less be strikingly exhibited by the apparatus which we have just been using. Substituting a jet of burning coal-gas for the glass mirror, and proceeding as before, we find that the sonorous pulsations coming from the vibrating reed are reflected so as powerfully to agitate the sensitive flame. By lowering the flame and causing the sound-waves to impinge against the sheet of heated air which arises from the flame, the result is unchanged. Substituting a red-hot bar of iron for the gas jet, the sensitive flame is still agitated. The stream of hot air now rising from the bar is the reflecting surface, although entirely invisible.

These last experiments explain many facts concerning the behavior of sound under circumstances that, until recently, were an enigma to all investigators. Humboldt, indeed, suspected the action of non-homogeneous air on the transmission of sonorous waves, and offered an explanation of a fact that is within the experience of every one; namely, that sounds are heard with greater distinctness at night than during the day. Speaking of the sound due to the Great Falls of the Orinoco, in South America, he says: "During the five days we passed in the neighborhood of the cataract we remarked, with surprise, that the noise of the river was three times as loud during the night as during the day. The same thing, it has been observed, holds true for all the waterfalls of Europe. What can be the cause, in a wilderness, where nothing disturbs the silence of nature? It must probably be sought in the current of hot air which ascends during the day, and which arrests the propagation of sound, but which ceases during the night, when the earth is cooled." Air rising from rocks or the bare ground would be more heated than that which rises from soil covered with water or vegetation. We should thus have produced air-columns of different temperatures, and, consequently, of different densities. In passing through such an atmosphere, sound would undergo successive reflections, which would entail a corresponding diminution of intensity. During the night, when



the homogeneity of the air is restored, such reflections are absent, and sound reaches the ear with proportionally augmented intensity. The admirable observations and experiments of Tyndall have cleared up all doubts regarding this matter, and what Humboldt and others only suspected, is now received as one of the established truths of science.

The familiar phenomenon of resonance, or echo, is due to the reflection of sound. If one speaks in a moderately large room with bare walls and little or no furniture, the sound-waves reflected from the walls and ceiling of the room reach the ear shortly after the direct waves, and both combine in such a manner as to augment the resultant sound. Such an augmentation is known as resonance. If the room be larger, the direct and reflected waves reach the ear in appreciably different times, and the result is that the words spoken appear to be doubled, and, for this reason, confused, and distinguished with difficulty.

But when the reflecting surface is about 110 feet distant from the speaker, he hears twice each syllable he pronounces, — one directly, and the other by reflection. The latter sound is known as a *simple* echo. If the reflecting surface is 220 or 330 feet away, the speaker will hear two or three syllables by reflection. Such a phenomenon is called a *polysyllabic* echo. The farther away the reflecting surface is, the greater the number of syllables that one may hear. Dividing the distance of the obstacle throwing back the sound by 110 will give approximately the number of syllables which an echo will furnish. I say approximately, because I proceed on the assumption that one can pronounce distinctly only five syllables per second. As sound at the ordinary temperature of the air travels about 1100 feet per second, this would allow about 220 feet for each syllable, or the half of this number for the distance of the object from the speaker. When sound is reflected from several different objects at suitable distances, or when it undergoes a series of reflections from parallel walls, for instance, we have what are called *multiple* echoes.

One of the most remarkable multiple echoes ever known was one formerly heard in the Château of Simonetta, near Milan. According to Father Kircher, a sound was here reflected no less than forty times. An echo in Woodstock Park, in England, repeats a sound seventeen times during the day, and twenty times at night. All European travellers are familiar with the celebrated echoes at the Gap of Dunloe, at Killarney, and that which is heard between Bingen and Coblentz, where the waters of the Nahe flow into the Rhine. The most remarkable echoes I know of in this country are found in the cañons of the Rocky Mountains. These deep chasms, as one might imagine, by reason of their precipitous and oftentimes parallel cliffs, are particularly well adapted to reflecting sound and to furnishing echoes of all kinds. I have also heard in the Grand Cañon of the Colorado River, in Arizona, some most extraordinary echoes, comparable, I think, with any that are to be heard elsewhere.

In whispering-galleries we have another illustration of the peculiar effects produced by reflected sounds. Sometimes the sound is greatly augmented, as in the crypt of the Panthéon in Paris, where a slight clapping of the hands gives rise to reverberations of great power and volume. In the large chambers and long passage-ways of the Great Pyramid of Gizeh the reverberations excited by the slightest noise are equally striking.

