THE EFFECT OF SPACING AND AREA OF ABSORBER ON THE ABSORPTION OF ACOUSTICAL MATERIALS

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INTRODUCTION

In an excellent paper by Edgar Buckingham[1] the theory of decay of sound in reverberant rooms is derived, and the theory underlying measurements of absorption coefficients of materials is discussed at some length. Other similar derivations are due to Jaeger[2], Franklin[3], Eckhardt[4], and the pioneer work of W. C. Sabine[5], who founded the science of Architectural Acoustics.

The formula for decay of sound in a room, as developed by Buckingham is

$$aS = \frac{4V}{Ct} \log \frac{Do}{D} \qquad (1)$$

where S = area of the surface exposed to sound,

aS = absorbing power of the room,

D = volume density of the sound energy at time, t,

Do = the steady (initial value of D),

V = volume of the room,

C = velocity of sound at the temperature of the room,

a = coefficient of absorption.

If we let t_1 be the duration of audibility of the residual sound when $D_0 = D_1$, and t_2 the corresponding time when $D_0 = D_2$, the final value of D being that of minimum audibility, it is shown by Buckingham that D_1/D_2 may be set equal to E_1/E_2 where this latter quantity is the ratio of the powers of two known sources. The equation then reduces to

$$aS = \frac{4V}{C} \log_e \frac{E_1}{E_2}\left(\frac{1}{t_1 - t_2}\right) \qquad (2)$$

The theory discussed applies to the ear method of measuring reverberation time, using the threshold of the ear as a standard fixed reference point. In order to adapt the theory to instrumental practice it is necessary only to have some means of determining the exact time

* This paper is part of a thesis for a Ph.D. degree at Indiana University in the Department of Physics, 1932.

[1] Edgar Buckingham, U. S. Bureau of Standards, Scientific Paper No. 506, May 26, 1925.

[2] C. Jaeger, Wiener Sitz. Ber., Vol. CXX, 2a p. 613, 1911.

[3] W. S. Franklin, Physical Review, Vol. 10, p. 372, 1903.

[4] E. A. Eckhardt, Journal Franklin Institute, June, 1923.

[5] W. C. Sabine, "Collected Papers," Harvard University Press, 1922.

"Proc. Ind. Acad. Sci., vol. 42, 1932 (1933)."

when the sound decay passes a certain point corresponding to E_1 and some later time corresponding to E_2. If for example a sound has been maintained in the empty room for a time sufficiently long for equilibrium to have been established, and it is then suddenly cut off, and if it requires a time t_1 for the sound intensity to pass the level E_1, and a time t_2 for it to pass the level E_2, the value for a_1 (the average coefficient of absorption of the walls, floor and ceiling of the room) is given by

$$a_1S_1 = \frac{4V \times 2.3 \log_{10} (E_1/E_2)}{C(t_2-t_1)} \qquad (3)$$

When absorbing material of area S_2 and coefficient a_2 is added, equation (3) becomes

$$a_1S_1 + a_2S_2 = \frac{4V \times 2.3 \log_{10} (E_1/E_2)}{C(t_2-t_1)} \qquad (4)$$

The reverberation method has been used by P. E. Sabine[6], Watson[7], Chrisler and Snyder[8], and others to measure the coefficient of absorption of standard materials. Various kinds of instrumental methods have been devised, notably that of Chrisler and Snyder in which oscillograph records of decay curves were made. Chrisler and Snyder describe also a more simplified apparatus which gives experimental values in good agreement with oscillograph records. These instrumental methods of measuring absorption coefficients eliminate the ear as a factor of probable error, but in some instances the apparatus is quite complex, and it might appear that other sources of possible error are introduced which would compensate for the possible error eliminated by discarding the ear as a device.

