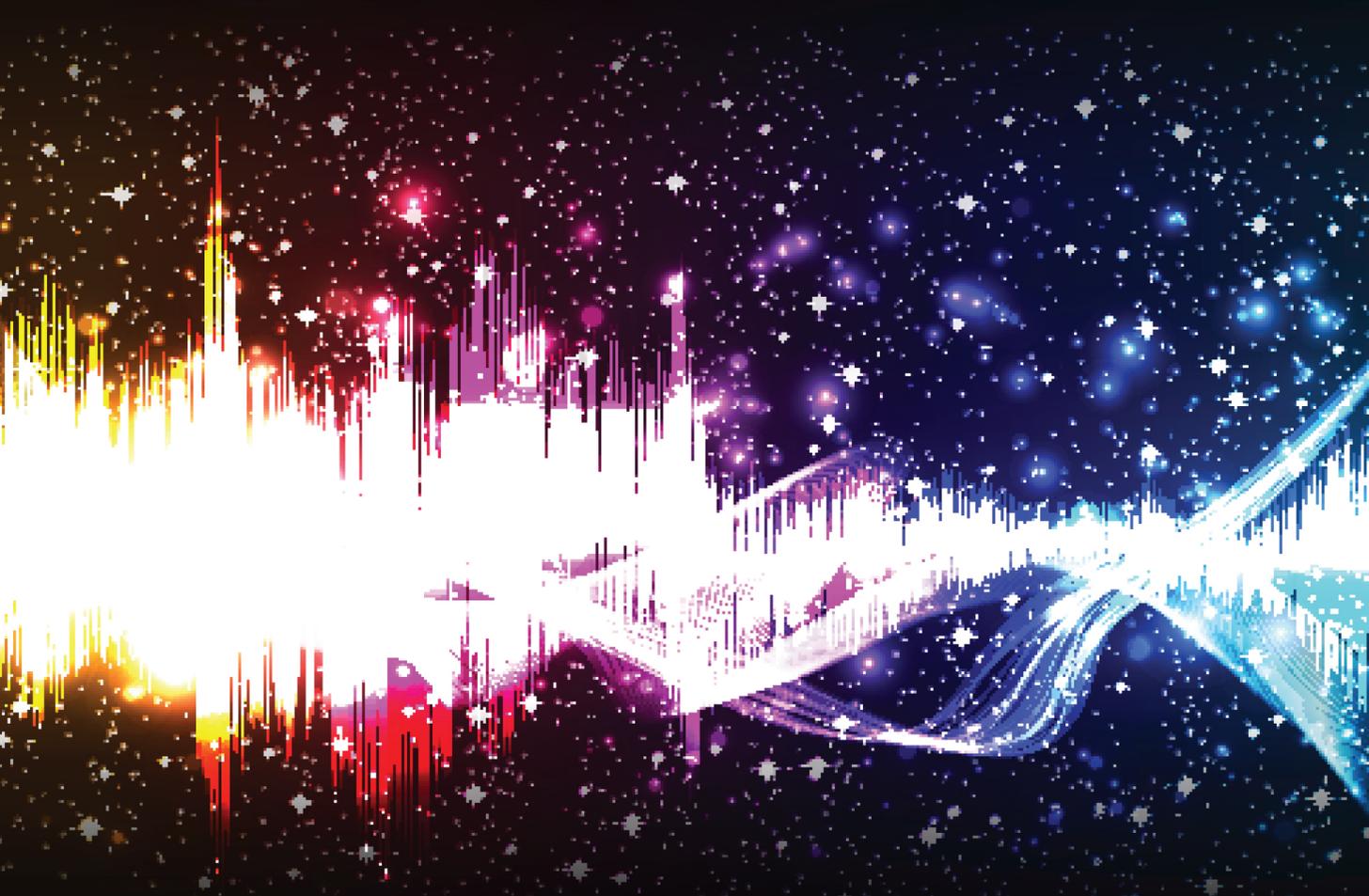


The FIRST BOOK of **SOUND**



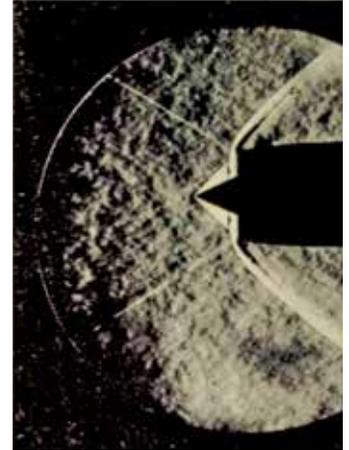
David C. Knight



Woods Hole Oceanographic Institution

Underwater camera with acoustic view-finder.

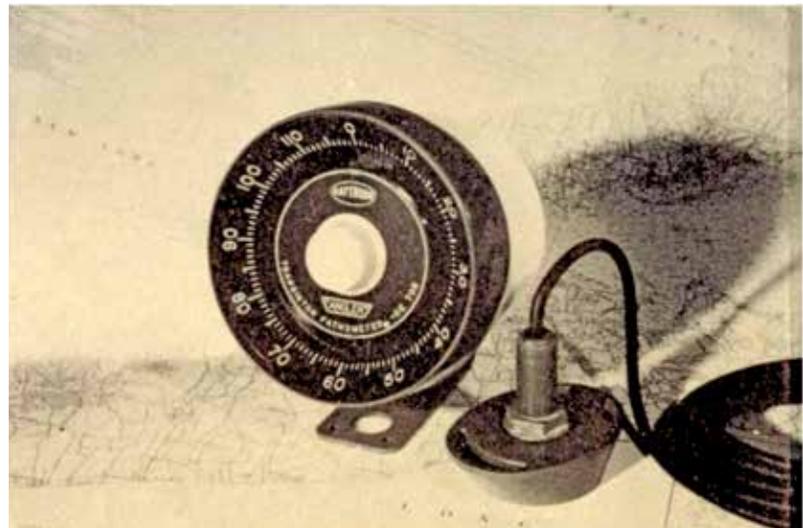
NACA Photo



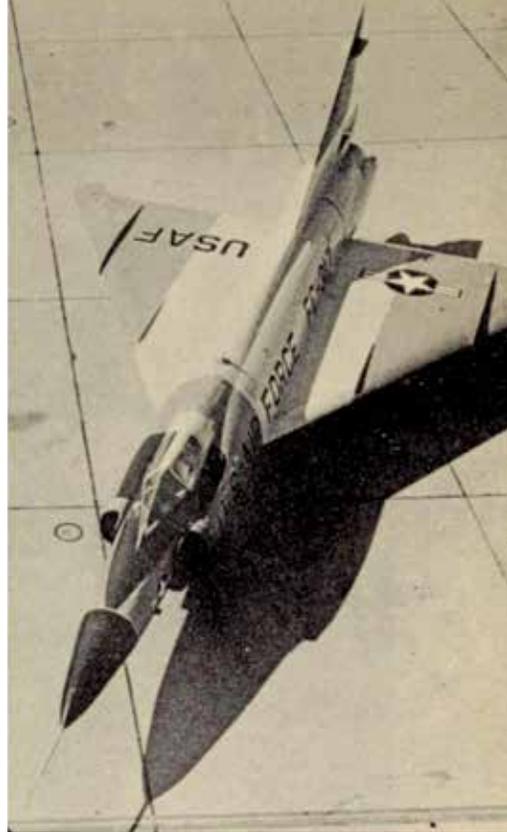
Supersonic shock waves arc air inlet of ram-jet engine.

