THE THERMOPHONE.

By Edward C. Wente.

Synopsis.

Acoustic Efficiency of Thermophones of the Heated Foil or Wire Type.—Theoretical formulæ are derived for the maximum value of the alternating pressure produced within the enclosure of any thermophone when a given alternating current, superposed on a direct current, is passed through the central foil or wire. The effect of certain simplifying assumptions which are made is shown to be small in practical cases. As an *experimental verification* of the formulæ, an electrostatic transmitter was calibrated for a wide range of frequencies with four thermophones which differed greatly in their physical constants, the formulæ being used to compute the pressures produced. The four calibrations thus obtained agree with each other closely and also with an independent calibration made with a pistonphone.

Methods of Calibrating Acoustical Transmitters.—In addition to the pistonphone, the thermophone is now available. The circuits used in calibrating an electrostatic transmitter are given.

Method of Measuring the Thermal Conductivity of a Gas by Using a Thermophone is Suggested.—It would have the advantage of avoiding difficulties due to convection.

In a paper on the theory of the thermophone, Arnold and Crandall [1] have developed formulæ for the absolute value of its acoustical efficiency as a function of the frequency. While these formulæ are sufficiently accurate for most practical purposes, certain discrepancies[2] have been observed, which cannot be attributed to experimental errors. In order to use the thermophone for calibrating acoustical apparatus throughout a wide range of frequencies it has therefore been necessary to make a more detailed analysis of its action.

In this paper formulæ are derived for the efficiency of a thermophone with a heating element of metal foil, which are found to agree closely with such experimental tests as it has been possible to apply. Expressions for the efficiency of the thermophone having a wire heating element are also obtained by the same method of analysis. Only those cases are considered in which the thermophone heating element is located within an enclosure the linear dimensions of which are small in comparison with the wave length of sound. When the element is not placed within a small enclosure the thermophone is of little importance as a precision instrument. Its sound output is not only small but indefinite in most practical cases. Since the sound waves are generated by the alternate expansion and contraction of a layer of air in the immediate

[1] Phys. Rev., X, 22 (1917).
[2] Phys. Rev., X, 52 (1917).

neighborhood of the foil, the characteristics of the system are similar to those of a source of sound consisting of a diaphragm of small mass and stiffness actuated by a constant alternating force. The radiation resistance, which varies with the position of surrounding objects, may in this case be an appreciable part of the mechanical impedance of the system.

Equation of Thermal Equilibrium of an Ideal Gas.

The differential equation of heat conduction for a continuously varying temperature in a solid is well known. The corresponding equation for gases, which is made the basis of the following study of the action of the thermophone, is obtained by putting the rate of increase of heat content of an element of volume of the gas equal to the rate at which work is done upon it plus the heat received by conduction. We thus get

$$\rho c_v \frac{DT}{Dt} = -Ap\rho\frac{DV}{Dt} - K\nabla^2 T,$$

where $V = 1/\rho$ is the specific volume of the gas. Since for an ideal gas $p = \rho RT$ and $c_p - c_v = AR$, this equation reduces to

$$\rho c_p \frac{DT}{Dt} - A\frac{Dp}{Dt} - K\nabla^2 T = 0. \tag{1}$$

The loss by radiation is small in any practical case and so has been neglected.

Thermophone with Heating Element of Metal Foil.

Pressure Produced by a Periodic Change in Temperature of a Metal Strip Within a Small Enclosure.—If the temperature of the foil varies periodically, a temperature wave will be set up in the medium surrounding the foil. At acoustic frequencies these waves are attenuated to a small fraction of their original amplitude at distances small compared with the dimensions of the foil. Hence, in this discussion these thermal waves may be regarded as plane waves; also, since the fluid velocity is small, D/Dt is very nearly equal to $\partial/\partial t$. If then the temperature of the strip is given by $\Theta_0 + \Theta_1 e^{i\omega t}$, where Θ_1 is small compared with Θ_0, and if second order effects are neglected,

$$T = T_0 + T_1 e^{i\omega t},$$
$$p = p_0 + p_1 e^{i\omega t},$$
$$\rho = \rho_0 + \rho_1 e^{i\omega t},$$

and from (1) it follows that

$$\rho_0 c_p i\omega T_1 - Ai\omega p_1 - K\frac{\partial^2 T_1}{\partial x^2} = 0. \tag{2}$$

