been deadened. What is meant by deadening a floor or wall? It is a very common practice in offices or any place where privacy is necessary to put some substance like felt or certain kinds of paper that are non-conductors between the walls or floors and thereby prevent sounds from passing through. They are then called sound-proof.

HOW FAST DOES SOUND TRAVEL?

We have already had proven to us by various experiments in transmitting sound by steel rails, cast iron pipe, wood and through water, that the speed with which the sound waves travel depends very much upon the medium.

A very interesting experiment on the velocity of sound was recorded in a demonstration made at Lake Geneva. An explosion was produced by powder at the same time that a bell was struck under the lake, and an observing station some eight miles away accurately measured the time from the flash as seen by the eye to the sound as recorded through the water. This is of interest because it shows the simplicity and the accuracy with which the velocity of sound in different matters can be recorded.

Noises of every variety, whether musical or discordant, high or low, move through the atmosphere over the surface of the earth at a velocity of 1,090 feet a second, 765 miles an hour at 0° centigrade. Just think how fast a racing auto goes. Sound travels through the air about ten times as fast. Light travels at the rate of about 670,000,000 miles an hour, or over one million times as fast as sound.

The velocity of sound and the rate at which it travels is of great importance in measuring the time of certain things. Take, for example, the timing of an athlete in a hundred-yard dash. The next time you see a college track meet watch the timers.

You will find that they are very careful to watch for the flash of the pistol. The man who knows how to time a race knows that the timing by the flash is the only accurate way. The poor timer is the one who listens for the sound. Their stop watches are set the instant the flash is seen and not when the pistol is heard. The timer who does not start his watch until he hears the sound of the gun gives the runner credit for more speed than he actually accomplishes.

This all explains to us why it is that we see the steam from a factory whistle before we actually hear the noise. It also explains why we see the lightning and then hear the thunder afterward. In reality they both occur at the same time; but it takes sound so much longer to travel than light it is easy to understand why we see the flash of lightning long before we hear the clap of thunder. The next time you witness a thunder storm watch for a flash of lightning; then count the number of seconds between the flash and the time at which you hear the clap of thunder and divide this by five, and it will tell you how many miles away the lightning is. This is a good experiment in itself.

WHAT DETERMINES THE VELOCITY OF SOUND

There are many things that enter into the velocity at which sound will travel, and particularly important are elasticity and density of the medium through which sound may be passing. In other words, the more elastic the medium the greater will be the velocity of sound traveling through it and the denser the medium the less will be the velocity. Therefore, through warm air, sound waves will move more rapidly than through cold air. Ask yourself why this is. You should know that warm air is expanded air because heat expands it. Consequently it is not so dense. While sound at zero temperature on a centigrade thermometer travels at the rate of only 1,090 feet per second, as the temperature increases, at each degree the velocity of sound will increase two feet per second.

Through other mediums sound travels much faster. Through water it travels at a velocity of 4,708 feet per second; through solids like tin, for instance, at a velocity of 8,175 feet per second and through solids like iron or glass and certain woods sound attains a velocity of 18,530 feet per second. Why these differences?

Perhaps the answer to this question had better be left until we have finished our next series of experiments and learned how sound travels.

Chapter IV

TRANSMISSION OF SOUND—CONCLUDED

What do we mean when we say sound travels? What is it that travels through air, water or steel so readily? There was a time when it was quite generally supposed that electricity was an invisible substance which flowed through wires. You are surely enough of a scientist to see very readily that, in the transmission of sound, as in that of electricity, no substance actually travels from place to place, as from tuning fork to the ear. What is transmitted may be very easily demonstrated.

Experiment No. 14. Take a metal tube or make a paper or cardboard tube by rolling some paper or cardboard around a stick and then remove the stick. Make this about 6 or 8 feet in length and at least 3 inches in diameter. Seal one end by means of a thin rubber dam tightly stretched across the opening, holding it in place with a rubber band, string or wire. At the other end make a cone with an inch opening. Place a little candle a few inches from the cone end of the tube so that the flame from the candle will be just opposite the hole in the end of the cone. Your apparatus is now ready for the experiment. (See Figure 21.)

