SUPERSONIC INTERFEROMETERS*

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Abstract

The methods of applying high frequency sounds to small scale measurements are discussed. An interferometer was constructed and used to measure the velocity of sound in gases, liquids, and solids at frequencies ranging from about 10 to 700 kc. Three types of sources were tried, viz: quartz and Rochelle-salt crystals and magnetostrictive rods. The determination of the velocity of sound in solids is based upon: (1) optimum transmission of sound through a partition whose thickness is an integral number of half wave-lengths; (2) relative displacement of the nodal planes in a given liquid due to the immersion of a solid slab in the acoustical path. In the same manner, a small quantity of an unknown liquid is placed in a parallel walled cell and the latter is immersed in a liquid of known acoustic properties. Reactance and effective resistance of the interferometer (with a liquid medium) as a function of the reflector distance from the sound source were investigated. Approximate values of the impedance, power factor and watts dissipated in the instrument were thus computed. An improved circuit for use in absorption measurements in gases is described as well as the extended use of the interferometer employing two identical sound generators.

Introduction

CERTAIN physical and thermodynamic properites of various substances may be deduced from their sound transmission and absorption characteristics. The latter are usually determined experimentally by employing some form of standing wave system. The Kundt's tube and its diverse interesting modifications have provided a large amount of useful data relating to the velocities of sound in gases,[1] liquids[2] and solids.[3] However, velocities measured by these so-called "tube methods" at audible frequencies require special corrections due to the yielding of the walls of the tube.[4] The disturbing effects caused in this way may be eliminated by increasing the frequency of the source to the extent that the emitted waves within the tube are plane. Under such circumstances the velocity of sound in a confined fluid, when calculated from a standing wave system is independent of the size or shape of the container. Practically, these conditions obtain when the ratio of the diameter of the radiating surface to that of the emitted wave-length is greater than 12. Furthermore, to be reliable, the measurements should be taken at a considerable number of wave-lengths from the source, particularly if the radiator is

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[1] Behn and Geiger, Ber. deut. Phys. Ges. 5, 657 (1907); Partington and Shilling, Phil. Mag. 45, 416 (1923); Shilling and Partington, Phil. Mag. 5, 920 (1928).

[2] Dorsing, Ann. d. Physik 25, 227 (1908); V. Ionescu, J. de Physique et le Radium 5, 377 (1924).

[3] H. O. Taylor, Phys. Rev. 2, 270 (1913); E. C. Wente and E. H. Bedell, Bell System Techn. J. 7, 1 (1928).

[4] L. G. Pooler, Phys. Rev. 35, 832 (1930).

composed of many elements, such as a mosaic of piezoelectric crystals. In general, the energy radiated by a circular plate emitting longitudinal waves is confined mainly to a central beam, the width of which is found by the expression

$$\sin \theta = 1.22\lambda/D$$

where θ is the angle between the axis of the radiator and the boundary of zero intensity of the central beam, D is the diameter of the aperture or radiating surface; λ is the wave-length of the emitted wave.

Langevin[5] was the first to make wide application of supersonic waves by utilizing the piezoelectric properties of quartz. In 1916 in an experimental water tank he demonstrated supersonic beam reflection at 100 kc. Since the original investigations of Langevin, Boyle[6] and his collaborators have done a great deal of work in supersonics (or "ultrasonics" as they called it) by the aid of quartz-steel generators. Among their researches are measurements on the velocities of sound in a number of liquids and solids by the stationary wave method. A separate detector was required to indicate the nodal or antinodal planes in their standing wave system.

The present paper deals with supersonic stationary waves in which the source also detects the nodal and antinodal planes of the system. Therefore, an instrument in which stationary plane waves of high frequency sound are generated and detected shall be termed a *supersonic interferometer*.[7]

During the past few years several investigators have applied this type of interferometer to the study of sound in fluids. Pierce[8] was the first to use it in his determination of the velocities of sound in air and CO_2 at high frequencies. His method employed an oscillating quartz crystal serving a threefold purpose; namely, to control the frequency in a vacuum tube circuit; to generate sound waves from one face to a movable piston which is plane and parallel to the radiating face; and to detect the sound waves reflected from the piston. A stationary wave system is thus set up between the crystal and reflector. As the latter is moved through a series of nodal planes periodic maxima and minima are indicated on a microammeter suitably connected in the plate circuit. By these changes in the electrical circuit Pierce was able to measure the wave-length to a very high degree of precision. With this method, several other researches have been reported,[9] in which the velocity as well as the absorption of supersonic waves in gases and vapors are measured.

[5] International Hydrographic Bureau **3**, (1924); La Nature, January 1921 and August 1921.

[6] Boyle and others, Roy. Soc. Canada Trans. **19**, 167 (1925); **20**, 245 (1926); **21**, 79 (1927); **21**, 115 (1927); **22**, 371 (1928).

[7] This type of self-detecting interferometer has been variously described as a sonic interferometer by Wood and Loomis and an acoustic interferometer by Crandall and others. In the opinion of the authors, neither of these terms distinguishes the instrument from a tube resonator used at audio frequencies.

[8] G. W. Pierce, Am. Acad. Proc. **60**, 271 (1925).

[9] W. H. Pielemeier, Phys. Rev. **34**, 1184 (1929); **36**, 1005 (1930); G. E. Thompson, Phys. Rev. **36**, 77 (1930); C. D. Reid, Phys. Rev. **35**, 814 (1930).

Hubbard and Loomis[10] developed a compact interferometer with which they determined accurately the velocity of sound in various liquids. Their arrangement differs from that of Pierce in that the quartz crystal does not control the frequency of the oscillating circuit but is driven by an alternating e.m.f. whose frequency is far removed from that of the crystal. One surface of the quartz disk radiates sound directly into the liquid which is being studied. The production of stationary waves in the liquid and their measurements are effected by the aid of a plane reflector attached to a micrometer screw. Here also the nodal and antinodal planes are located by their reactions on the crystal source.