Large domes, like those of St. Peter's in Rome or of St. Paul's in London, are interesting examples of the perfect manner in which sound is reflected by curved surfaces. In both cases the slightest whisper is conveyed by reflection, or by a series of reflections, from one side of the dome to the other, without any appreciable enfeeblement of sound. Two persons stationed at opposite sides of the dome can, without any difficulty, carry on a conversation that is almost, if not quite, inaudible to bystanders only a few feet distant. The dome of the Capitol in Washington is an almost equally good place for reflecting sounds and augmenting them by resonance. But perhaps the most



remarkable building for reflections and echoes to be found anywhere is the curiously designed Mormon Tabernacle in Salt Lake City, Utah. It is in the form of a semi-ellipsoid, and is capable of seating over ten thousand people. The speaker, as I can testify from personal experience, can be heard distinctly, and without the slightest effort on his part, in every part of this vast edifice. When the hall is empty, a whisper at one end of the building is easily heard at the other. Indeed, two persons may here carry on a conversation in a whisper, although over two hundred feet apart, so perfect is the reflection from the curved surfaces of the walls and ceiling. I do not think there is any other place in the world where a speaker can make himself heard by so many and with so little exertion. The acoustic properties of the building are certainly extraordinary, and as unexampled, I think, as the architectural style of the structure is unique.

Strange as it may appear, architects are still in the dark as to the laws governing the acoustic properties of buildings. For places of assembly, like public halls, theatres, churches, one would think that, by this time, architects would be able to determine, at least empirically, the best form to give to a building of determinate size; but they are not. Success is a matter of accident. There are many halls in this country that, from an acoustic point of view, are all that a speaker or singer could desire; while, as is well known, there are many others that are almost useless for the purpose for which they were designed. And what is said of the defectiveness of halls may be predicated more particularly of churches, especially those that are at all large. Gothic churches seem to suffer most in this respect, and it would appear that the Gothic style of architecture is incompatible with good acoustic effects.

Even in ordinary halls several expedients must frequently be resorted to in order that a speaker or singer may be heard to advantage. It is observed, for instance, that in certain halls there is too much resonance, — so much, indeed, as to interfere materially with a distinct perception of what is said or sung; and the only remedy is to dampen the sound by draping the walls, or to make the surface of walls and ceiling so irregular that resonance and echo are so diminished as not to be appreciable. Public speakers all know the difference in resonant effect observed in speaking in an empty hall and in one crowded with people. In the former case the resonance may be so great, and the direct and reflected sounds so interfere with each other, that what is uttered is indistinguishable. The presence of an audience in a hall in which such a difficulty is observed, is often sufficient to dampen this excess of resonance so that every word spoken or sung can be heard and understood. There is certainly much yet to be learned in the science of acoustics as applied to the construction of build-

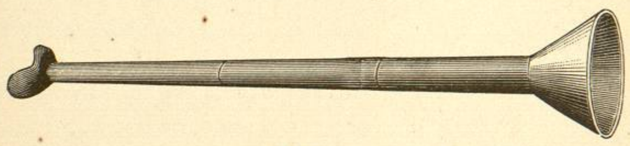

Fig. 39.

ings, and the one who shall supply even a part of the information still needed will confer a boon both on hearer and speaker.

Among the practical applications of the laws of reflected sounds may be mentioned speaking-tubes and speaking and ear trumpets. Sound, as every one knows, is conveyed to a much greater distance in tubes than in the open air. Hence their adoption in buildings and other places where it is desirable to carry on a conversation at any considerable distance. The smoother the interior, and the more elastic the material of such tubes, the less rapidly is the intensity of sound diminished, and the farther, consequently, is it carried.

A speaking-trumpet is usually of metal, conical in form (Fig. 39), with a mouthpiece at its smaller end, and a wide opening, called the bell, at the end opposite. Experience shows that the bell renders the trumpet more



effective; but the office it performs is not yet understood. By means of a series of reflections in the interior of the trumpet, the sonorous rays are rendered more or less parallel, and, hence, capable of being transmitted to much greater distances than would otherwise be possible. The loudness of the sound produced is most likely due to resonance.

