

ART. XXXVII.—*The Transmission of Sound through Solid Walls*; by F. L. TUFTS, PH.D.

IN a previous article\* the author gave the results of some experiments on the transmission of sound through materials pervious to air, and it was shown that such materials behave in the same way with respect to sound transmission and to the flow of air currents through them. In the present paper experiments are described which were undertaken for the purpose of studying the transmission of sound through materials impervious to air.

On account of the increased noisiness of cities and the desirability of excluding these noises from offices and dwellings, a knowledge of the laws governing the transmission of sound through various materials is becoming daily of greater importance, and the present investigation was, in fact, suggested by certain difficulties which had been encountered in excluding noises from telephone booths. The experiments, described below, were undertaken for the purpose of ascertaining the essential qualities which a wall must possess in order to render it impervious to the sound waves transmitted to it from the air.

Consider, for example, a sound wave traveling in air, and suppose it to impinge upon a solid wall; there are three conceivable ways in which the sound may be propagated through the wall to the air on the other side:

First, if the wall is pervious to air, the sound may be transmitted through the air in the pores of the material. The laws governing this kind of transmission were investigated in the previous paper.

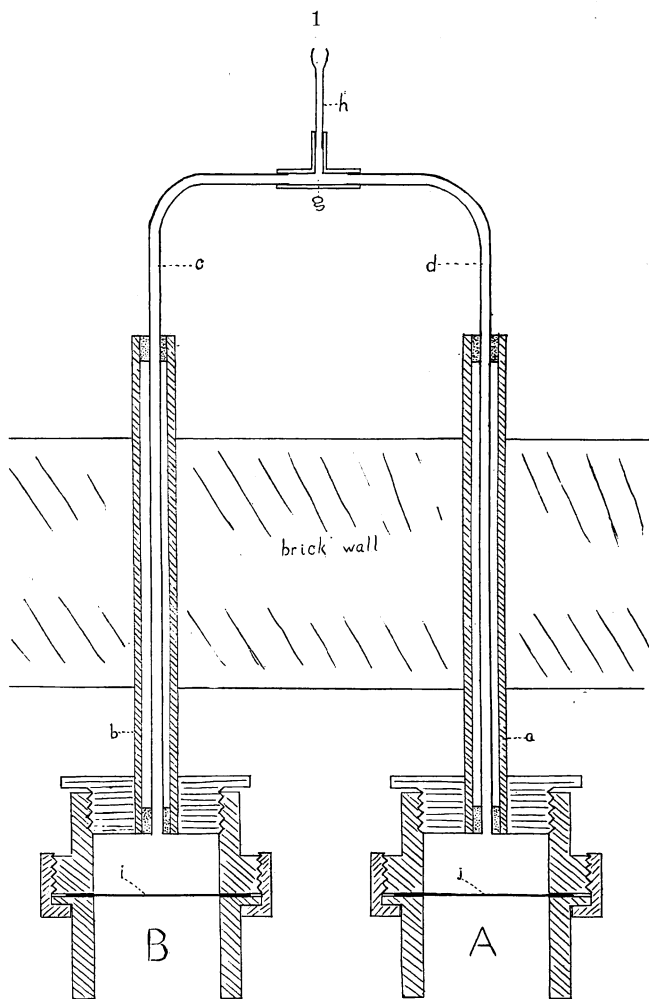
Second, if the material is impervious to air, the sound may be transmitted as an elastic wave in the material of the wall; or,

Third, the pressure of the sound wave against the wall may produce a slight displacement of it, and the sound may thus be transmitted as a vibration of the wall itself.

The apparatus used in studying the transmission of sound from the air on one side of an impervious wall, to the air on the opposite side, is shown in cross section in Fig. 1. A and B are two three-inch "gas unions," each fitted at one end with a "bushing" which reduces the opening to one inch. In these bushings, respectively, are screwed pieces of one inch gas pipe, *a* and *b*, about one foot in length. Rubber tubes, *c* and *d*, are passed through these pipes and are cemented in at their ends with beeswax. The rubber tubes are connected to

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a T-tube at *g*. One arm of the T-tube is provided with an ear piece, *h*, which can be inserted in the ear of the observer. The iron pipes, *a* and *b*, were inserted in openings in an eight-inch brick wall, and the observer could thus be placed in a



room adjoining the one in which the sound was produced. The materials, the transmission of sound through which was to be investigated, were cut into discs about  $10.5^{\text{cm}}$  in diameter, and clamped in the unions at *i* and *j*, respectively. The application of a little cement rendered the junction air tight.

