CHAPTER IV.

ACOUSTICS.

I.—PRODUCTION AND PROPAGATION OF SOUND.

Definition of Acoustics.

145. Acoustics is that branch of Physics which treats of the laws of generation and propagation of sound.

Definition of Sound.

146. Sound is a motion of matter capable of affecting the ear with a sensation peculiar to that organ.

Sound is caused by the vibration of some body, and is transmitted by successive vibrations to the ear. The original vibrating body is said to be *sonorous.* A body which transmits sound is called a *medium.* The principal medium of sound is the atmosphere; wood, the metals, water, &c., are also media.

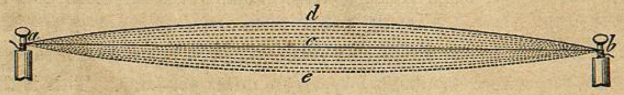

Fig. 107.

Let us take, for illustration, a stretched cord which is made to vibrate by a bow, as in a violin, for example. When the cord is drawn from its position of rest, *acb*, Fig. 107, to the position *adb*, every point of the cord is drawn from its position of equilibrium;

(**145.**) What is Acoustics? (**146.**) What is Sound? What is its cause? How is it transmitted? What is a sonorous body? A medium? Examples. *Explain the vibrating cord.*

when it is abandoned, it tends, by virtue of its elasticity, to return to its primitive state. In returning to this position, it does so with a velocity that carries it past *acb* to *aeb*, from which it returns again nearly to *adb*, and so on vibrating backward and forward, until, after a great number of oscillations, it at length comes to rest. These vibrations are the cause of a sound which may reach the ear through the atmosphere.

The oscillations of sonorous bodies are too rapid to be counted, or even to be seen distinctly. This may, however, be made manifest to the eye in several ways.

For example, if a hollow glass globe be made to vibrate by striking it, and a small ball of ivory be brought near it, a succession of shocks is sufficient to make the vibratory motion manifest.

If a plate of metal be fixed at one of its points, and then made to vibrate by drawing a violin bow over one of its edges, fine particles of sand strewn over it will be seen to dance up and down, and finally to arrange themselves in curious figures. This motion of the particles of sand is due to the vibrations of the plate, and it serves to make them manifest to the eye.

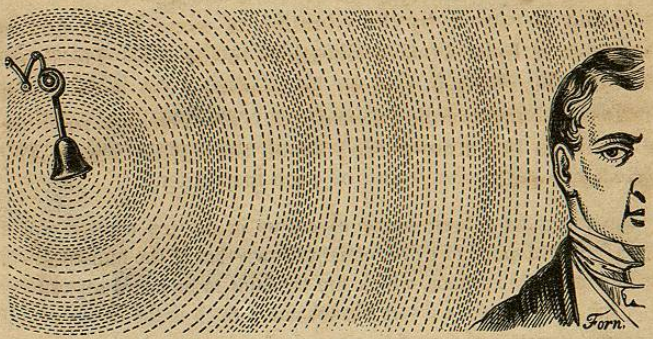

Fig. 108.

Propagation in Air.—Sound-Waves.

147. The vibrations of a sonorous body give rise to corresponding vibrations in the surrounding air, which are

How may sonorous vibrations be made manifest to the eye? Explain the vibrating globe. The vibrating plate. (**147.**) How is sound propagated?

transmitted by a succession of condensations and rarefactions, as represented in Fig. 108, until at last they reach the ear and produce the sensation of sound.

The vibrations of the air communicate corresponding vibrations to the tympanum or drum of the ear, whence they are transmitted by a very complex mechanism to the auditory nerve, and so to the sensorium, or seat of sensation.

The aerial vibrations emanating from a sonorous body spread outwards in successive spheres; hence sound is transmitted in all directions.

An idea of the successive spheres or undulations may be had by dropping a stone upon the surface of a pond of still water, and noticing the successive waves as they follow each other to the shores. The central particles continue to oscillate like those of the cord already described, and at each oscillation a new wave or undulation is generated.

Co-existence of Sonorous Waves.

148. It is to be remarked that many sounds may be transmitted through the air simultaneously. This shows that the sound waves cross each other without modification. In listening to a concert of instruments, a practiced ear can detect the particular sound of each instrument.

