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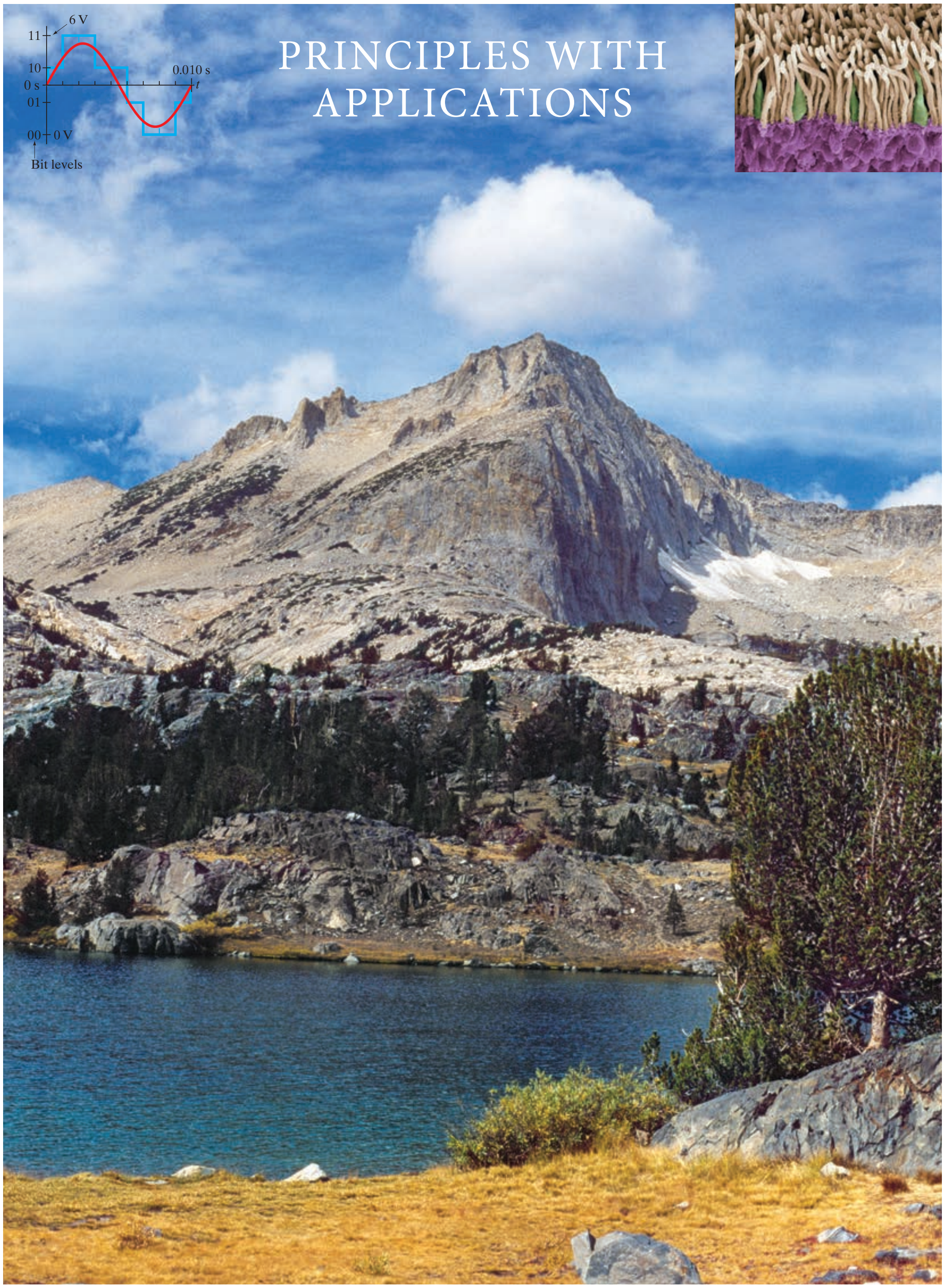
SEVENTH EDITION

PHYSICS

PRINCIPLES WITH APPLICATIONS



DOUGLAS C.