In all work with supersonic interferometers heretofore recorded quartz was used as the source of high frequency sound, and the investigations were limited to fluids. The present experiments deal with methods for using Rochelle-salt crystals or magnetostrictive rods as well as quartz for the interferometer source. It is further shown that the same interferometer can be used to determine the velocity of supersonic waves in solids and minute quantities of liquids.

Apparatus

The interferometer employed in the present investigation is composed of three principal units as shown in Fig. 1. The upper part, (a), consists of a specially constructed micrometer screw whose spindle has a maximum movement of four inches and whose barrel is graduated every 0.025 inches for the entire travel of the spindle. The least count of the instrument is 0.001 inch. To the lower end of the spindle is attached a plane brass reflector which is accurately machined so that its reflecting surface always remains normal to the axis of the cylinder in which it is traveling. The lowest portion of (a) is a threaded cap to fit the various fluid containers.

The central section, (b), may be a cylindrical or rectangular fluid container, each end of which is threaded so as to fit the adjoining units, (a) and (c), interchangeably.

Part (c) represents one of several holders for the elements used as sources of supersonic waves. The side tube at the bottom accomodates the leads to the electrodes of the crystal or groups of crystals used. The dimensions of (b) and (c) differed according to the range of frequency and substance studied. The fluid containers, (b), varied from four to sixteen inches in length and from three to nine inches in diameter. Among the elements used as sources are: a single disk of quartz 2.5 inches in diameter and 0.25 inch thick; a similar disk of Rochelle-salt; several rectangular slabs of the above crystals about $1\times1\times3/16$ inches; a mosaic of quartz about four inches in diameter and one of Rochelle-salt 2.5 inches in diameter; several magnetostrictive rods 0.5 inch in diameter and 4 to 10 inches in length.

In the photographs of Fig. 1 may be seen an assembled interferometer with a rectangular container, one side removed; the three separate units; and three of the generating elements.

[10] Hubbard and Loomis, Phil. Mag. 5, 1177 (1928); Loomis and Hubbard, J.O.S.A. **17**, 295 (1928); J. C. Hubbard, Phys. Rev. **35**, 1442 (1930).

The circuit employed for impressing an alternating e.m.f. upon the source of the interferometer when the latter is used in conjunction with liquids and solids is shown in Fig. 2. A quartz crystal controls the driver frequency when extreme constancy is required. For work in which a continuously variable

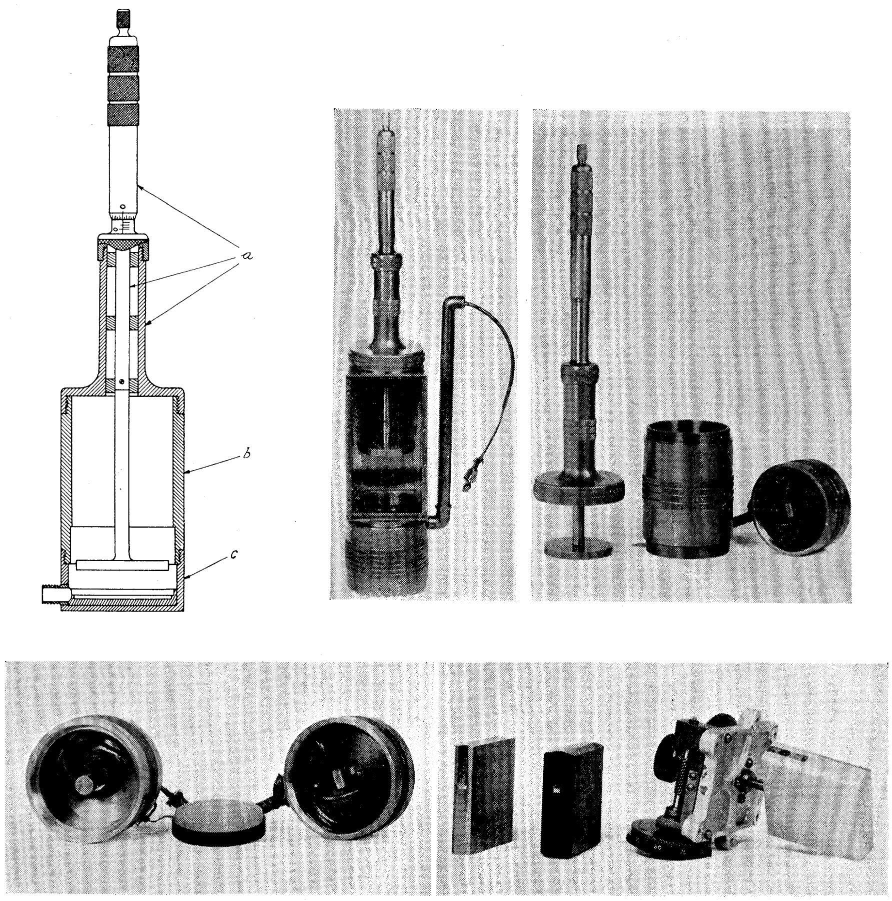


Fig. 1. Diagram of interferometer.

