explanation of its mode of action. The brass bar is made so as to move from side to side, under the influence of slight impulses. The rocker is heated, and on placing it upon this cold lead block, you at once hear a musical note. By pressing on the rocker with the point of a pencil the pitch of the sound is made higher, and any variations in the pressure, however slight, give rise to a corresponding change in pitch.

The origin of this singular sound is not difficult to account for. As soon as one side of the heated bar touches the lead, it induces, by communication of heat, sudden expansion of the part touched, which causes a tilting of the bar itself. This process is repeated from side to side, giving the bar a sufficiently rapid rocking, or vibratory motion, to produce the sound emitted. The sound may be made to vary with the size, form, weight, and arrangement of the bar, but it is in all cases the result of a more or less rapid oscillatory motion.

I turn now to an entirely different method of producing sound. In this case the motion required for the eliciting of an audible note takes the form of a rapid succession of puffs of air. On the rotator just used there is, in addition to Savart's wheel, a disk of brass having near its circumference a number of equidistant orifices. The instrument in this form was designed by Seebeck, and with it, under various forms, he made many interesting experiments. A modified form of the siren, together with the tuning-fork, will, as you shall see in our subsequent lectures, constitute our most efficient aids in elucidating the mysteries of sound. Bringing the nozzle of a small tube, connected with an acoustic bellows, over the circle of perforations of the disk, and causing the disk to revolve, you hear, when the air escapes from the bellows through the tube, first a succession of puffs, and then, as the wheel revolves more rapidly, the sound becomes more shrill, and reminds one of the weird wailing of the wind on a dark wintry night.

I hold in my hand a little instrument called the mill-siren of Cagniard de Latour. It is essentially a cylindrical tube

of brass, at the end of which is a revolving fan. When one blows into the mouthpiece the fan is made to revolve. The fan thus renders the current of air intermittent, and we have produced, therefore, the vibratory motion which, as we have seen in the preceding experiments, is the necessary precursor of sound. By increasing the blast of air the speed of the fan is accelerated, and the pitch is heightened as in the case of the siren just used.

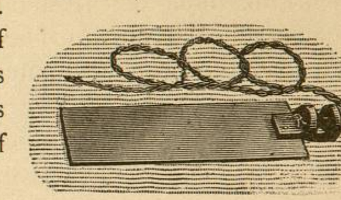

FIG. 10.

There is but one step from the mill-siren to a very simple and primitive instrument, to which I wish now to direct your attention. I show it to you to emphasize what I have thus far been insisting on, — namely, that sound externally to the ear is merely a mode of motion, and that when motion is properly timed, sound is always the result.

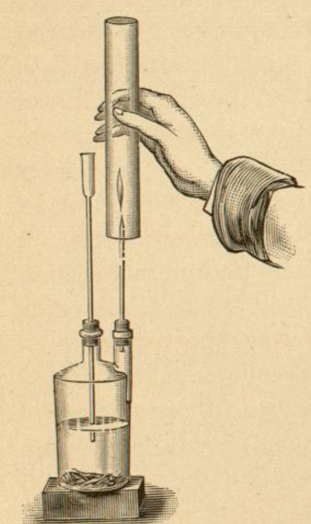

FIG. 11.

The instrument referred to is called a musical sling, and consists of simply a thin plate of metal (Fig. 10) about three by six inches in size, and attached to a string. I take hold of the string and give the plate a whirling motion, making it describe a circle in the air. The resistance of the air causes the plate rapidly to revolve around its longer axis, and to give forth, first a flutter, and then the more acute musical sound which is distinctly audible in every part of the room.

A more interesting way of throwing the air into periodic pulsations is by means of a jet of burning gas, preferably hydrogen. On introducing an ignited jet of this gas into a glass tube (Fig. 11) there is at once heard a note of singular purity and power. By causing a cubical mirror to revolve near the tube, we can see that the flame is rapidly extinguished and rekindled; and this rapid extinction and rekindling it is that causes the aërial column within the tube to vibrate so as to emit the sound you all hear. Such a flame is called a singing flame, and we shall have occasion to investigate it more in detail in a subsequent lecture.

Wertheim has taught us how we may vary our experiments by using electricity as an agent for producing the vibratory motion necessary to generate sound. We have here (Fig. 12) an iron bar firmly clamped in the middle to a solid metal stand. Around one of the ends of the rod

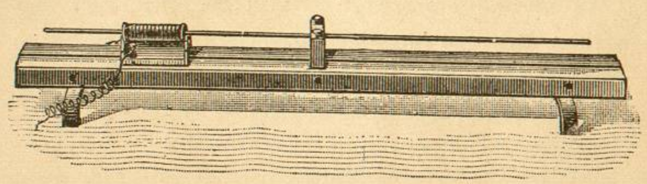

FIG. 12.

is placed a coil of insulated copper wire, through which may be sent a current of electricity. We allow a current from a battery to pass through the coil, and then intercept its flow by breaking the circuit. Every time the circuit is closed or broken, a faint sound is the result. When the current is passing through the bobbin the bar is magnetized; but as soon as the current ceases to flow, on account of the conductor being disconnected, the bar loses its magnetism. The alternate magnetization and demagnetization of the bar throw its molecules into such a state of vibratory motion that it at once becomes perceptible as sound.