In the solution of this equation ρ_0 and K may be assigned the values that obtain at the temperature of the foil, since at points near the foil the gas has approximately the same temperature as the foil itself. If the dimensions of the enclosure are small compared with a wave-length of sound, p_1 is independent of x. The complete solution of (2) then is

$$T_1 = Ce^{\sqrt{2i}\alpha x} + De^{-\sqrt{2i}\alpha x} + \frac{k-1}{k}\frac{\Theta_0}{p_0}p_1,$$

in which α is set equal to $\sqrt{\dfrac{\rho_0\omega c_p}{2K}}$, and k is the ratio of the specific heats.

The boundary conditions require that for $x = \infty$, T_1 shall not be ∞ and for $x = 0$, T_1 shall equal Θ_1. Hence,

$$T_1 = \left(\Theta_1 - \frac{A\omega p_1}{2\alpha^2 K}\right)e^{-\sqrt{2i}\alpha x} + \frac{k-1}{k}\frac{\Theta_0}{p_0}p_1. \tag{3}$$

Also

$$p_1 = \frac{2p_0 a}{T_a V_0}\int_0^{V_0/2a} T_1 dx,[1] \tag{4}$$

where V_0 is the volume, and T_1 the mean temperature of the gas in the enclosure. Since, in all practical cases, $e^{-V_0\alpha/2a}$ is small compared with unity, it follows from (3) and (4) that

$$\Theta_1 = \frac{k-1}{k}\frac{\Theta_0}{p_0}\left[1 - \left(1 - \frac{k}{k-1}\frac{T_a}{\Theta_0}\right)\frac{V_0\alpha}{2a}(1+i)\right]p_1. \tag{5}$$

This equation gives the periodic pressure within the enclosure in terms of the periodic temperature variation of the heating element. The problem remains to express Θ_1 in terms of quantities that can be measured directly.

Temperature of the Heating Element.—Consider the case in which the thermophone element is heated by both direct and alternating currents, *i.e.*, by a current equal to $I_0 + I_1 \cos \omega t$ amperes. If I_0 is large compared with I_1, the rate at which heat is developed in the foil is approximately equal to the real part of

$$0.239RI_0^2 + 0.478RI_0I_1e^{i\omega t} \text{ calories per second.}$$

Equating this value to the rate with which heat is lost by radiation and conduction plus the rate with which it is stored in the foil, we get for the fundamental frequency

$$04.78RI_0I_1 = 8aC\Theta_0^3\Theta_1 - 2aK\left(\frac{\partial T}{\partial x}\right)_{x=0} + a\gamma i\omega\Theta$$

$$= \Theta_1(a\gamma i\omega + 2a\alpha K\sqrt{2i} + 8aC\Theta_0^3) - \frac{Aa\omega\sqrt{2i}}{\alpha}p_1, \tag{6}$$

[1] See Arnold and Crandall, Phys. Rev., N.S., Vol. X, 32 (1917).

where C is the radiation constant of the foil and γ is the heat capacity per unit area of foil. Reintroducing the time factor and retaining only the real part, we get finally from (5) and (6) for the pressure developed within the enclosure,

$$p_1' = \frac{0.478RI_0I_1\cos(\omega t - \Phi)}{\left[\left(GQ - RF - \dfrac{Aa\omega}{\alpha}\right)^2 + \left(FQ + RG - \dfrac{Aa\omega}{\alpha}\right)^2\right]^{1/2}}, \tag{7}$$

where

$$F = \frac{V_0\alpha T_a}{2ap_0}\left(1 - \frac{k-1}{k}\frac{\Theta_0}{T_a}\right),$$

$$G = \frac{V_0\alpha T_a}{2ap_0}\left[1 - \frac{k-1}{k}\frac{\Theta_0}{T_a}\left(1 - \frac{2a}{\alpha V_0}\right)\right],$$

$$Q = 2a\alpha K + 8aC\Theta_0^3,$$

$$R = a\gamma\omega + 2a\alpha K,$$

$$\Phi = \tan^{-1}\frac{FQ + GR - \dfrac{Aa\omega}{\alpha}}{GQ - RF - \dfrac{Aa\omega}{\alpha}}.$$

In these expressions α and K must be assigned values corresponding to the temperature of the foil. If K_0 and α_0 are the values at 0° C., then

$$K = K_0\left(\frac{\Theta_0}{273}\right)^{1/2}; \qquad \alpha = \alpha_0\left(\frac{273}{\Theta_0}\right)^{3/4}.$$

The Thermophone with Cylindrical Heating Element.