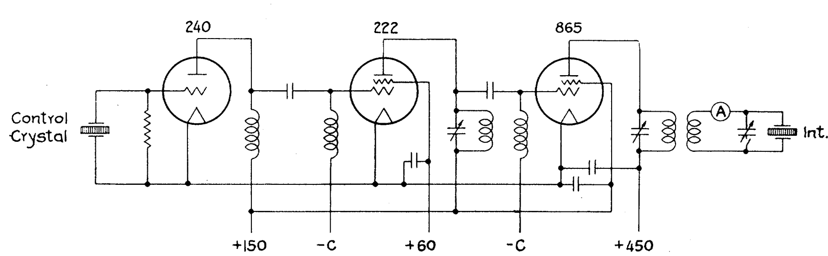


Fig. 2. Electrical driving circuit used with interferometer for work with liquids and solids.

frequency is desired a tuned-grid circuit is employed in the master oscillator stage. Extremely loose inductive coupling is used between the interferometer and the plate coil of the last tube. The circuit is designed to eliminate any effect of a variable load upon the frequency of the exciting e.m.f. The actual power drawn by the interferometer is a very small fraction of the available output power of the last tube.

Methods of Detection

There are numerous methods available for detecting the variations in impedance of the interferometer caused by changes in the position of the reflector. One of the simplest is to note changes in the series current. When the quartz disk is used as a sound source, it is essential to tune the output circuit sharply by means of the small variable capacity in parallel with the interferometer in order that the relatively small changes in impedance may become evident. The quartz interferometer at frequencies far removed from the resonant frequency of the disk reacts very nearly as a pure capacity which permits sharpness of tuning. On the other hand, when Rochelle-salt is employed the current through the instrument leads the voltage across its terminals by angles varying from 30° to 60° depending upon the reflector position, thus making sharp tuning impossible. The greatest fractional change in current observed with the quartz disk is about 15 percent, while if Rochelle-salt is used the fractional change in current ranges from 40 percent to 60 percent. To measure the series current, a vacuum thermocouple and microammeter with a full scale deflection of 200 microamperes was employed.

A novel method for detecting these impedance variations due to change in the reflector position is utilized by Hubbard and Loomis.[10] They actually permit the variations in load on the last tube to affect the driving frequency, then readjust the tuning condenser which varies the frequency so as to compensate for this change. The curves obtained are condenser settings plotted against reflector position.

A number of alternative methods were tried. In one set of experiments not only was the series current through the interferometer measured, but simultaneously the potential difference across its terminals was determined with a thermionic voltmeter. Again, instead of employing inductive coupling between the driving circuit and the interferometer, resistance-capacity coupling was used. The reactions, though much feebler than those obtained with inductive coupling, were in entire agreement with them.

The exact nature of the impedance changes taking place as the reflector position is varied was examined in detail by bridge measurements of the effective capacity and resistance of the interferometer (with a liquid medium). The circuit of the bridge is shown in Fig. 3. Two of the arms were equal capacities of 500 micromicrofarads each. The Rochelle-salt interferometer was placed in one arm and a calibrated air capacity in series with a resistance in the remaining arm. A thermionic voltmeter indicated the state of balance of the bridge. Simultaneously, the series current through the interferometer was measured. No high degree of accuracy is claimed for these measurements, due to the large phase angles encountered and due to difficulties with the shielding. The result of a set of observations at 122 kc is shown in Fig. 4. These curves show resistance, reactance, net impedance, power factor, phase angle, series current, potential difference across the interferometer terminals and milliwatts dissipated in it as a function of the position of the reflector.

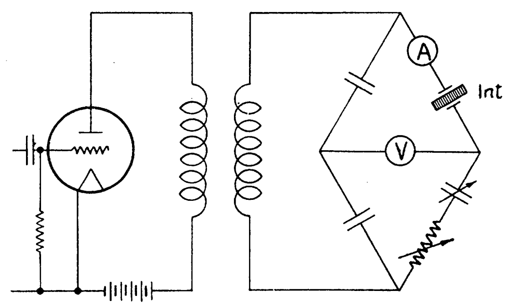


Fig. 3. Circuit used in bridge measurements of effective capacity and resistance of interferometer.

Examining the curves in detail, it is noted that to a first approximation, the capacitative reactance may be expressed by the equation:

$$X = X_0 + A \sin \alpha$$

and the resistance by

$$R = R_0 + A \cos \alpha$$

where $\alpha = 4\pi(l\text{-}L)/\lambda$; l is the micrometer reading; L is a reference point on the micrometer scale, and λ is the wave-length of sound in the medium. Also, it may be shown that to a first approximation:

$$Z = Z_0 + A \cos (\alpha - \theta)$$

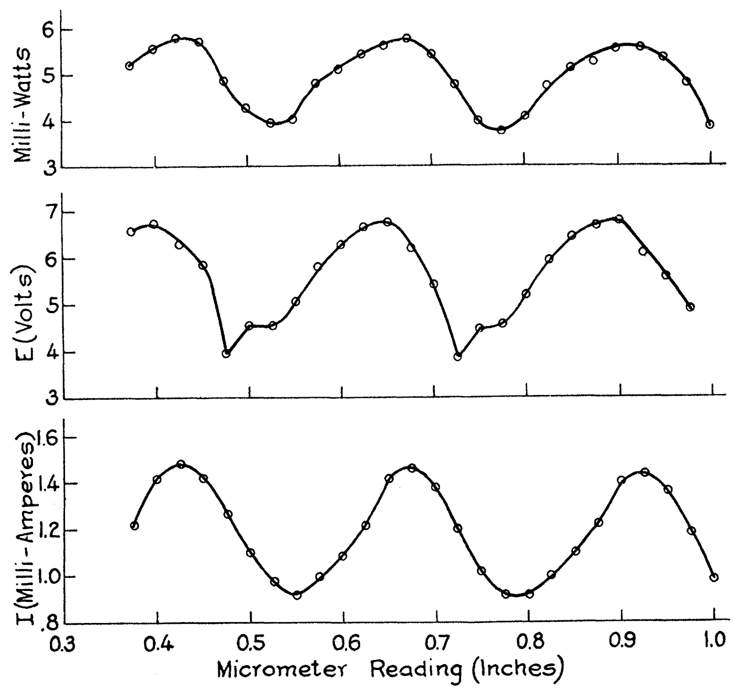
where $Z_0 = (X_0^2 + R_0^2)^{\frac{1}{2}}$ and $\theta = \tan^{-1}(X_0/R_0)$. That is, the impedance of the instrument may be represented by the vector sum of one impedance whose magnitude and direction is constant and a second impedance whose magnitude is very nearly constant but whose direction depends upon the position of the reflector. In general, the impedance of the interferometer may be expressed by the equation:

