INSTRUMENTATION FOR AUDIOLOGY AND HEARING SCIENCE

Theory and Practice

SECOND EDITION

Shlomo Silman, MS, PhD

Michele B. Emmer, PhD

Carol A. Silverman, PhD, MPH

Alexa Brody, AuD

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Contents

Introduction

The theoretical principles underlying instrumentation in audiology and hearing sciences and their calibration and operation represent the foundations of the fields of audiology and hearing sciences. Comprehensive understanding and knowledge of this instrumentation are central to the development of new technologies to overcome the limitations of current diagnostic, rehabilitative, and investigational research techniques. We also hold that knowledge and understanding of audiologic and hearing sciences instrumentation both facilitate and enhance successful applications of this instrumentation.

Informed by our teaching, research, and clinical experiences, we introduce basic concepts and applications to readers who may have little formal training in mathematics, physics, electronics, computers, or engineering. We do so without eliminating the mathematics, physics, or electronics underpinnings. Rather, we have attempted to provide explanations slowly and carefully, including only the necessary formulae and basic scientific principles so that students and clinicians can appropriately use the instrumentation and make valid, reliable, and accurate interpretations. Toward this goal, some of the previous chapters have been eliminated, and those that remain have been significantly revised and updated. We have added three new and important chapters. As in the previous edition, we have included numerous illustrations and examples. New to this edition are instructor PowerPoint presentations for all chapters as well as practical step-by-step video demonstrations and student PowerPoint explanations of how to construct direct- and alternating-current electrical circuits as well as low-pass, high-pass, and band-pass filters.

Because the research tools used by hearing scientists and audiologists largely involve the same instrumentation used by audiologists for clinical and research purposes, this text can serve as a basic instrumentation text not only for AuD and PhD students but also for hearing scientists and audiologists. We intend for this text to serve as a basic reference for clinicians, educators, and researchers in audiology and hearing sciences, as well as a tool for understanding material presented in more advanced instrumentation texts. It also can function as a supplementary text for doctoral courses in amplification.

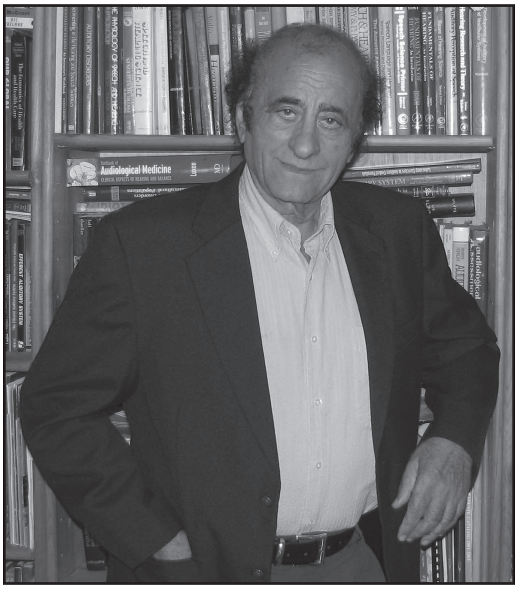
We have structured the text so that we present the basic concepts of general physics in Chapter 1, as these principles are fundamental to the understanding of concepts presented in subsequent chapters. In Chapter 2, we address the basic principles of direct current electrical energy. In Chapter 3, we present the foundations for alternating current electrical energy. In Chapter 4, we provide detailed information on filtering and electrical impedance. In Chapter 5, building on the information presented in previous chapters, we describe the construction of communication systems and their evolution from analog to digital. In Chapter 6, we describe the concepts and principles of acoustic immittance. Chapters 7, 8, and 9 are completely new to this edition. In Chapter 7, we describe amplification in terms of hearing aid components, standards governing quality control, amplification for children, advantages of bilateral hearing aid fittings, prevention and recovery from auditory deprivation, and binaural interference. Our purpose in Chapter 8 is to present a guide to assistive listening devices (ALDs), including the various types; underlying concepts; advantages and disadvantages; instrumentation and components; setup and installation; and specifications and verifications according to national and international standards. In Chapter 9, on electronystagmography (ENG) and videonystagmography (VNG), we discuss the principles underlying the recordings of eye movements; involved neurophysiologic mechanisms; types, components, and calibration of the instrumentation; advantages and disadvantages of ENG versus VNG; and the results of a VNG test battery on a normal subject to illustrate the clinical data that typically are obtained from such battery. In Chapter 10, we relate the principles and function of audiologic and hearing science instrumentation such as audiometers, acoustic immittance devices, otoacoustic emissions devices, and auditory evoked potentials devices as well as stimuli used in these fields. In Chapter 11, we address calibration of audiologic and hearing sciences instrumentation and the equipment for calibration, such as sound-level meters, 2-cc and 6-cc couplers, artificial mastoids, and oscilloscopes. We also discuss the related calibration standards of the American National Standards Institute (ANSI).

