THE USE OF THE HOT WIRE ANEMOMETER IN MEASURING COEFFICIENTS OF ABSORPTION OF SOUND

By

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INTRODUCTION

The problem of measuring the acoustical properties of materials has been one of academic interest for many years but a great deal of attention had not been given it in a commercial way until Sabine in 1895 so successfully applied the principles of sound transmission, reflection and absorption to the problem of correcting the acoustical properties of auditoriums. He developed an equation involving the absorption given, and, with other measurable data taken from any room, the area of such given material necessary to be applied for correcting any faulty acoustical condition could be calculated directly.

Immediately there arose the question of how to measure these absorption coefficients accurately and at the same time in a simple direct manner.

All the methods that have been devised for the purpose of measuring the coefficients of sound absorption of materials may be grouped under two main classifications.

(1) Reverberation method.

(2) Standing wave, or tube method.

However, Watson (*) is responsible for a method by which the coefficient of absorption was measured by putting a fairly large sample of the test material in place as part of a wall structure and, by use of suitable apparatus, directing sound against it at different angles and then by a suitable pickup apparatus testing the intensity of the sound as reflected, thus giving the necessary data for calculating the percent of energy of the sound absorbed.

(*) "Acoustics of Buildings."

THE REVERBERATION METHOD.

In the reverberation method observations are made upon the time of decay of sound intensity in a room after the room has been "filled" with sound; or, until the sound has reached its maximum loudness for that source. In other words, as sound is fed into a room at a definite rate, the energy density of the sound present reaches a maximum, stable condition, where energy is absorbed rapidly enough to keep the conditions in equilibrium. Then, upon shutting off the source of sound, the energy dies out exponentially and the time required for it to reach 10^{-6} of its maximum intensity is taken as the reverberation time. It was found by Prof. W. C. Sabine that this value of residual sound was about the threshold intensity for the average person. The relationship between reverberation time and absorption coefficients with the volume of the room is shown in the equation $a\,t = .16\,v$ where $\underline{v}$ is the volume of the room, $\underline{t}$ is the reverberation time and $\underline{a}$ the total absorpting power of the surfaces exposed in the room.

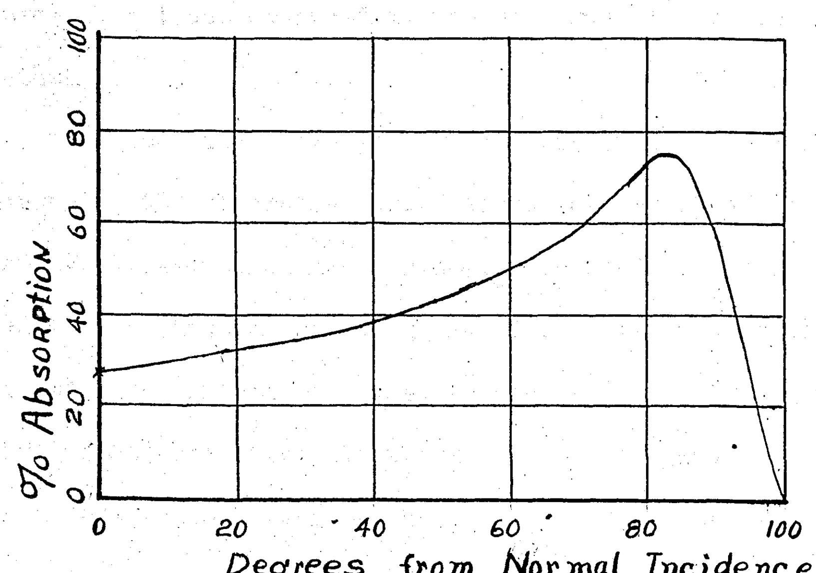


Fig 1

Perhaps the greatest argument in favor of the reverberation method is that by this treatment measurements are made with the sound incident at all angles, whereas by the tube methods the sound is incident perpendicular to the surface of the absorbent material. E. T. Paris (1) developed a striking equation for solving for the absorption coefficients at varying angles and found that the absorption coefficient ~~for sound incident~~ changed very materially with the angle. The variation is shown in the graph sketched in Fig. 1, on page 2. The material tested was a piece of acoustic plaster made by a London firm and, as the graph shows, the coefficient of absorption varied from .28 at normal incidence to .76 at 83 degrees from which value it rapidly dropped to zero for grazing incidence. This curve was built up by calculation from an equation set up from data taken by a tube method. Since the tube method measures absorption at normal incidence only, it appears that, if the above findings are correct, all values of absorption coefficients obtained by the tube method should be found to be much lower than those measured on the same material by the reverberation method.

The main disadvantage of the reverberation method has been that in measuring the absorption coefficients of any material a rather large sample-----several square yards----were needed in a room. Another objection is that in measuring the reverberation time the matter of individual judgement enters in to a large extent. Dr. Wallace Waterfall, of the Celotex Corporation, is reported to have met these two objections in a very satisfactory way but details of his method are not at hand.

(1) Proc. Roy. Soc. No. 115, P.418.

THE TUBE METHOD.

The only serious objection to the tube method is the possibility that values determined by this method might be so consistently lower than values found by the reverberation method as to make them of small value in a practical way; while, on the other hand this method is simple and direct of application and requires a relatively small sample of the material for a test.

In the tube method the sample under test is used as a stop to close the end of a tube in which standing waves are set up from some constant source of sound, and then, by appropriate measurements data is obtained from which the absorption coefficients may be easily computed.

THEORY OF THE TUBE METHOD

The theory of the tube method as worked out by H. O. Taylor ([1]) is as follows:-

The coefficient of absorption of sound is a function of the intensity of sound and therefore of the square of the amplitudes of the progressive and the reflected waves. As shown in Fig. 2, if the waves in a resonance tube reflects from a perfect reflecting surface the amplitude of the reflected wave will be equal to that of the progressive wave and there will be a series of points of zero amplitude, or nodes, and internodes where the amplitudes add. If, however, an absorbing material is put in place of the reflecting surface the amplitude of the reflected wave is decreased so that nowhere is there complete concellation of the waves; and where the waves re-enforce there is lower amplitude than with the perfect reflection while where there was zero amplitude, there is an amplitide which depends upon the amplitude of the reflected wave. Hence,

([1]) Phys. Rev. II, 1913, P.270.

there will be a series of maximum and minimum points along the tube as shown also in Fig. 2. In developing the mathematical relationships involved Taylor proceeded as below:-

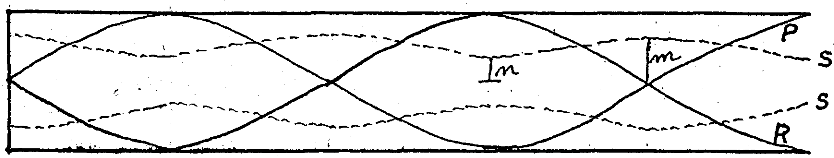


Fig 2

P- Progressive Wave
R-Reflected Wave
S-Envelope of Standing Wave System

Let the intensity of the progressive wave = kp^2

and the intensity of the reflected wave = kr^2

Then the coefficient of reflection is $P = \frac{r^2}{p^2}$

that is, the ratio of reflected energy to the incident energy. Now let <u>m</u> be the amplitude of the maximum position in the standing wave system and <u>n</u> be the amplitude of the minimum position

Then $m = (p+r)^2$ and $n = (p-r)^2$

Whence:-

$$p = \frac{\sqrt{m} + \sqrt{n}}{2}$$

and

$$r = \frac{\sqrt{m} - \sqrt{n}}{2}$$

Substituting these expressions for <u>p</u> and <u>r</u> in the value of P above --

$$P = \frac{(\sqrt{m} - \sqrt{n})^2}{(\sqrt{m} + \sqrt{n})^2}$$

Now the coefficient of absorption is 1 - P so that

$$\alpha = 1 - \frac{(\sqrt{m} - \sqrt{n})^2}{(\sqrt{m} + \sqrt{n})^2} = \frac{4}{\frac{\sqrt{m}}{\sqrt{n}} + \frac{\sqrt{n}}{\sqrt{m}} + 2}$$

In accordance with this theory Taylor measured intensities at these maximum and minimum points by use of an exploring tube, which was in resonance with the exciting sound and to which was attached a somewhat larger resonating cylinder in which was mounted a Rayleigh disc which gave deflections that were proportional to the intensity of the sound at the maximum and minimum points giving the values of _m_ and _n_ for use in his theoretical formula.

While his values of absorption coefficients found by this method compared favorably with values found by other methods, his apparatus consisted of so many resonating parts that errors due to attenuation in the tube as well as absorption effects from other sources than the test material were certain to be present.

Another experiment by the tube method was performed by E. T. Paris ([1]) in 1926. In his work he measured the intensity of the sound at the maximum and minimum points by means of a tuned resonator of his own design. This consisted of a small cylindrical resonator in the neck of which was mounted a grid of fine platinum wire which was heated by an electric current. The wire being in the neck of the resonator was subjected to the surging of the air motion in the sound waves and this caused a cooling of the wire. The amount of this cooling effect was measured by means of an amplifier, connected thru a Wheatstone bridge arrangement to the grid. Paris developed a formula for computing the absorption coefficients from this data which was identical with that developed by H. O. Taylor.

On account of the size of the resonator it was necessary for the resonance tube to be of relatively large size; one of 12 inches diameter

([1]) Phys. Soc. of London, Vol. 39, Part 4, June, 1927. P.269

being used. Paris concluded from his experiment that "the stationary wave method is well suited to the measurement of absorption coefficients at normal incidence when only small specimens of the absorbing material are available."

Paris was forced to correct for the presence of the relatively large reflecting area of the resonator itself as well as for the mutual resonance effects of the two tuned units.

PURPOSE OF THIS THESIS

The purpose of the present experiment is to test the fitness of a plain hot wire grid for measuring the maximum and minimum positions of the wave by introducing the heated grid into the standing wave system of a resonance tube at one end of which is placed the absorbing material in the same manner as in the above outlined methods of Taylor and Paris. Such a grid should be entirely free from resonance effects, is simple to construct and to manipulate, and can be made so that small reflection effects should be present. (A compaison of these results with Paris' theoretical curve shown in Figure 1 will be given.)

The grid forms one arm of a regular bridge circuit, connected as shown in Figure 3.

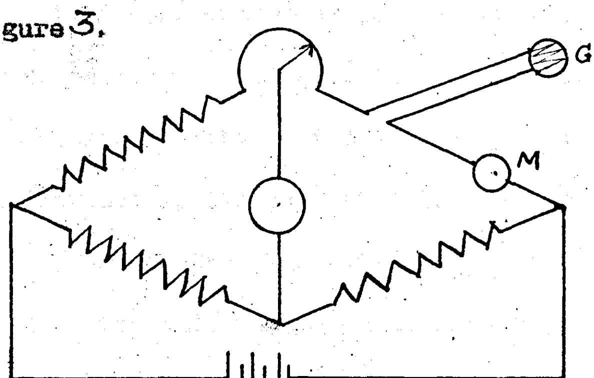


Fig 3

G- Grid M- Milliammeter

the exploring grid is moved along the tube and readings noted at regular intervals in the wave system until the maximum and minimum positions and deflections are found.

Deflections of the galvanometer are caused when the heated grid is located in a position where there is a to and fro motion of the air molecules. There is then a cooling effect depending upon the position in the wave. At the nodes there is no motion of the air particles and hence, there is no cooling effect and therefore no deflection of the galvanometer. As the grid is moved from a node there is a gradual increase in galvanometer deflection until a maximum deflection is found then the deflections gradually decrease until they fall to zero at the next node. When the reflecting surface at the end of the resonance tube is replaced by a piece of absorbing material, there is never a complete cancellation of the various wave components and no zero position is found, but, instead, a series of maximum and minimum positions are observed as was described in the discussion of Taylor's original theory of the method.

GALVANOMETER DEFLECTIONS A MEASURE OF THE INTENSITY OF THE SOUND

The question next arises as to just what interpretation is to be given the deflections of the galvanometer in this case. That is, whether the cooling effect on the grid is proportional to the amplitude of the oscillations of the air particles in the sound wave or whether it is proportional to the intensity of the sound which is the square of the amplitude. The galvanometer used gave a straight line relationship between voltage change and galvanometer deflection and since the grid current was kept constant there would be a corresponding increase in IR drop across the grid for any change in resistance; hence the deflections are proportional to resistance changes in the grid. The graph Plate No. 1 shows the relationship between deflections and voltage changes across the galvanometer terminals.

The question now resolves itself into whether the resistance changes in the grid are proportional to the intensity of the sound or to the amplitude of the sound vibration.

J. S. G. Thomas (1) in his study of the hot wire anemometer as a means of measuring rates of flow of fluids through tubes, found that when galvanometer deflections were plotted against the square root of the velocity of the fluid that there was always a portion of the plot which showed a straight line relationship, the extent of this characteristic depending upon the temperature to which the wire was heated; the straight portion of the graph being more extensive the higher the temperature at which the grid was run.

Since the velocity of the air particles in the vibrations of the sound wave is proportional to the amplitude of the wave (the frequency being the same in all parts) it appears reasonable to assume that deflections in the case of the hot wire grid are proportional to square of the amplitude over the small range of resistance changes met with in observations made on absorbing materials where the maximum resistance change was of the order of .007 ohms. In other words, even tho the curve of deflection vs. the square root of velocity did not show a straight line relationship over a wide range the relationship might be considered safely of a straight line nature over a small part of the curve.

