CHAPTER I

PRODUCTION AND PROPAGATION OF SOUND

THE term "sound" is used in two distinct senses. It is used to denote both the external cause of a particular sensation and that sensation itself. Thus we talk of the production of a sound and the propagation of a sound, referring to particular physical phenomena considered quite apart from any possible hearer, and under the same term we refer to the sensation which these external phenomena produce in ourselves and others.

The sensation of sound is always associated with the vibratory motion of some sounding body. The blurred outline of this body while sounding is sufficient as a rule to convince us of its rapid to-and-fro motion, and, immediately this motion is stopped by a touch of the finger, the sound ceases. Many experiments may be quoted in illustration of this fact. For instance, a moistened finger passed round the rim of a wine-glass or finger-bowl causes it to emit a strong note. If the surface of the liquid contained be examined by reflected light, the vibration of the glass will be found to have revealed itself by throwing the surface of the liquid into a beautiful pattern which moves round with the finger. A moment's thought will convince us that all musical instruments when sounding have vibrating parts—strings, air-columns, membranes &c.

But, though it is true that our sensation of sound is always associated with the vibratory motion of a sounding body, the converse does not always hold. It is possible to produce vibrations which do not affect our sense of sound at all. For instance, in the case of many sounding bodies where the vibrations die out slowly, it will be found that we cease to hear the sound before the vibrations have completely stopped. In this case the energy of the vibrations has become so small that it is insufficient to set in action the mechanism of the ear. In order that this may happen, the energy must be very small indeed. Thus, in ordinary conversation, the amplitude of vibration of the layers of air near the ear—that is the greatest distance which they move in either direction from their undisturbed position—is always less than the thousandth part of an inch and often less than the millionth part of an inch. Sounds are audible even when the amplitude of the vibrations is 20 or 30 times smaller still. The changes of pressure produced in the air in the ear may excite the sensation of sound when they are as small as the pressure in the highest vacuum obtainable.

Again, if a card be held in the hand and moved rapidly to and fro, no sound will be heard. This does not mean that the card is in all cases incapable of acting as a source of sound, for, if the edge of the card be touched with the shaft of a vibrating tuning-fork, the volume of sound coming from the fork will be largely increased, the increase being contributed by the vibrations of the card. A good deal of light is thrown on these observations by experiments with a metal strip clamped in a vice. If the end of the strip be pulled aside with the finger and released, it will execute to-and-fro vibrations which will be more rapid the shorter the length of the strip which is free to vibrate. If the strip is taken fairly long at first and then gradually shortened, it will be found that at first its vibrations produce only a feeble whirring sound, but that, as the length of the strip is diminished and the vibrations become more rapid, they produce a faint note of low pitch, the pitch rising as the strip is still further shortened. From this we conclude that vibrations may be too slow to affect our sense of sound.

At the other end of the scale a similar phenomenon is found. It may be illustrated by the use of a Galton whistle. This little instrument gives a very high shrill note, and the pitch of the note may be altered continuously by adjusting a stop. If this stop is moved so as to shorten the air-column of the whistle, the vibrations become more and more rapid and the note more and more shrill until suddenly a point is reached at which the note ceases to be heard. The vibrations have not ceased nor have they undergone any sudden change. They have merely become too rapid to affect our sense of sound. The limit varies for different people, becoming lower as a rule with advancing age. Thus we find that the sensation of sound always has its origin in vibration, but that such vibration may be too feeble, too slow or too rapid to produce the sensation.

We now come to consider how the vibrations of a sounding body reach the ear. It is natural to suppose that they are conveyed by some medium, and this is easily verified by experiment. If we exhaust the air from an enclosed space, the vibrations of a bell placed in it fail to excite the sensation of sound. Sound is usually carried by the air, but may also be carried by liquids and solids. A detailed discussion of the way in which the transmission of sound takes place would be out of place here, but some general idea of the process is essential to the right understanding of what follows. One of the most important methods of transmission of energy is by means of waves. All the energy reaching us from the sun—and most of

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our energy comes from the sun ultimately—is conveyed to us by waves. The energy by which the sensation of sight is excited is transmitted by waves. The energy used for sending wireless messages is carried by waves. The waves with which we are most familiar are no doubt those formed on the surface of water and they may be used to illustrate many important properties of waves, but we get a much clearer idea of the essential feature of wave motion if we think, instead, of the waves which pass across a field of corn under the action of wind. In this case, more perhaps than in any other familiar one, we are brought to realise clearly the distinction between the movement of the waves and the movement of the medium which transmits them. Thus while the wave moves forward, preserving its individuality and to some extent its form, the particular heads of corn whose arrangement gives the wave its form are always changing, being caught up by the front of the wave and then left behind. This is typical of all wave motion. The progressive movement of the wave is always associated with a to-and-fro movement of each part of the medium. The wave is a "form" imposed on the medium and is transmitted without any transference of the medium itself. One of the essential conditions for the propagation of waves is that, when the medium is disturbed, forces should be called into play tending to restore the original undisturbed condition. These forces are supplied in the case under consideration by the elasticity of the corn-stalk, which raises the head again after it has been depressed by the wind. In water waves the principal restoring force is gravity. If a ridge or a hollow is formed on the surface of water, gravity tends to restore the level surface.