We welcome feedback from our readers, which will inform us regarding the strengths of our text and guide us to areas where improvements and clarification may be needed.

Acknowledgments

To our students who have provided us with endless inspiration—this text is for you! To Michael Bergen, Chuck Comitto, Angelo Restivo, and Mati Wissner, we thank you all for your support in the preparation of this text, and your continued willingness to help over many years.

About the Authors



Shlomo Silman, MS, PhD, received his Master of Science from Columbia University and PhD in Audiology from New York University. He is Presidential Professor of Speech Communication Arts and Sciences at Brooklyn College, City University of New York (CUNY); Professor of Audiology, Doctor of Audiology Program, Graduate Center, CUNY; Professor of Hearing Sciences, PhD Program in Speech and Hearing Sciences, Graduate Center, CUNY; and Fellow of the American Speech-Language-Hearing Association. He has authored and coauthored approximately 100 articles, books, and chapters. His research has been supported by the Department of Veterans Affairs and the National Institutes of Health. Dr. Silman holds two U.S. patents for a medical device with Dr. Daniel S. Arick and another two U.S. patents for another medical device with his coauthor, Dr. Michele B. Emmer. His honors and awards include being the first recipient of the American Academy of Audiology Research Achievement Award in 2000 and corecipient of the 2006 National Tibbetts Award (category of Medicine), supported by the National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), U.S. Department of Defense (DOD), and other agencies, for the development and evaluation of the EarPopper. Silman is also the recipient of a medal in 2001 from the Escola Paulista Medicina of the Universidade Federal de São Paulo, Brazil, for humanitarian work with persons with hearing impairment in São Paulo, Brazil, and for scientific achievements relating to research on middle ear effusion and auditory deprivation, as well as recipient of the 2002 *Journal of the American Academy of Audiology* Editor's Award. He also has served as reviewer, editorial consultant, or assistant editor for various journals, including *American Journal of Audiology, Annals of Otology, Rhinology & Laryngology, Ear and Hearing, Hearing Research, Journal of the Acoustical Society of America, Journal of the American Academy of Audiology, Journal of Speech and Hearing Research, Pediatrics*, and *Perceptual and Motor Skills*.

Michele B. Emmer, PhD, Professor Emerita and former Chair of Speech and Hearing Sciences at Brooklyn College, City University of New York (CUNY) and former Professor of Audiology, Doctor of Audiology Program, Graduate Center (CUNY), received her Master of Science from Brooklyn College and her PhD in Speech and Hearing Sciences from the Graduate Center of CUNY. Her interests include middle ear effusion, acoustic reflex, adult-onset auditory deprivation, acclimatization, and hearing impairment in the elderly. She published many articles on these topics in medical, audiological, and scientific journals such as *Journal of the Acoustical Society of America, American Academy of Audiology, ENT Journal*, and *Rehabilitation R & D* (Department of Veterans Affairs). She was listed in the CUNY Salute to Scholars 2 years running and received the college-wide award for Excellence in Teaching at Brooklyn College. She was coinvestigator and senior research director for several federal grants, principal investigator for two CUNY grants, and a principal investigator for a grant from the New York City Department for the Aging. Dr. Emmer holds two U.S. patents for a medical device with her coauthor Dr. Shlomo Silman. Dr. Emmer taught courses in speech and hearing for over 20 years.