Make a noise at end of the tube just beyond the rubber diaphragm with any vibrating body, such as hitting two pieces of metal together or two blocks of wood, and watch the flame of the candle. If you have followed the directions, you will find that when the vibration—that is, the sound—is produced the flame will bend away from the opening. Now this should be conclusive proof to you in view of the fact that the tube is sealed up by means of a rubber dam that air cannot pass through. Therefore, if you reason as a scientist should reason, you will come to the conclusion that the flicker of the candle flame is due to energy which has been transmitted from the origin of the noise down the tube to the flame. The energy pro-

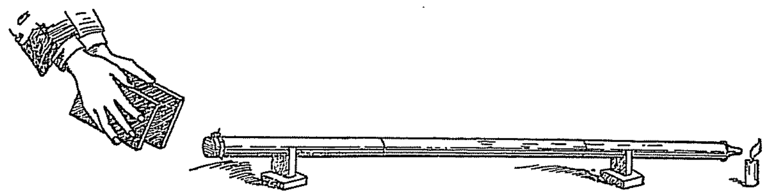


FIG. 21

duced at the point of origin of the sound strikes the rubber diaphragm, causing it to vibrate and thereby to transmit a certain amount of energy on to the flame.

MANOMETRIC FLAMES

Experiment No. 15. The manner in which this "sound energy" is transmitted may be beautifully shown by an experiment which you can perform for yourself. By using a little thought and ingenuity you can rig up the necessary apparatus, the ideal form of which is shown in the accompanying illustration. (See Figure 22.)

A wooden or metal box about 3 inches square is divided into two chambers by means of a thin rubber diaphragm placed fairly near to one side of the box. A stream of gas is admitted to the small chamber, from which it passes out again to a small jet, making an even, pointed flame. The small end of a mega-

phone is fitted into the other end of the box. About 2½ feet

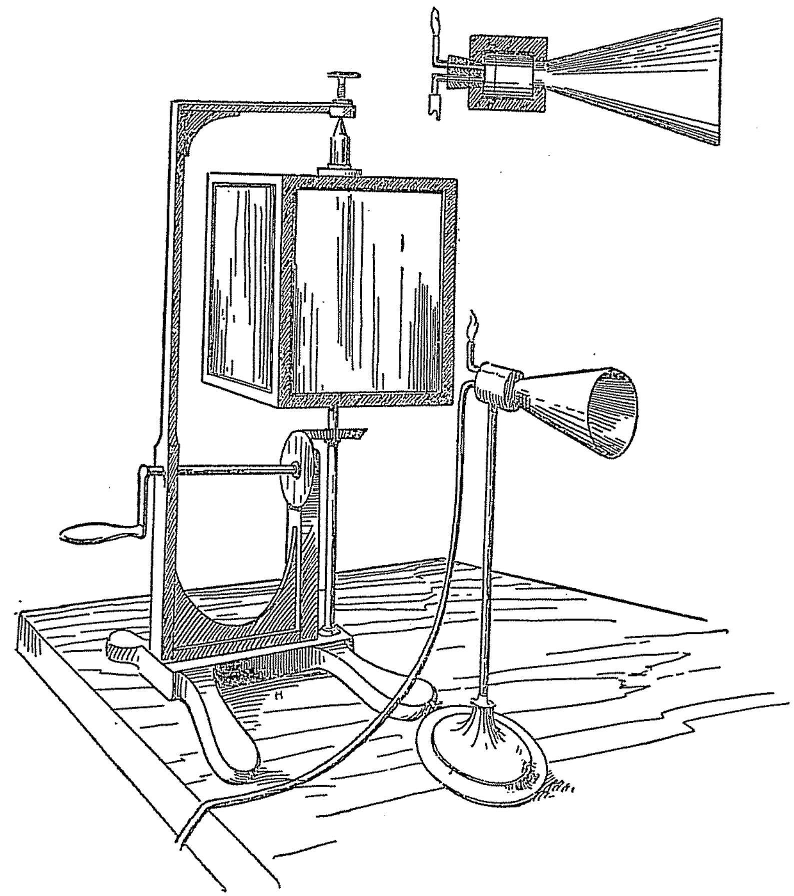


FIG. 22

away place a mirror, preferably arranged so that it can be rapidly revolved. For the revolving type, it is best to take four mirrors and fasten them to the four sides of a square box. When the room is darkened, you are ready for the experiment.

