If sound-waves encounter an obstacle in their path, and this obstacle be large in comparison with the length of the waves of sound, it will give rise to what is aptly called a sound-shadow. The sound behind the object is much less intense than that in front of it, and if the object be sufficiently large, the sound may be quenched entirely. But if the obstacle encountered is small, as compared with the length of the sound-wave, the wave will pass around it, and there will consequently be no sound-shadow. This property which waves of sound, like waves of water and light, have of bending around obstacles in their path, is known as *diffraction*.

It is ordinarily supposed that both sound and light rays travel only in straight lines; but this statement requires modification. Both luminous and sonorous rays are capable of diffraction; that is, of being bent round opaque bodies, to a greater or less extent. With diffraction of light we are not at present concerned; but it were an easy matter to instance numerous examples of sonorous diffraction. A railway train passing through a tunnel and around hills is a familiar example of the variation in the intensity of sound due to diffraction. In a mountainous country like Colorado, where the curves are sharp and the cuttings deep, and where there are numerous castellated buttes facing the road along which the train passes, the effect is particularly striking. All visitors to Manitou, the great summer resort of the Rockies, must have observed the peculiar and remarkable effects produced by the train on the "Midland Railway" as it passes around the base of Pike's Peak, now going through tunnels and deep cuts, now behind knolls and hillocks and immense masses of rock that have been detached from the mountain high overhead. A more interesting and instructive example of the diffraction of sound could not be found.

A remarkable illustration of diffraction is afforded when a person in motion puts between himself and a brass-band, playing some distance away, objects of varying sizes. The result is that the notes played are differently diffracted according to their respective wave-lengths. In some instances the objects passed may give rise to more or less perfect sound-shadows for the notes of higher pitch, while the graver notes bend round the object with but little diminution in sonorous intensity. The result is that the acute notes seem very much feebler comparatively than the grave ones, and there is, consequently, a change in the quality of the music that no one could fail to observe. For this reason, in order to hear music to the best advantage, one should always be in full view of the performers, where there will be no danger of sound-shadows for any of the notes played.

Diffraction also explains the peculiar behavior of some of the great dynamite and powder explosions that have taken place in the country during the last few years. It has often been remarked as strange that the windows on all sides of the houses near where these explosions have occurred have been forced inwards by the terrible concussion which was occasioned. The reason is simple. The sonorous waves in coming from the centre of disturbance encircled the houses, in which the phenomena referred to were observed, with a wave of condensation of such power that the windows on all sides of the houses were forced inwards at practically the same moment. Were it not for diffraction, — the property that sound-waves have of bending around obstacles, — such results as those indicated could not have occurred. And furthermore, were it not for diffraction, sound produced on one side of an object could not be heard on the side opposite, except by transmission directly through the obstacle, which in nearly all the cases alluded to would have been impossible.

The distance to which sound travels is often very great. Of course the distance to which it will be conveyed in any given case will, as we have seen, depend on circumstances, — on the elasticity and temperature of the medium through which it is transmitted, on the intensity of the sound itself, and on a number of other factors which need not now be indicated.

Thus, in 1762 the cannonading at Mayence was heard at Timbect, a village 148 miles distant. The booming of the cannon which preceded the taking of Paris in 1814 was heard at the distance of 132 miles, and the firing at Waterloo was audible at Dover. The cannonading at Antwerp in 1832 was, we are told, heard in the mines of Saxony, about 370 miles from the scene of action. According to Humboldt, the report of the volcano of St. Vincent was heard at Demerara, 750 miles off. In respect of distance, this would be the same as if an eruption of Vesuvius were heard in the north of France. At the time of the great eruption of Cotopaxi, in 1774, subterranean detonations were heard at Honda, on the Magdalena. The distance between these two points is over five hundred miles, and their difference of level is nearly 18,000 feet. Besides this, they are separated by the colossal mountains of Quito, of Pasto and Popayan, and by valleys and ravines without number. Evidently, then, sound in this case was not transmitted by the air, but by the earth, and at a very great depth.

It would appear from the last two examples, in which there can be no doubt that the earth was the medium by which sonorous vibrations were propagated, that the range of sound, under favorable circumstances, is very great indeed. But it may be asked, Is the reach of sound ever thus great in air? We have no means of answering this directly; but certain facts recorded by competent and trustworthy observers show that sound in air is sometimes, even under unfavorable circumstances, transmitted to almost incredible distances.