A still more interesting sound-producer is the radiophone, a simple form of which is before you. In a test-tube is placed a small tube of brass covered with lampblack. Through the perforated disk on the rotator,

intermittent flashes of heat, converged by a concave reflector from the gas jet, are allowed to impinge on the soot-covered brass tube. This, by producing rapid changes in temperature, causes corresponding expansions and contractions in the metal tube, and a continuous sound follows in consequence. The pitch of the sound depends on the number of flashes made to impinge on the tube. The more rapid the revolution of the disk, the greater the number of flashes of radiant energy, the higher the pitch of the resulting note.

M. Mercadier has devised a more elaborate instrument (Fig. 13), by means of which we can get the four notes of

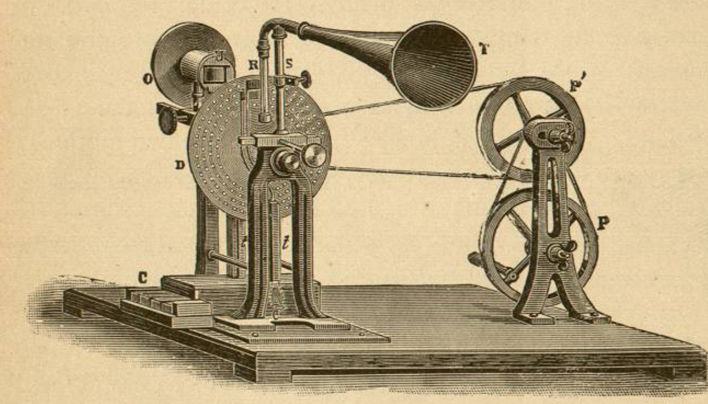

FIG. 13.

the perfect major chord[1] by pressing on suitable keys at *C*, connected with *t t*. By converging a beam of light through *O U*, from a powerful electric lamp on the soot-covered brass tube *R*, and reinforcing by a trumpet-shaped resonator, *S T*, the notes emitted, we can, by rotating, by means of the pulleys, *P P′*, the perforated wheel, *D*, with sufficient velocity, elicit notes that can be perceived at a considerable distance from the instrument.

In the experiments so far made we have seen a few of the many ways in which sound may be generated. In some cases it is directly caused by friction, as when a bow

[1] See chapter x., on Intervals, etc.

is used. In other instances it is produced by taps or puffs, as when Savart's wheel or the siren is used, or by a series of rapid explosions, as was observed in the singing flame. In others, still, the sounds elicited have their origin in rapid molecular motions induced by the intermittent action of heat or electricity.

In all cases motion precedes and accompanies sound. It appears sometimes as segmental mass-motion, when a part or a whole of the sound-producing body, divided into a greater or less number of segments, is seen to be in a state of rapid oscillation. More frequently, the motions which give rise to audible notes are nearly or entirely invisible. In the latter cases it is molecular rather than mass-motion — the motions of the molecules or ultimate particles of the vibrating body, rather than those of the vibrating body, considered as a whole — that is the cause of sound. We may not, however, separate the two motions, as they are always, to a greater or less extent, concomitant in all cases where sound is produced. Molecular motion gives rise to mass motion, and *vice versa.* In all cases under discussion one necessarily depends on the other. When, for instance, the tuning-fork is excited by the bow, the whole mass of the fork is set in periodic vibration, — a motion which would be impossible, were it not for the elasticity of the steel, — and at the same time there is a corresponding tremor of the smallest particles, the molecules, of which the fork is composed.

The physical cause, then, of sound is motion, — in all cases motion. If this one fact is duly appreciated, a great advance is made towards properly understanding what will follow.

We are now prepared to answer a question that must have suggested itself to all of you ere this; that, is, "What is the difference between a musical and a non-musical sound, between a musical sound and noise?" As a sensation, every one can, under ordinary circumstances, distinguish one from the other. The extremes of musical and non-musical sounds are easily separated.

But there are many instances in which the separation is not so easy.

Physically, musical sounds, as Helmholtz tells us, are always produced by periodic vibrations, noises by non-periodic vibrations.