For laboratory purposes it is generally more practicable to use a thermophone with a heating element of metal foil instead of Wollaston wire as proposed by DeLange.[1] However, there are some cases in which the latter is of value as a standard source of sound, particularly in measurements on ear sensitivity. Thermophones of this type can readily be placed within the ear passage. Complications arising from stationary waves are thus almost entirely eliminated.

Pressure Within an Enclosure Containing a Cylindrical Wire of Variable Temperature.—Consider an airtight cylindrical enclosure along the axis of which is placed a wire of small diameter, having a temperature which can be represented by the expression $\Theta_0 + \Theta_1 e^{i\omega t}$. As before, the fluid velocity in the surrounding medium is small so that the relation (1) reduces to

$$K\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) + A\frac{\partial p}{\partial t} - c_p\rho\frac{\partial T}{\partial t} = 0. \tag{8}$$

[1] Proc. Royal Soc., 91A, p. 239 (1915).

For the equation corresponding to (2) we have

$$\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} - 2i\alpha^2\right) T_1 = -\frac{i\omega A p_1}{K}. \tag{9}$$

If, as before, α is assumed to be constant, the complete solution of (9) is

$$T_1 = AJ_0(\sqrt{-2i\alpha r}) + BH_0(\sqrt{-2i\alpha r}) + \frac{k-1}{k}\frac{\Theta_0}{p_0} p_1.[1]$$

The boundary conditions require that, as r approaches ∞, T_1 shall not approach ∞, and when r is equal to a, the radius of the wire, T_1 shall be equal to Θ_1. Hence

$$T_1 = \frac{\left(\Theta_1 - \frac{k-1}{k}\Theta_0\frac{p_1}{p_0}\right)}{H_0^{(2)}(\sqrt{-2i\alpha a})} H_0^{(2)}(\sqrt{-2i\alpha r}) + \frac{k-1}{k}\Theta_0\frac{p_1}{p_0} \tag{10}$$

corresponding to (4) we have in this case the relation:

$$p_1 = \frac{p_0 l}{T_a V_0}\int_a^R T_1 2\pi r dr, \tag{11}$$

where R is the radius of the cylindrical enclosure, and l the length of the wire. In any practical type of thermal receiver R is large compared with a, and $aH_1^{(2)}(\sqrt{-2i\alpha a})$ is large compared with $RH_1^{(2)}(\sqrt{-2i\alpha R})$, so that to a close approximation we have from (10) and (11)

$$p_1 = \frac{2p_0\pi a l\left(\frac{k-1}{k}\frac{\Theta_0}{p_0}p_1 - \Theta_1\right)H_1^{(2)}(\sqrt{-2i\alpha a})}{\sqrt{-2i\alpha}V_0\left(T_a - \frac{k-1}{k}\Theta_0\right)H_0^{(2)}(\sqrt{-2i\alpha a}}. \tag{12}$$

Temperature of the Heating Element.—Setting the rate with which heat is supplied to the wire equal to the rate with which heat is lost by conduction and radiation plus the rate with which heat is stored, we obtain the following relation

$$\begin{aligned} 0.478RI_0I_1 &= l\left[-2\pi a K\left(\frac{\partial T}{\partial r}\right)_{r=a} + 8\pi a C\Theta_0^3\Theta_1 + \gamma' i\omega\right] \\ &= l\left[\gamma' i\omega\Theta_1 + 2K\pi\frac{\sqrt{-2i\alpha}aH_1^{(2)}(\sqrt{-2i\alpha a})}{H_0^{(2)}(\sqrt{-2i\alpha a})}\left(\Theta_1 - \frac{\omega A p_1}{2\alpha^2 K}\right)\right. \\ &\qquad \left. + 8\pi a C\Theta_0^3\Theta_1\right], \end{aligned} \tag{13}$$

[1] The notation here used for the Bessel functions is the same as given in Jahnke and Emde, "Functionen-tafeln," p. 90 ff.

where γ' is the heat capacity per unit length of the wire. Let

$$\frac{H_0^{(2)}(\sqrt{-2i\alpha a})}{H_1^{(2)}(\sqrt{-2i\alpha a})} = M + iN.$$

