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HARVEY BRACE LEMON

FROM GALILEO TO THE NUCLEAR AGE

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FROM GALILEO TO THE NUCLEAR AGE

AN INTRODUCTION TO PHYSICS

BY

HARVEY BRACE LEMON

PHOENIX SCIENCE SERIES

THE UNIVERSITY OF CHICAGO PRESS

TO THE UNDERGRADUATE STUDENTS
IN THE INTRODUCTORY GENERAL COURSE IN THE PHYSICAL SCIENCES
AT THE UNIVERSITY OF CHICAGO AND TO THOSE STUDENTS AT LARGE,
WHETHER THEY BE IN COLLEGE OR NOT, WHOSE NEEDS AND WHOSE
INTEREST IN THESE MATTERS HAVE FURNISHED ITS INSPIRATION
THIS BOOK IS DEDICATED

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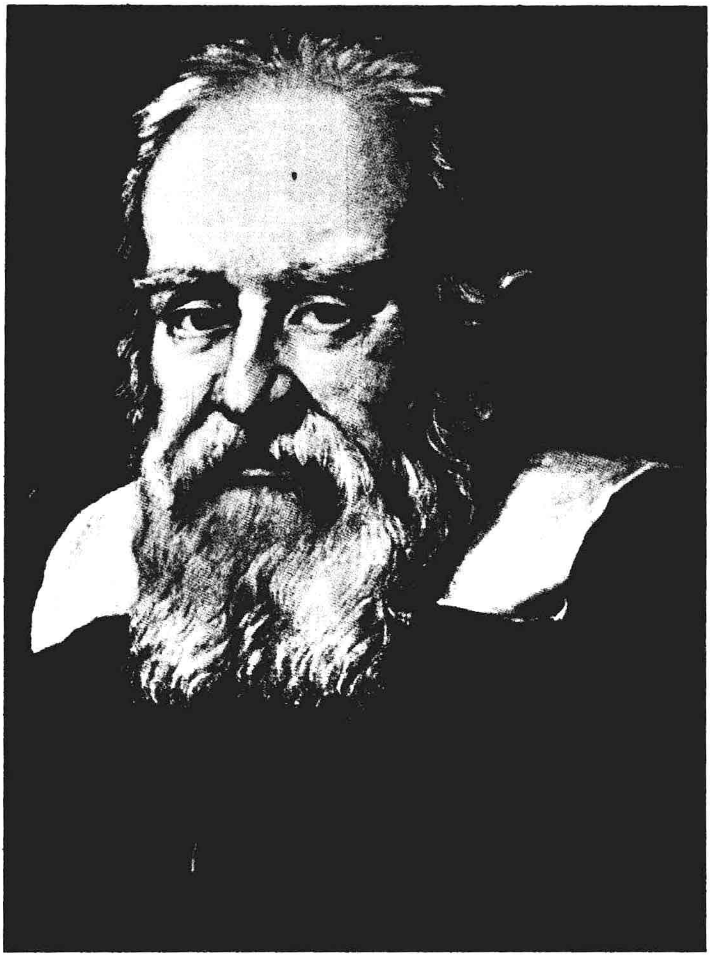

GALILEO GALILEI (1564-1642)

PREFACE TO FIRST EDITION

SINCE the adoption of the new undergraduate curriculum at the University of Chicago four years ago, it has become increasingly evident, as the annual revision of its four introductory general courses has been undertaken, that in addition to comprehensive syllabi an entirely new type of book is needed at least in certain fields of work.

In the physical sciences, an examination on the content of the Introductory General Course is required of all students. The majority of the students have no background in this field and little or no previous training in any of its departments. Nearly all of them are majoring in other fields. This is due to the fact that students entering the University with good preparation in mathematics, physics, or chemistry, or in any two of these subjects, are advised to read for their physical science examinations, or to review and prepare for them in some manner that requires less time than a full year's attendance in this course. Furthermore, a few of the best students in other fields find it possible to do creditable work and save much time by intensive individual study, guided by conferences with their instructors and advisers, and supplemented by attendance only for certain periods of the course.