In making measurements of absorption coefficients it is customary to use large blocks of from 25 square feet to 100 square feet of material spread in a compact area on the floor of the room, since it has been demonstrated by many observers that the position of the material in the room does not materially affect results except in unusual circumstances not usually met in test rooms. P. E. Sabine found, however, that in the case of one certain material tested by him, an appreciable area effect was noted, smaller areas giving abnormally large measured values for absorption coefficients. This effect has been reported by Parkinson[9] also. In the latter case, however, Parkinson observes that the effect is not present in the case of frequencies 256 or 128 for the one material which he studied in detail.

Since the area effects described by Sabine and Parkinson did not agree in every particular, especially in the case of the lower frequencies, and since it was felt that some theoretical significance might be attached to the effect especially as regards wave length, it was thought advisable to investigate the phenomenon somewhat thoroughly, using several kinds of materials and different test rooms as well as different methods.

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[6] P. E. Sabine, Journal Franklin Inst., Vol. 207, No. 3, March, 1929.

[7] F. P. Watson, Univ. Illinois, Eng. Ex. Sta. Press, Bull. 172, Nov., 1927.

[8] Chrisler and Snyder, Bur. Stand. Jour. Research, Vol. 5, Oct., 1930.

[9] John S. Parkinson, Jour. Acoustical Soc. of Am., Vol. 11, July 1, 1930.

Apparatus and Procedure

Two reverberation rooms were available, in one of which it was decided to use a simplified instrumental method devised by the author[10] and in the other room the ear method. A check on the results was thus afforded. Three different types of commercial absorbing material were used in the experiment (B. B. Celotex, Balsam Wool, and Sanacoustic Tile). Standard metal organ pipes of frequencies 128, 256, 512, and 1024 were used in each room. These pipes were blown by air under a constant pressure of 3 cm. of mercury. The temperature in each of the rooms was kept as near 24° C. as possible during the investigation and the variation was not more than one degree centigrade. The volume of the room in which the instrumental method was used was 2860 cubic feet with an exposed area of 1242 square feet. The other room had a volume of 3876 cubic feet and an area of 1600 square feet. Both were basement rooms with concrete floors and plastered walls and ceilings. The room in which the instrumental procedure was used had one heavily insulated door and no windows. The other room had a single window and two heavy iron doors.

The instrumental method which was employed is essentially as follows:

Sound is produced in a reverberation room by blowing a metal organ pipe of standard make with compressed air at constant pressure as measured by a manometer. After the sound has been maintained for a time, considerably longer than the reverberation time of the room, the air is suddenly cut off and a sound decay curve is made from points determined by the recording apparatus herein described.

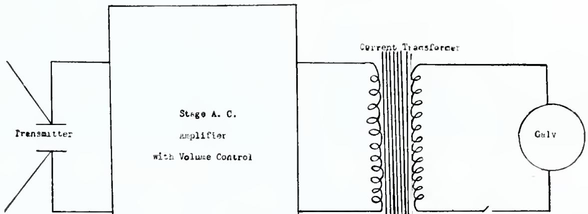

Figure 1.—Diagram of Recording Apparatus

The recording apparatus consists of a Jenkins and Adair condenser microphone[11], the output of which is amplified by a four stage transformer coupled A. C. amplifier as illustrated in the accompanying diagram, Fig. 1. The output of this amplifier is fed through a volume control potentiometer into a step down current transformer from which it passes to a thermo-couple galvanometer, which reads directly in arbitrary energy units. The observer and all the recording apparatus except the microphone are in a room adjoining the reverberation room. (See also Figures A, B, C and D).

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[10] J. F. Mackell, Science, Aug. 28, 1931.

[11] An ordinary double button microphone may be substituted for the condenser type, thus eliminating special batteries. The outfit then becomes all A. C. and quite portable.