With the flame burning steadily, start the mirror revolving or—to produce the same result—turn the eye quickly, throwing the line of sight across the image of the flame in the mirror. You will see the flame reflected as a straight band of light.

Now hold a tuning fork, mounted on a sounding box, near the

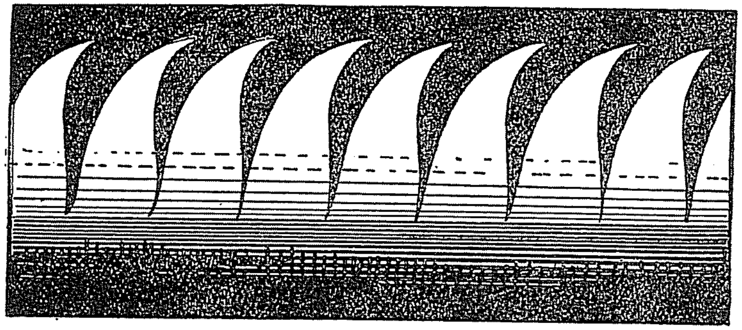


FIG. 23

large end of the megaphone and start it vibrating by means of a violin bow or cork hammer. When the mirror is revolved, you will see the flame reflected as a series of sharp points of light. (See Figure 23.) As the vibration of the tuning fork dies out, the points on the band of light in the mirror become shorter until, when the fork stops vibrating, the straight band of light is again seen in the mirror.

The one thing which this experiment shows more clearly than anything else is the fact that "sound energy" is transmitted in regular pulsations, which are called waves—air waves or sound waves. As a prong of the tuning fork moves forward toward the megaphone, it pushes the air particles next to it ahead,

condensing them. (See Figure 24.) The fork then suddenly changes direction and moves backward, leaving a partial vacuum or rarefaction behind it. The air particles which have been condensed now rush back to fill this rarefied space; but in the meantime they have acted upon the air particles next to them, thereby setting up a series of condensations and rarefactions which eventually reach the rubber diaphragm, causing it to vibrate. As the diaphragm vibrates, it causes the pressure of the gas in the chamber to change rapidly and these changes in gas pressure cause the flame to flicker up and down. The changes in the height of the flame are so rapid that the eye cannot detect them unless they are separated by one of the two methods previously described.

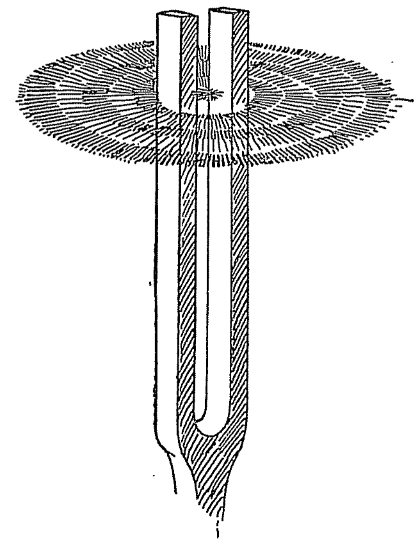
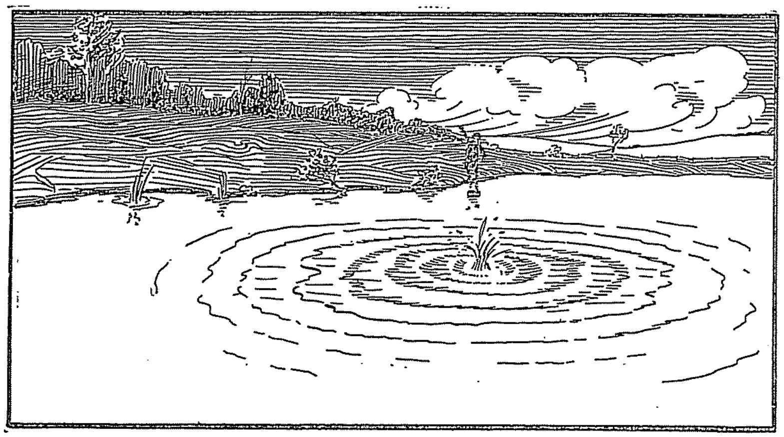


FIG. 24

There are many examples of the transmission of energy by means of wave motion. We have all seen a smooth pond of water thrown into ripples (wave motion) by throwing into it a stone. (See Figure 25.) Anyone living near the water knows the tremendous force of waves breaking upon the shore. We all know the sting the hand gets if, when holding a piece of steel, it is hit with a hammer at the other end. The jar of a door may be felt all over the house. An explosion miles away may rattle the windows and even break them. A huge tidal wave may be caused by the eruption of a volcano. In 1886 Krakatoa exploded, producing air waves that passed around the earth three times and a tidal wave that passed clear across the Pacific.

