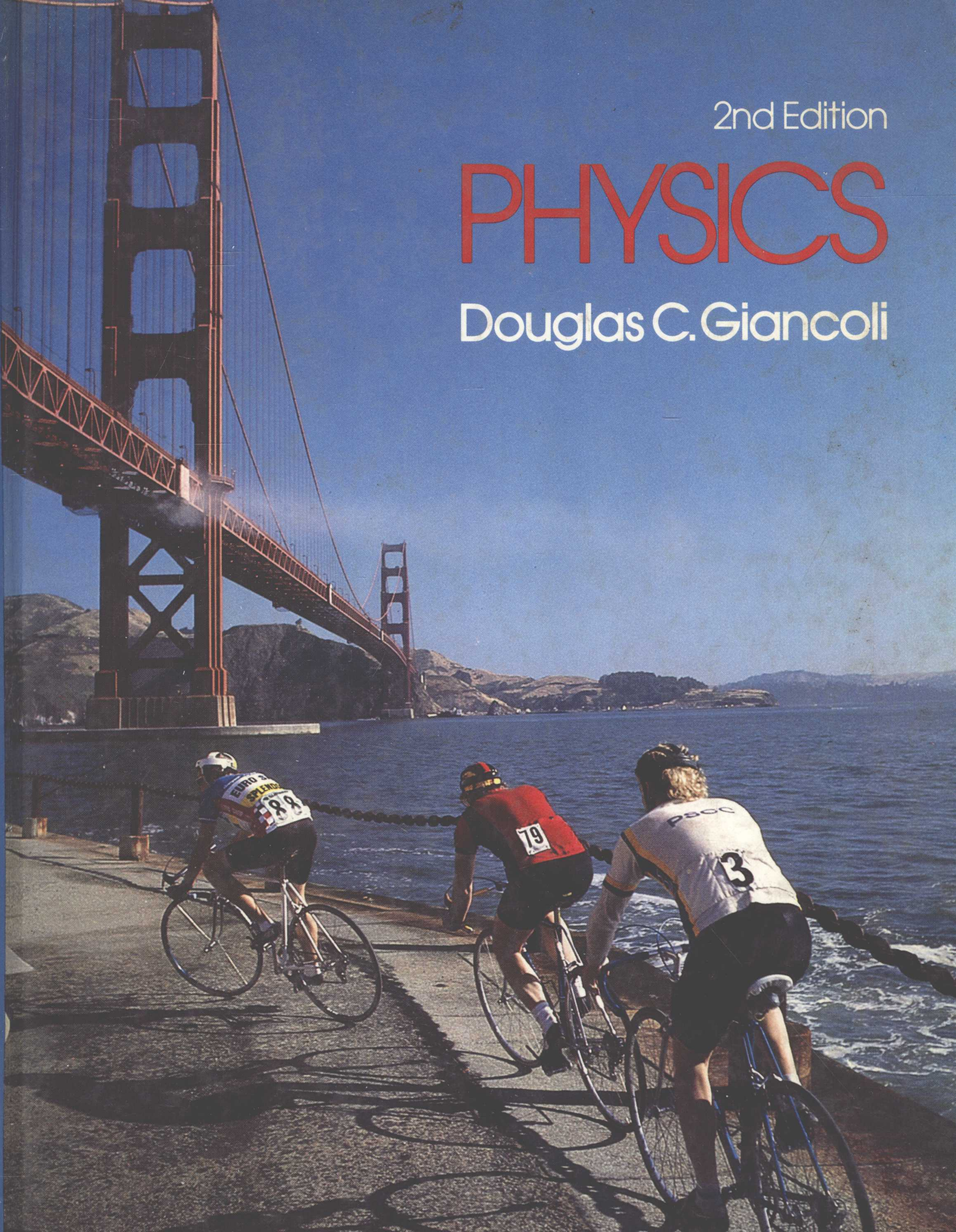
2nd Edition

PHYSICS

Douglas C. Giancoli



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PRINCIPLES WITH APPLICATIONS

Douglas C. Giancoli

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PREFACE

This revised introductory algebra-based physics textbook incorporates a number of changes and updatings (described below). But its basic intent and general outline remain the same. The book is intended to be readable, interesting, and accessible to students, and is meant to give them a thorough understanding of the basic concepts of physics and, by means of many interesting applications, to prepare them to use physics in their own lives and professions. It is particularly appropriate for introductory physics courses taken by students studying biology, (pre)medicine, architecture, technology, earth and environmental sciences, and other disciplines; it is also suitable for use in colleges that offer only one introductory physics course.