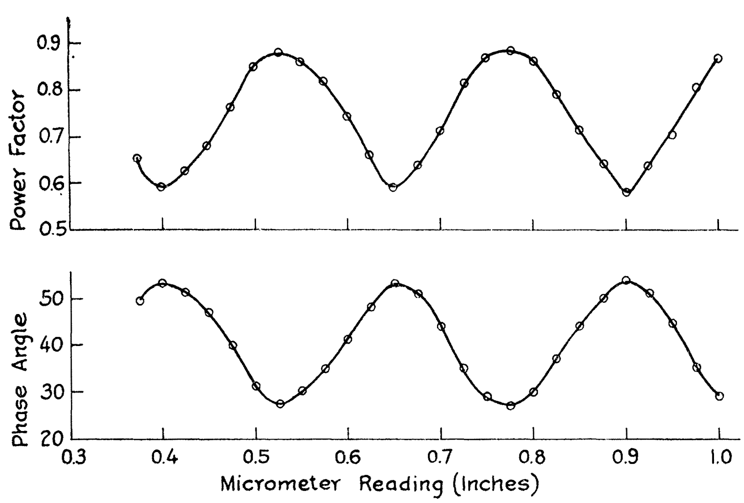
$$Z = Z_0 + \sum_{n=1}^{n=\infty} A_n \cos (n\alpha - \theta_n)$$

The impedance diagram obtained on plotting X against R possesses some similarities to those observed by Kennelly and Pierce[11] in their work on the motional impedance of telephone receivers and to those obtained by Black[12] in his work on magnetostrictive rods. However, in these particular cases the driving frequency is varied while the resonant frequency of the driven

[11] A. E. Kennelly and G. W. Pierce, Am. Acad. Proc. **48,** 113 (1912).
[12] K. C. Black, Am. Acad. Proc. **63,** 49 (1928).

remains constant. In the present case, the driving frequency is held constant, and the resonant frequency of the driven is varied by altering the length of the liquid column. Each time the length of this column is changed by a half wave-length, the set of observed points encircle the diagram once. By external mechanical means Kennelly, Pierce, and Black prevented any displacement on the part of the device whose motional impedance was being measured while here the motion of the crystals is never zero but is aided or impeded by sound reflected from the movable piston.





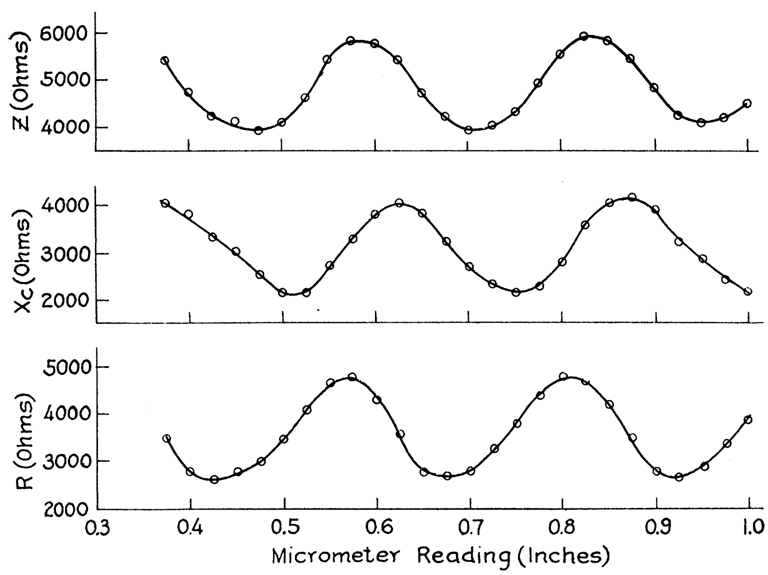


Fig. 4. Curves showing relationship between reflector position and resistance, reactance impedance, phase angle, and power factor of interferometer as well as current through it, e.m.f across its terminals, and watts dissipated in it.

Let ϕ denote the angle between the axis of resistance and the vector joining the center of the impedance diagram to any point on the perimeter. If the value of $d\phi/dl$ is constant around the diagram the simple set of resistance and reactance curves shown in Fig. 4 is obtained. In case $d\phi/dl$ varies around the diagram, the current curve no longer approximates a cosine function. It will be noted in Fig. 5 that the curves taken at 130 kc and 148 kc differ markedly from those taken at 122 kc. The constancy of $d\phi/dl$ and the shape of the curves are very closely dependent upon frequency. It is suspected that the sharpness of resonance in the liquid column is related to the selective transmission of the reflector.

Experimental Procedure

Liquids.—The velocity of sound in a number of liquids was measured by means of this instrument using different types of generators. The set of curve shown in Fig. 5 are typical for the Rochelle-salt interferometer. The liquid used was a high grade of transformer oil. Half wave-lengths were determined with an accuracy of 0.1 percent. Frequencies were measured to 0.03 percent. Hence a relatively high degree of accuracy may be obtained in velocity calculations. Curves possessing "fine structure" may be obtained by driving the interferometer at lower frequencies and favoring higher harmonics by the selection of proper coupling coils. Such a curve is shown in Fig. 6. The driving frequency was 45 kc while the third harmonic was emphasized by tuning. This curve is of interest in showing particularly the complexity which may arise in the standing wave system.

