



INQUIRY INTO
PHYSICS
SEVENTH EDITION

Vern J. Ostdiek
Donald J. Bord



PHYSICS CONNECTIONS TO THE REAL WORLD

Okay, so you are ready to learn about physics. But what, you may ask, is it good for? These two pages show you one part of the answer to that question: physics helps you better understand what is going on around you and in the rest of the Universe. Listed here are many of the applications of physics found in the text, along with the page(s) on which each appears. (Some references are to Problems or Challenge exercises that involve the application or device.)

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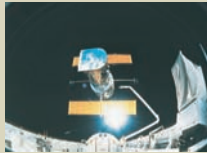
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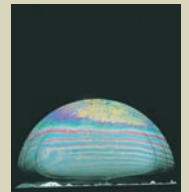
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Seventh Edition

INQUIRY INTO PHYSICS

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Australia • Brazil • Japan • Korea • Mexico • Singapore • Spain • United Kingdom • United States

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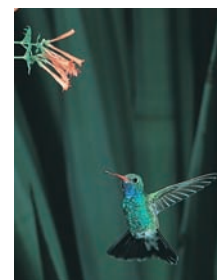


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PREFACE

Welcome to the 7th edition of *Inquiry Into Physics*. In this edition, we continue our emphasis on the inquiry approach to learning physics. We ask readers to try things, discover relationships between physical quantities on their own, and look for answers in the world around them rather than seek them only in books or on the Internet. As authors, we hope to serve as guides on a tour of the realm of the physical universe. It is our fervent desire that you, our companions, not simply remain on the tour bus the entire time, looking at the marvelous sights outside and listening comfortably to our entertaining patter. Instead, we urge, perhaps even prod, you to get out of the bus from time to time and walk about in this world, to examine things in a direct, hands-on fashion, and to be daring and experiment on the various systems and structures that surround you. Along the journey, give free reign to the innate curiosity that we all possess from birth. Don't be afraid to ask questions as we move from place to place in our travels. Keep in mind that learning is a more exciting, complete, longer remembered, and enjoyable process when you are fully engaged in it and not merely a passive recipient of facts and statistics offered by your instructors or other sources.

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 and even beyond. *Inquiry Into Physics* should be considered as a guidebook for a fascinating journey of exploration into those 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 that 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 in 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 came 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. 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. An expanded set of end-of-chapter (EOC) exercises, including nearly 50 new questions and problems, has been provided, and more than half the Explore It Yourself (EIY) application boxes have been modified to provide clearer instructions and outcomes.

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

Chapter 1. Updated Physics Potpourri on time reflecting current GPS technology. Three new EOC exercises added.

Chapter 2. Improved discussion of static friction and revised EIY box to accompany the new presentation. Three new EOC exercises added.

Chapter 3. New chapter opener on forensic physics. Updated Physics Potpourris on energy conservation and consumption and neutron star physics that reflect the latest data and models for each. Four new EOC exercises have been added.

Chapter 4. Updated Physics Potpourris on element nomenclature and superfluids to include the latest discoveries and naming conventions for the heaviest elements

and an emphasis on the “creep” effect in liquid helium-4. Six new EOC exercises have been added.

Chapter 5. Improved and expanded discussion of the perfect gas law. New treatment of entropy and energy quality. Four new EOC exercises have been added.

Chapter 6. Revised discussion of the Doppler effect with enhanced art. Two new EOC exercises have been added.

Chapter 7. Revised and updated chapter opener on iPods. Updated and improved instructions and outcomes for nearly all the EY boxes. Updated section on superconductivity to reflect recent developments in materials science. Refreshed Summary section. Three new EOC exercises have been added.

Chapter 8. Updated material on the Large Hadron Collider (LHC). Expanded discussion of uses of UV radiation in forensic physics. Explicit use of the Stefan–Boltzmann law for blackbody radiation. Three new EOC exercises have been added.

Chapter 9. Revised discussion of refraction to properly account for phase relationships between the primary and secondary (scattered) waves. New discussion of LASEK eye surgery. Three new EOC exercises have been added.

Chapter 10. Improved discussion of energy and angular momentum quantization in atomic systems. Expanded treatment of the Pauli exclusion principle. Six new EOC exercises have been added.

Chapter 11. New discussion of inverse beta decay. New example highlighting the atomic mass unit in calculations. New discussion of neutron bombs and the 2011 Fukushima Daiichi nuclear disaster in Japan. New equations describing radioactive decay in the Important Equations section. Nine new EOC exercises have been added.

