C. Chapter Discussions

PART ONE OF TEXTBOOK

PROLOGUE TO PART ONE

Objectives of the Prologue to Part One

This prelude is designed to provide students with an appreciation of the long tradition leading from ancient times to modern physics. The focus is on three characteristics of physics that ultimately derive from early Greek thinkers: the role of mathematics, the atomic hypothesis, and the notion that the properties of certain elements yield the properties of all matter. All of these were based on the assumption that the phenomena of nature can be understood as expressions of universal principles underlying the phenomena and that these "first principles" can be discovered through rational inquiry. Familiarity with this material will be important in Chapter 2 and occasionally in subsequent chapters.

In constructing the table on p. 4, we deliberately avoided scientific notation and consciously used non-SI units. Students will have plenty of opportunity to learn both in the weeks ahead, rather than at the very start.

Suggested Mini-Laboratory Explorations

- Our Place in Space.

Suggested Major Laboratory Explorations

- Investigating Measurements and Uncertainty.

Suggested Class Demonstration

This is a demonstration that Aristotle himself may have performed. It was later performed in the early Renaissance by a group of scholars who used sticky "Spanish wax" in a tub of water to demonstrate that Aristotle was "right" about the separation of the four elements.

Instead of representing the four elements, we use just two substances to represent only two elements: tea leaves to represent the earth element, and water in a petri dish. The tea leaves must be wet so that they do not float on the water. For greatest effect, place the petri dish containing water on an overhead projector. Drop a pinch of the moistened tea leaves into the water and stir the water to make sure they are evenly dispersed throughout the water. This represents the state of "chaos" in the Universe that Aristotle assumed to exist at the beginning.

Now use a stirring rod to turn the water slowly in one direction. As you do, the tea leaves will coalesce at the center, representing the formation of the Earth. Any floating leaves will move to the outside, representing a lighter element. As Aristotle suggested, the heavier "element" falls to the center, surrounded by the lighter "element," water. Students are surprised to see this happen. Ask them if this then proves the correctness of Aristotle's theory.

The modern explanation of this effect involves the pressure inward caused by the rotating water. Jumping to a contemporary problem, a similar process is believed to have played a role in the formation of our solar system from a rotating mixture of gas and dust. The pressure at the center became so great that it set off a fusion reaction, igniting the Sun. The remaining heavier elements were pushed toward the inner region of our solar system, eventually forming the inner planets.

Further Reading

G. Holton and S.G. Brush, *Physics, The Human Adventure* (Piscataway, NJ: Rutgers University Press, 2001), Chapters 1 and 3.

D.C. Lindberg, *The Beginnings of Western Science* (Chicago: University of Chicago Press, 1992).

K. Ferguson, *Measuring the Universe: Our Historic Quest to Chart the Horizons of Space and Time* (New York: Walker, 1999).

Suggestions for the First Few Class Meetings

Begin by explaining the purposes and approach of this course, and how it differs from the traditional, problem-solving type of physics course. Emphasize the active learning aspects of the course, the students' responsibility to participate in their own and one another's education, the fun and sense of achievement they will experience in doing so, and the use of history both to show the human element behind scientific progress, and to convince them that, despite any bad experiences they may have had earlier in science classes, they can and will learn physics. It is a grand subject, unlike any other, with a few grand, universal laws. At the start it may seem difficult and require work, but the work will pay off. In retrospect, physics will seem one of the "easiest" subjects because of the simplicity, parsimony, and generality of its fundamental ideas.

Summarize the topics of the course and how all of the various components—laboratory, text, group work, examinations etc.—will work together. Explain your grading system. Emphasize again the active learning aspects as well as the attempt to introduce a cooperative, noncompetitive atmosphere, in which everyone, including the instructor, will work together to help everyone to achieve the goals.