This book offers, above all, an in-depth presentation of physics. I have tried to avoid the dogmatic approach of treating topics formally and abstractly first, and only later (if at all) coming down to earth and relating the material to the students' own experience. This approach may be appealing (it's elegant), but it can slow down the learning process for all but the best students. My approach is to recognize that physics is a description of reality and thus to start each topic with concrete observations and experiences that students can directly relate to. Only then are readers led into the more formal and abstract treatment of topics. Not only does this make the material more interesting and easier to understand, but it is closer to the way physics is actually practiced. Historically, we didn't start with the first law of thermodynamics, for example, and then derive all kinds of consequences from it; rather, the law was a generalization of all kinds of phenomena. In addition, I have endeavored to present the basic concepts of physics in their historical and philosophical context. I have also tried to avoid the problem of leaving certain topics "hanging", with students wondering, "Why did we study that?" Thus I have tried to indicate why each topic is important, and to bring each topic to completion. We study static forces in structures, for example, partly because real materials are elastic and also can fracture; so I have included the latter topics in the statics chapter.

Another important feature of this book is the inclusion of a wide range of examples and applications from other fields: biology, medicine, architecture, technology, earth sciences, the environment, and daily living. These serve not only to enliven the book but also to show how physics is important in other disciplines and professions, and in everyday life. Some applications serve only as examples of physical principles. Others are treated in depth, with whole sections devoted to them (among these are the study of medical imaging systems, constructing arches and domes, and the effects of radiation). But applications do not dominate the text (this is, after all, a physics book!). They have been carefully chosen and integrated into the text so as not to interfere with the development of the physics but rather to illuminate it.

Much attention is given to problem solving. Explicit hints on how to attack problems (rewritten for this new edition) are given in several places early in the book, notably in Sections 1-9, 3-8, and 3-10 (whose title is "Notes on Problem Solving"). The last-named section is placed after the students have had some experience wrestling with problems and hopefully will then be motivated to read and pay attention to this section; it can, of course, be covered earlier if an instructor so desires. Some 250 examples are fully worked out in the text; these help students to fix ideas in their minds, to demonstrate interesting applications, and to help students develop problem-solving skills. Many examples are taken from everyday life and aim at being realistic. There are over 2250 end-of-chapter exercises, including more than 650 questions that require verbal answers based on an understanding of the concepts, and over 1600 problems involving mathematical calculation. The wide range of problems relates directly to the physics as well as the applications. They are arranged by sections, and they are graded according to difficulty: level I problems are simple, requiring an understanding of basic definitions and concepts and typically the use of a single equation; level II are normal problems, requiring more thought and often the combination of two different concepts; level III are the most difficult, often requiring synthesis of three or more concepts or perhaps dealing with more advanced material. The arrangement by section number means only that those problems depend on material up to and including that section; earlier sections and chapters are often relied upon, particularly in level II or III problems. The ranking of the problems by difficulty (I, II, III) is necessarily subjective and is intended only as a guide. Level II problems, particularly, are of a very wide range. I suggest that instructors assign a significant number of the level I and level II problems and reserve level III problems mainly to challenge superior students. Although most level I problems may seem easy, they help to build self-confidence—an important part of learning, especially in physics. Answers to odd-numbered problems are given at the back of the book. Throughout the text *Système international* (SI) units are used. Other metric and British units are defined for informational purposes.

