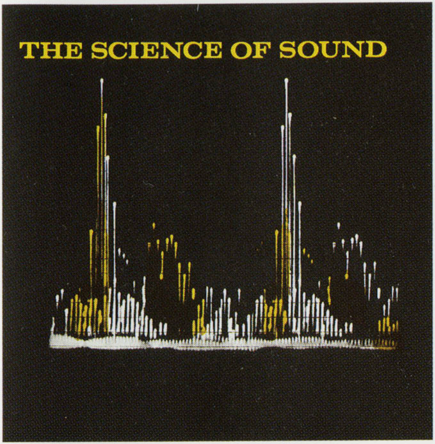
Smithsonian/Folkways Records
Office of Folklife Programs,
955 L'Enfant Plaza, Suite 2600
Smithsonian Institution, Washington, DC 20560
Smithsonian/Folkways C-SF 45038
℗© 1990 Smithsonian/Folkways Records
Nationally distributed by Rounder Records
One Camp Street, Cambridge, MA 02140 USA
Printed in Canada.

0 93074 50384 3

SMITHSONIAN/ FOLKWAYS

THE SCIENCE OF SOUND




# THE SCIENCE OF SOUND

**SIDE A:** HOW WE HEAR • FREQUENCY • PITCH • INTENSITY • THE DOPPLER EFFECT

**SIDE B:** ECHO AND REVERBERATION • DELAY DISTORTION • FUNDAMENTALS AND OVERTONES • QUALITY • FILTERED MUSIC AND SPEECH

*Additional notes enclosed.*
*Originally issued in 1960 as Folkways Records FX 6136*

C-SF 45038

# The Science of Sound

*Originally issued in 1960 as Folkways Records FX 6136*

*Copyright 1958, 1959 Bell Telephone Laboratories*

*Revised September 1959*

THE SCIENCE OF SOUND

These recordings describe and demonstrate various phenomena of sound as an aid to understanding how sound is put to work for the benefit and pleasure of man.

Produced by
**Bell Telephone Laboratories, Inc.**

Distributed by
**Smithsonian/Folkways Records**
**Office of Folklife Programs**
**955 L'Enfant Plaza, 2600**
**Smithsonian Institution**
**Washington, D.C. 20560**



11. **How We Hear**

*Narrator:* One of nature's greatest wonders is the ability of the human ear to distinguish among the millions of sounds around us. Listen:

*Sound:* Gun shot, trumpet fanfare, nightingale song, fog horn.

*Narrator:* Recognize those sounds? Surely. Each sound has a distinctive pitch, loudness, and quality. You will hear later how these characteristics are determined by the frequency, intensity, and form of sound waves in the air ... waves which your ears pick up and analyze. But first, let's investigate what causes sound.

The source of every sound is a vibrating body. Take, for example, a drum:

*Sound:* A drum roll.

*Narrator:* The vibrating drumhead pushes against the air every time it moves outward. It shoves the air molecules against other air molecules, compressing the air. This compression moves away, as the drumhead moves inward, leaving a region where the air is slightly thinner than normal. On the next outward push of the drumhead another region of compression is formed and started on its way outward. We call these pulses of compressions and rarefactions, "pressure waves." As long as the drumhead vibrates, pressure waves will be generated and sent through the air. When waves of sufficient strength reach your ears, they push on your eardrums, setting them to vibrating, too. It's these vibrations which your brain interprets as sound.

2. **Frequency**

*Narrator:* Despite your ears' sensitivity to minute changes in air pressure, it is only when the changes are repeated in rapid succession, at least twenty times a second, that your brain perceives them as sound. On the other hand, vibrations that occur more frequently than about 20,000 times a second, cannot be heard by the average human ear. This audible frequency range varies considerably with different people and different ages. Generally, as a person grows older the delicate membranes of the ears grow stiff. Then it becomes more difficult to hear the very high frequencies. Listen as we produce a series of vibrations starting at thirty cycles per second and gradually increase the frequency until it is 15,000 cycles per second.

*Sound:* Sweep tone with narrator's voice announcing frequencies: 30 to 15,000 cps.