GIANCOLI

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PRINCIPLES WITH APPLICATIONS

Global Edition

DOUGLAS C. GIANCOLI

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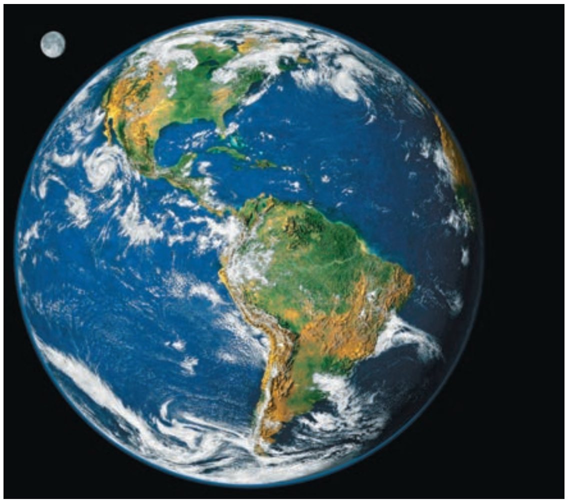

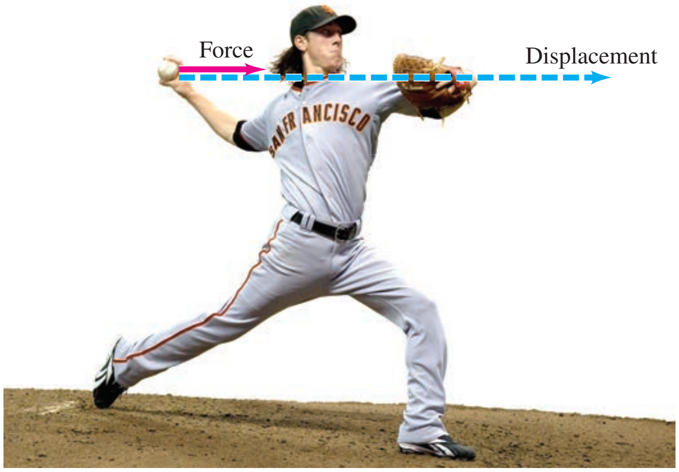
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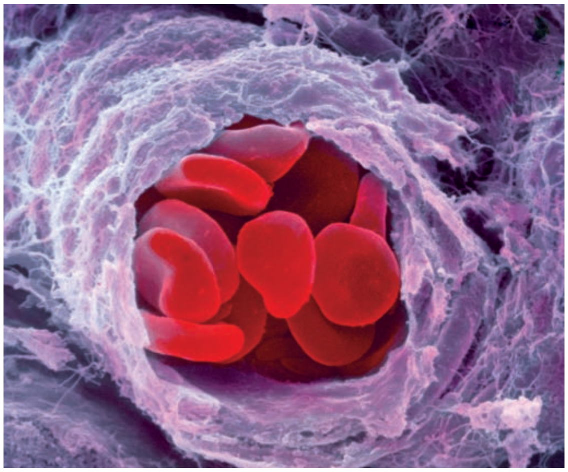

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Preface

What's New?

Lots! Much is new and unseen before. Here are the big four:

1. Multiple-choice Questions added to the end of each Chapter. They are not the usual type. These are called **MisConceptual Questions** because the responses (*a*, *b*, *c*, *d*, etc.) are intended to include common student misconceptions. Thus they are as much, or more, a learning experience than simply a testing experience.

2. **Search and Learn Problems** at the very end of each Chapter, after the other Problems. Some are pretty hard, others are fairly easy. They are intended to encourage students to go back and reread some part or parts of the text, and in this search for an answer they will hopefully learn more—if only because they have to read some material again.

3. **Chapter-Opening Questions** (COQ) that start each Chapter, a sort of "stimulant." Each is multiple choice, with responses including common misconceptions—to get preconceived notions out on the table right at the start. Where the relevant material is covered in the text, students find an Exercise asking them to return to the COQ to rethink and answer again.

4. **Digital.** Biggest of all. Crucial new applications. Today we are surrounded by digital electronics. How does it work? If you try to find out, say on the Internet, you won't find much physics: you may find shallow hand-waving with no real content, or some heavy jargon whose basis might take months or years to understand. So, for the first time, I have tried to explain
   - The basis of digital in bits and bytes, how analog gets transformed into digital, sampling rate, bit depth, quantization error, compression, noise (Section 17–10).
   - How digital TV works, including how each pixel is addressed for each frame, data stream, refresh rate (Section 17–11).
   - Semiconductor computer memory, DRAM, and flash (Section 21–8).
   - Digital cameras and sensors—revised and expanded Section 25–1.
   - New semiconductor physics, some of which is used in digital devices, including LED and OLED—how they work and what their uses are—plus more on transistors (MOSFET), chips, and technology generation as in 22-nm technology (Sections 29–9, 10, 11).

Besides those above, this new seventh edition includes

5. ***New topics, new applications, principal revisions.***
   - *You* can measure the Earth's radius (Section 1–7).
   - Improved graphical analysis of linear motion (Section 2–8).
   - Planets (how first seen), heliocentric, geocentric (Section 5–8).
   - The Moon's orbit around the Earth: its phases and periods with diagram (Section 5–9).
   - Explanation of lake level change when large rock thrown from boat (Example 10–11).

