WAVES OF SOUND AND SPEECH AS REVEALED BY THE PHONOGRAPH, PP. 3-41

Published @ 2017 Trieste Publishing Pty Ltd

ISBN 9780649258123

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Edited by Trieste Publishing Pty Ltd.
Cover @ 2017

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WAVES OF SOUND AND SPEECH

AS REVEALED BY THE PHONOGRAPH.

BY

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THE SCIENCE LECTURE FOR 1896 TO THE PHILOSOPHICAL SOCIETY
OF GLASGOW.

WITH NUMEROUS ILLUSTRATIONS AND TWO PLATES.

LONDON: MACMILLAN & CO., LIMITED.
NEW YORK: THE MACMILLAN CO.
1897.

PRICE ONE SHILLING.

As many, both at home and abroad, who are interested in the Phonograph, have expressed a desire to read this Lecture, and have applied for copies, the Council of the Society kindly authorised its publication in separate form. The Lecture also appears in the *Proceedings* of the Society for 1896-97.

Fer. Where should this music be? i' the air, or the earth?

* * * *

Ste. * * * come on, Trinculo, let us sing.

* * * *

Cal. That's not the tune.

* * * *

Ste. What is the same?
Trin. This is the tune of our catch, played by the picture of Nobody.
THE TEMPEST.

WHEN the Council did me the honour of inviting me to deliver the Science Lecture for 1896, I thought that I could not do better than endeavour to give you an account of a research in which I have been engaged during the last two years. This research relates to the interpretation of the marks on the wax cylinder of the phonograph, and it has an important bearing on certain questions connected with physiological acoustics. Perhaps I ought to apologise to the physicists for so far invading their territory in this research. The work, some of the results of which I shall place before you to-night, is, no doubt, mainly of a physical nature. But sciences dovetail into each other so as to render it impossible to draw a clear line of demarcation between those that are closely allied. Of this we have an example in the close relationship that exists between many departments of physiology and of physics. Take, for instance, the department we term physiological acoustics. The physicist deals with sound as consisting of certain movements of matter occurring outside the physiological organism, and he investigates these movements as dynamical problems. On the other hand, it is the business of the physiologist to show how these movements affect the mechanism of the sense organ, the ear, how the filaments of the auditory nerve are stimulated, and how the impulses transmitted by the nerve to the brain are there, in a way absolutely unknown at present, translated into consciousness. No physiologist can attempt to explain the mechanism of the ear without being acquainted with acoustics, nor can the physicist deal adequately with the phenomena of sound unless he takes into account the mechanism of the ear. Let me say to the physicists present that, if I have crossed into their territory in carrying out a purely physical research relating to hearing, I hope they will retaliate by pushing their researches into the physiological side, and apply their methods to the investigation of the mechanical phenomena in the body that end in a sensation of sound.

We have all more or less enjoyed, at one time or another of our lives, a certain amount of pleasure in the contemplation of wave movements. Rhythmic movement always gives pleasure, whether it be in the dance or in the undulations sweeping across a field of wheat when the winds of early summer are blowing. We have also, no doubt, stood on a rocky headland, or on the deck of an ocean steamer, and we have gazed with pleasure on the tumultuous action of the sea, as waves of many varying forms passed before our eyes. While the great rollers of the Atlantic have been distinctly visible, we have seen how their contours were moulded by numerous other waves, some possibly caused by the paddle-wheels or screws of passing vessels, by the eddies of wind that sweep over the surface of the water, or by the dip of a sea-bird's wing. While the infinite variety of form gave an abiding interest in the spectacle, the general feeling of rhythm probably contributed most to our feelings of pleasure.

The waves that we discuss in this lecture do not relate to movements that can be seen by the eye. Waves of sound appeal to the ear, not to the eye. They are invisible, and yet they are felt, because they excite variations of pressure on the drum-head of the ear; the effect of these variations is communicated to the nerve; the nerve carries the impulse to the brain, and we hear. Waves of sound differ in many respects from the waves which we see on the surface of water, and yet to explain sound waves we are often obliged to take our illustrations from the movements on the surface of water.

Let me, in the first place, lay before you a few general and elementary statements regarding waves of sound. A body that gives out sound is itself in movement.