In making a determination of sound absorption, a metronome is set vibrating with a certain period. In coincidence with a given click of the metronome the air is cut off by a valve. At some subsequent click (say the second or third) the key, K, is closed, which results in a deflection of the galvanometer. The process is repeated for other settings of the metronome, and of course several readings are taken for each setting to insure a representative average. If, now, the apparatus be calibrated to

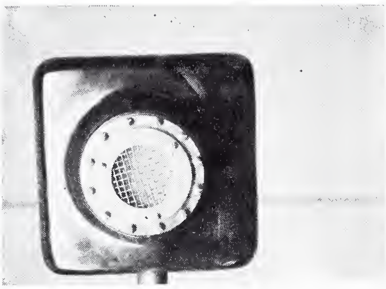

Fig. A.

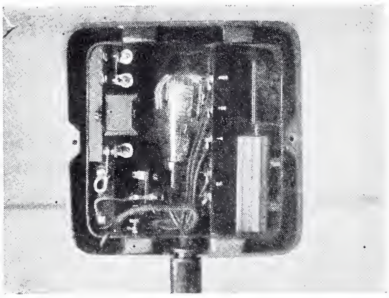

Fig. B.

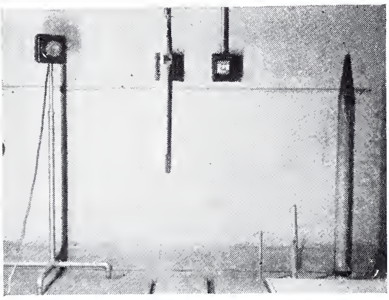

Fig. C.

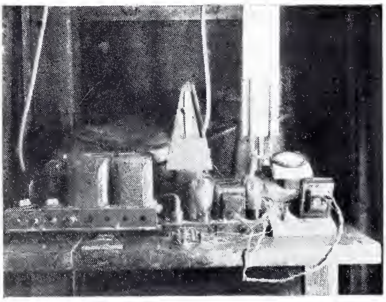

Fig. D.

read in decibels of decay and the output volume control is set accordingly, it is immediately apparent that the values for coefficient of absorption may be obtained from the slope of the curves obtained by plotting values of $\log_{10}E$ against corresponding values of t. The method of calibration will be described later in this paper.

Figure 2 is a set of curves plotted from data taken as indicated. These curves show the logarithmic nature of the decay quite as well as similar curves obtained by more complicated recording devices. The values of absorption coefficients obtained in this manner have been checked against values for the same kinds of materials found by observers in other laboratories and against values found by the ear method in another room at Indiana University. The agreement is very good in both cases.

It will be noted that the ear is still used in this instrumental procedure, but a coincidence determination is substituted for a duration of time measurement in the older method. It is obvious that coincidence determinations are capable of a very high degree of accuracy, a conclusion which is borne out by the fact that the points thus determined fall approximately on a logarithmic decay curve.

It was intended at first to make an automatic device to cut off the air, and, at some subsequent time to close the key, but measurements made in the manner described seem to indicate that little or no improve-

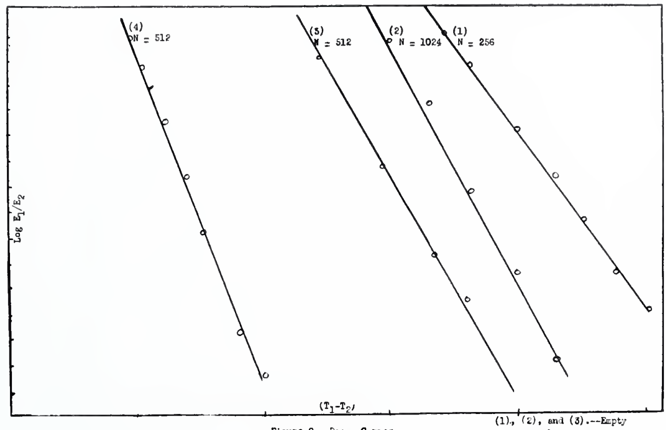

Figure 2.--Decay Curves

(1), (2), and (3).--Empty room values
(4).--Room treated with 30 square feet of material

ment would thus be afforded, probably not enough to warrant the added complication.

