do not give ear to them, or because we are not in the habit of expecting musical sounds except from musical instruments. It is true that musical instruments afford us the most agreeable tones, but there are instruments used in music that emit sounds which are far from pure, and frequently anything but agreeable. Among these are drums, tom-toms, cymbals, castanets, timbrels, tambourines, harmonicons, triangles, and others of the same class. They are, for the most part, used for keeping time, and the tones produced, are fortunately so modified by accompanying sounds that they lose most of their harshness.

From what has been said, and from the experiments made, we must conclude that the popular distinction between sound and music is singularly vague. Helmholtz's distinction, however, is always literally true. Periodic vibrations, whatever the source of sound, whatever the instrument used, always yield musical notes. They are smooth and agreeable to the ear, while, on the other hand, noises, or non-periodic vibrations, produce on the tympanic membrane a kind of jolting sensation, — a sensation of irregularly recurring shocks. A noise thus affects the auditory nerve painfully, just as a flickering light gives rise to a painful sensation in the nerves of sight.

But the motion, periodic or non-periodic, of sonorous bodies cannot be apprehended as sound except through the intervention of some medium connecting these bodies with the organ of hearing. This medium is, ordinarily, the air. Any other substance, however, solid, liquid, or gaseous, may serve as a transmitting medium.

Let us then inquire into the mode of the propagation of sound. If we can picture this clearly to our minds we shall have made a second important step in our investigations. That air or some other medium is indispensable for the transmission of sonorous vibrations has been known from the earliest stages of physical inquiry. We have seen how Seneca considered the elasticity of air as essential to the production and transmission of sound. That some medium was necessary was evident, but it was not possible to demonstrate experimentally the necessity of a medium until the invention of the air-pump by Otto von Guericke, in 1650. It was then shown by the inventor of this most useful instrument that sound cannot travel *in vacuo*, — that air or some other medium is always necessary for its propagation from one point to another.

We may here repeat the experiment of the illustrious burgomaster of Magdeburg, which is no less instructive than interesting. Thanks to improved forms of apparatus, we can now secure much better results than were possible in Von Guericke's time.

On the plate of our air-pump (Fig. 15) is placed a piece of clockwork, *H*, *C*, which causes a small hammer, *a*, to strike a bell, *T*. The clockwork is now wound up and set going. The bell-glass is next placed on the plate, and covers the clockwork; but still you hear the bell with almost undiminished intensity. A few turns of the crank of the pump are, however, sufficient to exhaust the air in the receiver to such an extent that the sound now audible becomes comparatively feeble. A few more strokes of the piston produce almost a perfect vacuum, and the sound is now so faint as to be inaudible even to those who are nearest the instrument. The hammer is still striking the bell, as you may observe, but it is entirely noiseless. To secure this result we have isolated the clockwork from the plate of the pump by interposing a layer of non-conducting material. Had the mechanism operating the bell been in contact with the plate, the strokes of the hammer would have been communicated to the outside air by the material of the plate itself.

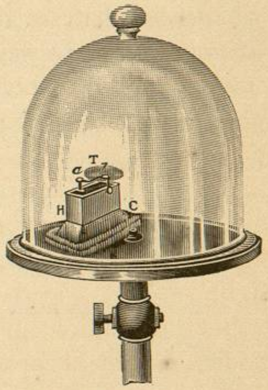

FIG. 15.

As soon as air is re-admitted into the receiver, the sound of the bell again breaks forth, so as to be heard by every one in the room.

Let us now admit hydrogen gas into the receiver instead of air, and note the result. Hydrogen is about fifteen times lighter than air, and sounds generated in such a medium are more feeble than they would be in a denser medium. Although the receiver is now filled with this gas, the sound of the bell is, as you remark, much weaker than when the receiver was filled with air. Exhausting the receiver as before, the sound disappears more rapidly, and becomes inaudible sooner than it did when air was used. This experiment shows that the more attenuated the medium, the less competent it is to convey sonorous vibrations to the ear. We might experiment with other gases or vapors, and we should find that the intensity of the sounds heard would in all cases depend on the density of the media employed.

Later on, in 1685, Papin repeated Von Guericke's experiment before the members of the Royal Society in London. As a source of sound, he used a whistle instead of a bell. In 1705, Hawksbee made the experiment in a somewhat modified form, using a simple bell suspended by a string instead of one operated by clockwork.

