Careers in Physics

Acoustics

FIELDS OF STUDY

Electrical, chemical, and mechanical engineering; architecture; music; speech; psychology; physiology; medicine; atmospheric physics; geology; oceanography.

DEFINITION

Acoustics is the science dealing with the production, transmission, and effects of vibration in material media. If the medium is air and the vibration frequency is between 18 and 18,000 hertz (Hz), the vibration is termed "sound." Sound is used in a broader context to describe sounds in solids and underwater and structure-borne sounds. Because mechanical vibrations, whether natural or human induced, have accompanied humans through the long course of human evolution, acoustics is the most interdisciplinary science. For humans, hearing is a very important sense, and the ability to vocalize greatly facilitates communication and social interaction. Sound can have profound psychological effects; music may soothe or relax a troubled mind, and noise can induce anxiety and hypertension.

Basic Principles

The words "acoustics" and "phonics" evolved from ancient Greek roots for hearing and speaking, respectively. Thus, acoustics began with human communication, making it one of the oldest if not the most basic of sciences. Because acoustics is ubiquitous in human endeavors, it is the broadest and most interdisciplinary of sciences; its most profound contributions have occurred when it is commingled with an independent field. The interdisciplinary nature of acoustics has often consigned it to a subsidiary role as a minor subdivision of mechanics, hydrodynamics, or electrical engineering. Certainly, the various technical aspects of acoustics could be parceled out to larger and better established divisions of science, but then acoustics would lose its unique strengths and its source of dynamic creativity. The main difference between acoustics and more self-sufficient branches of science is that acoustics depends on physical laws developed in and borrowed from other fields. Therefore, the primary task of acoustics is to take these divergent principles and integrate them into a coherent whole in order to understand, measure, and control vibration phenomena.

The Acoustical Society of America subdivides acoustics into fifteen main areas, the most important of which are ultrasonics, which examines high-frequency waves not audible to humans; psychological acoustics, which studies how sound is perceived in the brain; physiological acoustics, which looks at human and animal hearing mechanisms; speech acoustics, which focuses on the human vocal apparatus and oral communication; musical acoustics, which involves the physics of musical instruments; underwater sound, which examines the production and propagation of sound in liquids; and noise, which concentrates on the control and suppression of unwanted sound. Two other important areas of applied acoustics are architectural acoustics (the acoustical design of concert halls and sound reinforcement systems) and audio engineering (recording and reproducing sound).

Core Concepts

Ultrasonics. Dog whistles, which can be heard by dogs but not by humans, can generate ultrasonic frequencies of about 25 kilohertz (kHz). Two types of transducers, magnetostrictive and piezoelectric, are used to generate higher frequencies and greater power. Magnetostrictive devices convert magnetic energy into ultrasound by subjecting ferric material (iron or nickel) to a strong oscillating magnetic field. The field causes the material to alternately expand and contract, thus creating sound waves of the same frequency as that of the field. The resulting sound waves have frequencies between 20 Hz and 50 kHz and several thousand watts of power. Such transducers operate at the mechanical resonance frequency where the energy transfer is most efficient.

Piezoelectric transducers convert electric energy into ultrasound by applying an oscillating electric field to a piezoelectric crystal (such as quartz). These transducers, which work in liquids or air, can generate frequencies in the megahertz region with considerable power. In addition to natural crystals, ceramic piezoelectric materials, which can be fabricated into any desired shape, have been developed.

Physiological and Psychological Acoustics. Physiological acoustics studies auditory responses of the ear and its associated neural pathways, and psychological acoustics is the subjective perception of sounds through human auditory physiology. Mechanical, electrical, optical, radiological, or biochemical techniques are used to study neural responses to various aural stimuli. Because these techniques are typically invasive, experiments are performed on animals with auditory systems that are similar to the human system. In contrast, psychological acoustic studies are noninvasive and typically use human subjects.