It will be noted that thus far the values for E are merely in arbitrary units, and, while the logarithmic nature of the decay curves indicates that the instrument is functioning properly, yet, in order that absolute values for coefficient of absorption of materials may be obtained, it is necessary to calibrate the instrument to read in standard units of decay.

From a study of the decay curves in Figure 2 it is obvious that if the curves be produced to the right and down until they cut the time axis at a point corresponding to the reverberation time of the room for that frequency and respective room condition, we will then be at the threshold value for E.

It was decided therefore to determine by a great number of ear values the average reverberation time of the empty room for an organ pipe of frequency 512 vibrations per second blown at the established pressure. This was done by using a set of head phones in the output circuit of the amplifier just described. About five hundred readings were taken on different days over a period of a week. The average value for the room at this frequency came out to be 4.26 seconds.

The curve for the 512 pipe shown in Figure 2 was then drawn on a suitable scale and produced until it cut the time axis at 4.26 seconds, corresponding to 60 decibels of decay when the output of the amplifier was set so that the slope of the curve was 6/4.26. This was done by trial and error until a satisfactory setting was obtained. Since the ordinates represent values of Log_{10}E, we may now establish the zero ordinate at the threshold value and since reverberation time is defined as the time required for the sound to decay 60 decibels we may establish the 60 decibel point on the vertical axis by producing the curve for the 512 pipe till it cuts the Log E axis. Other curves for the empty room and other pipes should also converge at this point, and the points where they cut the time axis at threshold value for E should give their respective reverberation times. Figure 3 shows how these curves were produced.

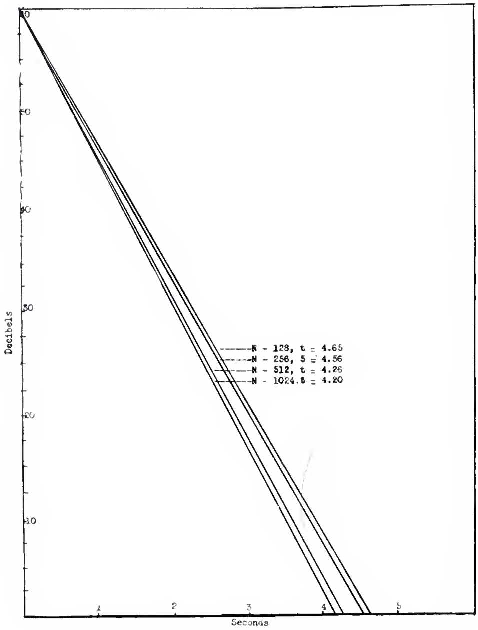

Figure 3.--Calibration Curves for Empty Room

The galvanometer scale was thus calibrated to read in decibels above threshold value as follows:

100 on galvanometer scale = 38 Db.
10 on galvanometer scale = 28 Db.
1 on galvanometer scale = 18 Db.

In a similar manner the values for the reverberation times for the other pipes were found to be as follows:

For 128 pipe t = 4.65 sec.
256 pipe t = 4.56 sec.
512 pipe t = 4.26 sec.
1024 pipe t = 4.20 sec.

It is thus seen that aside from the determination of the reverberation time of the empty room for the 512 pipe, all the subsequent values were instrumental. It might be added that a check was made at frequent intervals to establish the fact that the tube constants and other instrumental factors did not vary. This was done by resetting the output of the amplifier to make the decay curve for the 512 pipe in the empty room check with the original curve.

SPACING AND AREA EFFECTS

As was pointed out in the introduction, the principal purpose of this research was to investigate spacing and area effects upon measured values for coefficients of absorption of materials.

Enough has been said in the preceding paragraphs to indicate the general instrumental method of procedure, and, so far as the ear-reverberation method is concerned, the process of taking data by this method is so generally understood that no explanation is necessary. The latter method was resorted to merely to check results obtained by the instrumental method, and, while different rooms were used for each method, yet conditions as regards temperature, pressure, etc. in the two rooms were made as nearly identical as possible.