Carol A. Silverman, PhD, MPH, is Professor, Speech-Language Pathology and Audiology at Hunter College, City University of New York (CUNY), New York, NY; Professor, AuD Program and PhD Program in Speech-Language-Hearing Sciences, Graduate Center, CUNY, New York, NY; and formerly Adjunct Professor, Otorhinolaryngology-Head and Neck Surgery, New York Medical College, Valhalla, NY. Dr. Silverman previously held an appointment as Hearing Scientist and Epidemiologist in the Departments of Otorhinolaryngology and Communicative Sciences at New York Eye & Ear Infirmary of Mount Sinai in New York City. Dr. Silverman has authored and coauthored several books and book chapters and many peer-reviewed publications, and

she has served as reviewer and editorial consultant for various journals in audiology, hearing sciences, and otolaryngology. Her research focuses on auditory deprivation; on various aspects of diagnostic audiology, including acoustic immittance and otoacoustic emissions; and most recently on binaural interference. She is a graduate of Wellesley College, and her graduate degrees include an MS in Audiology from Teachers College of Columbia University, PhD in Audiology from New York University, and MPH in Quantitative Epidemiology from New York Medical College.

Alexa Brody, AuD, is a practicing audiologist who specializes in diagnostic evaluations and hearing aid amplification in Albany, NY. She received her AuD degree from the Graduate Center of CUNY. She holds an ASHA certificate of clinical competence-audiology (CCC-A) and is a Fellow of the American Academy of Audiology (F-AAA). Her special interests include deaf studies, tinnitus management, hearing aids, and assistive listening devices.

I dedicate this book to Menashe, Avi, and Benny, my dear sons;
Yael, Adi, Sarah, and Lilah, my dear granddaughters;
and Alan K. Silverman, my dear brother-in-law.

Shlomo Silman

This text is dedicated to my loving family—my dear husband, Michael, who has always been my tower of strength and whose sense of humor keeps me grounded; my adored children, Keith, Nolan, Lisa; their spouses, Reina, Ashley, and Vincent (Zev); my cherished grandchildren, Katherine, Taiga, and Akari; Brianna, Sage, and Scarlett; and Jacob and Amelia. And my dear parents, Sally and William Resnick, who still walk beside me. Everything is possible with your love and support.

Michele B. Emmer

I dedicate this text to my beloved brother, Alan K. Silverman, and to my cherished parents, Jerome and Dorothy Silverman.

Carol A. Silverman

I dedicate this book to my mom. Thank you for everything.

Alexa Brody

1

General Physics and Introduction to Sound Energy

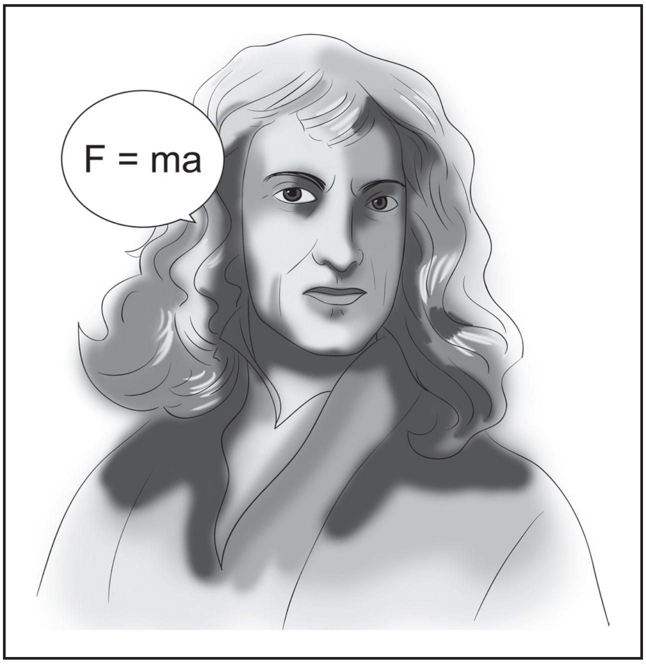


Figure 1–1. *Sir Isaac Newton.*

Dancing, singing, reading, crying, pushing, laughing, smiling, carrying. . . .