We then get from (12) and (13)

$$0.478RI_0I_1 = \Bigg[(\gamma' i\omega + 8\pi aC\Theta_0^3)\Bigg(\frac{k-1}{k}\frac{\Theta_0}{p_0}l - \frac{(1-i)\left(T_a - \frac{k-1}{k}\Theta_0\right)V_0}{2p_0\pi a}(M+iN)\Bigg) + \frac{2i\alpha^2KV_0\left(T_a - \frac{k-1}{k}\Theta_0\right)}{p_0}\Bigg]p_1. \tag{14}$$

In general, $8\pi aC\Theta_0^3$ is small compared with $\gamma'\omega$. For example, in the case of a thermophone having a wire heating element, 0.0003 cm. in diameter, for a frequency of 25 cycles per second and $\Theta_0 = 800°$ absolute, the error, introduced by neglecting $8\pi aC\Theta_0^3$ in (14), even for these extreme conditions, is only 4 per cent. If then $8\pi aC\Theta_0^3$ is neglected, we obtain finally for the real part of p_1, the alternating pressure developed within the enclosure,

$$p_1' = \frac{0.956\pi ap_0}{\left(T_a - \frac{k-1}{k}\Theta_0\right)\alpha V_0\omega\gamma'}\frac{RI_0I_1\cos(\omega t - \Phi)}{\left[(N-M)^2 + \left(\frac{k}{k-1}\frac{2\pi aAp_0}{\alpha\Theta_0\gamma'} + \frac{2\pi al}{V_0\alpha\left(\frac{k}{k-1}\frac{T_a}{\Theta_0} - 1\right)} - (M+N)\right)^2\right]^{1/2}}, \tag{15}$$

where

$$\Phi = \tan^{-1}\frac{\left[\frac{k}{k-1}\cdot\frac{2\pi aAp_0}{\alpha\Theta_0\gamma'} + \frac{2\pi al}{V_0\alpha\left(\frac{k}{k-1}\frac{T_a}{\Theta_0} - 1\right)} - (M+N)\right]}{N-M}.$$

In the calculation of the values of $N - M$ and $M + N$ for small values of αa, it is convenient to use the following approximation formulæ,

$$N - M = 2\alpha a\left[\log_e\frac{\alpha a}{\sqrt{2}} + 0.577\right]; \qquad N + M = \frac{\alpha a}{2}.$$

These formulæ are correct to within a few per cent. for values of αa even as large as 0.15. For larger values of αa, M and N may be calculated from the tables given in Jahnke and Emde's "Functionentafeln" pp. 139–140. $H_\nu^{(2)}(\sqrt{-i}X)$ is the conjugate complex quantity of $H_\nu^{(1)}(\sqrt{i}X)$.

Values for the maximum pressure developed have been calculated by the above formulæ for thermophones having the following constants.

I. Heating element of metal foil: volume of the enclosure = 14 cu. cm., thickness of the gold foil = 0.79×10^{-5} cm., area of the gold foil = 5.5 sq. cm., $\Theta_0 = 335°$ absolute, $T_a = 300°$ absolute.

II. Heating element of Wollaston wire: volume of the enclosure = 1 cu. cm., diameter of the wire = 0.0003 cm., length of the wire = 1 cm., T_a = 300° absolute, $\Theta_0 = 335°$ absolute.

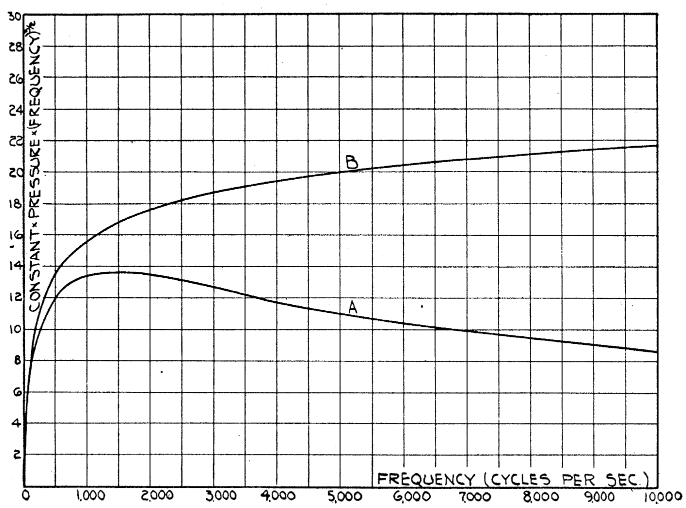

Fig. 1.

