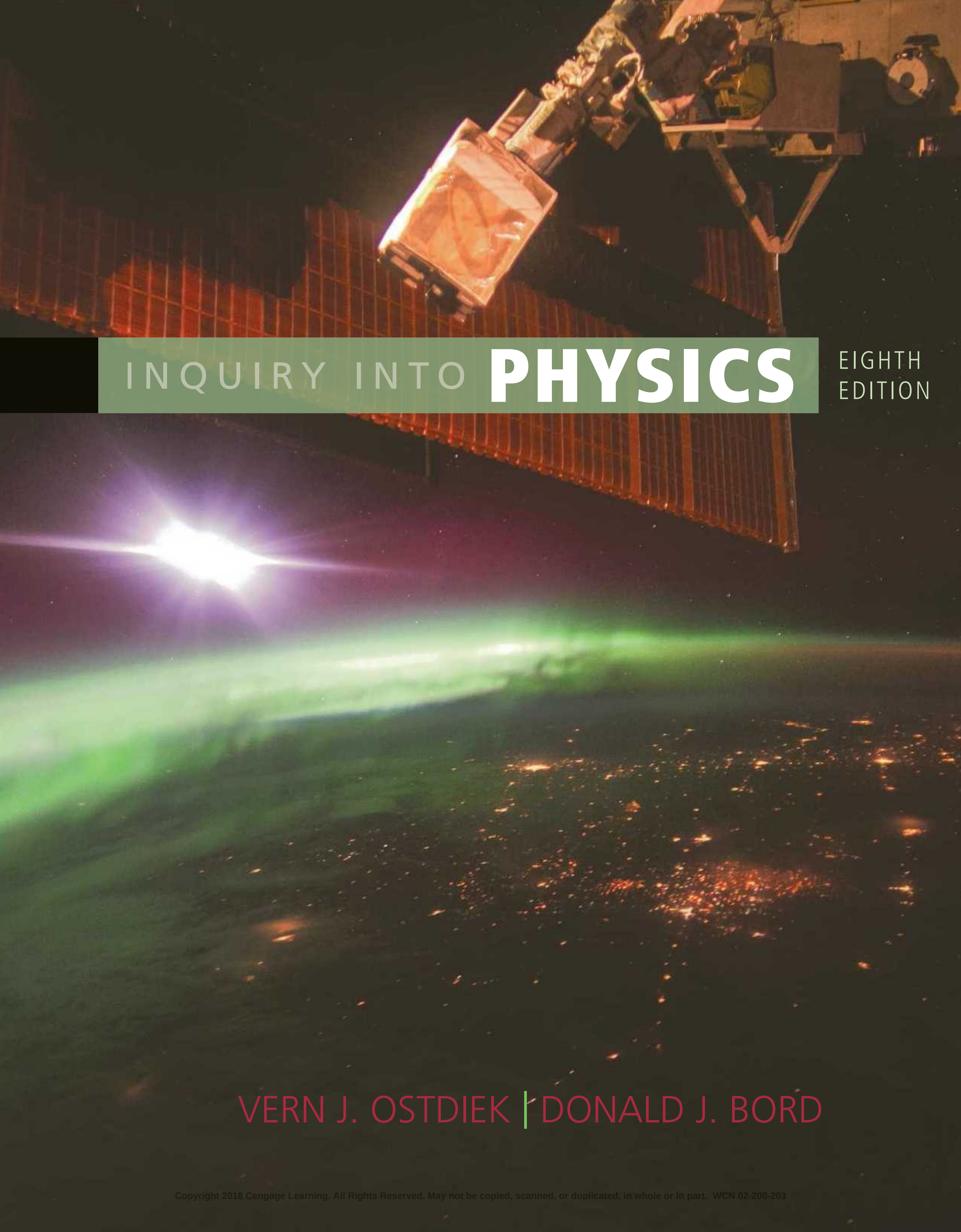
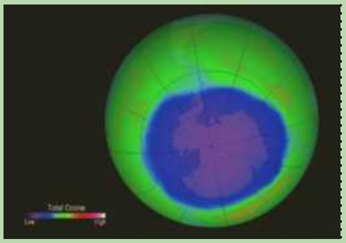


INQUIRY INTO PHYSICS

EIGHTH EDITION

VERN J. OSTDIEK | DONALD J. BORD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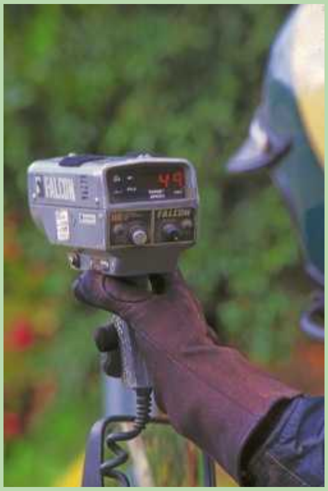
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Eighth Edition

INQUIRY INTO
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VERN J. OSTDIEK | DONALD J. BORD
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Library of Congress Control Number: 2016934469

Student Edition
ISBN: 978-1-305-95942-2

Loose-leaf Edition:
ISBN: 978-1-337-28964-1

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Printed in the United States of America
Print Number: 01 Print Year: 2016

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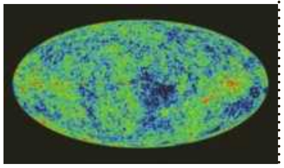
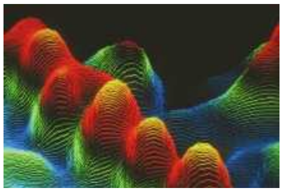
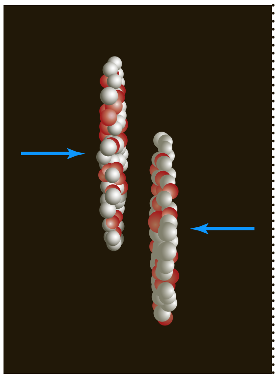
CONTENTS







Appendixes

PREFACE

Welcome to the eighth edition of *Inquiry Into Physics*. In this edition, the emphasis on the inquiry approach to learning physics is continued. Readers are encouraged to try things, to discover relationships between physical quantities on their own, and to look for answers in the world around them rather than seek them only in books or on the Internet. This book should not be treated as an answer key to the nature of physical phenomena (although it does offer many explanations of how things work), but as an extended invitation to examine things for yourself in a direct, hands-on fashion and to be daring and experiment on the various systems and structures that surround you. As you progress from topic to topic, give free rein to the innate curiosity that we all possess from birth, and don't be afraid to ask questions about the things you experience daily. Keep in mind that learning is a more exciting, complete, lasting, and enjoyable process when you are fully engaged in it and not merely a passive recipient of facts and statistics offered by your instructors, this text, and other print or electronic sources. Get in the game—of physics!