THERE are many excellent textbooks on physics. The present syllabus is replete with references to the two texts provided for our students in their rental sets. Abundant testimony from students of all types, however, has taught us that selected paragraphs, no matter how clear in their context in a well-organized body of material, become obscure to one who has almost no background in the subject. These books, furthermore, have been designed for full-year courses in physics. They cannot be used in entirety in a year's general course in the physical sciences that includes astronomy, chemistry, some mathematics, three months of geology, and some geography, in addition to physics.

For these reasons it has seemed desirable to put in the hands of our students, while physics is the subject of their study, a book with continuity, designed for reading from cover to cover within a reasonable time, stressing the source material, phenomena, and giving interpretations in non-technical style and by homely analogy. It should also have something of that human interest that attaches to great personalities, but most of all it should try to show explicitly and implicitly how a great scientific field of thought has come into being. Moreover, it should indicate the satisfaction enjoyed by those who participate in such a development of thought, as well as its practical advantages to mankind. A book of this kind is needed not only for physics but also for each of the other sciences listed above. These have been our reasons for taking our integrated lecture notes of the past three years and, in the same spirit of those lectures, and in the first person, attempting to set down in type and halftone a story to which no man can do justice.

THAT a book designed for the purposes outlined above may also meet the interests of the adult reading public, is not perhaps too much to be hoped. The latter comprise a great body of students at large—students whose years and experience in general are much greater than those of our undergraduate body but whose lack of background is almost identical with that of those in attendance upon our formal courses. Furthermore, where background does exist in the case of this older group, it has been, for the most part, acquired before the days when modern physics started on its meteoric career.

Adult lectures in physics, covering material identical to that given to college sophomores, draw capacity crowds, especially if source material in the way of demonstrated phenomena is presented. Our experience is that the attendance is quite as good when only the simpler undebatable material of the subject is presented as when the more modern controversial aspects are given. In the latter case it may be that the personal contact with, or at least the hearing of men recognized as experts in their subject, constitutes the major source of satisfaction to the listeners. For it is doubtful if the force of the arguments presented is fully appreciated by the audiences either at the time of the lecture or later.

The same thing may be said with respect to the reading of books. There have been, and there are being continually, offered to the reading public popular expositions of science. Many of these deal with subjects that are so recondite that they are still matters of controversy among scholars who have devoted a lifetime of study and experience to them. In regard to such books it must be the talent of the author as a writer, or a sense of personal contact with him through his writing, that remains afterward with the reader, rather than any real understanding or comprehensive knowledge of a subject that is not yet understood or fully comprehended by anyone.

THERE is in physical science, on the other hand, a large body of material, universally accepted by all well-trained and critical scholars, with which the layman, even if he has been formerly "exposed" to it in conventional courses for the brief time of a crowded academic year, is quite as unfamiliar as he is with the arguments for and against a pulsating universe. This material is the solid substance of science, proved, checked, cross-checked. It is not the tenuous stratosphere of its speculations. To do it justice no specially gifted pen is needed, no rhetoric is necessary. For the story enthralls if only it can be woven into the pattern of our everyday experiences and be told by words, rather than by equations, and by simple drawings that speak for themselves, rather than by cuts, inadequately explained and of too technical a character. The well-known psychological technique of alternation between intense concentration and relaxation is seldom used in books on the more difficult subjects, where it is most needed.

These are the devices we have tried to use to make readable a story about things largely unseen and entirely analytical in character. The critical physicist who looks at our pages may be somewhat shocked at times, but he will recognize that every effort has been taken to make our narrative authentic and without exaggeration or distortion with respect to its factual content.

PART I deals with the fundamental aspects of *Mechanics*, upon which all the rest of the physical sciences depend. In connection with falling bodies, there is discussion of several matters, such as terminal velocity, which, though they are of common knowledge and interest, seldom seem to be given any place except in more technical and advanced works. For integration with the sister-science of astronomy, such matters as speculations about tidal evolution have been included, chiefly to show the broad scope of application of fundamental principles but partly to provide relief after discussions that require concentrated attention. Energy, the central character in the entire story, is given four chapters, in the hope, perhaps vain, that the reader may acquire by manifold repetition an enduring impression of how it is defined and what it means.

