You will find that the fork sets the box in vibration and this increased volume of vibration produces a loud sound which lasts for a comparatively short time.

FIG. 35

The reason that the tuning fork stops vibrating so quickly and the noise subsides so soon is because the vibration of the box requires an extra amount of work from the fork and its energy is soon used up. You will notice that the sound dies out very quickly. The same principle is at work in the case of the swing. You can cause a swing to move to and fro faster or slower than its natural rate, but it is hard work and you soon become tired out.

As an example of forced vibration, let me tell you how to do a dandy trick. This is a very mystifying trick and one that you can perform at any time without any prepared apparatus. It is an exceptionally fine trick to perform at a dinner or house party.

Hold a fork in your left hand, as shown in Figure 35, with your wrist on the edge of the table and the handle of the fork

free from touching the table. Snap the prongs of the fork with your thumb and index finger and you will get a ringing sound from the fork. The trick now is to carry the sound with your right hand over to the glass on the table and throw the sound from your hand into the glass. As you lean forward to throw the sound into the glass you press the handle of the fork on the table unnoticed by your audience. This changes the faint ringing sound of the fork into a loud sound of short duration, and it appears to your audience that you really carried the sound from the fork to that glass.

The reproducer of a phonograph, the metal discs in the telephone transmitter and receiver, the rubber diaphragms used in Experiments No. 14 and No. 15 are all familiar instances of forced vibrations and you can doubtless think of other examples yourself. The transmission of energy in the form of waves is the important fact demonstrated in each case.

Chapter V

INTENSITY, PITCH AND QUALITY

So far in our experiments we have paid no attention to the difference between sounds. All the principles we have demonstrated in regard to the origin and transmission of sound are principles which apply to sound in general. But of course you know that all sounds are not alike. They differ from one another in regard to intensity (or loudness), pitch and quality.

INTENSITY

After tightening a string of the monochord, put it into vibration by plucking it as you would a guitar or mandolin string and watch it closely. As the extent of the vibration—in other words, their amplitude—becomes less, the sound grows fainter. This is because the vibrations of greater amplitude cause more sharply contrasted condensations and rarefactions of the air than those of less amplitude, and they consequently have a greater effect upon the ear which hears them.

In the accompanying illustration (Figure 36), **A** represents the well defined air waves produced by a violently vibrating body. **B** represents the air waves from the same body when vibrating through a smaller amplitude. You should note that the air waves are the same distance apart, indicating the same rate of vibration in each figure. Just as in the "to and fro" movement of the pendulum, the vibrations are at the same rate, regardless of their amplitude.

In explaining the trick of carrying sound from the fork to the glass, it was said that the vibration of the entire table

produced a louder sound than that of the fork alone. This suggests the second thing upon which the loudness of sound depends. Large vibrating bodies produce louder sounds than small ones, because they set more air in motion.

When a vibrating body sends out a series of sound waves, these waves move in all directions, and the further they go

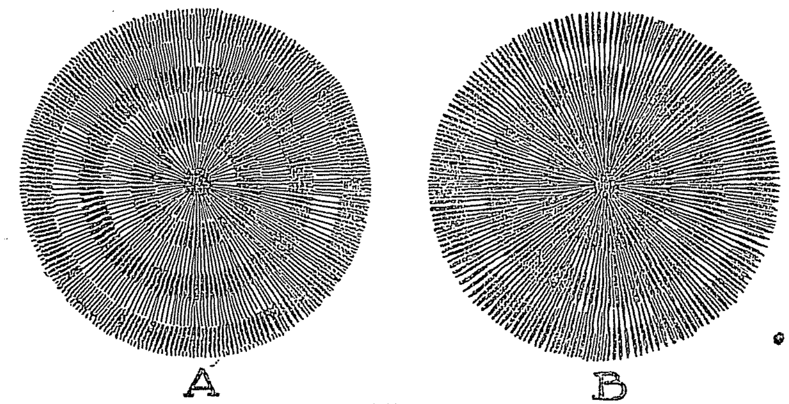

FIG. 36

from their source the more spread out they become and, therefore, more faint. The ripples caused by dropping a stone into the water grow less as they go away from the spot where the stone fell. It naturally follows that if these sound waves can be concentrated and not allowed to spread as they travel, their intensity can be maintained for a much greater distance. This is the principle of the speaking tube.

PITCH

We speak of high pitch and low pitch of tones. The pitch of a tone depends upon the number of sound waves reaching the ear per second. Therefore, rapidly vibrating bodies produce tones of higher pitch than bodies which vibrate more slowly. This may be proved in many ways.