Solids.—In order to measure the velocity of supersonic waves in solids a suitable liquid (oil) was chosen as the medium for the solid under considera-

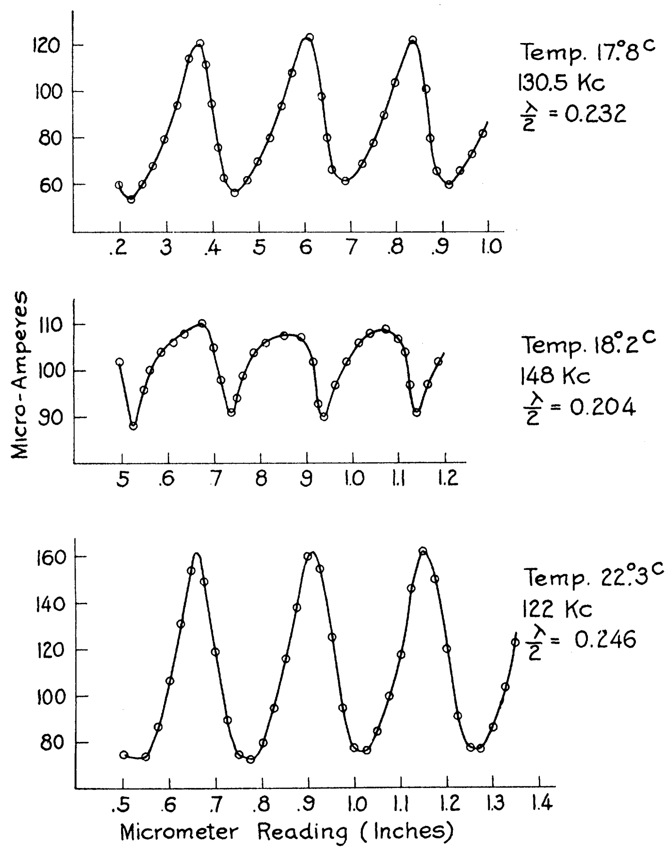


Fig. 5. Curves showing magnitude of series current variations obtained with interferometer and differences in general shape at various frequencies.

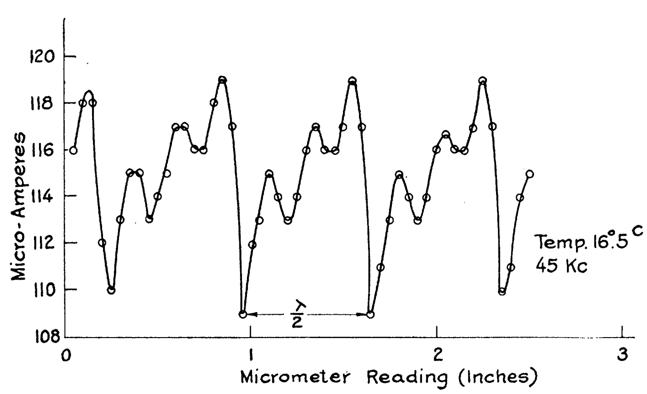


Fig. 6. "Fine Structure" curve. The standing wave system involves both a fundamental frequency and a third harmonic.

tion. The positions of the nodal and antinodal planes were accurately located in the liquid alone. Then with temperature and frequency unchanged a plane parallel slab of the solid was immersed in the sound beam and the relative displacements of the nodal and antinodal planes were ascertained. That is, the difference in acoustical path in the container when the liquid alone was present and when the solid was inserted in the beam was deduced from the micrometer readings, thus:

Let $d=$ actual thickness of slab traversed by the beam

$$\mu = \frac{V_s}{V_l} = \frac{\text{Velocity of sound in solid}}{\text{Velocity of sound in liquid}}\,.$$

Then the displacement of the nodal planes can be shown to be:

$$\Delta s = d(\mu - 1)/\mu$$

whence $\mu = d/(d - \Delta s)$.

This simple method works quite well when the product $V\rho$ for the solid is not greatly different from that product in the liquid, where V is the velocity of sound in the substance and ρ its density. This is the case in natural woods and wood compositions, in many varieties of bakelite and in rubber compounds. Table I illustrates the method for an amber bakelite of French manufacture.

TABLE I. *Illustration of measurement of velocity of sound in an amber bakelite of French manufacture.* Temperature 21°C. When micrometer reads zero reflector face is about 3 inches from source.

Micrometer Readings at Nodal Planes		Shift due to bakelite	Calculations
Oil alone	Amber bakelite in oil		
0.019	0.180	0.161	Measured thickness of slab =0.412 in.
0.318	0.479	0.161	Average shift =0.161 in.
0.620	0.780	0.160	$\mu = 0.412/0.251 = 1.64$
0.922	1.083	0.161	Known velocity in oil $= 1.50 \times 10^5$ cm/sec
1.223	1.384	0.161	$\therefore V_s = 1.50 \times 10^5 \times 1.64 = 2.46 \times 10^5$ cm/sec
1.526	1.687	0.161	
1.825	1.988	0.163	

However, if the two respective products mentioned above are very dissimilar, then it is necessary to choose such a thickness of material as will yield optimum transmission at a particular frequency. Generally, it is more convenient to use a slab of fixed thickness and then to find that frequency for which transmission of sound through the material is a maximum. This condition is realized when the slab thickness is an integral number of half wave-lengths. The theory of this method was suggested by Lord Rayleigh.[13] Boyle and Rawlinson[14] amplified Rayleigh's analytical treatment and applied it directly to supersonics. Later Boyle and Froman[15] verified their

[13] Rayleigh, Theory of Sound, Vol. II, p. 86.
[14] Boyle and Rawlinson, Roy. Soc. Canada, Trans. **22,** 55 (1928).
[15] Boyle and Froman, Canada Jour of Research **1,** 405 (1929).

theoretical conclusions by experiments in which they showed that at normal incidence transmission is a maximum when the thickness of the plate is an integral number of half wave-lengths. On the other hand, if the thickness is an integral odd number of quarter wave-lengths reflection is a maximum.