*Narrator:* Your ears are most sensitive to vibrations in the frequency range between about 1,000 and 4,000 cps. Changes in atmospheric pressure about one part in ten billion, if repeated about 3,500 times a second, will send audible sound to your brain. At this minute pressure variation, the eardrum moves less than one hundred thousandths the wave length of light, one tenth the diameter of the smallest atom. If your ears were very much more sensitive, you would probably be able to hear the motion of the molecules of the air as they vibrated with thermal energy.

3. **Pitch**

*Narrator:* Some sounds appear higher or lower to our ears than others. The term we use to describe this relative characteristic is pitch. Pitch depends chiefly on the number of times each second that the air pressure fluctuation on your ear is repeated. Listen as we cause a stretched string to vibrate 440 times a second.

*Sound:* Violin sounding A440.

*Narrator:* Here is a human voice with vocal cords vibrating at the same frequency.

*Sound:* Singer A440.

*Narrator:* Now, listen as we hold a piece of cardboard against a revolving gear. The gear teeth are striking the cardboard 440 times a second.

*Sound:* Cardboard vibrating 440 cps as gear teeth strike it.

*Narrator:* Here are these same sounds again. Notice that the pitch of each sound is the same although the sources are different.

*Sound:* Repeat three sounds consecutively.

*Narrator:* The pitch is the same because the vibrations striking your ears are repeated the same number of times per second. Now, if we double the frequency, to 880 times a second, the pitch sounds higher.

*Sound:* Repeat three sound consecutively at 880.

*Narrator:* But the pitch of an 880 cycle tone does not sound exactly twice as high as one at 440. Of course, some persons have been conditioned by their familiarity with musical intervals, such as octaves, to think that doubling or cutting frequency in half is the same as doubling or cutting pitch in half. However, psychological tests have shown that pitch and frequency of pure tones do not have a simple one-to-one relationship. For example, many persons would judge that this tone...

*Sound:* Pure tone at 200 cps

*Narrator:* ...is one-half the pitch of this tone...

*Sound:* Pure tone at 500 cps

*Narrator:* Although the pitch may sound one half, the frequency is not. The frequency of the higher tone is 500; the lower tone is 200 cycles per second. Apparently we cannot depend on our ears to determine relative frequency; nor can we use frequency numbers to designate relative pitch. The two are not linearly proportional. Science has, however, worked out a subjective pitch scale for pure tones. The commonly chosen reference frequency is one thousand cycles per second.

*Sound:* Pure tone 1,000 cps

*Narrator:* The tone you heard is designated to have a pitch of 1,000 subjective units, sometimes called m-e-ls, from the melody. A tone with pitch twice as high is designated 2,000 mels.

*Sound:* (Pure tone of 3,120 cps)

*Narrator:* Actually its frequency is 3,120 cycles per second. A tone which sounds to our ears three times as high as the reference is said to have a pitch three times as high, 3,000 mels.

*Sound:* (Pure tone at 9,000 cops)

*Narrator:* Actually its frequency is 9,000 cycles per second. As you can see, a mel scale provides an objective means for comparing pitches of various pure tones.

*Narrator:* Although pitch depends chiefly on frequency, it also varies slight with the loudness of a sound. Listen as we play two pure tones, one softly, then one loudly.

*Sound:* (200 cops tones, then same tone 20 db louder)

*Narrator:* Which tone has the lower pitch?

*Sound:* (Repeat three times)

*Narrator:* Actually both tones have the same frequency, 200 cycles per second, but the louder tone sounds a little lower pitched to most persons. In fact, experiments have shown that in general, low frequency tones seem lower pitched when played very loudly. On the other hand, high frequency tones seem higher pitched, when played very loudly. To be sure the difference in pitch is very slight; nevertheless it is discernible to some persons.

4. **Intensity**

*Narrator:* Sound vibrations may be generated by many different sources. Whether they originate in the orifice of a modern jet engine...

*Sound:* Jet engine

*Narrator:* ...or the throat of a 400 year-old tortoise calling its mate...

*Sound:* Tortoise

*Narrator:* ...or an electrical buzzer...

*Sound:* Square wave oscillator

*Narrator:* The vibrations have essentially the same effect: they fluctuate the pressure of the atmosphere on our eardrums, causing them to move rapidly back and forth. This pressure variation is measured in terms of a unit called a microbar, which is one dyne per square centimeter. We can decrease the pressure variation, and thereby make the sound less intense, by decreasing the amplitude of the source's vibrations. Listen as we decrease the power of the buzzer.