For all, we need a fundamental element without which we cannot participate in these activities. What is this element? If you said "force," then you are correct. Force is the fundamental element that keeps us on the move. As we will see later, we also need force to generate sound, the basis of our profession. The unit of force is newton N, named after Sir Isaac Newton (1642–1727), pictured in Figure 1–1.

If we move an object from one place to another, we have accomplished work. If for some reason the force was not great enough to move the object, it means that we did not do work, no matter how sweaty we became or how much force we actually used. When you move a block from one place to another, you're doing work.

Mathematically, Force × Distance = Work. Therefore, W = F × D. When a force of 1 newton moves an object a distance of 1 meter, the work is equal to 1 N/m equivalent to 1 joule. 1 joule = Force × Distance. There is no limit to the amount of work that we can do or the amount of energy that we can expend.

Adam and Eve are pushing blocks of equal weight from start to finish. In Figure 1–2, we see that Adam pushes his block from start to finish in 3 minutes using a force of 50 newtons, while Eve, using the same force, pushes her block from start to finish in just 1 minute. Who is more powerful? If you said Eve, you are correct. Because it took Eve only 1 minute versus 3 minutes for Adam, we can state that Eve is more powerful than Adam. Power = Work/Time or Energy/Time. The unit of Power is the watt. 1 watt = 1 joule/second. Joule, the unit of work, is also the unit of energy. We can therefore state that work and energy are interchangeable.

Another example of work is that done by a weightlifter trying his best to lift a dumbbell as in Figure 1–3. He uses a force as great as 160 newtons and yet he is unable to lift the weight. Therefore, even with all his strength, he didn't do any work. His muscles, however, are working by contracting and stretching.

As mentioned above, theoretically, there is no limit to work or energy. For example, a space shuttle's power at takeoff (Figure 1–4) is billions of watts or billions of joules of energy converted from potential chemical energy to kinetic energy and heat energy each second.

Baby Jacob is busy pushing a ball (Figure 1–5). He's doing work. He pushes the ball along a path. The ball is very light, weighing only a few grams. Jacob is struggling very hard but has succeeded in moving the ball only 100 cm. With the force Jacob is applying and the distance