A primary objective of psychological acoustics is to define the psychological correlates to the physical parameters of sound waves. Sound waves in air may be characterized by three physical parameters: frequency, intensity, and their spectrum. When a sound wave impinges on the ear, the pressure variations in the air are transformed by the middle ear to mechanical vibrations in the inner ear. The cochlea then decomposes the sound into its constituent frequencies and transforms these into neural action potentials, which travel to the brain where the sound is evidenced. Frequency is perceived as pitch, the intensity level as loudness, and the spectrum determines the timbre, or tone quality, of a note.

Another psychoacoustic effect is masking. When a person listens to a noisy version of recorded music, the noise virtually disappears if the music is being enjoyed. This ability of the brain to selectively listen has had important applications in digitally recorded music. When the sounds are digitally compressed, such as in MP3 (MPEG-1 audio layer 3) systems, the brain compensates for the loss of information; thus one experiences higher fidelity sound than the stored content would imply. Also, the brain creates information when the incoming signal is masked or nonexistent, producing a psychoacoustic phantom effect. This phantom effect is particularly prevalent when heightened perceptions are imperative, as when danger is lurking.

Psychoacoustic studies have determined that the frequency range of hearing is from 20 to about 20,000 Hz for young people, and the upper limit progressively decreases with age. The rate at which hearing acuity declines depends on several factors, not the least of which is lifetime exposure to loud sounds, which progressively deteriorate the hair cells of the cochlea. Moderate hearing loss can be compensated for by a hearing aid; severe loss requires a cochlear implant.

Speech Acoustics. Also known as acoustic phonetics, speech acoustics deals with speech production and recognition. The scientific study of speech began with Thomas Alva Edison's phonograph, which allowed a speech signal to be recorded and stored for later analysis. Replaying the same short speech segment several times using consecutive filters passing through a limited range of frequencies creates a spectrogram, which visualizes the spectral properties of vowels and consonants. During the first half of the twentieth century, Bell Telephone Laboratories dedicated considerable time and resources to the systematic understanding of all aspects of speech, including vocal tract resonances, voice quality, and prosodic features of speech. For the first time, electric circuit theory was applied to speech acoustics, and analogue electric circuits were used to investigate synthetic speech.

Musical Acoustics. A conjunction of music, craftsmanship, auditory science, and vibration physics, musical acoustics analyzes musical instruments to better understand how the instruments are crafted, the physical principles of their tone production, and why each instrument has a unique timbre. Musical instruments are studied by analyzing their tones and then creating computer models to synthesize these sounds. When the sounds can be recreated with minimal software complications, a synthesizer featuring realistic orchestral tones may be constructed. The second method of study is to assemble an instrument or modify an existing instrument to perform nondestructive (or on occasion destructive) testing so that the effects of various modifications may be gauged.

Underwater Sound. Also known as hydroacoustics, this field uses frequencies between 10 Hz and 1 megahertz (MHz). The deployment of submarines in World War I provided the impetus for the rapid

Interesting Facts about Acoustics

- Scientists have created an acoustic refrigerator, which uses a standing sound wave in a resonator to provide the motive power for operation. Oscillating gas particles increase the local temperature, causing heat to be transferred to the container walls, where it is expelled to the environment, cooling the interior.
- A cochlear implant, an electronic device surgically implanted in the inner ear, provides some hearing ability to those with damaged cochlea or those with congenital deafness. Because the implants use only about two dozen electrodes to replace 16,000 hair cells, speech sounds, although intelligible, have a robotic quality.
- MP3 files contain audio that is digitally encoded using an algorithm that compresses the data by a factor of about eleven but yields a reasonably faithful reproduction. The quality of sound reproduced depends on the data sampling rate, the quality of the encoder, and the complexity of the signal.
- Sound cannot travel through a vacuum, but it can travel four times faster through water than through air.
- The "cocktail party effect" refers to a person's ability to direct attention to one conversation at a time despite the many conversations taking place in the room.
- Continued exposure to noise over 85 decibels (dB) will gradually cause hearing loss. The noise level on a quiet residential street is 40 dB, a vacuum cleaner 60–85 dB, a leafblower 110 dB, an ambulance siren 120 dB, a rifle shot 160 dB, and a rocket launching from its pad 180 dB.

development of underwater listening devices (hydrophones) and sonar (sound navigation ranging), the acoustic equivalent of radar. Pulses of sound are emitted and the echoes are processed to extract information about submerged objects. When the speed of underwater sound is known, the reflection time for a pulse determines the distance to an object. If the object is moving, its speed of approach or recession is deduced from the frequency shift of the reflection, or the Doppler effect.