*Sound:* Decrease power of buzzer

*Narrator:* If we increase the power, the sound intensity will increase.

*Sound:* Increase power of buzzer

*Narrator:* What we are doing is varying the amount of sound energy which stimulates your ear each instant. This can be accomplished another way, too: by varying the distance the pressure waves have to travel to your ear. If we move our microphone away from the source, the intensity will decrease.

*Sound:* (Move microphone away from oscillator)

*Narrator:* Intensity may also vary according to the characteristics of the room in which you are listening. If we play a pure tone of constant intensity, you can, by moving your head slightly to the right and left, make the sound seem less or more intense. Try it:

*Sound:* (Pure 1,000 cops tone at constant intensity and frequency)

*Narrator:* This phenomenon occurs because sound waves that have been reflected from the walls interfere with sound waves that are coming from the loudspeaker. They combine to produce pressure waves that seem to stand still, thus forming areas of high and low intensity in the room. However, ideally, in free space where there are no reflecting walls, the energy at your ear will very inversely as the square of your ear's distance from the sound source. Listen:

*Sound:* (I am now speaking to you from a distance of three feet from the microphone)

(I am now speaking to you from distance of one foot from the microphone.)

*Narrator:* You see, by making a sound travel three times as far, we have decreased its intensity to about one ninth. Listen again:

*Sound:* I am now one foot from the microphone

I am now three feet from the microphone

*Narrator:* To sum up, the intensity of a sound depends chiefly on the energy of the source and its distance from your ear. Thus intensity may be measured in energy units (ergs per square centimeter) or converting to power units, in watts per square centimeter. For most purposes, however, it is more useful to measure the intensity of sound on a comparative scale. It's customary to express this relative intensity in a unit of measure called a bel, b-e-l, named after Alexander Graham Bell. Listen to these two sounds; they have an intensity difference of one tenth of a bel...one decibel:

*Sound:* (Two tones; one db apart; loud tone first)

*Narrator:* As you heard, a difference of one decibel is so small as to be barely perceptible. If one tone has one fourth the power — that's one half the sound pressure — of another, it is said to be six decibels less intense.

*Sound:* Two tones 6 db apart

*Narrator:* If one tone has one sixteenth the power or one fourth the sound pressure of another it is said to be 12 decibels lower.

*Sound:* Two tones 12 db apart

*Narrator:* If one tone had one hundredth the power, or one tenth the sound pressure of another, it is said to be 20 decibels less intense.

*Sound:* Two tones 20 db apart

*Narrator:* As you can see, the decibel scale is logarithmic and the decibel expresses a relative quantity; the ratio between acoustic powers. When it is desired to express the intensity of only one sound, a scale is used in which the reference intensity for zero decibels is ten to the minus sixteen watts per square centimeter. A person with very good hearing in an extremely quiet location can just barely hear a 1,000 cycle tone at this zero level of intensity. The corresponding pressure variation is only about point zero zero two dynes per square centimeter. That's less than one billionth normal atmospheric pressure; you see then: your ear is extremely sensitive.

So that you can become familiar with the decibel scale, listen as we vary the intensity of my voice.

Now I'm speaking to you in a voice with an intensity about six decibels lower than normal.

Now my voice has an intensity level about ten decibels lower than normal conversation.

Twenty decibels less intensity sounds like this.

Thirty decibels less intensity sounds like this.

### 5. The Doppler Effect

*Narrator:* Did you ever notice how the pitch of a train whistle suddenly lowers as the train rushes past you?

*Sound:* Train-whistle dopplering as it rushes past

*Narrator:* These are two examples of a phenomenon called the Doppler Effect, in honor of the Austrian physicist Christian Doppler, who first explained it in 1842. What happens is this: When you are on the moving train approaching the clanging bell, you are actually meeting the sound waves before they would ordinarily reach you. So more sound vibrations impinge on your ear each second than if you were not moving. Consequently your ear drum is made to vibrate faster, giving you the impression of higher pitch when you are moving away from the bell — in effect, running away from the sound waves — fewer vibrations reach you during any interval, and the pitch that you hear is lower than it would be if you were not moving. Listen again!