Our Intended Audience

This book is designed primarily for students who are taking an introductory physics course, perhaps for the first time, to satisfy collegiate requirements or who wish to satisfy their curiosity and thirst for understanding about the structure and range of interactions that characterize our physical universe. It offers a broad survey of the fundamental definitions, laws, and principles of the discipline of physics, as well as a large sampling of applications of these concepts in virtually every aspect of human experience. *Inquiry Into Physics* provides a first look into the things that comprise our universe, from the smallest subatomic particles to the largest galaxies, as well as the interactions that can occur between those things, from energy-releasing reactions among atomic nuclei to gut-wrenching collisions between automobiles, to gravitational interactions among stars and whole galaxies that result in catastrophic disruptions over time scales that dwarf modern humankind's 200,000-year history on Earth. In ways both large and small, physics principles and applications touch our lives literally from moment to moment: in the pumping action of the heart and the flow of blood in our arteries and veins, in the electrical impulses that enervate our muscles and organs, and in the processes that drive our senses of sight and sound and permit us to see and hear the goings-on in the world around us.

Physics also satisfies our intellectual curiosity by revealing Nature's secrets about things both mundane and exotic. Discoveries in physics, like the processes of nuclear fission and fusion, have shaped the political landscape of the world and are likely to continue to do so well into the future. A look back at the women and men who made many of these important discoveries connects us with our past and gives us deeper insight into the pathways that can lead to scientific understanding. These aspects and others are blended throughout the text in an effort to provide you with a sense of the unity both within the discipline of physics and between the subject and its human practitioners. The tools we use to present these facets of physics are basic ones: the written word; visualizations and models in the form of hundreds of photos, diagrams, and graphs; and simple mathematics to show how the conceptual side of physics is inextricably woven together with its quantitative side. By these means, we hope that you will complete your introductory study of physics, having achieved a greater appreciation not only for what we know about the physical universe, but also how we have come to know it.

What's New?

Each chapter has been thoroughly reviewed, and many sections have been rewritten to improve the clarity and accuracy of the prose. The text has been updated and in some cases expanded to reflect the latest scientific discoveries and achievements in the fields of physics and astronomy, and new material has been added to reflect current affairs and increasingly popular applications of physics principles in 21st-century life. Each major chapter section has been divided into subsections to better call out the content and organization of the main topic for students and to permit instructors to more finely tune reading assignments to their needs and preferences. The art program has been substantially improved throughout the book to offer more contemporary and relevant photos and figures to illustrate the connections between fundamental physical concepts and the modern world. In particular, in figures containing vectors, the arrows have been made bolder and the color scheme used to identify each vector expanded and made more internally consistent to aid in recognizing and relating such quantities. In addition, the format for the worked examples has been modified to better delineate the questions and the solutions, and the answers are now shaded to give them greater prominence.

The long-standing "Physics Potpourri" series has been reconceptualized and in some cases reorganized as a suite of "Applications" essays, focusing attention on ways that physics principles have been and continue to be applied to change—and hopefully enhance—our world. These text elements now also include one or two review questions to support student engagement. An expanded set of end-of-chapter (EOC) exercises, including more than 80 new questions and problems, has been provided, and the "explore-it-yourself" application boxes have been retitled "Physics to Go" to better emphasize the "take it with you" exploratory aspects of these features. The former "Physics Family Album" vignettes have been shortened in many cases and renamed "Profiles in Physics" to emphasize their focus on key personalities in the development of the discipline; like the "Applications" articles, the "Profiles" sections now contain review questions to better promote their use as important pedagogical elements of the book.

Some specific changes on a chapter-by-chapter basis include the following:

Prologue Updated *Application* highlighting the commercial aspects of the metric system and the new emphasis on units defined in terms of fundamental constants. Fifty percent of the art is new.

Chapter 1. More than a dozen new photos and line drawings are included. Three new EOC exercises and a new example have been added.

Chapter 2. Updated discussion of the *New Horizons* mission to Pluto, plus a new *Application* feature on *Chaos*. Five new EOC exercises and three new worked examples have been added.

Chapter 3. More than a dozen new figures have been introduced. An updated *Important Equations* section now appears to reflect new material on elastic energy and torque. Eight new EOC exercises and three new worked examples have been introduced.

Chapter 4. More than a dozen new figures have been included. The updated feature on element nomenclature includes the latest discoveries and naming conventions for the heaviest elements. New material on hydraulics and fluid flow has been introduced. Thirteen new EOC exercises and two new worked examples have been added.

Chapter 5. Expanded discussion of the ideal gas law. Expanded treatment of entropy and energy quality. Thirteen new EOC exercises and three new worked examples now appear.

Chapter 6. Twelve new figures and new material on the Hubble relation have been provided. Five new EOC exercises have been included.

Chapter 7. Revised and updated chapter opener on iProducts. More than a dozen new photos and refreshed line drawings. Updated information for Tables 7.1 and 7.2, plus additional material on superconducting power grid projects in the United States and Europe. Three new EOC exercises have been added.

Chapter 8. Nearly a dozen new or updated figures. Additional discussion of superconducting electromagnets and new information about the greenhouse effect and environmental evidence for climate change are presented. Two new EOC ranking exercises have been added.

Chapter 9. Explicit inclusion of mathematical treatment of double slit interference with a new worked example. Updated discussion of the Hubble Space Telescope focusing on instrumentation missions. Five new EOC exercises have been added.

Chapter 10. Nearly a dozen new or enhanced figures have been included.

Chapter 11. Updated discussion of clean-up work at the Fukushima Daiichi reactor site in Japan five years after the destructive earthquake and tsunami struck the plant. New material on radiation therapies for brain tumors using a gamma knife. Four new EOC exercises have been added.

Chapter 12. This chapter has been completely revised and merged with the former Epilogue on cosmology to produce a fresh and unified treatment of relativity, particle physics, and cosmology. A new section on general relativity with two new worked examples and a treatment of the LIGO discovery of gravitational waves now follows the opening discussion of special relativity. The subsequent three sections addressing particle physics and the Standard Model have been streamlined, while including material on the discovery of the Higgs boson and updates to the tabulated data for elementary particles and the Standard Model. Nearly a dozen new figures have been provided, and the *Summary* and *Important Equations* sections have been altered to reflect the new information. A new Mapping It Out! exercise dealing with the concepts and predictions of general relativity has been inserted, and 24 new EOC exercises have been added covering the new topics.

What's the Plan?

The traditional organization of topics followed in many introductory physics courses has been retained for this new edition. Once again, we have eschewed the use of shorter, more narrowly focused chapters and have continued with longer ones that offer the opportunity to present the overarching conceptual unity and continuity of the broad subdisciplines that make up our subject (kinematics and dynamics, energy, thermodynamics, optics, atomic and nuclear physics, etc.). Each of the 12 numbered chapters is built around the following common features:

Chapter Introductions. Opening each chapter, these examples of physics as it plays out in everyday life serve to motivate the reader to immediately engage with the material by showing how a common device or issue of current interest and importance connects to the concepts developed in the chapter.

Examples. Worked exercises that illustrate the roles of physics principles and simple mathematics in real-world situations are regularly presented as models for problem solving.

