cerning observations made to determine the velocity of sound, may, with equal truth, be asserted regarding every fact that now constitutes a part of that very comprehensive branch of knowledge which we call physical science. We shall have several equally striking illustrations of the truth of this statement during the course of our investigations in the domain of sound. What are now accepted as simple facts, often, apparently, of slight importance, represent, each one of them, weeks, months, yea, years, of labor on the part of one or more of the enthusiastic students of Nature and Nature's laws.

From the foregoing we have seen that the velocity of sound is independent of the density of the air, and, consequently, of its pressure, but that it is modified by temperature, moisture, and the direction of the wind. The question may now be asked, Is the velocity the same for all sounds, grave or acute, feeble or intense?

It is within the experience of every one that all sounds travel equally fast, whatever their pitch. If this were not so, a melody played on a musical instrument, and heard at a distance, would undergo alteration in the order in which the different notes follow each other; but such is not the case. Biot demonstrated this conclusively by his experiments on the velocity of sound in iron pipes. He caused a well-known air to be played on a flute, at one end of a pipe over three thousand feet in length, and, stationing himself at the other end, he found that the notes bore the same relation to each other, and that their sequence was the same, at one end of the pipe as at the other. From this and other observations, he concluded that all sounds, whatever their pitch, travel equally fast. And what is true for one instrument is equally true for any number of instruments. Thus the music of an orchestra or brass band remains unaltered whether the hearer be hard by or farther away.

It is proper to state here that Biot's observations require a slight correction. The correction, however, applies only to what might be called exceptional cases. Regnault's

experiments prove that very intense sounds, especially when passing through gases in pipes of small diameter, travel more rapidly than feeble sounds. But it is only when this difference in intensity is very marked that any variation in velocity is discernible. For ordinary sounds, under ordinary circumstances, no perceptible difference is ever observed.

When the velocity of sound in air is known, it is, obviously, an easy matter to compute the distance of any source of sound. As the velocity of light is so great, — about 190,000 miles per second, — its time of transmission, in all experiments on the velocity of sound, is so infinitesimal that it may be neglected. Counting, for instance, the number of seconds elapsing between the lightning's flash and the peal of thunder, and multiplying this number by the velocity of sound in air, according to its temperature, we have at once the distance of the point of discharge. It is only when the lightning's flash and the thunder's peal are nearly simultaneous that any danger from lightning is to be apprehended. In a similar manner the distance of any other source of sound can be computed.

The velocity of sound in gases may be determined both directly and indirectly. Regnault filled long tubes with gas, and thus measured the velocity of sounds directly. The results he arrived at agreed remarkably well with those required by theory, as expressed in Newton's formula, corrected by Laplace. Dulong, acting on a suggestion given by D. Bernouilli, measured indirectly the velocity of sound in air and various gases, by means of organ-pipes. I will not go into the details of his experiments, but simply tabulate the results at which he arrived: —

Velocity of sound in gases at the temperature of 0° *C.*

	Velocity.
Air	1092 feet.
Oxygen	1040 ”
Hydrogen	4164 ”
Carbon dioxide	858 ”
Carbon monoxide	1107 ”
Nitrous oxide	859 ”
Olefiant Gas	1030 ”

given liquid can always be determined experimentally, it is an easy matter, by using Newton's formula, to calculate the velocity of sound in any liquid whatever. And since Wertheim's method is almost equally comprehensive in its application, it is evident that the results arrived at by the two methods can serve as checks for one another, and that in no case can the calculations made vary from the truth by any considerable quantity.

In solids the elasticity, as compared with the density, is usually greater than in liquids, and hence the rate of transmission of sounds is correspondingly greater.

Biot determined the velocity of sound in cast iron by means of an iron pipe over three thousand feet in length. One end of the pipe was struck by a hammer, and an observer stationed at the other end heard two sounds, one transmitted by the air, the other by the metal. It was thus found that iron transmitted sound about ten and one half times as rapidly as air.

By calculations based on their coefficients of elasticity, which may be experimentally determined, Wertheim was able to deduce the velocity of sound in the solids named in the following table: —

Velocity of Sound in Metals at 20° C.

Lead	4,030 feet	Gold	5,717 feet
Silver	8,553	Copper . .	11,666
Steel Wire . .	15,470	Iron	16,822

Velocity of Sound in Wood along the Fibre.