Frequency characteristics of thermophones.

A. Cylindrical heating element.

B. Flat-strip heating element.

In Fig. 1 the products of pressure and the 3/2 power of the frequency are plotted as a function of frequency. The curves thus show the amount of deviation from a simple 3/2 power relation. It appears that as telephone receivers the two types of instruments produce approximately the same amount of distortion and so neither possesses an advantage in this regard.

In the preceding analysis the heating element was assumed to lie along the axis of a cylindrical enclosure. But since the temperature waves emanating from the wire have a large attenuation and a short wave length, the equations apply without alteration to any case in which the wire is located near the central part of the enclosure.

FURTHER CONSIDERATIONS OF THE FORMULÆ.

In the preceding discussion the following assumptions have been made: The walls of the enclosure are non-conductors of heat, the temperature of the foil has the same value throughout its entire length, and at the surface of the foil the gas has the same temperature as the foil itself. Although for most practical cases these assumptions do not introduce inaccuracies of any consequence into the formulæ, the order of magnitude of the errors will here be considered.

If the walls are perfect conductors, as is approximately true in most cases, it may be shown that a first order correction is obtained by multiplying (7) by

$$\sqrt{1 - \frac{S}{V_0\alpha} + \frac{S^2}{2V_0^2\alpha^2}},$$

where S is the area of the walls of the enclosure. This factor is in general nearly unity.

In practice, the ends of the foil are held between comparatively massive clamps, so that almost no temperature variation at these points is produced by the alternating current. To take account of this fact the values of p_1' as given by equations (7) and (15) should be multiplied by

$$\sqrt{1 - \frac{2}{\alpha' l} + \frac{2}{(\alpha' l)^2}},$$

where l is the length of the element and α' is the value of α for the heating element. It may be shown that this factor gives the correction to the first order and is in general also nearly equal to unity.

When heat flows from a solid wall to a gas, the temperature corresponding to the velocity with which a molecule leaves the wall after a single impact will not be the same as the temperature of the wall. This fact is equivalent to a temperature drop between the solid and the gas.[1] This temperature drop at the surface of the foil is given by

$$\Delta\Theta = -\gamma\left(\frac{\partial T}{dx}\right)_{x=0},$$

where γ is a constant depending on the gas and its mean free path and on the condition of the surface of the solid wall. For hydrogen and a

[1] Kundt and Warburg, Pogg. Ann., 156, p. 177 (1875).

smooth solid surface on platinum it is equal to 7.25λ,[1] where λ is the mean free path of the molecules of the gas. For normal atmospheric conditions we find in this case to a first approximation $\Delta\Theta_1 = 3 \times 10^{-4}f^{1/2}\Theta_1$. For a frequency as high as 10,000 cycles this is only $0.027\Theta_1$ or less than 3 per cent. of the maximum value of the periodic temperature of the foil. For all practical purposes, therefore, the temperature drop at the surface of the foil may be disregarded.

Experimental Verification of the Theory of the Thermophone with Heating Element of Metal Foil.

(a) *Comparison of Thermophones having Different Physical Constants.*—There appears to be no way in which the pressure produced by a thermophone within an enclosure can be measured over its useful frequency range. The validity of equation (7), therefore, cannot be tested in a direct way. However, the alternating pressure exerted on the diaphragm of an electrostatic transmitter by thermophones having different physical constants may be compared. Whatever the sensitivity of an electrostatic transmitter as a function of frequency may be, it does not vary appreciably with time. Thus it is possible to determine at a number of fixed frequencies whether the alternating pressure varies with the different physical constants in accordance with equation (7). Experiments to this end have been carried out for a wide range of frequencies.

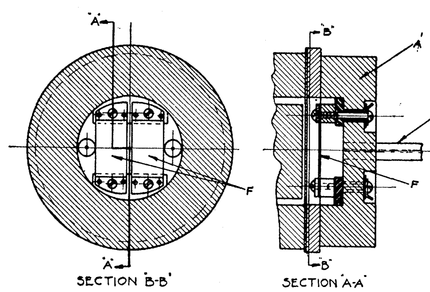

Fig. 2.