Various sources of sound were used in these experiments,

but that which proved the most satisfactory was obtained by dropping a metal ball upon a pine board, the height through which the ball dropped being adjusted until the sound was sufficiently intense to be heard through the discs under investigation. An observer in the adjoining room, with the ear-piece, *h*, in his ear, could, by alternately closing and opening the rubber tubes, *c* and *d*, easily ascertain which of the two discs transmitted the loudest sound.

The rigidities of the discs were measured in the following way; an upright index was cemented to the disc under investigation, and a microscope, provided with a micrometer ocular, was focused on a mark on the index. The disc was then subjected to a pressure of air through the tube, *c* or *d*, and the displacement of the index read off in the microscope. The excess of pressure of the air on the inner surface of the disc over the atmospheric pressure was measured by a suitable manometer. From the data thus obtained the displacement of the center of the disc, for a pressure of one gram per square centimeter of surface, was calculated. The value of this displacement is of course a measure of the rigidity of the disc. The following are some of the results obtained with the apparatus just described.

I. A lead disc  $10.5^{\text{cm}}$  in diameter and  $.012^{\text{cm}}$  thick, and a glass disc of the same dimensions, were clamped in the two unions respectively, and the intensities of the sounds transmitted through the two discs compared. It was found that the lead disc transmitted sound better than the glass one. The displacement of the center of the lead disc, for a pressure of one gram per square centimeter of surface, was  $.000106^{\text{cm}}$  and of the glass disc  $.000053^{\text{cm}}$ .

II. A disc of white pine  $.65^{\text{cm}}$  thick was compared with a disc of leather of the same thickness. Both discs had been treated with paraffine to render them impervious to air. The displacement of the center of the pine disc was  $.000013^{\text{cm}}$  and of the leather disc  $.000212^{\text{cm}}$  for a pressure of one gram per square centimeter of surface. It was found that the leather disc transmitted sound very much better than the pine disc.

In both of the above cases the more rigid disc was found to be the poorer conductor of sound, although, in both cases it was composed of a material much better suited to the transmission of an elastic wave than the less rigid disc.

III. A brass disc  $.015^{\text{cm}}$  thick was braced by soldering to it a few cross strips of brass. This disc was compared with one formed of two thicknesses of cardboard treated with paraffine. The total thickness of the cardboard disc was  $.44^{\text{cm}}$ . The displacements of the two discs for a pressure of one gram per square centimeter of surface were found to be the same,

viz:  $\cdot 00008^{\text{cm}}$ . It was also found that they transmitted sound equally well, although the cardboard disc was nearly thirty times as thick as the brass disc.

IV. A disc was built up of ten sheets of cardboard treated with paraffine. The total thickness was  $\cdot 70^{\text{cm}}$  and the displacement of the center for a pressure of one gram per square centimeter of surface was  $\cdot 0002^{\text{cm}}$ . This disc was compared with a single disc of cardboard  $\cdot 22^{\text{cm}}$  thick and which gave about the same displacement. It was found that the two discs transmitted sound equally well, although one consisted of many layers while the other was of a single homogeneous material.

V. The braced brass disc used in experiment III, above, was compared with a disc cut from the same piece of brass, and which had a small mass of brass soldered to its center. The total mass of the two discs was thus made the same. The displacement of the center of the loaded brass disc, for a pressure of one gram per square centimeter of surface, was  $\cdot 0022^{\text{cm}}$  while that of the braced disc was  $\cdot 00008^{\text{cm}}$ . The loaded disc transmitted sound very much better than the braced disc. Even the noises from the street which entered the room could be easily heard through the loaded disc, while nothing of this kind could be heard through the braced disc.