Most students will be unfamiliar with the historical approach in this chapter. Despite the opening section, some students will likely miss the point of why we are looking back at "wrong ideas" of thousands of years ago. There may also be confusion about what is expected of them. Should they concentrate on the history, the philosophy, or the physics? The answer is, all three, to the extent that it helps them to appreciate the nature and motivation of such ideas as:

(1) how similar the curiosity and many of the thoughts of people back then were to our thoughts and curiosity today;
(2) how plausible and rational their answers were when seen in the context of their times, just as our answers are to us today;
(3) that the physics of today is a story of vast intellectual progress over time that included deep puzzlement initially encountered by some of the best minds of science; and
(4) that physics generates ideas and tools for other sciences and for technology.

However, students should also understand that this is not a history or philosophy course but a physics course, and that the importance of these ideas will become more apparent as we enter into modern physics, starting with the next chapter.

One of the first questions students will have is: "Does this course involve a lot of mathematics?" Assure the students that, as they can see, there is some mathematics in the textbook and laboratory, but that they will learn to understand its meaning. Discuss your preferences regarding problem solving in homework and, especially, on examinations. Explain that the mathematics in physics is really not difficult at all; it is the result of the marvelous discovery that we can represent physical ideas in a type of intellectual shorthand known as mathematics, and that the manipulation of these shorthand symbols according to the "grammatical" rules of mathematics actually does correspond to the way nature operates. That is why mathematics is so useful in physics.

In order to continue to encourage that curiosity, students should attempt to work on the exploration questions designated by an asterisk, beginning even before the start of this chapter. They should write down their responses in their journal.

It is also important for students to follow the recommendations in the *Student Guide* about writing notes in their journal on their reading, class work, and laboratory experiences, and to compare all three with each other.

Students should be encouraged from the first meeting to feel comfortable about speaking in a large class and in small groups. As appropriate, you might encourage this participation by asking students about their interests in science, their knowledge of physics, and their hopes and fears regarding this course. This could also be done in a small-group setting.

Reiterating an earlier comment, it is also important that you convey to the students the notion that you are a partner with them in their efforts gain an understanding of physics, rather than an adversary who is there to judge their performance. It is also important for the instructor to communicate a sense of wonder and curiosity about the world around us, since students will naturally look to their instructor for cues about the proper attitude toward the material.

Supplementary Material: Aristotle's Longevity

In one way or another, Aristotle managed to provide a plausible account for practically every natural phenomenon we see around us. This is what made his system so appealing for so long. Not only did it "work," but it was a simple, plausible, common-sense system that could encompass every question you might have—and not just about nature. It didn't rely on difficult abstract mathematics, as does some research today, or on invisible lifeless atoms moving through empty space. In basic terms, what you see is what you get. If a thing is hard or hot, it is because it contains mostly hard or hot primary stuff. And it allows us to use our senses as well as our minds to understand our world. Moreover, all of Aristotle's work formed a single, coherent unified world view, a "cosmology," in which every question seemingly found an answer, from the big questions—who we are and what the Universe is like—to the enduring everyday questions of why a stone falls to the ground, or why the sea is salty.

But in accomplishing this truly amazing achievement, Aristotle rejected the alternative quantitative approaches of mathematical principles and the atomic hypothesis that eventually proved more fruitful for science, in favor of qualitative explanations.

So, despite its weaknesses, why did Aristotle's system last for over 2000 years? Historians are only now beginning to answer this question. Part of the answer is noted above: his system "works," it holds together, it's all-encompassing, and it's plausible—if you don't analyze it too closely. But another part is played by history itself. After the conquests by Aristotle's pupil, Alexander the Great, the Greeks colonized the known world, and the center of Greek thought and science shifted from Athens to Egypt. In 332 B.C., the Greeks founded a new city in Egypt, Alexandria, which contained a library housing scrolls of most of the world's ancient learning, and a museum similar to a modern research institute. But as Greek civilization gradually declined, the Romans captured Egypt and burned the museum and library at Alexandria with its vast trove of ancient writings. Interest in science declined in the Roman world along with the decline of the Roman empire.