Raytheon Company

A portable fathometer with transducer.

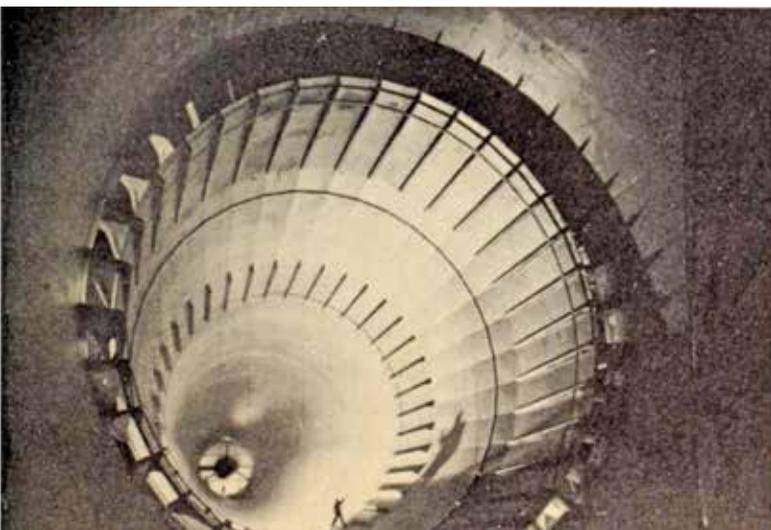


The F-102A Delta Dagger, a supersonic aircraft.



Convair

NACA Photo



Supersonic wind tunnel.



Solid sound. A plastic "loaf" model of the word "nine." This is a new technique enabling scientists to see sound as well as hear it. The model is constructed from "slices" of sound spectrograms recorded on special paper according to three dimensions – time, frequency and energy.

The FIRST BOOK of
SOUND

A Basic Guide to the Science of Acoustics

By David C. Knight

This edition published 2025
by Living Book Press

ISBN: 978-1-76153-432-4 (hardcover)
978-1-76153-433-1 (softcover)

This edition Copyright © 2025 Living Book Press

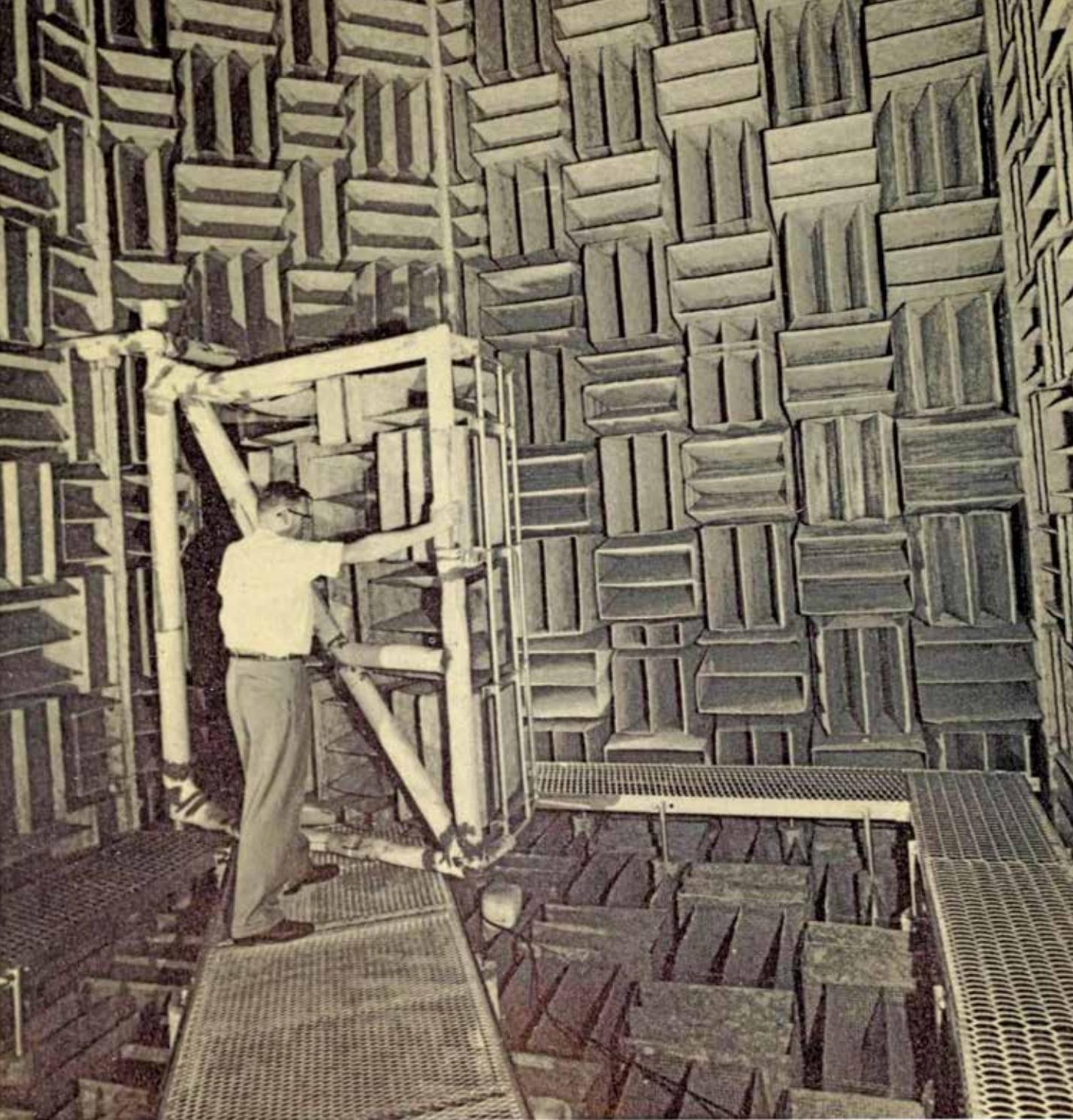
All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any other form or means – electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the copyright owner and the publisher or as provided by Australian law.