(1) Phil. Mag. 39 May 1920, P. 216.

Further light is given by Paris and Tucker in their investigations of the properties of a "Selective Hot Wire Microphone," [2] where they first analyzed by theoretical means and later verified by experiment the effects of the oscillating air particles on a hot wire grid. They deduced a series of equations involving the change in resistance of the grid and the velocity of the air particles in the sound waves and out of their investigation appeared two main causes of the change of resistance, namely:-

(1) A steady resistance change δR_1 proportional to the intensity of the sound affecting the microphone, and

(2) The amplitude of the oscillatory resistance δR_2 which was proportional to the amplitude of the sound which produces it. This effect was noted in the phones of the amplifier as a note of twice the frequency of the exciting sound.

It was noted that neither of these relations held exactly for very loud sounds.

They immediately took steps to test these results experimentally. In testing the first deduction the microphone was exposed to sounds of known relative intensity and the value of the deflection for each was observed. They did the experiment in open air on a still evening and varied the intensity of the sound by moving the source to measured distances from the microphone. They found complete verification of the theoretical deduction that the change in resistance is proportional to the intensity of the sound vibrations.

In testing the second theoretical relation ship they obtained less

[2] Phil. Trans. Roy. Soc. of London. A Vol. 221; P.412, 1912.

decisive results but they decided that the available evidence points to the conclusion that for faint sounds the deflection of the galvanometer for this oscillatory cause is approximately proportional to the amplitude of the sound. Thus it appears that the effect of this oscillatory cause is of small importance in its modification of the galvanometer deflection tho not entirely negligible.

Another investigation having bearing upon the present subject was carried out by Stewart and Stiles [1] in which they deduced from theoretical considerations that the energy in a system of standing waves in a tube is proportional to the energy of the incident wave in open air at the mouth of the tube.

It therefore appears that it is perfectly safe to assume that deflections observed from a hot wire grid in a standing wave system in a tube are proportional first to the intensity of the sound at that position of the grid together with a deflection of an oscillatory nature which is proportional to the amplitude of the vibration. Just what proportional part each one plays is somewhat indefinite except that the first condition seems in the present investigation to be the most important and apparently represents the steady state in the wave for in noting deflections for any particular position the galvanometer is at first observed to suffer a sudden throw from which it falls back somewhat then follow a steady increase in deflection which soon rises to a maximum steady value when a sound of constant energy and steady frequency is maintained. This maximum point usually closely co-incide with the position of the first throw.

[1] Phys. Rev. Apr. 1913, P. 309.

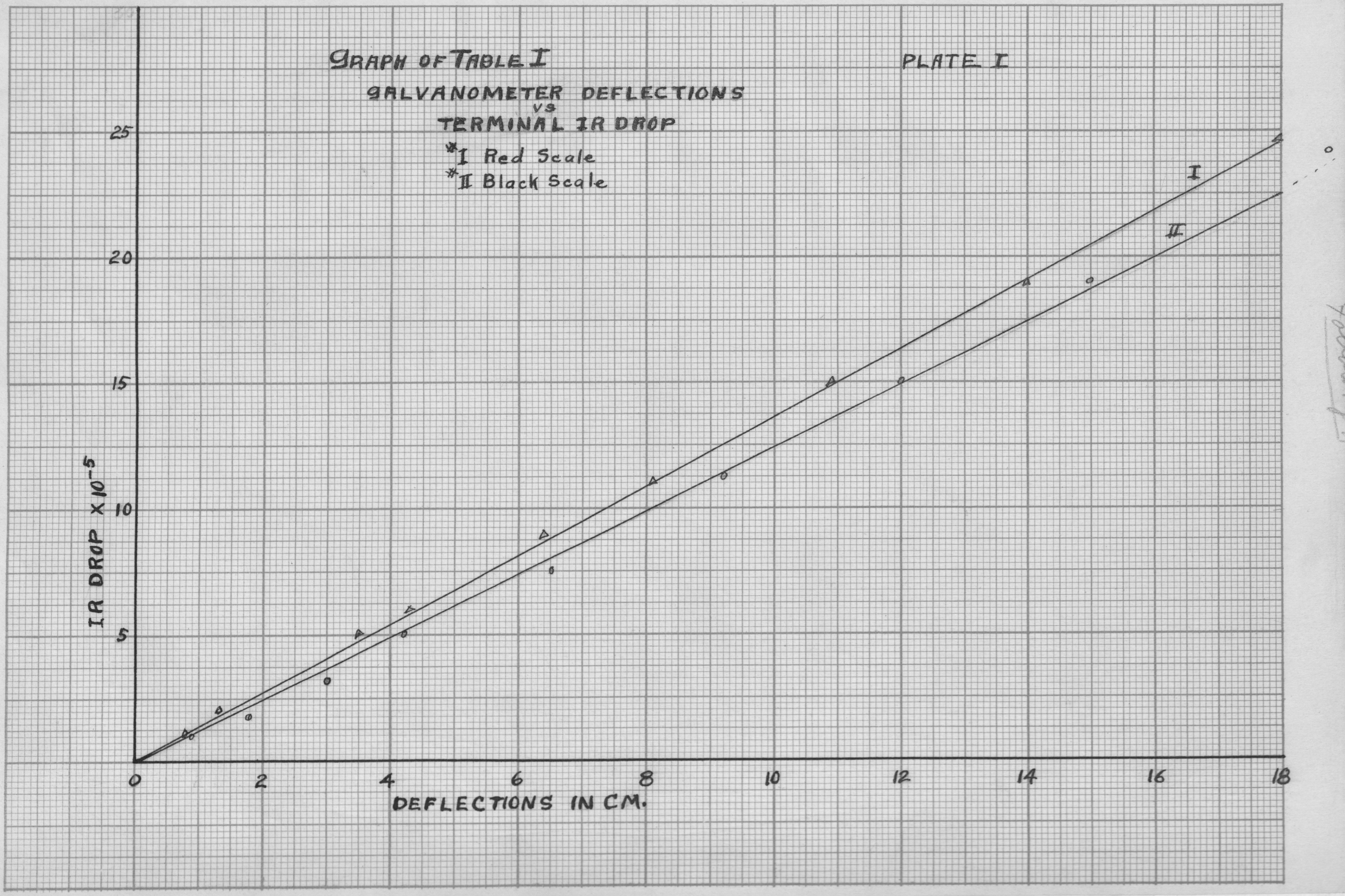
GALVANOMETER CHARACTERISTIC.

The following data was taken to determine the deflection characteristics of the galvanometer with change of voltage across its terminals.

The voltages were obtained by connecting the galvanometer across a known low resistance and then by passing small known currents thru this resistance the voltages were calculated and these values plotted with deflections. The low resistance used was a 1/99 ohm shunt from one of the Siemens-Halske millivoltmeters in the laboratory. The current thru the resistance was read by a Siemens-Halske milliammeter.

TABLE NO. 1.

Red Scale			Black Scale		
Def'l. Cm.	Milli amperes	IR $X10^5$	Def'l Cm.	Milli amperes	IR $X10^5$
.8	1.0	1.0	.9	1.0	1.0
1.3	2.0	2.0	1.8	1.7	1.7
3.5	4.9	5.0	3.0	3.1	3.1
4.3	6.0	6.0	4.2	5.0	5.0
6.4	9.0	9.0	6.5	7.5	7.5
8.1	11.0	11.0	9.2	11.6	11.7
10.9	15.0	15.0	12.0	15.0	15.0
14.0	19.0	19.0	15.0	19.0	19.2
18.0	24.5	24.7	19.0	23.8	24.0
20.0	27.5	27.9	22.0	27.5	27.7
22.0	30.0	30.8	25.0	32.0	32.3
25.0	34.0	34.0			


GRAPH OF TABLE I
PLATE I
GALVANOMETER DEFLECTIONS
VS
TERMINAL IR DROP
*I Red Scale
*II Black Scale
IR DROP X 10⁻⁵
DEFLECTIONS IN CM.
0
2
4
6
8
10
12
14
16
18
5
10
15
20
25
I
II

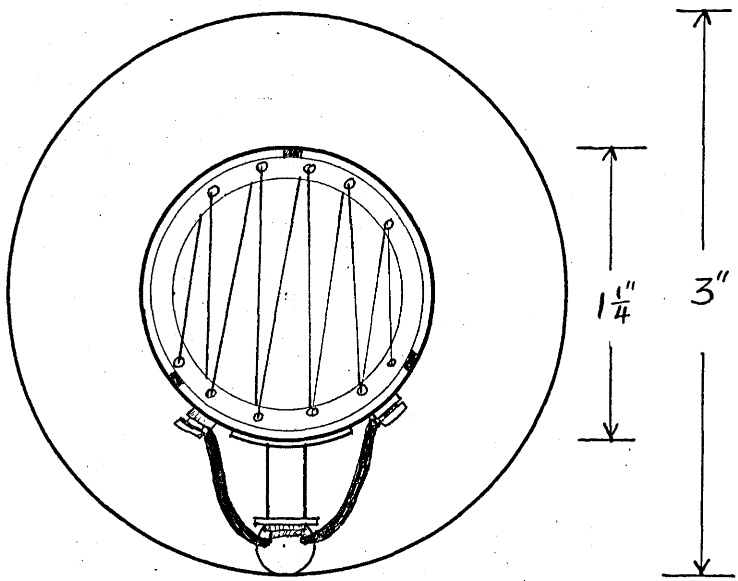


Fig 4

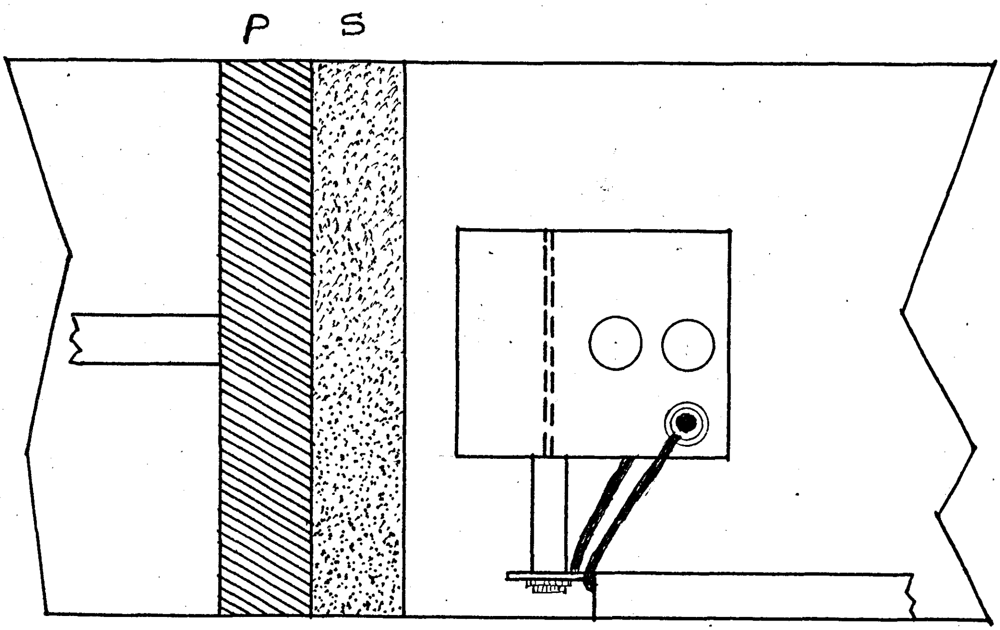


Fig. 5.

DESCRIPTION OF APPARATUS

The diagram Fig. 3 shows the circuit used in this work. The bridge used was an Elliott box bridge of English manufacture which has about twice the current capacity of the usual bridge. This gave a wider range of choice in the matter of grid current to use. The ratio arms were set a 10:10 and the variable branch set at 50 ohms. Accurate balance was obtained by a Leeds and Northrup slide wire connected as shown in Fig. 1. The galvanometer was a Leeds and Northrup Type "R" portable instrument of 10.2 ohms resistance and of 149 megohms sensitivity. The regular working current was 100 milliamperes to 120 milliamperes which was read on a Siemens-Halske milliammeter of 1 ohm resistance.

Fig. 4 shows the detail of the grid construction drawn to exact size and shown in position coaxial with the resonating tube. The wire of the grid was made of platinum Wollaston wire .02 mm. in diameter and of about 52.7 ohms hot resistance. The wire was strung across a small ring of sheet mica and this mica ring was mounted inside a brass tube 1 1/2 inches long and 1 1/4 inches diameter with walls 1/2mm. thick. The mica ring was supported at three points in the tube and held fast by a drop of glue at each point. The leads from the grid were of #30 copper wire soldered to the platinum; the other end of the copper being held by two small binding posts near the end of the brass tube. The brass tube, enclosing the mica ring was found to be necessary in order to avoid the disturbing effects of convection currents about the heated wire. The brass tube containing the grid was soldered to a brass machine screw 1/8 inch in diameter and the whole assembly mounted at the end of a 1/4 inch in diameter copper tube as shown in side view in Fig. 5. The connecting wires to the grid binding posts entered thru this tube and were attached at the small insulated binding posts in the brass tube. The wire used was stranded rubber covered copper wire gotten by taking common silk covered fixture cord and stripping off the silk braid thus leaving the two rubber covered conductors separate.