In A.D. 640 the Muslims captured Alexandria as they swept along the southern shore of the Mediterranean Sea and moved northward through Spain to the Pyrenees. Along the way, they seized and preserved many of the surviving collections of Greek documents, including the works of Aristotle. They carefully studied these documents and translated many of them into Arabic. During the following centuries, Islamic science achieved some of its greatest heights by taking Aristotle and others farther than they had been taken previously. But they made no fundamental changes in his theories. Perhaps one reason for this is that Aristotle's cosmology was so internally coherent that if one piece were removed or changed the entire system would collapse. This is, by the way, still a description of a good theory in its mature form. Without a suitable replacement at hand, people very rarely allow this to happen.

When Western Europeans rediscovered Aristotle during the crusades of the eleventh to the fourteenth centuries, Europe underwent a mini-Renaissance. European thinkers were astonished at Aristotle's advanced learning, but they were disturbed that it was essentially a nonreligious theory devoid of any Christian teachings, the dominant religion in Europe at that time. During the thirteenth century, the Dominican monk Thomas Aquinas (later Saint Thomas Aquinas) blended Aristotelean thought and Christian theology into a single philosophy. His work was widely studied and accepted for several centuries in Western Europe. Aristoteleans of this period carried the master's work into new directions. Because Aquinas had successfully united Aristotle with Christianity, any questioning of his philosophy and science seemed also to question Christian theology. Thus, for a time there was little effective criticism of Aristotle or the Aristoteleans in Europe. If anyone was going to refute Aristotle, they would have to confront both the secular and the religious leaders of the day. No wonder Aristotle survived so long in Europe, and no wonder those who argued against him did so with great difficulty and, in some cases, at great personal risk.

CHAPTER 1. MOTION MATTERS

The material in the first four chapters may be covered more or less rapidly depending on the class's level of prior experience. Since some instructors prefer to start with astronomy, while others prefer motion, we have designed these two chapters to be interchangeable.

Suggested Mini-Laboratory Explorations

- Reviewing Graphs. Those students who need to review graphs and to practice graphing data should work through this exercise before they begin the major laboratory Exploring Motion. This exercise also introduces simple spreadsheets and their graphing capabilities.
- Falling Objects (Section 1.9).
- Our Place in Space.

Suggested Major Laboratory Explorations

- Investigating Measurements and Uncertainty, if not performed earlier.
- Exploring Motion. This chapter was written with the expectation that students will engage in hands-on activities in close conjunction with the text. "Exploring Motion," was designed for this purpose. Each part of the laboratory can also be used as a mini-laboratory. The entire laboratory can be done all at once or on several different days.
- If the major laboratory "Exploring the Heavens," will be performed later (Chapter 2), students can begin gathering the data needed for Section B, "Observing the Sun's Motion."

See "Laboratory Explorations" later in this *Instructor Guide* for further discussion of these explorations.

Refer the students to the "Review of Units and Scientific Notation" in the *Student Guide*, and go over it with them during the course as needed.

Suggested Classic Video (Project Physics)

Acceleration Caused by Gravity, I, available in VHS format and DVD, *Physics: Cinema Classics* (Lexington, KY: Ztek Co): http://www.ztek.com.

Computer Resources

Depending upon your interests and technical resources, and the class's needs, some of the excellent available interactive computer learning programs might be introduced in order to reinforce and extend what students observed in the laboratory. They can return to the laboratory to compare with their computer results. One of the best learning programs designed for this subject is:

> D. Trowbridge, *Graphs and Tracks* (Physics Academic Software, American Institute of Physics, 1994). See the study, using this program, by D.J. Grayson and L.C. McDermott, Use of the computer for research on student thinking in physics, *Am. J. Phys.*, **64** (1996), 557–565.

Objectives of This Chapter

Motion is fundamental to all aspects of physics and it is essential for understanding where we are in this Universe and how the Universe is put together. And it is unavoidable to go through the study of motion at the start. *Yet one has to warn students that the early part of mechanics is also one of the most abstract fields in physics.* Nevertheless, it also involves several of the most fundamental measurements we can make of our world—distance, time, and mass—and it shows how mathematics and human definitions come together to form the new science of motion—mechanics.