- Biology and medicine, including:
  - Blood measurements (flow, sugar)—Chapters 10, 12, 14, 19, 20, 21;
  - Trees help offset CO_2 buildup—Chapter 15;
  - Pulse oximeter—Chapter 29;
  - Proton therapy—Chapter 31;
  - Radon exposure calculation—Chapter 31;
  - Cell phone use and brain—Chapter 31.
- Colors as seen underwater (Section 24–4).
- Soap film sequence of colors explained (Section 24–8).
- Solar sails (Section 22–6).
- Lots on sports.
- Symmetry—more emphasis and using italics or boldface to make visible.
- Flat screens (Sections 17–11, 24–11).
- Free-electron theory of metals, Fermi gas, Fermi level. New Section 29–6.
- Semiconductor devices—new details on diodes, LEDs, OLEDs, solar cells, compound semiconductors, diode lasers, MOSFET transistors, chips, 22-nm technology (Sections 29–9, 10, 11).
- Cross section (Chapter 31).
- Length of an object is a script ℓ rather than normal l, which looks like 1 or I (moment of inertia, current), as in $F = I\ell B$. Capital L is for angular momentum, latent heat, inductance, dimensions of length $[L]$.

6. ***New photographs*** taken by students and instructors (we asked).
7. ***Page layout***: More than in previous editions, serious attention to how each page is formatted. Important derivations and Examples are on facing pages: no turning a page back in the middle of a derivation or Example. Throughout, readers see, on two facing pages, an important slice of physics.
8. ***Greater clarity***: No topic, no paragraph in this book was overlooked in the search to improve the clarity and conciseness of the presentation. Phrases and sentences that may slow down the principal argument have been eliminated: keep to the essentials at first, give the elaborations later.
9. Much use has been made of physics education research. See the new powerful pedagogic features listed first.
10. ***Examples modified***: More math steps are spelled out, and many new Examples added. About 10% of all Examples are Estimation Examples.
11. ***This Book is Shorter*** than other complete full-service books at this level. Shorter explanations are easier to understand and more likely to be read.
12. ***Cosmological Revolution***: With generous help from top experts in the field, readers have the latest results.

See the World through Eyes that Know Physics

I was motivated from the beginning to write a textbook different from the others which present physics as a sequence of facts, like a catalog: "Here are the facts and you better learn them." Instead of beginning formally and dogmatically, I have sought to begin each topic with concrete observations and experiences students can relate to: start with specifics, and after go to the great generalizations and the more formal aspects of a topic, showing *why* we believe what we believe. This approach reflects how science is actually practiced.

The ultimate aim is to give students a thorough understanding of the basic concepts of physics in all its aspects, from mechanics to modern physics. A second objective is to show students how useful physics is in their own everyday lives and in their future professions by means of interesting applications to biology, medicine, architecture, and more.

Also, much effort has gone into techniques and approaches for solving problems: worked-out Examples, Problem Solving sections (Sections 2–6, 3–6, 4–7, 4–8, 6–7, 6–9, 8–6, 9–2, 13–7, 14–4, and 16–6), and Problem Solving Strategies (pages 30, 57, 60, 88, 115, 141, 158, 184, 211, 234, 399, 436, 456, 534, 568, 594, 655, 666, and 697).

This textbook is especially suited for students taking a one-year introductory course in physics that uses algebra and trigonometry but not calculus.† Many of these students are majoring in biology or premed, as well as architecture, technology, and the earth and environmental sciences. Many applications to these fields are intended to answer that common student query: "Why must I study physics?" The answer is that physics is fundamental to a full understanding of these fields, and here they can see how. Physics is everywhere around us in the everyday world. It is the goal of this book to help students "see the world through eyes that know physics."

A major effort has been made to not throw too much material at students reading the first few chapters. The basics have to be learned first. Many aspects can come later, when students are less overloaded and more prepared. If we don't overwhelm students with too much detail, especially at the start, maybe they can find physics interesting, fun, and helpful—and those who were afraid may lose their fear.

Chapter 1 is *not* a throwaway. It is fundamental to physics to realize that every measurement has an *uncertainty*, and how significant figures are used. Converting units and being able to make rapid *estimates* are also basic.

Mathematics can be an obstacle to students. I have aimed at including all steps in a derivation. Important mathematical tools, such as addition of vectors and trigonometry, are incorporated in the text where first needed, so they come with a context rather than in a scary introductory Chapter. Appendices contain a review of algebra and geometry (plus a few advanced topics).

Color is used pedagogically to bring out the physics. Different types of vectors are given different colors (see the chart on page xix).

Sections marked with a star * are considered optional. These contain slightly more advanced physics material, or material not usually covered in typical courses and/or interesting applications; they contain no material needed in later Chapters (except perhaps in later optional Sections).