In order that a thorough test might be made of area and spacing effects, three kinds of standard absorbing materials were selected, namely B. B. Celotex, Sanacoustic Tile, and Balsam Wool in metal screen containers. The thickness of each material was one inch.

The experimental procedure consisted of first taking a set of readings for the empty room for a given frequency pipe; when this was done a large area of one of the types of absorbing material was placed on the floor of the test room in a compact block and another set of readings was taken; then the material which consisted of small separate blocks of various sizes was spaced in checkerboard fashion leaving open spaces of a certain size, and readings were again taken. Again the size and shape of the blocks, as well as the size and shape of the spaces, were varied and the experiment repeated. The procedure was repeated for each of the frequencies used and for each of the three kinds of materials. The whole experiment was repeated several times for all materials and for all frequencies over a period of about three months, and the data submitted are in the main averages of many individual readings.

The organ pipes were suspended from the ceiling by a long cord, so that they could be set swinging in pendular fashion while readings were being taken. This was done to break up any sound pattern which might be present. It was found, however, that this pattern effect was negligible in so far as it affected results in the present procedure. This was true because no readings were taken until about one second after the sound was cut off, and by that time whatever pattern had been in the room had long since collapsed. In fact our measurements indicate that the pattern collapses almost immediately after the source is cut off; so it appears that the very elaborate devices used by some observers to prevent the formation of patterns in a test room are needless so far as reverberation time measurements are concerned. This is particularly true, however, when the method used is of an instrumental type, such as the one used in this experiment, since the pattern has had time to collapse before the first reading on the instrument is taken. In the case of the ear method, in which the ear of the observer is the sole judge of reverberation time, a psychological factor may enter, so that the presence of a pattern at the time when the decay sets in may to some extent modify results, but observations made in this experiment with the ear method indicate that the influence of patterns upon results is not of major importance.

Since the edges of absorbing materials when the materials are divided into separate blocks would add materially to the area of absorbing surface, the edges in the present case were covered with metal. In the case of one of the materials used a special type of metal container was furnished by the manufacturer and in the other two cases galvanized iron containers were made to fit around the blocks. Therefore none of the observed increment in absorption due to spacing may be attributed to an edge effect.

RESULTS AND DISCUSSION

An inspection of Tables I, II, and III will show that the spacing effect is quite decided in every instance, even in the case of the lower frequencies, for all the materials. In the case of the lower frequencies the effects are of lower order of magnitude numerically but of as high order from the standpoint of per cent of increase.

Judging from the data submitted there seems to be a relation between wave length and the spacing necessary to give maximum effect. This is especially noticeable in the case of frequencies 128 and 256 in which cases the effect was not noticeable until spacing of a half wave length prevailed. This may partially account for the fact that Parkinson did not get the effect for these frequencies.

P. E. Sabine attempted to explain this spacing and area effect from the standpoint of diffraction and screening. It occurred to us, however, that an effect so large as this should be investigated further in an effort to ascertain if any other factors might contribute to its existence.

An auxiliary experiment was therefore attempted in an effort to explain the effect. A small block of the material was placed on the floor of the test room, and the microphone was set at a distance of 10 feet from the material and at a height of about 6 inches from the floor. The organ pipe was blown for a few seconds and then shut off. After an interval of about 1.5 seconds a reading was taken. This procedure was repeated several times; the microphone was gradually moved up toward the block of material, readings being taken at intervals of about 1 foot. Finally the microphone was placed upon the block of material and readings taken. The experiment was repeated with the microphone in a plane 1 foot from the floor, 2 feet from the floor, and 3 and 4 feet from the floor. This procedure was repeated for all the pipes used and for each kind of material and for blocks of areas from 4 square feet to 9 square feet. Some results of this experiment are shown in Table IV.

Since the values recorded by the microphone in the cases just mentioned are values for sound pressures in horizontal planes only, it was thought advisable to repeat the experiment by setting the absorbing material against a wall and attempting to get similar values in vertical planes. This was done in a manner exactly similar to that followed in the former case and some values obtained are recorded in Table V.