A catalogue record for this
book is available from the
National Library of Australia

Contents

WHAT WE MEAN BY SOUND	11
HOW SOUND COMES TO US	12
WHAT CAUSES SOUND?	15
WHAT ARE THE DIFFERENT KINDS OF VIBRATIONS	16
THE HUMAN EAR AND HOW IT WORKS	18
YOUR VOICE AND HOW IT WORKS	20
SOUND WAVES - WHAT THEY ARE AND HOW THEY ACT	21
HOW SOUND WAVES TRANSMIT THEIR ENERGY	21
WHAT KIND OF WAVES ARE SOUND WAVES?	24
THE SPEED OF SOUND	26
HOW TEMPERATURE AFFECTS THE SPEED OF SOUND	30
THE THREE CHARACTERISTICS OF SOUND	32
PITCH	32
LOUDNESS	36
QUALITY	39
HARMONY AND MUSICAL INSTRUMENTS	44
REFLECTED SOUND - ECHOES	46
MULTIPLE ECHOES	52
ACOUSTICS - REVERBERATION AND INTERFERENCE	54
“ZONES OF SILENCE” – HOW SOUND IS REFRACTED	58
WHAT IS RESONANCE?	60
ULTRASONICS – THE MYSTERIOUS WORLD OF “SILENT SOUND”	63
SUPERSONICS	69
BREAKING THE SONIC BARRIER	71
SOUND AND THE ATOMIC BOMB	74
HOW SOUND IS REPRODUCED	76
SOUND AND YOU	78
A CHECK-LIST OF SOUND FACTS	81
SOUND EXPERIMENTS YOU CAN DO	86
INDEX	91



Douglas Aircraft Company

Anechoic chamber, or "room of silence." Douglas Aircraft engineers designed this special chamber to duplicate the vast quiet of the stratosphere. The walls break up and absorb sound waves so that special acoustical effects can be studied. The anechoic chamber especially eliminates reverberations and echoes.

What We Mean by Sound

SOUND is something that we hear. It comes to our ears in many different ways. It may be pleasant, like the voice of a friend, or unpleasant, like the screech of a train's wheel on a railroad track. Some sounds are loud, and some are soft. Some are high, and some are low.

It is curious that most of the words we use to describe various kinds of sound are like the sounds themselves.

The *ring* of a bell. The *bark* of a dog. The *shriek* of a ship's whistle. The *boom* of a firecracker. The *crack* of a thunderbolt. All of these are sound.

Other sounds are represented by words like pop, squeak, hiss, bang, gurgle, rustle, crash. You can probably imagine how some of these words came to be. For example, water flowing in a brook *gurgles*. Mice *squeak*. Leaves *rustle*. Without much trouble you could make a long list of sound-words.

Sound is a form of energy that your ear, like a sensitive microphone, picks up from sources that are vibrating, or trembling, nearby or far away. This energy enters the marvelous system of your ear, which in turn delivers the energy to your brain, and you are then able to hear what we call sound.

Sound is extremely important in our lives. It is our chief means of communicating our thoughts, ideas, and wishes to other people. Stop a moment and think what your life would be like without sound. You would not be able to hear your teacher's voice in class, or your favorite TV program. You would not be able to hear the tune a band is playing in the park, or your best friend's voice on the telephone. In fact, the telephone would be of no further use at all.

If there were no sound, you would have to depend for communication on your remaining senses of touch, sight, smell, and taste.

But how does sound travel to our ears?

How Sound Comes to Us

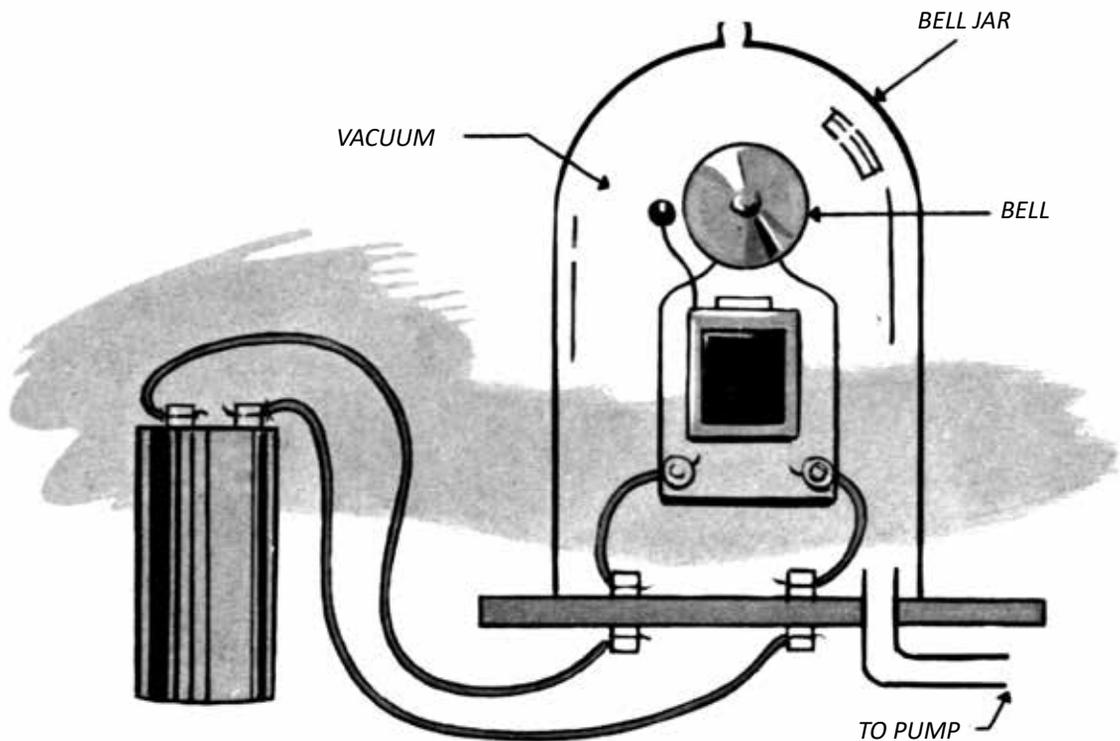
LET US pretend for a minute that you are standing on the surface of the moon. Some friends set off a charge of dynamite about a mile away. You can see the explosion, but you hear no report at all.

Why?

Because there is no air on the moon. You saw the flash of the explosion easily enough because light rays are able to travel through spaces where there is no air. But sound must have a medium to carry it along, or *transmit* it, from the place where it begins to your ear. A *medium* is simply the matter, or material, or substance, in which anything lives, or acts, or moves.