In addition to adapting many of the important features included in the earlier *Project Physics Text*, this chapter also takes inspiration from the operational approach suggested by A.B. Arons, *A Guide to Introductory Physics Teaching* (New York: Wiley, 1990). At the end of this chapter, students should have a good sense of what the measurements actually mean, how and why the various concepts are defined, and what the mathematical expressions of these concepts mean in physical terms.

Suggestions

Despite the operational and historical background material, mechanics is, as noted, abstract and essentially mathematical. Students should be reassured that they are not alone in the difficulties they may have in comprehending this material; after all, it took geniuses such as Galileo a lifetime to comprehend motion of various types, so they should not worry if they are finding it difficult at the start. At the same time, their efforts will pay off, especially if they take seriously both the laboratory work and the textbook reading. Reassure the students further that this is not primarily a problem-solving course, despite all of the equations they encounter in the text and the quantitative problems they will find in the exploration questions. Reiterate your policy regarding problem solving in examinations. They should realize that they will get plenty of practice using some of these equations in the laboratory and in class discussions—and they should understand what each equation means in the real world. Make maximum use of any "active learning" methods you wish to use: group work, oral presentations, outlining, careful reading and thinking, etc.

Further Reading

A.B. Arons, *A Guide to Introductory Physics Teaching* (New York: Wiley, 1990), Chapter 2.

G. Holton and S.G. Brush, *Physics, The Human Adventure* (Piscataway, NJ: Rutgers University Press, 2001), Chapters 6 and 7.

Web site

Exploratorium, San Francisco, the physics of skateboarding: http://www.exploratorium.edu/skateboarding

CHAPTER 2. MOVING THE EARTH

Suggested Mini-Laboratory Explorations

- Kepler's Third Law.
- Relative Motion (or reserve for Sections 3.9 or 9.3).

Suggested Major Laboratory

- Exploring the Heavens. This exploration was designed to be performed in close conjunction with this chapter. The components of this exploration can also be performed individually as "mini-laboratories."
- Skyglobe: A Computer Planetarium.

Suggested Classic Video

"Frames of Reference," in the PSSC series. Available from *Physics: Cinema Classics* (Lexington, KY: Ztek Co): http://www.ztek.com. This is indeed a cinema classic, but still one of the best presentations available, despite (or because of?) its "low-tech" approach.

Suggested Demonstration Activity: Frames of Reference

Two students, A and B, take hold of opposite ends of a meter stick or a piece of string 1- or 2-m long. If A rotates about on one fixed spot so that A is always facing B while B walks around A in a circle, A will see B against a background of walls and furniture. How does A appear to B? Ask B to describe how A appears against the background of walls and furniture. How do the reports compare? In what direction did A see B move, toward the left or right? In which direction did B see A move, toward the left or right?

Objectives of This Chapter

Continuing the story of motion, this chapter recounts one of the fundamental episodes in the formation of modern physics and Western culture. In addition, it provides some of the fundamental features of modern celestial physics; it raises many issues about the nature and selection of scientific theories and their impact upon the broader society; and it provides further insights into the nature of modern physics. Many students will still be vague (and even wrong) about the physical origins of such basic phenomena as the annual seasons and the phases of the Moon. Students will also begin to appreciate the meaning and significance of relative motion.

All of the characteristics of contemporary scientific research are clearly visible in the Scientific Revolution, along with the origins of these characteristics in the struggles of people then to understand their world and to establish methods and criteria that make understanding possible. As Newton's current successor at Cambridge University, the famed cosmologist Stephen Hawking, recently remarked:

> Our image of the universe today is full of strange-sounding ideas and remarkable truths. The story of how we arrived at this picture is the story of learning to understand what we see.

We considered placing the chapter on relativity theory here, but decided that it might be too disconcerting to go from inclined planes (Chapter 1) to relativity theory (Chapter 3) then to Copernicus, following by Newton.

Instead, this chapter offers a change of pace from Chapter 1, kinematics, before turning to dynamics (Chapter 3).

Suggestions

This chapter was inspired by *Project Physics*, Chapters 5–7. Section 1 attempts to show why it is legitimate to study astronomy as a problem in motion. Section 4 is a brief overview of geocentric astronomical observations. It is not intended that students will become proficient in geocentric astronomy. Rather, the purpose is to provide students with an appreciation of the observations, then to show how two completely incompatible theories can account for the same set of observations, and how this situation was resolved—the kind of story that, in science, is repeated to this day.