Experimental evidence presented indicates that something similar to the energy transfer in an electric or magnetic field is taking place here, and that a theory analogous to Maxwell's Theory of Stresses and Strains in Faraday tubes of induction will explain the phenomenon.

Let us assume that the sound energy density in the room at points far away from the absorbing medium is uniform and that the stream lines in all directions are equidistant. In other words we have a uniform field of three dimensions. For simplicity let us consider the stream lines from ceiling to floor only. At points far away from the absorber, the vertical field is uniform, but as we approach the absorbing slab the stream lines converge due to the fact that sound is being absorbed by the medium and energy will thus flow into the absorber in greater quantities due to a resultant force in that direction. In order that equilibrium may be again restored, it is necessary to assume with Maxwell that a stress is applied on the lateral faces of the tubes of force in such a way that the upward component of this force will be just equal and opposite to the force causing energy to flow to the absorber. A simple derivation due to Starling[12] shows that the pressure necessary to produce equilibrium is $2\pi D^2$ where D is the displacement or the number of tubes per square centimeter.

The regions in the vicinity of an absorbing medium should thus be somewhat devoid of stream lines and should show a low energy density or sound pressure measurement as experiment indicates. The points immediately above or in front of an absorber should also show low values for energy density or sound pressure. This is also true by experiment. The values for the rest of the room should be somewhat higher to maintain the flow of energy to the absorber and this is also indicated by experiment.

It thus appears that if small areas of sound absorbing material be spaced at intervals, a greater absorbing power might be expected than if the material were grouped in a compact area. Theory indicates that this effect should increase as the absorbing units are made smaller and as the spacing increases. However, since the absorption coefficients of materials for the sounds of longer wave length are quite small, a much larger spacing should be considered necessary to achieve this.

It is undoubtedly true that diffraction effects are present also, since an arrangement of material such as we describe approximates a reflection grating in the case of physical optics. We have the sound energy thus diffracted laterally and as a consequence a greater amount will be absorbed in a given time by the absorbing material. Since the diffraction effect is a function of wave length and grating spacing, we may expect results similar to those we found in this experiment. It is improbable, however that all this observed effect may be attributed to diffraction; it appears more likely that the phenomenon is due to a combination of the two effects described above.

CONCLUSIONS

The experimental evidence presented in this paper as regards spacing effects in the measured values for coefficients of sound absorption might result in a few conclusions as follows:

[12] S. S. Starling, "Electricity and Magnetism," pp. 133-136.

1. Measured values for coefficients of absorption are very materially dependent upon the size of the sample being tested and upon the spacing between the several units.

2. The measured values increase with the size of the spacing in a manner which depends somewhat upon the wave length of the sound being measured. In general no great increase is perceptible after the spacing has reached ½ wave length of the sound concerned.

3. The spacing effect is present for all wave lengths studied and the order of magnitude of the per cent of increase is as great for the lower frequencies as for the higher.

4. A decided saving in the amount of absorbing material necessary to improve the acoustics of a room might be effected by properly planning the spacing of materials.

5. The spacing effect is not a function of the material since the three materials used are quite dissimilar in composition and yet the effects are practically the same for each material.

6. Subsidiary tests, placing the microphone on the floor and on a stand near the wall and varying its position relative to blocks of absorbing material, serve to substantiate the theory that the presence of absorbing material affects the region adjacent in that the material becomes a sink for sound energy which would have been incident upon the region affected had the absorbing material not been present. This fact together with the well known increment expected due to diffraction may account for the phenomenon observed.

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TABLE 1.