This second edition of *Physics, Principles with Applications*, has been thoroughly revised to improve coverage, thoroughness, and clarity, as well as to include the latest developments in physics and its applications. The most significant improvements over the first edition involve some expansion and reorganization of mechanics, some reorganization of modern physics with the latest developments, and new applications. The principal changes are:

1. Kinematics is now divided into two chapters: Chapter 1 is devoted to one-dimensional motion, whereas Chapter 2 deals with kinematics in two (or three) dimensions, including projectile motion. This allows a more gradual introduction to physics, and also a more complete treatment of kinematics including more on relative velocity, vectors, and the use of Δ (to represent "change in").
2. There are now separate chapters on work and energy (Chapter 5) and on linear momentum (Chapter 6), with fuller and more careful treatments of each, particularly for potential energy, conservation of energy, collisions, and center of mass.
3. Rotational motion now has a chapter all to itself (Chapter 7), allowing a fuller treatment in one place of all aspects of rotation about an axis: angular

quantities, rotational kinematics and dynamics, torque, rotational kinetic energy, angular momentum and its conservation including its vector nature.

4. Circular motion and gravitation, now Chapter 4, is treated right after dynamics (before energy and momentum) since it deals with acceleration and force. (It could, instead, be treated just before Chapter 7 on rotational motion, if desired.)

5. The old chapter on ac circuits and electronics has been eliminated; ac circuits are now included in Chapter 20 with electromagnetic induction; semiconductors and their use in electronics are now included with modern physics in the new Chapter 28 on molecules and solids; vacuum tubes have been dropped except for the CRT, which is treated in Chapter 19.

6. Modern physics has been reorganized a little and brought up to date. Principal changes are: (a) a special chapter (28) on molecules and solids; (b) expansion of the effects and uses of radiation, addition of new imaging techniques (see below), NMR, and the new SI units for dosimetry; (c) new particles such as the τ lepton, $W^{\pm}$ and Z^0 particles, the bottom and top quarks; (d) quantum chromodynamics (QCD), electroweak theory, grand unified theories (GUT) and symmetry breaking.

7. Some parts of the book have been rewritten to improve clarity or pedagogy. Examples are more careful and consistent treatments of work, energy, potential energy, center of mass, Newton's third law, heat and thermal energy, electric potential, and sign conventions for lenses and mirrors.

8. There are new applications to biology and medicine, including the new imaging techniques using ultrasound (Chapter 14), computerized tomography (CT scanning) along with conventional X ray (Chapter 24), nuclear medicine, emission tomography (SPET and PET), and NMR imaging (Chapter 30).

9. New or expanded geophysical applications include examples involving continental plates (Sections 9-7 and 9-13), the tides (Chapter 4), gravity anomalies and mineral exploration (Chapter 4), the geophone or seismometer (Section 20-8).

10. Nearly all the figures have been redrawn to improve clarity and accuracy. As a general rule, real (tangible) objects are shown in color whereas our analysis (coordinate axes, graphs, field lines, arrows representing vectors, and so on) is shown in black.

11. The division of each chapter has been simplified so there are only main sections, and no subsections; many of the subsections of the first edition are now regular sections, and all section headings are in the table of contents.

12. Among other changes, this revision incorporates the new definition of the meter in terms of the speed of light. The worked-out examples include a number of more sophisticated ones so students can see how to treat more complex situations. Some of the old problems have been retained, sometimes with the numbers changed to protect the innocent (and foil the guilty), a few have been dropped, and many new problems (and questions) have been added.

To make room for the additional material in this new edition, it was necessary to eliminate some material that was in the first edition. Almost nothing of the basic physics was cut (except, perhaps, slightly, to improve clarity). To incorporate the expanded treatments of basic physics, a few of the more esoteric topics were dropped or shortened. And some of the applications which are less current, or for which adequate treatments can readily be found elsewhere, were shortened or dropped to make room for the latest applications, such as the various new forms of medical imaging, which are deeply based in physics and for which treatments at this level are not yet readily available.

Although there has been some reorganization of material within some areas, the general outline of this new edition retains the traditional order of topics: mechanics, including fluid mechanics (Chapters 1–9), kinetic theory and thermodynamics (Chapters 10–12), vibrations, waves, and sound (Chapters 13 and 14), electricity and magnetism (Chapters 15–21), light (Chapters 22–24), and modern physics (Chapters 25–31).