Experiment No. 22. Take two tuning forks, a long one and a short one. Set one into vibration, using method No. 1, page 18, and place it close to the ear. Note the tone. Now do the same with the other fork. You will find that the shorter fork gives a higher tone than the longer one. Since you already know that a short body vibrates more rapidly than a longer one, you can readily reason that the more rapid the vibrations the higher the pitch will be.

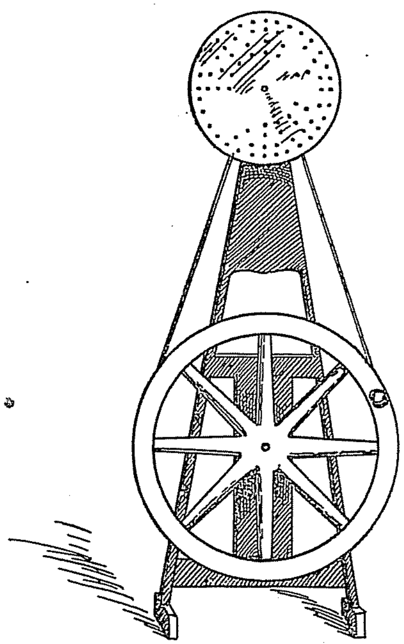

FIG. 37

Experiment No. 23. Use the apparatus described in Experiment No. 15 (Manometric Flames). While the mirror is revolving, sound first a high note then a low note near the megaphone. When the high note is sounded, the points on the band of light are closer together than when the low note is sounded. Since the mirror is revolving at the same speed in each case, we are forced to the conclusion that more sound waves are sent out per second in the case of the high note.

Experiment No. 24. By illustration (Figure 37) we show you a piece of apparatus that you can easily rig up for yourself and demonstrate with it the cause of differences in pitch of tones. Cut out a disc of metal about 12 inches in diameter. Lay out four concentric circles on this disc and punch holes in the metal so that around the four circles there will be sixteen, twelve, nine and six holes, evenly spaced. Set the disc up as shown, so that it can be rotated rapidly. While the disc is rotating, direct a stream of air, by means of a tube, toward one set of holes, then another. You will find that the highest pitch is obtained when the stream of air is directed toward the circle with the greatest number of holes. Since the holes in the disc permit air to pass through intermittently as the disc rotates, vibrations or air waves are set up, and their rate naturally depends upon the number of holes in the disc which pass by the air stream per second.

Have you ever noticed the bell or whistle on a locomotive which passes you rapidly? While the locomotive is approaching you, the whistle gives a high, shrill note. As the locomotive passes and goes away from you, the sound of the whistle changes to a note of lower pitch. This is due to the fact that, though the whistle is the same all the time, more sound waves reach the ear per second when the locomotive is approaching than when it is leaving you. As it is approaching, each succeeding sound wave produced by the whistle has a shorter distance to travel before reaching your ear. Hence, the sound waves as you receive them are crowded together. When the locomotive is going away, each succeeding sound wave from the whistle has further to travel before reaching you and the waves as you receive them are therefore spread out. Bearing in mind the appearance of the manometric flames in the case of the high tones and low tones, you will readily see the connection.

Experiment No. 25. Tighten a string on the monochord and, with the bridge at one end, cause it to vibrate. Note the tone. Move the bridge to the middle of the string (see Figure 38) and cause either half of the string to vibrate. This tone is higher than the first, is it not? If you have performed the experiment carefully, the second tone should be just an octave higher than the first. That is, if the first note was middle C, the second note should be high C. This is one of the laws about vibrating strings which Phagoras discovered long ago. **If you shorten a string to half its original length, it will produce a note one octave higher.** Likewise, by shortening a string to any degree at all, the pitch of the note produced will be increased in proportion. Isn't this just what a violinist does when he plays his violin? Watch his fingers.