Returning pulses have a higher frequency when the object approaches and lower frequency when it moves away.

Noise. Physically, noise may be defined as an intermittent or random oscillation with multiple frequency components, but psychologically, noise is any unwanted sound. Noise can adversely affect human health and well-being by inducing stress, interfering with sleep, increasing heart rate, raising blood pressure, modifying hormone secretion, and even inducing depression. The physical effects of noise are no less severe. The vibrations in irregular road surfaces caused by large rapid vehicles can cause adjacent buildings to vibrate to an extent that is intolerable to the buildings' inhabitants, even without structural damage. Machinery noise in industry is a serious problem because continuous exposure to loud sounds will induce hearing loss. In apartment buildings, noise transmitted through walls is always problematic; the goal is to obtain adequate sound insulation using lightweight construction materials.

Traffic noise, both external and internal, is ubiquitous in modern life. The first line of defense is to reduce noise at its source by improving engine enclosures, mufflers, and tires. The next method, used primarily when interstate highways are adjacent to residential areas, is to block the noise by the construction of concrete barriers or the planting of sound-absorbing vegetation. Internal automobile noise has been greatly abated by designing more aerodynamically efficient vehicles to reduce air turbulence, using better sound isolation materials, and improving vibration isolation.

Aircraft noise, particularly in the vicinity of airports, is a serious problem exacerbated by the fact that as modern airplanes have become more powerful, the noise they generate has risen concomitantly. The noise radiated by jet engines is reduced by two structural modifications. Acoustic linings are placed around the moving parts to absorb the high frequencies caused by jet whine and turbulence, but this modification is limited by size and weight constraints. The second modification is to reduce the number of rotor blades and stator vanes, but this is somewhat inhibited by the desired power output. Special noise problems occur when aircraft travel at supersonic speeds (faster than the speed of sound), as this propagates a large pressure wave toward the ground that is experienced as an explosion. The unexpected sonic boom startles people, breaks windows, and damages houses. Sonic booms have been known to destroy rock structures in national parks. Because of these concerns, commercial aircraft are prohibited from flying at supersonic speeds over land areas.

Construction equipment (such as earthmoving machines) creates high noise levels both internally and externally. When the cabs of these machines are not closed, the only feasible manner of protecting operators' hearing is by using ear plugs. By carefully designing an enclosed cabin, structural vibration can be reduced and sound leaks made less significant, thus quieting the operator's environment. Although manufacturers are attempting to reduce the external noise, it is a daunting task because the rubber tractor treads occasionally used to replace metal are not as durable.

Applications Past and Present

Ultrasonics. High-intensity ultrasonic applications include ultrasonic cleaning, mixing, welding, drilling, and various chemical processes. Ultrasonic cleaners use waves in the 150 to 400 kHz range on items (such as jewelry, watches, lenses, and surgical instruments) placed in an appropriate solution. Ultrasonic cleaners have proven to be particularly effective in cleaning surgical devices because they loosen contaminants by aggressive agitation irrespective of an instrument's size or shape, and disassembly is not required. Ultrasonic waves are effective in cleaning most metals and alloys, as well as wood, plastic, rubber, and cloth. Ultrasonic waves are used to emulsify two nonmiscible liquids, such as oil and water, by forming the liquids into finely dispersed particles that then remain in homogeneous suspension. Many paints, cosmetics, and foods are emulsions formed by this process.

Although aluminum cannot be soldered by conventional means, two surfaces subjected to intense ultrasonic vibration will bond—without the application of heat—in a strong and precise weld. Ultrasonic drilling is effective where conventional drilling is problematic, for instance, drilling square holes in glass. The drill bit, a transducer having the required shape and size, is used with an abrasive slurry that chips away the material when the suspended powder oscillates. Some of the chemical applications of ultrasonics are in the atomization of liquids, in electroplating, and as a catalyst in chemical reactions.