We are now in a position to picture to ourselves the propagation through air of waves set up by a vibrating plate. As the plate moves forward, it compresses the layer of air immediately in contact with it. The pressure of the air in this layer is consequently increased. But the layer in front of this again is still at the original pressure. The first layer therefore expands forward into the second in order to equalise the pressure. In doing so it compresses the second layer and this in turn compresses the third, so that a "wave of compression" is propagated outwards with a speed which depends only on the properties of the air and is quite independent of the subsequent motion of the plate. Meantime, the plate having arrived at the end of its forward motion starts backwards again. This gives the layer of air next it additional space to expand into, and the expansion is accompanied by a fall of pressure. This layer is therefore rarefied. But the second layer is still at normal pressure. It therefore expands back into the first layer, itself becoming rarefied. The third layer expands backwards into the second, and so a "wave of rarefaction" travels outward after the wave of compression.

The waves by which sound is propagated are, of course, ordinarily invisible. This is due to two causes. In the first place they travel with a speed which, compared with that of light waves, is extremely small but, compared with any ordinary standard, is very great indeed. Thus in air under common atmospheric conditions the waves will travel fully a mile in five seconds. This is a speed which the eye would find it impossible to follow. In the second place, portions of the air differently compressed are not easy to distinguish although they do exert a slightly different bending action on rays of light. This is frequently apparent in hot weather when layers of heated air which have expanded, and so become less dense, rise from the hot ground, causing a quivering of objects seen through them. This phenomenon may be utilised not only in photographing sound waves, but even in rendering them visible to the eye. No matter how rapidly an object may be moving, if it is illuminated instantaneously, it will be seen distinctly and apparently at rest. The more rapid its motion, the shorter must be the duration of the flash which reveals its presence. By using an electric spark as the source of light, the waves caused by the passage of a bullet through the air have been photographed.

The frontispiece is a photograph of a bullet in flight and shows V-shaped air waves spreading out from the front and rear of the bullet respectively. Sound waves, unlike water waves, are not confined to one plane, but spread out in every direction. Thus the waves are at any instant a series of concentric spheres surrounding the source, and not, as in the case of water waves, a series of concentric circles.

In due course these waves arrive at the layer of air in contact with the membrane which closes the inner end of the outer passage of the ear—the so-called "drum" of the ear. This layer is compressed, the layer of air on the inner side of the membrane is still at normal pressure, and so the membrane gets driven inwards. Conversely when the wave of rarefaction arrives, the pressure on the inner side being normal while that on the outer side is less than normal, the membrane gets driven outwards. Thus the motion of the plate is reproduced by the drum of the ear which moves out and in, keeping time with the vibrations of the plate.

Sound waves, like all other waves, experience reflection and refraction. When a series of sea waves wash against a sea wall or esplanade, a series of reflected waves may be seen moving outwards as if they came from behind the reflecting surface. This is of course exactly analogous to the echo; here the sound waves emitted by a source strike a cliff or some similar surface and are reflected back as if they came from a source behind the cliff. Refraction is a phenomenon, equally familiar, in which the waves concerned change their direction of propagation. It occurs whenever the waves move in a medium which is heterogeneous in the sense that some parts of it propagate the waves with greater velocity than others. For instance, in the case of water waves it is a familiar fact that, in whatever direction the waves may be travelling in the deep water, as they approach the shore they change their direction and wheel round, until the length of the wave is practically parallel with the shore. Now this is due to the fact that waves travel faster in deep water than they do in shallow water, and consequently the end of the wave nearer the shore is retarded while the end farther from the shore begins to overtake it, the direction gradually changing as shown in the diagram (Fig. 1).

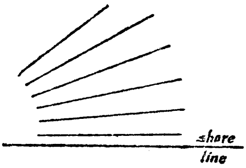

Fig. 1.

Two important examples of the refraction of sound waves occur frequently. So long as the pressure remains the same the velocity of sound waves is greater when the air is less dense and conversely. Consider the case of a hot still day. The layers of air in contact with the ground get heated and expand, thus becoming less dense. It follows that if sound waves are being propagated along the surface of the earth the edges nearest the earth will travel more quickly, and a glance at Fig. 2 will show the effect of this on the direction of propagation of the waves. It will readily be seen that the direction of propagation soon becomes so much changed that the waves move off into the upper layers of the atmosphere and we have a simple explanation of the well-known fact that under these circumstances sounds carry very badly. Consider now the evening of a day of the same kind. The earth radiates its heat quickly and so cools. It then cools the layers of air in contact with it so that these contract and become more dense. In this case the edges of the waves next the earth travel more slowly than the upper portions of the waves so that the direction changes as in Fig. 3, the waves being directed down towards the surface of the earth instead of moving off into the atmosphere. This explains the great distinctness with which sounds frequently carry in the evening of a hot day—a distinctness which is of course all the greater over a smooth surface, for instance a sheet of water.

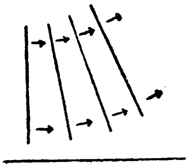

Fig. 2.

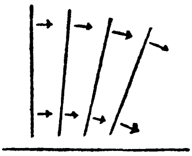

Fig. 3.