This brass tube, mounted as it is, with its axis parallel to the oscillations of the air particles in the sound waves should not distort the wave conditions beyond a slight reflection effect from the ends of the tube; and this area is relatively very small. Two 1/4 inch holes were drilled in each side of the protecting tube to avoid standing wave effects in the tube itself at high frequencies.

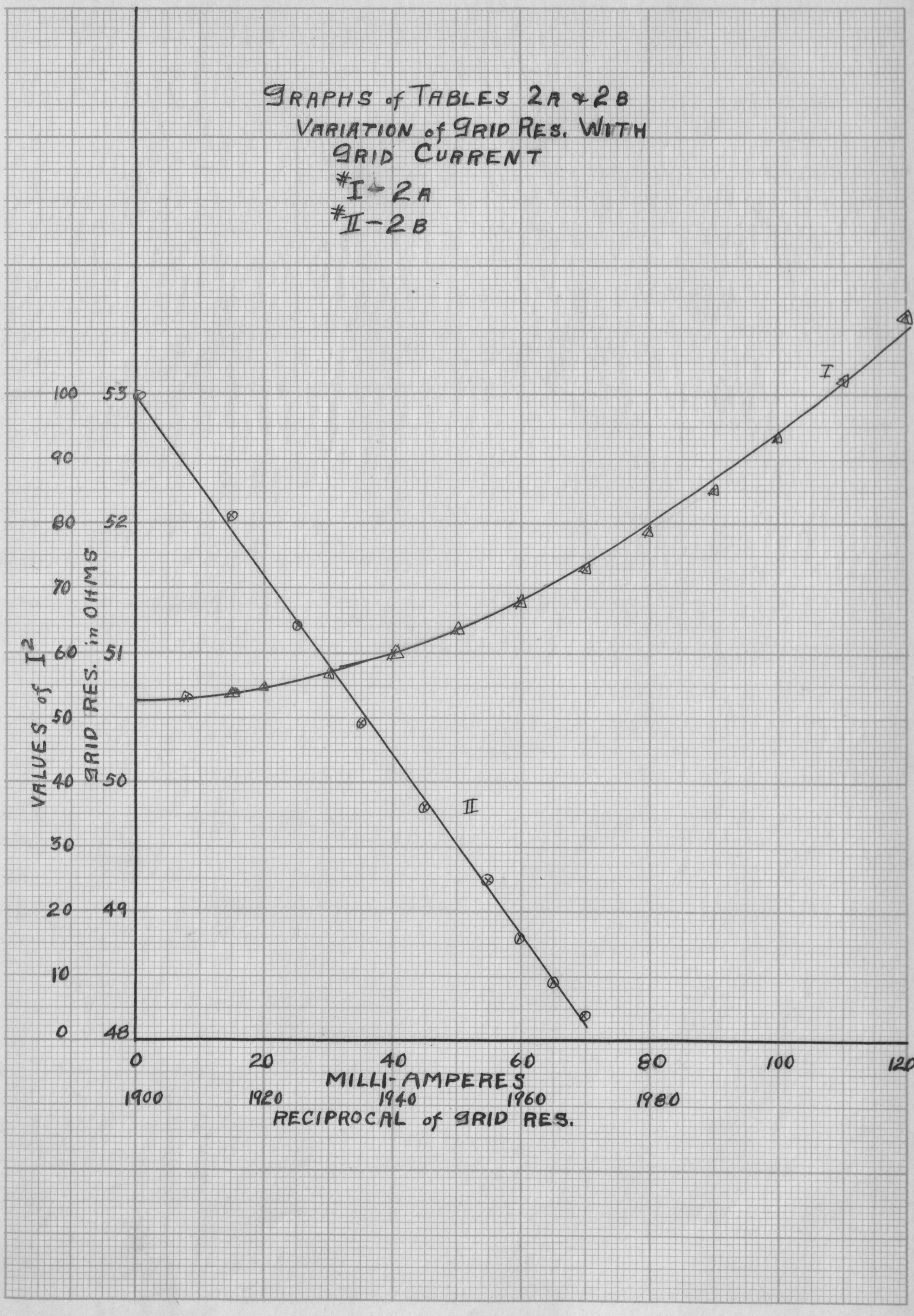
In Figure 5 is a diagram of the general plan of the method of mounting the test samples in position for testing. It was found convenient to place the samples within the tube and "back them up" with the tightly fitting plunger 5/8 inches thick. By this means the sample could easily be set in the proper position for the different frequencies. To avoid reactions from the portion of the tube back of the piston a 6 inch plug of loosely packed cotton was placed in this space so that any transmitted sound would be absorbed, and no standing wave system set up that would tend to feed energy back to the main system.

RESISTANCE OF THE HOT WIRE GRID

The grid resistance was measured by beginning at a low value of current and gradually increasing it until the maximum current used in the experiment was reached. Using these points as a guide the curve was extrapolated to zero current for the cold resistance value of the grid.

The resistance of the Leeds and Northrup slide wire was 7.1 ohms. The vertical scale was divided into 10 parts and the revolving drum was divided into 100 divisions which in turn could be read to 1/2 division

9	$\frac{1}{50.9}$	1965
16	$\frac{1}{51}$	1960
25	$\frac{1}{51.18}$	1955
36	$\frac{1}{51.4}$	1943
49	$\frac{1}{51.65}$	1935
64	$\frac{1}{51.95}$	1925
81	$\frac{1}{52.25}$	1915
100	$\frac{1}{52.68}$	1910



GRAPHS of TABLES 2A & 2B
VARIATION of GRID RES. WITH
GRID CURRENT
#I - 2A
#II - 2B
I
II
VALUES of I^2
GRID RES. in OHMS
0
10
20
30
40
50
60
70
80
90
100
48
49
50
51
52
53
0
20
40
60
80
100
120
MILLI-AMPERES
1900
1920
1940
1960
1980
RECIPROCAL of GRID RES.

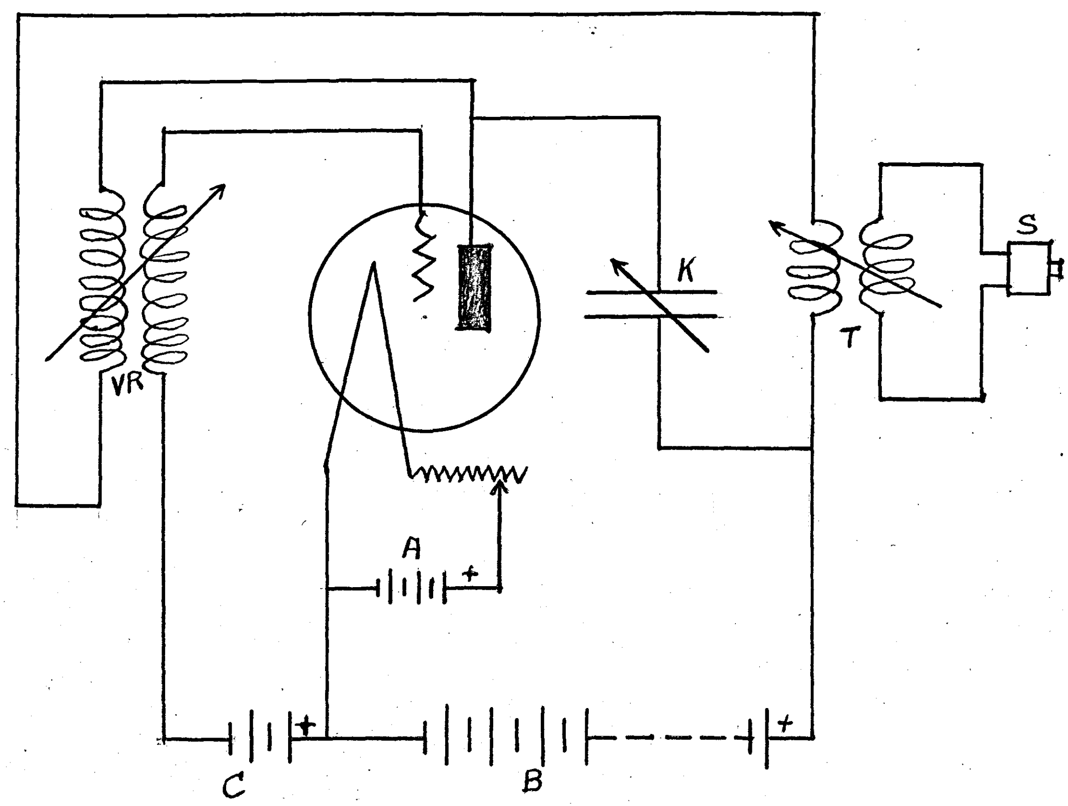


Fig 6

PREPARATION OF SAMPLES

Six samples of common commercial types of acoustical material were tested, namely;*

Two thicknesses of Acousti-Celotex furnished by the Celotex Corporation;

Four samples consisting of one sample of hair felt 3/4 inch thick with one burlap face; one sample of hair felt one inch thick; one sample of hair felt 1/2 inch thick mounted on a plaster base and another sample of "Asbestos-Acoustikos" felt one inch thick mounted on a plaster base. The last four were furnished by the Johns Manville Corporation.

Samples were prepared as carefully as possible in order not to disturb their acoustical properties. Samples were first cut from the entire piece much larger than the 3 inch disc needed for the test then the sample was gradually trimmed down by use of safety razor blades until the proper fit was obtined. In case of the plaster backed samples, the plaster was first formed to a 3 inch disc by means of a small fine rasp, after which, the felt was trimmed by razor blades to conform to the size of the plaster disc. When the samples were trimmed to a snug fit for the tube they were ready for test. Care was always taken to handle samples no more than absolutely necessary.

THE SOURCE OF THE SOUND.

The Soud was produced by a vacuum tube oscillator circuit as shown in Fig. 5.

VR is a General Electric Co. Induction Voltage Regulator Form IK5.

S. is the speaker unit from an old "electro Magnetic" type Magnavox outfit with the horn removed.

T is a tapped transformer. The primary was wound for 110 volts and the secondary was tapped for a total of 294 volts. The out put of the oscillator was run thru the 110 volt coil and the horn unit was connected across the 294 volt terminals.

K is a variable condensor of 5 mf. capacity of the plug in type.

B is a B-battery of 144 volts (storage type).

C battery voltage of 7.5 volts.

The tubes are of the regular UX 201A amplifier type. In working at the lower frequencies three tubes in parallel were used to give more power.

The circuit as shown gave a sensibly pure note free from objectionable overtones when the speaker was run at as light load as this made for it except as later described. A graph of the wave also shown a regular wave form free from irregularities as might be caused by the presence of overtones.

The pitch of the tone emitted by the outfit is very critical as to filament current so that during the taking of observations it was necessary to check up frequently on the frequency. To do this the filament rheostat was mounted at the test table with a tuning fork of the correct frequency used for comparison with the note of the oscillator. It was noted that very accurate tuning of the oscillator with the tuning fork could be obtained by watching the galvanometer during the tuning process. It was noted that with the oscillator and the tuning fork both being sounded the galvanometer would swing to and fro in response to the maximum and minnimum parts of the beats. When tuning was correct and no beats were present the galvanometer would, of course, read as a steady deflection. In tuning the circuit an approximate tuning was made by variation of the condensor and induction regulator after which the final adjustment was made by means of the filament rheostat.

METHOD OF TAKING OBSERVATIONS

Setting The Samples; There are two ways of setting the test sample in the tube.

(1) First find the position in which a smooth hard surface gives maximum resonance then set the sample to that its face is in this plane.

(2) Having the sound wave system established the sample is moved along the tube until a position of maximum resonance is found for it. This position is of the order of one centimeter nearer the source end than the other.

The reason for the above shift is due to the absorption of a portion of the energy. For instance with the sample set in position (1) above there is a shift of the wave crest toward the sample. Paris, in his work with the tube method already described, noted this same effect. He decided that the shift is due to a "virtual" reflecting surface at some distance below the surface of the test material. A comparison of the two curves shown on the graph Plate No. 3 will give some quantitative idea of the amount of this shift.

However, little difference in the values of absorption coefficients were noted as found in either of these positions, tho the deflections were somewhat larger in the case of the sample being set for resonance rather than setting the sample at the place where the good reflecting surface gave maximum resonance. This made the reading of the minimum deflections a little more certain hence the better practice would be to find the position of best resonance for the material by moving it along the tube until a maximum sound regeneration is noted, were it not that in locating the maximum position by moving the sample in the tube, the peak of the sound was much broader and the maximum therefore much less distinct than in the case of locating it with a good reflecting surface. The first position however can be very definitely located and so this was the standard practice.

With the sample placed in the tube the grid on its carrier was inserted in the resonance tube and set near the sample. The bridge current was then turned on and adjusted to the 100 ma. value and allowed to run for some time (ten to fifteen minutes) to warm the supporting ring and the other surrounding parts until a stable condition is attained. During the time that the inside of the tube is warming up there is a steady drift of the galvanometer due to the gradual increase in resistance as the wire and its surroundings increase in temperature. When stable conditions are reached however the galvanometer is very steady and at the same time very sensitive to disturbances in the air about the grid.

