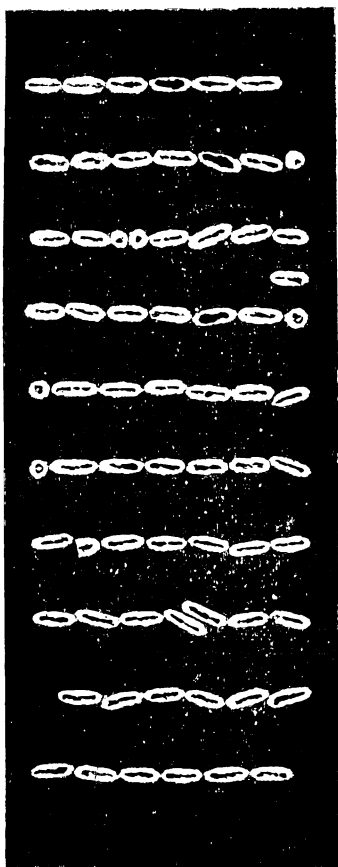


ART. XX. — *On the Behavior of Small closed Cylinders in Organ-pipes*; by BERGEN DAVIS, Ph.D.

WHILE experimenting with stationary sound waves in organ-pipes, the following striking effect was obtained. A considerable number of small gelatine capsules, such as are used for medical purposes, were thrown in a promiscuous pile in the center of the pipe, and when the pipe was blown so as to give its first overtone quite strongly, the small cylinders immediately moved to the middle of the loop of the stationary wave and there arranged themselves in rows across the pipe as shown in the figure. The spacing between the rows was quite regular and the capsules acted as though there was a strong attraction at their ends, in a direction perpendicular to the vibration, and a repulsion at their sides in a direction parallel to the vibration.

An investigation was undertaken to determine the effect of the size of the cylinders, of the number of rows, and of the amplitude of vibration, upon the distances between the rows.

The stationary wave was that produced in a stopped organ-pipe speaking its first overtone. The side of the pipe was removed and a glass plate substituted for it. At the node nearest the mouth a thin rubber diaphragm was placed across the pipe, which protected the portion back of the diaphragm from disturbances arising from blowing. This region of the pipe, from the diaphragm to the stopped end, enclosed one-half of the stationary wave. The amplitude of vibration was measured by means of the force acting on a small hollow cylinder closed at





one end, as was described by the writer in this Journal.\* The torsion balance carrying this cylinder was placed at the middle of the loop.

The small cylinders whose spacing in the sound wave was to be measured were of two kinds, consisting of small gelatine capsules and of paper tubes. These two kinds of cylinders were used in independent series of experiments.

Three sizes of gelatine capsules were used, commercial numbers of which are Nos. 00, 2 and 5.

The dimensions in centimeters of these cylinders are given below.

	Length.	Diameter.
No. 00 .....	2.42	.83
No. 2 .....	1.75	.63
No. 5 .....	1.03	.48

A sufficient number of one of the above sizes of capsules were placed in the organ-pipe to form a considerable number of rows. In order to obtain a desirable amplitude of vibration the torsion head was turned from the zero position by an amount corresponding to a desired amplitude, then the pressure of blowing was increased until the force acting on the measuring device just balanced the torsion previously given to the wire; at the same time the capsule cylinders arranged themselves in rows across the pipe. This previous setting of the torsion head enabled me to reproduce the same amplitude of vibration at will.

In the tables below are given the average distances in centimeters between the rows for the various sizes, with increasing amplitudes of vibration. The amplitude  $2A$  is here used to denote the total excursion of the vibrating air particles.

No. 00. Capsule cylinders.				
Amplitudes.	Number of rows.			
$2A$	2	3	6	10
.39	4.	3.5	2.8	2.2
.434	3.5	3.3	2.6	2.1
.476	3.3	3.5	2.6	2.1
.548	3.5	3.7	2.7	2.2
No. 2. Capsule cylinders.				
Amplitudes.	Number of rows.			
$2A$	2	3	6	10
.39	2.8	2.75	2.8	2.
.434	2.4	2.5	2.65	1.95
.476	2.5	2.5	2.55	2.
.548	2.5	2.5	2.45	2.