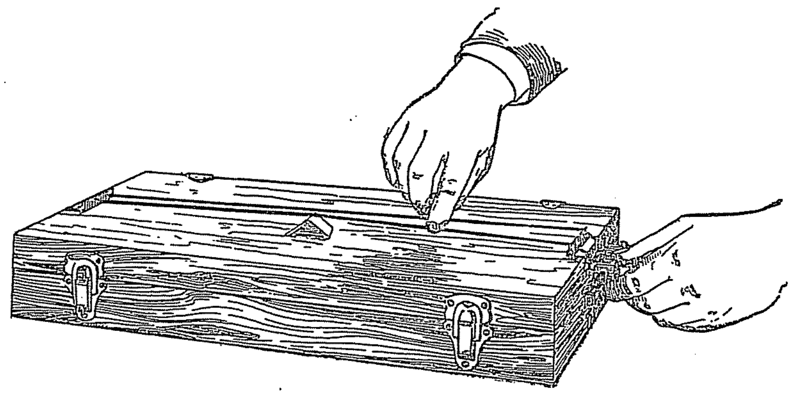

FIG. 38

Now recall the action of the pendulum. When we shortened the thread, we got a more rapidly vibrating pendulum. Therefore, we can conclude that when we shortened the string of the monochord we caused it to vibrate more rapidly, producing a note of higher pitch.

Experiment No. 26. Tighten a string on the monochord and cause it to vibrate. Note the tone. Now increase the tension of the string by taking part of a turn on the adjusting screw.

When the string is now vibrated it produces a higher tone than before. Isn't this just what the piano tuner does when he tightens the strings of a piano, or a musician in the orchestra, when he turns the thumb screws of his violin and "tunes up" before the concert? Other things being equal, then, the rate of vibration of a string is proportional to its tension.

Experiment No. 27. Stretch two strings on a monochord, one thick and one thin string. Tighten them to the same tension as nearly as possible and pluck them. The result will prove to you the third law of vibrating strings; other things being equal, the thicker the string, the more slowly it vibrates. Notice the strings on a violin, guitar or mandolin. The G string, which gives a low note, is very much thicker than the E string, for example, which produces the highest note on the instrument.

LIMITS OF AUDIBILITY

The limits of perceptible pitch vary a great deal with different individuals, but it has been estimated that there must be thirty vibrations per second in order to produce a continuous sound, and when these vibrations exceed 38,000 per second it has been determined that the sound becomes inaudible to the ear. Most of the musical sounds that we hear are produced by vibrations between 37 and 4,000 per second.

QUALITY

Everyone has his own idea as to the difference between noise and music. Classical musicians consider most musical comedy of the present day to be principally noise. Other persons, less critical perhaps, describe the sound of coal being shoveled into the basement as noise and the sound produced by a whistle, flute or piano, as music. In physics, a musical tone is defined as a sound whose waves are of a uniform character.

We are all more or less familiar with the different qualities of musical sounds, particularly that of voices. We speak of one person's voice as being rich and full. Another person may speak monotonously. This is the quality of tones. The cause of this difference in quality is due to the fact that sounding bodies

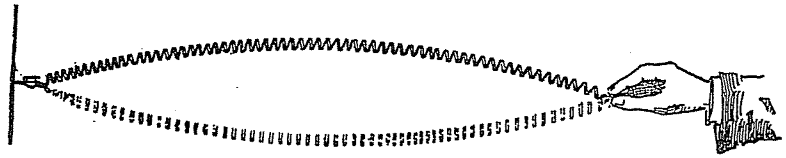

FIG. 39

vibrate as a whole and at the same time they vibrate in parts. This we are going to illustrate and explain to you in some interesting experiments on springs and strings. It is these vibrations and parts of vibrations that have to do with the quality of tone, and the tones produced by these vibrations inside of vibrations are known as overtones.

Experiment No. 28. Attach a spring by means of a hook to

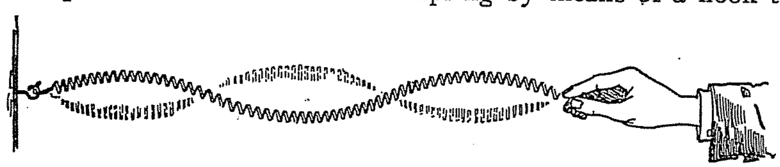

FIG. 40

the wall and set it in vibration as a whole. (See Figure 39 showing vibration as a whole). Now, by careful manipulation, you can throw it into vibration by halves, thirds and quarters. When it is vibrating in parts, these vibrations or points of vibrations are known as the loops (see Figure 40), and the points that do not vibrate are known as nodes. Now, as the two vibrations start, one at one end and one at the other, they meet in the

center. As the two movements are of the same velocity or strength, when they meet they neutralize each other and form a node.

STRINGED INSTRUMENTS AND THEIR NODES AND LOOPS

When a bow is drawn across the violin, it causes the strings to vibrate first as a whole and then it breaks into small vibrations just as the spring did in the last experiment. It is the vibrations of the string as a whole (shown in Figure 39) which causes the vital tones of sound and the other supplementary vibrations—those that we referred to as halves, thirds and quarters produce the overtones.