Cause of Unstable Conditions:-

There were two main causes for unstable conditions in the bridge circuit. (1) Unsteady battery due to the charge being low. Best results were gotten when the bridge battery was about half charge. (2) Unsteadiness caused by convection currents about the heated wire of the grid. The first objection was overcome of course by keeping the batteries well charged, and the second was corrected by enclosing the mica ring containing the grid wire, in the brass tube as described above. The bridge was carefully checked for balance before each reading so that each deflection was read from the same zero point.

ROOM CONDITIONS DURING OBSERVATIONS

With samples and grid in place the sound source was placed at the mouth of the tube in such a position that little reflection from the surface back into the tube was possible. The face of the speaker unit set at an angle of near 45 Deg. with the axis of the tube. Otherwise the end of the tube was un-enclosed except insofar as the room constituted an enclosure. The room was 21 ft. by 13 ft. with an 11 ft. ceiling. There were two doors. Conditions in the room were kept as near constant as possible. The doors werd always closed during the taking of data and no other sound or motion of the observer allowed during this time.

A few tests were made with the open end of the tube and the speaker unit covered with a layer of ordinary cool cotton. This cut off outside influences by shielding the tube and also absorbing some of the sound that would ordinarily be reflected at the open end of the tube. The only effect in the determining of the data desired was to reduce the deflection of the galvanometer at all positions so that the minimum was smaller thus again introducing the chances of error in reading this.

Stewart and Stiles (1) have shown that the energy of a standing wave system is proportional to the energy in open air at the mouth of the tube. Hence, there is no objection to leaving the end of the tube open; in fact it appears, from their findings, that it is advisable.

The nearness of the speaker unit to the tube for best results was

(1) Phys. Rev. Apr. 1913, P. 309.

determined by experiment for each frequency used. In each case the unit would be so placed that there would be a deflection of 12 to 16 cm for the maximum readings.

TAKING READINGS OF DEFLECTIONS.

In taking a reading the galvanometer was checked to zero on the scale and then the sound fed into the tube. The result was a cooling of the wire due to the to and fro motion of the air particles in the sound wave which of course changed the resistance of the grid causing an unbalancing of the bridge which was measured by the deflection of the galvanometer. Galvanometer deflections (as shown on Plate 1) were proportional to the voltage changes across its terminals and since this change is proportional to the resistance change in the grid it can safely be stated that the deflections of the galvanometer are proportional to the resistance changes in the grid. These in turn, are proportional to the intensity of the sound in the wave system within the resonance tube. Such readings of deflections were taken at intervals of 1 cm. along the tube to discover the wave form present. The form of wave obtained in this way with near perfect reflection is shown in the graph (Plate No. III). In determining the maximum and minimum points however the readings were taken at intervals of one half centimeter for accuracy. The form of the wave being of a uniform curvature, without irregularities showed that the sound being emitted by the speaker was of satisfactory purity and was usable in testing.

Next the reflecting surface was replaced by a sample of 3/4 inch, hair felt with one burlap side and a similar set of deflections taken. With this absorbing material in place of the good reflecting surface the deflections of the galvanometer were all much reduced near the maximum while at the points where there was zero deflection with the reflecting surface in place there was now a deflection. See Table No. 4. The graph of the data obtained in this case is shown on the same sheet (Plate No. III) for comparison. Here the shift of energy crest doward the sample is quite plainly seen. On the same sheet is a graph of a set of data obtained by sliding the sample up toward the source of sound so that the central place of the sample was in the plane formerly occupied by the face of the material; thus bringing the "virtual reflecting" surface nearer to the resonance plane for good reflection. The effect of this will be seen to be that the energy crest is shifted back to nearer the position of the crest during good reflection. This shows that the absorption is going on all thru the material and that the reflected energy comes from some sort of an average reflection region with much of the sound energy being reflected from the back of the sample; probably in this case from the wooden plunger itself. See table No. 3.

In order to check this assumption an interesting variation of the readings was made. First the wooden piston was placed one inch back of the sample being treated so as to form a dead air space between the sample and the piston. The result was a very noticeable increase in the coefficient of absoption over that obtained with the piston bakking up the sample. In the first case the coefficient of absorption was .39 while with the dead air space back of the sample the coefficient was increased to .75.

The test was next varied by setting the piston far enough back of the sample so that it was in the next position of resonance at this frequency (one half wave length back of sample). By this arrangement energy was transmitted thru the sample and reflected back from the plunger and since the sample was now at a node of the system of standing waves where there was small motion of the air particles the absorption effect should be found to be smaller. As expected, the value of the absorption coefficient was low eg. .200.

The next variation was to set the piston only one quarter wave length back of the sample thus placing it at an internode of the wave system where there was maximum displacement of the air particles. This caused a change in phase of the wave and caused greater motion of the air particles thru the sample. The test in this position showed a value of absorption coefficient of .594 or almost three times as great absorption as was found with the plunger one half wave length back of the sample.

Since the sound absorbent material is generally used against a wall of flat material all tests reported in data in this article were made with the wooden piston directly "backing up" the test material.

Date Taken for the Determination of the

Wave form with no Absorption.

The first column contains readings of the scale which was marked on the rod which carried the hot wire grid. The scale readings are more or less arbitrary so far as the position of the reflecting piston is concerned tho the readings are begun within the first internode from the piston. This set is taken with the reflecting piston set at one of the positions of maximum resonance; in this case the second position. The graph of this data is found on Plate No. 3.

TABLE NO. 3

Scale Cm.	Deflection Cm.	Scale Cm.	Deflection Cm.
0	.1	15	17.6
1	.5	16	15.1
2	1 .3	17	12.9
3	2.2	18	9.7
4	3.7	19	7.7
5	6.2	20	5.5
6	9.0	21	3.9
7	11.5	22	2.2
8	14.0	23	1.0
9	16.2	24	.4
10	17.6	25	.05
11	19.6	26	.0
12	19.6	27	.2
13	19.4	28	.8
14	17.7	29	1.4

Scale Cm.	Deflection Cm.	Scale Cm.	Deflection Cm.
31	5.7	41	16.4
33	11.0	43	11.4
35	16.2	45	7.5
36	17.5	47	3.5
37	19.0	49	.9
38	19.5	50	.3
39	18.4	51	.08
40	17.7	52	0.00

TEST DATA ON SAMPLES OF MATERIALS

FIRST SERIES

The first series of data is more of an exploratory nature to find the best conditions of grid current, position of samples in the tube and position of the sound source to use for consistent results.

The data given below is taken with Sample No. 3 set in place of the reflecting piston at the resonance point for that frequency. The grid current was 60 M.A. and the frequency about 650 vps.

TABLE NO. 4.

Scale Cm.	Def'l. Cm.	Scale Cm.	Def'l. Cm.
0	1.8	16	3.1
1	2.2	17	2.2
2	2.5	18	1.6
3	3.0	19	1.3
4	3.5	20	.6
5	4.0	21	.4
6	5.2	22	.2
7	5.6	23	.1
8	5.9	24	.2
9	5.7	25	.5
10	6.0	26	1.0
11	6.2	27	1.5
12	5.5	28	-
13	5.0	29	2.8
14	4.5	30	4.1
15	3.9	33	5.2

Scale Cm.	Def'l. Cm.
35	5.5
37	5.5
39	5.8
41	4.3
43	2.6
45	1.0
47	.2
49	.15
50	.25
51	.50

NOTE:- This data is graphed on the same sheet with the wave form gotten with good reflecting surface in place of the sample. It will be notéd that there is a shift in the crest ofthe wave toward the sample. This was also noticed by Paris in his work with the tube method. He states that it is due to the formation of a "virtual reflecting" surface within the material with a resulting shift in phase of the energy in the wave.

A Second Test on Sample No. 3

As an interesting test to locate the "virtual reflecting layer," the sample was pushed forward so that the plane of its central layer was in the position occupied by the piston form best resonance.

Other conditions remained the same.

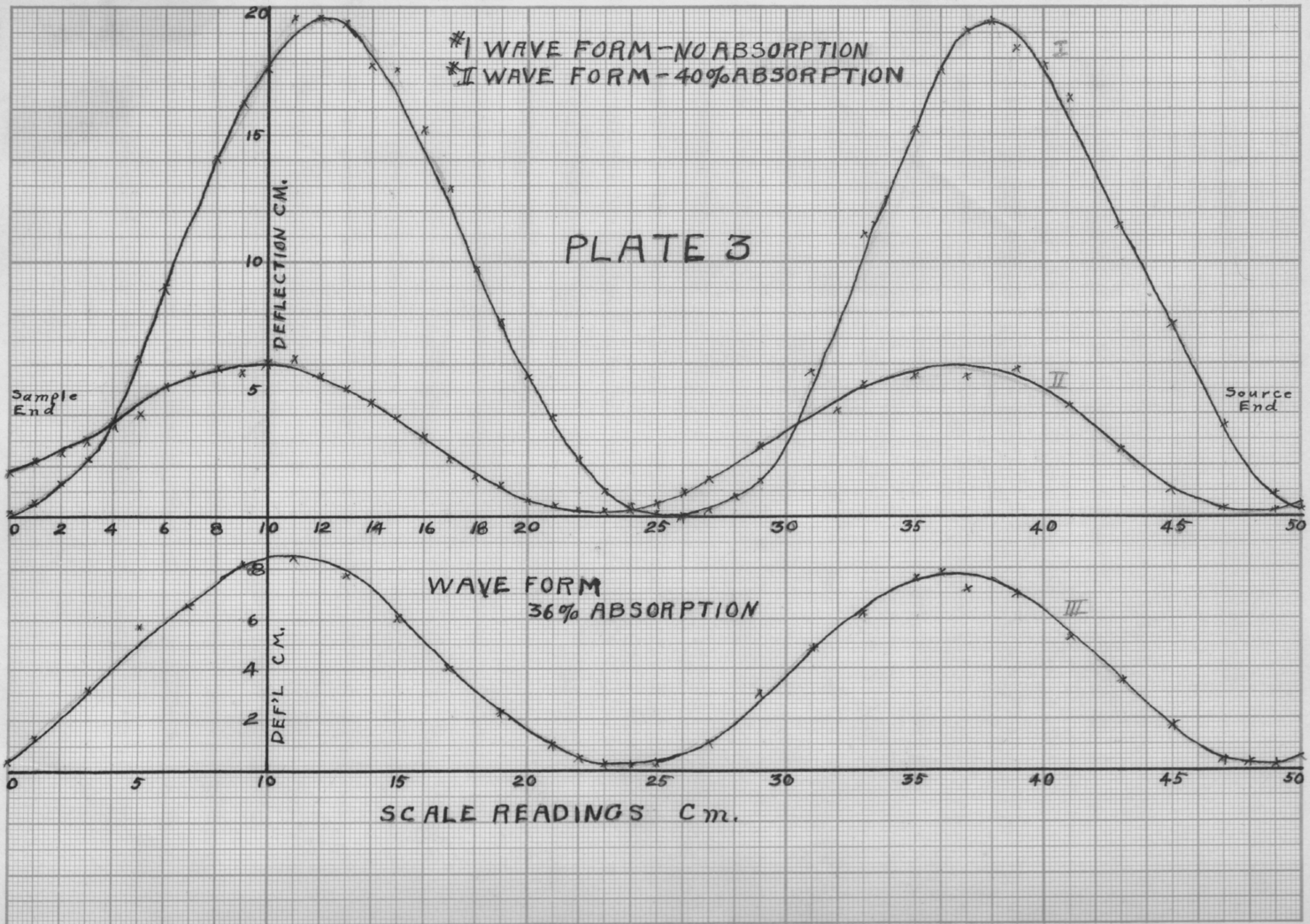
TABLE No. 5

Scale Cm.	Def'l. Cm.	Scale Cm.	Def'l. Cm.
0	.4	27	1.1
1	1.3	29	3.0
3	3.1	31	4.8
5	5.7	33	6.2
7	6.5	35	7.6
9	8.1	36	7.8
11	8.4	37	7.1
13	7.7	39	7.0
15	6.0	41	5.2
17	4.0	43	3.5
19	2.3	45	1.7
21	1.0	47	.35
22	.4	48	.25
23	.1	49	.10
24	.1	50	.1
25	.2	51	.3

In the graph of this data shown on the lower part of graph sheet No. 3 it will be noted that the crests of this wave are shifted back again toward source. It does not, however, bring the crest back to that of the purely reflected wave. This means that the "virtual Reflection" surface is probably the piston itself since the piston is always in place back of these samples during the time they are being tested.

Now, having the wave form and the operating characteristics known, the data on the rest of the samples tested was taken only at the maximum and minimum positions on the wave from which the coefficients were calculated.

On the following pages is given a list of data taken on individual samples with conditions under which it is taken after which each series is separately summarized; then at the last is a general summary of results for the different frequencies used in the test. There is also comparison given with results obtained by Sabine, Watson, Knudsen, and Bureau of Standards for these same materials when such is available.



#I WAVE FORM-NO ABSORPTION
#II WAVE FORM-40% ABSORPTION
PLATE 3
DEFLECTION CM.
Sample End
Source End
I
II
WAVE FORM
36% ABSORPTION
III
DEF'L CM.
SCALE READINGS Cm.

EFFECT OF GRID CURRENT ON DETERMINATIONS OF THE ABSORPTION COEFFICIENTS.