When there is no substance - like air, wood, water, or anything else





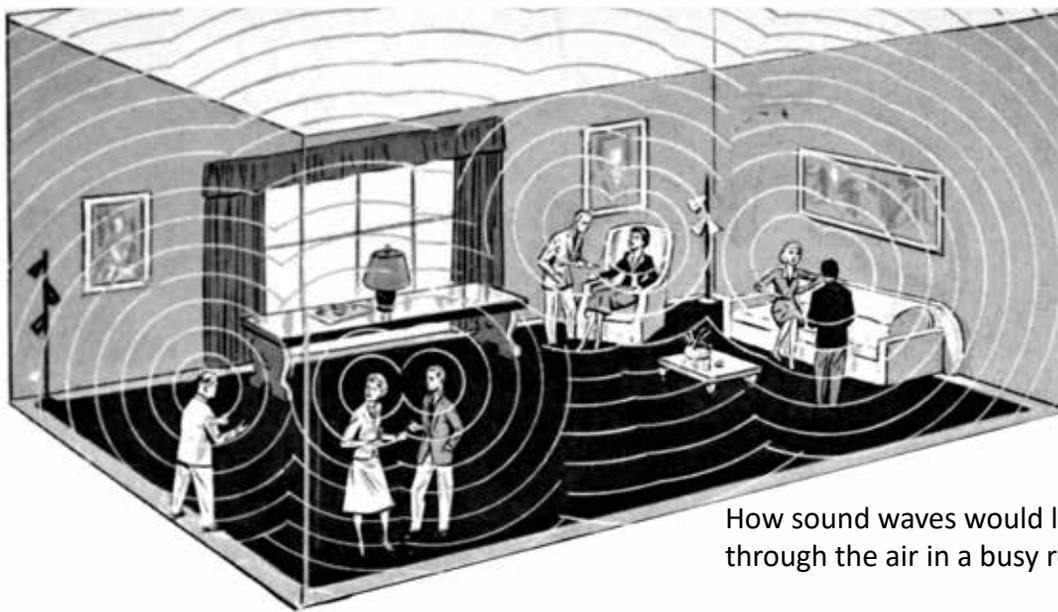
The bell-and-jar experiment.

you can name - in a given space, that space is called a vacuum. Sound is unable to travel in a vacuum, although it can go through a solid object like a building.

In other words, sound needs a substance, or medium, like air through which to go - or there is no sound.

To prove that sound cannot travel in a vacuum, you can perform an experiment. There are probably an electric bell and a large jar in your school science room. Set the bell ringing, place it under the jar, and start pumping the air out of the jar. Notice that the sound of the ringing bell becomes fainter and fainter as you pump. If you succeed in pumping most of the air out of the jar - thus creating a vacuum - you will not hear the bell at all. But let the air gradually creep back into the jar, and the ringing of the bell will grow louder and louder, because now the air is between your ear and the source of the sound.

Air is the most common medium through which sound comes to



How sound waves would look traveling through the air in a busy room.

us. Because air is so easily set in motion, hearing is possible. Without air, we should have to depend on other transmitters, or *conductors*, of sound, like water or steel. Can you imagine what it would be like if, every time you wanted to speak to someone, both of you had to stick your heads underwater?

We - you and I, your parents, your teachers, all of us who inhabit the planet earth - live at the bottom of a thick ocean of air, which forms the earth's atmosphere. In one way or another, we are forever disturbing this air. It is difficult *not* to disturb it. When we walk about we push it aside. When we speak, we push it about by means of our vocal cords. Air, of course, is invisible. But if we could "see" a roomful of it - a room, let us say, in which many people were talking and doing things - we would see a very stormy sight indeed. The air would be disturbed by shakings and quiverings in all directions as people talked and moved. In many ways it would be like a huge block of jelly shot through with ever-widening waves and ripples spreading out from their sources.

What are these sources? What happens to create sound?

What Causes Sound?

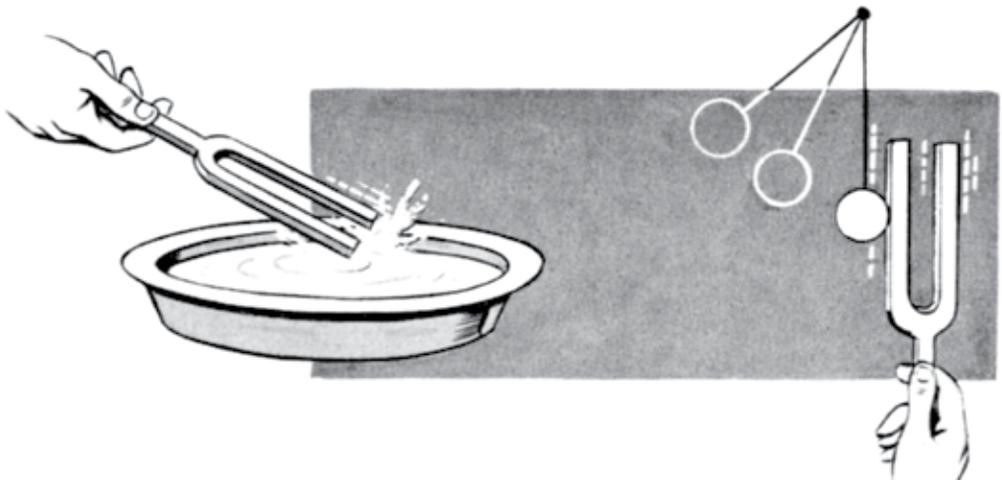
EVERY sound that we hear begins with a *vibration*. Vibrations even cause the sounds that we “hear” through our sense of touch - as we do when a friend taps a stick at one end and we feel the vibrations with our hand at the other.

What exactly is a vibration? It is *motion*, either backward and forward, or up and down.

You can see vibration in action by hitting a tuning fork with a rubber mallet. Notice the blurred appearance of the two prongs as they shake back and forth. Or take a rubber band and “twang” it between your thumb and forefinger and you will see the same thing.

Vibrations can be felt, too. Try this experiment: read the next sentence or two aloud. As you do so, place your fingers lightly in the vicinity of your Adam’s apple. The tiny vibrations you feel are being made by your vocal cords. Or touch your alarm clock the next time it goes off, and feel the vibrating movements produced by the bell inside.

There are other ways, too, of showing how sound and vibration are related. Hit a tuning fork and hold it to the surface of a dish of water. Notice how the water is disturbed. Or take a Ping-Pong ball and hang it on a piece of string. Hold a freshly hit tuning fork against the ball, and watch how the ball kicks and jumps.



Scientists have found out that an object must vibrate at least sixteen times a second before the human ear can hear it as sound. Likewise, most human ears cannot hear vibrations that are much faster than 20,000 times a second. If you took a broom, hung it on a nail, and started it swinging back and forth, there would not be enough vibrations produced to be *audible*, or hearable, to your ear. Or, if you blew the special kind of whistle made for calling dogs, you would not be able to hear it because there are too many vibrations. A dog, however, would be able to hear the whistle because his ear system can register higher vibrations than ours can.

The number of vibrations, or *oscillations*, that a sounding body makes *per second* is known as the *frequency* of that body. Any number of vibrations that a sounding body makes below 16 or much above 20,000 cannot be heard, or is *inaudible*, as far as man is concerned - although such vibrations do cause the eardrum to vibrate.

What Are the Different Kinds of Vibrations

SOUNDING bodies usually fall into three main classes or groups of vibrations.

When you strike a tuning fork or the top of a table or anything else, its material vibrates at a frequency that depends on what the material is, as well as its size and shape. Such vibrations are “natural,” and are known as *free vibrations*.