Fig. 7 is a sample curve showing the sharpness of selective transmission for a given thickness of commercial aluminum. As in the previous arrangement, the metal slab was immersed in oil at normal incidence. Series current through the interferometer source was observed at nodal and antinodal posi-

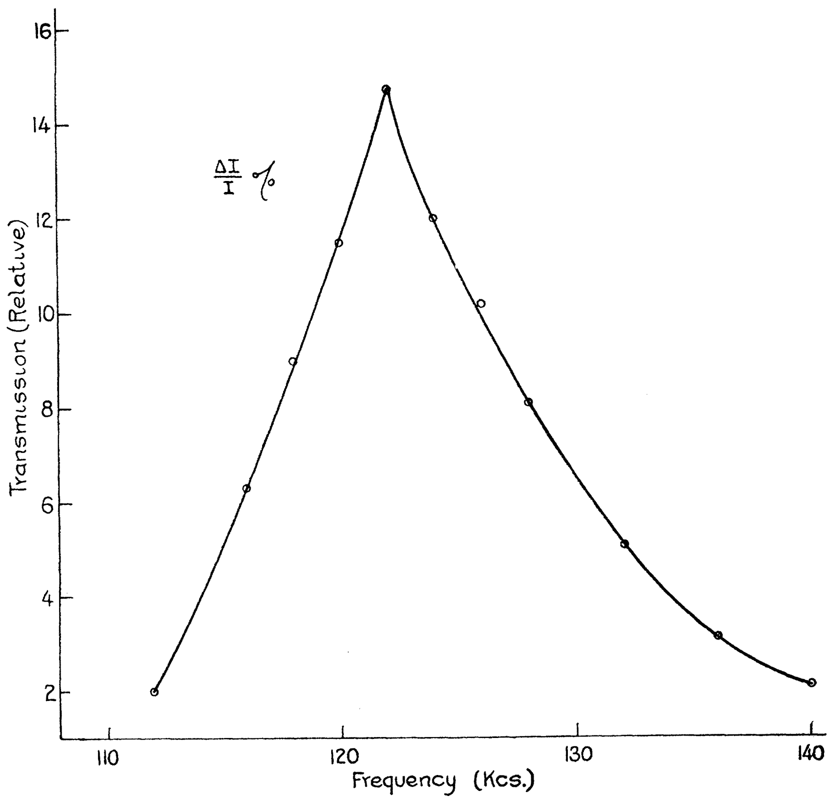


Fig. 7. Change in relative transmission with frequency for a slab of aluminum 0.825″ thick.

tions of the reflector for the range of frequencies noted. The difference between maximum and minimum currents divided by their sum is the ratio $\Delta I/I$ used as ordinates in the curve. This ratio indicates the relative transmission of any substance assuming that no selective absorption or scattering is present. The frequency for which the specimen is an integral number of half wave-lengths is thus readily determined. In general, by varying the thickness of the material studied; or, by changing the frequency of the source sufficiently, the exact number of half wave-lengths included in a given sample can be ascertained. Quite often, the approximate number of half waves in the substance may be calculated from a preliminary knowledge of some of its physical properties. The determination of the supersonic velocity in the solid from the measured wave-length in it and the frequency of the source is then easily verified by the nodal displacement method described above.

Example: Thickness of aluminum slab = 0.825 inches = $\lambda/2$. Best transmission frequency = 122 kc.

$$\therefore V = 122 \times 10^3 \times 0.825 \times 2 \times 2.54 = 5.11 \times 10^5 \text{ cm/sec.}$$

Displacement method in oil: Av. shift at 126 kc = 0.583 inches.

$$\mu = 0.825/0.242 = 3.31$$

$$\therefore V = 1.5 \times 10^5 \times 3.31 = 5.12 \times 10^5 \text{ cm/sec.}$$

Temperature 21°C.

One of the photographs shows slabs of brass, aluminum, and bakelite used in these measurements as well as a holder for the slab which permits other than perpendicular incidence to be used.

Small quantities of liquids.—When only small quantities of liquids are available, (say, less than 100 cc) the methods so far described are not readily applicable. In the first place the measurement of wave-length in the specimen must of necessity be made very close to the sound generator. And as was pointed out earlier, the phase relations close to the source are such as would tend to diminish the sharpness of nodal plane locations. Also the number of wave-lengths that are measurable in the liquid is small; hence the accuracy is reduced. Furthermore, it is often undesirable to have the liquid come in contact with the reflector and container, especially if these are not gold or platinum plated. Such difficulties were obviated in the present experiments by putting the small quantities of liquid to be tested in a parallel walled cell, which was immersed in a liquid medium of known acoustic properties. For example, the procedure for a specimen of turpentine was as follows: a bakelite cell was immersed in the oil previously studied. The cell was filled with the same oil. Micrometer readings for a series of nodal planes in the oil were recorded. Now with the turpentine in the cell, all other conditions remaining the same, the displacement of the nodal planes was measured. The supersonic velocity in the liquid was calculated by the same formula as in the experiment with the bakelite slab, thus:

Shift due to 1 inch layer of turpentine = −0.115 in. $\mu = 1/1.115 = 0.897$.

$$\therefore V = 1.5 \times 10^5 \times 0.897 = 1.34 \times 10^5 \text{ cm/sec.} \quad \text{Temperature } 21°C$$

In Fig. 8, curve I was taken when transformer oil only separated the reflector from the source; curve II was taken after the parallel walled cell filled with the same oil had been interposed in the acoustic path; and curve III when turpentine had been substituted for the oil.