Sometimes an intense sound covers up or drowns a more feeble one; thus, the sound of a drum might drown that of the human voice. Sometimes feeble sounds, which are too faint to be heard separately, by their union produce a sort of murmur. Such is the cause of the murmur of waves, the rumbling sound of a breeze playing through the leaves of a forest, and the indistinct hum of a distant city.

It has been shown that two sound-waves may, under certain circumstances, neutralize each other, producing silence.

How imparted to the auditory nerve? *What is the form of a sound-wave in the air? Illustrate by waves on a pond.* (**148.**) Do sound-waves interfere with each other's progress? How shown? *Explain the murmur of leaves. Waves. Of a city.*

Sound is not propagated in a Vacuum.

149. That some medium is necessary for the transmission of sound, may be shown by the following experiment.

In a glass globe with a stop-cock, is suspended a bell, as shown in Fig. 109. When the globe is shaken, the sound of the bell is distinctly heard. If the air be exhausted from the globe, no sound is heard when the globe is shaken.

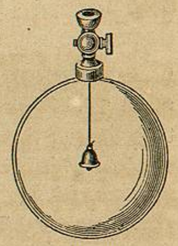

Fig. 109.

This experiment may be performed otherwise as follows:

A bell is placed under the receiver of an air-pump, provided with a striking apparatus set in motion by clock-work. Before the air is exhausted, the strokes of the hammer on the bell are distinctly heard, but as the air is exhausted the sound becomes fainter and fainter, till at last it ceases to be heard.

For the complete success of this experiment, the bell and clock-work should be placed upon a cushion, of some substance which does not readily transmit sound.

In ascending high mountains, the air becomes rarefied, and a corresponding diminution in the intensity of sounds is observed. Saussure, on firing a pistol on the summit of Mt. Blanc, reports that it only produced a feeble sound, like that heard on breaking a stick.

Propagation of Sound in Liquids and Solids.

150. Sound is transmitted, not only by gases, but also by liquids and solids. Divers hear sounds from the shore when

(**149.**) How is it shown that sound is not transmitted in a vacuum? Another method of showing the same thing. *Effect of elevation on sound.* (**150.**) How is it shown that liquids and solids transmit sounds?

under water, and sounds made under water are heard on shore. A slight sound made at one end of a long stick of timber is distinctly heard by an ear at the other end, even when it might be inaudible at an equal distance through the air.

The earth transmits sounds, and by placing the ear in contact with it, sounds may be distinguished at a great distance. This method of hearing approaching footsteps of men or animals, is well understood by hunters. In the construction of subterranean galleries for mining purposes, the miner is often guided, as to the direction he should take, by sounds transmitted through large masses of earth and rock.

Velocity of Sound in the Air.

151. That sound occupies an appreciable time in passing from point to point may be shown by many familiar examples. If we notice a man cutting wood at a distance, we shall perceive his axe fall some time before the sound of the blow reaches the ear. If a gun is discharged, we see the flash before we hear the report. In like manner the flash of lightning is seen before we hear the thunder.

In 1822, a number of scientific men undertook a series of very nice experiments to determine the velocity of sound. They placed a cannon on the hill of Montlery, near Paris, and another on a plain near Ville-Juif, the distance between them being 61,047 feet. At each station twelve discharges were made at intervals of ten minutes; the discharges alternating between the stations at intervals of five minutes. Observers placed at each station observed the intervals of time that elapsed between seeing the flash and hearing the report of the cannon at the other station. (See Fig. 110.)

How is it shown that the earth transmits sound? Illustrate. (**151.**) How is it shown that sound requires an appreciable time to pass from place to place? Illustrate. Explain the experiments made near Paris.

The average of these intervals at both stations was found to be 54.6 sec., giving for the actual velocity of sound, 1118 feet per second.

The temperature of the air was 61° F. Sound travels faster in heated than in cold air. Making allowance for this change of velocity, and reducing the velocity to what it would have been at 32° F., we have for this temperature, the velocity equal to 1090 feet per second.