Low-intensity ultrasonic waves are used for nondestructive probing to locate flaws in materials for which complete reliability is mandatory, such as those used in spacecraft components and nuclear reactor vessels. When an ultrasonic transducer emits a pulse of energy into the test object, flaws reflect the wave and are detected. Because objects subjected to stress emit ultrasonic waves, these signals may be used to interpret the condition of the material as it is increasingly stressed. Another application is ultrasonic emission testing, which records the ultrasound emitted by porous rock when natural gas is pumped into cavities formed by the rock to determine the maximum pressure these natural holding tanks can withstand.

Low-intensity ultrasonics is used for medical diagnostics in two different applications. First, ultrasonic waves penetrate body tissues but are reflected by moving internal organs, such as the heart. The frequency of waves reflected from a moving structure is Doppler-shifted, thus causing beats with the original wave, which can be heard. This procedure is particularly useful for performing fetal examinations on a pregnant woman; because sound waves are not electromagnetic, they will not harm the fetus. The second application is to create a sonogram image of the body's interior. A complete cross-sectional image may be produced by superimposing the images scanned by successive ultrasonic waves passing through different regions. This procedure, unlike an x-ray, displays all the tissues in the cross section and also avoids any danger posed by the radiation involved in x-ray imaging.

Physiological and Psychological Acoustics. Because the ear is a nonlinear system, it produces beat tones that are the sum and difference of two frequencies. For example, if two sinusoidal frequencies of 100 and 150 Hz simultaneously arrive at the ear, the brain will, in addition to these two tones, create tones of 250 and 50 Hz (sum and difference, respectively). Thus, although a small speaker cannot reproduce the fundamental frequencies of bass tones, the difference between the harmonics of that pitch will re-create the missing fundamental in the listener's brain.

Another psychoacoustic effect is masking. When a person listens to a noisy version of recorded music, the noise virtually disappears if the individual is enjoying the music. This ability of the brain to selectively listen has had important applications in digitally recorded music. When sounds are digitally compressed, as in MP3 systems, the brain compensates for the loss of information, thus creating a higher fidelity sound than that conveyed by the stored content alone.

As twentieth-century technology evolved, environmental noise increased concomitantly; lifetime exposure to loud sounds, commercial and recreational, has created an epidemic of hearing loss, most noticeable in the elderly because the effects are cumulative. Wearing a hearing aid, fitted adjacent to or inside the ear canal, is an effectual means of counteracting this handicap. The device consists of one or several microphones, which create electric signals that are amplified and transduced into sound waves redirected back into the ear. More sophisticated hearing aids incorporate an integrated circuit to control volume, either manually or automatically, or to switch to volume contours designed for various listening environments, such conversations on the telephone or where excessive background noise is present.

Speech Acoustics. With the advent of the computer age, speech synthesis moved to digital processing, either by bandwidth compression of stored speech or by using a speech synthesizer. The synthesizer reads a text and then produces the appropriate phonemes on demand from their basic acoustic parameters, such as the vibration frequency of the vocal cords and the frequencies and amplitudes of the vowel formants. This method of generating speech is considerably more efficient in terms of data storage than archiving a dictionary of prerecorded phrases.

Another important, and probably the most difficult, area of speech acoustics is the machine recognition of spoken language. When machine recognition programs are sufficiently advanced, the computer will be able to listen to a sentence in any reasonable dialect and produce a printed text of the utterance. Two basic recognition strategies exist, one dealing with words spoken in isolation and the other with continuous speech. In both cases, it is desirable to teach the computer to recognize the speech of different people through a training program. Because recognition of continuous speech is considerably more difficult than the identification of isolated words, very sophisticated pattern-matching models must be employed. One example of a machine recognition system is a word-driven dictation system that uses sophisticated software to process input speech. This system is somewhat adaptable to different voices and is able to recognize 30,000 words at a rate of 30 words per minute. The ideal machine recognition system would translate a spoken input language into another language in real time with correct grammar. Although some progress is being made, such a device has remained in the realm of speculative fantasy.