Nearly all topics customarily taught in introductory physics courses are included here. The tradition of beginning with mechanics is sensible, I believe, since it was developed first, historically, and since so much else in physics depends on it. Within mechanics, there are various ways to order the topics, and this book allows for considerable flexibility. Statics, for example, can be covered either before or after dynamics. I prefer to cover statics after dynamics partly because many students seem to have trouble with the concept of force. (They tend to associate force with motion, and it seems to help if they understand the nature of this connection before dealing with forces without motion.) This order also allows full development of the concept of torque before it is used in statics. Moreover statics is a special case of dynamics—we study statics so that we can prevent structures from becoming dynamic (falling down)—and that sense of being at the limit of dynamics is intuitively helpful. Nonetheless, statics (Chapter 8) can be covered earlier, if desired, before dynamics, after a brief introduction to vectors. Another option is the position of the chapters on light. I have placed them after electricity and magnetism and EM waves, as is typical. However, light could be treated immediately after the chapters on waves (Chapters 13 and 14), thereby keeping the various types of wave motion in one place. Another position choice involves special relativity (Chapter 25), which is located along with the other chapters on modern physics, after EM waves and light have been covered. Relativity could be covered, if desired, along with mechanics—say after Chapter 6—since it depends (except for the optional Section 25-2) mainly on material through Chapter 6.

The book contains more material than can be covered in most one-year courses. This was done to give instructors flexibility in choice of topics. The wide range of subjects also means that students can learn about many topics even though there is not class time for them. This aspect makes the book more valuable to students as a resource and as a reference book. Sections marked with a star (asterisk) are considered optional. These sections contain slightly more advanced physics material, often material not usually covered in typical courses, and/or interesting applications. They contain no material needed in later chapters (except, perhaps, in later optional sections). This does not imply that all non-starred sections must be covered; there still remains considerable flexibility in the choice of material to suit the needs of students and instructors.

For use in a two-semester course, the book can be considered to be divided roughly in half between Chapters 14 and 15. The first half would then include mechanics, heat, and sound, with the second half containing electricity and magnetism, light, and modern physics. (The slightly longer second half has more optional sections.) As mentioned earlier, the order and choice of topics is flexible, so other course outlines are possible. For a brief or "bare bones" course, all the optional material could be dropped as well as major parts of Chapters 9, 14, 18, 21, 27, and 31, as well as selected parts of Chapters 6, 7, 8, 12, 20, 23, 24, and 30.

Mathematics can be an obstacle to student understanding. To avoid frightening students with an initial chapter on mathematics, I have instead used an appendix for review of algebra, geometry, accuracy and significant figures, exponents, powers of ten, and proportionality. Other appendixes cover order-of-magnitude estimating and dimensional analysis. Other important mathematical tools, such as addition of vectors and trigonometry, are dealt with in the text where first needed. Difficult language too can hinder understanding; and to put students at their ease, I have tried to write in a relaxed, colloquial style, avoiding jargon. New or unusual terms are carefully defined when first used. It is necessary, I feel, to pay careful attention to detail, especially when deriving an important result. Whether it is a verbal discussion, or a mathematical one, I have aimed at including all steps in a derivation so that students don't get bogged down in details and then fail to understand the concept as a whole. I have tried to make clear which equations are general, and which are not, by explicitly stating the limitations of important equations in brackets next to the equation, such as