Pine	10,900 feet	Oak	12,622 feet
Ash	13,314	Elm	13,516
Fir	15,218	Aspen	16,677

From the preceding tables we observe that the solids in which the velocity of sound is greatest are iron and steel for the metals, and fir and aspen for the woods. According to Chladni's measurements, however, the velocity in fir is much greater than that given in the table. His experiments gave for this wood a velocity of 19,685 feet, — fully

twelve times the rapidity of transmission of sonorous pulses in air.[1]

It is to be noted that the rate of propagation of sound-vibrations is not the same in all directions in wood. The figures above given are true only when the direction of transmission is along the fibres. When sound is made to pass parallel or across the rings of the wood, its velocity is very much less.

It is to be remarked, also, that augmentation of temperature in metals has not the same effects which it has in gases and liquids of increasing the velocity of sound. The result, except in the case of iron between 20° and 100° C., is just the opposite. Increase of temperature entails a corresponding decrease in velocity. Iron is an exception to the rule which obtains with other metals, by reason, very likely, of some peculiar molecular structure; for it has been observed that iron and steel, prepared in different ways — iron and steel as wire and cast steel, for instance — do not transmit sound-waves with the same velocity.

Chladni and Kundt have devised two beautiful methods of calculating the velocity of sound in different solids, which I shall dwell on more at length when we come to study the vibrations of rods.[2] Interference of sound also affords us an interesting way of computing the rate of propagation of sound-vibrations in air and gases. But we shall see more of this in the sequel.

Many methods have been devised for measuring the velocity of sound at short distances. The best and simplest of these is, probably, that contrived by Bosscha. His method depends on the principle of coincidence of two sounds coming to the ear from points at different distances. The apparatus required consists essentially of two electric sounders, *A* and *B* (Fig. 33), which, under the influence of a vibrating spring, beat exactly ten times a

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[1] Prof. A. M. Mayer has recently made a very accurate determination of the velocity of sound in clear white pine (American), thoroughly seasoned. This wood had a density of .395, and the velocity in it at 24° C. was 17,260 feet per second.

[2] See chapter v.

second. When the two sounders are placed side by side, as they are now on the table, they sound as one, because as the sounds of both reach the ear, *O*, at the same time, it is impossible to distinguish one from the other. As soon, however, as the instruments are separated the sounds they emit cease to coincide. You now hear twenty instead of ten strokes per second, — ten from each sounder. The reason of this is that the sounds emitted by the instrument farthest from the ear are behind those emitted by the nearer one. If the sounders were to be so placed that one should be about 112 feet farther from the ear than the other, then the sounds coming from the two sources would again coincide. The explanation of this is to be found in the fact that at the temperature of this hall, 112 feet is the distance that sound travels in one tenth of a second. For a similar reason the sounds from the two instruments would be coincident whenever the distance separating them is any multiple of 112 feet. It is obvious that the same appliance could be used for measuring the velocity of sound both in gases and liquids.

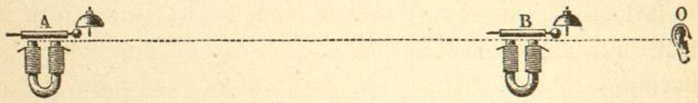

FIG. 33.

The vibrating spring is, as you see, provided with a mirror, as is also a tuning-fork making forty vibrations per second, which forms a part of the apparatus. By means of a discovery of Lissajous, of which we shall see more in its place, the spring can be so adjusted as to close and break the circuit exactly ten times per second, and thus cause the sounders to strike with unfailing regularity the tenths of a second as long as may be desired. This is not an apparatus for giving rigorously exact measurements, and yet the results obtained are probably more reliable than those obtained by any other instrument for measuring the velocity of sound at short distances.

Sir Charles Wheatstone, to whom the sciences of acoustics and of optics are indebted for many beautiful inventions, has devised a means of exhibiting, in a most pleasing manner, the transmission of sound through solid bodies. On the table is a music-box wrapped in several layers of felt. Although the instrument is now in operation, not the slightest sound is perceptible. I hold in my hand a rod of fir three feet long, the lower end of which is now brought into contact with the lid of the music-box. Still, no sound is heard. On the top end of the rod is now placed a guitar, and all at once it appears to be animated with the spirit of music. The harmony that was buried in the manifold layers of felt has now found a means of making itself audible. Through the fir rod the sounds in the box are carried to the guitar, and this, acting as a sounding-board, — it does nothing more, — communicates to the air, in perfect rhythm and cadence, all the most delicate shades of harmony that have their origin in the complex mechanism in the box below. So faithfully is every note and every chord of the piece that is being played reproduced, so perfect is the illusion as to the real source of sound, that it is difficult at first to realize that the sweet sounds to which you are listening are issuing from a shapeless mass of felt, and not from the guitar itself.

