calculated for a series of temperatures and compared with the values found experimentally. They are collected in table VIII.

TABLE VIII.

t	T	P_7	P_8	α	P_5 (calculated)	P_5 (observed)
720°	993	33	0.0951	0.895	211	195
740	1013	55	0.1803	0.915	338	308
760	1033	90	0 3342	0 921	526	500
780	1053	144	0.6054	0.907	784	810

Considering the inaccuracy of the extrapolation of P_8 over fully 200° below the field of observation, the agreement may be called a complete one. It furnishes a proof of the correctness of our measurements as well as of those of WOHLER in connexion with the dissociation of copper oxide.

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Physiology. — *"On measurement of sound."* By Prof. H. ZWAARDEMAKER.

(Communicated in the meeting of April 1915.)

I have previously pointed out the benefit to be derived from Lord RAYLEIGH's arrangement, if we wish to perform a relative or even an absolute measurement of sound. Originally [1]) it was applied to the measurement of stationary sound-waves. W. KÖNIG [2]) extended its use to the theory of progressive waves in detail. It also enabled W. ZERNOV [3]) to carry out experiments on the intensity of the human voice. All earlier researchers and myself at first also, gave to the mirror, which was placed obliquely to the sound-wave, a peculiar position by attaching to it a small magnet. I now departed from this principle, at first by bifilar suspension, afterwards by simply hanging the mirror up by a long Wollaston fibre, flattened or not. [4])

1) Lord RAYLEIGH. Scientific Papers. Vol II, p. 132.

2) W. KÖNIG. Ann. d. Physik. Bd 42 and 43, 1891.

3) W. ZERNOV. Ann d. Physik (4). Bd 24 p. 79, 1908.

4) H. ZWAARDEMAKER "On hearing-apparatus". Ned. Tijdschrift v Geneesk. 1912, II. p. 1101. Proc of the meeting of 27 Sept. 1913. Vol. 22. p. 273, Congress at Delft, March 1913, Multiple resonantie. Ned. Tijdschr. v. Geneesk., 1913. II. p. 640.

To my knowledge ZERNOV was the first to place the measuring mirror in a space entirely free from resonance. To increase the sensitiveness I took some years later, for application to medical problems, an afferent tube of the dimensions of the auditory canal and the auricle. This enables us to perform an accurate measurement even of whispered speechsounds. However, occasional currents of air must be arrested by putting a very small plug of cotton-wool in the artificial auditory canal. The mirror is placed at an angle of 45° close in front of the aperture of the tube, so that the sound-wave, issuing from the auditory canal is driven against it as fully as possible. The mirror is consequently tilted with maximum power to a more transversal position.

If weak sounds in the speechzone a_1 to e_3 are to be measured, it will be well to use large receiving funnels. Phonograph horns in their various shapes will be found to work very well. Small amplitudes are recorded more accurately, when the scale is placed at a great distance. Then, however, a constant position of rest is expedient, which is hardly practicable, unless the streams of air in funnel and auditory canal are removed through the insertion of an india-rubber diaphragm of the size of a phonograph membrane. Cover-glass or thin mica will do as well. Thus I was in a position to establish the ratio of the average intensities of whispered and spoken sounds. The experiment was made (together with Dr. REUTER) with 20 monosyllabic, aequisonorous and aequidistant words. The ratio appeared to be 1 : 170. (The intensity is in the ratio of 1 : 170, the distance at which sounds are heard of 1 : 13)[1]). The modifying influence of funnel and membrane may be controlled by going through the gamut first with a simple physiological conducting tube and afterwards with the same tube associated with a funnel and phonograph membrane.

In the following pages I shall briefly state the rules which have proved generally reliable in measuring sound.

§ 1. *Physiological measurement of sound.*

When the measurement of sounds with regard to their audibility is the subject under consideration, it is permissible to use an artificial auricle and an artificial auditory canal to direct the sound-wave on to the measuring mirror. Provided the resonance of the artificial conduit be equal to that of the natural canal, nothing foreign is added to the sound, for when perceived by the human ear, it is transmitted through a similar tube. The artificial canal

[1]) Proceedings of the 14th Dutch Congress for Phys. and Med. at Delft.

used by me, has with a small plug of cotton-wool a tone of resonance equivalent to f_4, without a plug to e_4. The funnel in front of it was different in either experiment. When it was simply a flat wooden platter, a peculiar resonance was not noticeable.