Chapter 12. Updated tables of subatomic particle properties. Updated information on top quark experiments using the LHC. Two new EOC exercises have been added.

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:

Topic Trails. Unlike standard chapter outlines or topic lists, these flowchart-like diagrams show how the sections in the various chapters are interconnected and reinforce one another as well as link with other related or dependent topics elsewhere in the book.

Physics in Action. 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 illustrating the roles of physics principles and simple mathematics in real-world situations are regularly presented as models for problem solving.

Explore It Yourself 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. Where appropriate, answers to these activities appear in an appendix.

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

Physics Potpourris. These self-contained essays explore selected topics drawn from astronomy, the history of science, biophysics, and other areas and are provided to deepen and enrich the student’s understanding of physics and its applications. Here the word *potpourri* (pronounced “po-pu-ree”) means a *miscellaneous collection*, but two other metaphors based on its other meanings might be helpful in expressing the purpose of these features in the book: an aromatic blend that arouses a sense of mystery and intrigue, or a fine stew consisting of a mixture of hearty ingredients and tangy spices personally selected by a chef.

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

Physics Family Album. 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. This is a brief, bulleted review of the key points in the chapter and a quick, helpful list of the major concepts to master when preparing for tests and quizzes.

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

Mapping It Out! These exercises, some 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 endsheets of the 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;
- 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; and
- Answers to the odd-numbered Problems and Challenges and to the Explore It Yourself 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 **Physics Potpourris** and the **Physics Family Albums** and sections 2.9, 4.6, 4.7, 5.2, 5.5, 5.7, 6.4, 6.5, 6.6, 8.4, 8.7, 9.5, 10.7, 10.8, and 12.5. The **Topics Trails** at the beginning of each chapter show more detail concerning the interdependence of the various sections of the book.

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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 Brooks/Cole|Cengage Learning. First, thanks goes to Charlie Hartford, our publisher, for having confidence in and advocating for this project. Thanks are also due to our senior development editor, Peter McGahey, who provided crucial advice

about current trends in the publishing industry, particularly as they impacted the preparation of this edition of *Inquiry*, and for his support in identifying a wonderful cover image that continues the dynamic, physics-filled series of images that have graced prior editions of the book. As she did in the 6th edition, Brandi Kirksey, our development editor, provided primary oversight for this revision and offered valuable support at any number of critical decision points during the development and editing process. Brendon Killian, our editorial assistant, deserves kudos for his careful and effective handling of several of the ancillaries for the book, including the Instructor's Manual. As content project manager, Jessica Rasile, was instrumental in smoothly and efficiently managing the day-to-day details of the copyediting and page proofing, including coordinating the numerous file transfers with Charu Khanna, the project manager at our publishing and printing partner, Macmillan Publishing Solutions in India. Finally, deep appreciation is expressed to Sara Golden, our photo researcher with PreMediaGlobal, Inc., whose efforts to locate just the right image or diagram to illustrate clearly and effectively the physical concepts under consideration went above and beyond the call of duty and were always carried out with composure, good humor, and dedication.

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. Each new edition offers the authors a chance to combine a deep love and appreciation of physics with an equally deep love and commitment to effective teaching practice. The fact that so many of you have taught and learned the basics of the world of physics through the fruit of this fusion of professional passions for so long is both humbling and gratifying. Thank you.

Preparing this edition without the benefit of the advice, counsel and abiding friendship of my long-time co-author, Vern Ostdiek, has been a special challenge, not simply because of the additional work and responsibility that Vern's absence produced, but because of the loss of his keen eye, clear head, and firm voice in support of relevant physics correctly presented, elegantly exemplified and simply expressed. I hope I have fairly and adequately represented Vern's philosophy and passion in this latest edition of *Inquiry Into Physics*.

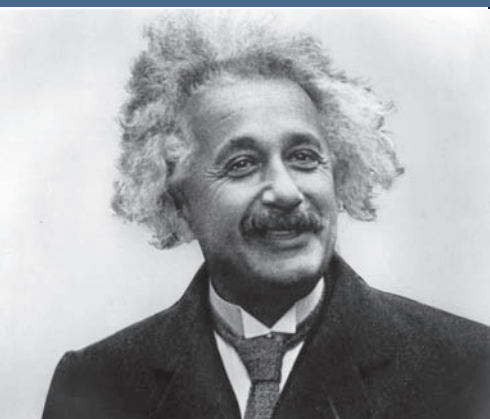
Don Bord

Dedication

This book is dedicated to the memory of Vern Ostdiek—friend, colleague, and co-author—whose passion for physics and for teaching infuses every page.



