the state of equilibrium of an elastic body is disturbed by a shock or by friction, it tends to regain its condition of equilibrium, but does so only after a greater or less number of vibrations, or oscillatory movements, of the molecules of which the mass of the body is composed.

We are now prepared to show that in all cases where the sensation of sound is produced, motion is a necessary antecedent, and is always the efficient cause. Before going any farther, however, permit me to explain a few terms of constant recurrence. The term *vibration* has been used several times, and this term must be defined first of all. It is, too, more frequently used than any other, and when employed in connection with sound it has a very precise and definite signification.

A movement of a particle, or molecule, to *and* fro constitutes what is called a *complete* or *double vibration*, and is the kind of vibration I shall always speak of, unless otherwise stated. In France, however, a movement of a particle to *or* fro is called a vibration. This we should denominate a *single*, or *semi-vibration*. It is also called an *oscillation*. Newton measured by double vibrations, whereas Chladni always used single, or semi-vibrations.

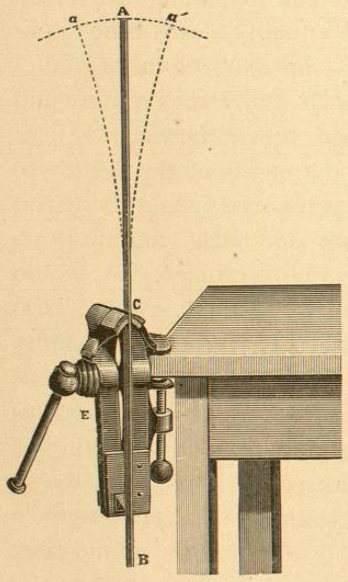

FIG. 1.

Let me illustrate. In a vice, E (Fig. 1), is fastened an elastic steel strip or bar, $B\ C\ A$. Drawing the free end aside to a, and letting it go, the elasticity of the strip will carry it back to its original position A; but the energy now stored up in it will cause it to move onward to a', nearly as far from A as a is. At a and a' the motion, as is evident, will be *nil*, while at

A, intermediate between a and a', its velocity will be at a maximum. At points between aA and Aa' the velocity will be accelerated or retarded, according as the strip moves to the right or the left.

Once started, the bar will continue to move to and fro for some time, the distance through which it passes gradually decreasing, until it finally comes to rest. The motion from a to a' constitutes a single vibration; that from a to a' and return, is a complete vibration. The time required for executing a complete vibration is called its *period*,[1] and when a motion always returns to the same condition after equal intervals of time, it is said to be *periodic*. The distance through which any particle of the bar moves, as from a to a', is called the *amplitude* of vibration. The movements themselves are of the kind called *vibratory*.

The period of the successive vibrations of an oscillatory, or sounding, body, like those of the pendulum, are equal. The term used to express this equality of periodic vibration is *isochronous*.[2] Thus two or more vibrations, executed in the same time, are said to be *isochronous*, and the motions themselves are said to *synchronize*. In the case before us, the vibrations, by reason of the length of the strip, may be perceived by the eye. As the strip is shortened, however, the amplitude of the vibrations is lessened, and they also become so rapid as to be no longer visible. But if we cannot see them, we can hear them. A musical sound is the result of the vibratory motion communicated to the strip, and you will observe that as the length of the strip is shortened, the pitch of the sound it emits becomes higher and higher.

In the experiment just made, you have seen how a vibrating body may generate sound. In the place of a straight strip, or bar, let me take a bent one mounted on

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[1] Mersenne appears to have been the first to employ this term — Latin, *periodus* — in the sense here indicated, in his *Harmonicorum Libri.*

[2] This is the word — ἰσόχρονοι — used by Mersenne, *Harm. Lib. ii.*, Prop. 29, in which the law of synchronism is discussed. It is from the Greek ἴσος, equal, χρόνος, time.

a box (Fig. 2). The bar thus fashioned is called a tuning-fork, and is the most useful instrument the student of acoustics has at his command. The box reinforces the sound produced by the fork for a reason we shall see later on.[1]

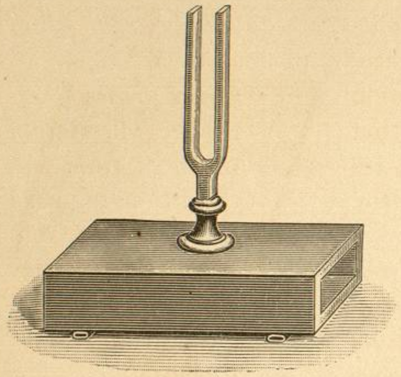

FIG. 2.

When a violin-bow is drawn across the end of one of the prongs of the fork, a loud, clear note is produced. You cannot, however, see the motion of any part of the fork, although every part of it, as well as of the box, is in a condition of violent oscillation. By touching one of the prongs, or even the box, one can feel the tremors that agitate them and give rise to the sound that fills the room. Permit me now to give you a simple proof of the existence of these unseen vibrations.