*Sound:* (Repeat bell)

*Narrator:* In the case where you are stationary and the train whistle moving, the sound waves ahead of the whistle are crowded together and made shorter, while the waves behind the whistle are spread out and made longer. This change in wave length does not change the speed with which the waves travel, but it does change the number of waves that hit your ear in a second. So as the train approaches you, more vibrations per second reach your ear and you hear a higher pitch than you would if the whistle wasn't moving, and as the train goes away, fewer vibrations per second reach your ear and the pitch you hear is lower than it would be if the whistle wasn't moving.

*Sound:* (Repeat train whistle)

*Narrator:* Here is another example of the Doppler Effect: racing cars.

*Sound:* (Racing cars at Watkins Glen)

*Narrator:* The roar of the first car you heard changed pitch almost a musical fifth as it passed close by. The slower cars, bringing up the rear, changed pitch about a minor third. Obviously, the Doppler Effect can be used to measure the speed of a sound source. The greater the change in pitch, the faster the source is moving.

End Side A

Side B

### 6. Echo and Reverberation

*Narrator:* The old proverb "Empty vessels make the most noise" is an ancient observation of the phenomena of echo and reverberation. When sound waves impinge on hard surfaces, they are reflected. Often we may hear the reflected waves or echos a short time after we hear the original source of sound. Like this:

*Sound:* (Voice: "Hello")
(Echo: Hello)
(Voice: "Hello")
(Echo: Hello)
(Voice: "Are you there , echo?)
(Echo: Are you there, echo?")

*Narrator:* The time lag between the original sound and the echo depends upon the distance between the sound source and reflecting surface. Here is how speech sounds accompanied by echo from reflecting surfaces at various distances:

*Sound:* (500 feet. You are now listening to speech accompanied by an echo from a reflecting surface 500 feet away.)

(50 feet. You are now listening to speech accompanied by an echo from a reflecting surface 50 feet away.)

*Narrator:* The echo sounds fainter than the source because the original sound energy is spread out and lost traveling to and from the surface. It's quite possible for echos to have echos. Large auditoriums or halls — like empty barrels — often have more than one reflecting surface. Sounds may bounce from wall to wall, that is reverberate, like this:

*Sound:* (Hello)
(Echo — Hello, hello, hello)
(Hello, ladies and gentlemen
(Echo — Hello, ladies and gentle men, Hello, ladies and gentlemen)

*Narrator:* When echos are numerous and overlapping, they may merge into a babel of noise, making normal speech difficult to understand.

*Sound:* (Hello, ladies and gentlemen. I am speaking in a hall that reverberates with many echos.)

*Narrator:* Biblical legends tell us that inside the famous Tower of Babel even the words of learned men sounded like nonsense. This could have been a case of poor acoustical design. The Tower was made of sun-baked bricks and tiles which reflected sounds from one wall to another, setting up reverberations that scrambled speech until it was unintelligible.

*Sound:* The Tower of Babel may have sounded like this.

*Narrator:* Reverberation is responsible for the slowness with which sound fades away. It may be controlled by carefully selecting wall materials and coverings to absorb the sound energy.

The time it takes a sound to diminish sixty decibels — or two one millionths of its original intensity — is called reverberation time. We use reverberation time as a measure of the acoustic characteristics of a hall. Listen: I am now speaking in a room that has a reverberation of several seconds. Rooms which have a reverberation time of several seconds or more may be suitable for some forms of music but generally they are undesirable for speech.

Reverberations fade away more rapidly in small rooms because it takes less time for the sounds to bounce back and forth between the walls and be absorbed.

I am now speaking to you in a room that has a reverberation time of only a few tenths of a second.

Rooms which are moderately reverberant, that is having reverberation times of about 1 second for a small auditorium and about two seconds for a large auditorium — are usually pleasant for both speakers and listeners.

I am now speaking in an auditorium that has a reverberation time of about one second. This auditorium has been specifically designed to give satisfactory acoustics no matter where the listener is sitting.

As you can hear, speakers rely on some reverberation to give resonance and sustenance to their voices. If you've even sung in a bath tub you will understand how reverberation may make a voice sound better than it really is.