The rod that connects the box with the guitar might be of any other wood as well as of fir, or might be made of metal, and the result would be the same. Or, instead of being only three feet long, it might be several hundred feet in length, and still the result would be unchanged. Instead of a music-box, we might use a piano, or any other musical instrument, and in lieu of a guitar we might substitute a violin, mandolin, or simply a resonant box. The only purpose served by the musical instrument, or box, placed on top of the rod, connected with the music-box, is, by exposing to the air a large surface, to distribute to it all the tremors which the revolving cylinder and steel tongues of the instrument engender. The rod alone is incompetent to render the sounds of the box audible, be-

The preceding table affords a remarkable experimental confirmation of theoretical results. According to theory, as expressed in Newton's formula, $V = \sqrt{\frac{e}{d}}$, the velocities of sound in any two gases are inversely proportional to the square roots of their densities. The density of hydrogen is, to that of oxygen, as 1 is to 16. Hence, according to theory, the velocity of sound in the former should be to its velocity in the latter as 4 is to 1. The velocity in oxygen being 1,040, the velocity in hydrogen, according to the law indicated, should be 4,060.

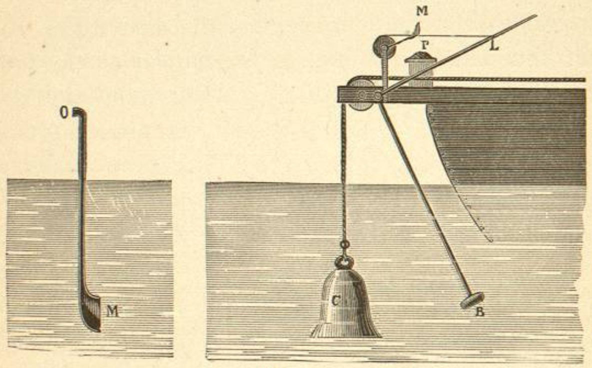

FIG. 32.

Experiments, as made by Dulong, fix the velocity of sound in hydrogen at 4,164.

The velocity of sounds in liquids may also be determined both directly and indirectly. Beudant, at Marseilles, was the first to measure the velocity of sound in water. But the most exact determination of the velocity of sonorous waves in water was made by two French physicists, Colladon and Sturm, in 1827, in the Lake of Geneva. The method adopted was similar to that employed by Beudant. The two observers stationed themselves on boats (Fig. 32), at opposite sides of the lake. The source of sound was a submerged bell, *C*, attached to one of the boats. The signal, announcing when the hammer, *B*, moved by the lever, *L*, connected with a torch, *M*, struck the bell, was a flash of gunpowder, *P*. On the other boat the observer was provided with a peculiarly shaped ear-trumpet, *O M*, the bell of which was held in the water, and a good stop-watch, by means of which he was able to register exactly the time of the arrival of the sound-pulse through the water. As an average of many observations, it was found that the velocity of sound in water, at a temperature of 8.1° C., was 4,707 feet per second, — more than four times greater than it is in air.

By means of a specially constructed apparatus, that need not be described here, Wertheim was able to measure indirectly the velocity of sound in other liquids as well as water. The following table gives the velocity in feet per second obtained for the liquids mentioned at the temperatures given: —

	Temperature	Velocity
River Water (Seine)	15 C	4,714
" " "	30	5,013
Sea Water (artificial)	20	4,768
Solution of Common Salt	18	5,132
Solution of Sulphate of Sodium	20	5,194
Solution of Carbonate of Sodium	22.2	5,230
Solution of Nitrate of Sodium	20.9	5,477
Absolute Alcohol	23	3,804
Ether	0	3,801

The velocity of sound in liquids, as in gases, increases with the temperature. But the changes of temperature, which are due to the condensations of sonorous undulations in water, are so insignificant as to affect no appreciable change in the medium. For this reason we may apply Newton's formula, $V = \sqrt{\frac{e}{d}}$, without Laplace's correction, for calculating the velocity of sounds in liquids, and the results given closely approximate to those obtained by experiment. Thus by direct measurement the velocity of sound in water was found to be 4,708 feet per second; by Wertheim's indirect method it was found to be 4,714 feet; and by the application of Newton's formula a velocity of 4,671 feet is given. As the elasticity and density of any