THE TRANSMISSION OF SOUND THROUGH POROUS AND NON-POROUS MATERIALS.

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THE object of this investigation was to study more extensively the nature of sound transmission through porous and non-porous materials and to quantitatively determine the transmitted intensity. Up to the present time little attention has been given to the experimental phase of the subject. It was determined in 1901 by Tufts[1] that "The resistance offered by granular materials to the to-and-fro motion of the air particles in a sound wave is proportional to the thickness of the material, other things being equal." Also "Observations were made upon the transmission of sound and of direct currents of air through porous materials of a woven texture. The results showed that the resistance which such materials offered to the transmission of sound and direct currents of air was directly proportional to the thickness or number of layers of the material used, as was the case with granular materials."

Weisbach[2] working along similar lines arrived at the following conclusion: The acoustic transmission and reflection of thin sheets are not easily measured because the vibrations of the sheet as a whole often complicate and obscure the sound otherwise transmitted. If one eliminates these swings, as far as possible, then one arrives at a result which agrees with theory, namely, that the transmission and reflection for given wave-lengths depend only on the mass per unit area of the sheet.

APPARATUS.

The source of sound was an open organ pipe, pitch 768 complete vibrations, with pressure supplied by a motor-driven centrifugal blower and controlled by a pressure regulator. In the path of the stationary sound waves was placed a telephone receiver P, which was connected through a capacity C, to the primary of a transformer T.

The secondary of the transformer was connected in series with a resistance R, a Siemens and Halske direct current, high sensibility gal-

[1] Transmission of Sound through Porous Materials, Am. J. of Sc. (4), 11, 1901, p. 357.

[2] Versuche über Schalldurchlässigkeit, Schallreflexion, und Schallabsorption, Ann. d. Phys., 14, p. 763, 1910.

vanometer G, and a crystal rectifier M. This sound detector was devised by G. W. Pierce.[1]

Preliminary experiments showed conclusively that a telephone transmitter with battery, although extremely sensitive, could not be relied upon for quantitative results. The telephone receiver, more constant in its action although less sensitive, was therefore employed. A number of receivers were tried before one of sufficient sensitiveness was found. The one finally employed was of the Stromberg Carlson type which was so constructed as to respond best to variation in pressure, that is, at the node of the stationary wave. In order that the sheets of material could be conveniently exposed before the mouth of the receiver and that the incident sound could have no other access to the diaphragm than through the material, the receiver was encased in a thick lead tube closed at one end.

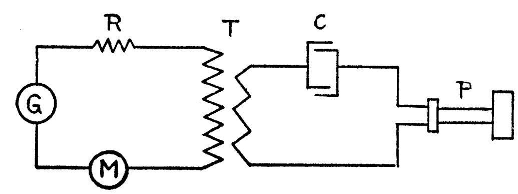

Fig. 1.
Receiving circuit.

A one to twenty step-up transformer gave best satisfaction for the particular constants in the circuit. Its primary resistance was 5.7 ohms and secondary resistance 850 ohms. In order to determine the best magnitude of capacity, a resonance curve was taken. This curve showed that 0.2 micro-farad gave the highest deflection for the particular pitch used.

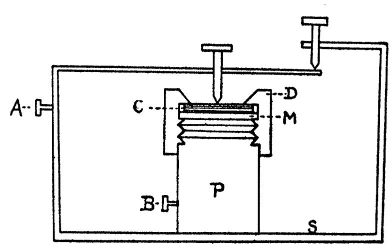

Fig. 2.
Mounting for crystal.

The crystal rectifier mounting, with terminals AB is shown in Fig. 2. A threaded, cylindrical, brass pillar P supports a sheet of mica M, which in turn supports the crystal C. The screw cap D holds the crystal in position. A hard-rubber base S supports the brass pillar and also the two metal posts which carry the regulating screws. A mutual adjustment of these screws produces any desired pressure on the crystal. Crystals of molybdenite proved to give sufficient rectification and were used throughout the research, but satisfactory ones were obtained only after many trials. Even for one particular pressure the percentage

[1] A Simple Method of Measuring the Intensity of Sound, Proc. Am. Acad., XLIII., No. 13, 1907.

rectification did not remain constant for any great length of time, so that it became necessary after each reading to check the original reading by an additional observation. Oftentimes a tedious manipulation of the pressure was necessary to maintain a proper deflection.

CALIBRATION.