Another check on apparatus was made to find whether the temperature of the grid in any way influenced the final values found for the coefficients. In general the only effect noted was that at lower values of grid heating current the deflections were smaller thus again making the determination of the minimum deflection less accurate. For instance; with a grid current of 40 M.A. the average of a number of deflections at the minimum position when the frequency was 512 v.p.s. was .05 cm. and the maximum deflection of 2.7 cm. The value of the coefficient of absorption calculated from this data was .410. With 80 m.a. grid current the minimum deflection was .10 cm and the maximum deflection 7.6 cm.giving a value of .390 for the absorption coefficient, the difference between the two undoubtedly being largely due to errors in reading the minimum deflection points. By using 100 M. A. the minimum deflections was .3 cm while with 120 ma. the deflection at minimum was .50 cm. in some cases.

It would appear therefore that the 120 M.A. current in the grid is the more satisfactory, but, in making adual tests the 120 M.A. current was a little less satisfactory to use than the 100 ma. current on account of the greater amount of drift of the galvanometer due to the gradual warming up of the apparatus and air in the tube which, tho' slow, was rapid enough to cause an appreciable irregularity of deflections repeated at any given position unless considerable time were allowed between readings. On the average about one half hour was required for equilibrium conditions to obtain after the grid current was first turned on then after taking one observation the air would be mixed to some extent and more time needed to again reach an equilibrium. With 100 M.a. however there was much less drift while the deflections were still quite easily readable.

The ratio of percents of error in reading this minimum deflection plotted against corresponding errors thus produced in absorption coefficients is shown in the graph (Plate IV.).

In running an actual test on any particular sample after the form of the wave for any particular frequency was known it was necessary only to take about five observations about the known maximum and minimum areas of the wave. These readings were always taken 1 cm. apart at first then if there seemed to be any doubt about the points wanted other readings on the half centimeter distances were made. In finding the minimum point the common practice was to read deflections on the half centimeter intervals since this point was most difficult to find correctly.

TABLE NO. 6

The following table is based upon a set of readings taken on Sample #3 where the maximum deflection was 12 cm. and the minimum deflection was .2 cm and the calculated absorption coefficient was .40. Beginning with this a series of "errors" were impressed upon the minimum reading to note the corresponding error caused in the calculated value of the absorption coefficient.

"Error" %	n	$\sqrt{n}$	α	% change in α
+ 10	.22	.469	.432	3.7
+ 20	.24	.490	.434	6.7
+ 40	.28	.530	..467	15.0
+ 50	.30	.548	.474	16.7

"Error" %	n	$\sqrt{n}$	α	% change in α
-10	.18	.424	.394	3.2
-20	.16	.400	.376	7.7
-40	.12	.347	.334	18.0
-30	.14	.374	.352	11.0
-50	.11	.327	.296	27.5

The graph of this table is shown in Plate 4. It will be noted that any error in reading the minimum value of deflection will introduce about one third as great a percent of error in the calculated value of absorption coefficient. It will also be noted that the relationship is of a straight line character from -30% to 40%.

Now the value of n can be read with fair certainty to 10% even at the low deflections, but assuming even a 20% error in taking this reading the error introduced in absorption coefficient is at most 7.7% which is well within the variation commonly found between tests by the reverberation method made by different authorities.

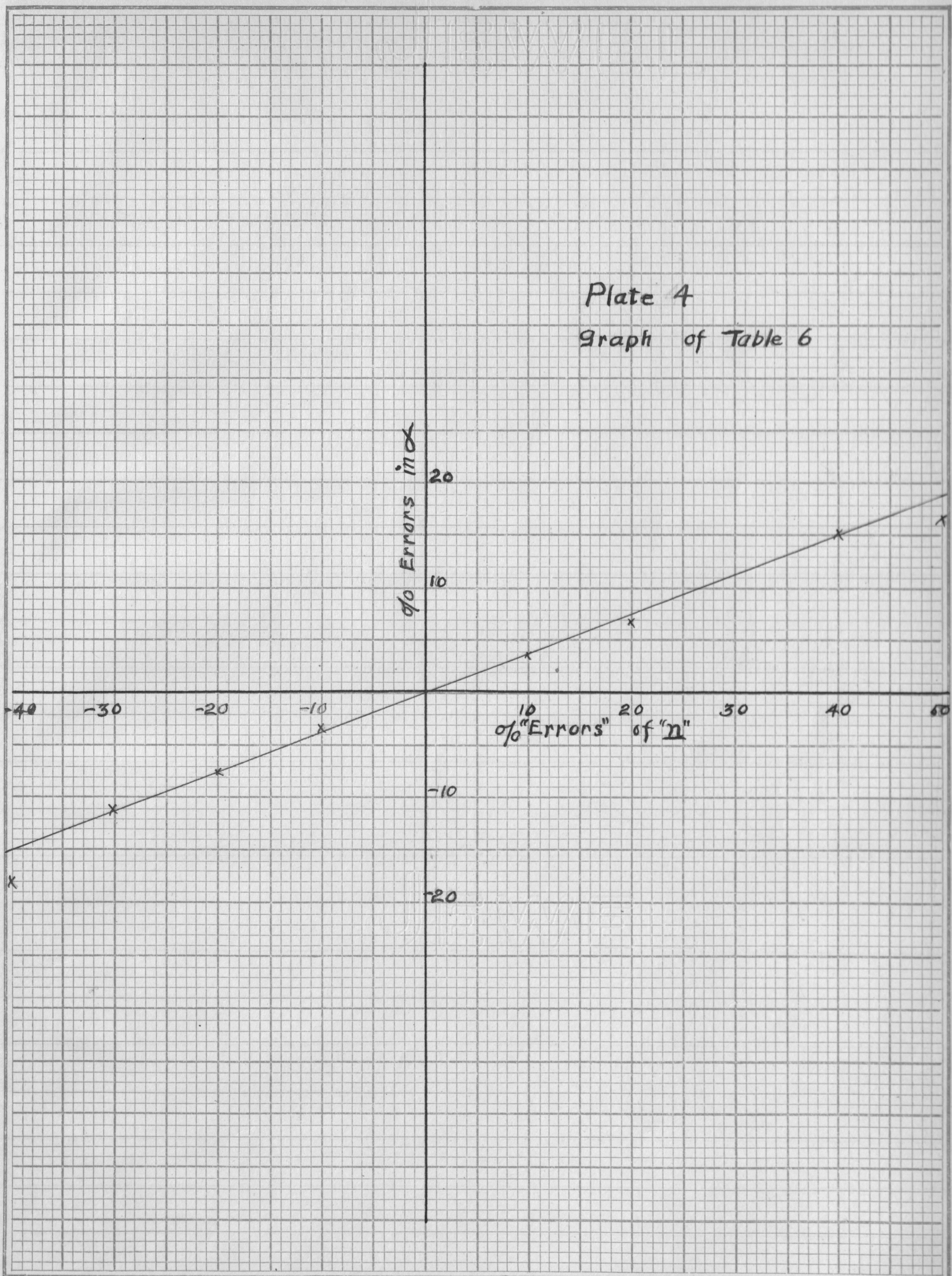


Plate 4

Graph of Table 6

A LIST AND DESCRIPTION OF SAMPLES OF MATERIALS TESTED

The samples tested were furnished by the Johns-Manville Corporation and the Celotex Corporation.

Sample No. 1 -- This sample was made of 1/2 inch hair felt backed by plaster board 3/8 inch thick. Furnished by J.M.Corp.

Sample No. 2 -- This is sold under the trade name of Nashkote B-316. It consists of 3/4 inch of hair felt mounted on 3/8 inch plaster board with the face of the felt covered with a sheet of white oil cloth material perforated with about 440 quarter-inch holes per square foot. J.M.Corp.

Sample No. 3 -- Hair felt 3/4 inch thick with one face of burlap.JM.Corp.

Sample No. 4 -- J.M. Corp. Asbestos-Acoustikos felt 1 in. thick.

Sample No. 5 -- Type B Acosti Celotex 7/8 inch. thick and having 441 quarter-inch holes per square foot. This material is made of the fiber refuse of sugar cane from the southern sugar refineries.

Sample No. 6 -- Type BB Acousti Celotex 1 1/4 inch. thick. Otherwise the same as sample No. 5. The last two samples furnished by the Celotex Corporation.

In the following sections is given a detailed report of five series of tests made upon the above described samples with discussions of certain phases of the tests as may appear important from time to time. A set of sample data, taken on a piece of Type "B" Acousti Celotex is shown in the following table.

Frequency 512 vps.

GRID I — 100 ma.

Position of grid		Av. Defl. cm.
2		14.0
3		14.5
4	MAX.	15.0
5		14.8
6		14.5
20		.50
21		.35
21.5	MIN.	.300
22		.40
23		.50

Here the maximum deflection is evidently between 3 cm. and 4 cm. so some further readings are taken in that region to find the real peak deflection which in this case was found to be 14.9 cm. which gives the value of "m" in Taylor's formula.

The value of "n" or the minimum here is as closely .30 as can be read on the scale. Substituting these values in Taylor's formula:-

$$\alpha = \frac{4}{\frac{\sqrt{m}}{\sqrt{n}} + \frac{\sqrt{n}}{\sqrt{m}} + 2} = \frac{4}{\frac{\sqrt{14.9}}{\sqrt{.3}} + \frac{\sqrt{.3}}{\sqrt{14.9}} + 2}$$

$$= \frac{4}{\frac{3.86}{.547} + \frac{.547}{3.86} + 2} = \frac{4}{7.05 + .115 + 2} = \frac{4}{9.16} = .436$$

Tests on this material by Watson, Knudsen, Sabine and the Bureau of Standards gave values for the absorption coefficient of this material at .470; .460; .400; .400 respectively or an average of .432. The average obtained in a number tests on this material by the above described method gave .420 as the average of the following series of results:- .422; .436; .402; .407; .388; .470. Some of the values in this series were obtained with the face of the sample in the plane of resonance for good reflection and some with the sample itself set for position of maximum resonance.

DATA SERIES 1 CONTINUED.

SAMPLE NUMBER 3
Test No. 4

40 MA. Grid Current   612 vps. (Approx.) frequency

With this small grid current a very small minimum deflection was observed thus making results very uncertain. In the data lists the first number in columns in the scale reading and the second number is the deflection in centimeters.

10---- 2.5		22---- .10		
11---- 2.7	(max.)	23---- .05	(min)	Abs. Coef. of .410
12---- 2.5		24---- .10		

Test No. 5

80 MA. grid current   612 vps. (approx.)

10---- 7.0		22---- .25		
11---- 7.6	(max.)	23---- .10	(min)	Abs. Coef. of 390
12---- 6.8		24---- .30		

In two rechecks of the data in test No. 5 values of coefficient of absorption of .380 and .390 respectively were obtained.

Test No. 6

Same conditions prevailed here as in other tests except that the sample was moved forward in the tube until it was in the position giving maximum resonance, instead of being placed so that its face was in the plane of resonance for a good reflecting surface.

10---- 12.5		23---- .3		
11---- 13.1	(max.)	24---- .2	(min.)	Coef. of .380
12---- 12.5		25---- .3		

SAMPLE NO. 2

Test No. 1.

80 M.A. grid current 612 vps. (approx.)

10---- 7.5		24---- .4		
11---- 7.7	(max.)	25---- .2	(min)	Abs. Coef. of .472
12---- 7.5		26---- .3		

Test No. 2.

Repetition of Test No. 1 with samples set in position of best resonance for its own reflection.

10---- 9.2		23---- .4		
11----10.0	(max.)	24---- .2	(min.)	Abs. Coef. .430
12---- 9.8		25---- .3		

SAMPLE No. 2

Test No. 1

80 MA 512 vps.

For this and the following tests of series one and two the oscillator is tuned to 512 vibrations per second by comparison with a standard tuning fork. Tuning was done by "ear" noting the beats between the two notes.

27---- 1.2		9---- .15		
28---- 1.4	(max.)	10---- .05	(min.)	
29---- 1.4		11---- .05		Abs. Coef. .530
30---- 1.3		12---- .10		

Test No. 2

27---- 3.2		9---- .20		
28---- 3.5	(max.)	10---- .10	(min.)	Abs. Coef. .520
29---- 3.3		11---- .15		

Test No. 3.

7---- 3.3 11---- .20

8---- 3.5 (max.) 12---- .10- (min.) Abs. Coef..510

9---- 3.2 13---- .15

SAMPLE NO. 5

Test No. 1

80 M.A. Grid current 512 vps.

6---- 3.7 12---- .11

7---- 3.8 (max.) 13---- .10 (min.) Abs. Coef..470

8---- 3.3 14---- .15

Test No. 2

100 MA grid current 512 vps.

Grid current increased to find whether larger minimum readings might be obtained.

6---- 6.3 12---- .2

7---- 6.7 (max.) 13---- .1 (min) Coef. of Abs. .388

8---- 6.5 14---- .25

Test No. 3.

120 MA. 512 vps.

6---- 11 11---- .3

7---- 12 (max.) 12---- .2 (min) Abs. Coef. of .407

8---- 11.6 13---- .3

Test No. 4.

120 M.A. 512 vps.

The sample was moved 2 cm; nearer the source to note whether the change in position had much effect upon the final results of the value of absorption coefficients.

6---- 7.2	13---- .15
7---- 8.0 (max.)	14---- .10 (min) Abs. Coef. .352
8---- 7.5	15---- .12

It will be noted that by moving the sample out of position all readings were reduced and the reading of the minimum was again very uncertain.