Vern J. Ostdiek
1953–2008



Pictorial Press Ltd/Alamy.

PROLOGUE: GETTING STARTED

“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.)

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.

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, Aaron . . .). Like them, only his last name is needed to identify him. 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.



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. 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 computers 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 (see ● 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 CD player (see ● 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 headphones help convert those signals into sound, and a liquid crystal display provides information for the user. If you could send this device back in time to when your grandparents were children, it would astound the greatest 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 fac-



● **Figure P.1** It took a lot of physics to get astronaut Neil Armstrong to the Moon.

NASA



● **Figure P.2** Portable CD player: one product of decades of research in physics.

Clynt Garnham
Technology/Alamy

ing 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, aircraft altimeters, refrigerators, lasers, microwave ovens, guitars, and Polaroid sunglasses will give you a better appreciation of how these devices do what they do.

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 Explore It Yourself 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.

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.

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,

● **Table P.1** Some commonly identified divisions of physics, ranked roughly 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. Astronomy and Astrophysics	stars, galaxies, evolution of the universe
3. Particles and Fields	fundamental particles and fields, high-energy accelerators
4. Nuclear Physics	nuclei, nuclear matter, quarks and gluons
5. Atomic and Molecular	atoms, molecules
6. Optics and Photonics	light, laser technology
7. Biophysics	physics of biological phenomena
8. Materials Science	applications of condensed-matter physics
9. Plasma and Fusion Physics	plasmas, fusion research
10. Atmospheric and Space Physics	meteorology, Sun, planets

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.

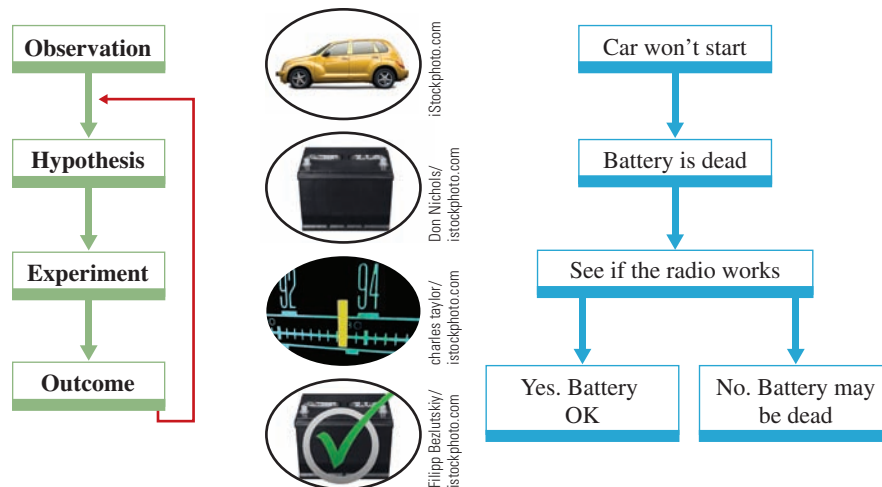
How Is Physics Done?

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 (see ● Figure P.3). Let's say that you get into your car and find that it won't start (observation). You speculate 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 Explore It Yourself 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.