Physics to Go activities. These hands-on experiments and exercises give students the chance to see and do physics without the need for specialized equipment or highly sophisticated techniques. These investigations are generally strategically placed before the relevant text discussion, inviting the reader to directly experience the upcoming concepts and to begin to formulate their own understanding of them.

Learning Checks. Simple self-quizzes, designed to test the reader's basic comprehension of the material on a section-by-section basis, are included in each chapter.

Physics Applications essays. These self-contained features explore selected topics drawn from astronomy, the history of science, engineering, biophysics, environmental physics and other areas. These essays are provided to deepen and enrich the student's understanding of physics and especially its applications.

Concept Maps. Based on principles developed from educational research, these visual displays offer an alternative representation or organization of the relationships between important chapter concepts.

Profiles in Physics. The final content section of each chapter presents a look at the historical development and the human side of physics by describing aspects of the lives and work of some of the key men and women responsible for the discovery and expression of the laws and concepts presented in the chapter.

Summary. Each chapter summary is a brief, bulleted review of the key points in the chapter and a short, helpful list of the major concepts for students when preparing for tests and quizzes.

Important Equations. An annotated list of the equations included or developed in the chapter is presented for quick reference when problem solving.

Mapping It Out! These exercises, many intended for group collaboration, are included to help students use concept-mapping techniques to organize, unify, and improve their understanding of important concepts and relationships introduced in each chapter.

Questions. These end-of-chapter queries check students' basic understanding of the material and their ability to extend that understanding to new and different situations. A special icon (■) is used to distinguish the first type of question from the second for ease of identification and selection.

Problems. These end-of-chapter exercises offer students opportunities to hone their critical thinking skills using logic and simple mathematics to solve problems based on realistic applications of the physics developed in each chapter.

Challenges. More advanced questions and problems designed to test a reader's mastery of the material at a deeper level are included at the close of each chapter for the benefit of highly motivated students. Many of these exercises can be used as starting points for small group or whole class discussions.

Conveniently located in the appendices and front and back endsheets of the print version of this book are several additional resources that are helpful in problem solving or in gaining further appreciation of the scope of physics applications in the 21st century. These include:

- **Selected Applications** of physics concepts and principles ("Physics Connections to the Real World")
- **Tables of Conversion Factors** and other information (for example, tables of metric prefixes, physical constants, and other often-used data)
- **Periodic Table of the Elements**
- **Winners of the Nobel Prize in Physics**
- **Math Review**
- **Answers** to the odd-numbered Problems and to many of the Challenges and the Physics to Go activities (where appropriate).

There is more than enough material in the text than can usually be covered in a typical one-semester course. However, about 30 of the more specialized sections may be omitted with minimal impact on the later topics. Specifically, these include the **Applications** features and the **Profiles in Physics** segments and Sections 2.8, 3.8, 5.6, 5.7, 6.4, 6.5, 6.6, 8.4, 8.7, 9.5, 9.7, 10.7, 10.8, and 12.1–12.6.

What Else Is There?

What else is there? You've got it all.

MindTap® for Physics is the digital learning solution that helps instructors engage and transform today's students into critical thinkers. Through paths of dynamic assignments and applications that you can personalize, real-time course analytics, and an accessible reader, MindTap® helps you turn cookie cutter into cutting edge, apathy into engagement, and memorizers into higher-level thinkers.

Developed and designed in response to years of research, MindTap® leverages modern technology and a powerful answer evaluation system to address the unmet needs of students and educators. The MindTap® assessments incorporate assorted just-in-time learning tools such as displayed solutions, solution videos for selected problems, and targeted readings and examples from the textbook. These just-in-time tools are embedded directly adjacent to each question to help students maintain focus while completing automatically-graded assignments.

The MindTap® Learning Path groups the most engaging digital learning assets and activities together by week and topic, including readings and automatically graded assignments, to help students master each learning objective. Interactive Video Vignettes encourage an active classroom where students can address their alternative conceptions outside the classroom. Interactive Video Vignettes include online video analysis and interactive individual tutorials to address learning difficulties identified by Physics Education Research (PER).

Easy to use, efficient, and informative, MindTap® provides instructors with the ability to personalize their course with dynamic online learning tools, videos, and assessments; a student diagnostic pre-test; and personalized improvement plans to help students improve their foundational arithmetic skills outside of class time, plus just-in-time resources available to students while doing homework.

Instructor Companion Site for Ostdiek & Bord *Inquiry Into Physics*, 8th edition

Everything you need for your course in one place! This collection of book-specific lecture and class tools is available online via www.cengage.com/login. Access and download PowerPoint presentations, images, the Instructor's Manual, videos, and more.

Each chapter of the **Instructor's Manual** by Thomas E. Sieland of Embry-Riddle Aeronautical University provides the following:

- Chapter outline
- Chapter overview
- Learning objectives
- Teaching suggestions and lecture hints
- Common misconceptions and how to counter them
- "Consider This" (additional tips and suggested resources)
- Answers to "Mapping It Out!"
- Answers to Questions
- Answers to even-numbered Problems
- Answers and brief solutions to Challenges

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Who's Responsible?

The production of this newest edition of *Inquiry Into Physics* involved the collaboration of many talented professionals at Cengage Learning. First and foremost, sincere thanks goes to Susan Dust Pashos, Senior Content Developer, for her steadfast support, keen eye, physics savvy, and deep understanding of what's possible and what's not in the publishing business. Without her wise advice, careful review, and effective advocacy, it is doubtful that this project would have come to fruition in as timely and successful manner as it has. Thanks are also due to Rebecca Berardy Schwartz, our Product Manager, whose confidence in this project and careful assembly of a team of consummate professionals within the Cengage Learning organization have produced what is arguably the best and most attractive edition of the book yet. Tanya Nigh, Content Project Manager, provided able and timely advisement and intervention on in-house production matters to resolve problems and maintain project momentum. The efforts of Michael Jacobs, Content Developer, to adapt content for the Learning Path in MindTap® for this edition of *Inquiry* are gratefully acknowledged, as are the contributions of Christine Myaskovsky, Intellectual Property Analyst, whose skill and perseverance in securing permissions for many critical images were unparalleled. The art program for this eighth edition has been updated and improved to an extent not seen since the first edition in 1985, and much of the credit for this transformation goes to Cate Barr, Senior Art Director, and Bruce Bond, Executive Director for Design, who, among other contributions, guided the thorough-going program of vector enhancements that are visible on practically every page of the book. Hats off to Cate as well for locating the exquisite cover image for this edition, which continues *Inquiry's* tradition of using striking images from Nature to call out the many ways in which physical principles are on display around us.

Kudos also go out to the vendors and contractors who have provided special services throughout the production of the book including Nitesh Sharma, project manager at our publishing and printing partner, Macmillan Publishing Solutions, in India, and Justin Karr and Susan Ordway who were instrumental in directing the XML coding for Mindtap®.