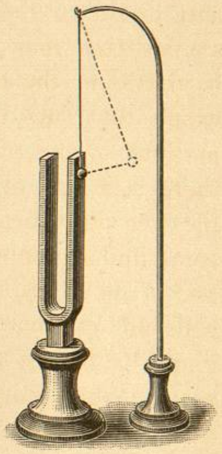

FIG. 3.

Close beside one of the prongs of the fork (Fig. 3) is suspended a small pith ball. Exciting the fork as before, you again hear the sound emitted, and you remark at the same time that the pith ball is thrown aside with considerable force. Every time it comes in contact with the fork it is violently repelled. Here, as in the case of the vibrating bar, sound is a concomitant of motion. And although the rapidity and small amplitude of the vibrations prevent them from being directly perceived by the eye, the repulsion of the ball, when it comes in contact with the fork, leaves us in no doubt as to their existence. Holding a lead pencil against one of the prongs gives the same results. The loud clatter that follows, assures us of the reality of the motion of the sonorous body.

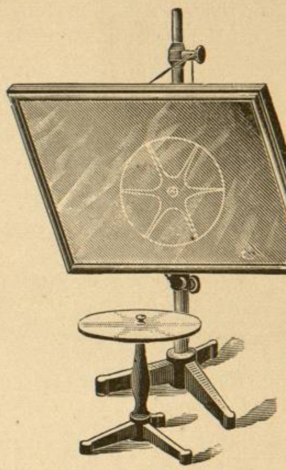

FIG. 4.

We may now go a step farther. Instead of a bar of steel I shall take a circular plate of brass (Fig. 4), mounted on a heavy iron support. On agitating the plate with the bow, a very marked sound is heard, and, in the case of the lowest sounds that may be produced, the motion of the plate is visible to the eye. When, however, the higher notes which the plate is competent to yield are sounded, the motions of the plate are lost to the unaided vision. But there is a way of showing their presence in a most simple yet most beautiful and striking manner. Strewing some find sand upon the plate, and drawing the bow across one of its edges, we not only evoke a musical sound, but call into existence, as if by magic, a figure of the most exquisite design and symmetry. The mirror behind the plate enables you to see the figure by reflection. Each note, as we shall see in its proper place, has its characteristic figure.

It would be easy to fashion this plate into a bell, as a tuning-fork is made, by bending, out of a straight bar. Instead of taking a metal bell, it will answer our present purpose much better to have one of glass. Almost in contact with the edge of the large bell, *A* (Fig. 5), is suspended, from a convenient support, a small ball of cork, *B*. On drawing the bow across the edge of the bell, a loud,

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[1] The tuning-fork was invented by John Shore, a trumpeter in the service of George I. of England, in 1711, — nearly two hundred years ago. The resonant case was added subsequently by a French instrument-maker, Marloye.

pure sound is emitted. But observe: directly the sound is emitted, the ball is violently agitated, and keeps up a rapid oscillatory motion as long as the sound lasts. This experiment should convince any one that the molecules of the glass bell are in a state of tremor; but it is easy to vary the experiment so as to demonstrate the same fact in an equally conclusive manner.

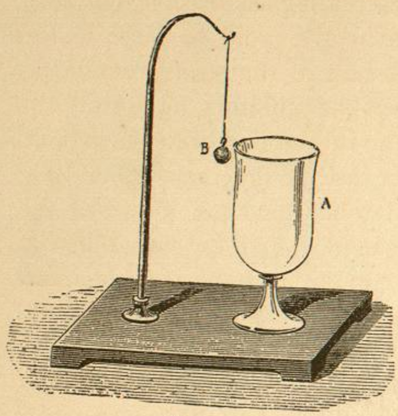

FIG. 5.

We may do this by removing the cork ball and pouring a little water into the bell. By causing it to vibrate as before, beautiful ripples play over the surface of the water, and if the bow is vigorously drawn, the water is projected as spray from the portions of the bowl where the quivering motion is greatest. If a little more force were applied to the bow, the bell would shiver into fragments.

Every one is familiar with the fact that when stringed instruments like the violin, piano, or harp emit a note, the string producing the note is in a state of greater or less vibration. Frequently the vibrations can be seen; they can always be felt.

We have in the apparatus before us (Fig. 6) a simple and effective means of showing the vibrations of strings. It consists of a black board, and a white string passing over two bridges, *A* and *B*. The tension of the string is regulated by the peg *C*. When stretched but slightly and plucked, one is able without difficulty to follow its to-and-fro motion on either side of its position

of equilibrium. As the tension is augmented, the vibrations become more rapid. The string now appears as an airy, transparent spindle. Increasing the tension still more, the vibrations become sufficiently rapid to generate an audible sound, while the motion of the string remains as marked as before. But when the vibratory motion of the string ceases, the sound due to this motion becomes extinct.

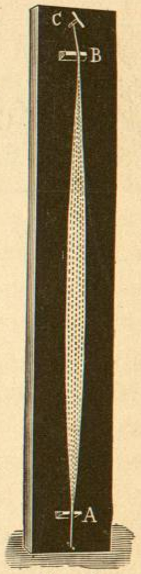

FIG. 6.

