ultrasonics

physics

Alternate titles: ultrasonic wave, ultrasound

By Richard E. Berg • Edit History

ultrasonics, vibrations of frequencies greater than the upper limit of the audible range for humans—that is, greater than about 20 kilohertz. The term *sonic* is applied to ultrasound waves of very high amplitudes. Hypersound, sometimes called praetersound or microsound, is sound waves of frequencies greater than 10^{13} hertz. At such high frequencies it is very difficult for a sound wave to propagate efficiently; indeed, above a frequency of about 1.25×10^{13} hertz it is impossible for longitudinal waves to propagate at all, even in a liquid or a solid, because the molecules of the material in which the waves are traveling cannot pass the vibration along rapidly enough.

Many animals have the ability to hear sounds in the human ultrasonic frequency range. A presumed sensitivity of roaches and rodents to frequencies in the 40 kilohertz region has led to the manufacture of "pest controllers" that emit loud sounds in that frequency range to drive the pests away, but they do not appear to work as advertised.

BRITANNICA QUIZ

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Some ranges of hearing for mammals and insects are compared with those of humans in the table.

Frequency range of hearing for humans and other selected animals

animal	frequency (hertz)	
	low	high
humans	20	20,000
cats	100	32,000
dogs	40	46,000
horses	31	40,000
elephants	16	12,000
cattle	16	40,000
bats	1,000	150,000
grasshoppers and locusts	100	50,000
rodents	1,000	100,000
whales and dolphins	70	150,000
seals and sea lions	200	55,000

Transducers

An ultrasonic transducer is a device used to convert some other type of energy into an ultrasonic vibration. There are several basic types, classified by the energy source and by the medium into which the waves are being generated. Mechanical devices include gas-driven, or pneumatic, transducers such as whistles as well as liquid-driven transducers such as hydrodynamic oscillators and vibrating blades. These devices, limited to low ultrasonic frequencies, have a number of industrial applications, including drying, ultrasonic cleaning, and injection of fuel oil into burners. Electromechanical transducers are far more versatile and include piezoelectric and magnetostrictive devices. A magnetostrictive transducer makes use of a type of magnetic material in which an applied oscillating magnetic field squeezes the atoms of the material together, creating a periodic change in the length of the material and thus producing a high-frequency mechanical vibration. Magnetostrictive transducers are used primarily in the lower frequency ranges and are common in ultrasonic cleaners and ultrasonic machining applications.

By far the most popular and versatile type of ultrasonic transducer is the piezoelectric crystal, which converts an oscillating electric field applied to the crystal into a mechanical vibration. Piezoelectric crystals include quartz, Rochelle salt, and certain types of ceramic. Piezoelectric transducers are readily employed over the entire frequency range and at all output levels. Particular shapes can be chosen for particular applications. For example, a disc shape provides a plane ultrasonic wave, while curving the radiating surface in a slightly concave or bowl shape creates an ultrasonic wave that will focus at a specific point.

Piezoelectric and magnetostrictive transducers also are employed as ultrasonic receivers, picking up an ultrasonic vibration and converting it into an electrical oscillation.

Applications in research

One of the important areas of scientific study in which ultrasonics has had an enormous impact is cavitation. When water is boiled, bubbles form at the bottom of the container, rise in the water, and then collapse, leading to the sound of the boiling water. The boiling process and the resulting sounds have intrigued people since they were first boiling process and the resulting sounds have intrigued people since they were first observed, and they were the object of considerable research and calculation by the British physicists Osborne Reynolds and Lord Rayleigh, who applied the term *cavitation* to the process of formation of bubbles. Because an ultrasonic wave can be used carefully to control cavitation, ultrasound has been a useful tool in the investigation of the process. The study of cavitation has also provided important information on intermolecular forces.

Understand the concept of sonoluminescence which is a phenomenon of turning sound into light

Learn how collapsing bubbles with sound can create sonoluminescence.

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Research is being carried out on aspects of the cavitation process and its applications. A contemporary subject of research involves emission of light as the cavity produced by a high-intensity ultrasonic wave collapses. This effect, called sonoluminescence, can create instantaneous temperatures hotter than the surface of the Sun.

