957, and Ph. D. in nuclear physics from the University of Minnesota in 1963. Presently, he is chairman of the physics department and holder of the Albert Blake Dick endowed chair in Lake Forest College. Besides directing annual summer holography workshops since 1972, he consults and lectures on holography in hundreds of institutions around the world. He is a Fellow of the Optical Society of America and a recipient of the Robert A. Millikan Medal from the American Association of Physics Teachers. His hobbies include skiing, tennis, and playing the violin in the Lake Forest Symphony Orchestra.

KENNETH LAWS

Kenneth Laws (Essay 3) is professor of physics at Dickinson College in Carlisle, Pa., where he has been teaching since 1962. He earned his B. S., M. S., and Ph. D. degrees from Caltech, the University of Pennsylvania, and Bryn Mawr College, respectively. For the last dozen years he has been studying classical ballet at the Central Pennsylvania Youth Ballet, and he has recently been applying the principles of physics to dance movement. This work has lead to numerous lectures and classes around the country, and has culminated in a book, *The Physics of Dance,* published in 1984 (paperback 1986) by Schirmer Books.

PETER LINDENFELD

Peter Lindenfeld (Essay 12) has degrees in electrical engineering and engineering physics from the University of British Columbia and a Ph. D. in physics from Columbia University. Since his graduation he has been at Rutgers University where he is professor of physics. His research and publications are on low temperature physics and superconductivity as well as on activities related to physics teaching. He is a fellow of the American Physical Society and an honorary life member of the New Jersey Section of the American Association of Physics Teachers. He has received awards for his booklet "Radioactive Radiations and their Biological Effects," for his work on a solar calorimeter, and for some of his photographs.

RICHARD L. MORIN

Richard L. Morin (Essays 8 and 21) is an associate professor in the Department of Radiology and Director of the Physics Section in Radiology at the University of Minnesota. He received his undergraduate training in chemistry at Emory University and his Ph. D. in radiological sciences from the University of Oklahoma. His research interests are in the area of computer applications in radiology and nuclear medicine.

SUZANNE R. NAGEL

Suzanne R. Nagel (Essay 17) is head of the Glass Research and Engineering Department at AT&T-Bell Laboratories, Murray Hill, N.J. She received her Ph. D. in ceramic engineering from the University of Illinois in 1972 after her undergraduate studies at Rutgers University. She has authored 30 technical papers in the area of glass science and lightguide technology, and her research has involved the processing and property optimization of optical fibers for communications, as well as close interaction with their manufacture. She is actively involved in promoting careers in science and engineering for women and minorities, and was recently featured in the Chicago Museum of Science and Technology Exhibit "My Daughter the Scientist," which is touring the country.

GERARD K. O'NEILL

Gerard K. O'Neill (Essay 13) holds a bachelor's degree from Swarthmore College, a Ph. D. from Cornell University (1954), and an honorary D. Sc. from Swarthmore. He was a member of the faculty at Princeton University from 1954 to 1985, and was made full professor of physics in 1965. In 1985, he retired early from Princeton, becoming Professor Emeritus of Physics. He is the author of several books and many articles in his field. In March 1985, he was appointed by President Reagan to the National Commission on Space. In 1983 he founded the Geostar Corporation, a communications and navigation satellite company based on patents issued to him. His latest commercial start-up company is O'Neill Communications, Inc.

SALLY K. RIDE

Sally K. Ride (Essay 5) is a NASA Space Shuttle astronaut. She earned a B. S. in physics and a B. A. in English from Stanford University in 1973, and a Ph. D. in physics from Stanford in 1978. After graduate school, she was selected for the Astronaut Corps. She has flown in space twice: on the seventh Space Shuttle mission (STS-7, the second flight of the *Challenger,* launched in June, 1983), and the thirteenth Shuttle mission (STS-41G, launched in October, 1984). In 1986, she was appointed to the Presidential Commission investigating the Space Shuttle *Challenger* accident. Since the completion of the investigation, she has acted as Special Assistant to the Administrator of NASA, helping to develop NASA's long-range plans for human exploration of space. She is currently affiliated with the Center for International Security and Arms Control at Stanford University.

JOHN S. RIGDEN

John S. Rigden (Essay 7) received his Ph. D. from Johns Hopkins University in 1960. After postdoctoral work at Harvard University, he started the physics department at Eastern Nazarene College. After one year at Middlebury College, he moved to St. Louis where he is now professor of physics at the University of Missouri–St. Louis. He is the author of *Physics and the Sound of Music* (Wiley, 1977; Second Edition, 1985). More recently, he has written the definitive biography of the great American physicist, I. I. Rabi: *Rabi: Scientist and Citizen* (Basic Books, 1987). Since 1978 he has been the editor of the *American Journal of Physics.*

JOHN L. ROEDER

John L. Roeder (Essay 2) began investigating the physics of the amusement park with an article in the September 1975 issue of *The Physics Teacher* and now takes his physics classes at The Calhoun School in New York City on field trips to Six Flags Great Adventure, the site of his "original research." In addition to serving as a double Resource Agent — for both the American Association of Physics Teachers and the New York Energy Education Project — John is a cofounder of and the newsletter editor for the Teachers Clearinghouse for Science and Society Education, Inc. He received his A. B. from Washington University and his M. A. and Ph. D. from Princeton University.

WILLIAM A. SHURCLIFF

William A. Shurcliff, Physics Department, Emeritus, Harvard University (Essay 9) received his Ph.D. from Harvard in 1934. He has held positions such as senior scientist and research fellow in nu-

merous government, industrial, and university laboratories, including American Cyanamid Company, Polaroid Corporation, Office of Scientific Research and Development, and the Cambridge Electron Accelerator. He is the author of books on polarized light, solar heated houses, and superinsulated houses.

RAYMOND C. TURNER

Raymond C. Turner (Essay 15) is well known for his work with the physics of toys. He received his B. S. in physics from Carnegie Institute of Technology and his Ph. D. in solid state physics from the University of Pittsburgh in 1966. He is now a professor of physics at Clemson University in South Carolina where he conducts research on electron-spin-resonance studies of polymers. He has presented numerous workshops and lectures at national teachers' meetings on the use of toys in physics education, and he has served on local and national committees of the American Association of Physics Teachers. He has published articles on physics and toys in the *American Journal of Physics* and *The Physics Teacher.*

JEARL WALKER

Jearl Walker (Essays 1, 2, 10 and 16) is professor of physics at Cleveland State University. He received a B. S. in physics from M. I. T. and a Ph. D. in physics from the University of Maryland. Since 1977 he has conducted "The Amateur Scientist" department of *Scientific American,* where he is read in 10 languages in world-wide publication. His book *The Flying Circus of Physics with Answers* is also published in 10 languages.

LIST OF HINTS

These Hints, which occur in the early chapters and are closely correlated with the Sample Problems, should help in working assigned homework problems and in preparing for exams. Collectively, they represent the stock in trade of experienced problem solvers and of practicing scientists and engineers.

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