A deep debt of gratitude and appreciation is owed to Dr. Tom Sieland of Embry-Riddle Aeronautical University who once again, with skill and precision, developed the Instructor's Manual for the eighth edition of *Inquiry*. Tom's extensive experience as a physics teacher and his long-time classroom use of this book combine to infuse the Instructor's Manual with helpful pedagogical advice, accurate and authoritative solutions, and an extensive set of teaching suggestions and lecture hints specially matched to the book, thus making this ancillary a valuable resource for practitioners both new and more seasoned.

Thanks are also due to the many instructors and students who have used *Inquiry Into Physics* since its first appearance in 1985. Your advice, encouragement, and suggestions for improvement have been instrumental in keeping the book faithful to its original philosophy and purposes, up to date with regard to important developments in the field, and clear and accurate in its exposition. For this edition, a special expression of gratitude is owed to Dr. Vitaly Kresin at the University of Southern California and Dr. Brian Utter of Bucknell University for their evaluation of an early draft of the new Chapter 12; their suggestions for improvement have been instrumental in yielding a more coherently organized and vibrantly expressed presentation of relativity and high-energy physics than was initially presented.

I sincerely thank all of you and hope you enjoy this latest edition of *Inquiry Into Physics*.

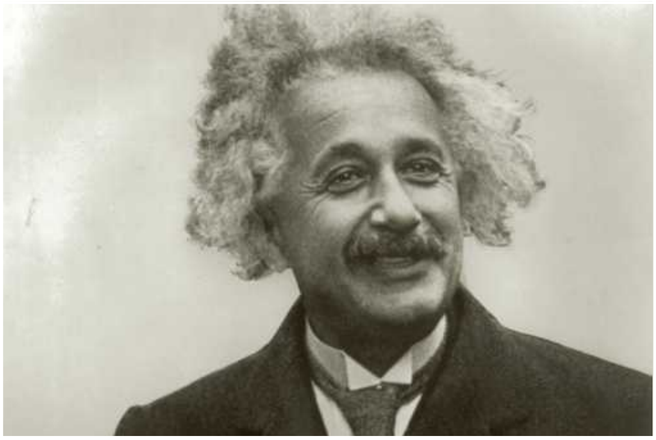
Don Bord
September 2016

Dedication

*This book is lovingly dedicated to my wife, Cheryl, who,
through seven editions and nearly 30 years, has unstintingly
and with great good humor offered me her support,
encouragement, loyalty, advice, and foremost, her love,
without which this text and so many of my other personal
and professional achievements would never have been possible.
Thank you, C.*

PROLOGUE OUTLINE

PROLOGUE: GETTING STARTED



Pictorial Press Ltd/Alamy

Figure PO-0 "In a century that will be remembered foremost for its science and technology—in particular for our ability to understand and then harness the forces of the atom and universe—one person clearly stands out as both the greatest mind and paramount icon of our age: The kindly, absent-minded professor whose wild halo of hair, piercing eyes, engaging humanity, and extraordinary brilliance made his face a symbol and his name a synonym for genius, Albert Einstein." (*Time* magazine.)

P.1 Introduction

In 1999, *Time* magazine, known for naming an annual "person of the year," set out to choose its "person of the century." A daunting task it was, considering the events of the turbulent 20th century and the inevitable criticism that would come from those favoring someone not named. Would it be a world leader who shaped significant spans of the century—for good or bad—such as Franklin D. Roosevelt (a runner-up for person of the century) or Joseph Stalin (1939 and 1942 person of the year)? Perhaps a military figure such as Dwight D. Eisenhower (1944 person of the year) or a spiritual leader such as Pope John Paul II (1994 person of the year)? Would it be a champion of peace or justice such as Mahatma Gandhi (the other runner-up) or Martin Luther King, Jr. (1963 person of the year)? In the end, the selection was someone with enormous name recognition, but whose work most people would confess ignorance about: the physicist Albert Einstein (**Figure PO-0**).

Einstein was chosen because he symbolized the great strides made during the 1900s in deciphering and harnessing fundamental aspects of the material universe. But his style, his manner, and his allure had something to do with it as well. At times, he dominated physics with spectacular results, in a way that is reminiscent of certain "athletes of the 20th century" (Ali, Gretzky, Jordan, Montana, Navratilova, Nicklaus, Pele, Ruth . . .). In 1905, while working as a civil servant far removed from the great centers of physics research, Einstein had three scientific papers—on three different subjects—published in a German physics journal. They were so extraordinary that any one of them would likely have led to his receiving a Nobel Prize in physics—then, as now, the highest award in the field.

Had *Time* magazine been in business during previous centuries, the editors might well have honored other physicists in the same way, perhaps Galileo or Newton for the 17th century or Maxwell for the 19th. Such is the high regard that Western civilization has for the field of physics and those who excel in it. Partly, it is the impact their discoveries often have on our lives, by way of technological gadgets or civilization-threatening weaponry. But often it is the intellectual resonance we have with the revolutionary insights they give us about the universe (it is Earth that moves around the Sun, it is matter being converted into energy that makes the Sun shine . . .).

Welcome to the world of physics! You are embarking on an introduction to a field that continues to fascinate people in all walks of life. Tell a friend or family member that you are now studying physics. That will quite likely impress them in a way that most other subjects would not. Whether it should do so is an interesting question. We hope that when you finish this endeavor, you will answer yes.

P.2 Why Learn Physics?

The answer is easy for those majoring in physics, engineering, or other sciences: physics will provide them with important tools for their academic and professional lives.

NASA Images

Figure P.1 It took a lot of physics to get *Apollo* 17 to the Moon. Here mission commander Eugene A. Cernan makes a short checkout of the Lunar Roving Vehicle during the early part of the first *Apollo* 17 extravehicular activity at the Taurus-Littrow landing site in 1972.

The technology that our modern society relies on comes from applying the discoveries of physics and other sciences. From designing safe, efficient passenger jets to producing sophisticated, inexpensive tablets and cell phones, engineers apply physics every day.

Landing astronauts on the Moon and returning them safely to Earth, one of the greatest feats of the 20th century, is a good example of physics applied on many levels (**Figure P.1**). The machines involved—from powerful rockets to on-board computers—were designed, developed, and tested by people who knew a lot about physics. The planning of the orbits and the timing of the rocket firings to change orbits involved scientists with a keen understanding of basic physics such as gravity and the "laws of motion." Often, the payoff is not so tangible or immediate as a successful Moon landing. Behind great technological advances are years or even decades of basic research into the properties of matter.

For instance, take a portable Blu-ray DVD player (**Figure P.2**). A laser reads data off a spinning disc, integrated circuit chips inside "translate" the digital data into electrical signals, tiny magnets in the speakers help convert some of these signals into sound, and a liquid crystal display (LCD) provides information for the user. If you could send this device back in time to when your grandparents were children, it would astound physicists and electrical engineers of the day. But even at that time, scientists were studying the properties of semiconductors (the raw material for lasers and integrated circuit chips) and liquid crystals.