To get a clear idea of the nature of these secondary vibrations, which are more rapid than that of the string as a whole, consider the waves on a lake during a strong wind. You will see large, slowly changing swells, and, on top of them, little ripples that seem to dance.

Experiment No. 29. Make some very small paper washers and put them on a string of the monochord. Stretch the string and then cause it to vibrate by means of a violin bow. The interesting part of this experiment is that you will soon see the washers group themselves at certain fixed positions. These positions are the nodes and the washers gather there because the vibration is less at those points.

Experiment No. 30. The connection between nodes and loops of vibrating strings and the quality of the tones they produce may be strikingly demonstrated by an experiment that you can do on any good piano. If you are at all familiar with a piano, you know that when the keys are in their normal position, felt-covered dampers are resting on the strings so they cannot vibrate. When you strike a key, the damper is raised and remains away from the string as long as the key is held down, but when the key is released to its normal position, the damper falls back on the string, deadening its vibration.

First, hold down the keys for the following notes, not striking them, but holding the dampers away from the strings so they will be free to vibrate: C in the bass clef, the C one octave above that, and the E, G and B flat above that. Now strike loudly the low C below the bass clef and, after two or three seconds, release the key to its normal position. The fundamental tone produced by the key that was struck is silenced, but you now hear a soft, sweet chord made up of the five notes you held down but did not strike.

The explanation of this should be apparent to you now. The string which was struck vibrated in parts or sections, producing overtones. The phenomenon of sympathetic vibration then came into play and the strings that were held open were set into vibration, producing the same sounds as the overtones of the lower string. You should bear in mind that these overtones are present in tone from the low C string, but cannot be easily distinguished since the fundamental tone is so much louder. They add quality to what would otherwise be a simple tone.

Why a good piano makes better music than a cheap one is explained by the number and variety of its overtones, especially those of the lower notes. From the experiments with vibrating strings, you will realize that you can produce a given tone with a short, thick string or with a longer, thinner string. Now if you examine a good piano you will find it is overstrung—that is, the strings which produce the lower notes are strung diagonally across the other strings of the piano. The object of overstringing is to obtain greater length, and the object of length is to obtain more overtones. You can readily see that a long, thin string has more chance of vibrating in halves, thirds, quarters, etc., than a short, thick one. In cheaper pianos, all

strings are strung parallel and you do not get the richness of tone from them that you do in the case of a piano that is overstrung.

The fiddle string that can be made to laugh or cry has always been a source of wonder to people not acquainted with the scientific principles involved. In the first place, you must realize that, in the violin, we have a fine example of forced vibration. The tones from the instrument last only a very short time after the bow is removed from the strings. Also, a violin string without the violin gives a very weak and unpleasant sound. The bow sets the strings into vibration and the strings cause the violin itself to vibrate, amplifying and enriching the tones produced. This is why the construction of a violin is so important a factor in the quality of its music, and explains the great premium placed on instruments made by the old master, Stradavarius, over those made by less skilled workmen.

But, after all, the secret of the laughing or weeping suggested by tones from the violin lies in the bowing of the great player. The number, variety and arrangement of secondary vibrations (which produce the overtones) depend entirely upon how and where the string is bowed. These secondary vibrations are so complex and so changeable that it is almost impossible to describe them or to say when or where they begin or end, yet the great player has them under his control at all times, and is therefore able to do what cannot be done with any other musical instrument.

Experiment No. 31. The nodes and loops of vibrating plates may be illustrated in a very fascinating experiment. Procure several metal plates about 6 inches square. (See Figure 41.) Round plates may also be used. Fasten these plates securely, either by clamps at the edges or by putting rods through the center. Scatter fine sand or powder evenly over the plates and set them vibrating by the use of a violin bow. Draw the bow across the edges of the plates at different points and you will see the sand or powder arrange itself in lines, describing fantastic patterns on the plates. The spaces between the lines of sand are loops—areas of vibration—while the lines themselves