7. **Delay Distortion**

*Narrator:* When speech or music is transmitted along communication lines, sometimes the various frequencies may not travel with equal velocities. They arrive at the receiving end with a type of distortion known as delay distortion. This sounds similar to the following demonstration in which frequencies above 3,000 cycles are delayed one tenth of a second behind frequencies lower than 3,000 cycles:

*Sound:* The upper frequencies of this speech are arriving one tenth of a second later than the lower frequencies.

*Narrator:* That much delay distortion rarely occurs. Here is how a delay of seven hundredths of a second sounds:

*Sound:* The upper frequencies of this speech are arriving at seven hundredths of a second later than the lower frequencies.

*Narrator:* Now, listen to the effect of a delay of thirty-five thousandths of a second.

*Sound:* The upper frequencies of this speech are arriving thirty-five thousandths of a second later than the lower frequencies.

*Narrator:* In transmitting music, the distortion that results from small delays or phase shift is usually not noticeable. This is because the various sounds are sustained longer in music than in speech.

Listen as we delay the upper frequencies of music seven hundredths of a second.

*Sound:* Music selection — trumpet fanfare
(phase delay 0.07 seconds)

*Narrator:* On the other hand, longer delays are quite noticeable in music. They give an echo effect. Listen as we play the same selection so that frequencies above 3,000 cycles are delayed three tenths of a second.

*Sound:* Same music (delay 0.3 second)

8. **Fundamentals and Overtones**

*Sound:* Tuning fork

*Narrator:* That was the sound of a tuning fork. It is practically a pure tone; that is, the vibrations are of only one frequency and they have a smooth, regular wave form.

Sounds from other sources, such as musical instruments, the human voice, or noises, have wave forms that are less smooth and more complicated. For instance, if we pluck a stretched string, it will vibrate not only as a whole, but also, at the same time, in parts... in segments that are a half, a third, a fourth, and so on, of the whole string. These segments vibrate at two, three, four, and so on, times the frequency of the entire string. Listen:

*Sound:* Pluck a stretched string 200 cps

*Narrator:* The lowest frequency present in a complex sound is called the fundamental; frequencies higher than the fundamental are called overtone frequencies. The frequencies of a musical sound are simple multiples of the fundamental and are called harmonics. For instance, the fundamental frequency of the musical tone you just heard was 200 cycles per second.

*Sound: (Pure tone at 200)*

*Narrator:* The first overtone, sometimes called the second harmonic, was 400 cycles per second.

*Sound:* (Pure tone at 400)

*Narrator:* The second overtone, or third harmonic, was 600.

*Sound:* (Pure tone at 600)

*Narrator:* The third overtone or fourth harmonic was 800 cycles per second.

*Sound:* (Pure tone at 800)

Narrator: ... and so on at intervals of 200 cycles per second.

*Sound:* (Pure tones 1000, 1200, 1400, 1600, 1800, 2000)

*Narrator:* Some sounds have thirty or forty overtones in the audible frequency range of the human ear. For many sounds the pitch of the entire tone is the same as that of the fundamental, but the overtones add distinctive qualities. Listen as we play a fundamental tone and then add its overtones one by one:

*Sound:* (Fundamental, then overtones one by one)

*Narrator: Did you notice, a fundamental* with only a few overtones sounds empty and uninteresting. A fundamental with many overtones sounds full and rich. It's the relative number, pitch and intensity of a sound's overtones which determine its quality.

9. **Quality**

*Narrator:* All sounds have characteristic qualities which your ear learns to recognize. Listen:

*Sound:* (We have consecutively a factory whistle, a piano and a human voice, all at the same pitch)

*Narrator:* We're sure you had no difficulty distinguishing these sounds — a factory whistle, a soprano and a piano — even though they all had the same pitch and intensity. That's because the distinguishing characteristics of a sound, by which we recognize an instrument of voice, is due largely to the proportions of the overtones in the sound, as well as its pitch and intensity. Listen as we play the same sounds, only this time we will filter out the overtones and allow only the fundamental notes to reach your ears.

*Sound:* Factory whistle, soprano, piano, with overtones eliminated

*Narrator:* The slight difference in the sounds is due to their dynamic characteristics such as attack and decay and vibrato, but the tonal qualities are almost indistinguishable. Listen again.