For you and others like you taking perhaps just one physics course in your life, the usefulness of physics is probably not a big reason for studying it. We will see that with even one course, you can use physics to determine, for example, how large a raft has to be to support you or whether using a toaster and a hair dryer at the same time will trip a circuit breaker. But you are not going to make a living with your understanding of physics, nor will you be using it (knowingly) every day. So why should *you* study physics? There are both aesthetic and practical reasons for learning physics. Seeing the order that exists in Nature and understanding that it follows from a relatively small number of "rules" can be fascinating—similar to learning the inspirations behind a musician's or an artist's work. Learning how common devices operate gives you a better understanding of how to use them and may reduce any frustration you have with them. An elementary knowledge of physics also helps you make more informed decisions regarding important issues facing you, your community, your nation, and the world. As you progress through this book, keep track of news events through the media of your choice. You may be surprised at just how often physics is in the news—directly or indirectly.

If you start this excursion into the world of physics with a sense of curiosity and a thirst for knowledge, you won't be disappointed. And you will have the two most important characteristics needed to make the endeavor both easy and successful. Learning how sunlight and raindrops combine to make a rainbow will deepen your appreciation of its beauty. Knowing about centripetal force will help you understand why ice or gravel on a curved road is dangerous. Learning the basics of nuclear physics will help you understand the danger of radon gas and the promise of nuclear fusion. Knowing the principles behind stereo speakers, iPhones, radar guns, MRIs, refrigerators, lasers, microwave ovens, acoustic guitars, and Polaroid sunglasses will give you a better appreciation of how these devices do what they do.

Ethan Miller/Getty Images

Figure P.2 Portable Blu-ray DVD player: one product of decades of physics research.

Throughout this book, we encourage the reader to be inquisitive. Just memorizing definitions and equations doesn't lead you to a real understanding of a subject, any more than memorizing a manual on playing soccer means you can jump into a game and do well. You have to practice, try things, think of situations and how events would evolve, and so on. So it is with physics. Being able to recite Newton's third law of motion is good, but understanding what it means and how it works in the real world is what's really important.

Often, we pose questions or ask the reader to try something, so that when you realize what the answer or outcome is you will have truly learned something. You might think of it as "learning by inquiry." The *Physics to Go* activities are particularly designed for this purpose. Many of the questions at the ends of the chapters are inquiry-based. Once you get used to this method of learning, you will find that you will master the material faster and more deeply than before.

P.3 What Is Physics?

Because physics is one of the basic sciences, it is important to first have an idea of just what science is. Science is the *process* of seeking and applying knowledge about our universe. Science also refers to the *body of knowledge* about the universe that has been amassed by humankind. Pursuing knowledge for its own sake is pure or basic science; developing ways to use this knowledge is applied science. Astronomy is mostly a pure science, whereas engineering fields are applied science. The material we present in this book is a combination of fundamental concepts that we believe are important to know for their own sake and of examples of the many ways that these concepts are applied in the world around us.

There are other ways to classify the different areas of science besides pure and applied. There are physical sciences (physics and geology are just two examples), life sciences (biology and medicine), and behavioral sciences (psychology and sociology). As with most such schemes, there are overlaps: the subfield of biophysics is a good example.

Physics is not as easy to define as some areas of science such as biology, the study of living organisms. If you ask a dozen physicists to define the term, you are not likely to get two answers exactly alike. One suitable definition is that physics is the study of the fundamental structures and interactions in the physical universe. In this book, you will find much about the structures of things such as atoms and nuclei, along with close looks at how things interact by way of gravity, electricity, magnetism, and so on. Within physics, there is a wide range of divisions. **Table P.1** lists some of the common areas based on one measure of research activity. There is a lot of overlap between the divisions, and some of them are clearly allied with other sciences like biology and chemistry.

Table P.1 Some commonly identified divisions of physics, ranked by number of doctorates earned each year. (Based on information from the American Institute of Physics.)

Area	Topics of Investigation
1. Condensed Matter	Structures and properties of solids and liquids
2. Particles and Fields	Fundamental particles and fields; high-energy accelerators
3. Astrophysics	Planets, stars, and galaxies; evolution of the universe
4. Nuclear Physics	Nuclei; nuclear matter and forces; quarks and gluons
5. Biological Physics	Physics of biological systems and phenomena
6. Atomic and Molecular Physics	Atoms and molecules; spectroscopy and quantum processes
7. Optics and Photonics	Study of light; laser technology
8. Applied Physics	Engineering applications; electronic devices; nanotechnology
9. Plasma and Fusion Physics	Laboratory and astrophysical plasmas; fusion research
10. Materials Science	Applications of condensed-matter physics

The field of physics is divided differently when the basics are being taught to beginners. The topics presented to students in their first exposure to physics are usually ordered according to their historical development (study of motion first, elementary particles and cosmology last). This ordering also approximates the ranking of areas by our everyday experience with them. We've all watched people in motion and things collide, but few people encounter the idea of quarks before taking a physics class—even though we and all of the objects we deal with are mainly composed of quarks.

The vast majority of students who take an introductory course in physics are not majoring in it. Most of those who do earn a degree in physics find employment in business, industry, government, or education. The latest data compiled by the American Institute of Physics indicate that the majority of individuals with bachelor's and master's degrees are employed in the first two areas, whereas those with doctorates were mainly found in the last two. In addition to the expected occupations like researcher and teacher, people with physics degrees also have job titles like engineer, manager, computer scientist, and technician. Often, physicists are hired not so much for their knowledge of physics as for their experience with problem solving and advanced technology.

P.4 How Is Physics Done?

So how does one "do" physics or science in general? How did humankind come by this mountain of scientific knowledge that has been amassed over the ages? A blueprint exists for scientific investigation that makes an interesting starting point for answering these questions. It is at best an oversimplification of how scientists operate. Perhaps we should regard it as a game plan that is frequently modified when the action starts. It is called the **scientific method.** One version of it goes something like this: careful *observation* of a phenomenon induces an investigator to question its cause. A *hypothesis* is formed that purports to explain the observation. The scientist devises an *experiment* that will test this hypothesis, hoping to show that it is correct—at least in one case—or that it is incorrect. The outcome of the experiment often raises more questions that lead to a *modification* of the hypothesis and further experimentation. Eventually, an accepted hypothesis that has been verified by different experiments can be elevated to a *theory* or a *law*. The term that is used—*theory* or *law*—is not particularly important in physics: physicists hold Newton's second *law* of motion and Einstein's special *theory* of relativity in roughly the same regard in terms of their validity and importance.

