until the music becomes painfully shrill. Diminish the speed, and the pitch falls.

To find, therefore, the number of vibrations in a given sound, force the air through the siren until the required pitch is reached. See on the dial, at the end of a minute, the number of revolutions of the disk. Suppose the number of holes in a disk to be 10, and the tone produced to be in unison with that of a C_3 tuning-fork. The number of revolutions indicated on the dial at the end of a minute is found to be 1,536. There were 10 puffs, or 10 waves of sound, for each revolution. 1,536 × 10 = 15,360. Dividing this by 60, we have 256, the number per second. Increasing now the blast until the tone produced is in unison with a C_4 tuning-fork, the octave above the first, the number of vibrations per second is found to be 512. Hence the *octave* of a tone is caused by double the number of vibrations.

(4.) To Find the Length of the Wave.—Suppose the air in the last experiment was of such a temperature that the foremost sound-wave traveled 1,120 feet in a second. In that space there were 256 sound-waves. Dividing 1,120 by 256, we have $4\frac{3}{8}$ ft. as the length of each. We thus find the wave-length by dividing the velocity by the number of vibrations per second. As the pitch is elevated by rapidity of vibration, we perceive that the low tones in music are produced by the long waves and the high tones by the short ones.*

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* The aerial waves are seemingly shortened when the source of sound is approaching, whether by its own motion or the hearer's, and lengthened

(5.) Tones in Unison.—If the string of a violin, the cord of a guitar, the parchment of a drum, and the pipe of an organ, produce the same tone, it is because they are executing the same number of vibrations per second. If a voice and a piano perform the same music, the steel strings of the piano and the vocal cords of the singer vibrate together and send out sound-waves of the same length.

6. Interference of Sound-waves. — Just as two water-waves by meeting in opposite phases may destroy one another, so by a proper adjustment two sound-waves may be made to interfere, and, if exactly equal and opposite, to produce silence. Fig. 126 represents a piece of apparatus intended to show this. Let a tone, such as C_3, be sounded in the mouth-piece at *a*. The waves divide at the end of the first India-rubber tube and reunite on entering the second, before entering the ear at *b*. One branch of the channel is made of two tubes, one of which slides over the other so that the branch may be lengthened at will. If it be pulled up so high that the waves passing through it shall traverse a half wave-length more in distance than those in the fixed branch, opposite phases will meet where they reunite, and the list-

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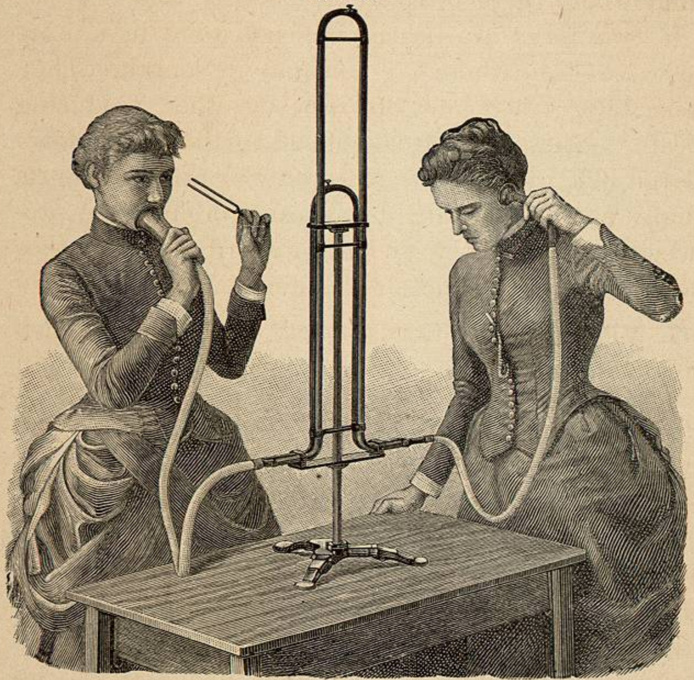
when it is receding. In the former case, the tone of the sound is more acute; in the latter, graver. This is strikingly illustrated when a swift train rushes past a station, the whistle blowing. While the cars are approaching, a person hears a note somewhat sharper; after it has passed, one somewhat flatter than the true note. Still more obvious is the change when two trains pass each other. A person unfamiliar with the arrangement would suppose a different bell was rung. In one case more and in the other fewer waves reach the ears in a second.

ener notices great weakening of the sound. By proper handling, the sound received may be made to become alternately strong and weak without any change in the sound given.*

FIG. 126.



Tube for Interference of Sound.