The calibration consisted in finding the relation between the intensity of the incident sound and the deflection of the galvanometer. The intensity of the sound source was kept constant by regulating the air pressure which was indicated by a water manometer. The intensity of the sound incident on the diaphragm of the receiver was varied by the use of lead plates containing circular apertures of different diameters. The galvanometer showed no deflection when a lead plate was clamped over the end of the lead casing containing the receiver. The clamping was done as follows: A flat brass ring was permanently fixed to the end of the lead casing. A similar brass ring was screwed to the first one and between them the lead plates were held in position. The circular apertures of the lead plates were small compared to the size of the diaphragm so that allthe energy passing through the openings was incident near the center of the diaphragm. Hence the intensity of the incident sound was directly proportional to the area of the aperture. A reversion to the ⅜-inch aperture after each observation checked the constancy of the crystal. Fig. 3 shows that the deflection of the galvanometer is directly proportional to the area of the aperture and hence to the intensity of the incident sound. For apertures as large or larger than the diaphragm opening the law no longer holds.

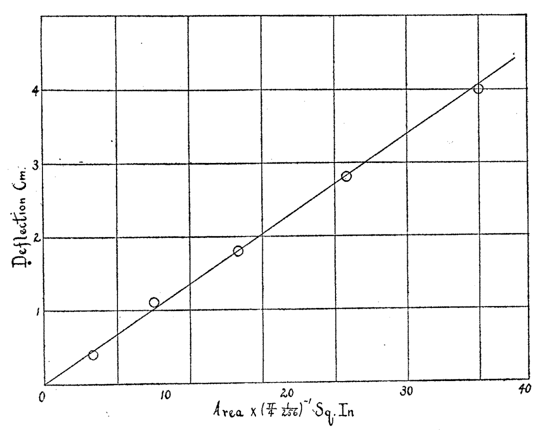

Fig. 3.

Observations and experimental details.

Preliminary experiments showed conclusively that the method of clamping the materials investigated influenced to a high degree the percentage of sound transmitted. A more thorough study of the matter showed that different methods of clamping produced different degrees of lateral vibrations. Thus a special method of clamping was devised which practically eliminated the lateral vibrations. Until this was done it was impossible to procure results which were independent of the clamping pressure and the tension in the specimen. Fig. 4 shows the clamp employed.

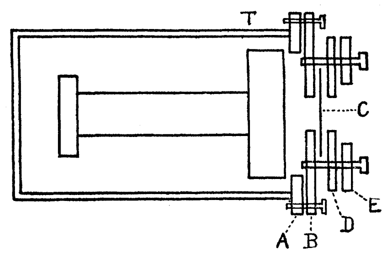

Fig. 4.
Device for damping lateral vibrations.

A is a flat brass ring 0.2 cm. thick and 6 cm. internal diameter which is fastened permanently to the end of the lead tube *T*. *B* is a brass plate 0.15 cm. thick with aperture ½ inch in diameter. *C* is the specimen and *D* is a lead sheet 0.05 cm. thick with ½-inch aperture. *E* is a brass ring 0.35 cm. thick with 1-inch aperture.

Since the galvanometer registered a maximum deflection when the receiver was placed in a node of the stationary wave, that position was employed in all observations. The following substances were investigated, namely, blotting paper, wrapping paper, roofing paper, oil cloth, tin-foil, asbestos, curtain material, lawn, longcloth, percale, cretonne, curtain scrim, linen, calico, felt, velvet, copper wire gauze, mica and aluminum.

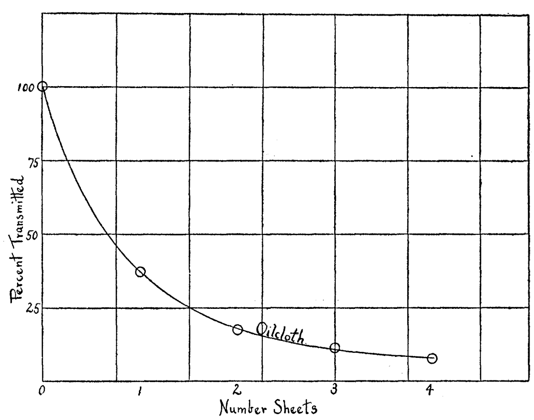

Fig. 5.

In order to explain definitely how the lateral vibrations of the material affected the observations we will confine our discussion to oil cloth which is non-porous, that is, does not allow air currents to pass through. Fig. 5 shows the relation between the percentage transmitted and number of sheets when the apertures in *D* and *E* of Fig. 4 were large, so that the oli cloth was clamped only at the outer edge.