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



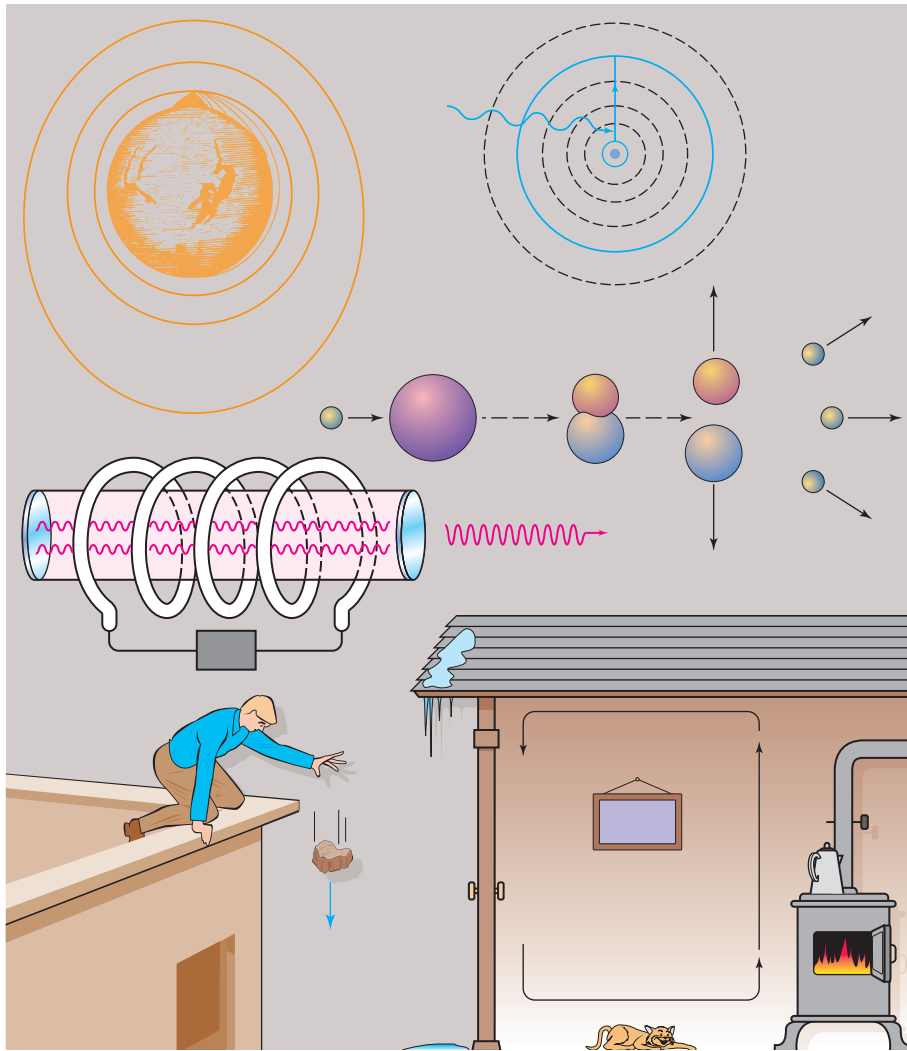
One of the architects of the scientific method was Galileo Galilei (1564–1642). He thought a great deal about how science should be done and applied his ideas to his study of motion. Galileo believed that science had to have a strong logical basis that included precise definitions of terms and a mathematical 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. Newton predicted artificial satellites, and Einstein unlocked relativity 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 Physics Family Album sections, along with a few of the Physics Potpourris, give you some idea of the variety of ways that discoveries have been made and glimpses of the personalities of the discoverers.

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 (see ● Figure P.4).



● **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.

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 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 above. 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 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 Explore It Yourself activities and worked-out examples based on real-world situations to help you in this process.

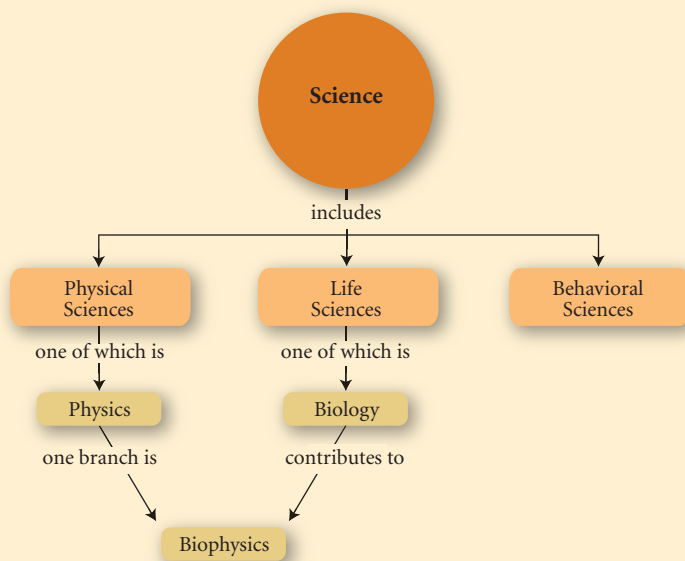
Another tool we use to help you visualize the relationships in physics is the *concept map*. Concept maps were developed in the 1960s and are used in a wide range of fields in a variety of ways. A concept map presents an overview of issues, examples, concepts, and skills in the form of a set of interconnected *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 there are many possible maps that 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 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

CONCEPT MAP P.1



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.

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

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

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 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 *kilometer*, then, is 1,000 meters. ● Table P.2 illustrates the common