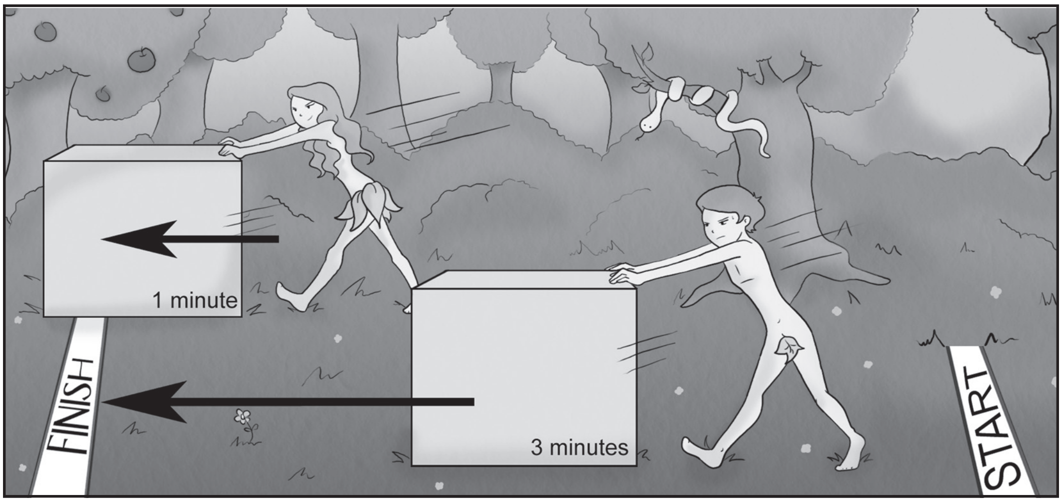


Figure 1–2. *Adam and Eve pushing blocks of equal weight.*

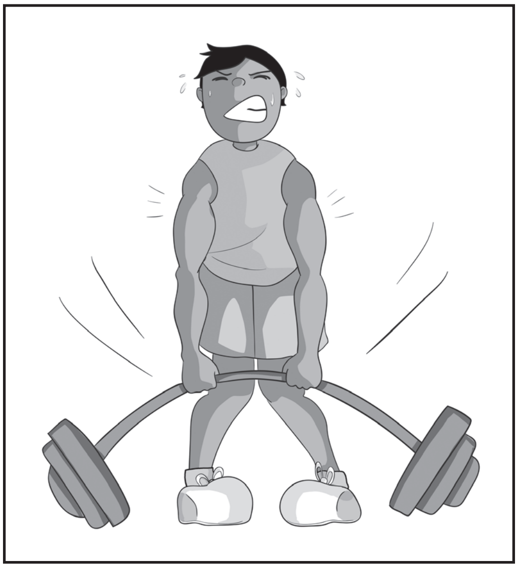


Figure 1–3. *Weightlifter.*

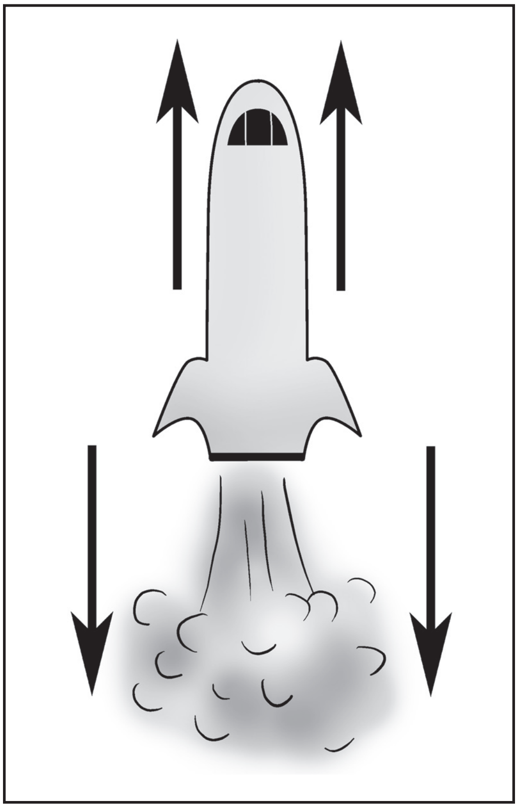


Figure 1–4. *Rocket.*

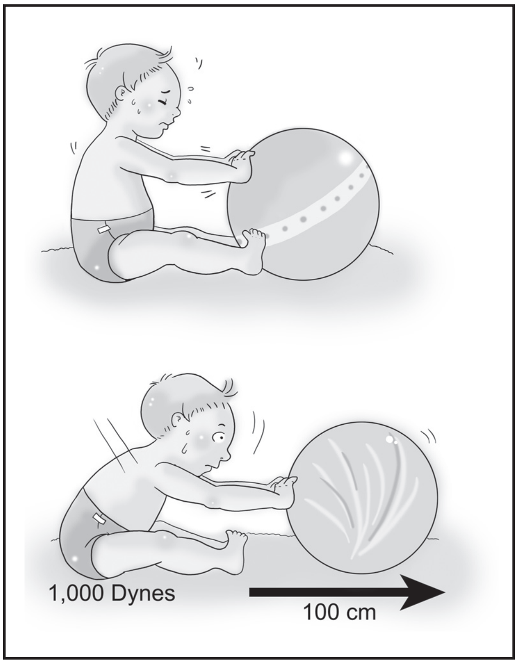


Figure 1–5. *Baby Jacob.*

he's pushing the ball, we no longer can use newton as the unit of force, but only a fraction of the newton, a dyne (1 newton of force = 100,000 dynes). In addition, he's moving the ball in centimeters, rather than meters. With his baby strength, he was able to use 1,000 dynes of force. This baby worked hard and used energy to do the work. 1,000 dynes × 100 cm = 100,000 dynes per centimeter or 100,000 ergs. 1 dyne/cm of work or energy = 1 erg. The baby's power, therefore, is 100,000 ergs/100 seconds = 1,000 ergs per second.