Data for 25 Square Feet of Balsam Wool by Two Methods. (Subscript 1 Indicates Instrumental Method in One Room and Subscript 2 Indicates Ear Method in Another Room)

	Absorption Coefficient at Frequency							
	128_1	128_2	256_1	256_2	512_1	512_2	1024_1	1024_2
25 sq. ft. Compact, No Spacing..	.14	.19	.22	.28	.60	.66	.60	.72
1 x 1 spaced 6 inches...........	.12	.17	.21	.29	.67	.67	.72	.79
1 x 1 spaced 1 foot..............	.12	.17	.24	.29	.74	.78	.78	.79
1 x 1 spaced 2 feet..............	.13	.18	.38	.41	.78	.82	.81	.84
1 x 1 spaced 3 feet..............	.15	.17	.41	.44	.80	.82	.81	.92
1 x 1 spaced 4 feet..............	.21	.24	.41	.47	.81	.81	.81	.97
2 x 2 spaced 6 inches...........	.11	.15	.25	.32	.62	.64	.71	.74
2 x 2 spaced 1 foot..............	.12	.14	.30	.32	.77	.79	.82	.84
2 x 2 spaced 2 feet..............	.11	.14	.41	.47	.82	.84	.81	.85
2 x 2 spaced 3 feet..............	.14	.16	.41	.46	.84	.86	.81	.88
2 x 2 spaced 4 feet..............	.19	.21	.44	.48	.81	.84	.80	.92
2½ x 2½ spaced 6 inches.......	.13	.20	.27	.32	.65	.74	.73	.84
2½ x 2½ spaced 1 foot..........	.12	.19	.27	.33	.87	.84	.81	1.05
2½ x 2½ spaced 2 feet..........	.16	.19	.39	.44	.87	.84	.80	1.05
2½ x 2½ spaced 3 feet..........	.17	.17	.40	.44	.86	.88	.82	1.00
2½ x 2½ spaced 4 feet..........	.22	.23	.41	.40	.88	.86	.80	1.04

TABLE 2.

Data for 20 Square Feet of B B Celotex by Two Methods. (Subscript 1 Indicates Instrumental Method in One Room and Subscript 2 Indicates Ear Method in Another Room)

	Absorption Coefficient at Frequency							
	128_1	128_2	256_1	256_2	512_1	512_2	1024_1	1024_2
20 sq. ft. Compact, No Spacing.	.12	.14	.26	.30	.65	.72	.65	.72
1 x 1 spaced 6 inches...........	.11	.12	.27	.31	.66	.71	.80	.92
1 x 1 spaced 1 foot..............	.13	.15	.27	.32	.78	.89	.82	.91
1 x 1 spaced 2 feet..............	.14	.15	.44	.47	.79	.99	.83	.94
1 x 1 spaced 3 feet..............	.15	.17	.46	.47	.82	1.04	.80	1.01
1 x 1 spaced 4 feet..............	.18	.21	.45	.50	.81	1.02	.82	1.03
2 x 1 spaced 6 inches...........	.11	.15	.27	.32	.67	.71	.78	.82
2 x 1 spaced 1 foot..............	.11	.14	.28	.29	.70	.70	.82	.84
2 x 1 spaced 2 feet..............	.12	.16	.41	.44	.82	.81	.84	.98
2 x 1 spaced 3 feet..............	.14	.17	.45	.47	.81	.93	.84	.99
2 x 1 spaced 4 feet..............	.19	.20	.48	.47	.84	.88	.84	.98
2 x 2 spaced 6 inches...........	.12	.16	.27	.34	.73	.81	.78	.80
2 x 2 spaced 1 foot..............	.11	.17	.30	.32	.86	1.00	.83	1.00
2 x 2 spaced 2 feet..............	.14	.17	.45	.49	.82	.97	.87	1.01
2 x 2 spaced 3 feet..............	.15	.18	.47	.49	.83	1.02	.86	1.02
2 x 2 spaced 4 feet..............	.23	.27	.51	.50	.85	1.03	.85	1.02

TABLE 3.