SUMMARY OF RESULTS OF SERIES NUMBER 1.

Test No.	1	2	3	4	5	6	Av.	Sabine
Sample No. 3	.400	.369	.379	.410	.390 .380 .390	.380	.387	.380
Sample No. 2	.472	.430	.	.	.	.	.451	.50
Sample No. 4	.530	.520	.510				.520	.59
Sample No. 5	.470	.388	.407	.352			.404	.40

Only the different types of material at hand are used in this set. Sample No. 1 was a plaster backed material much similar to No. 2.

Sample No. 6 is the same type of material as sample No. 5 except for thickness, hence it is not tested in this set which is the run to find the operating characteristics of the hook up.

DATA ON THE SECOND SERIES OF TESTS.

This series begins with all operating conditions known; that is, the operator can tell by the action of the test set the cause of any irregularities in performance that may occur. Conditions suitable for maximum sensitivity and steadiness have been found in the preliminary set and these are followed as closely as possible in all the following data. All batteries are freshly charged.

Grid currents of 100 MA or 120 MA are used as desired and in this particular series a frequency of 512 vps is used thruout.

In placing the samples, it was found in the preliminary tests that when the position of maximum resonance was found by moving the sample to the best position, there was a great deal of difficulty in locating the position of resonance exactly since with the absorbing material the maximum is so broad. It was also found that the values of absorption coefficient varied a great deal with the position of the sample when set in this way. It was therefore decided to find the position of resonance with the smooth piston and then set each sample with the face of the sample in this plane. In this way all are known to be set alike. The tuning of the oscillator is checked frequently by comparison with the standard tuning fork.

Different sets of data for each sample are obtained by varying such conditions as might be unavoidably varied in one repeating the experiment. For instance, the speaker is set near or far from the resonance tube or some sort of absorbing material is laid over the open end of the tube to change the amount of deflection. This absorbing material was a strip of roll cotton and its being placed there may be considered as equivalent to an extreme change in room conditions with the end of the tube open. For instance, it might be similar to opening all the doors and windows of the room.

SAMPLE NO. 1.

Test No. 1

100 MA Grid current 512 vps

3---- 24.4		11.0---- .3
4---- 24.6	(max.)	11.5---- .2 (min) Abs Coef..307
5---- 24.5		12.0---- .23

Test No. 2.

4---- 21.8	11.0-----.25
5---- 22.4 (max.)	11.5---- .22
6---- 21.5	12.0---- .20 (min) Abs. Coef..317
	12.5---- .35

SAMPLE No. 2.

Test No. 1

4---- 16.0	11.5---- .24
5---- 16.5 (max.)	12.0---- .28
6---- 15.5	12.5----..30 Abs. Coef. .408

Test No. 2 (Sample No. 2)

4---- 10.9	11.5---- .25
5---- 11.4 (max.)	12.0---- .22 (min) Abs. Coef. .447
6---- 10.7	12.5---- .25

SAMPLE NO. 3

Test No. 1

3---- 17.5	10.5---- .5
4---- 17.7 (max.)	11.0---- .4 (min) Abs. Coef. .459
5---- 17.4	11.5---- .5

SERIES NO. 2 (Cont.)

Test No. 2 (Sample #3)

2---- 14.8   10.5---- .5

3---- 16.0 (max.)   11.0---- .4 (min.) Abs. Coef. .448

4---- 15.8   11.5---- .5

Test No. 3

2---- 12.2   10.5---- .25

3---- 12.3 (max.)   11.0---- .20 (min.) Abs. Coef. .397

4---- 11.6   11.5---- .30

SAMPLE NO. 4

Test No. 1

3---- 9.2   10.5---- .32

4---- 9.3 (max.)   11.0---- .30 (min.) Abs. Coef. 517

5---- 8.8   11.5---- .32

Test No. 2

3---- 8.0   10.5---- .32

4---- 8.2 (max.)   11.0---- .30 (min.) Abs. Coef. .537

5---- 7.8   11.5---- .33

Test No. 3

Cotton layed over the end of the resonance tube

3---- 6.7   10.5---- .25

4---- 7.4 (max.)   11.0---- .25 (min.) Abs. Coef. .551

5---- 6.8   11.5---- .30

SAMPLE NO. 5

Test No. 1

120 M. A. Grid current.   512 vps.

3---- 14.5   21.---- .35

4---- 14.9 (max.)   21.5-- .30 (min.) Abs. Coef. .434

5---- 14.8   22.0-- .40

SERIES NO. 2 (Cont.)

Test No. 2 (Sample No.5)

3---- 10.6 20.5---- .3

4---- 10.8 (max.) 21.0---- .25 (min.) Abs. Coef. .459

5---- 10.7 21.5---- .30

Test No. 3

Sample set up to resonance for its own surface

6---- 7.6 22.0---- .20

7---- 7.8 (max.) 23.0---- .10 (min.) Abs. Coef. .363

8---- 7.7 24.0---- .20

SAMPLE NO. 6

100 MA 512 vps.

Test No. 1

4---- 6.5 (max.) 21---- .2 (min.)

Absorption coefficient ---------- .509

Test No. 2

4---- 8.7 (max.) 20.5---- 25 (min)

Absorption Coefficient ---------- .496

Test No. 3

29---- 8.1 (max.) 10.5---- 25 (min.)

Absorption Coefficient ----------- .509

SUMMARY OF SERIES NO. 2

512 vps. frequency. 100 M.A. to 120 M.A.

Test No.	1	2	3	4	Av.	Sabine
Sample 1	.307	.317			.312	.33
" 2	.408	.447			.427	.50
" 3	.453	.448	.480	.397	.444	.38
" 4	.517	.537	.551	.	.535	.59
" 5	.363	..459	.434	.452	.414	.40
" 6	.509	.496	.509		.505	.70

An average value for sample No. 5 taken from results by Sabine, Watson, Knudsen and the Bureau of Standards is .435. These results being in agreement to within 6 to 8 points would be considered satisfactory since the repeated handling of the samples must necessarily affect their acoustics properties.

Samples 1 & 2 were given only two tests as conditions were steady and all readings reproduced accurately at the two positions tested. Sample No. 6 shows a wide variation from Sabine's reverberation value however.

DATA ON THE THIRD SERIES OF TESTS

100 MA Grid current and 1350 vps frequency.

SAMPLE No. 1

Test No. 1

9---- 18.0	16.5---- .4	
10--- 18.5 (max.)	17.0---- .3 (min.)	Abs. Coef. .400
11--- 18.0	17.5---- .7	

Test No. 2.

9---- 9	17.0---- .32	
10--- 9.8 (max.)	17.5---- .20 (min.)	Abs. Coef. .440
11--- 8.8	18.0---- .30	

Test No. 3

9---- 16.8	16.5---- .4	
10--- 19.2 (max.)	17.0---- .3 (min.)	Abs. Coef. .400
11--- 18.9	17.5---- .4	

SAMPLE NO. 2

Test No. 1

5---- 5.4	11---- .4

SERIES NO. 3 (cont.)

Test No. 1 (Sample No. 2 cont.)

6---- 6.2 (max.)	12---- .3 (min.) Abs. Coef. .590
7---- 5.9	13---- .4

Test No. 2

11---- .4	17---- 5.1
12---- .20 (min)	18---- 5.7 (min) Abs. Coef. .530
13---- .45	19---- 4.9

SAMPLE NO. 3

Test No. 1

9---- 21.5	16---- .2.2
10--- 23.2 (max.)	16.5-- 2.1 (min) Abs. Coef. .713
11---- 21.7	17---- 2.4

Test No. 2

9---- 9.8	16---- .7
10--- 10.5 (max.)	16.5-- .5 (min.) Abs. Coef. .588
11--- 9.0	17.0-- .6

SAMPLE NO. 4

Test No. 1

1---- 6.5	11.0---- .4
2---- 7.5 (max.)	11.5---- .3 (min) Abs. Coef. .645
3---- 7.4	12.0---- .5

Test No. 2

2---- 7.2	11.0---- .35
3---- 7.5 (max)	11.5---- .30 (min.) Abs. Coef. .645
4---- 5.2	12.0---- .50

Test No. 3.

3---- 7.8	11---- .30
4---- 8.0 (max.)	11.5-- .25 (min.) Abs. Coef. .515
5---- 7.5	12---- .3

SERIES NO. 3 (Cont.)

SAMPLE NO. 5

Test No. 1

1---- 3.4	11.5---- .35	
2---- 4.2 (max.)	12.0---- .30 (min.)	Abs. Coef. .667
3---- 4.1	12.5---- .4	

Test No. 2

1---- 8.5	11.5---- .6	
2---- 9.8 (max.)	12.0---- .5 (min.)	Abs. Coef. .621
3---- 8.9	12.5---- .7	

SUMMARY OF SERIES NO. 3
(1350 vps.)

Test No.	1	2	3	Av.	Sabine at 1024	Range of Results
Sample 1	.400	.440	.400	.413	.58	
" 2	.590	.530		.560	.68	
" 3	.713	.588		.650	.65	
" 4	.645	.645	.515	.601	.68	
Sample 5	.667	.621		.644	.53	
" 6	.692	.701		.696	.74	

No values for this frequency are available for comparison as 1350 is not a common test frequency but values at 1024 vps by Sabine are the nearest. The frequency is calculated from measurements on the wave form as there is no tuning fork available for the higher frequencies.

In order to keep the frequency checked after it is once determined, a quarter-wave tube is made as shown in the diagram below.

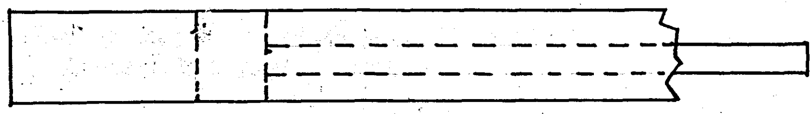


Fig 7

Quarter Wave Tube

The piston is moved back to the first resonance position when the set is first tuned then to check up at any time later on the frequency the tube is held to the ear while the set is sounding and if the set is still on the desired frequency the small tube will be found to be resonating. During this listening process it is best to shield the other ear.

SUMMARY OF DATA SERIES NUMBER 4

100 MA. grid current 1200 vps.

SAMPLE No. 1

Test No. 1

2---- 20. (max.) 9.5---- .25 (min.)
Absorption Coefficient - - - - - - - - - - .296

Test No. 2

2---- 23 (max.) 11---- .40 (min.)
Absorption coefficient - - - - - - - - - - .315

Test No. 3

17---- 24.3 (max.) 11.0---- .15 (min.)
Absorption coefficient - - - - - - - - - - .334

SAMPLE NO. 2

Test No. 1

3.0---- 19.0 (max.) 11.0----.15 (min.)
Absorption coefficient - - - - - - - - - - .285

Test No. 2

3.0---- 19.6 (max.) 11.0---- .10 (min.)
Absorption coefficient - - - - - - - - - - .294

DATA SERIES NO. 4 (Cont.)

Test No. 3 (Sample No. 2)

3.5---- 11.4 (max.) 11.0---- .09(Min)
Absorption Coefficient - - - - - - - - - - - .283

SAMPLE NO. 3

Test No. 1

3.0---- 9.3 (max.) 10.0----.30 (min.)
Absorption coefficient - - - - - - - - - - -.514

Test No. 2

3.0---- 15.2 (max.) 10.0---- .6 (min)
Absorption coefficient - - - - - - - - - - - .532

SAMPLE NO. 4

Test No. 1

3.0---- 8.3 (max.) 10.5---- .2 (min)
Absorption coefficient - - - - - - - - - - - .465

Test No. 2

3.0---- 16.0 (max.) 10.5---- .3 (min)
Absorption coefficient - - - - - - - - - - -- .424

SAMPLE NO. 5

Test No. 1

4---- 17.2 (Max.) 11---- .7 (min)
Absorption coefficient - - - - - - - - - - - .559

Test No. 2

3.5--- 9.7 (Max.) 11.0---- .14 (min)
Absorption coefficient - - - - - - - - - - - .561

SAMPLE NO. 6

Test No. 1

3---- 8.0 (max.) 11.0---- .7 (min.)
Absorption coefficient - - - - - - - - - - - .705

Test No. 2

3---- 12.1 (max.) 11.0---- .1.1 (min)
Absorption coefficient - - - - - - - - - - - .695

SUMMARY OF DATA OF SERIES 4

100 M. A. grid. 1350 Vps.

Test No.	1	2	3	Av	Sabine at 1024
Sample 1	.296	.315	.334	.315	.58
" 2	.235	.294	.283	.287	.68
" 3	.514	.552		.533	.65
" 4	.465	.424		.445	.68
" 5	.559	.561		.560	.46 (.532 Av. of Sabine and three others)
" 6	.705	.695		.700	.74

Samples 5 and 6 are Types B and BB Acousti-Celotex respectively.

The .532 average for sample five is from results by Sabine, Knudsen, Watson and Bureau of Standards. Their values ranged from .460 to .620 for a frequency of 1024 vps.

This set of data represents the greatest variation noted in any of the tests made.

At this frequency however there was unsteadiness in the sound source at all times and a very high overtone persisted and could not be wholly suppressed by common tuning methods. The only explanation offered therefore is that the wave form was modigied by this other tone to such an extent that inconsistent results are noted.