The speed of propagation of an ultrasonic wave is strongly dependent on the visco[...] of the medium. This property can be a useful tool in investigating the viscosity of materials. Because the various parts of a living cell are distinguished by differing viscosities, acoustical microscopy can make use of this property of cells to “see” into living cells, as will be discussed below in Medical applications.

Ranging and navigating

Sonar (sound navigation and ranging) has extensive marine applications. By sending out pulses of sound or ultrasound and measuring the time required for the pulses to reflect off a distant object and return to the source, the location of that object can be ascertained and its motion tracked. This technique is used extensively to locate and track submarines at sea and to locate explosive mines below the surface of the water. Two boats at known locations can also use triangulation to locate and track a third boat or submarine. The distance over which these techniques can be used is limited by temperature gradients in the water, which bend the beam away from the surface and create shadow regions. One of the advantages of ultrasonic waves over sound waves in underwater applications is that, because of their higher frequencies (or shorter wavelengths), the former will travel greater distances with less diffraction.

Ranging has also been used to map the bottom of the ocean, providing depth charts that are commonly used in navigation, particularly near coasts and in shallow waterways. Even small boats are now equipped with sonic ranging devices that determine and display the depth of the water so that the navigator can keep the boat from beaching on submerged sandbars or other shallow points. Modern fishing boats use ultrasonic ranging devices to locate schools of fish, substantially increasing their efficiency.

Even in the absence of visible light, bats can guide their flight and even locate flying insects (which they consume in flight) through the use of sonic ranging. Ultrasonic echolocation has also been used in traffic control applications and in counting and sorting items on an assembly line. Ultrasonic ranging provides the basis of the eye vision systems for robots, and it has a number of important medical applications (see *below*).

The Doppler effect

If an ultrasonic wave is reflected off a moving obstacle, the frequency of the resulting wave will be changed, or Doppler-shifted. More specifically, if the obstacle is moving toward the source, the frequency of the reflected wave will be increased; and if the obstacle is moving away from the source, the frequency of the reflected wave will be decreased. The amount of the frequency shift can be used to determine the velocity of the moving obstacle. Just as the Doppler shift for radar, an electromagnetic wave, can be used to determine the speed of a moving car, so can the speed of a moving submarine be determined by the Doppler shift of a sonar beam. An important industrial application is the ultrasonic flow meter, in which reflecting ultrasound off a flowing liquid leads to a Doppler shift that is calibrated to provide the flow rate of the liquid. This technique also has been applied to blood flow in arteries.

Materials testing

Nondestructive testing involves the use of ultrasonic echolocation to gather information on the integrity of mechanical structures. Since changes in the material present an impedance mismatch from which an ultrasonic wave is reflected, ultrasonic testing can be used to identify faults, holes, cracks, or corrosion in materials, to inspect welds, to determine the quality of poured concrete, and to monitor metal fatigue. Owing to the mechanism by which sound waves propagate in metals, ultrasound can be used to probe more deeply than any other form of radiation. Ultrasonic procedures are used to perform in-service inspection of structures in nuclear reactors.

Structural flaws in materials can also be studied by subjecting the materials to stress and looking for acoustic emissions as the materials are stressed. Acoustic emission, the general name for this type of nondestructive study, has developed as a distinct field of acoustics.

High-intensity applications

High-intensity ultrasound has achieved a variety of important applications. Perha[illegible]e most ubiquitous is ultrasonic cleaning, in which ultrasonic vibrations are set up in small liquid tanks in which objects are placed for cleaning. Cavitation of the liquid by the ultrasound, as well as the vibration, create turbulence in the liquid and result in the cleaning action. Ultrasonic cleaning is very popular for jewelry and has also been used with such items as dentures, surgical instruments, and small machinery. Degreasing is often enhanced by ultrasonic cleaning. Large-scale ultrasonic cleaners have also been developed for use in assembly lines.

Ultrasonic machining employs the high-intensity vibrations of a transducer to move a machine tool. If necessary, a slurry containing carborundum grit may be used; diamond tools can also be used. A variation of this technique is ultrasonic drilling, which makes use of pneumatic vibrations at ultrasonic frequencies in place of the standard rotary drill bit. Holes of virtually any shape can be drilled in hard or brittle materials such as glass, germanium, or ceramic.