One nice thing about the scientific method is that it is a logical procedure that is practiced by nearly everyone from time to time (**Figure P.3**). Let's say that you get into your car and find that it won't start (observation). You speculate

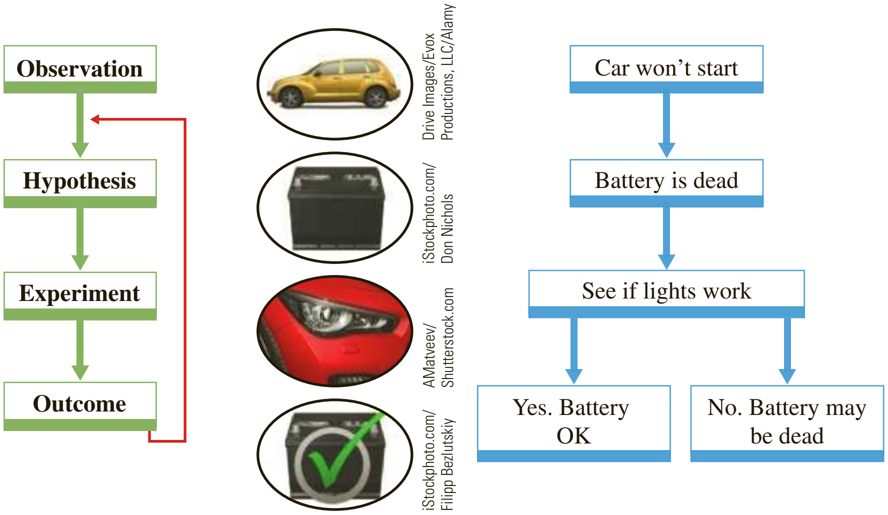


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Figure P.3 The basics of the scientific method, with an example.

that maybe the battery is dead (hypothesis). To see if this is true, you turn on the radio or the lights to see if they work (experiment). If they don't, you may look for someone to give you a jump start. If they do, you probably guess that something else, such as the starter, is causing the problem. Clearly, a good mechanic must be proficient at this way of investigating things. A health-care professional making a medical diagnosis uses similar procedures.

Does the outline of the scientific method appear in some "how-to" manual for scientific discovery? Are scientists required to take an oath to follow it faithfully every day at work? Of course not. But the individual elements of the method are essential tools of the scientist. They are useful to students as well. In the *Physics to Go* activities found throughout this book, we ask you to try things (experiment) and then draw conclusions based on the outcomes. Understanding how Nature works based on what you do and observe is a great way to learn.

One of the architects of the scientific method was Galileo Galilei (1564–1642). He thought a great deal about how science should be done and applied his ideas to his study of motion. Galileo believed that science had to have a strong logical basis that included precise definitions of terms and a mathematical structure with which to express relationships. He introduced the use of controlled experiments, which he applied with great success in his studies of how objects fall. By ingenious experimental design, he overcame the limitations of the crude timing devices that existed in his era and measured the acceleration of falling bodies. Galileo was a shrewd observer of natural phenomena from the swinging of a pendulum to the orbiting of the moons of Jupiter. By drawing logical conclusions from what he saw, he demonstrated that rules could be used to predict and explain natural phenomena that had long seemed mysterious or magical. We will take a closer look at Galileo's work and life in Chapter 1.

The scientific method is important, particularly in the day-to-day process of filling in the details about a phenomenon being studied. But it is not the whole story. Even a brief look at the history of physics reveals that there is no simple recipe that scientists have followed to lead them to breakthroughs. Some great discoveries were made by traditional physicists working in labs, proceeding in a "scientific method" kind of way. Occasionally, unplanned events come into play, such as accidents (Galvani discovered electric currents while performing biology experiments) or luck (Becquerel stumbled on nuclear radiation because of a string of cloudy days in Paris). Sometimes "thought experiments" were required because the technology of the time didn't allow "real" experiments to be performed. Newton predicted artificial satellites, and Einstein unlocked relativity in this way. Often, it was hobbyists, not professional scientists, who made significant discoveries; the statesman Benjamin Franklin and schoolteacher Georg Simon Ohm are examples. Sometimes, it is scientists correctly interpreting the results of others who failed to "connect the dots" themselves (Lise Meitner and her nephew Otto Frisch identified nuclear fission that way).

The point is that there are no "hard and fast" rules for making scientific discoveries, and this is no less true in physics than it is in chemistry, biology, or any other scientific discipline. One of the best ways to learn about the nature of scientific discovery is to study the past. Throughout this book, the *Profiles in Physics* sections, along with a few of the *Applications* features give you some idea of the variety of ways that discoveries have been made and glimpses of the personalities of the discoverers.

P.5 How Does One Learn Physics?

The goal of learning physics and any other science is to gain a better understanding of the universe and the things in it. We generally focus attention on only a small segment of the universe at one time, so that the structural complexities and interactions within it are manageable. We call this a *system*. Some examples of systems that we will talk about are the nucleus of an atom, the atom itself, a collection of atoms inside a laser, air circulating in a room, a rock moving near Earth's surface, and Earth with satellites in orbit around it (**Figure P.4**).

The kinds of things a person might want to know about a system include: (1) its structure or configuration, (2) what is going on in it and why, and (3) what will happen in/to it in the future. The first step is often relatively easy—identifying the objects in the system. Protons, electrons, chromium atoms, heated air, a rock, and the Moon are some of the things in the systems mentioned earlier. Often, the items in a physical system are already familiar to us. But a host of other intangible things in a system must also be identified and labeled before real physics can begin. We must define things like the *speed* of the rock, the *density* of the air, the *energy* of the atoms in the laser tube, and the *angular momentum* of a satellite to understand what is going on in a system and what its future evolution will be. We will call these things and others like them **physical quantities**. Most will be unfamiliar to you unless you have studied physics before. Together with the named objects, they form what can be called the *vocabulary of physics*. There are hundreds of physical quantities in regular use in the various fields of physics, but for our purposes in this book, we will need only a relatively small fraction of these.

Physics seeks to discover the basic ways in which things interact. Laws and principles express relationships that exist between physical quantities. For example, the law of fluid pressure expresses how the pressure at some location in a fluid depends on the weight of the fluid above. This law can be used to find the water pressure on a submerged submarine or the air pressure on a person's