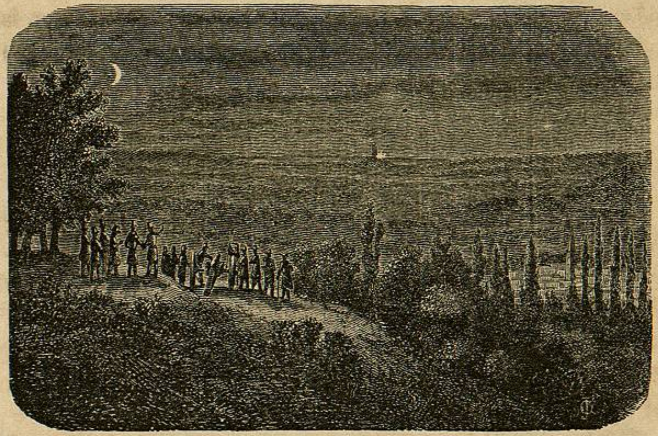

Fig. 110.

A knowledge of the velocity of sound enables us to determine the distance between two points. Let a gun be fired at one point, and let an observer note the time between the flash and report; multiply the number of seconds elapsed by 1090, we have the distance required. When great accuracy is required, the temperature of the air must be taken into account. In a similar way we may determine the depth of a well, by dropping a stone and noting the time between the instant when it strikes the water and that at which the sound reaches the ear.

The velocity of sound is not the same in all gases. It is, in general, greater in the rarer gases. But in the same gas, all sounds,

What is the velocity of sound at 32° F.? *Application to determine distance between two points. Depth of a well. Does sound travel equally fast in all gases?*

whether strong or feeble, grave or acute, are transmitted with the same velocity. If we listen to a band at a distance, the notes reach us exactly in the same order that they are played, and the sounds of all the instruments are heard together.

Velocity of Sound in Liquids and Solids.

152. Liquids and solids transmit sound more rapidly than air. Experiments made by transmitting sound across the Lake of Geneva, in Switzerland, show that the velocity of sound in water is about 4700 feet per second, which is more than four times its velocity in air.

That sound travels faster in iron than in air, may be shown by placing the ear at one extremity of a long iron bar or tube, whilst it is struck on the other end with a hammer. Two sounds will be heard, the first transmitted through the iron, and the second through the air. It has been shown that sound is transmitted seventeen times faster in iron than in air. The velocity of sound is not so great in the other metals.

Reflection of Sound.

153. Sound is propagated through the air in spherical waves. (Fig. 108.) When these waves meet with an obstacle they are driven back, as an elastic ball is when thrown against a hard wall. The waves driven back take a new direction, or are reflected. The laws of reflection are the same as those which govern the reflection of heat and light, which will be explained hereafter.

Echoes.

154. An ECHO is a repetition of a sound, caused by a reflection of the sound-waves from an obstacle more or less

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Do all sounds travel with equal velocity? How shown? (**152.**) How was it shown that sound travels faster in water than in air? In iron than in air? (**153.**) Explain the reflection of sound. (**154**) What is an Echo?

remote. Thus, if we pronounce in a loud voice a sentence at a certain distance from a rock or a building, we often hear, after an instant, the same sentence as if repeated at a distance by another person.

This is due to reflection of the sound-waves from the rock or building. In order that any echo may be clearly distinguished, the reflection must take place from an obstacle which is at least 109 feet distant.

It is not possible to pronounce or to hear distinctly more than five syllables in a second. The velocity of sound being 1090 feet per second, it follows that sound travels 218 feet in one fifth of a second. If, then, an obstacle be placed at the distance of 109 feet, sound will go to it and return in one fifth of a second. At the distance of 109 feet, the last syllable only of the echo will reach the ear after the sentence is pronounced. Such an echo is called *monosyllabic*. If the echo takes place from an obstacle at a distance of 218 feet, we hear two syllables; that is, the echo is *dissyllabic*. At distances of 327 feet, the echo is *trisyllabic*, and so on.

Sound may be reflected from several objects situated in different directions and at different distances. Such echoes are called *multiple echoes*. It is said that at a place three leagues from Verdun, a multiple echo formed by parallel walls fifty or sixty yards apart, repeats a sound twelve times. At the chateau of Simonnetta, in Italy, there is an echo which repeats the report of a pistol from forty to fifty times.

Echoes modify the tones of sound. Some repeat sounds with a roughened, others with a softened tone; some with a sneering, others with a plaintive accent.

Resonance.