Everything in nature vibrates and has its own natural, or free, rate of vibration.

If a freely vibrating object, however, is left alone, the vibrations” die out. “In other words, they will eventually grow weaker and stop. But if we take an alarm clock and start the alarm ringing, the vibrations are

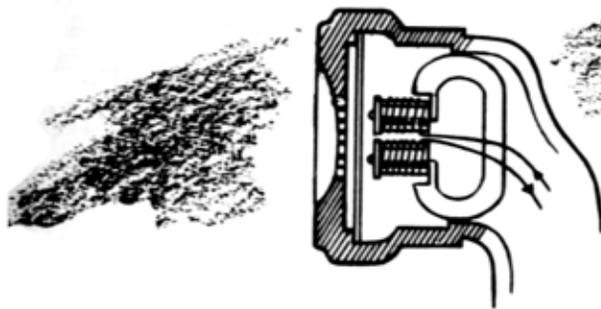
renewed again and again. This is known as a *maintained vibration* - a vibration that is kept going. Another example would be that of a violin string which, when played with a bow, maintains its vibration until the bowing stops.



TUNING FORK
(Free vibration)



CLOCK - RADIO ALARM
(Maintained vibration)



TELEPHONE DIAPHRAGM
(Forced vibration)

When a sounding body is made to vibrate at a frequency that is different from its natural one, this is a *forced vibration*. The diaphragm of a telephone receiver is made to shake with a forced vibration. So is the eardrum, which we shall consider next. Of course, the eardrum has its own frequency of free vibration, too. But it is curious that its free vibration is outside our range of hearing!

The Human Ear and How It Works

AS WE know, our daily lives would be difficult without sound for communication purposes. But suppose that, although there was plenty of sound about us, we had no ear systems to receive it. Again, we would be forced to depend on our remaining senses of taste, touch, smell, and sight, to do our communicating.

The human ear is a highly complex organ. Look at the cross-sectional illustration of it, and you will see that it is made up of three main parts: the *outer* ear, the *middle* ear, and the *inner* ear. In the outer ear, the part that sticks out from the head is called the *auricle*. The *canal*, in which wax forms as protection against foreign matter, leads into the skull.

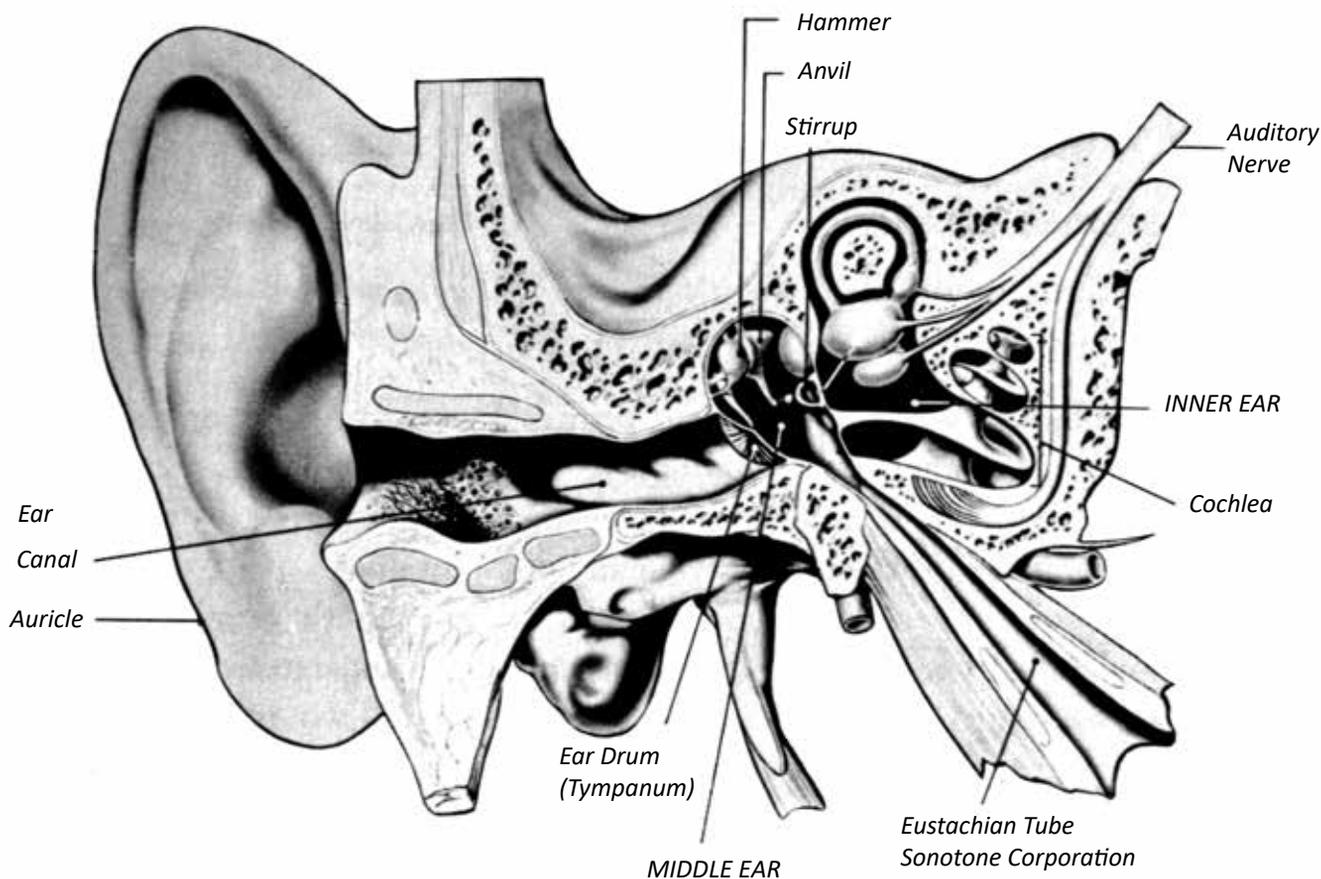
The middle ear begins with the eardrum, sometimes called the *tympanum*. In the middle ear there are also three tiny bones called the *hammer*, the *anvil*, and the *stirrup*. These three tiny bones form a chain connecting the eardrum to the wall of the inner ear. The *Eustachian tube* is what connects the middle ear to the throat and serves to balance the air pressure on both sides of the eardrum.

The inner ear contains a spiral section called the *cochlea*. It is filled with a liquid, and is lined with many tiny nerve endings which are designed to receive sound vibrations.

When a vibrating wave of sound reaches the outer ear, it then passes through the canal to the eardrum. The eardrum then begins to vibrate, too. These vibrations are in turn passed along to the hammer, the anvil, and the stirrup, whose cross-piece is set into the shell-shaped cochlea. The fluid contained in the cochlea then acts on the many tiny nerve endings. Finally, these nerve endings transmit the vibrations to the brain by means of the *auditory nerve*.