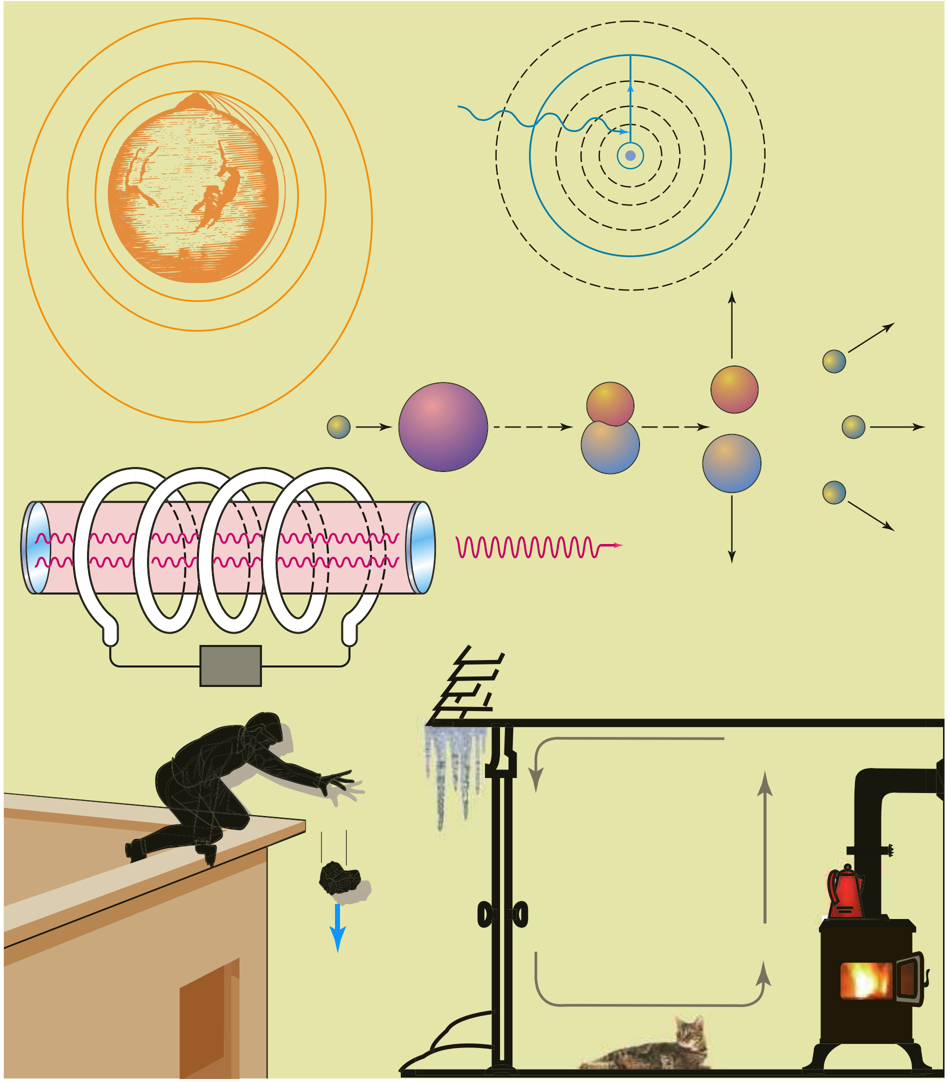

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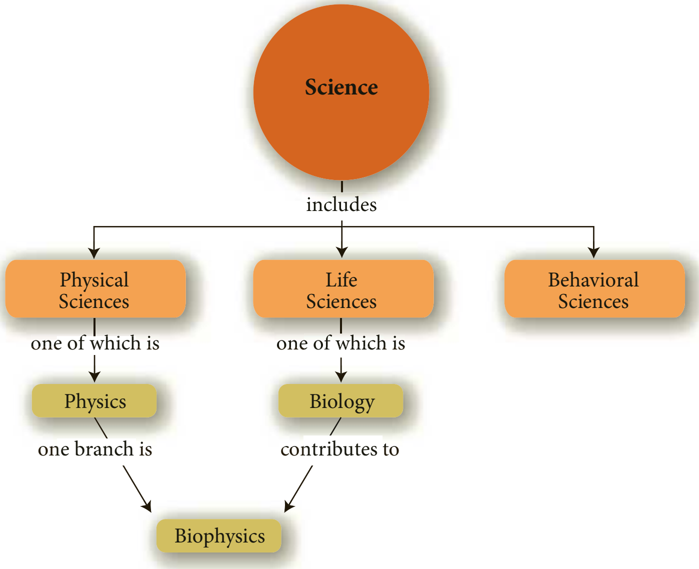
Figure P.4 Combination of six figures representing different systems we will be examining. The scale of the different parts varies greatly, from smaller than can be seen with a microscope to thousands of miles.

CONCEPT MAP P.1



chest. These “rules” are used to understand the interactions in a system and to predict how the system will change with time in the future. The laws and principles themselves were formed after repeated, careful observations of countless systems by scientists throughout history. They withstood the test of time and repeated experimentation before being elevated to this status. You might regard physics as the continued search for, and the application of, basic rules that govern the interactions in the universe.

The process of learning physics has two main thrusts: the need to develop an understanding of the different physical quantities used in each area (establish a vocabulary), and the need to grasp the significance of the laws and principles that express the relationships among these physical quantities. Let us caution you again: memorizing the definitions and laws is only a first step—that alone won’t do it. See, do, think, interact, visualize. Get involved in the physical world. That’s how you learn physics. This book includes dozens of *Physics to Go* activities and worked-out examples based on real-world situations to help you in this process.

Another tool we use to help you visualize the relationships in physics is the *concept map*. Concept maps were developed in the 1960s and are used in a wide range of fields in a variety of ways. A concept map presents an overview of issues, examples, concepts, and skills in the form of a set of interconnected *propositions*. Two or more concepts joined by linking words or phrases make a proposition. The meaning of any particular concept is the sum of all the links that contain the concept. To “read” a concept map, start at the top with the most general concepts, and work your way down to the more specific items and examples at the bottom. **Concept Map P.1** is one example. It is used to show some of the connections between the general concept, science, and one branch of physics, biophysics. This particular concept map could easily be expanded by, for example, showing all of the behavioral sciences or all of the branches of physics.

In this book, each chapter contains concept maps designed as summaries to help you organize the ideas, facts, and applications of physics. You should understand that many possible maps could be constructed from a given set of concepts. The maps drawn in this book represent one way of organizing and understanding a particular set of concepts.

You will have opportunities at the end of each chapter to develop lists of important concepts and to construct from them your own concept maps. Most people find it easier to understand relationships if they are displayed visually. You should find that the process of completing a concept map yourself gives you deeper insights into the ideas that are involved.

One of the main reasons physics has been so successful is that it harnesses the power of mathematics in useful ways. Many of the most important relationships involving physical quantities are best expressed mathematically. Predictions about the future conditions in a system usually involve math. The successes of Einstein, Newton, and others largely came about because they used mathematics to predict or explain things that no one could before (moving clocks appear to run slow, tides are caused by the Moon's gravity). An essential part of learning physics is developing an understanding of, and an appreciation for, this powerful side of physics.

The good news for beginners is that the simplest of mathematics—what most of us learned before age 16 or so—is all that is needed for this purpose. So hand in hand with the conceptual side of physics, we give you a taste of the mathematical side through worked-out examples and end-of-chapter problems. Over the years, we have found that even the most math-wary students often become very comfortable with this aspect of the material. An added benefit of your excursion into the world of physics is that you are likely to emerge with a better feel for the usefulness of simple mathematics.

P.6 Physical Quantities and Measurement

To be useful in physics, physical quantities must satisfy some conditions. A physical quantity must be *unambiguous*, its meaning clear and universally accepted. Understanding the meaning of a term involves more than just memorizing the words in its definition. To understand a concept, you must go beyond words. For example, the simple definition "energy is a measure of the capacity to do work" does not really convey our complete conceptual understanding of energy. Many physical quantities (speed, pressure, power, density, even energy) can be defined by an equation. Mathematical statements tend to be more precise than ones in words, making the meanings of these terms clearer.

