Basic Fundamentals in Hearing Science

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Contents

Foreword

Hearing science is a multidisciplinary subject that is rooted in a diverse array of fields, including physics, engineering, anatomy, physiology, cell biology, and psychology. Bringing together the vast reservoir of knowledge from all these disciplines into a single textbook that does justice to the field's complexity without alienating its readers is not a simple task and few have done so effectively. Sahley and Musiek are among the exceptions. Drawing on their many years of combined teaching and research experience/expertise in clinical audiology, hearing science, and auditory neuropharmacology, as well as their combined expertise in general medical physiology, neuroanatomy, and neurophysiology, they have done a masterful job of making this complex body of knowledge approachable and straightforward. The book is organized into 10 chapters, each describing a different core aspect of hearing science. The book's first two chapters are introductory to students new to science, providing an overview of what science is and summarizing basic concepts, quantities, and measurement systems that are used to describe and characterize the physical world. These chapters set the stage for Chapters 3 and 4, focusing on the terminology of hearing science and the application of its basic principles. Chapters 5 and 6 describe harmonic motion and all the properties of sound waves and how they are measured, while Chapter 7 journeys into the domain of acoustics, examining the propagation of sound waves through space and the complex interactions that shape the sound field. This provides a perfect segue into Chapter 8, summarizing the principles and concepts of psychoacoustics, the science of auditory perception. This chapter deals with what we hear and how the psychophysical attributes of sound vary with changes in the physical parameters of auditory stimulation. The last two chapters focus on the biology of hearing, beginning with a summary of terminology used to describe the various components and principles of nervous system organization (Chapter 9) and ending with a review of the anatomy and physiology of the three subdivisions of the ear (Chapter 10). Each of these chapters is characterized by a well-organized text that is prefaced by an inspiring quote and a list of terms to be defined, and each ends with a clear and succinct summary of concepts and principles introduced. Those chapters with a more quantitative bent also include numerous questions and/or problems to encourage students to put their knowledge to work or think beyond the boundaries of the book's pages. The text is written with meticulous and thorough attention to detail and accuracy. This is especially apparent with regard to the formulas and tables provided for the computations of the Bel, decibel, and RMS amplitude. An additional feature that adds to the attractiveness and flair of the book is the frequent reference to historic discoveries and to those who made them. Concepts presented in the text are beautifully complemented by illustrations, graphs, and equations. This is a book I wish I had had when I was a student, and I believe it will become a first choice textbook among undergraduate and graduate students. It will provide quick answers to questions, both simple and complex, and will provide ever-deepening insights into hearing science when knowledge of details is the goal.

—James A. Kaltenbach, PhD
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The Cleveland Clinic

Chapter 4

Application of the Basic Principles in Hearing Science

> *In a letter to Robert Hooke dated February 5, 1675, Newton wrote, "If I have seen further than others it is by standing upon the shoulders of giants"* (Gianopoulos, 2006, p. 49; Hawking, 2002, p. 725). *Perhaps Newton should have said, "I used the shoulders of giants as a springboard."*
>
> Hawking, 2002, p. XIII

Alphabetized Listing of Key Terms Discussed in Chapter 4

acceleration
action
atmospheric pressure
bar
CGS metric system
collisions
compliance
cycle
displacement
dynamics
dyne
Einstein, Albert
elastic collision
energy
erg
first law of motion, Newton's
force
friction
frictional resistance
Galilei, Galileo
geocentric
gravitational potential energy
gravity
Halley, Edmond
heliocentric
Hooke's law
horsepower
Huygens, Christiaan
inertia
inertia, law of
Inquisition
interactive forces
joule
Joule, James Prescott
kinematics
kinetic energy
law of inertia
laws of motion, Newton's
Leibniz, Gottfried Wilhelm
mass
mechanics
Medicean stars
microbar
MKS metric system
momentum
motion
natural motion

net force
newton (of force)
Newton, Isaac
one atmosphere of pressure
pascal (Pa)
Pascal, Blaise
pendulum
peripatetics
Pope, Alexander
potential energy
pounds per square inch (psi)
power
pressure
Principia
rate
reaction
recoil
reflecting telescope
refracting telescope
restorative force
Rome, Holy Office of
Rules of Reasoning, Newton's
scalar quantity
scalars
second law of motion, Newton's
Slinky
spring-mass system
stretching force (tension)
support force
telescope, Newtonian
third law of motion, Newton's
time
vector quantity
vectors
velocity
violent motion
watt
Watt, James
weight
work
Wren, Christopher

A Brief Historical Account of Motion

The connection between vibratory motion and sound was introduced in the previous chapter. Historically, the study of motion, known also in physics as mechanics, has occupied the interests of scholars that have originated from the time of the ancient philosopher Aristotle (384–322 BC), up to and beyond the era of the eminent Albert Einstein (1879–1955). Today, a thorough understanding of motion remains an essential component within the study of contemporary hearing science. What follows is a brief historical account of Galileo Galilei (1564–1642) and Isaac Newton (1642–1727), both of whom made significant contributions that advanced the study of motion, and of hearing science.