Ultrasonic soldering has become important, especially for soldering unusual or difficult materials and for very clean applications. The ultrasonic vibrations perform the function of cleaning the surface, even removing the oxide layer on aluminum so that the material can be soldered. Because the surfaces can be made extremely clean and free from the normal thin oxide layer, soldering flux becomes unnecessary.

Chemical and electrical uses

The chemical effects of ultrasound arise from an electrical discharge that accompanies the cavitation process. This forms a basis for ultrasound's acting as a catalyst in certain chemical reactions, including oxidation, reduction, hydrolysis, polymerization and depolymerization, and molecular rearrangement. With ultrasound, some chemical processes can be carried out more rapidly, at lower temperatures, or more efficiently.

The ultrasonic delay line is a thin layer of piezoelectric material used to produce a short, precise delay in an electrical signal. The electrical signal creates a mechanical vibration in the piezoelectric crystal that passes through the crystal and is converted back to an electrical signal. A very precise time delay can be achieved by constructing a crystal with the proper thickness. These devices are employed in fast electronic timing circuits.

Medical applications

Although ultrasound competes with other forms of medical imaging, such as X-ray techniques and magnetic resonance imaging, it has certain desirable features—for example, Doppler motion study—that the other techniques cannot provide. In addition, among the various modern techniques for the imaging of internal organs, ultrasonic devices are by far the least expensive. Ultrasound is also used for treating joint pains and for treating certain types of tumours for which it is desirable to produce localized heating. A very effective use of ultrasound deriving from its nature as a mechanical vibration is the elimination of kidney and bladder stones.

Diagnosis

Much medical diagnostic imaging is carried out with X-rays. Because of the high photon energies of the X-ray, this type of radiation is highly ionizing—that is, X-rays are readily capable of destroying molecular bonds in the body tissue through which they pass. This destruction can lead to changes in the function of the tissue involved or, in extreme cases, its annihilation.

One of the important advantages of ultrasound is that it is a mechanical vibration and is therefore a nonionizing form of energy. Thus, it is usable in many sensitive circumstances where X-rays might be damaging. Also, the resolution of X-rays is limited owing to their great penetrating ability and the slight differences between soft tissues. Ultrasound, on the other hand, gives good contrast between various types of soft tissue.

Ultrasonic scanning in medical diagnosis uses the same principle as sonar. Pulses of high-frequency ultrasound, generally above one megahertz, are created by a piezoelectric transducer and directed into the body. As the ultrasound traverses various internal organs, it encounters changes in acoustic impedance, which cause reflections. The amount and time delay of the various reflections can be analyzed to obtain information regarding the internal organs. In the B-scan mode, a linear array of transducers is used to scan a plane in the body, and the resultant data is displayed on a television screen as a two-dimensional plot. The A-scan technique uses a single transducer to scan along a line in the body, and the echoes are plotted as a function of time. This technique is used for measuring the distances or sizes of internal organs. The M-scan mode is used to record the motion of internal organs, as in the study of heart dysfunction. Greater resolution is obtained in ultrasonic imaging by using higher frequencies—i.e., shorter wavelengths. A limitation of this property of waves is that higher frequencies tend to be much more strongly absorbed.

Because it is nonionizing, ultrasound has become one of the staples of obstetric diagnosis. During the process of drawing amniotic fluid in testing for birth defects, ultrasonic imaging is used to guide the needle and thus avoid damage to the fetus or surrounding tissue. Ultrasonic imaging of the fetus can be used to determine the date of conception, to identify multiple births, and to diagnose abnormalities in the development of the fetus.

Ultrasonic Doppler techniques have become very important in diagnosing problems in blood flow. In one technique, a three-megahertz ultrasonic beam is reflected off typical oncoming arterial blood with a Doppler shift of a few kilohertz—a frequency difference that can be heard directly by a physician. Using this technique, it is possible to monitor the heartbeat of a fetus long before a stethoscope can pick up the sound. Arterial diseases such as arteriosclerosis can also be diagnosed, and the healing of arteries can be monitored following surgery. A combination of B-scan imaging and Doppler imaging, known as duplex scanning, can identify arteries and immediately measure their blood flow; this has been extensively used to diagnose heart valve defects.