The degree of sensitiveness is inversely proportional to the size of the mirror. A mirror of 2 mm. in diameter and 60 μ thickness, hung up by a Wollaston fibre of 2 μ have thus far proved to be the smallest dimensions for easy handling. In the same proportion the auditory canal should also be made narrower. Since we generally experiment on continuous waves (only e_4 yields a stationary wave), the distance at which the mirror is placed is of little consequence, provided it be axial. The sensitiveness is about inversely proportional to the distance from the aperture. It is remarkable that acoustic attraction will often concur in the case of powerful sounds. It should be precluded by all means. [1]) Electric attraction is obviated by connecting the auditory canal with the point, from which the mirror is suspended, by a small metallic chain. Should rather high tensions occur in the neigbourhood, also a conductive connection to the earth should be constituted.

In physiological experiments the walls of the space in which the mirror is suspended, are generally lined with gauze, which method was also followed by ZERNOV. To this there can be hardly any objection, when experimenting with receiving funnels, the progressive sound being in large part transmitted to the mirror along the artificial canal. What is conducted from other quarters may be disregarded altogether.

The afferent tube is fitted to a copper plate. A more accurate axial position must be effected by means of three adjusting screws at the foot of the apparatus. The distance from the mirror to the aperture of the tube is determined by a horizontal measuring microscope mounted on a heavy vertical LEITZ-stand.

§ 2. *Physical measurement.*

If instead of experimenting on the intensity of audible sounds we wish to determine the objective intensity of a pure sound-motion, auricle and auditory canal are of course disturbances. For this purpose a conduit of a more physical nature is desirable. The simplest is either a tube or a cone. A tube, if short, is liable to become a resonator with a very sharp and narrow resonance.

[1]) Attraction seemingly acoustic, but in reality involved by eddies, will occur with any fine puncture in the canal or in the membrane.

Mr. Ws. VAN DER ELST, assistant in our laboratory, established the resonance curves of such small resonators by shutting off one end of the tube with wax and placing a suitable mirror before the open end. In very long tubes the tone of resonance is so low, that it need not be taken into account. Earlier experiments on the propagation of sound in air showed that there is a marked decrease in the velocity of propagation, when the tubes are narrower than 4 mm. This at least is the case, when they are made of india-rubber. It must be deemed advisable, therefore, to take glass or metallic pipes of no less than ± 4 mm. in diameter. A mirror of, say 3 mm. diameter, placed just in front of a straight-cut aperture, will be found very suitable in most cases. Still, for very high tones even this pipe is too narrow, as was demonstrated by researches years ago [1]). The tones of GALTON's whistle (six-legerlined octave) change, when passing through a canal of from 3—5 mm. bore, which after the foregoing need not cause surprise, the tones lying near the upper limit of musical sounds. We found it suitable to provide the afferent tubes with leaden taps [2]). The sound conducted to the measuring apparatus, may be generated at a considerable distance.

Another simple conduit is the cone. The funnel may be given an angle of 40° and a mouth of 50 cm². Some American hearing apparatus (operaphone) are provided with a similar funnel. HELMHOLTZ discusses its resonance in his "Tonempfindungen". The one I used, resounds to d_2. This is easy to determine when an opening is left in the apex of 2 mm., before which the RAYLEIGH mirror is placed. The latter will deflect considerably, when the tone of resonance is given. With all other tones the waves will be progressive, the cone being merely an indifferent receiving funnel. Again a small plug of cotton wool had to be used to arrest disturbing streams of air.

§ 3. *Point-shaped soundsources.*

Outlets in the shape of a mere puncture are obtainable through a fine orifice, say of 1 mm. 1. in a little leaden disc that serves for a septum in a speaking tube; 2. in the covering disc of the air-chamber of a thermotelephone. In either case the mirror is placed right opposite to the fine opening, through which the sound is con-

[1]) H. T. MINKEMA, On the sensitiveness of the human ear to the various tones of the gamut. Dissertation Utrecht 1905.