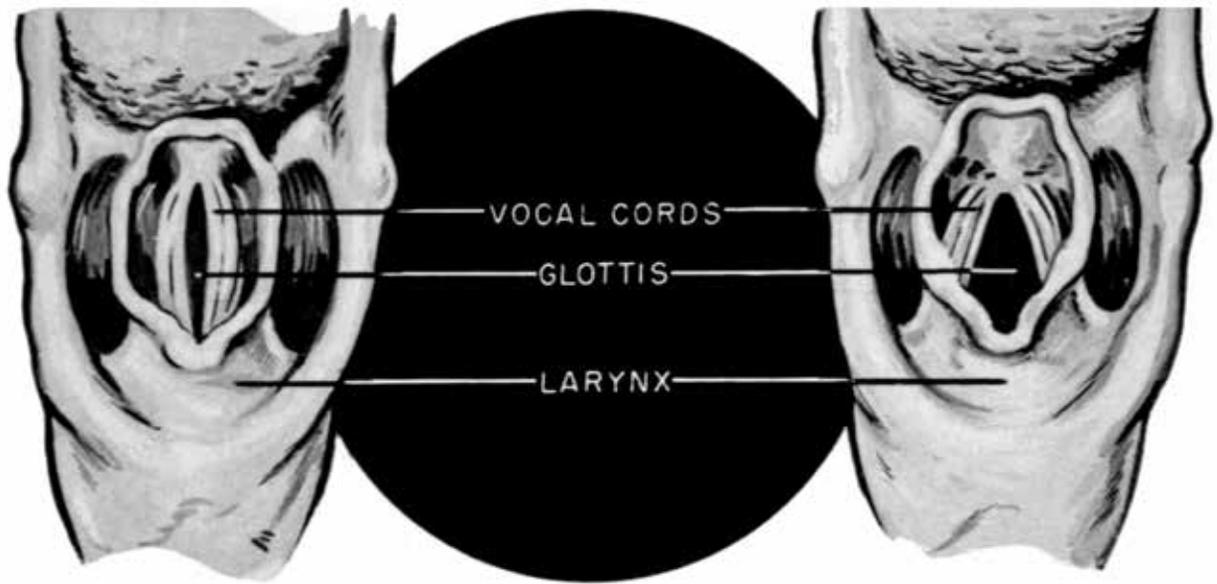
The brain interprets these vibrations, or impulses, as one of the many varieties of sound.

A word of caution about your ears: never poke or probe carelessly into them. This can cause infection or serious injury to the sensitive eardrum. Be careful when diving from very high places.



The human ear system.

Remove excess water from the ears after swimming; it may be impure and could cause infection. Protect your ears as well as you can against sharp blows. Your ears are two of the most precious instruments you own. Take care of them well.



SPEAKING OR SINGING

BREATHING (Glottis wide)

Your Voice and How It Works

THE human voice system is our principal means of communicating with one another. It is important to know how it works.

When the human voice produces sound, it produces it by means of vibrations, just as any other sounding body does.

In your upper throat, under your chin, is a slightly bulging portion, called your Adam's apple. Inside it is an apparatus called the *larynx*, which is a kind of boxlike chamber. Two tough membranes, called the *vocal cords*, are stretched across the larynx. Between the vocal cords is a narrow opening that is known as the *glottis*.

When you speak or sing, air is forced through the glottis, and your vocal cords vibrate and produce sound. If the vocal cords are close together (with the glottis opening small), your voice sounds are high. But when the glottis opening is wider, your voice sounds are lower because the vibration rate is lower. The shape of your mouth can also vary your speaking or singing voice.

A low bass singer's voice produces about 60 vibrations per second, while a high soprano's can vibrate as high as 1,200 times a second.

Sound Waves - What They Are and How They Act

WHEN a piano string or a tuning fork is struck so that it vibrates audibly, the air that surrounds it is disturbed by a series of tiny pushes.

These disturbances, which spread out in all directions from the vibrating source through the medium of air, are called *sound waves*. It is by means of these regularly spaced, or *rhythmic*, waves that sound energy is transmitted first to your outer ear, then through your middle ear, into your inner ear, and finally to your brain.

Although we usually think of sound waves as traveling through the medium of air, they can also be transmitted through other substances, or conductors such as glass, wood, steel, and water.

How Sound Waves Transmit Their Energy

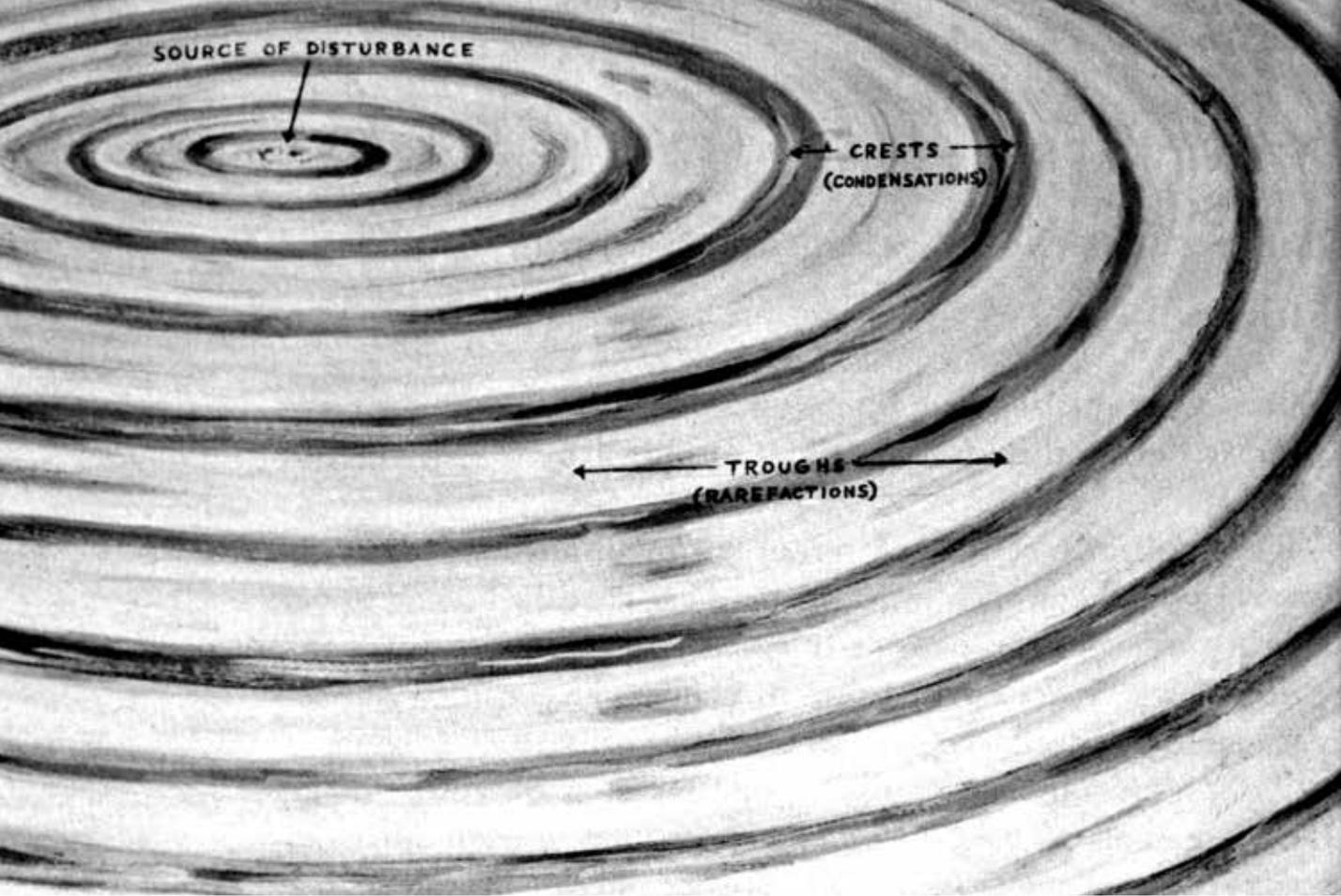
SOUND waves behave very much like water waves.