Using ultrasound with frequencies up to 2,000 megahertz, which has a wavelength of 0.75 micrometre in soft tissues (as compared with a wavelength of about 0.55

micrometre for light), ultrasonic microscopes have been developed that rival light microscopes in their resolution. The distinct advantage of ultrasonic microscopes lies in their ability to distinguish various parts of a cell by their viscosity. Also, because they require no artificial contrast mediums, which kill the cells, acoustic microscopy can study actual living cells.

Therapy and surgery

Because ultrasound is a mechanical vibration and can be well focused at high frequencies, it can be used to create internal heating of localized tissue without harmful effects on nearby tissue. This technique can be employed to relieve pains in joints, particularly in the back and shoulder. Also, research is now being carried out in the treatment of certain types of cancer by local heating, since focusing intense ultrasonic waves can heat the area of a tumour while not significantly affecting surrounding tissue.

Trackless surgery—that is, surgery that does not require an incision or track from the skin to the affected area—has been developed for several conditions. Focused ultrasound has been used for the treatment of Parkinson's disease by creating brain lesions in areas that are inaccessible to traditional surgery. A common application of this technique is the destruction of kidney stones with shock waves formed by bursts of focused ultrasound. In some cases, a device called an ultrasonic lithotripter focuses the ultrasound with the help of X-ray guidance, but a more common technique for destruction of kidney stones, known as endoscopic ultrasonic disintegration, uses a small metal rod inserted through the skin to deliver ultrasound in the 22- to 30-kilohertz frequency region.

Richard E. Berg

acoustic impedance

physics

By The Editors of Encyclopaedia Britannica • Edit History

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Related Topics: sound • electrical impedance • impedance mismatch • acoustic absorption • acoustic ohm

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acoustic impedance, absorption of sound in a medium, equal to the ratio of the sound pressure at a boundary surface to the sound flux (flow velocity of the particles or volume velocity, times area) through the surface. In analogy to electrical circuit theory, pressure corresponds to voltage, volume velocity to current, and acoustic impedance is expressed as a complex number, the real part being referred to as the resistance and the imaginary part the reactance.