The to-and-fro movements, say, of the limbs of a tuning fork, are called vibrations. These movements may be communicated to the air, or to liquids or solids. Let us confine our attention to the transmission of movements, vibrations, through the air, as it is by the medium of the air that we usually hear sounds. Each movement of the limb of the tuning fork causes first a greater pressure, and then, owing to the elasticity of the air, a smaller pressure on the air near it, and these variations of pressure are communicated through layer after layer of the air until they reach the drum-head of the ear. When there is an increase of pressure on the drum-head it is pushed in, and when the pressure becomes less, the drum-head passes back to its first position. These variations of pressure, usually periodic in character, as they occur in the air, constitute sound waves. So far they are purely physical movements, and if we could see the air as it is traversed by sound waves we would see shells, as it were, of condensed air alternating with shells of rarified air—that is to say, the condensed portions would correspond to positions of greater pressure, while the rarified portions would represent the positions of smaller pressure. The positions of greater pressure correspond to the crests of waves on the surface of water, and those of smaller pressure to the trough between two adjacent waves. As you are aware, we determine the length of a wave by taking any point on its surface and measuring the distance to a corresponding point on the next succeeding wave. Thus we say the length of a wave is from crest to crest, or from trough to trough. In like manner we say that the length of a wave of sound is the distance of any point of condensation or of rarefaction to a corresponding point in the next wave.

Think, again, of waves on the surface of water. These may vary in length, or in amplitude, or in form, as is well shown by the diagram now thrown on the screen, from Mr. Sedley Taylor's interesting book on *Sound and Music*—

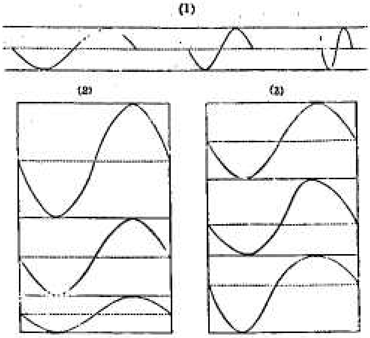

Fig. 1.—Waves.

Here you see, in (1) three waves the same in amplitude and form, but different in *length*; in (2) three waves the same in length and form, but different in *amplitude*; and in (3) three waves the same in length and amplitude, but different in *form*. Thus we may have waves varying much in length from long rollers to those of a few inches in length; we may have waves with high crests and deep troughs, or they may be merely feeble ripples on the surface of the water; finally, the waves may vary much in form, some having a slanting ascent and a less slanting descent, or they may have flat crests and shallow crests, or the reverse. Thus there may be an almost infinite variety of wave forms, although they may not differ as to wave length and wave amplitude.

This illustration must now be applied to our conceptions of waves of sound. Thus a sounding body, such as a vibrating tuning fork, may cause waves, each of which is exactly similar to any one of the series, or to all in the series. If we cause the tuning fork to record its vibrations on a moving surface, such as a drum moved with great regularity by clock work, and covered by paper blackened in a sooty flame, we obtain tracings like those now thrown on the screen:—

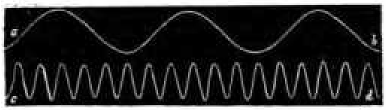

Fig. 2.—Tracings of the Vibrations of a Tuning Fork—10 vibrations per second. *a*, *b*, cylinder moving rapidly; *c*, *d*, cylinder moving slowly.*

These we may term simple waves, and they are caused by pendular vibrations—that is to say, by movements like the periodic oscillations of a pendulum. Apply this again to help out the conception of a wave of sound. The crests would correspond to the condensations, or greater pressures, and the troughs to the rarefactions, or lesser pressures.

From these simple waves we may now form compound waves. Thus I sound this large fork by drawing a fiddle bow across its prongs, and it gives out a strong, deep tone. This tone is caused by varying pressures on the drum-head, as I have explained. Then I sound this other fork, which gives out the octave of the first. It sets up a series of waves of half the length of those of the first, and the resultant tone is caused by a compound wave made up of the two waves, the form of which (if the two waves started simultaneously) is shown in the diagram now on the screen:—

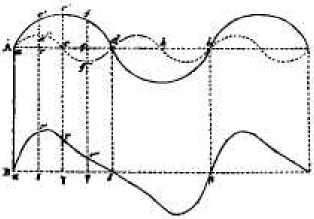

Fig. 3.—Formation of a Compound Wave, 1 : 2.

You observe that the lower wave is produced by combining the two upper waves. In like manner I now sound a fork which vibrates three times as fast as the first. The resultant tone now

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* M'Kendrick's "Physiology," Vol. I., Fig. 236, p. 385.