155. When sounds are reflected from obstacles at a less distance than 109 feet, the reflected sound is superposed

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Illustrate. What causes the echo? *Explain the monosyllabic, dissyllabic, and trisyllabic echoes.* What are multiple echoes? Examples. What effect have echoes on the tone of a sound? (**155.**) What is a Resonance?

upon the direct one, giving rise to a strengthened sound, which is called a *Resonance.*

It is the resonance from the walls of a room that makes it easier to speak in a closed apartment than in the open air. The resonance is more clearly perceived when the walls are elastic. In rooms where there are carpets, curtains, stuffed furniture, and the like, the sound-waves are broken up, and the resonance is diminished; but in houses where there is no furniture, the resonance is strengthened. Hence it is, that the sound of voices, footsteps, and the like, is so strongly marked in deserted and unfurnished buildings.

Intensity of Sound.

156. The INTENSITY of sound is its loudness. The intensity of sound depends upon the force with which the vibrating particles of air strike upon the drum of the ear. The original intensity depends upon the power of the exciting cause.

Causes that modify the Intensity of Sound.

157. The following are some of the causes that modify the intensity and rate of propagation of sound:

1. It is shown by theory and confirmed by experiment, that the intensity of sound diminishes as the square of the distance from the sonorous body increases.

This is expressed by saying that, *the intensity of sound varies inversely as the square of the distance from the sonorous body.*

2. The intensity of sound diminishes with the *amplitude* of the vibration of the aerial particles.

When a cord vibrates, the sound is observed to diminish as the vibrations become smaller, and when the vibrations cease, the sound

Illustrate by examples. (156.) What is Intensity? On what depend? (157.) What are the laws of intensity? 1. Effect of distance? 2. Amplitude of vibration?

is no longer heard. In this case the length of vibration of the cord determines *the length*, or *amplitude* of the vibrations of the aerial particles.

3. The density of the air modifies sound. When the air is rarefied, the intensity is diminished. This fact has been shown by the experiment of a bell in an exhausted receiver.

The presence of watery vapor in the air also modifies sound, that substance being a good conductor of sound. When the air is cooled, it becomes more dense, hence, sounds are louder in cold than in warm weather.

4. The wind modifies sound. The velocity of sound is increased or diminished by the velocity of the wind, according as the direction of the wind conspires with or opposes the propagation.

The effect of the wind is to move the whole mass of air, carrying along the sound-waves unaltered.

5. Sound is increased in intensity when the sonorous body is in contact with, or even in the neighborhood of another body capable of vibrating in unison with it.

Hence, the sound of a vibrating cord is reinforced or strengthened by stretching it over a thin box filled with air, as in the violin. In this case the air in the body of the violin vibrates in unison with the cord. The ancients placed in their theatres vessels of brass, to reinforce and strengthen the voices of the actors.

Intensity of Sounds in Tubes.

158. When a sound is transmitted through a tube, the sound-waves can not diverge laterally, and consequently the

Illustrate. 3. Density of the air? *Illustrate.* 4. How does wind modify sound? 5. Effect of a neighboring sonorous body? *Illustrate.* (158.) What effect has a tube on sound?

sound is transmitted to a great distance without much loss of intensity.

M. Biot was able to carry on a conversation in a low tone through a tube a thousand feet in length. He says that the sound was transmitted so well, that there was but one way to avoid being heard, and that was not to speak at all.

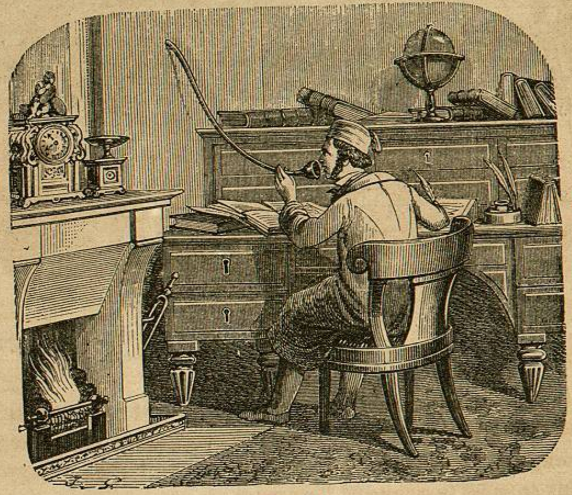

Fig. 111.