Hold one end of a piece of rope about 16 feet long and ask



Reproduced through the courtesy of *Popular Science Monthly*

FIG. 25

If you throw a stone into a pond, an ever-widening train of waves spreads in all directions. The waves have two dimensions only. A similar wave action takes place when you strike a bell.

a friend to hold the other end. Strike the rope sharply a few inches from your hand. You will see a wave run along the length of the rope and cause a sudden jerk at the other end. You may substitute for the rope a coil spring about 8 feet long, which may be made by winding wire on a piece of gas pipe.

Attach one end of this coil to a hook on the wall and hold

the other end in your hand, stretching it out to some length. (See Figure 26.) Strike this coil with the hand and you will notice that a wave will run to the fixed end and return, when a sudden jerk will be felt by the hand. This is a reflex or return

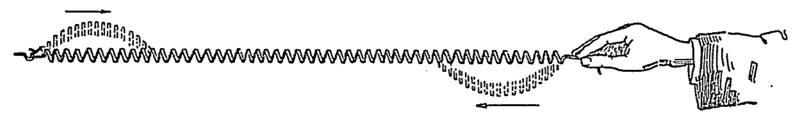


FIG. 26

wave which demonstrates that the wave transmits the force of the blow. In other words, this vibration, or oscillation, that is set up in one part of the wire is transmitted to the other parts in the form of waves.

WATER WAVES

Let us study the action of water waves. Take a bowl of water and drop into it a ball and watch it produce a series of waves. Here you will see a form of motion. Now if a cork is thrown upon these waves you will observe that it rises, moves forward with the crest of the water, or wave, and then it sinks and moves backward, repeating this action with each wave motion that follows it; but the cork doesn't move from its original position. This demonstrates conclusively that the water itself does not move with the wave but that the motion is passed along from one mass of water to the next.

To make this clear to you let us assume, and the theory is, that water is made up of molecules (small particles). Note the illustration (Figure 27) which should convey to you a series of balls suspended by strings so that they nearly touch each other. If one of these balls is touched a wave motion is produced and still the balls will remain in their same position.

AIR WAVES

The air waves we explained in the experiment with the revolving mirror are like the water waves produced by dropping a ball in the water in one respect—that is, they both go out in all directions from the point of original vibration. But air waves are different from water waves in regard to the type of vibration. In the case of water waves, the motion of the water is in a circular direction (remember the bobbing of the cork).

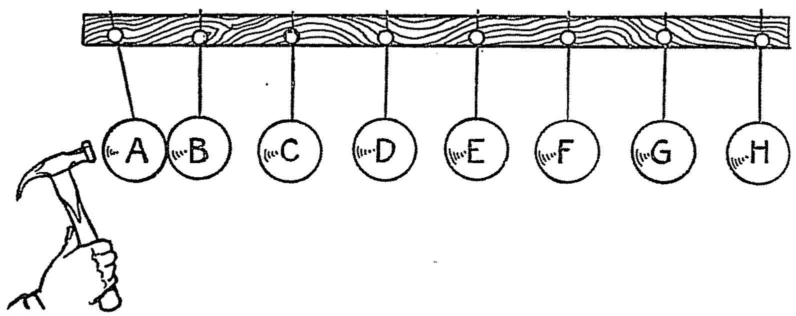


FIG. 27

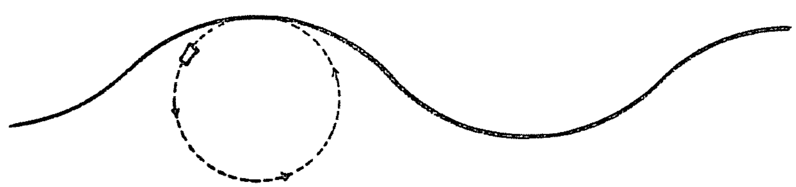


FIG. 28

In air or sound waves, the air particles vibrate back and forth in the same direction in which the waves are traveling. In water waves we have not only this but also the up and down motion. (See Figure 28.) In air waves we have longitudinal

vibration, which was explained by the ball and elastic in Chapter I.