Musical Acoustics. The importance of musical acoustics to manufacturers of quality instruments is apparent. During the last decades of the twentieth century, fundamental research led, for example, to vastly improved French horns, organ pipes, orchestral strings, and the creation of an entirely new family of violins.

Underwater Sound. Applications for underwater acoustics include devices for underwater communication by acoustic means, remote control devices, underwater navigation and positioning systems, acoustic thermometers to measure ocean temperature, and echo sounders to locate schools of fish or other biota. Low-frequency devices can be used to explore the seabed for seismic research.

Although primitive measuring devices were developed in the 1920s, it was during the 1930s that sonar systems began incorporating piezoelectric transducers to increase their accuracy. These improved systems and their increasingly more sophisticated progeny became essential for the submarine warfare of World War II. After the war, theoretical advances in underwater acoustics coupled with computer technology have raised sonar systems to ever more sophisticated levels.

Noise. One system for abating unwanted sound is active noise control. The first successful application of active noise control was noise-canceling headphones, which reduce unwanted sound by using microphones placed in proximity to the ear to record the incoming noise. Electronic circuitry then generates a signal, exactly opposite to the incoming sound, which is reproduced in the earphones, thus canceling the noise by destructive interference. This system enables listeners to enjoy music without having to use excessive volume levels to mask outside noise and allows people to sleep in noisy vehicles such as airplanes. Because active noise suppression is more effective with low frequencies, most commercial systems rely on soundproofing the earphone to attenuate high frequencies. To effectively cancel high frequencies, the microphone and emitter would have to be situated adjacent to the user's eardrum, but this is not technically feasible. Active noise control is also being considered as a means of controlling low-frequency airport noise, but because of its complexity and expense, this is not yet commercially feasible.

Impact on Industry

Acoustics is the focus of research at numerous governmental agencies and academic institutions, as well as some private industries. Acoustics also plays an important role in many industries, often as part of product design (hearing aids and musical instruments) or as an element in a service (noise control consulting).

Industry and Business. Many businesses (such as the manufacturers of hearing aids, ultrasound medical devices, and musical instruments) use acoustics in their products or services and therefore employ experts in acoustics. Businesses are also involved in many aspects of acoustic research, particularly controlling noise and facilitating communication. Raytheon BBN Technologies in Cambridge, Massachusetts, has developed low-data-rate Noise Robust Vocoders (electronic speech synthesizers) that generate comprehensible speech at data rates considerably below other state-of-the-art devices. Acoustic Research Laboratories in Sydney, Australia, designs and manufactures specialized equipment for measuring environmental noise and vibration, in addition to providing contract research and development services.

Government Agencies and Military. Acoustics is studied in many government laboratories in the United States, including the US Naval Research Laboratory (NRL), the Air Force Research Laboratory (AFRL), the Los Alamos National Laboratory, and the Lawrence Livermore National Laboratory. Research at the NRL and the AFRL is primarily in the applied acoustics area, and Los Alamos and Lawrence

Occupation	Sound Engineering Technicians
Employment 2010	19,000
Projected Employment 2020	19,100
Change in Number (2010–20)	100
Percent Change	1%

**Bureau of Labor Statistics, 2012*

Livermore are oriented toward physical acoustics. The NRL emphasizes fundamental multidisciplinary research focused on creating and applying new materials and technologies to maritime applications. In particular, the applied acoustics division, using ongoing basic scientific research, develops improved signal processing systems for detecting and tracking underwater targets. The AFRL is heavily invested in research on auditory localization (spatial hearing), virtual auditory display technologies, and speech intelligibility in noisy environments. The effects of high-intensity noise on humans, as well as methods of attenuation, constitute a significant area of investigation at this facility. Another important area of research is the problem of providing intelligible voice communication in extremely noisy situations, such as those encountered by military or emergency personnel using low data rate narrowband radios, which compromise signal quality.

