Fundamentals of

Physics

and Applications

SECOND EDITION

Fundamentals of Physics
and Applications

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Preface to the Second Edition

A limited but clear understanding of the fundamentals of physics has become an absolute necessity for those working in the fields of medicine, optometry, nursing, physical therapy, the biological sciences, and related areas of endeavor. A knowledge of the functions of the human body, various medical instruments, and nuclear phenomena must of necessity be based upon an understanding of the application of physical principles to them.

Accordingly, this revised edition of *Fundamentals of Physics and Applications* is essentially a standard text in physics, with illustrative material drawn from the fields of the biological sciences and medicine. As in the first edition, emphasis has been placed on a simple and concise presentation of the subject matter. Several chapters have been rewritten for further simplification or to bring the discussion up to date, the most extensive revisions having been made in those concerning accelerated motion and nuclear phenomena. The former "Introduction," consisting of a brief review of mathematics, has been included as Appendix I; it is thus available in case of need but does not occupy as prominent a place as in the first edition. The new "Introduction" contains a very brief history of physics. A few errors, known to have existed in the first edition, have been corrected. New problems have been added to further emphasize the understanding of physical principles, and answers to all odd-numbered problems have been listed in Appendix IV.

The author again welcomes any suggestions for the improvement of the book from teachers or students.

Preface to the First Edition

For many years teachers in the various sciences have assumed that all that was required of them was to give the students a reasonably good experience in the fundamentals of a science, after which the students were expected to see how these applied to each new situation encountered. It has been the author's experience in teaching nurses and premedical-school students and in talking with medical-school graduates engaged in practice or research that they want to know the applications while they are studying the principles.

The foundation material of this book does not differ much from that of other elementary texts, for, after all, physics comprises a certain body of material that is essential to all sciences. The difference between this book and most others is in the effort the author has made to point out to the student where and how the laws and theories of physics are applied in the biological sciences or in the equipment and operation of a hospital.

Physics has been defined, rather too briefly, as the science of measurement. This is an important aspect of the subject that involves the use of numbers and units. Therefore, numerical problems have been included throughout most of the book. These give the student a better measure of his or her degree of understanding than do more general questions. There are, however, times when nonnumerical problems, which have been included in each chapter as study questions, require a more searching analysis of the fundamentals than numerical problems involving no more mental exercise than substituting numbers for letters in a formula. In both kinds of problems the author has attempted to make the understanding of principles more important than the facility in the arithmetical operations.

The author hopes the book will prove useful, and to that end he would greatly appreciate suggestions for improvement from those who use it either as teachers or as students.

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INTRODUCTION

A Brief Look at the History of Physics

Until as late as the latter part of the nineteenth century, physics was known as *natural philosophy*. It was part of the general field of philosophy, which included other subjects such as logic, metaphysics, epistomology, and ontology.

The earliest of the philosophers about whom definite records exist is **Thales of Miletus** (640–546 B.C.). He was acquainted with the action of magnets and of amber when rubbed with wool. He believed that both matter and electricity were atomic in nature.

Anaxagoras (500–428 B.C.) is credited with the view that the moon does not shine by its own light and that the moon is eclipsed because the earth shuts off the light of the sun.

Democritus (460–372 B.C.) was the first to state the atomic nature of matter definitely, though by a purely philosophical argument. He believed the creation of matter impossible since *nothing* was all that could be obtained from *nothing*.

Aristotle (384–322 B.C.), a pupil of the philosopher Plato, contributed extensively to all branches of knowledge: logic, rhetoric, metaphysics, psychology, and natural science. His intellectual brilliance and achievements in so many branches of learning exerted a profound influence among philosophers and theologians for hundreds of years.

Aristotle did occasionally draw on observed facts to substantiate his arguments. For example, he tried to show by abstract reasoning that the

earth was spherical, as shown by the shadow cast on the moon at the time of a lunar eclipse and also by the change in the altitude of the stars as one travels north or south. He is credited with maintaining that a heavier body falls faster than a lighter one; yet it is difficult to be sure from Aristotle's extant writings just what he held in regard to this point.[1]

Aristotle believed the earth to be the center of the universe, with the sun, moon, planets, and stars revolving about the earth in concentric spheres. His authority was so generally recognized that the brilliant work of Aristarchus in the following century was not given the credit it deserved.

Aristarchus of Samos (about 310–230 B.C.) developed a theory of the universe which was the same as that proposed by Copernicus 2000 years later.

Archimedes (287–212 B.C.) is known to all students of elementary physics for the principle in hydrostatics which bears his name.