The length of water waves is measured from the crest of one wave to the crest of the next. The length of sound waves is measured from the center of one condensation to the center of the next. (See Figure 29.)

Experiment No. 16. You can show the similarity between water waves and the transverse vibration of the pendulum, tuning fork, etc., in the following manner:

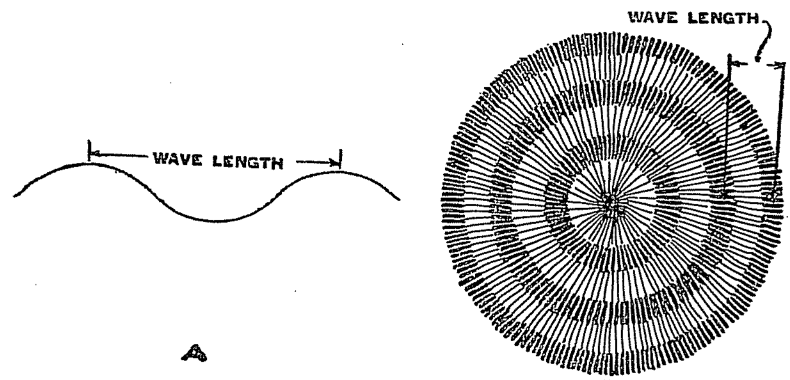


FIG. 29

Prepare a strip of glass with a few drops of kerosene and sprinkle some flour over it. Attach a whalebone with a hole bored near the end of it to a block screwed to a board. (See Figure 30.) Place the glass between two strips attached to the board and underneath the whalebone. Attach a bristle to the whalebone in a position so that it just touches the glass. By vibrating the whalebone and pulling the strip of glass out in a uniform movement you can trace these vibrations in the form of waves.

Experiment No. 17. A fine way of demonstrating the "to and fro" motion which takes place in compressional waves (of which sound waves are an example) is as follows:

Take a stiff coil spring about 2½ or 3 feet long and attach

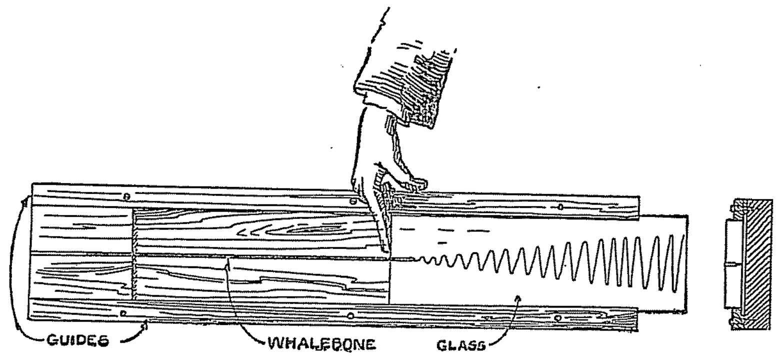


FIG. 30

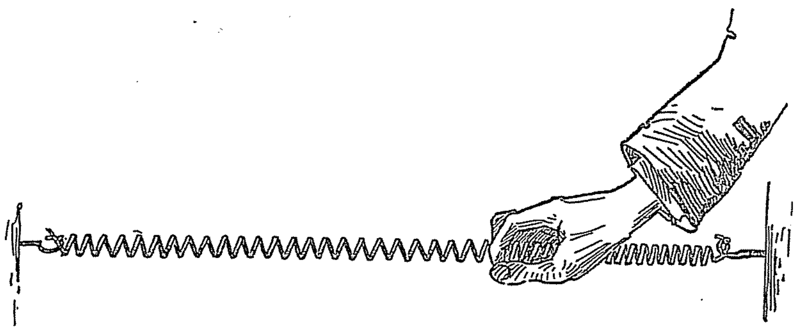


FIG. 31

each end firmly to hooks or nails on the wall so that the spring is somewhat stretched out. (See Figure 31.) Grasp the spring 3 or 4 inches from one end and draw it toward that end, producing a condensation of the spring between your hand and the hook. Now quickly release your hold of the spring so as

not to start it vibrating up and down. Place one finger lightly anywhere on the spring. What happens?