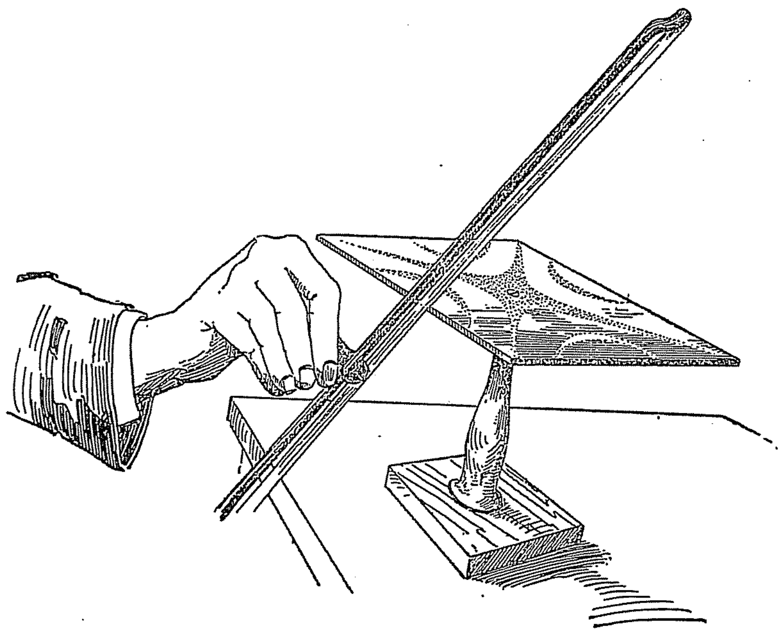

FIG. 41

are nodes, or points of rest. To complete the experiment, scatter some lycodium powder on the plates, together with the sand. Now, when the plates are vibrated, the powder will go to the places of greatest vibration instead of to the nodal lines, and will demonstrate the loops completely.

Experiment No. 32. Draw a bow across the top of a thin, cut-glass goblet filled with water (see Figure 42) and sift some powdered sulphur evenly over the top of the water. You will find a striking experiment, the water being covered with ripples proceeding from the several segments into which the vibrating body is divided.

Experiment No. 33. Take a thin, high-sounding cut-glass tumbler three-fourths filled with water. It is very important

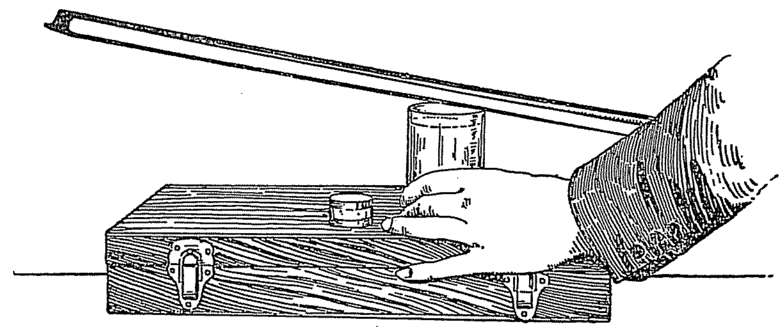

FIG. 42

to use a tumbler which has a good clear ring when vibrated. See that the circumference of the upper part is thoroughly dried and place on top of this, as in Figure 43, paper branches cut and bent at little angles. This will make it impossible for the paper to move off the glass when you produce certain vibrations. Now, by rubbing the surface of the glass with moistened finger, you can cause the glass to vibrate and emit musical tones. The intensely interesting part of the experiment is that if you rub your finger on the glass under one of the branches of the paper it will not move; therefore, the paper branches are the points where there is no vibration of the glass and would be known as nodes.

Now, if you vibrate the glass at a point between the branches, it will begin to move and turn about on the circumference of the rim of the glass as if some magic influence were at work, and

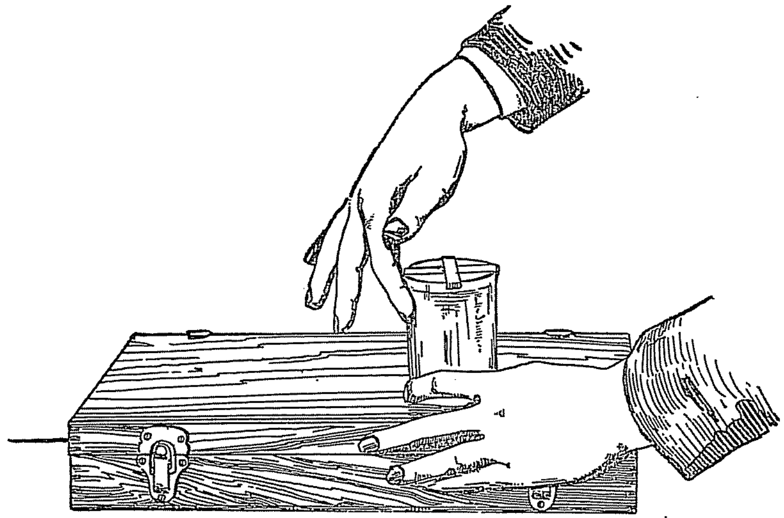

FIG. 43

this movement will continue until it reaches the point above that part rubbed by the finger.