For a brief course, all optional material could be dropped as well as significant parts of Chapters 1, 10, 12, 22, 28, 29, 32, and selected parts of Chapters 7, 8, 9, 15, 21, 24, 25, 31. Topics not covered in class can be a valuable resource for later study by students. Indeed, this text can serve as a useful reference for years because of its wide range of coverage.

†It is fine to take a calculus course. But mixing calculus with physics for these students may often mean not learning the physics because of stumbling over the calculus.

Thanks

Many physics professors provided input or direct feedback on every aspect of this textbook. They are listed below, and I owe each a debt of gratitude.

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The final responsibility for all errors lies with me. I welcome comments, corrections, and suggestions as soon as possible to benefit students for the next reprint.

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Douglas C. Giancoli obtained his BA in physics (summa cum laude) from UC Berkeley, his MS in physics at MIT, and his PhD in elementary particle physics back at UC Berkeley. He spent 2 years as a post-doctoral fellow at UC Berkeley's Virus lab developing skills in molecular biology and biophysics. His mentors include Nobel winners Emilio Segrè and Donald Glaser.

He has taught a wide range of undergraduate courses, traditional as well as innovative ones, and continues to update his textbooks meticulously, seeking ways to better provide an understanding of physics for students.

Doug's favorite spare-time activity is the outdoors, especially climbing peaks. He says climbing peaks is like learning physics: it takes effort and the rewards are great.

To Students

HOW TO STUDY

1. Read the Chapter. Learn new vocabulary and notation. Try to respond to questions and exercises as they occur.
2. Attend all class meetings. Listen. Take notes, especially about aspects you do not remember seeing in the book. Ask questions (everyone wants to, but maybe you will have the courage). You will get more out of class if you read the Chapter first.
3. Read the Chapter again, paying attention to details. Follow derivations and worked-out Examples. Absorb their logic. Answer Exercises and as many of the end-of-Chapter Questions as you can, and all MisConceptual Questions.
4. Solve at least 10 to 20 end of Chapter Problems, especially those assigned. In doing Problems you find out what you learned and what you didn't. Discuss them with other students. Problem solving is one of the great learning tools. Don't just look for a formula—it might be the wrong one.

NOTES ON THE FORMAT AND PROBLEM SOLVING

1. Sections marked with a star (*) are considered **optional**. They can be omitted without interrupting the main flow of topics. No later material depends on them except possibly later starred Sections. They may be fun to read, though.
2. The customary **conventions** are used: symbols for quantities (such as m for mass) are italicized, whereas units (such as m for meter) are not italicized. Symbols for vectors are shown in boldface with a small arrow above: $\vec{\mathbf{F}}$.
3. Few equations are valid in all situations. Where practical, the **limitations** of important equations are stated in square brackets next to the equation. The equations that represent the great laws of physics are displayed with a tan background, as are a few other indispensable equations.
4. At the end of each Chapter is a set of **Questions** you should try to answer. Attempt all the multiple-choice **MisConceptual Questions**. Most important are **Problems** which are ranked as Level I, II, or III, according to estimated difficulty. Level I Problems are easiest, Level II are standard Problems, and Level III are "challenge problems." These ranked Problems are arranged by Section, but Problems for a given Section may depend on earlier material too. There follows a group of **General Problems**, not arranged by Section or ranked. Problems that relate to optional Sections are starred (*). Answers to odd-numbered Problems are given at the end of the book. **Search and Learn Problems** at the end are meant to encourage you to return to parts of the text to find needed detail, and at the same time help you to learn.
5. Being able to solve **Problems** is a crucial part of learning physics, and provides a powerful means for understanding the concepts and principles. This book contains many aids to problem solving: (a) worked-out **Examples**, including an Approach and Solution, which should be studied as an integral part of the text; (b) some of the worked-out Examples are **Estimation Examples**, which show how rough or approximate results can be obtained even if the given data are sparse (see Section 1–7); (c) **Problem Solving Strategies** placed throughout the text to suggest a step-by-step approach to problem solving for a particular topic—but remember that the basics remain the same; most of these "Strategies" are followed by an Example that is solved by explicitly following the suggested steps; (d) special problem-solving Sections; (e) "Problem Solving" marginal notes which refer to hints within the text for solving Problems; (f) **Exercises** within the text that you should work out immediately, and then check your response against the answer given at the bottom of the last page of that Chapter; (g) the Problems themselves at the end of each Chapter (point 4 above).
6. **Conceptual Examples** pose a question which hopefully starts you to think and come up with a response. Give yourself a little time to come up with your own response before reading the Response given.
7. **Math** review, plus additional topics, are found in Appendices. Useful **data**, **conversion factors**, and math **formulas** are found inside the front and back covers.