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timbre

sound

Alternate titles: quality of sound, sound quality, timber, tone colour

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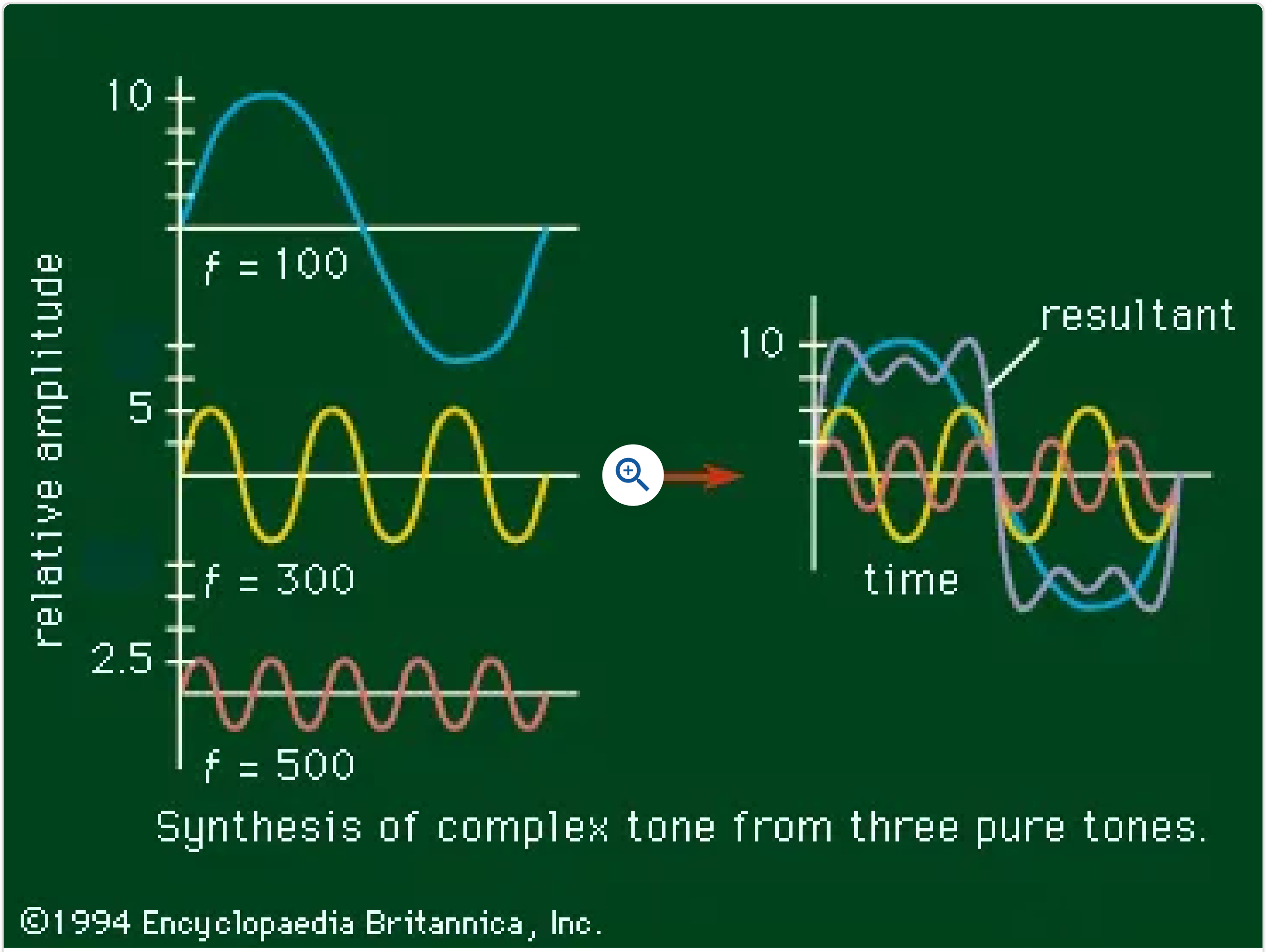

timbre

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timbre, also called **timber**, quality of auditory sensations produced by the tone of a sound wave.

The timbre of a sound depends on its wave form, which varies with the number of overtones, or harmonics, that are present, their frequencies, and their relative intensities. The illustration shows the wave form that results when pure tones of frequencies 100, 300, and 500 hertz (cycles per second) and relative amplitudes of 10, 5, and 2.5 are synthesized into a complex tone. At the right is the resultant of the three

sine curves when their ordinates are added point by point along the time scale. In equation form, the amplitude y of the wave form at any time t would be represented by $y = 10 \sin (2\pi\, 100t) + 5 \sin (2\pi\, 300t) + 2.5 \sin (2\pi\, 500t)$. The timbre of this form would be recognizable and different from others having a fundamental tone of 100 hertz but a different harmonic amplitude.

In music timbre is the characteristic tone colour of an instrument or voice, arising from reinforcement by individual singers or instruments of different harmonics, or overtones (*q.v.*), of a fundamental pitch. Extremely nasal timbre thus stresses different overtones than mellow timbre. The timbre of the tuning fork and of the stopped diapason organ pipe is clear and pure because the sound they produce is almost without overtones. Timbre is determined by an instrument's shape (*e.g.,* the conical or cylindrical pipe of a wind instrument), by the frequency range within which the instrument can produce overtones, and by the envelope of the instrument's sound. The timbre of spoken vowels or of a singing voice is modified by constricting or opening various parts of the vocal tract, such as the lips, tongue, or throat.

> *This article was most recently revised and updated by William L. Hosch.*

sound intensity

physics

Alternate titles: acoustic intensity

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Related Topics: Fletcher-Munson curve • fullness • clarity • dynamic range • frequency just noticeable difference

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sound intensity, amount of energy flowing per unit time through a unit area that is perpendicular to the direction in which the sound waves are travelling. Sound intensity may be measured in units of energy or work—*e.g.*, microjoules (10^{-6} joule) per second per square centimetre—or in units of power, as microwatts (10^{-6} watt) per square centimetre. Unlike loudness, sound intensity is objective and can be measured by auditory equipment independent of an observer's hearing.