Chladni, for instance, tells us of meteors whose explosion was not heard until ten minutes after the appearance of the luminous globe. This would indicate that the meteor had an altitude of at least 125 miles at the time of the explosion. A meteor observed in the south of France in 1864 exhibited the same peculiarity, and the observers noted an interval of full four minutes between the appearance of the flash and the hearing of the detonation. Speaking of

this subject, M. Daubrée declares that "in order that an explosion produced in air so rarefied may give rise at the earth's surface to a report of such intensity, and over such an extended area, we must admit that its violence in these high altitudes far exceeds anything with which we are acquainted here below."

The amount of matter, solid, liquid, and gaseous, put into a state of tremor by the explosions just referred to is measured by hundreds of thousands and millions of cubic miles. But although we may make some attempt to express in numbers the magnitude of the disturbance, the mind fails to grasp their full significance. No better illustration could be asked of the elasticity of the different kinds of matter which compose the earth's crust and its circumambient atmosphere, nor could we desire stronger evidence of the extreme sensitiveness of the auditory apparatus capable of appreciating, at such distances, vibratory motion that must, for individual particles, be all but infinitesimal.

In all the cases cited, however, sonorous waves are originated by titanic forces. But even when the source of sound is quite insignificant, the amount of matter set in motion is simply amazing. Thus the lark, as it rises in the air and breaks forth into its morning carol, may put into vibration many millions of cubic feet of the medium in which it warbles its notes of gladness.

But far more remarkable for their ability to impart vibratory motion to large masses of air are certain crickets, locusts, and grasshoppers. "The stridulation produced by some of the locustidæ," says Darwin, "is so loud that it can be heard at night at the distance of a mile." Calculation shows that it thus excites, according to the condition of the atmosphere, sonorous tremors in no less than from five to ten million tons of matter. And yet the insect that accomplishes this extraordinary work does not weigh more than a quarter of a pennyweight.

Facts like these bring us face to face with phenomena that seem to elude the equations and the formulæ of the mathematician, and to defy all attempt to bring them within the range of mathematical analysis. In the instance last given the magnitude of the volume of matter set in motion by a tiny, insignificant insect is something calculated to excite our astonishment. But more wonderful still, when we come to think of it, is the fact that notwithstanding the small amplitude of movement of the air particles a mile distant from the stridulating locust, the vibratory motion excited by this insignificant little insect is still competent to excite the sensation of sound. We know, indeed, that very slight, almost infinitesimal, periodic tremors are sufficient to generate sonorous pulses. Lord Rayleigh has shown that sound-vibrations may be produced when the amplitude of movement is not more than the $\frac{1}{250000000}$th part of an inch. But such reflections and calculations, far from detracting from the marvellous in the case we are considering, tend only to enhance it and to place it in a brighter light. Nothing could give us a better idea of the transcendent delicacy of the ear, nor could we have a better example of the perfect conservation and correlation of force, than that afforded by the illustration just given. But here I must close. We have again come into contact with more of those innumerable mysteries of the natural order which hitherto have baffled all attempts at their solution, and which will, most likely, ever remain as they are at present, — fascinating, yet inscrutable.

CHAPTER IV.

MUSICAL STRINGS.

REVIEWING the ground over which we have thus far travelled, we shall find that we have been dealing with only the more general laws and phenomena of sound. We are now prepared to consider, in greater detail, the laws and phenomena that are observed in connection with special forms of sonorous bodies. Most of our attention will, naturally, be given to such vibrating bodies as are used in music. Chief among these are strings, wires, reeds, bars, plates, bells, membranes, and various forms of sonorous tubes.

To-day we shall occupy ourselves in studying the very interesting phenomena which characterize the vibration of wires and strings. By the term *string*, in acoustics, we mean "a perfectly uniform and flexible filament of solid matter stretched between two fixed points." It thus includes wires as well as strings properly so-called. An acoustic string, however, is quite ideal, as no string is perfectly elastic or perfectly uniform. The most that is ever realized in the strings employed in musical instruments is a more or less close approximation to the ideal string which the mathematician has in view in all of his calculations.

From the earliest times strings have been used in the construction of musical instruments, for we have records of them that date back to the twilight of fable. Figures of what are evidently primitive forms of the harp and the lute are to be found on Egyptian monuments all along the Nile valley. Similar instruments were used by the earliest inhabitants of western Asia, as is evidenced by