USE OF COLOR

Vectors

A general vector

resultant vector (sum) is slightly thicker

components of any vector are dashed

Displacement ($\vec{\mathbf{D}}, \vec{\mathbf{r}}$)

Velocity ($\vec{\mathbf{v}}$)

Acceleration ($\vec{\mathbf{a}}$)

Force ($\vec{\mathbf{F}}$)

Force on second object

or third object in same figure

Momentum ($\vec{\mathbf{p}}$ or $m\vec{\mathbf{v}}$)

Angular momentum ($\vec{\mathbf{L}}$)

Angular velocity ($\vec{\boldsymbol{\omega}}$)

Torque ($\vec{\boldsymbol{\tau}}$)

Electric field ($\vec{\mathbf{E}}$)

Magnetic field ($\vec{\mathbf{B}}$)

Electricity and magnetism

Electric field lines

Equipotential lines

Magnetic field lines

Electric charge (+) + or +

Electric charge (–) – or –

Electric circuit symbols

Wire, with switch S

Resistor

Capacitor

Inductor

Battery

Ground

Optics

Light rays

Object

Real image (dashed)

Virtual image (dashed and paler)

Other

Energy level (atom, etc.)

Measurement lines

Path of a moving object

Direction of motion or current

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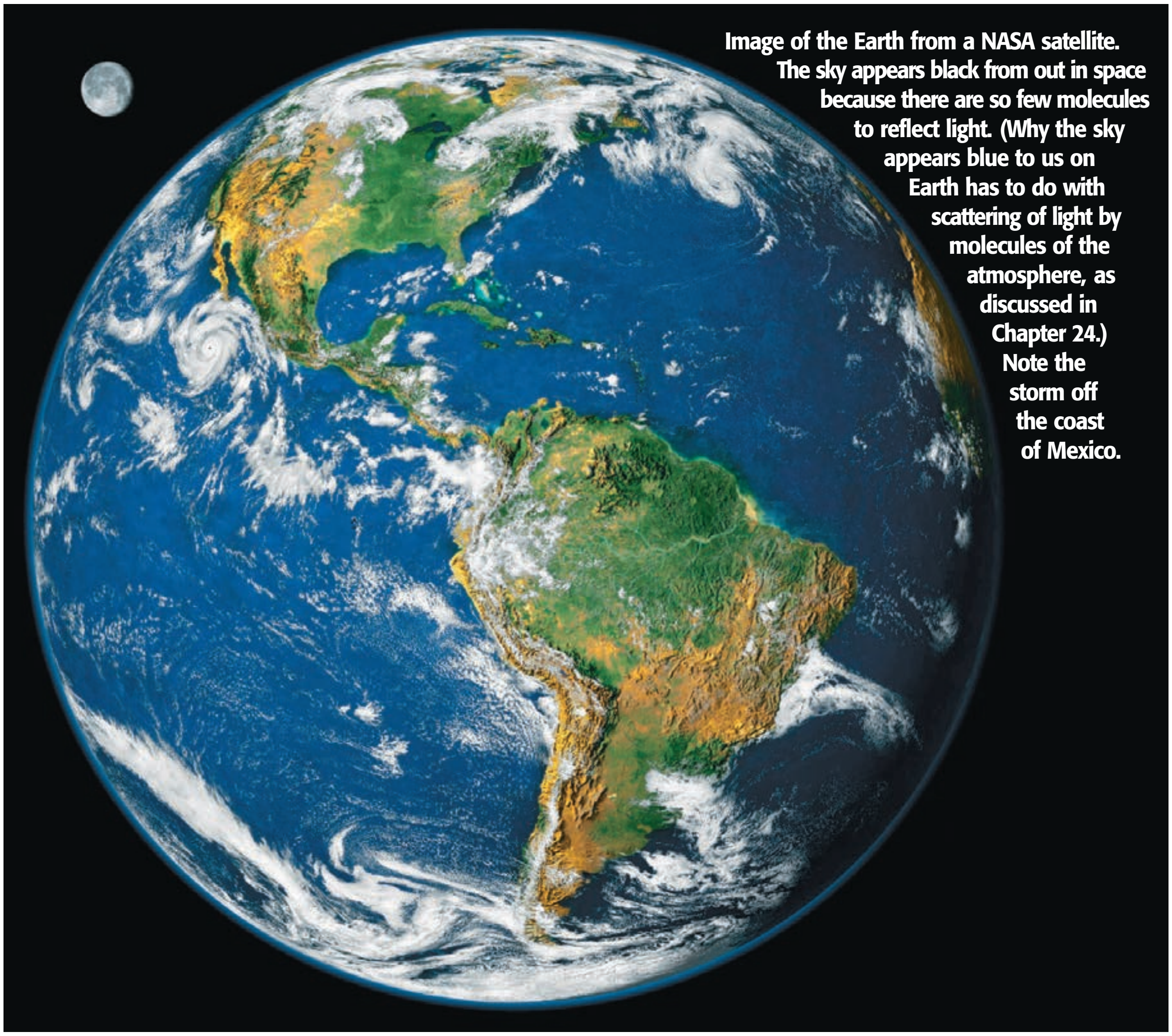


Image of the Earth from a NASA satellite. The sky appears black from out in space because there are so few molecules to reflect light. (Why the sky appears blue to us on Earth has to do with scattering of light by molecules of the atmosphere, as discussed in Chapter 24.) Note the storm off the coast of Mexico.

