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

"structure and method in physical science," as is Chapter 11 on Newton's law of universal gravitation.

I.B. Cohen, *Science and the Founding Fathers* (New York: Norton, 1995).

T.A. Heppenheimer, *Turbulent Skies: The History of Commercial Aviation* (New York: Wiley, 1998).

T.S. Kuhn. *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought* (Cambridge, MA: Harvard University Press, 1957/82).

D.H. Levy, *More Things in Heaven and Earth: Poets and Astronomers Read the Night Sky* (Wolfville, Nova Scotia: Wombat Press, 1997).

C.E. Swartz and T. Miner, *Teaching Introductory Physics: A Sourcebook* (Woodbury, NY: AIP Press, 1997), Chapter 5.

Supplementary Material: The System of the World

Newton's law of universal gravitation was so successful that scientists believed that they could now understand the entire physical world using this law. Newton himself titled the section of his book on gravitation, the "System of the World." One scientist, the French mathematician Pierre Simon Laplace, took this idea to the limit. Using Newton's law of universal gravitation, he attempted to work out mathematically the entire motion of the solar system by taking into account all of the mutual gravitational attractions between the Sun and all of the known planets, publishing his work in five volumes in 1799–1825. Although it is mathematically not possible to solve this problem exactly, he did obtain approximate solutions that agreed almost perfectly with the observed motions of the planets. He called this the *Système du Monde*, the *System of the World*. This was another brilliant triumph of Newtonian science, and an inspiration to scientists like Laplace who believed that they had learned at last the deepest secrets of nature. Laplace presented his system in a special lecture to the emperor, Napoleon, who had a strong interest in science and technology. Napoleon listened politely. When Laplace had finished, the emperor asked: "But, Monsieur Laplace, where is God in your system?" To which Laplace is said to have replied, "God? I have no need for that hypothesis."

With or without that "hypothesis," scientists today still make use of Laplace's system. Although for technical reasons it is still not possible to solve exactly for the precise motions of many objects under gravitation, we can use computers to obtain very close approximations. Whenever satellites are sent to other planets, scientists employ high-speed supercomputers to obtain the desired trajectory by using Newton's gravitational force equation and his laws of motion to calculate the trajectory required. They even make good use of the attraction to nearby planets in order to accelerate the satellites further into outer space.

Technology Insert: Aviation

Further Reading

Sloan Technology Series source

T.A. Heppenheimer, *Turbulent Skies: The History of Commercial Aviation* (New York: Wiley, 1998).

Also:

E.O. Allen, *The Airline Builders* (Alexandria: Time Life Books, 1981).
W.W. Bathie, *Fundamentals of Gas Turbines* (New York: Wiley, 1984).
W. Biddle, *Barons of the Sky* (New York: Simon and Schuster, 1982).
P.W. Brooks, *The Modern Airliner* (Manhattan, KS, Sunflower University Press, 1982).
E.W. Constant, *The Origins of the Turbojet Revolution* (Baltimore, MD: Johns Hopkins University Press, 1980).
P. Hanle, *Bringing Aerodynamics to America* (Cambridge, MA: MIT Press, 1982).
I. Mcintyre, *Dogfight: The Transatlantic Battle over Airbus* (Westport, CT: Coon, Praeger, 1992).
M.S. Nolan, *Fundamentals of Air Traffic Control* (Belmont, CA: Wadsworth, 1990).
R.J. Serling, *Howard Hughes' Airline: An Informal History of TWA* (New York: St. Martin's/Marek, 1983).

CHAPTER 5. CONSERVING MATTER AND MOTION

Suggested Mini-Laboratory Explorations

- Galileo and Inertia (Sections 5.9 and 5.10), if not already used with Chapter 4.

Suggested Major Laboratory Explorations

- Exploring Force, Work, Energy, and Power.
  This laboratory is designed for the springs, hangers, and masses available from Frey Scientific, but the instructions may be adapted to equipment from other vendors. In setting up the spring, an initial mass of 550 g is attached to the spring (hanger + 500-g mass) in order to overcome the initial spring tension. This is defined as zero mass, which may be confusing to some students. The laboratory calls for the study of two springs, if there is sufficient time. We usually skip the second spring, in order to spend more time on the energy concepts which follow.

Project Physics Classic Videos

One-Dimensional Collisions. I
One-Dimensional Collisions. II
Inelastic One-Dimensional Collisions
Two-Dimensional Collisions. I
Two-Dimensional Collisions. II
Inelastic Two-Dimensional Collisions
Scattering of a Cluster of Objects
Explosion of a Cluster of Objects
Available in VHS and DVD formats with new audio tracks and sound effects, *Physics: Cinema Classics* (Lexington, KY: Ztek Co.): http://www.ztek.com.

Objectives

The emphasis in this chapter is on the concepts of energy, work, and power, the conservation laws, and the mechanical world view.

Suggestions

Energy and its conservation are difficult concepts to grasp, yet their practical significance is profound. And the concepts of energy and energy conservation serve to provide much of the common ground among all natural sciences.

Further Reading

G. Holton and S.G. Brush, *Physics, The Human Adventure* (Piscataway, NJ: Rutgers University Press, 2001), Chapters 15–17.
C.E. Swartz and T. Miner, *Teaching Introductory Physics: A Sourcebook* (Woodbury, NY: AIP Press, 1997), Chapter 9.
A.B. Arons, *A Guide to Introductory Physics Teaching* (New York: Wiley, 1990), Chapter 5.
R.S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (New York: Cambridge University Press, 1978).

CHAPTER 6. THE DYNAMICS OF HEAT

Suggested Major Laboratory Explorations

- Finding the Mechanical Equivalent of Heat.

Further Reading

C. Canine, *Dream Reaper: The Story of an Old-Fashioned Inventor in the High-Tech, High-Stakes World of Modern Agriculture* (Chicago: University of Chicago Press, 1997).

R. Kanigel, *The One Best Way: Frederick Winslow Taylor and the Enigma of Efficiency* (New York: Viking Press, 1997).

Technology Insert: Agricultural Steam Technology

Sloan Technology Series Source

C. Canine, *Dream Reaper: The Story of an Old-Fashioned Inventor in the High-Tech, High-Stakes World of Modern Agriculture* (Chicago: University of Chicago Press, 1997).

Other Sources:

D. Fitzgerald, Beyond tractors: The history of technology in American agriculture, *Technology and Culture*, **32**, (1991), pp. 114–26.

R. Leffingwell, *The American Farm Tractor: A History of the Classic Tractor* (Osceola, WI: Motorbooks International, 1991).

J.T. Schelbecker, *Whereby We Thrive: A History of American Farming, 1607–1972* (Ames, IA: ISU Press, 1975).

R.C. Williams, *Fordson, Farmall, and Poppin' Johnny: A History of the Farm Tractor and Its Impact on America* (Chicago: University of Illinois Press, 1987).

CHAPTER 7. HEAT—A MATTER OF MOTION

Suggested Mini-Laboratory Explorations

- Three States of Matter.
- How Do We Know That Atoms Really Exist? The Brownianscope.

Suggested Major Laboratory Explorations

- Exploring Heat Transfer and the Latent Heat of Fusion.

Demonstrations

One demonstration of the concept of entropy as disorder involves the use of marbles of two different colors in a box. One color might represent an ice cube or a small amount of a gas, placed together in one corner of the