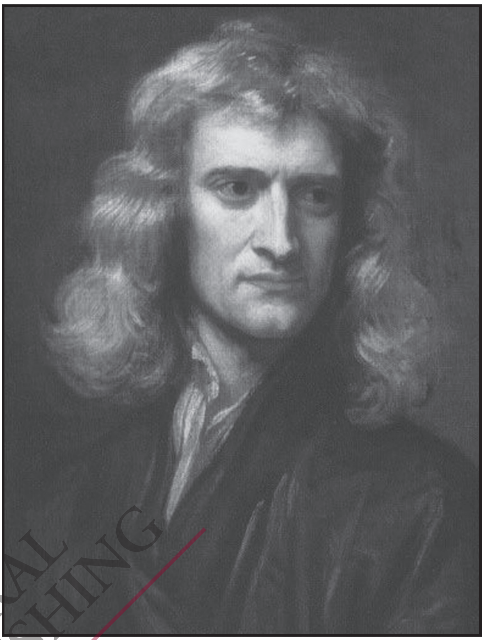
Galileo Galilei (1564–1642)

Recall the image of Galileo (see Portrait 1–1) that was presented in Chapter 1. Galileo was born in Pisa, Italy, and became the foremost scientist of the early 17th century. He studied medicine and the philosophy of Aristotle at the University of Pisa from 1581 to 1584. At the age of 20, Galileo discovered the properties of the pendulum. As indicated in the previous chapter, Galileo demonstrated that the rate of harmonic motion of a pendulum is inversely dependent on its length. This discovery made accurate time-keeping possible. It is not known whether Galileo actually built a pendulum clock, though Christiaan Huygens (1629–1695) did build one more than ten years after Galileo's death (Giancoli, 2005).

In 1585, Galileo abandoned the study of medicine for research in mathematics (Hawking, 2002). His approach to science included idealization and simplification, the quantification of theories (operationism), the development of theories (induction) with testable hypotheses (deduction), and the completion of empirical investigations in order to test his predictions (or simply, hypothesis testing). For these reasons, Galileo is often called the "father of modern experimental science" (Hawking, 2002). In 1589 at the age of 25, Galileo became a professor of mathematics at the University of Pisa. From his experiments with falling and rolling objects, he developed the concept of *acceleration*. He demonstrated that for a given location on the earth, solid objects with different amounts of mass would fall to the earth at roughly equivalent speeds or with constant acceleration, provided the air resistance was equivalent, or zero, as in a vacuum. Galileo, however, could not explain why. This explanation would require the genius of Isaac Newton. Galileo additionally determined that objects forcibly set into motion by a push or a pull on a horizontal surface eventually come to rest due to a force, called "friction" and not "nature," as Aristotle had originally asserted. He also reasoned that if friction were completely removed, an object forcibly set into motion would continue to move indefinitely in a straight line with constant velocity, provided that no other force acted to alter its motion. Galileo coined the term "inertia," and inertia became central to Galileo's laws of motion. Hence, according to Galileo, the constant horizontal motion of an object was no less natural than the condition of rest. This way of thinking was in direct contradiction to the popularly held metaphysical philosophies of Aristotle. Hence, Galileo discredited the contemporarily held Aristotelian concepts of nature and motion and this led to the creation of a new vision of the universe (Gianopoulos, 2006). From his prudent observations and experimentation, Galileo helped advance a new worldview in which the affairs of the mind were separate from the affairs of matter. In turn, advocates of Aristotelian thinking (called Peripatetics) eventually forced Galileo to leave the University of Pisa. In 1592, Galileo became professor of mathematics at the University of Padua where he made significant discoveries in astronomy (Gianopoulos, 2006). Galileo built a refracting telescope that was an improvement on a design first proposed in 1610 by Hans Lipperhey (Hawking, 2002). His conclusions, based on his earlier observation in 1604 of a supernova, and his telescopic observations in 1610 of the moon, Jupiter, and the galaxy, were again in direct opposition to the prevailing philosophy of an unchanging universe, as put forth by Aristotle (Hawking, 2002).

In 1610 Galileo discovered and named the four brightest moons of Jupiter, which he called the Medicean stars (Hawking, 2002). Later he detected the phases of Venus, and the sunspots of the Sun. In total, Galileo's scientific conclusions gave credence to a heliocentric Copernican view of the cosmos