We have been using the terms newton and force. It appears from the above discussion that force forms the core of all physical activity and the basis of Newton's three laws. Although Newton's laws are studied in basic science courses in high school and college, they are worth reviewing. As you will see in several sections of this text, Newton's laws relate in one way or another to our study of audiology.

Newton's first law states that every object continues in a state of rest or in uniform motion in a straight line unless a force disturbs the object. To illustrate this law, let us borrow from a well-known experiment. We have a cup covered by cardboard. A quarter lies on the cardboard (Figure 1–6). Pull the cardboard and the quarter will fall into the cup rather than following the cardboard. The quarter has preserved its inertia by resisting a change in its position.

Why do we jerk forward in a car that has suddenly stopped moving? Again, the body is resisting a change in its position. In this case, we were already moving and therefore continued our motion. If you didn't have the good sense to wear a seatbelt, you continued through the windshield and then to a hospital (Figure 1–7). Inertia is the property that resists a change in position.

Newton's second law describes the relationship among force, mass, and accel-

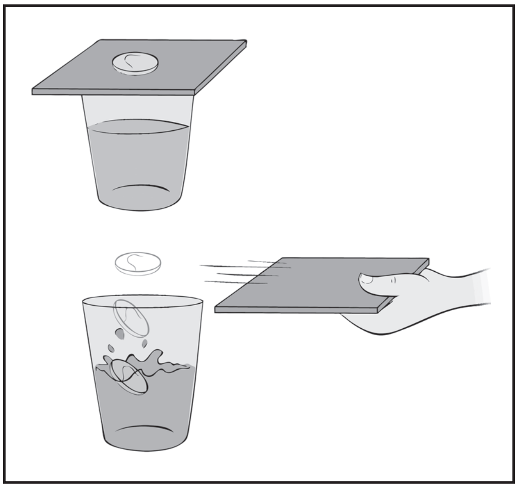


Figure 1–6. *Quarter on cardboard.*

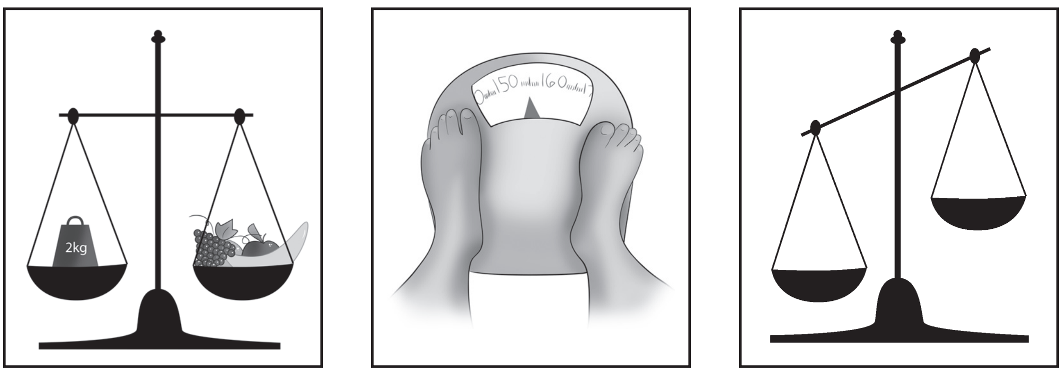
Figure 1–7. *The unfortunate driver.*

eration. We need a force to push a mass from its resting position. When the mass moves from its point of equilibrium (resting position), it accelerates. A force causes this acceleration. When a force accelerates a mass, friction between the mass and the ground reduces the net force. Friction is not restricted to a hard, solid material pushed by a force against another solid material. In fact, friction exists in liquid and gas as well. For example, water molecules can collide with water molecules and air molecules can collide with air molecules, thereby creating friction. In physics, fluid refers to both liquid and gas because both flow. The force of friction is always opposite that of the moving body, that is, resisting a motion, and can be expressed as $F_f = \mu N$ where μ is the static or kinetic coefficient of friction for a given set of materials, N is the normal force or (usually) weight pressing one object into another, F is force, and *f* is frictional force.