Part II first presents the phenomena of *Heat* entirely from the experimental point of view and stresses the difference between heat and temperature; then it gives the interpretation of the kinetic theory of heat. In this way when the theory is taken up some desirable repetition as to the facts is made necessary. Furthermore, the method by which a hypothesis becomes acceptable and is made the reference point for all future work can thus be set off by itself and be illustrated by one of the most magnificent cases in the history of the development of science.

Part III, on *Electricity and Magnetism*, takes up aspects of the subject in which it begins to recede far from the realm of daily experience. The historical approach is used; and the experiments are associated, as far as possible, with the experimenters. A very definite attempt is made from the outset to induce the reader to formulate various interpretations for himself and then, following through their implications, to recapitulate in his own thinking what has been the racial development in regard to them.

Part IV, dealing with *Electricity and Matter*, introduces modern physics. The events of the twentieth century cast their shadows ahead of them out of the nineteenth; and from such early indications as the discoveries of conductivity in gases, the photoelectric and thermionic effects, of the latter part of that century, and those of X-rays and radioactivity that ushered in the next one, the story is put together.

Part V, on *Waves and Radiation*, combines in a very unconventional association a great variety of things: mechanics again, and sound and light. Emphasis on wave characteristics is certainly demanded in an age that attempts the solution of every unknown problem or the interpretation of any new set of data by the writing of the wave-equation. Sins of omission are bound to be numerous in any attempt to cover so vast a field. That our account may at times, at least on a first reading, submerge the reader beyond his depth is almost inevitable. We can but hope that the more general aspects of the subject will be impressed upon him and that some basis for future reading may be laid.

ACKNOWLEDGMENTS are due to so many who have co-operated in the making of the book that we hardly know where to begin the list. To Mr. Egbert G. Jacobson, for time and unrequited effort in planning and design, as well as to Mrs. Chichi Lasley, the artist illustrator, goes all credit for such artistic merit as the volume possesses. Mr. Donald Bean, the Manager of the University of Chicago Press, and his able staff have been inspired and sagacious collaborators as to methods, ways, and means. Professor A. H. Compton has read helpfully that section of the manuscript that deals with cosmic rays, and Professor Walter Bartky has done the same for the section on mechanics. Mrs. Ardis T. Monk and Dr. Reginald J. Stephenson, of our staff, who have participated in the design, administration, and teaching of small group sections of the General Course, have read the manuscript with great care and have made many valuable suggestions. The same has been done by Dr. W. K. Chandler, of the Department of English. To the Director and staff of the Museum of Science and Industry of Chicago, especially to Dr. A. M. MacMahon, we wish to express our appreciation of their co-operation in the development of a physics museum used by our students in these courses. Apparatus provided by them has furnished us with no small amount of material for our illustrations. For the rest, Mr. Stanley Anderson, our assistant in preparing demonstration experiments, has furnished and set up special settings for the cameraman. To Erpi Picture Consultants, New York City, our collaborators in educational sound pictures, our acknowledgments are due for prints and films for reproduction. To Professor Paul Kirkpatrick, of Stanford University, for valuable suggestions based on careful class use of the first printing received in time to be incorporated in subsequent impressions. Last but not least, our esteemed friend, the other co-director of this course, Professor Hermann I. Schlesinger, of the Department of Chemistry, has this year generously assumed more than his share of responsibilities in that work to free the author for the purpose of writing this book. Moreover, on those sections of the volume where physics and chemistry are not to be differentiated his suggestions have been of the utmost value.