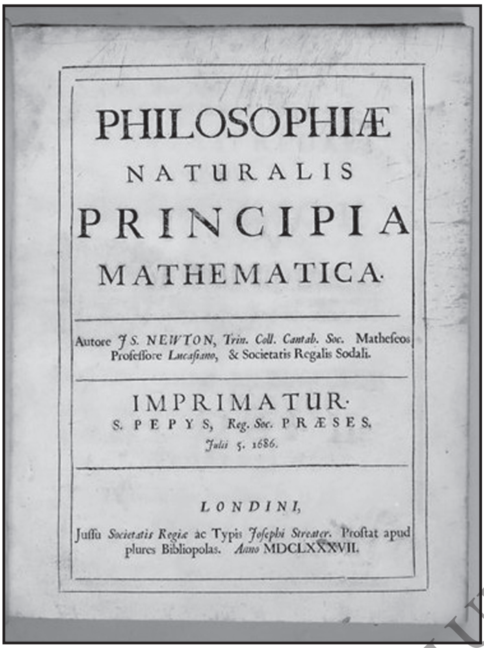
(Gianopoulos, 2006). By displacing the earth from the center of the universe, he was able to conclude that the earth and the heavens both operated under similar laws (Hawking, 2002). He attacked, with empirical evidence, the belief that mechanics and cosmology were separate subject matters. In 1616, officials of the Church, together with other Peripatetics, warned Galileo to abandon his belief in the Copernican view of the cosmos. In 1632, the Holy Office of Rome (The Inquisition) imprisoned Galileo for his published writings and confined him for an indefinite time to his villa in Florence (Gianopoulos, 2006; Hawking, 2002). Galileo remained there under house arrest in Tuscany, where he later died in 1642 (Giancoli, 2005; Hewitt, 2010).



Portrait 4–1. Isaac Newton (1642–1727). "Nature and nature's laws lay hid at night: God said, 'Let Newton be! And all was light.'" Written by Alexander Pope to describe Newton's gift to humanity (Hawking, 2002, p. 732). Printed with permission. Wikimedia Commons, public domain.

Isaac Newton (1642–1727)

Newton was born in Woolsthorpe, Lincolnshire, England, in the same year that Galileo died in Florence, while under house arrest (Gianopoulos, 2006; Hawking, 2002) (Portrait 4–1). At the age of 11, while attending grammar school, Newton discovered his particular talent for building clocks, sundials, and a working model of a windmill that was powered by a running mouse (Hawking, 2002). Newton led a rather solitary life (Gianopoulos, 2006), and much of Newton's adulthood was filled with episodes of harsh, vindictive attacks, not only against perceived enemies, but against friends and family as well. It has been speculated that Newton's achievements were the result of his vindictive obsessions and arrogance (Hawking, 2002). Beginning at the age of 19, and from 1661 to 1665, Newton attended Trinity College, which was part of Cambridge University (Gianopoulos, 2006). While at Cambridge, Newton studied the philosophy of Aristotle and Descartes, the science of Thomas Hobbs and Robert Boyle, the mechanics of Copernicus, the astronomy of Galileo, and the optics of Kepler (Hawking, 2002). While Newtonian mechanics has guided astronomers and scientists in their search for knowledge for more than 200 years, it was Newton's work with prisms and light (1704) (Portrait 4–2) that initially brought him fame (Gianopoulos, 2006). Newton was the first to use a prism to break a ray of light into a spectrum of colors. He then used a second prism to combine the colors back into white light (Stutz, 2006).



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S.* NEWTON, *Trin. Coll. Cantab. Soc.* Matheſeos
Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater*. Proſtat apud
plures Bibliopolas. *Anno* MDCLXXXVII.

Portrait 4–2. Newton's mathematical principles of natural philosophy. Printed with permission. Wikimedia Commons, public domain.

Newton was a rationalist whose emphasis was often based on defining true mathematical notions, independent of observation (Gianopoulos, 2006). The British physicist Robert Hooke, the English astronomer Edmond Halley, the Dutch mathematician Christiaan Huygens, and the architect Christopher Wren were all contemporaries of Isaac Newton (Hawking, 2002). At the age of 23 (1665) Newton formulated his universal law of gravitation and later, from 1666 to 1667, developed the binomial theorem. The law of universal gravitation stated that all matter is mutually attracted with a force directly proportional to the product of their (individual) masses, and inversely proportional to the square of the distance between them. He was also able to use his inverse square law theory of gravity to explain the elliptical motions of the planets and the rising and falling of the tides (Gianopoulos, 2006; Hawking, 2002). Newton invented the calculus (1666), though the differential and integral calculus developed by Gottfried Wilhelm Leibniz (1646–1716) in roughly the same period, is more commonly used by mathematicians and engineers. Nevertheless, Newton is still considered to be the father of infinitesimal calculus, mechanics and planetary motion, and theories of light and color. He secured his place in history by formulating the law of gravitational force and defining his three laws of motion (Hawking, 2002).

Newton, like Galileo, adhered to the heliocentric-Copernican view of the cosmos, and he viewed changes in the motion of a mass as originating from sources external to the mass, rather than representing internal activity within the mass (Hawking, 2002). In 1668, Newton developed (Stutz, 2006), constructed, and later made revisions (1671–1672) to the first reflecting telescope (Gianopoulos, 2006). Newton's original telescope was only 6 inches long and is still on display at the library of the Royal Society of London. His invention was the prototype for the design that later came to be called the "Newtonian telescope," a term that is practically synonymous with the reflecting telescope (Stutz, 2006). Newton became a mathematics professor at Cambridge in 1669 and was appointed the Lucasian Professor of Mathematics at Trinity College (in Cambridge) which is the same position held today by the renowned physicist Stephen Hawking (Gianopoulos, 2006). Extending the work of Galileo, Newton formulated his three laws of motion in his great work, the *Principia*