As we are dealing with mass in this section, we should note that there often is confusion regarding the concepts of mass and weight. Mass is a measurement of the amount of matter in an object and is usually quantified in kilograms on a balance scale (Figure 1–8A). We place weights in kilograms on one side of the scale and the matter to be quantified on the other. At this point, the quantity of the matter is unknown. We add and subtract the unit of measurement, that is, the kilograms, until balance is achieved. The quantification in kilograms that achieved the balance is the quantification of the matter being measured. In another example, when we already know the quantity we want, for example, if you wish to purchase 5 kg of sugar, a 5-kg weight will be placed on one side of the balance and sugar on the other. We add/subtract sugar until the scale is balanced. Such quantification does not change with height or location because the gravitational pull will work equally on both sides of the scale when the scale is balanced.

Weight is the measurement of the gravitational force that pulls a mass toward Earth. For example, when we stand on a scale, we are pulled to Earth by the force of gravity (Figure 1–8B) and our weight is measured in pounds.

It is not correct to say that mass has no weight when it is measured on a scale. When a balance scale is unequal, gravity



A B C

Figure 1–8. ***A.*** *Balance scale.* ***B.*** *Standard scale.* ***C.*** *Unequal balance.*

will act on both sides proportional to the size of the mass (Figure 1–8C). One side will have more weight than the other.

Although mass will not change with height or location, weight is impacted by height or location. For example, Mrs. Thomas weighs 160 lb in California (Figure 1–9A). She takes a trip to the moon. Much to her delight, her weight is now 25.6 lb (Figure 1–9B). What a diet! Mrs. Thomas continued on her travels with a stop at Jupiter. To her horror, she weighs 374.4 lb on Jupiter (Figure 1–9C). These weight discrepancies are because the force of gravity is different at each location. For example, on the moon, the gravitational force is 0.16 times Earth's gravity. By contrast, Jupiter's gravity is 2.34 times the gravity on Earth.

Newton's third law is also called the law of action and reaction. When an Object A exerts a force on Object B, the second object exerts the same force against Object A. Let's consider the example of a car moving along a road (Figure 1–10). What is the actual force moving the car forward? Is it the road or the tires? Believe it or not, the road itself pushes the car.

The road exerts a horizontal force on the car. The tires push back on the road (the action) while the road provides the reaction by pushing the tires forward with an equal force!

Another example of action and reaction is as follows: A man is driving his car along the road when suddenly a bee hits the car's windshield. The bee is flattened against the windshield (Figure 1–11). Is it possible that the action of the car is actually equal to the action of the bee? In other words, is the force of the car (the action) equal to the force of the bee (reaction)? According to Newton's third law, the forces are equal. This doesn't seem possible. There must be something wrong with Newton's third law. Remember that Force = Mass × Acceleration. In this case, the car was unaffected by the motion of the bee. The car's acceleration decreased only minimally because the mass of the car is so much greater than the mass of the bee. But the deceleration