Once again, some students may wonder why we are looking back at these old, "wrong" ideas, especially astronomical ideas in a physics textbook. Reassure them once again that this is not a history book; our eye is always on the present. However, it is important for them, as educated persons, to be aware of this important episode in Western culture, and of some of the close parallels with analogous conflicts appearing in the science of today. In fact, one really cannot understand today's science without some knowledge of the revolution that brought about the foundations of today's science. As often stated, the story of the revolution in science that brought us contemporary physics is as necessary to understanding our current technological age as is the story of the American Revolution and the Constitution to an understanding of America today.

Further Reading

G. Galilei, *Galileo on the World Systems—A New Abridged Translation and Guide*, M.A. Finocchiaro, transl. and ed. (Berkeley, CA: University of California Press, 1997).

G. Holton and S.G. Brush, *Physics, The Human Adventure* (Piscataway, NJ: Rutgers University Press, 2001), Chapters 1–5.

T.S. Kuhn, *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought* (Cambridge, MA: Harvard University Press, 1982).

J.R. Jacob, *The Scientific Revolution: Aspirations and Achievements, 1500–1700* (Amherst, NY: Prometheus Books, 1998).

M. Caspar, *Kepler*, C.D. Hellman and O. Gingerich, transl. (New York: Dover, 1993).

O. Gingerich, *The Eye of Heaven: Ptolemy, Copernicus, Kepler* (Woodbury, NY: AIP Press, 1993).

M. Shermer, *Why People Believe Weird Things: Pseudoscience, Superstition, and Other Confusions of Our Time* (New York: Freeman, 1997). Useful throughout this course.

D. Sobel, *Galileo's Daughter: A Historical Memoir of Science, Faith, and Love* (New York: Walker, 2000).
H. Thurston, *Early Astronomy* (New York: Springer-Verlag, 1994).

Supplementary Material

Why Europe? One of the more profound questions that historians are attempting to answer may also occur to students: Why didn't this scientific revolution occur elsewhere before this time? After all, other cultures were much farther advanced in science and technology than was Western Europe in the seventeenth century. For instance, China in the Han Dynasty, 202 B.C. to A.D. 220 achieved such notable technological inventions as paper, the magnetic compass, and the casting of iron. Later dynasties invented gunpowder, the first efficient horse harness, an early type of vaccination, even the first wheelbarrow. Many of these inventions were later transmitted to the West. The Chinese were also known since ancient times for their sophisticated astronomical observations (needed for an accurate calendar), for their advanced researches in chemistry and alchemy, and for mathematics.

The emperors of the Han dynasty also founded the first state university for intelligent young men training to enter the bureaucracy of "mandarin" scholars who governed the empire. This enabled the best minds of the empire to receive state-sponsored education, and it enabled the state to reap the benefits of a highly educated bureaucracy. But, ironically, according to the leading scholar of Chinese science and technology, Joseph Needham, this enlightened arrangement also seems to have prevented the Scientific Revolution from occurring in China. Intellectual revolutions require independent thinkers, and independent thinkers are usually the product of an independent and individualistic commercial middle class, such as arose in Europe during the Renaissance.

It has been suggested that, for roughly the same reason, the Arabic world also did not bring forth the Scientific Revolution. Like Chinese culture, Arabic culture, from the eighth to the thirteenth centuries AD, was far advanced over that in Western Europe. Many of the manuscripts of ancient Greek science were transmitted to the Islamic world, where scholars eagerly translated, studied, and expanded upon the work of the Greeks. During Europe's Middle Ages, Muslim thinkers were enjoying their own Renaissance, making many significant and original contributions to optics, medicine, mathematics, astronomy, and technology. Commerce and trade were also highly prized in the Islamic world and an independent middle class did arise. However, despite their many original contributions, for reasons that are still not year clear, Muslim thinkers never went beyond the inherited Greek conceptual framework. Scholars have suggested that apparently they saw their originality in the correction and enhancement of Greek works, rather than in their critical study and replacement. Even today, much research everywhere is aimed primarily at the improvement and elaboration of established thought rather than at the search for completely new alternatives.