[2]) H. DE GROOT, Zschr. f. Sinnesphysiologie Bd. 44 S. 18 (experiments by Dr VAN MENS) and these Proceedings Vol. **14** p. 758 (experiments by Dr. P. NIKIFOROWSKY).

ducted. Either method allows of altering the sound at will, the number of sounds and intensities, transmissible through a long, wide pipe to the diaphragm, being indefinite. The tones embraced by the thermotelephone are also a great many, from the low, non-coalescent tone of an interruptor to the high hissing-sound [1]). Likewise the intensity of the thermotelephone-sound can be varied through artificial appliances within far-extended limits. Selection occurs with the latter appliance only as far as the peculiar tone of the air-chamber is concerned, but when the air-chamber is small — as is deemed advisable — it is so high, that it may be left out of calculation.

Both methods yield progressive soundwaves, whose energy is constantly procured by the generator, and emerges through the point-shaped orifice of 1 mm. If the latter is in circuit with an air-chamber, through which the sound is conveyed to the measuring mirror, the results vary roughly according to the size of the chamber. The differences are markedly perceptible with an outlet of $^1/_2$ mm. in diameter. As original sound-generator may be used a telephone, actuated by an electrically driven tuning fork or a large powerful organpipe.

§ 4. *Investigation of resonators.*

The mode of arrangement can also be easily applied to test resonators. When a puncture (2 mm.) is made in the wall of the resonator, right opposite to the mouth, the sound passing through it may readily be directed on to RAYLEIGH's mirror via a canal of the same bore [2]). It will be expedient, however, to arrest by means of a very small plug of cottonwool or a piece of lint, the streams of air escaping, like the sound, through the fine opening of the resonator. Without this precaution the mirror will never be steady, not even in a perfectly quiet environment.

The sound thus emitted through the puncture, is made up of progressive waves. By means of a long tube it can also be sent to a comparatively long distance, provided that fresh acoustic energy be constantly supplied through the orifice. The energy collected and adjusted in the resonator, emerges via the fine opening, as well as through the wide orifice. A mirror, subjected to these progressive waves, deflects, when the amplitudes are small, proportionally to the amount of acoustic energy produced. Spherical resonators yield fairly

1) According to the assistant W. v. D. ELST the pitch agrees with the tone of resonance of a c_6 resonator (8000 v. d.).

2) H. ZWAARDEMAKER. Multiple resonantie. Ned. Tijdsch. v. Gen. 1913. II. p. 640.

symmetrical resonance curves (see l.c. p. 642); those generated by paraboloid-shaped resonators or such as are more complicated, like some hearing apparatus, are surprisingly variable [1]).

A very curious shape of resonators is offered by the familiar shells, found on the beach after stormy weather, and in which the murmuring of the rolling waves is heard. Here numerous tones coalesce into a murmur. Testing them involves peculiar difficulties for the very reason, that narrow conduits are not appropriated to the examination of high tones. Nonetheless the difficulty can be overcome by exposing the measuring mirror directly to the point-shaped outlets, afforded by the fine openings in the wall of the shell.

Chemistry. — *"The viscosity of colloidal solutions."* By Dr. E. H. BUCHNER. (Communicated by Prof. A. F. HOLLEMAN.)

According to EINSTEIN, the viscosity of a liquid, in which a great number of particles are floating, is connected with the relative total volume of the particles. If the viscosity of the pure liquid is represented by z, that of the suspension by z', and its volume by v, if further v' is the total volume of the suspended particles, then

$$\frac{z'-z}{z} = 2,5\frac{v'}{v}$$

This formula has been applied to gamboge suspensions by BANCELIN, who obtained fairly satisfactory results; the factor had to be taken, however, 2,9 instead of 2,5. Admitting the formula to be correct, we may, conversely, calculate the volume of the floating particles from measurements of the viscosity. If, then, we determine the number of the particles (e. g. ultramicroscopically), the volume of one separate particle may even be deduced.

The application of this formula to colloidal solutions will greatly deepen our insight in the nature of these systems. We might feel some doubt, whether the suppositions, made by EINSTEIN, when deducing the formula, hold good in the case of colloidal solutions, the particles of which are so much smaller. But EINSTEIN himself has applied it to sugar solutions, and has calculated from the result, in connection with determinations of the diffusion constant, AVOGADRO's number. The fact, that he found in this way $6,6.10^{23}$, shows, that his assumptions are not far from being correct. For the rest, I have found, that even several observations on the viscosity of ordinary

[1]) H. ZWAARDEMAKER. These Proceedings, Vol. **16**, p 496.