This property of tubes is utilized in hotels and dwelling-houses, for transmitting messages from one story to another. The tubes employed for this purpose are called speaking tubes. The method of employing the speaking tube, is illustrated in Fig. 111.

The Speaking Trumpet.

159. The Speaking Trumpet, as its name implies, is a conical tube employed to transmit the voice to a great

Biot's *experiment. Practical applications.* (**159.**) What is a Speaking Trumpet?

distance. It is used by firemen and by mariners, as shown in Fig. 112.

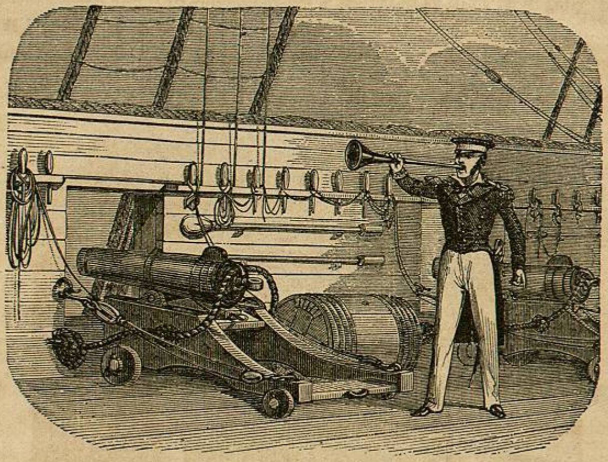

Fig. 112.

By means of the speaking trumpet, the voice of the captain can be heard above the noise of the winds and waves in a tempest. According to Father Kircher, Alexander the Great employed a speaking trumpet to command his armies.

The effect of the speaking trumpet has been explained by successive reflections of sound-waves from the sonorous material of which the instrument is composed, by virtue of which the voice is only transmitted in the direction of the tube.

But the fact is, that sound is transmitted in all directions, which would indicate that its effect should be attributed to a reinforcement of the voice by the vibration of the column of air contained in the trumpet, according to the principle that sound is reinforced by an auxiliary vibrating body.

How is the effect of the speaking trumpet explained?

The Ear Trumpet.

160. The Ear Trumpet is a trumpet employed by persons whose hearing is defective, as shown in Fig. 113.

Fig. 113.

It is simply the speaking trumpet reversed. It serves to collect and concentrate the sound-waves, which are thus enabled to produce a more powerful impression on the drum of the ear. The shape of the ear in man and in animals is such as to perform the function of the trumpet.

II.—MUSICAL SOUNDS.

Difference between a Musical Sound and a Noise.

161. A Musical Sound results from a succession of vibrations of equal duration. Such vibrations are called *isochronal.*

(**160.**) What is an Ear Trumpet? How does it differ from the speaking trumpet? What is its use? (**161.**) What is a Musical Sound?

Noise results from a single impulse, or from a succession of vibrations of unequal duration. Thus, the crack of a whip, the discharge of a pistol, the rattling of thunder, or the roar of the waves of the ocean, are destitute of musical value, and are simply noises.

Pitch of Sounds.—Music.

162. The Pitch of a musical sound depends upon the frequency of the vibrations. Those sounds which result from very rapid vibrations, are called *acute*, whilst those which arise from very slow vibrations, are called *grave.*

The terms acute and grave are relative; thus, a given sound may be acute with respect to a second, whilst it is grave with respect to a third; thus, a sound which corresponds to 160 vibrations, is acute with respect to one corresponding to 80 vibrations, and grave with respect to one corresponding to 320 vibrations per second. A well arranged and happy combination of grave and acute sounds according to the principles of harmony, constitutes *music.*

Limits of perceptible Sounds.

163. M. Savart investigated the subject of sound with respect to the number of vibrations, corresponding to the most grave and acute sounds perceptible by the human ear, by means of an apparatus devised for that purpose.

As the result of his investigations, he concluded that the gravest perceptible sound was produced by 16 vibrations per second, and the most acute by 48,000 vibrations per second. Allowing 1090 feet as the velocity of sound, we find for the length of the waves, corresponding to the gravest sounds, 68 feet, and for the length corresponding to the most acute sounds, a little more than a quarter of an inch.

What is a Noise? **162.** What does Pitch depend upon? What is an acute sound? A grave one? *Illustrate by examples. What is music?* (**163.**) Who investigated the limits of audible sounds? Give the results of his investigation.