$$x = x_0 + v_0 t + \tfrac{1}{2} a t^2. \qquad \text{[constant acceleration]}$$

The new revision of this book has depended to a great extent on the hundreds of instructors who have used the book in class and were kind enough to send me their comments and suggestions for improvement. To all of them I owe a debt of thanks. I also wish to thank the professors who read through the text, either the first edition or the newly revised manuscript (or both), and offered valuable suggestions; these include John Anderson (University of Pittsburgh), Gene Barnes (CSU, Sacramento), Isaac Bass, Paul A. Bender (Washington State University), Joseph Boyle (Miami-Dade Community College), Peter Broncazio (Brooklyn College, CUNY), Warren Deshotels (Marquette), Laurent Hodges (Iowa State), Gordon Jones (Mississippi State), Michael Lieber (U. Arkansas), Robert Messina, David Mills (College of the Redwoods), Ed Nelson (U. Iowa), John Reading (Texas A & M), William Riley (Ohio State U.), D. Lee Rutledge (Oklahoma State U.), Paul Urone (CSU, Sacramento), Jearl Walker (Cleveland State U.), Gareth Williams (San Jose State U.), Peter Zimmerman (Louisiana State U.). I owe special thanks to Professors John Heilbron, Richard Marrus, and Howard Shugart for many helpful discussions and suggestions, and for their hospitality at the University of California, Berkeley, as well as to Professors Tito Arecchi, Director of the National Optics Institute, University of Florence, and Paolo Galluzzi and the staff of the Institute and Museum of the History of Science, Florence. I also wish to acknowledge the work of Joseph Boyle in preparing a study guide for this new edition and of John Reading who prepared the solutions manual with the assistance of Ed Gibson, Stewart Ryan, and J. Neal Huffaker. Finally, I wish to thank the many people at Prentice-Hall who worked on this project and made it possible, especially Ray Mullaney, Doug Humphrey, John Davis, Tim Moore, and Virginia Huebner. The responsibility for all errors lies, of course, with me. I welcome comments and corrections.

Douglas C. Giancoli

NOTES TO STUDENTS AND INSTRUCTORS ON THE FORMAT

1. Sections marked with a star (*) are considered optional (see the Preface).

2. The customary conventions are used: Symbols for physical quantities are italicized (such as m for mass), whereas units are not italicized (m for meter); boldface (**F**) is used for vectors, and this is discussed in the text.

3. Important terms are italicized where they are introduced, and the most important are in boldface (such as *coefficient of friction* and **acceleration**).

4. Few equations are valid in all situations. Where practical, the limitations of important equations are stated in square brackets next to the equation.

5. Worked-out Examples and their Solutions in the text are set off with a vertical colored line in the margin.

6. Each chapter ends with a Summary, giving a brief review of important concepts and terms (the most important ones are italicized here). The summaries are not intended to give an understanding of the material, which can only be had from a study of the chapter. Optional topics are not normally included in the summaries (except for Chapter 28 which is all optional).

7. Following the Summary in each chapter are sets of Questions that students should attempt to answer (to themselves at least) and Problems arranged according to section and difficulty (see the Preface). Questions and Problems that relate to optional sections are starred.

8. The appendixes contain useful background and reference material such as a mathematical review, discussions of order-of-magnitude estimating and dimensional analysis, and a table of isotopes with atomic masses and other data. Tables used frequently are located inside the front and back covers.

9. The extensive Index can be a useful tool. For example, it can be used to look up concepts or words whose meanings have been forgotten.

CONTENTS

INTRODUCTION

Physics is the most basic of the sciences. It deals with the behavior and structure of matter. The field of physics is usually divided into the areas of motion, fluids, heat, sound, light, electricity and magnetism, and the modern topics of relativity, atomic structure, and nuclear physics. We will cover all these topics in this book, beginning with motion (or mechanics, as it is sometimes called). But before we begin on the physics itself, let us take a brief look at how this activity called "science," including physics, is actually practiced.

The practice of science: science and creativity

The principal aim of all sciences, including physics, is generally considered to be the ordering of the complex appearances detected by our senses—that is, an ordering of what we often refer to as the "world around us." Many people think of science as a mechanical process of collecting facts and devising theories. This is not the case. Science is a creative activity that in many respects resembles other creative activities of the human mind.

Let's take some examples to see why this is true. One important aspect of science is *observation* of events. But observation requires imagination, for scientists can never include everything in a description of what they observe. Hence, scientists must make judgments about what is relevant in their observations. As an example, let us consider how two great minds, Aristotle (384–322 B.C.) and Galileo (1564–1642), interpreted motion along a horizontal surface. Aristotle noted that objects given an initial push along the ground (or on a table top) always slow down and stop. Consequently Aristotle believed that the natural state of a body is at rest. Galileo, in his reexamination of horizontal motion in the early 1600s, chose rather to study the idealized case of motion free from resistance. In fact, Galileo imagined that if friction could be eliminated, an object given an initial push along a horizontal surface would continue to move indefinitely without stopping. He concluded that for an object to be in motion was just as natural as to be at rest. By seeing something new in the same "facts," Galileo is often given credit for founding our modern view of motion (more details in Chapters 1, 2, and 3). This seeing of something new was surely inspired thinking.