If you have carefully followed the preceding explanation of longitudinal waves you will readily understand that the rapid back and forth motion which you feel with your finger is due to a series of compressional waves which were set up along the spring when the condensation at one end was released.

SYMPATHETIC VIBRATIONS

Now that you have seen to your entire satisfaction that the transmission of sound is nothing more or less than the transmission of energy in the form of waves, you will understand one of the most interesting phases of the Science of Sound.

THE MONOCHORD OR SONOMETER

More than 2,000 years ago a Greek scientist, by the name of Phagoras, invented an instrument called a monochord. It was with this instrument that he discovered many things about

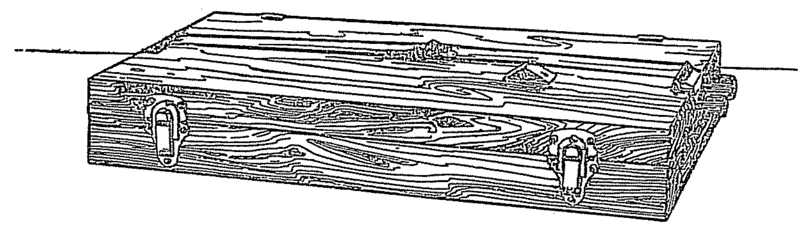


FIG. 32

sound produced by strings when vibrating. You should construct a monochord for yourself, as many of the experiments to follow will require its use.

This is not a difficult piece of apparatus to rig up, and the illustration (Figure 32) will probably help you more than a detailed explanation. The essential features are the sounding box, the strings (mandolin, violin or wire strings), the sliding bridge and the tightening screws.

Experiment No. 18. By using the tightening screws, get two of the strings of the monochord tuned to the same note as the tuning fork you are using. Now set the fork into a strong vibration, using method No. 3, described on page 18, and place

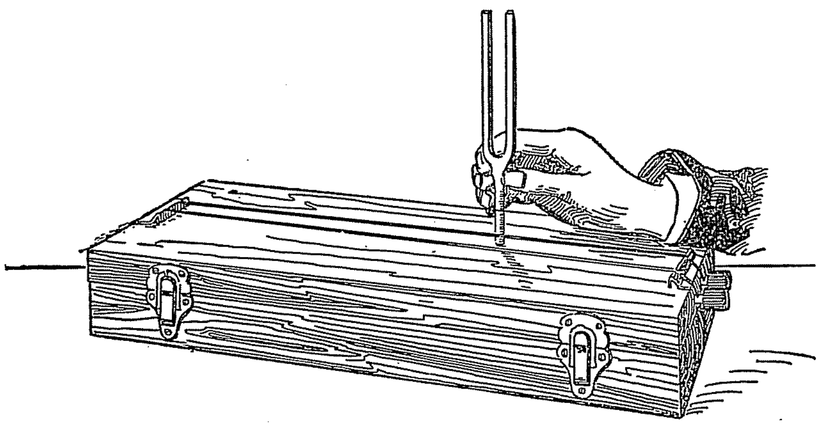


FIG. 33

it on the box between the two strings of the monochord, as shown in the illustration (Figure 33). After two or three seconds, stop the vibration of the fork by placing your fingers on the prongs. You will be astonished now by hearing the two strings singing to you with some note that the tuning fork gave.

We believe that by this time you are enough of a scientist to reason out that the air waves from the fork, which you set in vibration with the violin bow, have traveled to the two strings and, having enough strength, have set them into similar vi-

bration. This means that when a sounding body is near another that has the same rate of vibration, the waves from the first will set the second body into vibration.