An examination of the above cases, I to IV inclusive, makes it evident that the amount of sound transmitted through the discs as an elastic wave in the material, must be negligibly small as compared to that transmitted as a to and fro vibration of the disc itself; were this not so, then in case IV, where the two discs possess the same rigidity, one would expect the sound heard through the single homogeneous disc to be louder than that heard through the built-up disc with its many reflecting surfaces. In other experiments, where comparatively rigid discs of materials well suited to the transmission of elastic waves, were compared with less rigid discs composed of materials not so well suited to the transmission of such waves, it was found in every case that the less rigid disc transmitted sound better than the more rigid one in spite of its unfavorable composition. The experiments, therefore, show that when sound is transmitted from the air on one side of the disc, through the disc, to the air on the opposite side, the transmission takes place almost entirely as a to and fro vibration of the disc.

The experiment described under V shows that the effect of mass in a wall is of minor importance as compared to rigidity. The lead disc, in I, had nearly six times the mass of the glass disc, but even this great increase in mass was more than compensated for by the fact that the lead disc gave a displace-

ment twice as great as the displacement of the glass disc for the same pressure.

In order to investigate the effect of the mass of a wall on its conductivity for sound, two cardboard discs of the same dimensions were used. Both were treated with paraffine, and when clamped in the unions, both gave displacements of  $\cdot0004^{\text{cm}}$  for a pressure of one gram per square centimeter of surface. The intensity of the sound heard through the two discs was, as far as could be judged, the same. The discs were  $\cdot22^{\text{cm}}$  thick, and each weighed 17 grams. To the center of one of the discs was now cemented a mass of lead weighing 34 grams, and it was found that this cut down the intensity of the sound transmitted through the disc by a very appreciable amount. The effect due to the addition of a mass of five grams could be readily detected if the mass was cemented to the disc at its center, but not when the mass was cemented about half way between the center and circumference. This experiment shows that, other things being equal, the wall possessing the greatest mass will be the poorest conductor for sound. When the mass is uniformly distributed through the disc, however, a very slight increase in rigidity will more than compensate for a very considerable decrease in mass. For example, a lead disc, weighing 145 grams, was compared with a disc of red cedar, weighing only 17 grams, the lead disc gave a displacement of  $\cdot00008^{\text{cm}}$  and the red cedar disc a displacement of  $\cdot00005^{\text{cm}}$  for a pressure of one gram per square centimeter. It was found that the lead disc transmitted very perceptibly better than the red cedar disc, although it contained over nine times the mass.

It is a common practice in the construction of telephone booths to make them of two, and sometimes of four walls, separated by air spaces, and there seems to be an opinion that such a form of construction is better adapted for the exclusion of sound than one in which the same amount of material is put into a single wall. In order to test the relative merits of the two types of construction, six discs were cut out of cardboard and treated with paraffine in order to render them impervious to air. In one of the unions three of the discs were placed, and separated by cardboard washers, so that an air space of two millimeters was left between the discs. In the other union three discs were clamped in contact. It was found that the discs separated by air spaces transmitted sound better than the discs which were placed in contact. The same experiment was repeated using brass discs and with a similar result. The increased rigidity obtained by placing the discs in contact more than balanced any advantage there might be in having the intervening air spaces.

In all of the experiments above described the source of sound, as has been stated, was a single pulse obtained by dropping a metal ball on a pine board. Some of the experiments were repeated using an organ pipe as the source of sound. In this case it was found that the results might be much influenced by the pitch of the note used. If the natural period of vibration of a disc was in unison with the source of sound, while that of another less rigid disc was not, the transmission might be greater through the more rigid disc.

In conclusion, it may be stated that the experiments described above are representative of many others of a similar character. In every case the rigidity of the disc was found to be the main factor in determining the intensity of the sound transmitted from the air on one side of the disc to the air on the opposite side. The only other factor which seemed to have an appreciable influence on the transmission of sound through the disc was its mass. It was found that of two discs having the same rigidity the one possessing the greatest mass was the poorest conductor of sound. The effect of increasing the mass of a disc is, however, many times smaller than the effect of increasing its rigidity.

The above experiments show that the commonly accepted analogy between the transmission of sound and that of light does not hold where the sound is transmitted from the air on one side of a solid medium, through the medium, to the air on the other side. In such cases it has been found that an entirely different principle is involved, and that the transmission takes place as a to and fro vibration of the wall itself, and not as an elastic wave traveling through it.

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