CHAPTER 1

Introduction, Measurement, Estimating

CONTENTS

CHAPTER-OPENING QUESTIONS—Guess now!

1. How many cm^3 are in $1.0\ m^3$?

(a) 10. **(b)** 100. **(c)** 1000. **(d)** 10,000. **(e)** 100,000. **(f)** 1,000,000.

2. Suppose you wanted to actually measure the radius of the Earth, at least roughly, rather than taking other people's word for what it is. Which response below describes the best approach?

(a) Use an extremely long measuring tape.
(b) It is only possible by flying high enough to see the actual curvature of the Earth.
(c) Use a standard measuring tape, a step ladder, and a large smooth lake.
(d) Use a laser and a mirror on the Moon or on a satellite.
(e) Give up; it is impossible using ordinary means.

[*We start each Chapter with a Question—sometimes two. Try to answer right away. Don't worry about getting the right answer now—the idea is to get your preconceived notions out on the table. If they are misconceptions, we expect them to be cleared up as you read the Chapter. You will usually get another chance at the Question(s) later in the Chapter when the appropriate material has been covered. These Chapter-Opening Questions will also help you see the power and usefulness of physics.*]

Physics is the most basic of the sciences. It deals with the behavior and structure of matter. The field of physics is usually divided into *classical physics* which includes motion, fluids, heat, sound, light, electricity, and magnetism; and *modern physics* which includes the topics of relativity, atomic structure, quantum theory, condensed matter, nuclear physics, elementary particles, and cosmology and astrophysics. We will cover all these topics in this book, beginning with motion (or mechanics, as it is often called) and ending with the most recent results in fundamental particles and the cosmos. But before we begin on the physics itself, we take a brief look at how this overall activity called "science," including physics, is actually practiced.

1–1 The Nature of Science

The principal aim of all sciences, including physics, is generally considered to be the search for order in our observations of the world around us. Many people think that science is a mechanical process of collecting facts and devising theories. But it is not so simple. Science is a creative activity that in many respects resembles other creative activities of the human mind.

One important aspect of science is **observation** of events, which includes the design and carrying out of experiments. But observation and experiments require imagination, because scientists can never include everything in a description of what they observe. Hence, scientists must make judgments about what is relevant in their observations and experiments.

Consider, for example, how two great minds, Aristotle (384–322 B.C.; Fig. 1–1) and Galileo (1564–1642; Fig. 2–18), interpreted motion along a horizontal surface. Aristotle noted that objects given an initial push along the ground (or on a tabletop) always slow down and stop. Consequently, Aristotle argued, the natural state of an object is to be at rest. Galileo, the first true experimentalist, reexamined horizontal motion in the 1600s. He imagined that if friction could be eliminated, an object given an initial push along a horizontal surface would continue to move indefinitely without stopping. He concluded that for an object to be in motion was just as natural as for it to be at rest. By inventing a new way of thinking about the same data, Galileo founded our modern view of motion (Chapters 2, 3, and 4), and he did so with a leap of the imagination. Galileo made this leap conceptually, without actually eliminating friction.

FIGURE 1–1 Aristotle is the central figure (dressed in blue) at the top of the stairs (the figure next to him is Plato) in this famous Renaissance portrayal of *The School of Athens*, painted by Raphael around 1510. Also in this painting, considered one of the great masterpieces in art, are Euclid (drawing a circle at the lower right), Ptolemy (extreme right with globe), Pythagoras, Socrates, and Diogenes.

Observation, with careful experimentation and measurement, is one side of the scientific process. The other side is the invention or creation of **theories** to explain and order the observations. Theories are never derived directly from observations. Observations may help inspire a theory, and theories are accepted or rejected based on the results of observation and experiment.

Theories are inspirations that come from the minds of human beings. For example, the idea that matter is made up of atoms (the atomic theory) was not arrived at by direct observation of atoms—we can't see atoms directly. Rather, the idea sprang from creative minds. The theory of relativity, the electromagnetic theory of light, and Newton's law of universal gravitation were likewise the result of human imagination.