But musical sounds may be so combined as to produce a noise. If, for instance, one were to sound simultaneously all the eight notes of the gamut on a piano or harmonium, the result would be designated as a noise, although each of its components, taken separately, is recognized as a musical note. Similarly, what is usually regarded as a noise may be shown to be, in reality, a distinct musical sound. In my hand is a small piece of wood, which I let fall on the table. Certainly no one would think of calling the sound musical. And yet it does possess quite a marked musical character when one's attention is properly directed to it, and when the sound is compared with others of the same kind in a proper sequence.

When the same piece of wood is dropped again, and, in succession, seven others of gradually decreasing size, you at once recognize the notes of the gamut. Choosing three from the number, and allowing them to fall on the table as before, you distinguish a series of sounds that constitute, in music, the perfect major chord. If all three are let fall at once, the sound is still agreeable.

The sounds thus generated are not, if you will, as pure as those furnished by the harp or the flute, but they must be classified as musical, and are, indeed, used in music. The instrument known as a xylophone is made up of just such pieces of wood. Substituting metal bars for wood, we have the well-known instrument called the metallophone. Pieces of glass or compact stone, like slate, might be used, and these would give us what are known as glass or rock harmonicons. The Chinese, in an instrument called the *king*, use pieces of flint suspended from cords, and by striking the flints they manage to elicit from them quite agreeable music. The well-known "Anvil Chorus" is another illustration of how what are ordinarily reckoned as noises, may be made to do service as music.

But we may go still farther. When a cork is drawn from a bottle you hear a quick, explosive report. Surely no one would call this a musical sound. Let us compare it with a proper sequence of similar sounds. Drawing corks from these three bottles, whose sizes vary according to a fixed ratio, we have three sounds of different pitch produced. Every one near recognizes the same sequence of sounds as was produced with the three wooden bars. The sounds are unmistakably those of the major chord. With a sufficient number of properly tuned bottles a skilful performer could, by merely withdrawing the corks, easily evoke a simple melody that every one would recognize.

Koenig has devised an interesting piece of apparatus (Fig. 14), in which sounds are elicited in the manner just illustrated. Here, instead of bottles, we have four brass tubes attached to the same base, and furnished with accurately fitted pistons. When these are withdrawn in succession, you hear the notes C_3, E_3, G_3, C_4, constituting the perfect major chord.[1]

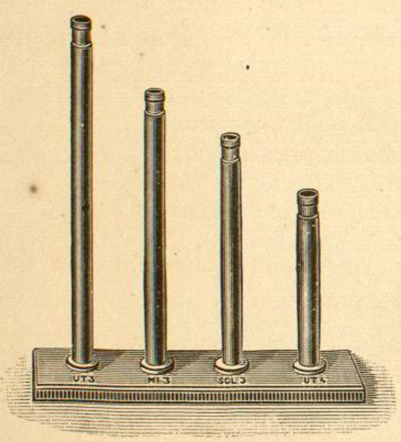

FIG. 14.

From these experiments it is obvious that the line of demarcation between musical sounds and noises is not so easily drawn as one might imagine. Dr. Haughton gives an excellent illustration of the truth of this statement. "The granite pavements of London," he says, "are four inches in width, and cabs driving over this, at the rate of

[1] See Appendix I. for value in musical notation of the notes here mentioned.

eight miles an hour, cause a succession of noises at the rate of thirty-four in the second, which corresponds to a well-known musical note that has been recognized by many competent observers; and yet nothing can be imagined more purely a noise or less musical than the jolt of the rims of a cab-wheel against a projecting stone. Yet if a regularly repeated succession of jolts takes place, the result is a soft, deep, musical sound that will bear comparison with notes derived from more sentimental sources."

So, too, we may hear musical notes in the plashing of a fountain, the roar of a cataract, the murmur of a river, the howling of the wind, the hum of machinery, the rumble of a railway train passing over a bridge or through a tunnel, and in the complex result occasioned by the manifold noises of a neighboring city. Carlyle, therefore, tells a profound truth when he says, "See deep enough, and you see musically; the heart of Nature being everywhere music, if you can only reach it." Byron expresses the same idea still more elegantly when he sings, —

> "There 's music in the sighing of a reed;
> There 's music in the gushing of a rill;
> There 's music in all things if men had ears, —
> Their earth is but an echo of the spheres."

Equally true, and almost equally beautiful, are the following lines of another poet: —

> "We have not heard the music of the spheres,
> The song of star to star; but there are sounds
> . . . .
> That Nature uses in her common rounds, —
> The fall of streams, the cry of winds that strain
> The oak, the roaring of the sea's surge, might
> Of thunder breaking off afar, or rain
> That falls by minutes in the summer's night:
> These are the voices of earth's secret soul,
> Uttering the mystery from which she came."[1]

We do not hear many of the musical sounds that keep the atmosphere in a state of constant tremor, because we

[1] Archibald Lampman, in "Scribner's Magazine."