HARVEY B. LEMON

RYERSON PHYSICAL LABORATORY
UNIVERSITY OF CHICAGO
July 1, 1934

PREFACE TO SECOND EDITION

IN THE twelve years that have elapsed since the first edition of this book was offered to nonprofessional students and to the public, the boundaries of physical knowledge have been vastly extended. Items in the first edition, like the neutron tentatively mentioned in a footnote, have become firmly established in atomic architecture; contrariwise, nuclear structures, believed in 1934 to be composed of electrons and protons, have been entirely abandoned in view of new evidence; and proton-neutron composition has taken their place. Cosmic rays are no longer the last word in the present nuclear age, although still most suggestive by their recent disclosure of energies much greater, per particle, than those released in the sadly misnamed "atomic" bombs, of such grave moment to the entire world.

Educational experimenting likewise has produced curricula, at least in some institutions, as altered from those of twelve years ago as are details of nuclear structure; whether they are as sound only time and experience in this swiftly changing world can decide.

Fortunately for those intensely concerned in both aspects of our subject, there are solid and unchanging foundations on which the science rests and at least a few ideas with respect to its pedagogy that still find increasingly wide acceptance.

Thus our title has been brought up to date—a simple matter, at least for the author. The later chapters that come close to the border line of knowledge have been advanced with it, largely by re-writing and considerable additions of things undreamed of even seven years ago. Here and there in earlier chapters, where the longest shadows of coming events reached back, minor alterations have been made—the most difficult part for the author.

Finally, lest educational changes of emphasis and later experiments may cause earlier ones to be forgotten—since here we inevitably are less objective and build more on sand and less on rock—this second edition carries without alterations the Preface to the first—for the record, ill or good.

HARVEY B. LEMON

UNIVERSITY OF CHICAGO
October 1, 1946

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PART I

MECHANICS

CHAPTER 1

GALILEO AND THE PRINCIPLE OF INERTIA

MODERN science, that has done so much in the last one hundred and fifty years to transform the conditions under which mankind lives, has in large part adopted a new manner of attack upon the unknown. To a limited degree this approach was hesitatingly attempted by men before the sixteenth century. Galileo (1564–1642), (Plate 1), however, was the first to use it openly, consistently, and effectively. As a result, to him more than to any other single individual goes the credit of being the father of modern science.


The scientific method before Galileo

His method was to ask, not *why* things happen as they do, but rather what it is that happens. He searched for accurate descriptions of events and interrelations between various aspects of them. He did not attempt to find in his own consciousness reasons why things were as they seemed; rather, he inquired whether they really were what they seemed to be.

Galileo performed experiments

One great field of Galileo's endeavor had to do with the motions of inanimate objects. He was an ardent student of astronomy. He investigated what it was that happened to terrestrial objects that caused their motion. Thus, in a world where everything from the skies above to the whispering winds below spoke of movement both seen and unseen, his studies were most fundamental. The analyses he was the first to make with respect to the motions of objects, celestial or terrestrial, hold good to this day. He began with the study of pendulums and inclined planes. It has since been found that the analyses he used not only apply as well to the basic aspects of modern intricate machines but also are fundamental in wider ranges including stars and galaxies.

If to his contributions be added those of Isaac Newton (1643–1727), (Plate 2), then it can be said that more recent times, up to the twentieth century at least, have done little but amplify and add detail, then adapt and apply to a myriad of uses. In every connection there has been found new confirmation of the correctness of Galileo's and Newton's ideas, principles, and laws. Not until the twentieth century were new fields in the microcosmos entered where new genius was, and still is, needed for unerring guide.

WITH respect to the motions of ordinary material bodies, such as a stone that is thrown, or a rock that becomes detached and crashes down a mountain side, the ancients had what seem to us curious, naïve, and conflicting ideas. They held a doctrine about "natural places"—levels, as it were—toward which fire, air, water, and the different materials of the earth showed a "natural" tendency to settle or to rise. Each substance sought to return to its own special plane when for any reason it was disturbed and moved elsewhere. A ball thrown by the hand, according to one view, was kept moving onward in its journey because it displaced some air in its passage. The moving-in of the air behind it kept pressing it forward and thus supplied the motive power. Elasticity also was appealed to. When one bent a short bit of spring between finger and thumb and snapped it forward, its elasticity furnished in some fashion the driving mechanism to keep it going after it had left one's hand.