A long gap appears in almost all histories of science from soon after the beginning of the Christian Era to the time of Galileo Galilei. During this interval most Christian philosophers were theologians more concerned with the Second Coming than with problems of the world around them. About the eighth century the Arabs translated many Greek writings into Arabic.

Leonardo da Vinci (1452–1519) was an Italian painter, architect, sculptor, engineer, and philosopher. He made extensive studies of the flight of birds with the idea of developing some kind of a flying machine.[2] He also attacked problems in mechanics and dynamics. For example, on the subject of perpetual motion he wrote: "Oh speculators on perpetual motion, how many vain projects of the like character you have created. Go and be the companions of the searchers after gold!"[3]

Da Vinci's writings created less opposition than those of Galileo and Copernicus, who followed him, because they were left in manuscript form and he did not teach in any of the universities. For this reason he exerted very little influence on science of his time; in fact, it is only in recent years that his scientific ideas have received the credit they deserve.

Copernicus (1473–1543), a mathematician and astronomer, perceived a simplified solar system with the sun at the center to displace the Ptolemaic system of an earth-centered universe. Ptolemy (about A.D. 127–

[1] Richtmyer, F. K.; Kennard, E. H.; and Lauritsen, T.: *Introduction to Modern Physics*, 5th ed. McGraw-Hill Book Company, New York, 1955, p. 8.

[2] Hart, I. B.: *The Mechanical Investigatiors of Leonardo da Vinci*. Chapman & Hall, Ltd., London, 1925. Chap. VII.

[3] *Ibid.*, p. 95.

151) had developed a complicated structure of deferents and epicycles. As better observations were made, the epicycles were complicated by adding epicycles to epicycles until each planet was provided with from forty to sixty epicycles turning one upon another.[4]

Because the theories proposed by Copernicus were so revolutionary and contrary to the accepted theories taught by the theologians of his time, he refrained from having them published until the close of his life.

Galileo Galilei (1564–1642) is generally considered to be the first to adopt the methods of modern science. He excelled in the classics and literature as a young student. He later studied medicine at the University of Pisa. It was here that he made his first discovery concerning the uniformity of oscillation of a pendulum. He checked the period of the swinging of a hanging lamp by comparing it with his pulse. He found the period of oscillation stayed the same even though the amplitude of the swings became less.

He abandoned the study of medicine for his interest in mathematics and at the age of twenty-six became professor of mathematics at Pisa. While there he is supposed to have performed his famous experiment of dropping dissimilar weights simultaneously from the leaning tower. He did this to show that the heavier weight did not travel faster. Forced to leave Pisa, in 1592 he became professor of mathematics at the University of Padua.

In 1610 Galileo invented a telescope with a power of 30 diameters. With this he discovered four of the satellites of Jupiter. He made numerous other astronomical discoveries, all of which tended to support the hated Copernican theory. Because of this and some of his later writings he was called before the Inquisition. At that time he was old, impaired in health and spirit, so he expressed his willingness to "abjure, curse, and detest" his heresies. His work in mechanics aided Newton to state his three laws of motion. Galileo died the year that Newton was born.

In the period just before the time of Newton came such men as *Snell* (1591–1626), who discovered the true law of refraction; *Torricelli* (1608–1647), who discovered the principle of the barometer and the variation of barometric pressure with altitude; and *Pascal* (1623–1662), who explained the variation of pressure with altitude and later announced the principle of the transmission of pressure in a confined fluid (known as Pascal's principle).

Sir Isaac Newton (1642–1727) was born on Christmas Day in 1642 in Woolsthorpe. After an unsatisfactory early school experience he sud-

[4] Baker, R. H.: *An Introduction to Astronomy*, 4th ed. D. Van Nostrand Company, Inc., New York, 1952, p. 150.

denly exhibited a remarkable aptitude for mathematics. He worked hard to prepare himself for Trinity College, Cambridge. While still in his twenties he had developed differential calculus, perfected the reflecting telescope, discovered the law of universal gravitation, and had to his credit a host of other less-well-known achievements. At the age of twenty-six he was appointed to the professorship of mathematics at Cambridge University. He was truly a "giant among giants." [5]

Newton would be famous for almost any one of the many investigations he conducted. His work on optics was monumental, yet he failed to detect two flaws in his theories. One was that dispersion of light was proportional to refraction, and the other was that light must consist of particles in order to account for the straight-line propagation. It was not until 1730 that achromatic lenses were first made.