Data for 30 Square Feet of Sanacoustic Tile by Two Methods. (Subscript 1 Indicates Instrumental Method in One Room and Subscript 2 Indicates Ear Method in Another Room)

	Absorption Coefficient at Frequency							
	128_1	128_2	256_1	256_2	512_1	512_2	1024_1	1024_2
30 sq. ft. Compact, No Spacing..	.13	.15	.30	.27	.67	.69	.63	.63
1 x 1 spaced 6 inches............	.13	.16	.31	.30	.65	.69	.74	.78
1 x 1 spaced 1 foot..............	.12	.14	.30	.31	.86	.96	.83	.88
1 x 1 spaced 2 feet..............	.11	.15	.43	.45	.85	.92	.82	.86
1 x 1 spaced 3 feet..............	.14	.17	.45	.48	.84	.90	.81	.87
1 x 1 spaced 4 feet..............	.19	.21	.44	.50	.82	.88	.81	.87
2 x 2 spaced 6 inches............	.12	.14	.27	.31	.63	.67	.74	.67
2 x 2 spaced 1 foot..............	.13	.14	.31	.33	.77	.81	.72	.82
2 x 2 spaced 2 feet..............	.12	.16	.38	.39	.78	.84	.81	.82
2 x 2 spaced 3 feet..............	.13	.15	.40	.44	.78	.84	.81	.82
2 x 2 spaced 4 feet..............	.20	.20	.41	.43	.82	.86	.80	.84
6 x 1 spaced 6 inches............	.14	.18	.32	.35	.65	.72	.63	.69
6 x 1 spaced 1 foot..............	.12	.17	.37	.35	.79	.78	.78	.88
6 x 1 spaced 2 feet..............	.12	.19	.43	.36	.90	.89	.93	.90
6 x 1 spaced 3 feet..............	.12	.15	.43	.37	.88	.86	.92	.96
6 x 1 spaced 4 feet..............	.18	.20	.40	.37	.86	.82	.90	.93

TABLE 4.

Data Showing Relation between Intensity and Proximity to Material
(t = 1.1 seconds after cut-off)

N = 512

Empty Room E = 90

2½ x 2½ block Balsam Wool on floor. Microphone stationary 4 inches above floor.

Microphone stationary, material being moved		Material stationary, microphone being moved	
6 feet from microphone.......	E = 60	6 feet from material..........	E = 60
5 feet from microphone.......	E = 55	5 feet from material..........	E = 60
4 feet from microphone.......	E = 56	4 feet from material..........	E = 60
3 feet from microphone.......	E = 55	3 feet from material..........	E = 60
2 feet from microphone.......	E = 50	2 feet from material..........	E = 50
1 foot from microphone.......	E = 50	1 foot from material..........	E = 45
6 inches from microphone.....	E = 30	6 inches from material........	E = 25
3 inches from microphone.....	E = 20	3 inches from material........	E = 20
On material anywhere........	E = 40	On material anywhere........	E = 40

TABLE 5.

Data Showing Relation between Intensity and Proximity to Material
(t = 1.6 seconds after cut-off)

N = 512

Empty Room E = 90

2 x 2 block Celotex in vertical position against wall. Microphone on stand one foot high in vertical position and capable of rotation on a vertical axis 6 inches from wall.

Transmitter vibrating perpendicular to wall		Transmitter vibrating parallel to wall	
8 feet from material	E = 65	8 feet from material	E = 70
7 feet from material	E = 60	7 feet from material	E = 65
6 feet from material	E = 60	6 feet from material	E = 60
5 feet from material	E = 60	5 feet from material	E = 60
4 feet from material	E = 55	4 feet from material	E = 60
3 feet from material	E = 55	3 feet from material	E = 55
2 feet from material	E = 50	2 feet from material	E = 55
1 foot from material	E = 50	1 foot from material	E = 45
6 inches from material	E = 40	6 inches from material	E = 35
3 inches from material	E = 35	3 inches from material	E = 35
In front of center of block	E = 25	In front of center of block	E = 40
In front of edge of block	E = 35	In front of edge of block	E = 40

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