Thermophone in place for calibrating an electrostatic transmitter.

The thermophone was placed in front of the electrostatic transmitter in the manner shown in Fig. 2. The face of the transmitter together with the brass block, A, form an enclosure in which the heating elements, F, are centrally located. The enclosure is airtight except for the two equal capillary tubes, C. By means of these tubes gas is passed at a slow rate through the enclosure. To keep the pressure at atmospheric value, the pressure head on the intake tube is made equal to the suction

[1] S. Weber, A.d.P., 54, 439 (1917).

head on the outlet tube. These capillary tubes have a high impedance to the transmission of sound waves so that they do not affect the magnitude of the alternating pressure within the enclosure.

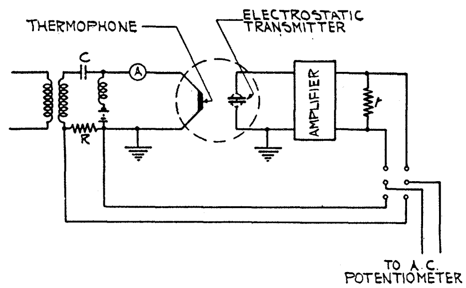

Fig. 3.

Circuit for calibrating an electrostatic transmitter with a thermophone.

The circuit used in the measurements is shown in Fig. 3. The ratio of the alternating potential drop across r and R was determined with an *a.c.* potentiometer.[1] This ratio multiplied by R and divided by the amplification of the amplifier gives the ratio of the voltage generated by the electrostatic transmitter to the alternating current passing through the thermophone heating element. The voltage per unit of pressure was then calculated by equation (7). Measurements were made with platinum foil, 6.81×10^{-5} cm. $\times$ 1.0 cm. $\times$ 5.35 cm., within an enclosure of 25.25 cu. cm. capacity, and with gold foil, 7.85×10^{-6} cm. $\times$ 1.0 cm. $\times$ 5.5 cm., within an enclosure of 13.9 cu. cm. capacity, both with hydrogen and with air within the enclosure. The conductivity of air was taken as 5.68×10^{-5} and of hydrogen, 41.6×10^{-3} c.g.s. units.

The values of voltage per dyne pressure as obtained with these thermophones for a particular electrostatic transmitter are given in the following table.

TABLE I.

Frequency	Gold Foil in Hydrogen.	Gold Foil in Air.	Platinum in Air.	Platinum in Hydrogen.
Cycles per sec.				
60	6.75		6.75	
300	4.85	5.00	4.82	
600	4.40	4.45	4.47	4.47
1000	4.20	4.30	4.45	4.30
2000	4.06	4.20		4.25
4000	4.40			4.55

[1] E. C. Wente, A Vacuum-Tube Alternating Current Potentiometer, Journal of the A.I.E.E., 40, p. 900, December, 1921.

It is seen from this table that the different thermophones yield practically the same results. Observations were not extended over the whole frequency range for each thermophone, since equation (7) applies only for a limited region. The frequency must be lower than the resonant frequency of the enclosure, and the wave length of the temperature wave emanating from the foil must be small compared with the dimension of the enclosure.

At the lower frequencies the predominating quantity in the denominator of equation (7) for gold in hydrogen is $2\alpha K$, while for platinum in air it is $\gamma\omega$. The tests, therefore, cover extreme conditions. Hence the fact that the values obtained with the different thermophones lie very near together is evidence for the correctness of equation (7), on the basis of which they were determined.

(*b*) *Comparison with a Pistonphone.*—If at some part of the frequency range it is possible to determine by an independent method the sensitivity of the electrostatic transmitter, a more direct experimental check of formula (7) can be obtained. Measurements were made on the electrostatic transmitter similar to those just described but with the thermophone replaced by a pistonphone. The construction of this apparatus is shown in Fig. 4. This pistonphone is similar to that described in a

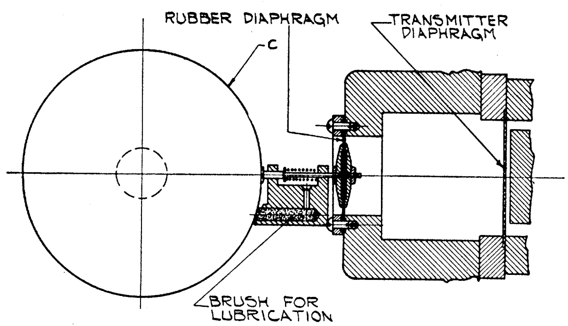

Fig. 4.