SUMMARY OF DATA SERIES NO. 5

100 M. A. Grid current.   2225 vps.

SAMPLE NO. 1

Test No. 1

.5---- 1.0   5.0---- 18.0

1.0--- .3 (min)   5.5---- 18.8 (max.)

1.5--- .6   6.0---- 17.8

Absorption coefficient - - - - - - - - - - .400

Test No. 2

5.5--- 18.5 (max.)   9.0---- .9 (min)

Absorption Coefficient - - - - - - - - - - .592

Test No. 3.

5.0--- 29.5 (max.)   9.0---- .4 (min)

Absorption Coefficient - - - - - - - - - - .586

Test No. 4.

5.0--- 9.7 (max.)   9.0---- .4 (min)

Absorption coefficient - - - - - - - - - - .561

Test No. 1, was taken before conditions were quite stable. It is noted that deflections are steadier if the grid is not placed in the internode nearest the material. There seems to be more or less turmoil in the air about this point; especially at the minimum reading, for the galvanometer often deflects in the opposite direction showing that the wave is coming in from both sides on compression and the heat is held there about the wire instead of being carried away. This effect is not present in the second internode.

SAMPLE NO. 2

Test No. 1

6.0---- 35.0 (max.)   10.0---- 1.3 (min)

Absorption coefficients - - - - - - - - - - .537

SERIES NO. 5 (Cont.)

Test No. 2 (Sample No. 2)

6.0---- 16.5 (max.) 10.0---- .35 (min)
Absorption coefficient - - - - - - - - .502

Test No. 3

5.5---- 7.5(max.) 10.0---- .25 (min)
Absorption coefficient - - - - - - - - .522

SAMPLE NO. 3

Test No. 1

5.5---- 16.1 (max.) 10.00--- 2.1 (min)
Absorption coefficient --- - - - - - - .789

Test No. 2

5.5---- 22.6 (max.) 10.0---- 3.7 (min)
Absorption coefficient - - - - - - - - .821

Test No. 3

5.5---- 18.3 (max.) 9.5---- 2.3 (min.)
Absorption coefficient - - - - - - - - .778

SAMPLE NO. 4

Test No. 1

5.0---- 21.4 (max.) 9.5---- 1.0 (min.)
Absorption Coefficient - - - - - - - - .586

Test No. 2

5.0---- 7.5 (max.) 9.5---- .25 (min.)
Absorption coefficient - - - - - - - - .522

Test No. 3

5.0---- 28.4 (max.) 9.5---- 1.8 (min.)
Absorption coefficient - - - - - - - - .643

SAMPLE NO. 5

Test No. 1

6.0---- 10.2 (max.) 10.00---- 1.8 (min.)
Absorption coefficient - - - - - - - - .830

SERIES NO? 5 (Cont.)

Test No. 2 (Sample No. 5)

6.0---- 9.5 (max.) 10.0---- 1.3 (min.)
Absorption coefficient - - - - - - - - - - .789

Test No. 3

6.0---- 22.0 (max.) 10.0---- 2.4 (min.)
Absorption coefficient - - - - - - - - - - .739

SAMPLE NO. 6

Test No. 1

5.5---- 13.0 (max.) 10.0---- 1.5 (min).
Absorption coefficient - - - - - - - - - - .756

Test No. 2

5.5---- 23.5 (max.) 10.0---- 2.0 (min).
Absorption coefficient - - - - - - - - - - .699

Test No. 3

6.0---- 18.0 (max.) 10.0---- 1.4 (min.)
Absorption coefficient - - - - - - - - - - .674

SUMMARY OF SERIES No. 5

100 M. A. 2225 vps.

Test No.	1	2	3	Av.	Sabine
Sample 1	.592	.586	.561	.579	.56
" 2	.507	.502	.522	.520	.52
" 3	.789	.821	.778	.796	.63
" 4	.586	.522	.643	.583	.58
" 5	.830	.789	.839	.812	.62 (.79 Bell Labs)
" 6	.760	.699	.674	.709	.77

In this test the tone of the oscillator was very steady and seemed ideally clear and free from overtones. Large minimum deflections were obtained and all indications are that this is the best controlled set of observations that has been made.

A "STANDARD" ABSORBER

It was thought that some sort of check upon the action of the testing circuit could be made by making a surface which should be of a definite absorption coefficient. Accordingly, a disc was turned out from a piece of brass about 1/4 inch thick. This was drilled with enough 1/4 inch holes to equal half of the surface, and placed in the tube backed up by 6 inches of loosely packed cotton; the wooden piston backing up the whole. It has been commonly considered that 4 inches of cotton constitutes perfect absorption. Accordingly it was supposed that this would constitute a .500 absorbing surface. The completed plug was first tested at a frequency of 512 vps.

TEST NO. 1

4---- 5.8 (max) 20.5---- .2 (min)
Absorption coefficient - - - - - - - - - - .529

TEST NO. 2

4---- 3.2 (max) 20.6---- .15 (min)
Absorption coefficient - - - - - - - - - - .577

TEST NO. 3

4---- 11.1 (max.) 21.0---- .50 (min)
Absorption coefficient - - - - - - - - - - .577

TEST NO. 4

4---- 5.8 (max.) 20.5---- .25 (min)
Absorption coefficient - - - - - - - - - - .564

Test No. 3 was very steady and would be taken as being as accurate as is possible to get as the speaker was set close to the tube and all deflections were easily readable.

The same plug was then tested at a frequency of 2225 vps.

TEST NO. 1

4---- .6 (min.) 8---- .7.4 (max.)
Absorption coefficient - - - - - - - - - - .689

TEST NO. 2

8.5---- 5.2 (max.) 4---- .45 (min.)
Absorption coefficient - - - - - - - - .703

TEST NO. 3.

8.5---- 5.0 (max.) 4---- .45 (min).
Absorption coefficient - - - - - - - - .710

The results show that there is some other effect than fine reflection and absorption in the case of the higher frequencies. The results at 512 vps are near enough 50% so that the variation may be attributed to errors in drilling out the surface -- that is the holes may have reamed out slightly thus each one adding a little absorbing area more than the 1/4 inch hole expected from the drill and the cotton evidently is more absorbent at the higher frequencies.

GENERAL SUMMARY OF RESULTS

Material	512 vps		1350 vps		2225 vps	
	T	R	T	R 1024	T	R 2048
Sample 1	.312	.33	.41	.58	.58	.56
Sample 2	.427	.50	.56	.68	.52	.52
Sample 3	.444	.38	.65	.65	.79	.63
Sample 4	.53	.59	.60	.68	.58	.58
Sample 5	.41	.40	.64	.46#	.78	.62
Sample 6	.50	.70	.70	.74	.71	.77

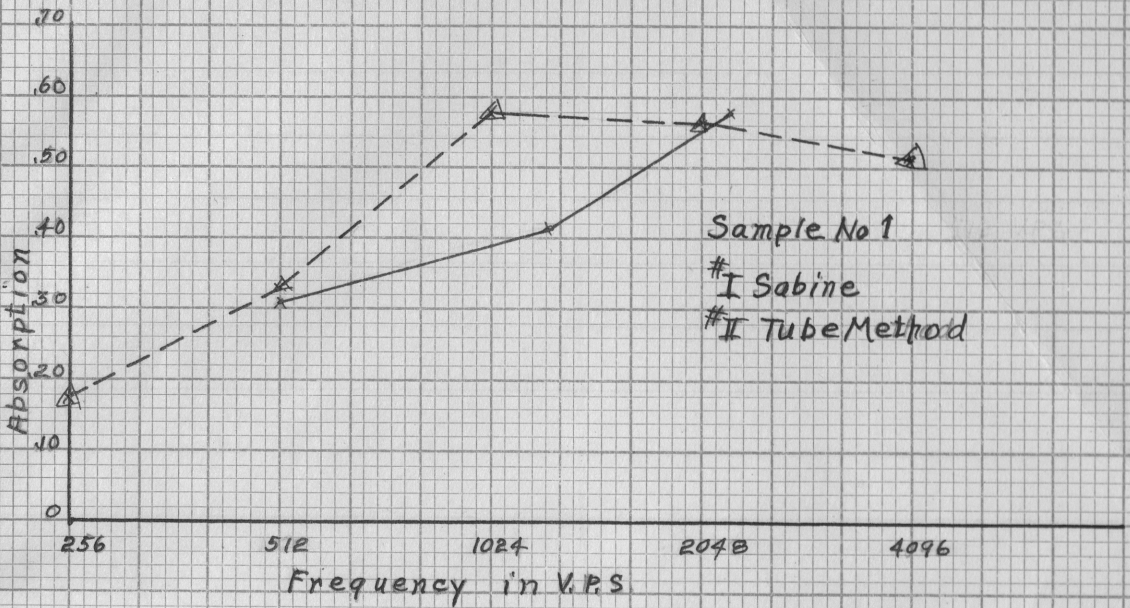
Column "T" gives values by tube method.

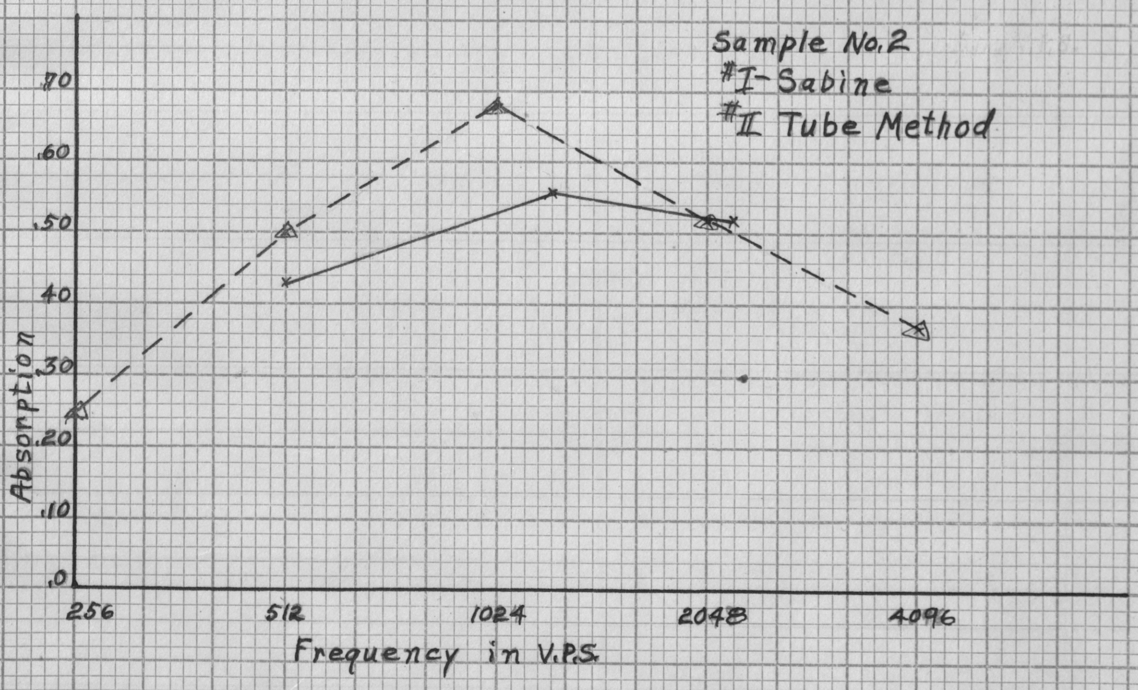
Column "R" gives values by reverberation methods.

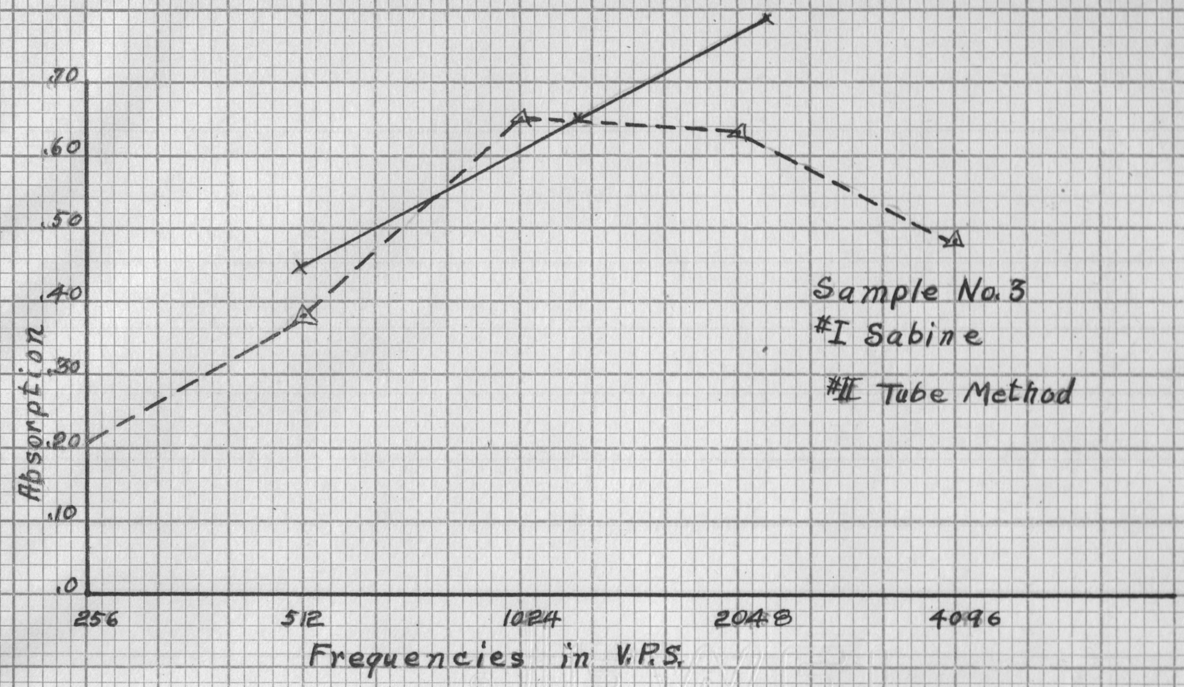
the Bureau of Standards gives this value as .62 while the average by Sabine several others is .532.