The great theories of science may be compared, as creative achievements, with great works of art or literature. But how does science differ from these other creative activities? One important difference is that science requires **testing** of its ideas or theories to see if their predictions are borne out by experiment. But theories are not "proved" by testing. First of all, no measuring instrument is perfect, so exact confirmation is not possible. Furthermore, it is not possible to test a theory for every possible set of circumstances. Hence a theory cannot be absolutely verified. Indeed, the history of science tells us that long-held theories can sometimes be replaced by new ones, particularly when new experimental techniques provide new or contradictory data.

A new theory is accepted by scientists in some cases because its predictions are quantitatively in better agreement with experiment than those of the older theory. But in many cases, a new theory is accepted only if it explains a greater *range* of phenomena than does the older one. Copernicus's Sun-centered theory of the universe (Fig. 1–2b), for example, was originally no more accurate than Ptolemy's Earth-centered theory (Fig. 1–2a) for predicting the motion of heavenly bodies (Sun, Moon, planets). But Copernicus's theory had consequences that Ptolemy's did not, such as predicting the moonlike phases of Venus. A simpler and richer theory, one which unifies and explains a greater variety of phenomena, is more useful and beautiful to a scientist. And this aspect, as well as quantitative agreement, plays a major role in the acceptance of a theory.

FIGURE 1–2 (a) Ptolemy's geocentric view of the universe. Note at the center the four elements of the ancients: Earth, water, air (clouds around the Earth), and fire; then the circles, with symbols, for the Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, the fixed stars, and the signs of the zodiac. (b) An early representation of Copernicus's heliocentric view of the universe with the Sun at the center. (See Chapter 5.)

(a) (b)

An important aspect of any theory is how well it can quantitatively predict phenomena, and from this point of view a new theory may often seem to be only a minor advance over the old one. For example, Einstein's theory of relativity gives predictions that differ very little from the older theories of Galileo and Newton in nearly all everyday situations. Its predictions are better mainly in the extreme case of very high speeds close to the speed of light. But quantitative prediction is not the only important outcome of a theory. Our view of the world is affected as well. As a result of Einstein's theory of relativity, for example, our concepts of space and time have been completely altered, and we have come to see mass and energy as a single entity (via the famous equation $E = mc^2$).

1–2 Physics and its Relation to Other Fields

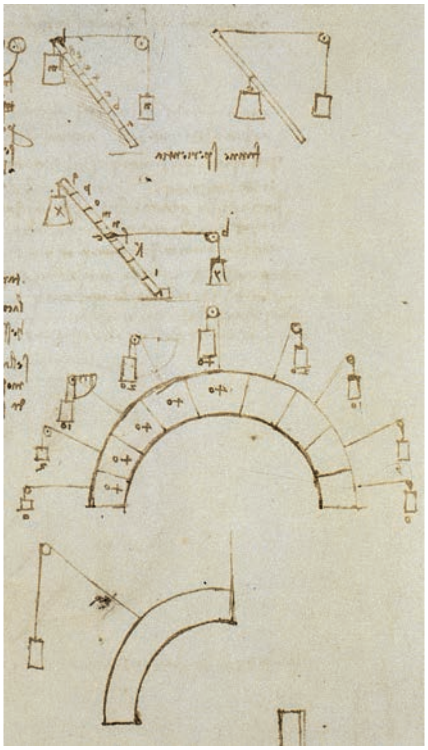


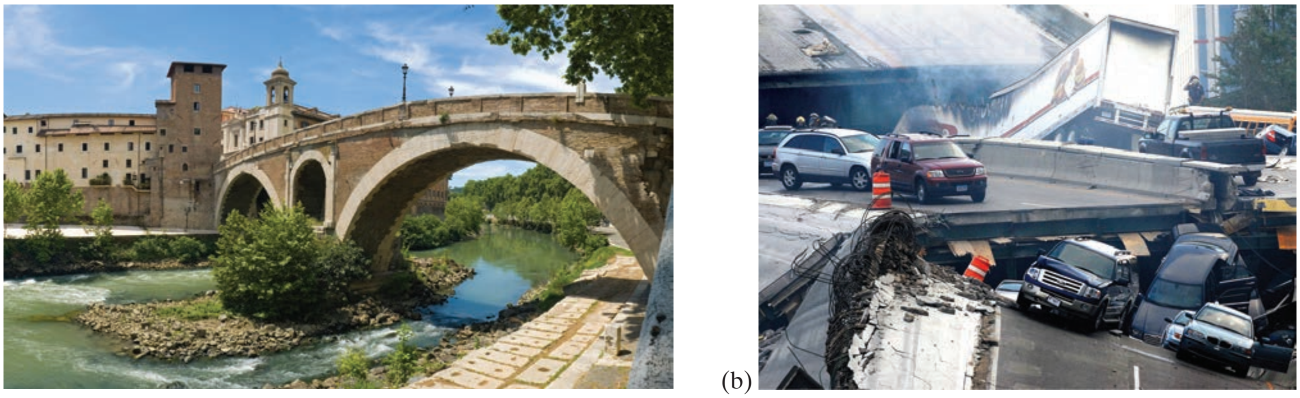
FIGURE 1–3 Studies on the forces in structures by Leonardo da Vinci (1452–1519).