It is to be noted that the percentage transmitted ranges from 37 per cent. for one sheet to 7.5 per cent. for four sheets. When a lead plate was used in place of oil cloth the galvanometer deflection was zero, showing that there were no leaks. Fig. 5 is in very close agreement with results obtained by Weisbach for oil cloth of a similar mass per unit area, namely, 0.034 gram per sq. cm. When the oil cloth was clamped exactly as shown in Fig. 4 and when the open deflection was 4 cm. as was the case in Fig. 5, the galvanometer showed no deflection, thus indicating that the transmission as shown in Fig. 5 was due to the

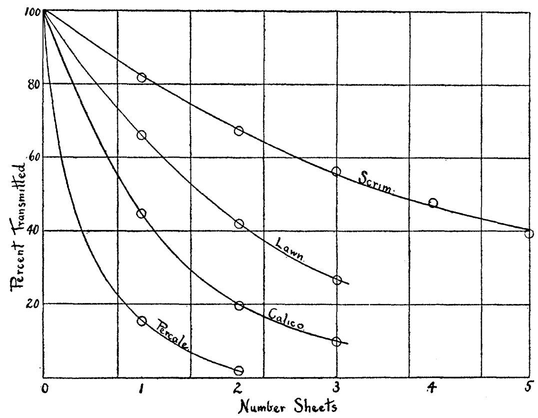

Fig. 6.

oil cloth being set in vibration and acting as an independent vibrating source. This discrepancy is of great significance and will be discussed later. Other non-porous substances or those nearly so, acted in a similar manner. Roofing paper, wrapping paper, asbestos, blotting paper,

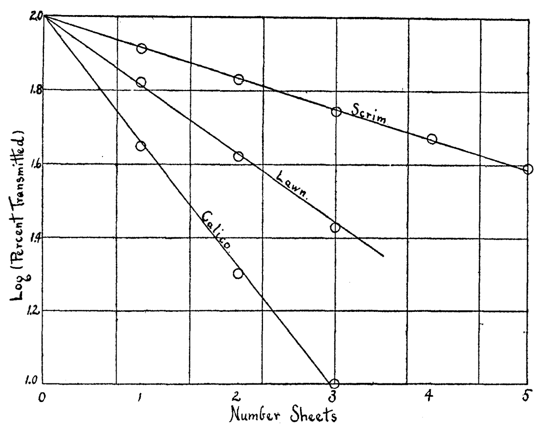

Fig. 7.

curtain material, tin foil, mica and aluminum transmitted either zero or considerably less than one per cent. The more porous substances of woven texture, were used to determine the relation between the intensity transmitted and the number of sheets. Table I. shows the numerical results.

The curves for calico, percale, curtain scrim and lawn, showing the relation between number of sheets and percentage transmitted, are shown in Fig. 6, while the relation between number of sheets and logarithm of percentage transmitted, is shown in Fig. 7.

TABLE I.

Material.	$\frac{\text{Mass}}{\text{Area}}$ in $\frac{\text{gms.}}{\text{cm.}^2}$	Per Cent. Trans-mitted.	Material.	$\frac{\text{Mass}}{\text{Area}}$ in $\frac{\text{gms.}}{\text{cm.}^2}$	Per Cent. Trans-mitted.
Lawn.			*Longcloth.*		
1 sheet........	0.00537	65.9	1 sheet........	0.00984	27.6
2 sheets........		41.8	2 sheets........		7.6
3 sheets........		26.7	*Cretonne.*		
Calico.			1 sheet	0.0120	27.8
1 sheet........	0.00868	44.5	2 sheets........		15.5
2 sheets........		19.7	3 sheets........		11.8
3 sheets........		10.0	*Linen.*		
Percale.			1 sheet........	0.0129	6.3
1 sheet........	0.0121	15.3	*Linene.*		
2 sheets........		2.0	1 sheet........	0.0167	2.0
Curtain scrim.			*Felt.*		
1 sheet........	0.0051	81.6	1 sheet........	0.0266	1.6
2 sheets........		67.2	*Velvet.*		
3 sheets........		56.1	1 sheet........	0.0158	1.6
4 sheets........		47.5	*Copper wire gauze.*		
5 sheets........		39.1	1 sheet........	0.102	76.4
			2 sheets........		58.6

DISCUSSION OF RESULTS.

It is readily seen from the results that non-porous substances such as oil cloth, paper, tin foil, etc., do not transmit sound when the lateral vibrations are eliminated, at least in so far as our apparatus will detect. This would limit the transmission to a very small fraction of one per cent. Porous substances, on the other hand, do transmit a considerable percentage of incident sound, the percentage depending upon the diameter, length and nature of the channels. Inspection of the materials would lead one to expect a much greater transmission than was found. The general law appears to be

$$I = I_0 e^{-kn}, \tag{1}$$

$$\log \frac{(I)}{(I_0)} = -kn, \tag{2}$$

where I = transmitted intensity,
I_0 = incident intensity,
n = number of sheets,
k = constant.