The intensity of one sound can be compared to that of another of the same frequency by taking the ratio of their powers. When this ratio is 10, the difference in intensity of the sounds is said to be one bel, a unit named in honour of the United States inventor Alexander Graham Bell. Accordingly, the relative intensities of two sounds in bels is equal to the logarithm of the intensity ratio—*i.e.*, if I is the intensity of one sound and I_0 is that of another, then the intensity ratio B in bels is $B = \log_{10} (I/I_0)$. The unit in general use is the decibel (abbreviated db), equal to 0.1 bel. Thus the equation for relative intensities b in decibels may be written $b = 10 \log_{10} (I/I_0)$. It may be calculated from this equation that one decibel corresponds to a 26 percent change in intensity. If I_0 is taken as a reference standard intensity equal to 10^{-16} watt per square centimetre, the intensity of the faintest sound that can be heard, then the intensity, or level, of any sound can be measured in decibels. Thus speech of intensity 10^{-12} watt per square centimetre has a sound level of $b = 10 \log_{10} (10^{-12}/10^{-16}) = 40$ decibels.

speed of sound

physics

By The Editors of Encyclopaedia Britannica • Edit History

Key People: Charles-François Sturm • August Kundt

Related Topics: sound

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speed of sound, speed at which sound waves propagate through different materials. In particular, for dry air at a temperature of 0 °C (32 °F), the modern value for the speed of sound is 331.29 metres (1,086.9 feet) per second. The speed of sound in liquid water at 8 °C (46 °F) is about 1,439 metres (4,721 feet) per second.

This article was most recently revised and updated by Adam Augustyn.

loudness

acoustics

Alternate titles: SPL, sound pressure level, volume

Related Topics: sound • sound intensity • phon • sone

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loudness, in acoustics, attribute of sound that determines the intensity of auditory sensation produced. The loudness of sound as perceived by human ears is roughly proportional to the logarithm of sound intensity: when the intensity is very small, the sound is not audible; when it is too great, it becomes painful and dangerous to the ear. The sound intensity that the ear can tolerate is approximately 10^{12} times greater than the amount that is just perceptible. This range varies from person to person and with the frequency of the sound.

A unit of loudness, called the phon, has been established. The number of phons of any given sound is equal to the number of decibels of a pure 1,000-hertz tone judged by the listener to be equally loud. The decibel scale is objective in that the intensity is defined physically and any intensity can be compared directly with the physically defined reference point. The phon scale is partially subjective in that the judgment of a listener is involved in comparing any arbitrary sound with the physically defined reference in order to establish its loudness in phons. The average result from a large number of people then establishes the definition of equal loudness curves (i.e., curves that show the varying absolute intensities of a pure tone that has the same loudness to the ear at various frequencies).

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The human ear typically serves to distinguish between about 1,500 levels of pitch. For **loudness**, differential-threshold...

A third, more-subjective loudness scale involves listener judgment as to what constitutes "doubling" of the loudness of a sound. A tone having a loudness of 40 p[...]s is defined as having a subjective loudness of one sone; a tone judged by the listener to be "twice as loud" would have a loudness of two sones, three times as loud would be three sones, and so forth. As in the case of the definition of the phon, the average values from observations by a large number of people would then define the details of the scale for purposes of classifying and measuring sound levels.

Subjective scales were developed because they tend to be more useful than a totally objective scale in describing how the ear works. In general, the physical sciences and engineering use more-objective scales such as the decibel, while measurements in biological and medical fields tend to use the more-subjective scales.