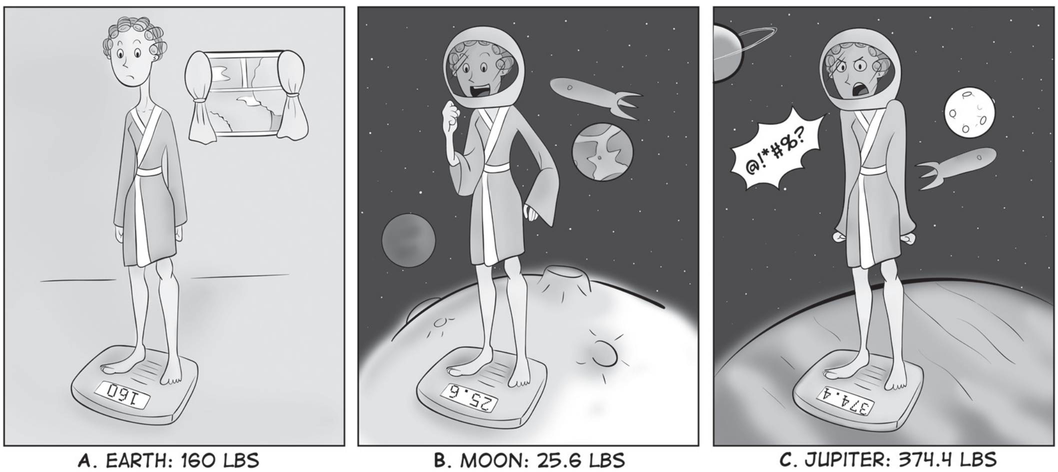


Figure 1–9. ***A–C.*** *We see Mrs. Thomas weighing herself on Earth, the moon, and Jupiter, respectively.*

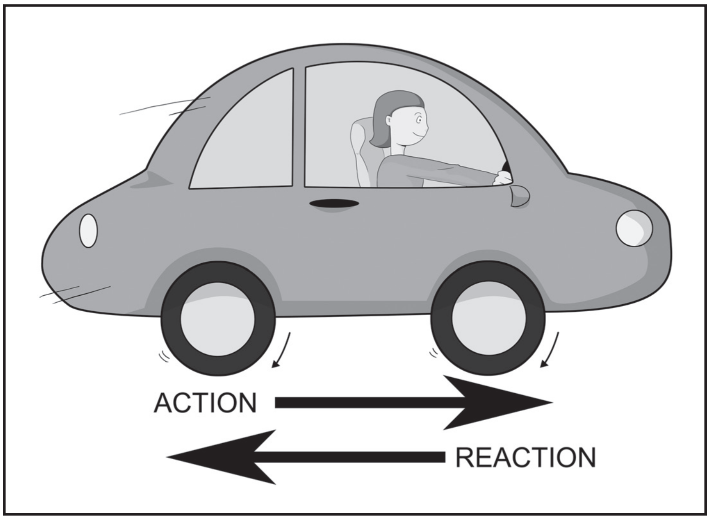


Figure 1–10. *Action/reaction.*

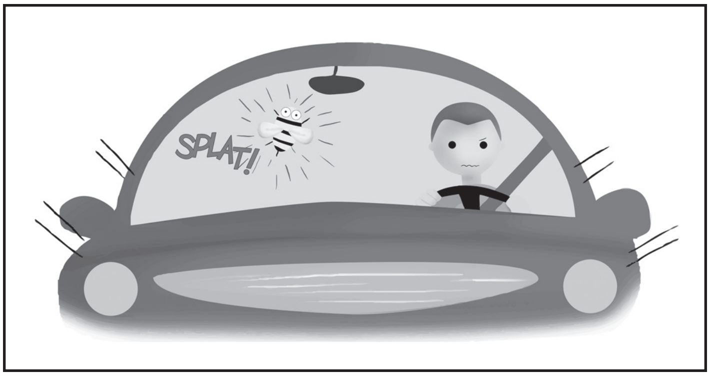


Figure 1–11. *Bee meets windshield.*

of the bee was so extreme that it flattened. So, mathematically speaking, mass of the car × slight deceleration = mass of the poor bee × colossal deceleration. So, according to Newton's third law, there is equal action and reaction.

We can find energy in myriad forms, such as sound, light, heat, motion, solar energy, atomic energy, and so forth. There are two main classes of energy: kinetic and potential. Kinetic energy is also known as the energy of motion, for example, moving cars, flying airplanes, and so forth. Radiant energy is an example of kinetic energy. Among the best-known examples of radiant energy are visible light and the gamma ray generated by controlled or uncontrolled (such as the disaster in Chernobyl) nuclear explosion or by radiated atoms used in medicine to destroy cancer cells. Forms of radiant energy can be generated from radioactive material found in space. Solar energy, heat, and light are also radiant energy. Sound is an