All substances investigated agreed with this law with the exception of cretonne which proved to be a decided exception. In cretonne the channels are not so definite and clear cut as in the other cases. The exponential form of equation (1) suggests at once that whatever sound is transmitted goes through the pores. This would immediately suggest an investigation of the channel action. Preliminary experiments on a single channel of diameter 3/16 inch, in lead plates, showed that the percentage transmitted, as the length of the channel was changed, agreed with the above law very closely. This matter will be further investigated.

Our results differ widely from those of Weisbach who attempted to apply Rayleigh's[1] formula for the amplitude[2] of the sound reflected from thin plates, namely,

$$-\frac{\frac{\pi\rho_1 l}{\rho\lambda}}{\sqrt{1+\pi^2\left(\frac{\rho_1 l}{\rho\lambda}\right)^2}}, \tag{3}$$

where l = thickness of plate,

ρ = density of first medium,

ρ_1 = density of second medium (plate),

λ = wave-length.

When the first medium is air and the pitch 768 double swings, as used in our experiments, formula (3) may be written

$$I_r = I_0\frac{\rho_2^2}{.00034+\rho_2^2}, \tag{4}$$

where I_r = reflected intensity,

I_0 = incident intensity,

ρ_2 = mass per unit area of the plate.

If there is no absorption the transmitted intensity I_t will be $I_0 - I_r$,

$$I_t = \frac{.00034}{.00034+\rho_2^2}. \tag{5}$$

Weisbach's results did not agree with Rayleigh's theoretical values but could be brought into approximate agreement by shortening the ordinates by a large constant factor. He did not fulfill the conditions imposed by the formula. For a statement of these conditions and a complete interpretation of the formula we are indebted to Baron Rayleigh.

The formula applies to the reflection of plane waves incident normally on a free and thin lamina which lamina is incompressible as compared

[1] Theory of Sound, Vol. II., p. 88.

[2] Note misprint in Rayleigh, Vol. II., p. 88, of intensity for amplitude.

with the first medium and is completely uniform in its mechanical properties. The lamina acts as a body possessing inertia under the pressures of the three waves, incident, reflected and transmitted Experimentally it would be almost impossible to satisfy the requirement of freedom. However a membrane such as oilskin spread over a large enough hoop might possibly satisfy the requirement, *i. e.*, that the motion shall be independent of any tension due to the outside fastening. The vibrations which Rayleigh's formula permits are those controlled by the inertia of the membrane and the elasticity of the air and not those which depend on the elastic constants of the material. Therefore Weisbach should not have applied Rayleigh's formula in any case, since the condition of freedom was not satisfied.

We also wish to emphasize the fact that formula (5) cannot be applied to our results, even to those substances such as tin foil, paper, mica, etc., whose mechanical properties are uniform, since the condition for freedom is not satisfied. In any case it cannot be applied to porous substances. If the lateral vibrations are damped the substances which are uniform in their mechanical properties should act as a fixed wall, namely, reflect all incident sound. This is conclusively shown by our results.

Weisbach's results could not be expected to agree with ours since his membrane was not thoroughly damped while in our case the lateral vibrations were completely eliminated. Our results verify the latter statement. For non-porous substances or those nearly so as paper, oil cloth, curtain material, etc., we found the transmission to be either zero or a small fraction of one per cent., while Weisbach found from 30 to 60 per cent. For porous substances such as linen, calico, lawn, etc., we likewise found a much smaller percentage transmitted.

Summary.

1. The crystal rectifier, with apparatus as described, is reliable when used for the comparison of sound intensities but cannot be used for absolute determinations since the percentage of rectification is liable to change.

2. For non-porous substances or those nearly so, the intensity of sound transmitted is either zero or considerably less than one per cent.

3. For porous substances of woven texture the general law for the transmitted intensity is $I_t = I_0 e^{-kn}$, *i. e.*, each sheet transmits a definite percentage of the sound incident upon it.

4. Most of the sound which is commonly said to be transmitted is due to the lateral vibrations of the material as an independent sound source. The intensity actually transmitted depends upon the size and nature of

the pores, *i. e.*, absorption is the predominating factor. This is in agreement with Tufts' general idea as previously stated, namely, that the transmission of sound depends definitely upon the facility with which the substance transmits currents of air.

In conclusion we wish to thank Professors H. C. Richards and R. H. Hough for their valuable suggestions and coöperation.

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