As in China earlier, the formation of the Caliphate in Baghdad about A.D. 750 brought with it the establishment of a bureaucratic state and the creation of a civil service of highly educated bureaucrats. It has been suggested that this social arrangement, though beneficial to both parties, accounts as it did in China for the weakening of the impulse to break with the scientific heritage.

The European discovery of Arabic texts of the Greek masters during and after the Crusades, combined with a different social and cultural situation in Renaissance Europe, resulted in the new and wide-ranging break in scientific thought that we call the seventeenth century revolution in science. However, although this revolution in human thought may have started in Western Europe, it quickly spread throughout the entire world. It grew and progressed only through the contributions of many different cultures and peoples around the globe. The Scientific Revolution has resulted in the most powerful and successful invention ever devised by humankind, modern science, including contemporary physics. This invention continues to expand and multiply through the contributions of scientists everywhere, leading to ever new insights into ourselves and into the world in which we live.

Reckoning Time and the Calendar Today. Today's system of reckoning time intervals and establishing a calendar also go back to ancient times—to the Babylonians of the third millennium B.C. Observing the cycles of the Sun and Moon, the Babylonians divided the solar year into 12 lunar months of 30 days each. This made 360 days per year. Of course the solar year is actually about 365¼ days, and the lunar month is actually about 27⅓ days. But no matter: they simply added an extra month occasionally to bring their calendar back into "sync" (very much as we add an extra day every leap year). The Egyptians, however, began with the solar year of about 365 days, which they then divided into 12 equal months. They simply declared any extra days to be holidays.

As an alternative, other cultures, such as the ancient Israelites, used a lunar calendar, consisting of 12 lunar months per year. Again this did not match the solar year, so various adjustments were again required.

It is from the Babylonians that we have not only our year of 12 months but also the division of the circle into 360°, corresponding to the 360 days of their reckoning of the Sun's annual cycle. They also gave us the corresponding 12–60 time system, dividing each day into two segments of 12 hours (from the 12 months), each hour into 60 minutes, and each minute into 60 seconds—just as they divided each degree on the circle into 60 minutes, and each minute into 60 seconds of arc.

The Babylonians also first divided the week into 7 days, which they named after the seven nonstellar celestial objects: the Sun, the Moon, and the five visible planets. The names of the days of the week in most romance languages still retain the corresponding names. Sunday, Monday, Tuesday (Mardi in French, "Mars day"), Wednesday (Mercredi in French, "Mercury's day"), Friday (Vendredi in French, "Venus's day"). Jupiter (or Zeus in Greek) was the thunder god. His name was replaced in English by that of the Norse thunder god, Thor, rendering "Thursday" in English ("Donnerstag" in German, "Thunder's day").

The calendar we use today has gone through several major changes since the ancient days of the Babylonians. In 45 B.C. the Roman emperor Julius Caesar decreed a new 365-day calendar (the Julian calendar) with one extra day (a "leap day") inserted every fourth year, to make up for the approximately one-quarter day lost each year. He also provided most of the current names of the months (July is named for Julius, August for Augustus).

The Julian calendar was used for centuries until the seemingly minor discrepancy between one-quarter day and the actual 0.24220 day left over each year added up to several days. This caused inaccuracies in predicting the Vernal Equinox, which in turn caused inaccuracies in setting the dates for important religious holidays, such as Easter. Copernicus, in particular, worked on attempting to resolve this problem. Finally, not long after the appearance of Copernicus's work, in A.D. 1582 Pope Gregory announced a new calendar—the Gregorian calendar, which was gradually accepted throughout the world. This calendar is based on 365 days per year divided into 12 months of varying length. Every 4 years a leap day is added to make up for the approximately one-quarter day that is lost each year. Since the actual year is slightly less than 365¼ days, the Gregorian calendar occasionally skipped the extra leap day, resulting in only 97 leap days in 400 years, instead of the expected 100 leap days. As a result, there was no leap day in the year 1900, but there was one in the year 2000. This is one reason for the concern about the dates shown on computers as the year 2000 approached. For example, the valid date of February 29, 2000, would not have existed on a computer that acted as if the year is 1900.