Academic Research and Teaching. Research in acoustics is conducted at many colleges and universities in the United States, usually through physics or engineering departments, but, in the case of physiological and psychological acoustics, in groups that draw from multiple departments, including psychology, neurology, and linguistics. The Speech Research Laboratory at Indiana University investigates speech perception and processing through a broad interdisciplinary research program. The Speech Research Lab, a collaboration between the University of Delaware and the A. I. duPont Hospital for Children, creates speech synthesizers for the vocally impaired. A human speaker records a data bank of words and phrases that can be concatenated on demand to produce natural-sounding speech.

Academic research in acoustics is also being conducted in laboratories in Europe and other parts of the world. The Laboratoire d'Acoustique at the Université de Maine in Le Mans, France, specializes in research in vibration in materials, transducers, and musical instruments. The Andreyev Acoustics Institute of the Russian Acoustical Society brings together researchers from Russian universities, agencies, and businesses to conduct fundamental and applied research in ocean acoustics, ultrasonics, signal processing, noise and vibration, electroacoustics, and bioacoustics. The Speech and Acoustics Laboratory at the Nara Institute of Science and Technology in Nara, Japan, studies diverse aspects of human-machine communication through speech-oriented multimodal interaction. The Acoustics Research Centre, part of the National Institute of Creative Arts and Industries in New Zealand, is concerned with the impact of noise on humans. A section of this group, Acoustic Testing Service, provides commercial testing of building materials for their noise attenuation properties.

Academic positions dedicated to acoustics are few, as are the numbers of qualified applicants. Most graduates of acoustics programs find employment in research-based industries in which acoustical aspects of products are important, and others work for government laboratories.

Social Context and Future Prospects

Acoustics affects virtually every aspect of modern life; its contributions to societal needs are incalculable. Ultrasonic waves clean objects, are routinely employed to probe matter, and are used in medical diagnosis. Cochlear implants restore people's ability to hear, and active noise control helps provide quieter listening environments. New concert halls are routinely designed with excellent acoustical properties, and vastly improved or entirely new musical instruments have made their debut. Infrasound from earthquakes is used to study the composition of Earth's mantle, and sonar is essential to locate submarines and aquatic life. Sound waves are used to explore the effects of structural vibrations. Automatic speech recognition devices and hearing aid technology are constantly improving.

Many societal problems related to acoustics remain to be tackled. The technological advances that made modern life possible have also resulted in more people with hearing loss. Environmental noise is ubiquitous and increasing despite efforts to design quieter machinery and pains taken to contain unwanted sound or to isolate it from people. Also, although medical technology has been able to help many hearing- and speech-impaired people, other individuals still lack appropriate treatments. For example, although voice generators exist, there is considerable room for improvement.

Further Reading

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Swift, Gregory. "Thermoacoustic Engines and Refrigerators." *Physics Today* (July, 1995): 22–28. Explains how sound waves may be used to create more efficient refrigerators with no moving parts.

About the Author: George R. Plitnik, BA, BS, MA, PhD, is a professor of physics at Frostburg State University. He received bachelor's degrees from Lebanon Valley College, a master's degree from Wake Forest University, and a doctorate from Brigham Young University. His academic specialty is acoustics, and he is interested in anthropogenic climate modification, energy, pollution control, and music. He lives in a passive solar house, which he designed and built. He teaches courses on solar energy and global warming.

Sound Engineering Technician

Earnings (Yearly Median): $47,080 (Bureau of Labor Statistics, 2012)

Employment and Outlook: Slower than average growth (Bureau of Labor Statistics, 2012)

O*NET-SOC Code: 27-4014.00

Related Career Clusters: Arts; Audio/Video Technology & Communications; Information Technology; Marketing

Scope of Work

Sound engineering technicians operate the machinery and equipment used to record, mix, and produce music, voices, or sound effects for a variety of purposes. They are employed by recording studios, sporting arenas, theater productions, and film studios in addition to any number of jobs in which sound recording or reproduction is required. They are the technological backbone of the sound engineering industry, playing an important role in developing musical-instrument digital-interface programs, live audio systems, and postproduction audio equipment.

Sound engineering technicians work in dynamic, fast-paced environments such as radio and television broadcasting and live concert entertainment, mixing sound and maintaining equipment to keep