If we strike a tuning-fork and turn it slowly around before the ear, we shall find four points where the interference of the sound-waves causes

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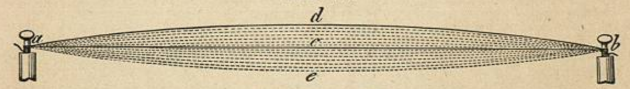
* We can not produce complete extinction because, 1. The sound is conducted not only by the inclosed air, but by the solid tube also; 2. There is loss by friction in the longer branch; 3. There is loss by leakage between the tubes that slide against each other.

great weakening. The two prongs swing alternately toward and from each other. When a condensation is produced between the prongs, a rarefaction is produced on their outer sides. Certain lines can be found where these interfere.

If two forks are nearly but not quite in unison, the waves from them are unequal in length. They alternately conjoin and oppose each other, producing "beats." These are often noticed in the sound from a large bell, the opposite sides of which are not quite equally elastic. A pair of mistuned organ-pipes produces a similar effect, and the discord of an inferior piano, or indeed all discord, is due to beats.

7. Vibrations of Cords.—Let *ab* be a stretched cord made to vibrate. The motion from *e* to *d* and back again is termed a *vibration;* that from *e* to *d*, a *half-vibration.* The distance, *cd*, from the middle to either of the extreme positions is the *amplitude.*

FIG. 127.

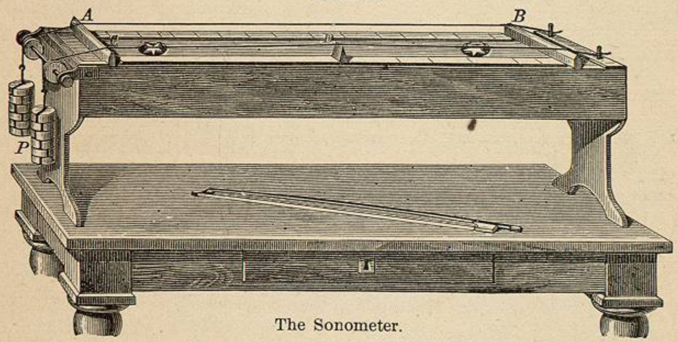


Vibrating Cord.

(1.) THE SONOMETER is an instrument used to investigate the laws of vibration of stretched cords. It consists of two cords stretched by weights, *P*, across fixed bridges, *A* and *B*. The movable bridge, *D*, serves to lengthen or shorten the vibrating part of either cord. Beneath is a resonance box, to which the vibrations are conducted by the bridges. This is the body whose sound is chiefly heard.

(2.) THREE LAWS.—I. *The number of vibrations per second increases as the length of the cord decreases.* By plucking the cord with the finger, or drawing a violin bow across it, make it vibrate, giving the note of the entire string. Place the bridge *D* at the center of the cord, and the sound will be the *octave* above the former. Thus, by taking one half the length of the cord we double the number of vibrations.—*Examples:* If an entire cord make 20 vibrations per second, one half will make 40, and one third, 60.—The violin or guitar player elevates the pitch of a string by moving his finger, thus shortening the vibrating portion.—In the piano, harp, etc., the long and the short strings produce the low and the high notes respectively.

FIG. 128.

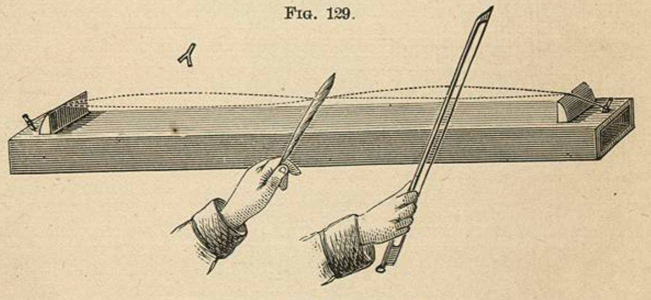


The Sonometer.

II. *The number of vibrations per second increases as the square root of the tension* The cord when stretched by 1 lb. gives a certain tone. To double the number of vibrations and obtain the octave requires 4 lbs. Stringed instruments are provided with keys, by which the tension of the cord and the corresponding pitch may be increased or diminished.

III. *The number of vibrations per second decreases as the square root of the weight of the cord increases.* If two strings of the same material be equally stretched, and one have four times the weight of the other, it will vibrate only half as often. In the violin the bass notes are produced by the thick strings. In the piano fine wire is coiled around the heavy strings to increase their weight.