His famous *Principia*, published in 1697, was "without exception the most important work in natural philosophy extant." [6] "In this treatise the famous three laws of motion are assumed as axioms." [7]

The eighteenth century witnessed many additional contributions to an understanding of the material world. **Bernoulli** (1700–1782) made many discoveries in hydrodynamics; **Euler** and **Lagrange** developed mathematical tools for the solution of many problems. The aberration of light was discovered by **Bradley** in 1728. **Du Fay, Benjamin Franklin, Cavendish,** and **Coulomb** discovered many of the fundamental facts about electricity, with **Ampère, Oersted,** and **Faraday** discovering the relationship between electricity and magnetism.

The nineteenth century was a period of such extensive progress that it would take most of the rest of this book to describe only a part of it. The law of the conservation of energy was announced during this century. The first qualitative experiment bearing on the nature of heat was performed by **Count Rumford,** an American who was opposed to the Revolution and fled to England; from there he went to Bavaria where his famous experiments were carried out. **Joule** (1818–1889) measured quantitatively the equivalence of heat and energy.

The revival of the wave theory of light on the basis of the experiments of **Thomas Young** (1773–1829) led to the abandonment of Newton's corpuscular theory. Other researches in light were carried on by **Fraunhofer, Doppler, Kirckhoff,** and **Bunsen.** Maxwell developed the mathematical foundation for the electromagnetic theory.

[5] Hart, I. B.: *Makers of Science.* Oxford University Press, London, 1924, p. 140.
[6] *Ibid.,* p. 162.
[7] Richtmyer, F. K.; Kennard, E. H.; and Lauritsen, T.: *Op. cit.,* p. 26.

In the field of electricity *Michael Faraday* and *Sir Humphry Davy* developed the relations between electricity, magnetism, and the chemical effects of an electric current. In this country the work of *Joseph Henry* on electromagnets led to the invention of the telegraph.

James Clerk Maxwell (1831–1879) was one of the greatest mathematical physicists of the nineteenth century. His papers cover three main fields: color vision, molecular theory, and electromagnetic theory. In the latter theory he utilized displacement currents in the dielectric field surrounding charges to account for the propagation of an electromagnetic disturbance. His *Treatise on Electricity and Magnetism,* published in 1873, ranks in importance with Newton's *Principia.*

Hermann L. F. von Helmholtz (1821–1894) is the outstanding contributor to medical physics during the nineteenth century. He was descended on his mother's side from William Penn. His first training was as a surgeon in the Prussian army. At the age of 21 he wrote a thesis on his discovery of nerve cells in ganglia. He was professor of physiology first at Königsberg, then at Bonn, and later at Heidelberg. In 1871 he became professor of physics at Berlin. His investigations covered almost the whole field of science—physiology, physiological optics, physiological acoustics, chemistry, mathematics, electricity and magnetism, and theoretical mechanics. In 1847 he read a paper on *The Conservation of Force* which made him one of the founders of our generally accepted law of the conservation of energy. His two great works, *Physiological Optics* (which appeared in 1856) and *Sensations of Tone* (published in 1862), are still authoritative in many respects.

Twentieth century physics really started shortly before the century began. In 1895 *Wilhelm K. Roentgen* discovered x-rays. This discovery was followed by the work of *Becquerel* and the *Curies* on radioactivity. The behavior and nature of electrons were studied by *Sir J. J. Thomson* and his associates in England, while in this country *R. A. Millikan* measured the charge on the electron in his famous oil-drop experiment. *F. W. Aston* in England and *A. J. Dempster* in this country made accurate measurements of atomic masses which led directly to the discovery of a host of isotopes.

About the beginning of the century *Max Planck,* in attempting to explain the radiation of light from a black body, supposed the energy to be emitted in tiny packets of energy called quanta. This led through the experimental and mathematical researches of *Bohr, Einstein, de Broglie, Schrödinger,* and *Heisenberg* to the modern quantum mechanics,

a domain in which mathematical equations have displaced physical models of the interaction of matter and energy.

The more recent developments of twentieth century physics deal with nuclear phenomena such as cosmic rays, nucleons, and nucleonics. Our knowledge of cosmic rays was expanded by the studies of *R. A. Millikan, C. D. Anderson,* and *A. H. Compton.* Nuclear theories were advanced by the work of men like *H. Yukawa, H. A. Bethe,* and *J. R. Oppenheimer.* Atomic fission was discovered in Germany by *L. Meitner* and *O. Hahn.* Experiments on atomic nuclei were carried on in this country by *E. Fermi, E. O. Lawrence, G. T. Seaborg,* and many others.

A glance at the table of contents of any recent number of the *Physical Review* will show the diversity of problems being studied and the number of people who are studying them.