For a long time science was more or less a united whole known as natural philosophy. Not until a century or two ago did the distinctions between physics and chemistry and even the life sciences become prominent. Indeed, the sharp distinction we now see between the arts and the sciences is itself only a few centuries old. It is no wonder then that the development of physics has both influenced and been influenced by other fields. For example, the notebooks (Fig. 1–3) of Leonardo da Vinci, the great Renaissance artist, researcher, and engineer, contain the first references to the forces acting within a structure, a subject we consider as physics today; but then, as now, it has great relevance to architecture and building.

Early work in electricity that led to the discovery of the electric battery and electric current was done by an eighteenth-century physiologist, Luigi Galvani (1737–1798). He noticed the twitching of frogs' legs in response to an electric spark and later that the muscles twitched when in contact with two dissimilar metals (Chapter 18). At first this phenomenon was known as "animal electricity," but it shortly became clear that electric current itself could exist in the absence of an animal.

Physics is used in many fields. A zoologist, for example, may find physics useful in understanding how prairie dogs and other animals can live underground without suffocating. A physical therapist will be more effective if aware of the principles of center of gravity and the action of forces within the human body. A knowledge of the operating principles of optical and electronic equipment is helpful in a variety of fields. Life scientists and architects alike will be interested in the nature of heat loss and gain in human beings and the resulting comfort or discomfort. Architects may have to calculate the dimensions of the pipes in a heating system or the forces involved in a given structure to determine if it will remain standing (Fig. 1–4). They must know physics principles in order to make realistic designs and to communicate effectively with engineering consultants and other specialists.

FIGURE 1–4 (a) This bridge over the River Tiber in Rome was built 2000 years ago and still stands. (b) The 2007 collapse of a Mississippi River highway bridge built only 40 years before.



(a) (b)

From the aesthetic or psychological point of view, too, architects must be aware of the forces involved in a structure—for example instability, even if only illusory, can be discomforting to those who must live or work in the structure.

The list of ways in which physics relates to other fields is extensive. In the Chapters that follow we will discuss many such applications as we carry out our principal aim of explaining basic physics.

1–3 Models, Theories, and Laws

When scientists are trying to understand a particular set of phenomena, they often make use of a **model**. A model, in the scientific sense, is a kind of analogy or mental image of the phenomena in terms of something else we are already familiar with. One example is the wave model of light. We cannot see waves of light as we can water waves. But it is valuable to think of light as made up of waves, because experiments indicate that light behaves in many respects as water waves do.

The purpose of a model is to give us an approximate mental or visual picture—something to hold on to—when we cannot see what actually is happening. Models often give us a deeper understanding: the analogy to a known system (for instance, the water waves above) can suggest new experiments to perform and can provide ideas about what other related phenomena might occur.

You may wonder what the difference is between a theory and a model. Usually a model is relatively simple and provides a structural similarity to the phenomena being studied. A **theory** is broader, more detailed, and can give quantitatively testable predictions, often with great precision. It is important, however, not to confuse a model or a theory with the real system or the phenomena themselves.

Scientists have given the title **law** to certain concise but general statements about how nature behaves (that electric charge is conserved, for example). Often the statement takes the form of a relationship or equation between quantities (such as Newton's second law, $F = ma$).

Statements that we call laws are usually experimentally valid over a wide range of observed phenomena. For less general statements, the term **principle** is often used (such as Archimedes' principle). We use "theory" for a more general picture of the phenomena dealt with.

Scientific laws are different from political laws in that the latter are *prescriptive*: they tell us how we ought to behave. Scientific laws are *descriptive*: they do not say how nature *should* behave, but rather are meant to describe how nature *does* behave. As with theories, laws cannot be tested in the infinite variety of cases possible. So we cannot be sure that any law is absolutely true. We use the term "law" when its validity has been tested over a wide range of cases, and when any limitations and the range of validity are clearly understood.

Scientists normally do their research as if the accepted laws and theories were true. But they are obliged to keep an open mind in case new information should alter the validity of any given law or theory.

1–4 Measurement and Uncertainty; Significant Figures

In the quest to understand the world around us, scientists seek to find relationships among physical quantities that can be measured.

Uncertainty

Reliable measurements are an important part of physics. But no measurement is absolutely precise. There is an uncertainty associated with every measurement.