With the organ-pipe the case is different. One may, it is true, by the sense of touch become aware of the vibratory motion in an organ-pipe, but the invisibility of air prevents our seeing the condition of the particles constituting the aërial column. As it is the vibration of the column of air within the pipe, and not the pipe itself, which chiefly gives rise to the note of an organ-pipe, it is well that we are able to render evident to the eye that this motion actually exists. This can be done very easily indeed. Into an organ-pipe, one of whose sides is of glass, is lowered a thin membrane stretched on a frame and strewn with fine sand. As soon as the pipe is made to speak, the sand is violently agitated, as may be seen by one who is near, and the rattling noise produced by the grains of sand dancing about on the membrane is sufficiently loud to be heard some distance away.

The existence of the vibratory motion of a column of air in a sonorous tube can be shown still better by another method. Before the condensers of the lantern is placed a glass whistle, the inside of which is strewn with a very light powder such as amorphous silica. As soon as the whistle is sounded, the powder forms groups of thin vertical plates, which are now projected on the screen. As long as the sound persists, the powder retains its present position. When it ceases, the powder falls to the bottom of the tube.

But it may be urged that the agitation here produced is really due to a current of air from the mouth, and not to a vibratory motion of the particles of the aërial column. The form and the grouping of the vertical plates of powder should convince any one who reflects on the matter that this is impossible. To remove all doubt, let us modify the experiment somewhat, and excite the air column in another way. Taking the mouthpiece away from the whistle, we have left only a glass tube, stopped at one end. Let us now excite this tuning-fork, which emits the same note as the vibratory column of air within the tube. As soon as the fork is sounded, the powder springs up into groups of plates as before, and that notwithstanding the fact that the fork is several feet away from the tube. The vibratory motion of the fork, it is obvious in this instance, is communicated to the air enclosed within the tube through the medium of the air separating the fork from the tube. When the sound of the fork dies out, the agitation of the air in the tube ceases, the powder becoming quiescent as before.

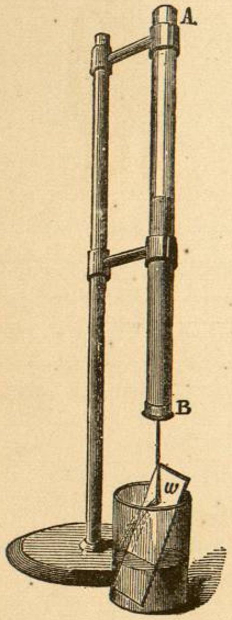

FIG. 7.

Supported on a suitable stand, we have a large glass tube, *A B* (Fig. 7), about three feet in length and two inches in diameter. Its lower extremity is covered by a brass cap, in the centre of which is a circular orifice whose diameter is equal to the thickness of the cap. If we fill this tube with water and allow it to issue from the orifice below, striking at *w*, we shall hear a low, variable note of great purity and sweetness. It is produced by the intermittent flow of the water through the aperture, the rhythmic action of the flow communicating a vibratory motion to the entire liquid column above. This experiment is due to the distinguished French physicist, Félix Savart, to whom, as we shall learn, we are indebted for many interesting apparatus and methods of research in acoustics.

Let me now show you how sound can be generated by a motion different from any we have yet considered.

Before you, mounted on a rotator, is an instrument (Fig. 8), called, from its inventor, Savart's wheel. It is nothing more than a toothed wheel made of brass, and is very like a small circular saw. There are in reality four of these wheels attached to the stand, but we shall for the present employ but one of them, — it is immaterial which. When the wheel is turned, and the teeth are allowed to strike against a card, you hear at first a succession of taps. But by giving the wheel a more rapid motion, these taps coalesce and form a continuous sound, — a sound that can be rendered so loud and shrill as to become actually painful to the ear. A circular saw rapidly revolving in the air, or cutting wood, produces a similar sound, and for the same reason. A circular saw, as we shall soon learn, gives a louder sound than the serrated wheel we have just used, because of the greater force applied, and a higher pitch, on account of its more rapid revolutions.

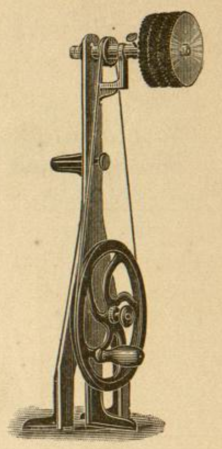

FIG. 8.

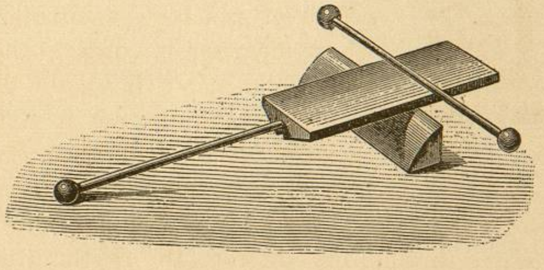

FIG. 9.

In this connection permit me to show you a still more remarkable way of producing sound by taps. The instrument used consists (Fig. 9) of a peculiarly shaped brass bar and a block of lead. It is named Trevelyan's rocker, from Mr. Trevelyan, who invented it and first gave an