NODES AND LOOPS OF COLUMNS OF AIR

Like the stringed instruments, air instruments have their loops and nodes. The loop is the point at which the motion of air particles is the greatest. The node is where the air is at rest. These may be demonstrated in a very striking manner.

Experiment No. 34. In one end of a glass tube, about 2 inches in diameter and 3 feet long, fit a cork piston **A** (see Figure 44) attached to the end of a small rod, so that it may move freely in

the tube. Close the other end of the tube with a rubber dam, **D.** Now attach a cardboard disc the size of the glass tube to the

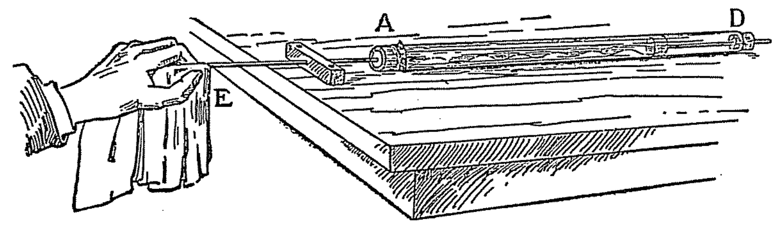

FIG. 44

end of a glass or steel rod, **E,** and clamp this rod firmly in the middle. Place the rod, **E,** so that the cardboard disc on the end just touches the rubber dam, **D,** across the end of the glass tube. Now set the rod, **E,** in longitudinal vibration by drawing a wet cloth, held firmly around the rod, from the center to the outer end. By pushing the cork piston, **A,** in or out, a position will be found where the air column enclosed in the tube will respond to the vibration of the rod. The air will then be set in such powerful vibration that any fine dust or powder in the tube will gather in heaps at the nodes, as it cannot remain in the loops, where there is a rapid vibrating movement of air particles.

In the illustration there are six loops, indicating that the rod makes six vibrations while the wave runs to the end of the tube and returns. The distance between the nodes is half a wave length and may be measured quite

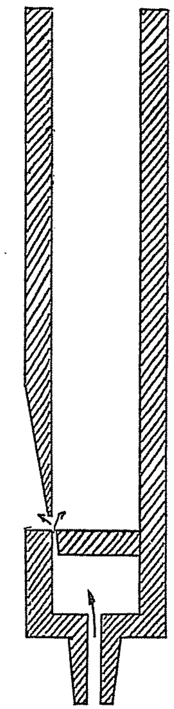

FIG. 45

accurately. You may now substitute some other gas for the air in the tube and repeat the experiment, again adjusting the position of the piston and measuring the distance between the nodes. In this way the velocity of sound in different gases may be determined. Since the rate of vibration of the rod is the same in each case, the velocity of sound in the gas will bear the same ratio to the velocity of sound in air as the distances between the nodes in the two cases.

Now let us study the action of organ pipes. Figure 45 represents a cross section of an open organ pipe. Air rushes from the small chamber through a narrow slit and strikes the edge directly opposite. At this point, small air waves are set up in much the same manner as ripples are produced on the up-stream side of a pile standing in a river or flowing tide. These air waves cause the stream of air coming up from the small chamber to be deflected alternately to the right and left, so that the entire column of air within the pipe is set into vibration, producing a strong, rich musical tone.

Chapter VI

REFLECTION, REFRACTION, INTERFERENCE AND RESONANCE

The reflection of sound is very interesting. In the experiment with the spring we demonstrated that in striking the spring the wave traveled to one end and, returning, the recoil was felt by the hand. Sound does exactly the same thing.

ECHO

An echo is nothing more than a reflected sound. Throw a ball against the side of a building so that it strikes at right angles. You know the ball will come straight back to you. Now if you hit the wall at any angle other than straight against the side, it will glance off. This is exactly what sound waves do when they hit a building or a hill. If they hit at right angles the sound will be reflected back to you, and this is called an echo. We know that sound waves may act like the ball striking something at an acute angle and glancing off, in which case they will not revibrate back and do not make an echo.

MULTIPLE ECHOES

When you make a sound between two hills the echo may be repeated many times—that is, it rebounds from one hill to the other, etc., producing a number of echoes.