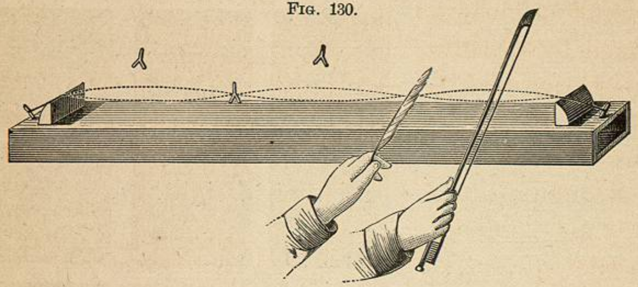
FIG. 129.



Production of Two Segments.

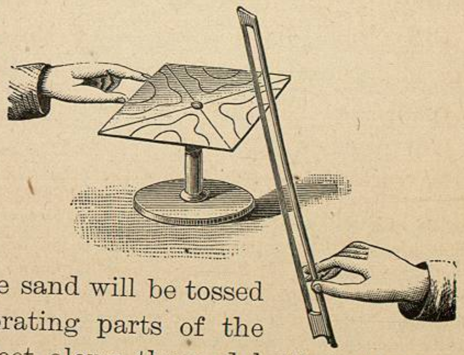
(3.) NODES.—In the experiments just described, the cord is shortened by means of a firm, movable bridge. If, instead, we rest a feather lightly on the string, and draw the bow over one half, the cord will vibrate in two portions and give the octave as before. Remove the feather, and it will continue to vibrate in two parts and to yield the same tone. We can show that the second half vibrates by placing across that portion a little paper rider. On drawing the bow it will be thrown off. Hold the feather so as to separate one third of the string and cause it to vibrate; the remainder of the cord will vibrate in two segments. When the feather is removed, the entire cord will vibrate in three different parts of equal length, separated by stationary points called *nodes*. This may be shown by the riders; the one at the node remains, while the others are thrown off.

Fig. 130.



Production of Three Segments.

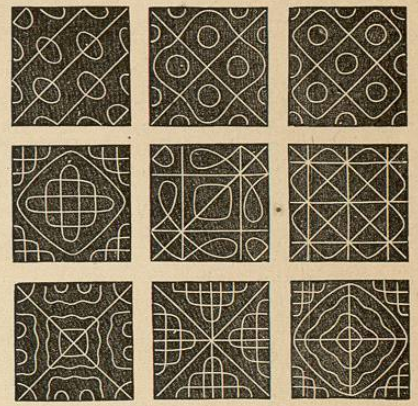
Fig. 131.



Vibration of a Plate.

(4.) Acoustic Figures.—Sprinkle fine sand on a metal plate. Place the finger-nail on one edge to stop the vibration at that point, as the feather did in the last experiment, and draw the bow lightly across the opposite edge. The sand will be tossed away from the vibrating parts of the plate and will collect along the nodal lines, which divide the large square. It is wonderful to see how the sand will seemingly start into life and dance into line at the touch of the bow. Fig. 132 shows some of the beautiful patterns obtained by Chladni.

Fig. 132.



Chladni's Figures.

(5.) Harmonics.*—Whenever a cord vibrates, it separates into segments at the same time. Thus we have the full or *fundamental* note of the entire string, and superposed upon it the higher notes produced by the vibrating parts. These are called *overtones* or *harmonics*. The mingling of the two classes of vibrations determines the *quality* of the sound, and enables us to distinguish the music of different instruments.

(6.) Nodes of a Bell.—Let the heavy circle in Fig. 133 represent the circumference of a bell when at rest. Let the hammer strike at *a*, *b*, *c*, or *d*. At

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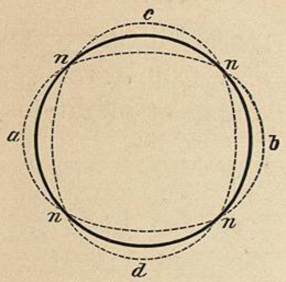
* Press gently but firmly down the notes C, G, and C, in the octave above middle C, on the piano-forte. Without releasing these keys, give to C below middle C a quick, hard blow. The damper will fall, and the sound will stop abruptly. At the same instant a low, soft chord will be heard. This comes from the three strings whose dampers are raised, leaving them free to sound in sympathy with the overtones of the lower C, which sounds are identical with their own.—When a goblet or wine-glass is tapped with a knife-blade, we can distinguish three sounds, the fundamental and two harmonics.

one moment, as the bell vibrates, it forms an oval with *ab*, at the next with *cd*, for its longest diameter. When it strikes its deepest note, the bell vibrates in four segments, with *n*, *n*, *n*, *n*, as the nodal points, whence nodal lines run up from the edge to the crown of the bell. It tends, however, to divide into a greater number of segments, especially if it is very thin, and to produce harmonics. The overtones which accompany the deep tones of the bell are frequently very striking, even in a common call-bell, and often make it hard to determine at once what is its fundamental. Usually they die away sooner than the fundamental.

