DETERMINATION AND COMPARISON OF SOUND INTENSITIES.

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WE are now able to compare the power and efficiency of different luminants with considerable ease. For similar measurements dealing with the energy from sounding bodies we have, however, at present no method. Several properties of the vibrations and waves concerned in the two cases, as well as the peculiarities of the sense-organs involved, are responsible for this. To compare the illumination power of two lamps, the common procedure is either to produce equal illumination from the two sources on adjacent parts of the same screen, or so to adjust the two that shadows, of equal depth are cast. Now, both of these methods depend upon the fact that light travels very nearly in straight lines. Sound waves, having so much greater wave length, do not even approximate rectilinear propagation.

The eye is very sensitive to changer of intensity, but not to small shadings of color. With the ear the reverse is true. Very small changes of pitch can be perceived, while variation of loudness is required to make itself noticed. A lamp varying even slowly is unpleasant, while, in music, the accent and shading are necessary, and so by habit we are less able to discriminate slight changes of sound intensity. Again, the ear has a power of analysis which the eye does not possess. A white light may really be made up of a number of different combinations of colors. In the sound from a number of instruments, however, the ear can pick out, not only the separate pieces, but the overtones given by them, amounting in all to hundreds.

All these things make it impossible to compare tone intensities as we do those of light. The effect of a given source of light might be measured by its chemical action, but, so far as we know, there is no corresponding effect due to sound. There are several effects produced by sound, and of these we will speak briefly, and give a short account of the attempts to solve the problems of sound-intensity measurement. The action of the microphone has long been known. If in the circuit with a battery and a telephone receiver is placed a carbon rod, resting loosely upon carbon supports at its ends, a very slight jar varies the resistance of the contacts and causes a sound in the receiver. Three nails in H shape make a fairly sensitive microphone. The ordinary transmitter is a device on the same principle. A number of years ago Wm. Weber suggested the use of the variable current thus produced as a measure of sound intensity. The currents in the secondary circuit of a local battery telephone set are so exceedingly small, however, that there has until recently been no reliable instrument to measure them, though several have been proposed. Even now it is not certain that the instruments suggested for this purpose will be successful. This method will be touched upon later.

In 1878 and 1881 Vierordt published several papers in which he describes methods of comparing sound intensities by the distances to which they were audible. He found that the law of inverse squares does not hold as in the case of light, but that the intensity decreases as the inverse first power of the distance. Here he depends upon the ear, which is very unreliable, especially at the *threshhold of sensation.* Rayleigh has found that, under certain circumstances, no relation seems to exist between the intensity of the stimulus and that of the resulting sensation. Certainly the ear is much more sensitive to sounds of some pitches than to others. Even if the method of Vierordt were trustworthy it could not well be used, as considerable space must be had out of doors, and quiet.

Next in the point of time came the suggestion of Overbeck. He used a microphone with but two carbon contacts, the one resting lightly on the other and the whole upon a resonance board. He showed that, to a certain degree of approximation, the increase of the resistance of this arrangement, when acted upon by a sound vibration, was proportional to the intensity of the sound falling upon it. It was therefore put into one arm of Wheatstone's bridge, a balance obtained when the microphone was at rest, and the deflection of the galvanometer produced by a sound wave falling upon the apparatus measured. This was useful only for sounds of moderate intensity and for the range of pitch c to c′.

Dvorak describes a number of contrivances depending upon the repulsion of resonators and of light aluminum vanes perforated with holes larger on the one side than on the other. In a similar way Professor Wood, of Baltimore, has made a sound pedometer, the speed of which depends upon the intensity of the tone, but which cannot be used as a measure of it. Lord Rayleigh suggested placing a light mica vane within a tube at an angle of forty-five degrees to the axis of the tube. At the open end of the tube was an elastic diaphragm at the node of a standing wave of the sound to be studied. When the sounding body was in action the vane tended to set itself along the axis of the tube. This motion was balanced by the action of a magnet upon the vane and held in position by the field of the earth. E. Grimsehl used a similar arrangement.

None of the methods so far described, however, with the exception of that of Weber, is of more than incidental interest. All depend upon assumptions and have very limited possibilities. Prof. Max Wien, in 1889, constructed his *optical telephone*. Upon the diaphragm of a special receiver he placed a small mirror which vibrated with the varying current in the magnet spools, thus giving a measure of the amplitude of the vibration of the diaphragm. Later, he placed the mirror directly upon a membrane actuated by the vibration to be studied, without the intervention of the telephone. If the tone under consideration is *pure*, that is, if it can be represented by a simple sine function, the intensity in absolute measure may be calculated from the amplitude thus found. For complex tones, and those with which we have most to do are very complex, this method is of no direct value.

G. Stern, in 1891, used a special microphone to study the intensity of sound in the various parts of a room. The method is merely qualitative and gives us little of any value.

Mr. B. F. Sharpe, working with Professor Webster, at Clark University, estimated the intensity of sound as follows: One total reflecting mirror of a Michelson refractometer is made small and light and mounted upon a thin plate forming part of the wall of a Helmholtz resonator. The objective of the observing telescope was a lens mounted upon one prong of a tuning-fork of the same period as the tone to be studied. A system of oblique bands was formed, the inclination of which is a function of the intensity of the sound. Here also the method is inapplicable to anything but a pure tone.

As shown mathematically by Rayleigh, radiation must exert a steady pressure upon a surface that opposes its advance. Nichols and Hull demonstrated the existence of this pressure in the case of light several years ago. More recently Altberg constructed an apparatus consisting of a reflecting wall in which there was a circular hole. Within this hole was a plunger supported upon one arm of a torsion balance. In this way he succeeded in measuring the actual energy given out by a glass tube set in longitudinal vibration by the friction of a rapidly rotating rubber of cloth wet with alcohol. With a sound so loud that he was obliged to stop his ears while working with it he found a radiation pressure of 0.25 dynes cm^2. If this method could be applied to sounds of ordinary intensity it would certainly be very valuable, but this noise was probably hundreds of times more intense than those with which we ordinarily have to do. When working with light the suspended parts could be put within an air-tight vessel and so protected from air currents, but in the case of sound measurements this is impossible, as that would shut off the pressure that we desire to measure. This puts a very definite limit to the delicacy of the suspended system that may be used in such an instrument. Some form of microphone, properly calibrated, will perhaps prove in the end the most satisfactory means of estimating sound intensities.