Gases.—For measuring supersonic velocities in gases the Pierce interferometer is perhaps the simplest method yet devised. Fig. 9 shows a curve obtained in air with a Rochelle-salt crystal instead of quartz in the Pierce circuit. At lower frequencies in air, magnetostrictive rods served admirably well as sources of a stationary wave system. The driving circuit for the rods was similar to that described by Pierce.[16] On the other hand, for the measurement of sound absorption in gases, the Pierce arrangement may lead to erroneous results. For it should be noted, that both the frequency and amplitude of the exciting e.m.f. are influenced by the resonant reaction of the gas column upon the crystal. The change in frequency is so small that only in cases of extreme accuracy need it be taken into account. However, it is the periodic fluctuation

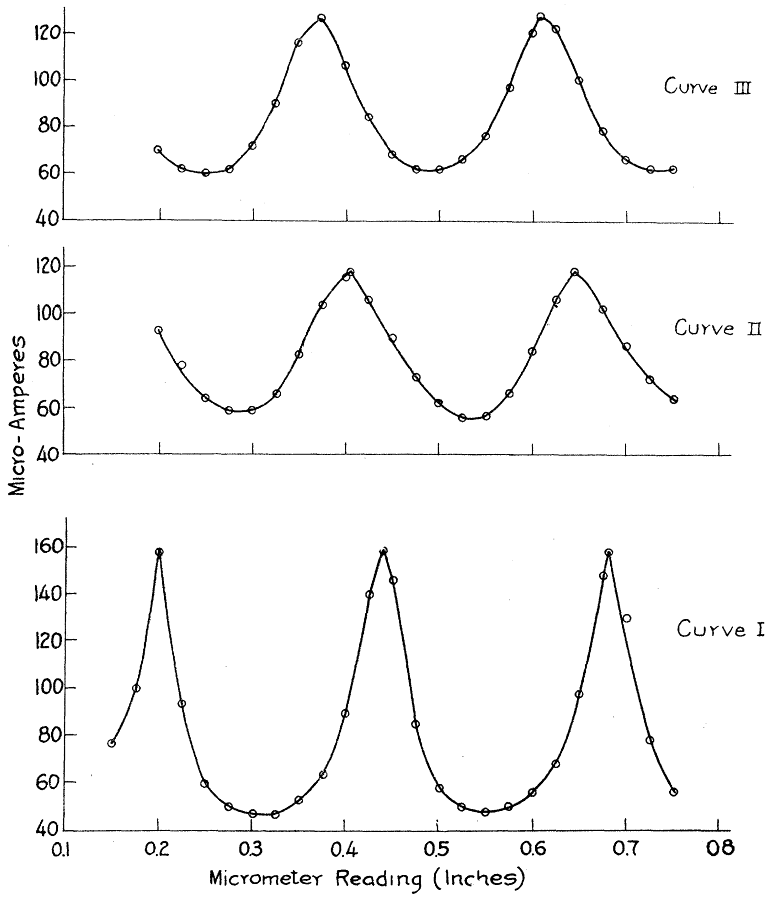


Fig. 8. Shift in position of nodal planes illustrated.

in amplitude of the e.m.f. across the crystal that makes possible the location of the nodal and antinodal planes in the gas. That is, the vacuum tube acts as a rectifier and the changes in the rectified plate current, as the length of the gas column is altered, are a measure of variations in the e.m.f. across the crystal.

The experiments of Pielemeier, Reid, and others show that as the length of the acoustic path in the gas is increased, the changes in plate current di-

[16] G. W. Pierce, Am. Acad. Proc. 63, 1 (1928).

minish. This diminution is due largely to absorption. Nevertheless, absorption coefficients calculated from this rate of diminution are inconclusive unless we possess an exact knowledge of the operating—not the static— characteristics of the tube and in addition how the emitted sound wave amplitude varies with that of the driving e.m.f., as well as what part the received sound wave amplitude plays in determining the net e.m.f. across the crystal. Observations made at 130 kc show that the rate of diminution of plate current variations, with increasing path length, may be altered at will by a factor of 80 percent merely by changing circuit constants.

In order to eliminate some of these difficulties Hubbard[17] proposes to use two quartz crystals tuned approximately to the same frequency. One crystal is used in a master oscillator circuit which supplies an e.m.f. of constant frequency and amplitude, to the second crystal serving as a driven source of

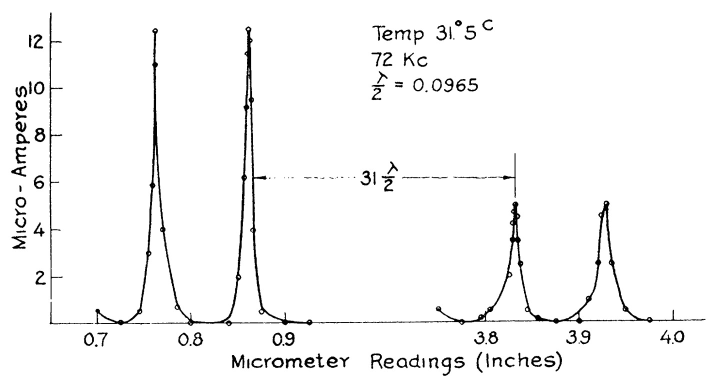


Fig. 9. Air interferometer curve. The change in magnitude of the peaks with increasing path length is shown in pronounced fashion.

sound. This method should prove valuable if and when constant mechanical amplitude can be maintained in the second crystal during a complete cycle of changes introduced by the motion of the reflector in the gas. Inherently, a quartz crystal displays a rather narrow resonance curve, and the task of holding to a fixed point on this curve as the reflector is displaced is troublesome even though the temperature remains constant.