An ear-trumpet is just the reverse of a speaking-trumpet. The smaller end is inserted in the ear, and the sound to be heard is produced at the larger end. By a series of

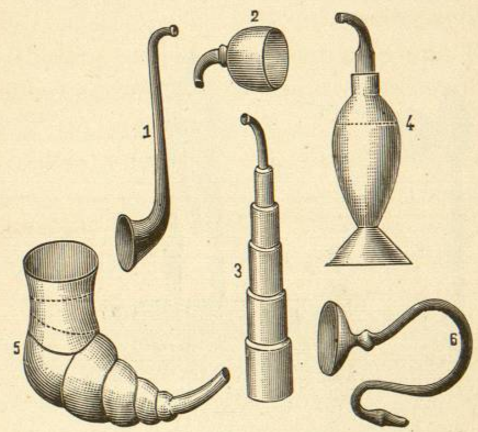


Fig. 40.

reflections the sonorous waves are condensed as they enter the tube, and, on arriving at the tympanic membrane, are of sufficient intensity to excite the sensation of a sound that the unaided ear could not perceive. Although the general principle obtaining in all ear-trumpets is identical, many forms have been devised. A few of these are shown in Fig. 40, the *modus operandi* of which is apparent.

Sound, like light and radiant heat, when passing from one medium to another of different density, or from one point to another in the same medium, when it lacks homogeneity, deviates more or less from a direct course. It is then said to be refracted. From theoretical considerations, based on the different velocities of sound in media of different densities, Poisson and Green demonstrated that sonorous waves are subject to laws of refraction similar to those that prevail for light and heat.

Sondhaus was the first to demonstrate this experimentally by means of lenses of peculiar construction, and Hajech, shortly afterwards, showed that the same results are obtained by using suitable prisms filled with gases or liquids of different densities. A lens (Fig. 41) similar to the one employed by Sondhaus in his researches is before you. It is made of a broad brass ring, to the two sides of which are attached sheets of thin India-rubber, *A*.

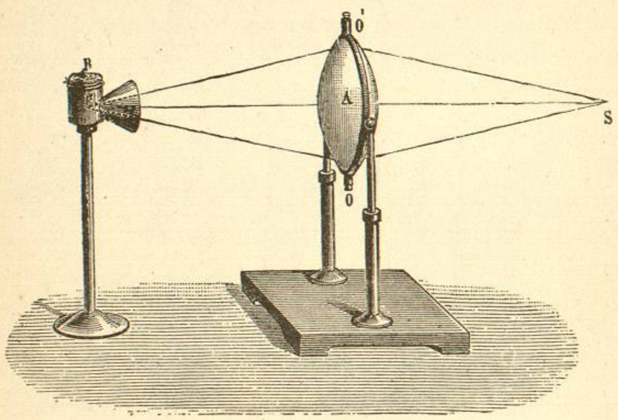


FIG. 41.

Through a stopcock, *O* or *O'*, carbonic-acid gas is admitted into the apparatus until the sheets are sufficiently distended, and have the form of a double convex lens. As carbonic-acid gas is more dense than air, a sound produced in the surrounding air has its velocity retarded while passing through the heavier gas in the lens. The result is that sonorous rays, which were divergent before entering the lens, are made to approach each other when leaving the lens on the opposite side and to converge to a focus. Suspending a watch in the axis of the lens on one side, the sound-pulses are collected at a point on the axis on the other side. Bringing the ear to this point, the



ticking of the watch is far more distinctly heard than would be possible with the unaided ear.

This concentration of sound-rays by means of a lens can also be exhibited in another way devised by Sondhaus. At the point occupied by the ear is placed a small cylindrical box, *F*, covered with a thin membrane, *B*, strewn with fine sand, and a funnel which collects the sound-rays and conveys them to the interior of the case. When a note of suitable pitch and of some intensity is sounded at *S* (Fig. 41), the sonorous pulses are concentrated at the other side of the lens, and cause the sand to dance about on the membrane as long as the sound lasts. To prove that there is really a refraction of sound in this instance, it is only necessary to remove the lens, when the movement of the sand subsides.

Refraction and reflection explain many phenomena connected with the propagation of sonorous waves that would otherwise remain unintelligible. The investigations of Prof. Joseph Henry and Professor Tyndall on the audibility of fog-signals have disclosed many facts before unknown regarding the transmission of sound-waves; but there are many apparently abnormal acoustic phenomena which are far from being understood. Henry seems to think that the very capricious action sometimes observed in fog-signals can in almost all cases be explained by refraction. Tyndall lays more stress on reflection; and the experiments made in support of his views are, in at least some instances, apparently conclusive as to the truth of his theories. We have shown experimentally that a sheet of heated air or gas is capable of reflecting sound, and according to Tyndall, a heterogeneous condition of the atmosphere is competent to produce reflections of sufficient power to produce an echo. In Tyndall's opinion the reverberations of cannon and thunder are in many, if not in all, cases due to limiting surfaces of strata and columns of heterogeneous atmosphere, and not, as has been long supposed, to clouds or other reflecting surfaces.