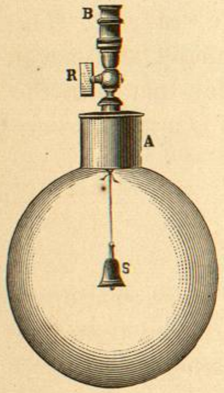

Fig. 16.

By means of a large glass globe (Fig. 16), in which is suspended a little bell, we may repeat Hawksbee's experiment in a very pleasing and effective way. Swinging the globe back and forth while full of air, the bell is made to ring so as to be clearly heard throughout the hall. Connecting it by means of the metallic part, *A B*, with our pump, we withdraw the air from it, and then close the tube by the stopcock *R*. Now, on agitating the bell anew, we find that the sound is so faint as to be barely perceptible.

These experiments, then, prove conclusively that sonorous vibrations cannot be propagated in a vacuum; some medium is necessary. Ordinarily it is air, but all elastic bodies are capable of transmitting sound, and some of them, as we shall see, with much greater readiness and velocity than others.

From the foregoing experiments we should infer that in a vacuum there is absolute silence, and that, if we could exist *in vacuo*, we should be able to hear nothing, not even the most powerful detonations. Balloonists, in the higher regions of the atmosphere, encounter conditions which afford an approximation to this utter silence. Those who have ascended very high mountains have noted a similar circumstance. The sensation is strange, indescribable, awe-inspiring, almost startling. It is so entirely different from any experience that one can have near the earth's surface, where there is always more or less sound, even when everything is apparently in perfect quiescence.

I had some years ago an opportunity of experiencing a sensation of this kind on the summit of the volcano of Popocatapetl. This peak, as you know, has an elevation of nearly eighteen thousand feet above sea-level. The feeling that then came over me is something I shall never forget. The silence there is "the silence that is in the starry sky," — a silence where no sound is uttered, where no sound may be, a silence that —

> " Pours a solitariness
> Into the very essence of the soul."

And here again it will be interesting to know what opinions the early physical investigators entertained regarding the subject we are now discussing. We are often wont to imagine, and without any warrant for so doing, that the theories of the ancient philosophers in matters of physical science were entirely futile, and that their consideration is simply a loss of time. But the truth is that their views on many subjects in physics are often nearly identical with our own. They seemed at times to have had an almost intuitive conception of the truth. The wonder is how they were able to acquire such exact notions about matters that even now are not easily understood. Nothing indeed can be more interesting or instructive than to observe their gropings after truth, and to see how closely they anticipated, in many instances, the discoveries and generalizations of modern science. It is simple justice to these old students of Nature to give them credit for what they have achieved, and to admit that many of the theories and doctrines that are usually regarded as the fruits of modern research, had, in reality, their starting-point in the observations and hypotheses of those who labored and thought long ages ago. If there is evolution in the organic world, there is evolution also in the world of science; and the grand intellectual achievements of our own time owe not a little of their lustre to the glory of the distant but brilliant past.

We have a striking illustration in the question before us, — the mode of propagation of sound. Aristotle in his treatise on "Sound and Hearing" says: "Sound takes place when bodies strike the air, not by the air having a form impressed upon it, as some think, but by its being moved in a corresponding manner; the air being contracted and expanded and overtaken, and again struck by the impulses of the breath and the strings. For when the air falls upon and strikes the air which is next to it, the air is carried forward with an impetus, and that which is contiguous to the first is carried onward; so that the same voice spreads every way as far as the motion of the air takes place."

In reading this we could almost fancy we are perusing some modern treatise on sound, so nearly does the view of the illustrious Stagyrite coincide with that now held by all men of science. Indeed, as Whewell truthfully observes: "The admirers of antiquity might easily, by pressing the language closely, and using the light of modern discovery, detect in this passage an exact account of the production and propagation of sound."