> *This article was most recently revised and updated by William L. Hosch.*

Doppler effect

physics

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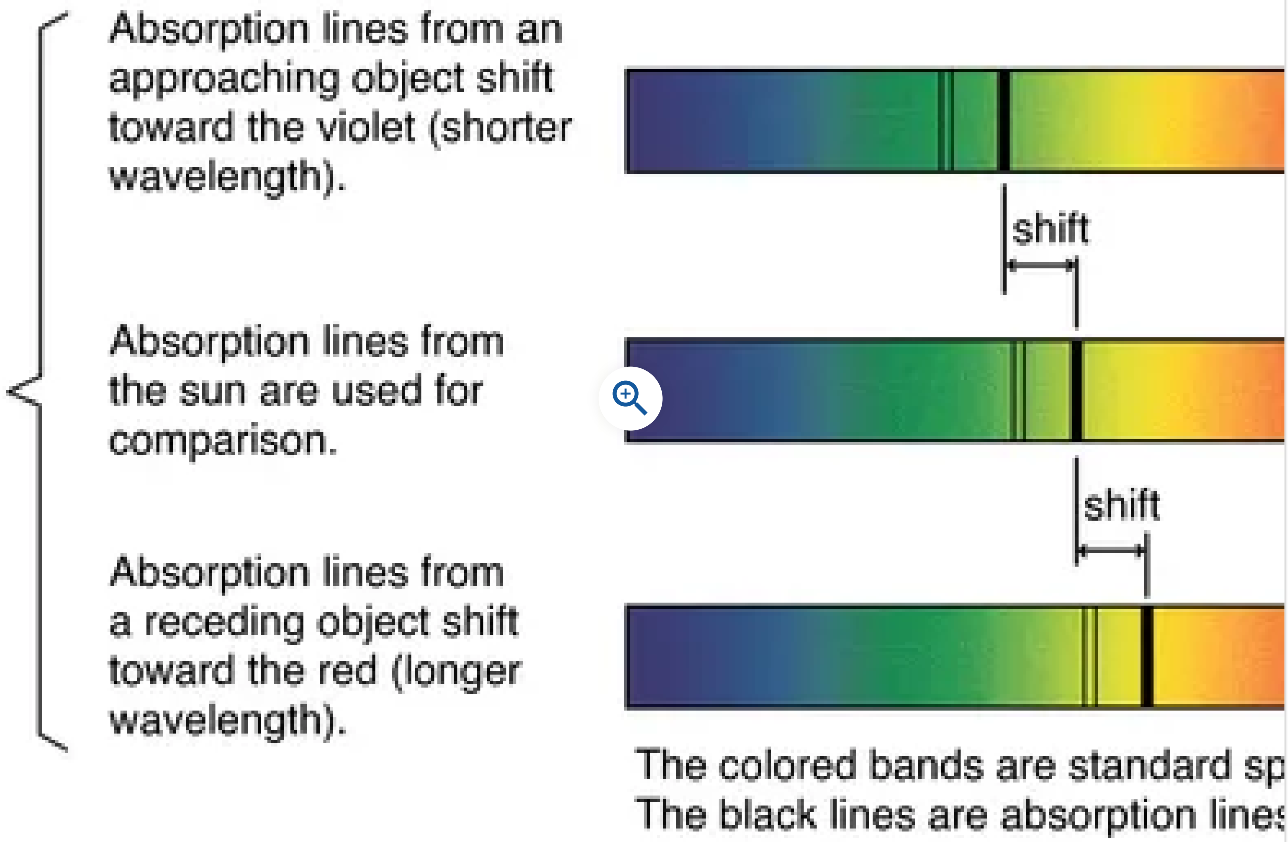

Doppler shift

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Key People: Christian Doppler

Related Topics: wave • Doppler frequency shift

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Doppler effect, the apparent difference between the frequency at which sound or light waves leave a source and that at which they reach an observer, caused by relative motion of the observer and the wave source. This phenomenon is used in astronom measurements, in Mössbauer effect studies, and in radar and modern navigation. I as first described (1842) by Austrian physicist Christian Doppler.

The following is an example of the Doppler effect: as one approaches a blowing horn, the perceived pitch is higher until the horn is reached and then becomes lower as the horn is passed. Similarly, the light from a star, observed from the Earth, shifts toward the red end of the spectrum (lower frequency or longer wavelength) if the Earth and star are receding from each other and toward the violet (higher frequency or shorter wavelength) if they are approaching each other. The Doppler effect is used in studying the motion of stars and to search for double stars and is an integral part of modern theories of the universe. *See also* red shift.

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This article was most recently revised and updated by Adam Augustyn.