Experiment No. 19. You may use two tuning forks, instead of a tuning fork and the monochord strings, and demonstrate the same phenomenon. When two forks are used, they must be

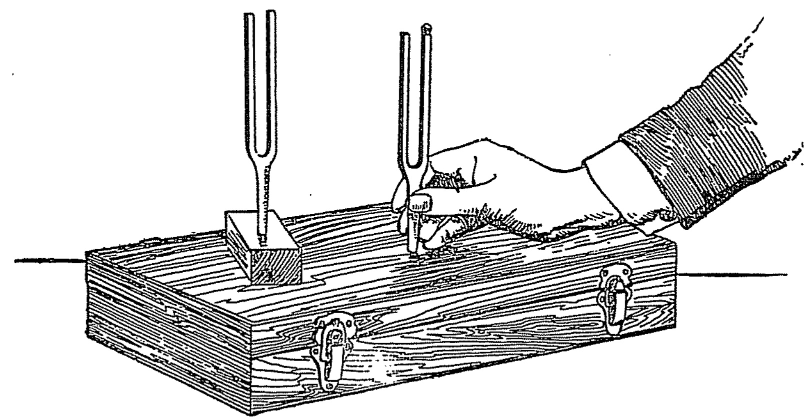


FIG. 34

of exactly the same rate of vibration. If you have two forks that vibrate at slightly different rates, you can get them the same by putting a small piece of wax on one prong of the fork which vibrates more rapidly. You may have to try several times before you get just the right amount of wax to make the two forks give exactly the same tone. Place each fork on a block and set them on a table or large box, about 18 inches apart. (See Figure 34.) Set one of the forks in vibration and, after a few seconds, dampen it with the fingers as described in the preceding experiment. Now, as before, you will hear the note of the fork you struck being sounded by the other fork which was not struck.

Experiment No. 20. By using two strings of the monochord you will be able to get a result similar to that obtained with the two tuning forks. First, by means of the adjusting screws, tighten the strings so that they give the same note. Now hold one of the strings with the fingers of your left hand so it cannot vibrate, and pluck the other string as you would in the case of a mandolin. After a few seconds take your hand away from the string you have been holding and dampen the string which you plucked. You should be able to hear a clear distinct note being sounded by the string which you at first held.

Now compare this sympathetic vibration of the tuning forks with things in every-day life. The act of pushing a swing is a simple illustration. You exert your energy at regular intervals, which are the same as the natural rate at which the swing moves to and fro. Bridges have a natural rate of swinging to and fro. People who frequently walk across the Brooklyn Bridge get into the habit of adapting their stride to the swing of the bridge. It has been said that, were it not for offsetting influences, you could strike the Brooklyn Bridge (or any other large bridge) with a hammer at the natural rate at which the bridge swings and in time cause it to swing so violently that it would topple over.

The swinging motion of bridges has long been recognized in military manoeuvers. The next time you see a large body of men cross a bridge or viaduct you will notice that the officer in charge will command his men to "break step"—that is, to walk out of step. This is because the "measured tread" of a large body of men is liable to cause the bridge to vibrate or swing to such an extent as to become unsafe.

The phenomenon of sympathetic vibration explains why things jingle when we play the piano. Vases on the parlor table, picture frames on the wall, cut glass in the cupboard, knives and forks all have their natural rates of vibration. When

sound waves of the same rate of vibration are sent out from the piano and strike them, they vibrate just as the second tuning fork did in our last experiment.

BREAKING A GLASS WITH THE VOICE

Experiment No. 21. A very striking experiment showing the strength of sound waves caused by the human voice can be admirably illustrated by an experiment or demonstration that oftimes is made by great singers. Probably you have heard of singers having such strong voices that the vibrations produced from their throat would actually break glasses, and by the following experiment you can demonstrate that this is possible with your own voice. Take a very thin, sensitive cut-glass goblet and set it in vibration by hitting it with a cork hammer or by rubbing it with your moistened finger if you are adept in doing this; this should cause the glass to emit loud and musical tones. After you have set the tumbler in vibration, place the opening close to your mouth and shout into it as loud as you possibly can. At the same time try to imitate the same tone or key that is emitted from the glass. This will render double the amplitude of the vibrations and the glass will break into pieces.

A famous bass singer by the name of Labache always demonstrated this feat to show the strength of his voice much to the admiration of his friends and, although he had a wonderful voice, he also knew the secret of doing the trick that we have given you here.

FORCED VIBRATIONS

It sometimes happens that one vibrating body will set another body into vibration even though not possessing the same natural rate of oscillation. Set a tuning fork in vibration and place the lower end of it on a light wooden box that will readily vibrate.