Fig. 133.



Vibration of a Bell.

(7.) Nodes of a Sounding-board.—The case of a violin or guitar is composed of thin wooden plates which divide into vibrating segments, separated by nodal lines according to the pitch of the note played. The inclosed air vibrating in unison with these, re-enforces the sound and gives it fullness and richness.

(8.) Musical Scale.—The lowest tone that can be distinctly perceived as musical by most ears is produced by 32 vibrations per second. This is called C_0. The octave above this is C_1, 64 vibrations; the double octave, C_2, 128 vibrations, etc. If a string be stretched so as to give C_2, the tones of the common musical scale between this and C_3 are obtained from

the parts of the string indicated by the following fractions:

C_2	D_2	E_2	F_2	G_2	A_2	B_2	C_3
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

As the number of vibrations varies inversely as the length of the cord, we have only to invert these fractions to obtain the relative number of vibrations per second; thus,*

C_2	D_2	E_2	F_2	G_2	A_2	B_2	C_3
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
128	144	160	170	192	214	240	256

8. Vibration of Columns of Air.—If a tuning-fork be excited and its prongs be held before the open end of a tube of proper length, the sound will become much louder. If the pitch of the fork is C_4, 512 vibrations, the length of such a tube, open at both ends, is about 13 inches; if open at only one end, 6½ inches. A hollow globe of proper size, with an opening on one side, will respond in like manner. Such bodies are called *resonators*.

9. Wind Instruments produce sounds by the vibration of the columns of air which they inclose. An organ-pipe is merely a tube-resonator. The sound-

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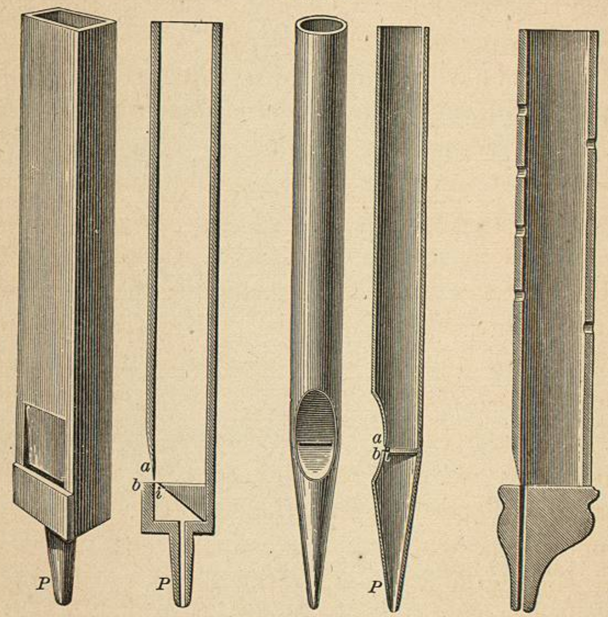
* In this table, "$C_3 = 256$ vibrations" represents the middle C of a piano-forte. This number is purely arbitrary. The so-called "concert-pitch" varies in different countries. The Stuttgart Congress of 1834 fixed the standard tuning-fork—middle A—at 440 vibrations per second, which would make middle C = 264; while the Paris Conservatory (1859) gave to middle A 437.5, and to middle C 261. The common English tuning-fork represents C_4, and makes 528 vibrations, the pitch being the same as the Stuttgart. The ratio of the different numbers is identical, whatever the pitch.

waves in organ-pipes are set in motion by either fixed mouth-pieces or vibrating reeds. The air is forced from the bellows into the tube *P*, through the vent *i*, and striking against the thin edge *a*, produces a flutter. The column of air above, thrown into vibration, re-enforces the sound and gives a full musical tone. The length of the pipe, if open, should be ½ wave length corresponding to the pitch to which it responds; if closed, ¼ wave length. If a tuning-fork which produces this pitch be held at *b* while vibrating, the sound will at once become much stronger.

Fig. 134.



Organ-pipes.

The air co-vibrates, whatever may be the source of sound, if only the pitch be properly adjusted.