The Gregorian calendar has lasted satisfactorily to this day without revision, although very slight corrections are still needed nearly every year. They are introduced at midnight on New Year's Eve (e.g., a "leap second"), to account for the gradual slowing of the Earth's rotation owing to the loss of rotational energy caused by the action of the tides.

CHAPTER 3. UNDERSTANDING MOTION

Suggested Mini-Laboratory Explorations

- Relative Motion (Section 3.9). This may be used instead with Chapters 9 or 2.
- Galileo and Inertia. This may be used instead with Chapter 5.
- Finding the Centripetal Acceleration Vector (Sections 3.3, 3.12).

Suggested Major Laboratory Explorations

- Exploring Forces. This laboratory should be performed in conjunction with Section 3.4.
- Exploring Force, Work, Energy, and Power. The first part of this laboratory might be performed in conjunction with Chapter 3, but the second part must be postponed until Chapter 5. See P. Froehle, Reminder about Hooke's law and metal springs, *Phys. Teach.*, **37** (1999), 368, on the initial tension of a spring.

Suggested Videos

Project Physics: "Frames of Reference," "Galilean Relativity," "Vector Addition: Velocity of a Boat." Available in VHS and DVD with new audio tracks, *Physics: Cinema Classics* (Lexington, KY: Ztek Co.): http://www.ztek.com.

"Sir Isaac Newton: The Gravity of Genius." A&E Television Networks, 1996. VHS.

Objectives of This Chapter

In this chapter students will gain an even deeper understanding of motion by studying its causes; appreciate the relationship between astronomy and mechanics; and gain an understanding of such phenomena as weight, weightlessness, projectile motion, and satellites.

Suggestions

This chapter was inspired by *Project Physics*, Chapters 3–4, and it draws upon the suggestions offered by A.B. Arons, *A Guide to Introductory Physics Teaching* (New York: Wiley, 1990), Chapters 3–4.

This chapter is similar to Chapter 1 in content and difficulty. Students who had difficulty in Chapter 1 will probably have similar difficulties here. This chapter was designed to be studied in conjunction with hands-on laboratory explorations. This will help to reduce some of the more unfamiliar and abstract aspects of the material. Connections with contemporary events, such as the launching of a Space Shuttle, or the orbiting of another planet, should be made as much as possible. Examples in the text and in the chapter questions are intended to promote this. The first discovery question should also be used before, during, and after this chapter.

CHAPTER 4. NEWTON'S UNIFIED THEORY

Objectives

This chapter serves as a culmination of the previous chapters, bringing together all of the various concepts, laws, and assumptions about the mechanical aspects of nature into one unified theory—the theory of universal gravitation. Equally important, the formation of this theory is an outstanding example of how new theories may be formulated, tested, and received by the public. Students can appreciate from this chapter the origins and nature of our current understanding of the everyday world, as well as the nature of theory construction and evaluation in physics.

Suggestions

Since this chapter marks the introduction of the current outlook in physics, students should take time to evaluate the nature of the outlook as displayed by Newton's synthesis. The exploration questions are designed to help facilitate this evaluation, but they are only a beginning. As time permits, more could be done with the nature of physical theories and with the impact of new theories on the broader culture and society. Students should be encouraged to appreciate how the world changed for everyone in the transition from the Aristotelean world view to the Newtonian world view. What would a hypothetical conversation between denizens of these two worlds be like?

This chapter was inspired by *Project Physics*, Chapter 8, and by G. Holton and S.G. Brush, *Physics, The Human Adventure* (Piscataway, NJ: Rutgers University Press, 2001), Chapter 12.

Further Chapter Reading

G. Holton and S.G. Brush, *Physics, The Human Adventure*, Part D (Piscataway, NJ: Rutgers University Press, 2001), (Chapters 12–14) is especially helpful on