Let us take another opinion, — that of Vitruvius, the celebrated Roman architect. His views regarding the motions of the air which give rise to sound, and the illustration which he uses, seem more like those found in a modern text-book on physics than those of an author who wrote two thousand years ago. He says: "Voice is breath flowing and made sensible to the hearing by striking the air. It moves in infinite circumferences of circles, as when, by throwing a stone into still water, you produce innumerable circles of waves, increasing from the centre and spreading outwards till the boundary of the space or some other obstacle prevents their outlines from going farther. In the same manner the voice makes its motion in circles. But in water the circle moves breadthways upon a level plain, the voice proceeds in breadth, and also successively ascends in height."[1]

Let us now, in the light of modern research, investigate the condition of the air when under the influence of vibratory motion. And that we may better understand this motion, let us suppose an elastic strip to vibrate at one of the extremities of a cylindrical tube (Fig. 17). A little reflection will make it apparent that each time the strip moves from L' to L'' it will impress on the vertical layer of air, X, a series of condensations whose intensity increases during the first half and decreases during the last half of its excursion. Every time, however, that the strip moves in the opposite direction — that is, from L'' to L' — the layer X will be subject to a series of rarefactions whose intensity increases during the first half, and decreases during the last half of its swing. And as long as the strip continues to vibrate, this terminal layer X will be subject

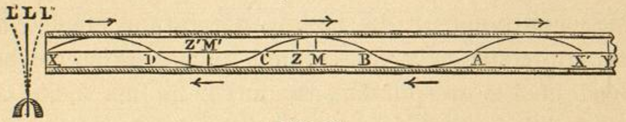

FIG 17.

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[1] Quoted in Whewell's "History of the Inductive Sciences," ii. 25.

alternately and periodically to similar conditions of condensation and rarefaction.

But these condensations and rarefactions are not confined solely to the terminal layer X. They are communicated in succession to all the succeeding layers, and affect the entire mass of air enclosed in the tube. As the vibrations of the elastic strip are periodic and isochronous, so also are the pulses of condensation and rarefaction periodic and isochronous. Condensations and rarefactions of equal length alternate with one another, and persist as long as the strip continues to vibrate. A simple vibration of the strip — that is, an excursion to *or* fro — generates a single wave of condensation or rarefaction. A complete vibration of the strip — that is, an excursion to *and* fro — produces a complete wave, one, namely, that is composed of both a condensation and a rarefaction.

Fig. 17, as we see, exhibits the condition of the aërial column after the elastic strip L has executed five single vibrations. We have, accordingly, five single sonorous waves, of the same length, abutting one another. These waves, composed of alternate condensations and rarefactions, are graphically represented by a continuous curve, which cuts the axis of the tube at the points X, D, C, B, A, X'. The portions of the tube above the axis are conventionally considered to represent waves of condensation, of which we have here three, while the parts below the axis represent waves of rarefaction, of which two are exhibited.

Arrows indicate the direction of movement of the air particles constituting the condensed and rarefied pulses. The direction is always the same for pulses of the same kind, but opposite in condensed from what it is in rarefied pulses.

The perpendiculars to the points Z and M represent the degrees of condensation and the velocities of movement of the air-particles at these points. Similarly, the ordinates at the points Z' and M represent the amount of rarefaction and the relative velocities at the points intersected. At the points where the continuous curve cuts the axis of the tube the air is in a state of equilibrium, and there is neither condensation nor rarefaction, and consequently no movement. But even at the points of maximum condensation and rarefaction the amount of displacement for any determinate particle is extremely small.

The time required for the bar L to execute a complete vibration is, as we have learned, called its period. The time required for a particle of air set in motion by the vibrating bar to make a complete vibration is called its period. The periods of both the bar and the air-particles excited by the bar are obviously equal. The wave-length is the distance from one condensation to the next condensation, as from X to C, or from one rarefaction to the next rarefaction, as from D to B, or from any one given particle to the next particle in a like position and moving in the same direction.

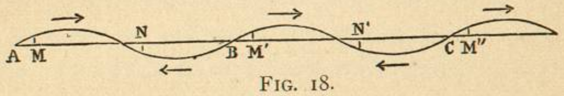

FIG. 18.

The wave always moves one wave-length in the time required for a particle to make one complete vibration. Any two points separated by one or more wave-lengths are in similar conditions, and are said, therefore, to be in the same *phase*. If any two points are separated by an interval greater or less than one or more complete wave-lengths, they have phases which are different. Thus in Fig. 18 the points where M, M', M'', cut the continuous curve are in the same phase. Similarly the points cut by the ordinates N and N' are in the same phase. M and N, or M' and N' are in different phases.

In Fig. 19 we have a very instructive graphic representation of sonorous waves. It must, however, always be borne in mind that it is only an arbitrary representation, a symbol, and not a picture, of a sound-wave that is indicated by such curves and lines. From what has been said, the figure needs but little explanation. The portions of the curve above the horizontal line correspond, as has been