VARIATIONS OF ABSORPTION COEFFICIENTS
WITH FREQUENCY OF SOUND

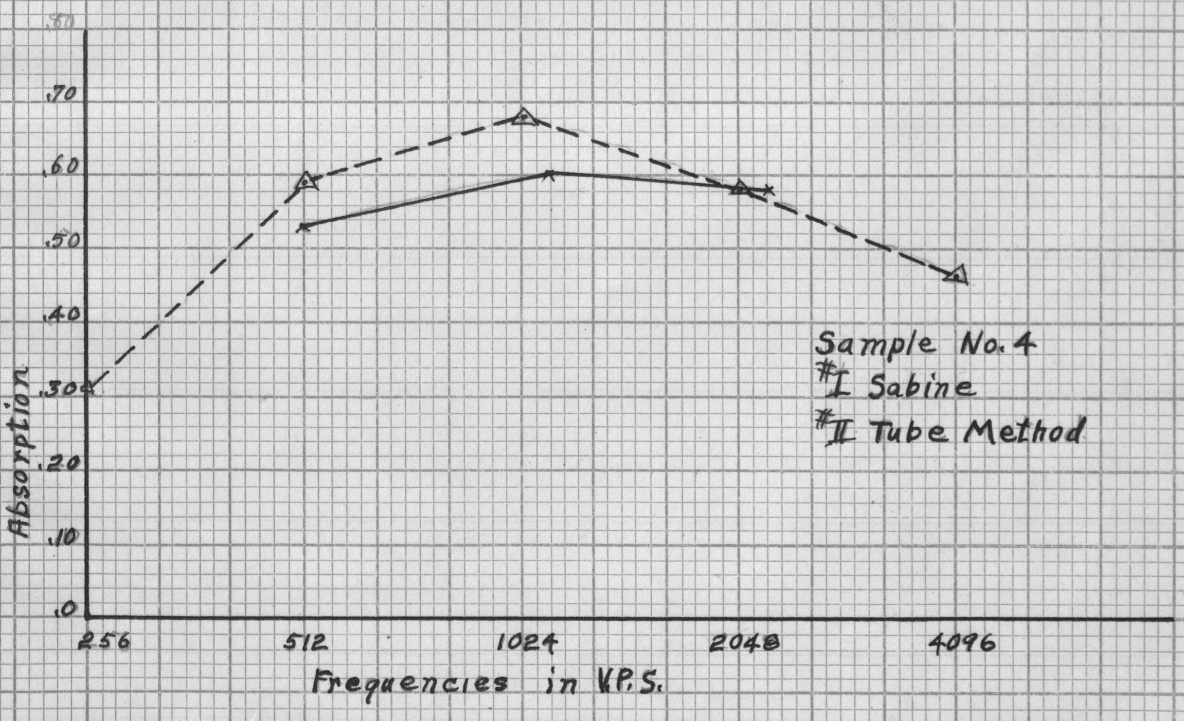
The following graphs show the effect of variation of frequency upon the values found for absorption coefficients together with a comparison of those values found by Sabine or else composite values obtained from results by Sabine, Knudsen, Watson, Bu. of Standards and data from installations by the Celotex and Johns*Manville Corporations.


.70
.60
.50
.40
.30
.20
.10
0
Absorption
256
512
1024
2048
4096
Frequency in V.P.S
Sample No 1
#I Sabine
#II Tube Method

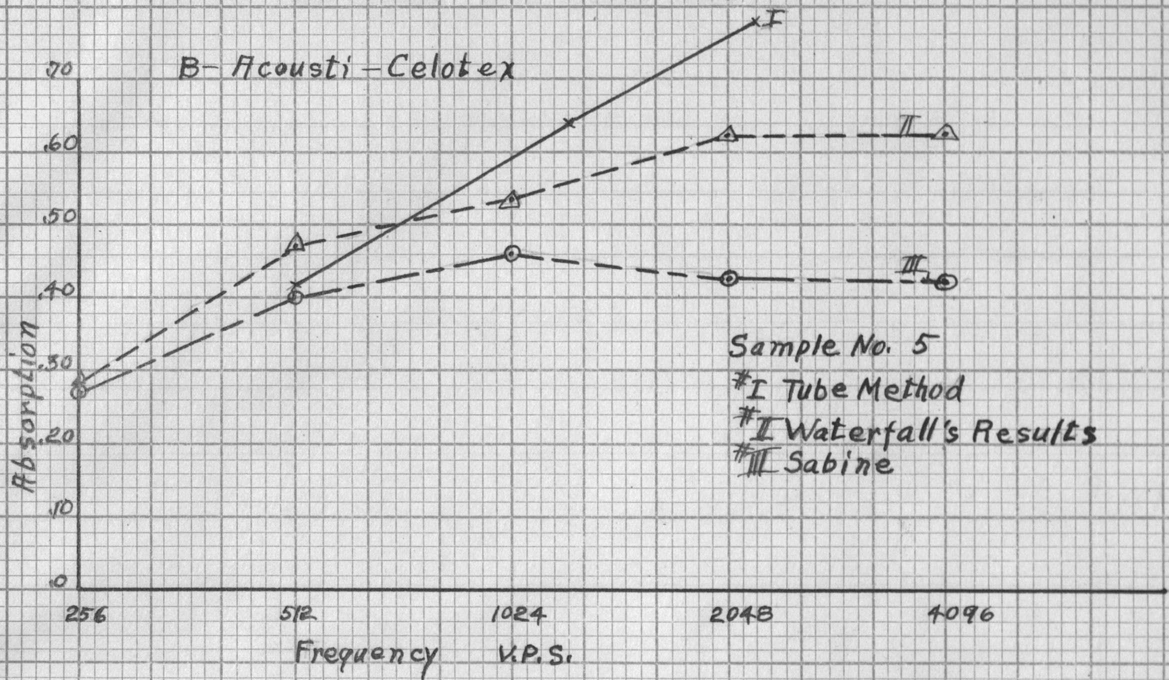

.70
.60
.50
40
30
.20
.10
.0
Absorption
256
512
1024
2048
4096
Frequency in V.P.S.
Sample No.2
#I-Sabine
#II Tube Method

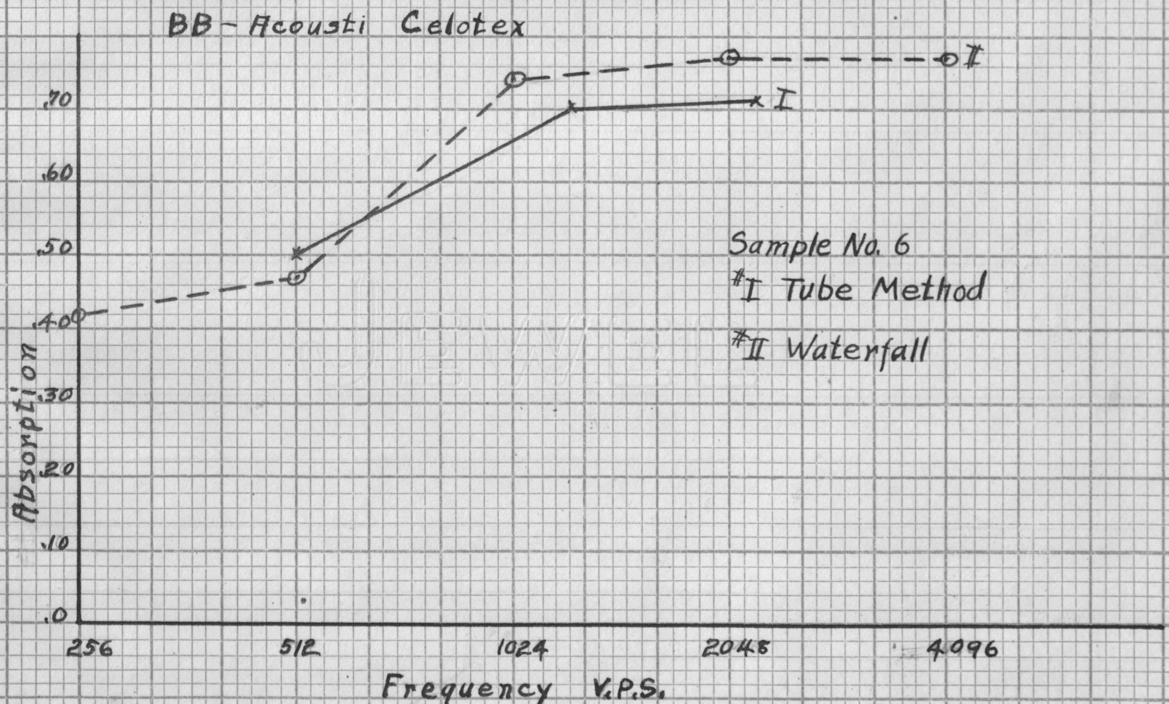


Sample No. 3
#I Sabine
#II Tube Method
Absorption
Frequencies in V.P.S.



Sample No. 4
#I Sabine
#II Tube Method
Absorption
Frequencies in V.P.S.


B- Acousti - Celotex
Absorption
.70
.60
.50
.40
.30
.20
.10
.0
256
512
1024
2048
4096
Frequency V.P.S.
I
II
III
Sample No. 5
#I Tube Method
#II Waterfall's Results
#III Sabine


BB - Acousti Celotex
Absorption
.70
.60
.50
.40
.30
.20
.10
.0
256
512
1024
2048
4096
Frequency V.P.S.
I
II
Sample No. 6
#I Tube Method
#II Waterfall

CONCLUSIONS

1. The tube method in which the hot wire anemometer is used to measure sound absorption coefficients will give results that check favorably with those obtained by the reverberation method when used under favorable conditions. That is, if the source of sound gives a pure note and the batteries used are in good condition, thus making for steady current conditions.

2. Great variation from reverberation values at the 1350 frequency. This is probably due to the fact that at this frequency the oscillator note was noticeably impure. There was one overtone of very high pitch that persisted throughout. The exact effect of these overtones upon the deflections of the galvanometer is impossible to predict but they would certainly modify the wave form to some extent; and any modification at all would introduce errors.

3. The "virtual reflecting surface" within a given material might be at a different depth for different frequencies. This must be true in those materials which show marked differences in absorption coefficients for different frequencies. This is the case in many materials and so the overtones, being different frequencies, will originate different reflected waves from different planes in the material so that the whole wave system will have a more or less complicated phase relation when they combine out in the resonating tube. In general the minimum readings will be made larger which would result in high calculated values of absorption coefficients. Any material, however, that shows little change in absorption coefficients with frequency changes should give more comparable results by the two methods. This will be seen to be true to an appreciable extent in comparing Sabines' results with the average in this test

in the cases of samples 1, 2, and 4.

4. The tube method demands a note free from overtones.

5. The tube arrangement used in this test requires the minimum of apparatus and is very simple to adjust and use.

6. Results obtained in this test indicate a much closer agreement between the tube and reverberation methods than that predicted by E.T.Paris' theoretical curve shown in Fig. 1.

7. Better results would be obtained if the whole set were in a room lined with sound absorbing material; especially at the higher frequencies for with them it was possible to note the formation of standing waves in the room.

8. An exact method of tuning the set to unison with a tuning fork is found.

9. Though the tube method occasionally shows wide variations from results obtained by the reverberation methods yet the variation is little greater in most cases that may be found among users of the reverberation methods themselves. For instance, the results on Type B Acousti-Celotex obtained by Sabine, Watson, Knudsen and Bureau of Standards range from .46 to .62 at 1024 vps. while Watson and Sabine differ by as much as 17% on their tests as reported in the bulletin "Less Noise -- Better Hearing."

10. The best source of sound for this work would be an electrically driven tuning fork for each frequency. Sabine [1] tells of trying a loud speaker unit as a source of sound in his reverberation chamber and, tho an extensive filter system was used, there was still trouble from overtones. He uses organ pipes as the sound source in his work.

[1] Jour. Franklin Institute Mar. 1929.

11. The principal source of error in taking readings is in reading the minimum deflection.

12. The greatest source of error in the final results considering every influence is probably the impure sound wave from the oscillator. Another factor which should be considered is the position of the resonator tube in the room in case a pronounced system of standing waves in the room was present. However, since the covering of the open end of the tube with cotton brings about no appreciable change in final results the indication is that the formation of a standing wave system in the room has little effect.

The writer desires to thank Dr. C. V. Kent and Dr. F. E. Kester for their many valuable suggestions and general cooperation during this investigation.

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