Suppose you throw a stone into a perfectly quiet pond. The splash creates waves that spread out circularly in all directions.

Why?

Because the water level has been disturbed and is trying to get back to normal. But in doing so, the disturbance that was created only succeeds in spreading farther in the form of waves.

Soon a toy boat on the other side of the pond gets the “message” of the disturbance created by tossing in the stone. The boat now vibrates, oscillates, too. In a sense this is how the boat “pays for” the energy it has received from the original splash. Of course, the farther away the waves get from the splash point, the weaker they become, just as sound waves become weaker as they travel from their source.



Sound waves compared to water waves. A stone tossed into a pond creates waves with alternating *crests* and *troughs*, corresponding to *condensations* and *rarefactions* of sound waves.

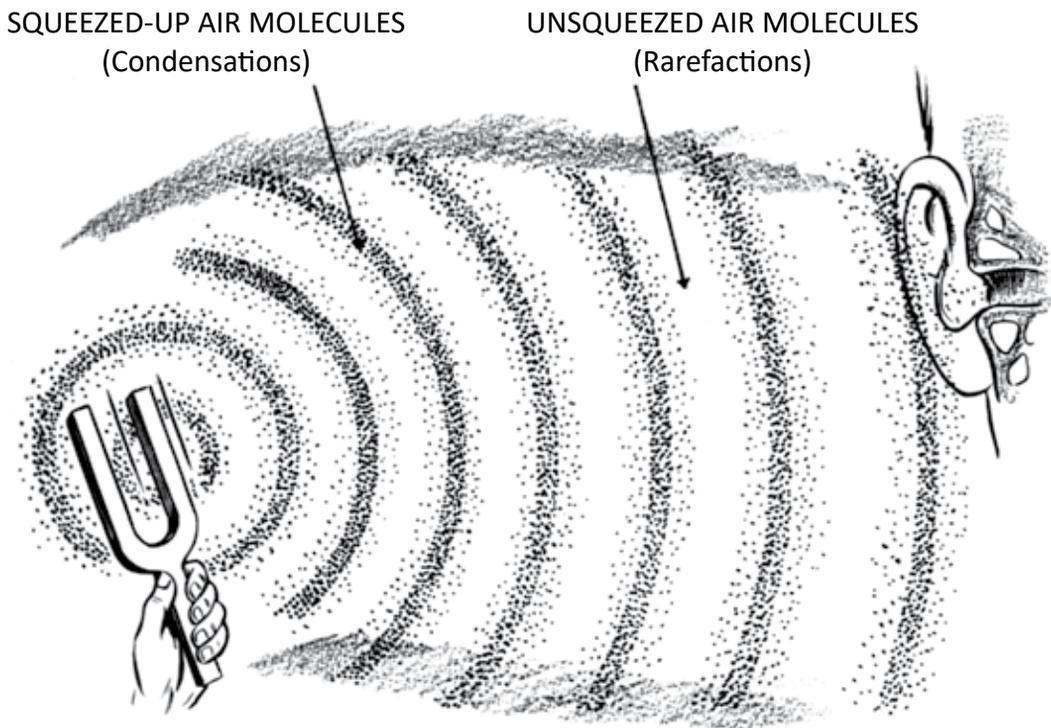
Sometimes these rhythmic waves, whether they are of water, sound, or electricity, are called *wave trains*. It is by means of them that the energy waves of a radio or TV signal are transmitted to a receiver, which is able to pick them up and replay them.

In the same way as the water waves transmitted energy to the toy boat, sound waves can transmit energy to your ear through air or some other elastic medium.

It is important to get a clear picture of how this is done. Notice the word “elastic” in the preceding paragraph. When we say that a medium or substance or conductor is elastic, we mean that it can be stretched or squeezed.

Suppose you take a tuning fork, tap it sharply with a rubber mallet, and hold it up to your ear. When one of the prongs of the fork vibrates *toward* your ear, particles of air called *molecules* are squeezed in the direction of your ear.

But when the prong snaps back *away* from your ear, the air molecules rush back, or *unsqueeze* themselves. Soon air molecules farther away, having been shoved by the first ones, transmit the original disturbance to your ear as a tiny dose of energy.



The same basic thing would happen with a line of people, each with their hands on their neighbors' shoulders. If the person at the end of the line pushed or pulled on the shoulders of the person ahead of him, the same back-and-forth motion would be transmitted down the line from one person to the next.

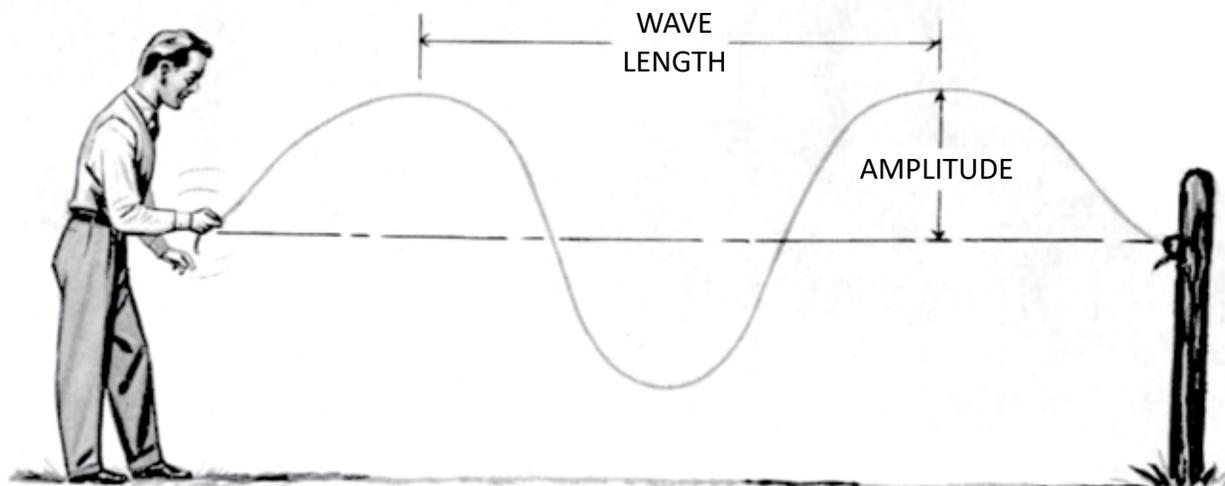
What Kind of Waves Are Sound Waves?