10. Co-vibration.—We have already seen (p. 158) how one tuning-fork may co-vibrate with another through the medium of the air. Vibrations thus produced are often called *sympathetic*, and bodies which thus strengthen sound are said to be *resonant*. Produce a musical tone with the voice near a piano, and a certain wire will seem to select that sound and respond to it. Change the pitch, and the first string will cease, while another replies. If a hundred tuning-forks of different tones are sounding at the foot of an organ-pipe, it will strengthen the sound of the one to which it can reply, and answer that alone. Helmholtz has applied this principle to the construction of the *resonance globe*, an instrument which will respond to a particular harmonic in a compound tone, and strengthen it so as to make it audible.

(1.) Sensitive Flames.—Flames are sensitive to sound. At an instrumental concert the gas-lights vibrate with certain pulsations of the music. This is noticeable when the pressure of gas is so great that the flame is just on the verge of flaring, and the vibration of the sound-wave is sufficient to "push it over the precipice."*

(2.) Singing Flames.—If we lower a glass tube over a small gas-jet, we soon reach a point where

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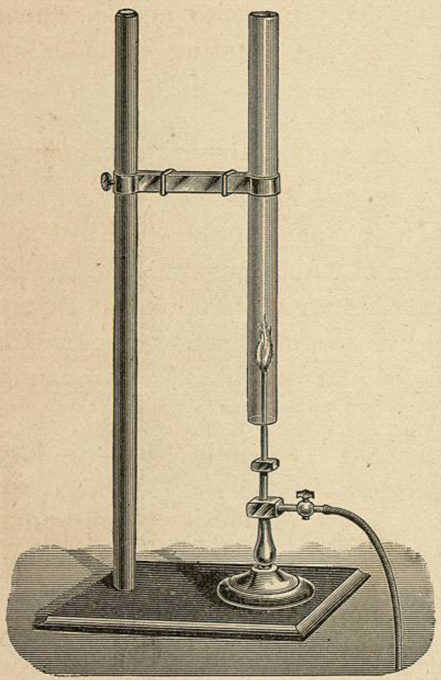
* Prof. Barrett, of Dublin, describes a peculiar jet which is so sensitive that it trembles and cowers at a hiss, like a human being, beats time to the ticking of a watch, and is violently agitated by the rumpling of a silk dress.

the flame leaps spontaneously into song. At first the sound seems remote, but gradually approaches until it bursts into an almost full song. The length of the tube and the size of the jet determine the pitch of the note.* The flame, owing to the friction at the mouth of the pipe, is thrown into vibration. The air vibrates in unison with the jet, and, like that in the organ-pipe, selects the tone corresponding to the length of the tube.

Fig. 135.



Singing Flame.

11. The Phonograph is an instrument for recording and reproducing the vibrations of sound. Its essential features are as follows:

(1.) A metallic cylinder which can be rotated on a screw as axis, so as to secure motion that is sideward as well as rotary.

(2.) A hollow cylinder of wax which fits over the

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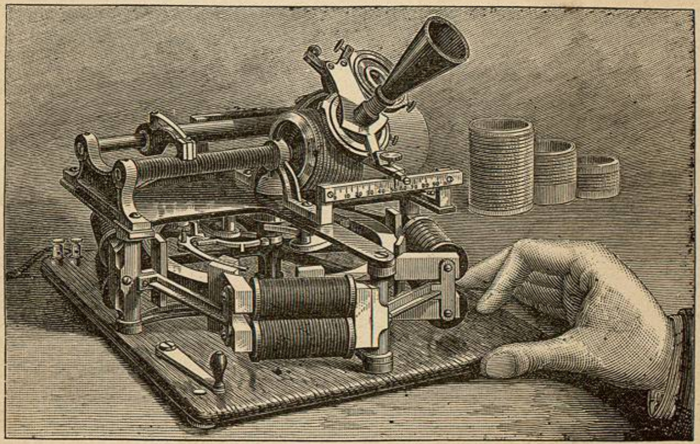
* The jets are easily made by drawing out glass tubing to a fine point over a spirit-lamp.

metallic cylinder, and may be removed after receiving impressions from a source of sound.

(3.) A mouth-piece into which the speaker vocalizes. At the bottom of this is an elastic disk, which is set into vibration by the voice.

(4.) A lever which is actuated by the disk. At one end of it is a specially prepared needle, which makes indentations upon the rotating cylinder of wax.

Fig. 136.



The Phonograph.

After the line of indentations has been made on the wax, the cylinder is brought back to its first position. On turning it, the needle, pressing on the serrated surface, receives vibratory motion like that which had been given it by the voice. This is received by the disk, and the instrument thus talks out what had been talked into it.