Use of pistonphone for calibrating an electrostatic transmitter.

former paper,[1] except that a cam, C, is used, which is cut so that with uniform rotation, a simple harmonic motion of 2 cycles per revolution is imparted to the piston. The pressure exerted on the diaphragm is given by

$$\frac{kp_0\sigma\xi \cos \omega t}{V_0}\sqrt{1 - \frac{S}{V_0\alpha} + \frac{S^2}{2V_0^2\alpha^2}}, \qquad 16)$$

[1] E. C. Wente, Phys. Rev., X, p. 48 (1917).

where σ is the effective area of the face of the piston,

S is the area of the walls of the enclosure,

$\xi \cos \omega t$ is the displacement of the piston.

The last factor in (16) takes account of the fact that, due to the heat conduction of the walls, the compression does not take place quite adiabatically.

A diagram of the circuit used in this test is shown in Fig. 5. If the electrostatic capacities of the transmitter and voltmeter are known, the open-circuit voltage of the transmitter may be determined from the voltmeter readings. Measurements were made for frequencies ranging from 10 to 200 cycles per second. The open-circuit voltages per dyne pressure are plotted in Fig. 6 together with values obtained for the same electrostatic transmitter with a gold leaf-hydrogen thermophone. The points are seen to lie very near together. This fact shows that for this frequency range the absolute value of the pressure produced by the thermophone as a function of frequency is correctly given by equation (7). At the lower frequencies the pressure produced by the thermophone varies with the different factors entering into the

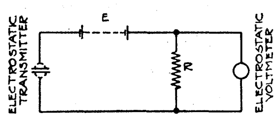

Fig. 5.

Circuit for calibrating electrostatic transmitter with pistonphone.

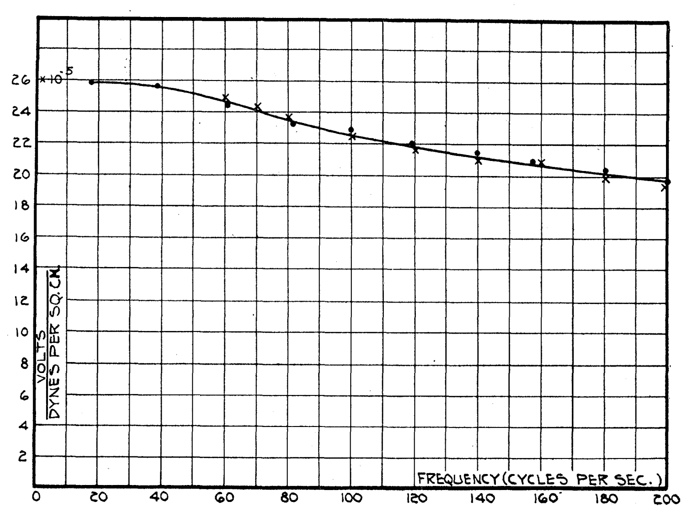

Fig. 6.

Efficiency of electrostatic transmitter.
• Values obtained with the pistonphone.
× Values obtained with the thermophone.

expression (7) more than at the higher frequencies. Therefore, it is reasonable to assume that this expression also gives correct values at higher frequencies.

The Use of the Thermophone for Measurements of the Thermal Conductivity of Gases.

One cause of uncertainty in the measurements with the thermophone is the fact that the thermal conductivity of gases is not well known. For example, in the case of hydrogen good authority can be found for values which differ from each other as much as 15 per cent. The thermophone suggests itself as a possible method for determining the conductivity of a gas. The principal source of error in conductivity measurements as heretofore carried out lies in the transport of heat by convection currents. In the case of the thermophone this source of inaccuracy is entirely eliminated.

Various arrangements of the apparatus for carrying out thermal conductivity measurements with the thermophone could be suggested. Some independent method of measuring an alternating pressure or producing one of known magnitude is required. Apparatus of the pistonphone type is perhaps the simplest arrangement that could be devised for thc purpose.

Research Laboratories of the
American Telephone and Telegraph Co.
and the Western Electric Co., Inc.,
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