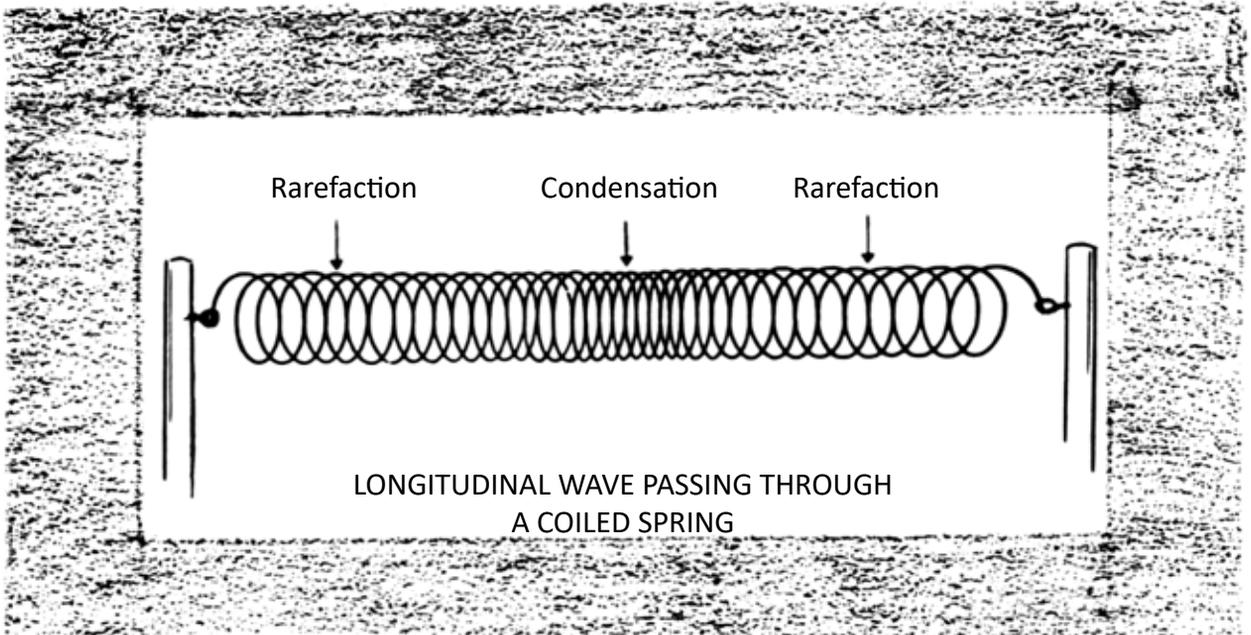
SOUND waves are back-and-forth waves *only*. Physicists call this type of wave *longitudinal*, meaning lengthwise.

But there is another kind of wave called a *transverse* wave. It is important to recognize the difference between the two. Two simple experiments will show us the difference.

Take a rope about eight feet long and tie it to a post. With the rope held slack, shake it up and down until you have created wave motion along the whole length of the rope.

Although the waves travel easily from your fingers to the post, every part of the rope is moving up and down, or *transversely* (perpendicularly), to the waves. No part of the rope is actually moving back-and-forth, or longitudinally.





The *wave length* of this type of wave is the distance between any two successive tops, or crests. The *amplitude* is the distance that any particle of the rope moves up and down, out of its usual place, as shown in the picture on the opposite page.

Light waves, as well as other kinds of electromagnetic radiation (such as radio waves), are transverse waves.

Now, take a long spring - one of the "Slinky" variety will do and stretch it slightly between two posts. Take something thin, like a letter opener, and insert it between two coils in the middle of the spring. Jam some of the coils together in one direction and then pull the blade out quickly. Watch the resulting disturbance chase itself back and forth across the length of the spring.

What you have created in the spring is a longitudinal wave, sometimes called a *compression* wave. Longitudinal waves are back-and-forth waves, while transverse waves are up-and-down ones.

Sound waves are longitudinal waves.

The jammed-up places in the spring (like the squeezed-up air mole-

cles between your ear and the tuning fork) are called *condensations*. And the stretched-out places in the spring (like the unsqueezed air molecules between your ear and the tuning fork) are called *rarefactions*.

Just as with transverse waves, we are able to measure two dimensions of longitudinal waves. The distance from one condensation to the next is called the *wave length* and, in the case of air, the distance that any given molecule is pushed back and forth is known as the *amplitude*.

The human ear can hear wavelengths ranging in length from about one inch to seventy feet. The faintest amplitude we can hear is about one-billionth of a centimeter, while the greatest amplitude we can hear is about one-thousandth of a centimeter. Sounds of greater amplitude than that would pain or even damage our ears.

Let us go back for a minute to the water waves created when the stone was tossed into the pond. What kind of waves are water waves? They are waves that are considered to be transverse because the water molecules move up, forward, down, and back, in a nearly circular path.

The Speed of Sound

IT always takes a certain amount of time for any sound wave to travel from one place to another through any medium. Even light rays, which do not need a medium through which to travel, are not transmitted all in an instant. Light waves, which travel through a vacuum at the incredible speed of 186,000 miles *per second* are of course much swifter than sound waves.

As a matter of fact, sound, when compared to the speed of other waves, is rather a slow traveller.

We know that sound waves must have some kind of medium through which to go before they can reach our ear systems. They cannot travel in a vacuum, as we saw from the bell-and-jar experiment.

Sound waves can, however, travel through liquids such as water, through solids such as glass or steel, and through gases such as air. Mediums such as glass and iron are good transmitters, or conductors, of sound waves. Some other mediums are poor conductors. For example, cloth and rubber are mediums that absorb or “soak up” sound waves.

Through “dry” air (air that is at 0 Centigrade), sound can travel at a speed of about 1,100 feet per second, or 700 miles per hour - about the speed of a bullet fired from a rifle.

As a general rule, we can say that most common liquids and solids transmit sound at a greater speed, or velocity, than air does. For example, sound travels about four times faster in water than in air. It also travels faster through the ground than in the air. Native Americans, by putting an ear to the ground, were able to hear the sound of approaching horses or buffaloes long before they could be heard through the air.