Observation yields *qualitative* information about a system. Measurement yields *quantitative* information, which is central in any science that strives for exactness. Consequently, physical quantities must be measurable, directly or indirectly. One must be able to assign a numerical value that represents the amount of a quantity that is present. It is easy to visualize a measurement of distance, area, or even speed, but other quantities, like pressure, voltage, energy, or power, are a bit more abstract. Each of these can still be measured in prescribed ways, however. They would be useless if this were not so.

The basic act of measuring is one of comparison. To measure the height of a person, for instance, one would compare the distance from the floor to the top of the person's head against some chosen standard length such as a foot or a meter (**Figure P.5**). The height of the person is the number of units 1 foot or 1 meter long (including fractions) that have to be put together to equal that distance. The **unit of measure** is the standard used in the measurement—the foot or meter in this case. A complete measurement of a physical quantity, then, consists of a number and a unit of measure. For example, a person's height might be expressed as

$$\text{height} = 5.75 \text{ feet} \qquad \text{or} \qquad h = 5.75 \text{ ft}$$

Here h represents the quantity (height) and *ft* the unit of measure (feet). The same height in meters is

$$h = 1.75 \text{ m}$$

So when we introduce a physical quantity into our physics vocabulary—another "tool," so to speak—we must specify more than just a verbal definition. We should also give a mathematical

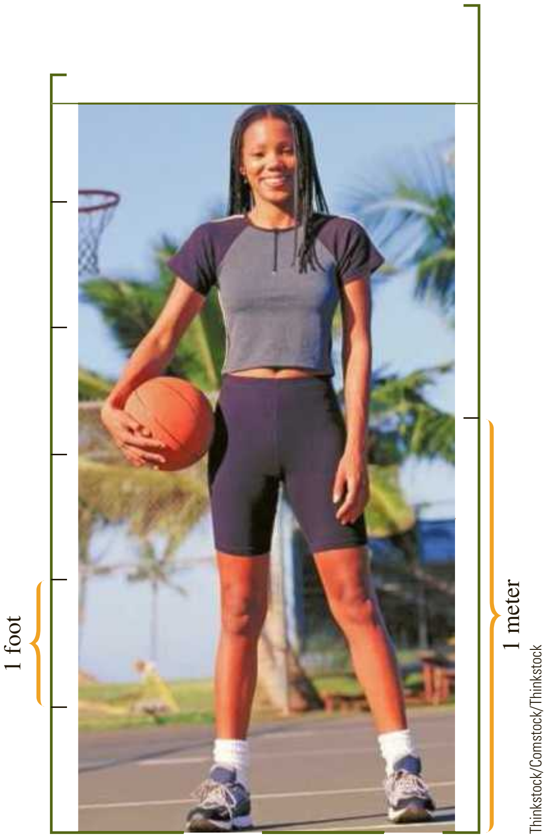


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Figure P.5 Measurement is an act of comparison. A person's height is measured by comparison with the length of a chosen standard. In this case, height equals five 1-foot lengths plus a segment 0.75 feet long. The same person's height is also equal to 1 meter plus 0.75 meter.

Table P.2 Common Metric Prefixes and Their Equivalents

1 *centi*meter = 0.01 meters	1 meter = 100 centimeters
1 *milli*meter = 0.001 meters	1 meter = 1,000 millimeters
1 *kilo*meter = 1,000 meters	1 meter = 0.001 kilometers
EXAMPLES	
189 centimeters = 1.89 meters	72.39 meters = 7,239 centimeters
25 millimeters = 0.025 meters	0.24 meters = 240 millimeters
7.68 kilometers = 7,680 meters	23.4 meters = 0.0234 kilometers

definition (if possible), relate it to other familiar physical quantities, and include the appropriate units of measure.

In the world today, there are two common systems of measure. The United States uses the **English system,** and the rest of the world, for the most part, uses the **metric system.** An attempt has been made in the United States to switch completely to the metric system, but so far it has not succeeded. The metric system has been used by scientists for quite some time, and we will use it a great deal in this book. It is a convenient system to use because the different units for each physical quantity are related by powers of 10. For example, a kilometer equals 1,000 meters, and a millimeter equals 0.001 meter. The prefix itself designates the power of 10. *Kilo-* means 1,000, *centi-* means 0.01 or $\frac{1}{100}$, and *milli-* means 0.001 or $\frac{1}{1000}$. A *kilo*meter, then, is 1,000 meters. Table P.2 illustrates the common metric prefixes. You may not know what an *ampere* is, but you should see immediately that a *milliampere* is one thousandth of an ampere.

The special *Applications* feature at the end of this section gives a brief look at the origins of the metric system. More than 20 of these special features appear throughout the book. They are intended to give you a deeper, richer view of selected topics in the history and applications of physics.

Having to use two systems of units is like living near the border between two countries and having to deal with two systems of currency. Most people who grew up in the United States have a better feel for the size of English-system units such as feet, miles per hour, and pounds than for metric-system units such as meters, kilometers per hour, and newtons. Often, the examples in this book will use units from both systems so that you can compare them and develop a sense of the sizes of the metric units. A *Table of Conversion Factors* relating the units in the two systems is included in the inside back cover of the print edition of this book. Fortunately, we won't have to deal with two systems of units after we reach electricity (Chapter 7).

A prologue is an introductory development. This prologue is an introduction to the field of physics, our approach to teaching it, and how to get started learning it. The groundwork has been laid, and we are now ready to proceed.

COMMERCIAL APPLICATIONS The Metric System: "For All Time, for All People."

The French Revolution, beginning with the storming of the Bastille on 14 July 1789, gave birth not only to a new republic but also to a new system of weights and measures. Eighteenth-century France's system of weights and measures had fallen into a chaotic state, with unit names that were confusing or superfluous and standards that differed from one region of the country to another. Seizing on the opportunity presented to them by the political and social turmoil accompanying the revolution, scientists and merchants, under the leadership of Charles-Maurice de Talleyrand, presented a plan to the French National Assembly in 1790 to unify the system. The plan proposed two changes: (1) the establishment of a decimal system of measurement and (2) the adoption of a "natural" scale of length. Neither of these two notions was new to scholars of this period. The first had been discussed as early as 1585 by Simon Stevin, a hydraulic engineer in Holland, in a pamphlet called *De Thiende* (i.e., *The Tenth Part*). The second notion was introduced in 1670 by Abbé Gabriel Mouton, who proposed that a standard of length be defined in terms of the size of Earth—specifically a fraction of the length of the meridian arc extending from the North Pole to the equator.

After much give and take, the plan was finally adopted into law on 7 April 1795. The new legislation defined the meter as the measure of length equal to 1 ten-millionth of the meridian arc passing through Paris from the North Pole to the equator and the gram as the mass of pure water contained in a cube 1/100th of a meter (a

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