To attain the same end, we have developed a circuit which promises to be useful in absorption measurements. The schematic diagram is shown in Fig. 10. Three electrodes are used on the crystal plate, similar to an arrangement of Cady.[18] The essential feature of this method is that it permits the amplitude of the exciting e.m.f. to be maintained constant, irrespective of the reaction of the gas column, by varying the resistance marked P. Moreover, since regeneration is employed, the difficulty in the two crystal system arising from the necessity of exact tuning is eliminated.

Another method for the determination of absorption coefficient of super-

[17] J. C. Hubbard, Phys. Rev. **36**, 1668 (1930).
[18] W. G. Cady, U. S. Patent No. 1472583, Oct. 30, 1923.

sonic waves in gases which appears to be free from many of the difficulties mentioned above is an adaptation of the hot wire microphone of Tucker and Paris.[19] Richardson[20] has shown the possibility of using a single wire for the measurement of sound decay in tubes at low frequencies. The scheme proposed here is to mount a very fine platinum wire cross on a ring which is inside the gas container (*c*) and is subject to small displacements parallel to the sound beam and may be moved independently from the reflector. Further investigation of this sort may be reported later.

From the foregoing discussion it is readily seen that the general use of the interferometer is considerably enhanced by having similar sound generators available in pairs For example if the second source is placed in the position

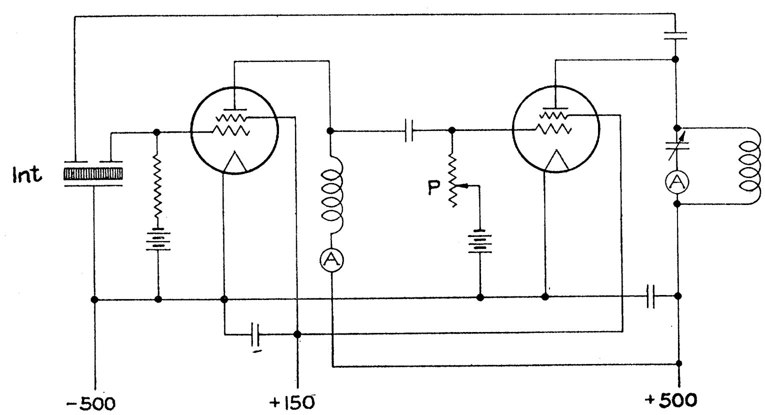


Fig. 10. Improved circuit for gas interferometer.

normally occupied by the reflector and these two identical generators are excited by the same electrical driving circuit, the amplitude of the interfering sound waves may be made to be nearly equal and the precision of velocity measurements be extended. Since this method was tried, Boyle and Froman[21] have described a similar scheme for producing stationary waves. In one set of our experiments two sources were so disposed that either alone acted as the sound generator while the other served as a reflector. Also, the movable was made to receive supersonic waves while the fixed acted as a transmitter, after the manner of Hehlgans.[22] In absorption measurements two identical generators are most valuable.

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[19] Tucker and Paris, Roy. Soc. Phil. Trans. **221,** 389 (1921).
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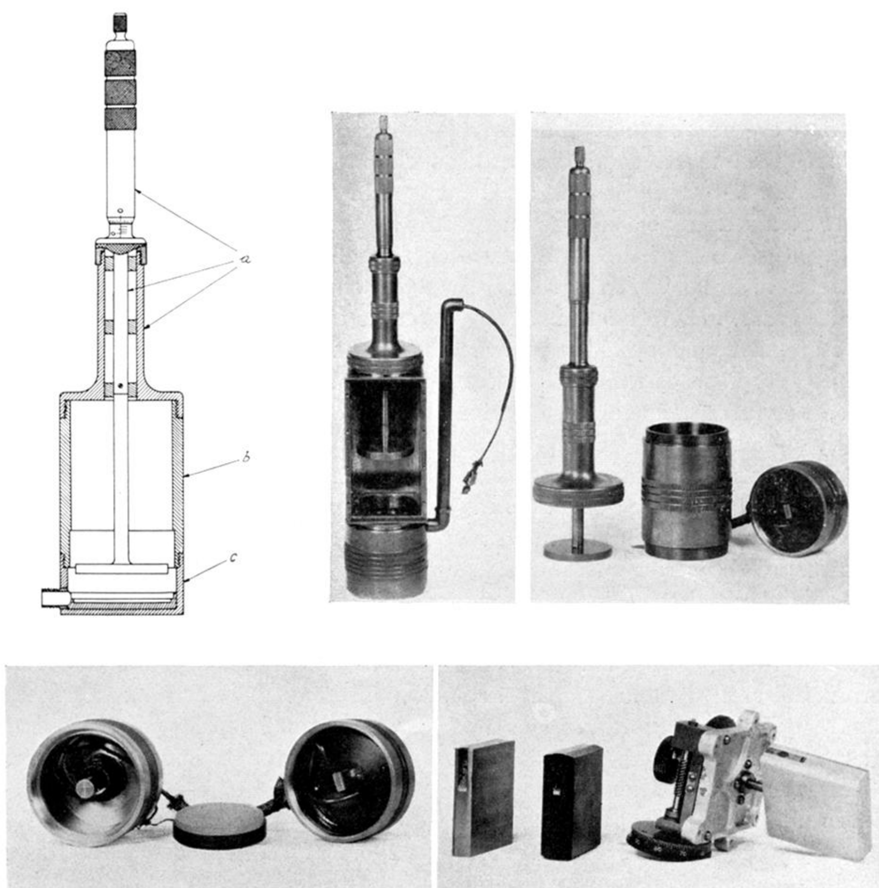

Fig. 1. Diagram of interferometer.