*Sound:* (Repeat)

*Narrator:* Now we'll allow you to hear the fundamental and the first overtone. We will filter out all the other overtones. Notice just the beginnings of a difference in tonal quality.

*Sound:* First overtone

*Narrator:* Now we'll allow the fundamental and first four overtones to reach your ear. Listen how the overtones help distinguish a sound.

*Sound:* First four overtones

*Narrator:* If we cut out all filters, permitting all overtones to be heard, the sounds will again sound normal and distinctive.

*Sound:* All overtones

10. **Filtered Music and Speech**

*Narrator:* If for any reason your ears are prevented from vibrating throughout the entire normal range of frequencies, either because they have some physical defect, or because the phonograph equipment is of low fidelity, sound quality will be quite different from normal. Listen to the orchestra as it might have sounded on an early phonograph record.

*Sound:* (Greig's Wedding Day at Troldhaugen, band pass between 375 and 2,000)

*Narrator:* By means of filters we eliminated high and low frequencies and allowed only those frequencies between about 375 and 2,000 cycles per second to be heard. Now listen to the improved tonal quality when all frequencies reach your ears.

*Sound:* (Same music, no filters)

*Narrator:* If we cut out only the low frequencies, all those below 375 cycles per second, the music sounds like this.

*Sound:* Same music filtered

*Narrator:* Now we'll cut out all frequencies below 2,000 and let only the higher frequencies get through tc your ears.

*Sound:* Same music filtered

*Narrator:* If we eliminate high frequencies, all those above 4,000, and let only the lower frequencies through, the music sounds like this.

*Sound:* Same music filtered

*Narrator:* Now let's cut out some more high frequencies. All those above 2,000 cycles are prevented from reaching your ears.

*Sound:* Same music filtered

*Narrator:* Here again is how the orchestra sounds with the full range of frequencies.

*Sound:* Same music, no filters

*Narrator:* Speech, too, sounds different if some of the frequencies are prevented from reaching the ear. My voice is now coming through with a normal range of frequencies.

(Pause)

Now, my voice sounds as it does because we have filtered out all frequencies below 375 cycles per second. Only those frequencies above 375 cycles per second are reaching your ear.

(Pause)

If we allow only those frequencies above 2,000 cycles per second to reach your ear, my voice sounds like this. You are being prevented from hearing frequencies below 2,000 cycles per second.

(Pause)

And here's how my voice sounds with all frequencies above 2,000 cycles eliminated from it.

You are now hearing only those frequencies below 2,000 cycles per second.

(Pause)

Now we have filtered out all frequencies above 375 cycles per second.

You are now hearing speech made up of only those frequencies below 375 cycles per second.

(Pause)

*Narrator:* Here's how my voice sounds if we eliminate both very high and very low frequencies.

If we allow only those frequencies between 375 and 2,000 cycles to be heard, my voice will sound like this.

(Pause)

*Narrator:* As you can hear, there is quite a difference in the quality of the filtered voice and the normal voice that you are now hearing.

Smithsonian Folkways Records

Folkways Records was one of the largest independent record companies of the mid-twentieth century. Founded by Moses Asch in 1947 and run as an independent company until its sale in 1987, Folkways was dedicated to making the world of sound available to the public. Nearly 2,200 titles were issued, including a great variety of American folk and traditional music, children's songs, world music, literature, poetry, stories, documentaries, language instruction and science and nature sounds.

The Smithsonian acquired Folkways in order to ensure that the sounds and the genius of the artists would continue to be available to future generations. Every title is being kept in print and new recordings are being issued. Administered by the Smithsonian's Office of Folklife Programs, Folkways Records is one of the ways the Office supports cultural conservation and continuity, integrity, and equity for traditional artists and cultures.

Several hundred Folkways recordings are distributed by Rounder Records. The rest are available on cassette by mail order from the Smithsonian Institution. For information and catalogs telephone 202/287-3262 or write Folkways, Office of Folklife Programs, 955 L'Enfant Plaza, Suite 2600, Smithsonian Institution, Washington, D.C. 20560, U.S.A.

*This insert accompanies*
*Smithsonian/Folkways SF-45038*