\* This Journal, September, 1900.



Amplitudes.	No. 5. Capsule cylinders.			
	Number of rows.			
2A	2	3	6	10
·39	2·	2·75	2·4	1·9
·434	1·8	2·5	2·1	1·55
·476	2·	2·1	2·1	1·6
·548	2·	2·5	2·2	1·66

The most striking result obtained from the above tables is that the distances between rows slightly decrease with increasing amplitudes of vibration. The average distance between the rows decreases in general as the number of rows increases, excepting in the case of the smallest, No. 5 cylinders, in which case the spacing increased when three and six rows were used. This tendency to increase with these particular rows is also exhibited by the No. 2 cylinders. The general rule may also be deduced, that the larger the cylinders, the more the spacing decreases with the number of rows, as will be evident by comparing the two-row and the ten-row columns in the three tables. At the higher amplitudes the capsule cylinders were quite violently agitated, as though the position of the loop were somewhat unsteady, which increased the difficulties of accurate measurement.

The corresponding experiments were performed with paper cylinders of various diameters. These cylinders were each 6·3<sup>cm</sup> in length and were open at both ends, on account of the circumstance that the length of one of them was nearly equal to the diameter of the pipe. Since the effect to be observed was a result of the forces acting at the sides and not at the ends, the open ends did not affect the experiment. The open ends were of advantage in that they lessened the force with which the cylinders in all cases adhered to the walls of the pipe.

The diameters of these cylinders in centimeters are given below:

No. 1	·5
No. 2	·71
No. 3	1·00
No. 4	1·4

These paper cylinders were introduced into the closed chamber of the pipe and the same experiments performed as with the capsule cylinders. Each cylinder now corresponds to a row as described in the previous experiments. The same amplitudes of vibration were retained for the purpose of comparison. The results are given in the following tables:



No. 1. *Paper cylinders.*

Amplitudes.	Number of rows.			
	2	3	6	10
2A				
·39	3·2	3·2	2·6	2·1
·434	2·6	3·2	2·5	1·9
·476	2·3	3·2	2·5	1·9
·548	2·3	3·2	2·4	1·9

No. 2. *Paper cylinders.*

Amplitudes.	Number of rows.			
	2	3	6	10
2A				
·39	6·5	3·	2·7	2·3
·434	6·	3·	2·8	2·3
·476	6·	3·2	2·9	2·2
·548	6·	3·2	2·8	2·2

No. 3. *Paper cylinders.*

Amplitudes.	Number of rows.			
	2	3	6	10
2A				
·39	6·	4·3	3·9	2·
·434	5·5	4·	3·	2·
·476	5·	4·	----	----
·548	5·	4·	----	----

No. 4. *Paper cylinders.*

Amplitudes.	Number of rows.			
	2	3	6	10
2A				
·39	7·	5·5	3·3	2·8
·434	6·5	5·	----	----
·476	6·5	----	----	----
·548	----	----	----	----

Here again it will be noticed that the space between the cylinders slightly decreases with increasing amplitudes of vibration. The space between the rows decreases as the number of rows increase. This result is somewhat different from that obtained with the No. 2 and No. 5 capsule-cylinders, while the same result was obtained as with the large No. 00 capsule-cylinders. The blanks in the columns with the larger cylinders when several rows were used, are due to the fact that the tone passed over into the next overtone before the required amplitude was reached. This was probably due to the effect of friction. The presence of so much obstruction tended to form a node at this point, which is near the natural



position of the node of the next overtone. When this overtone occurred, the rows would divide into two portions, which moved toward the middles of the two loops of the new stationary wave.

A striking effect was obtained by placing a number of the smallest capsule-cylinders a short distance from the node. When the pipe spoke, they immediately ran rapidly to the middle of the loop, and there assumed a regular arrangement.

The effects described in this paper are of course of the same nature as the Kundt dust figures. The individual capsule-cylinders may be considered as dust particles in which the size has been much increased, the particles still remaining light enough to respond readily to the delicate forces to which they are subjected.

Prof. Rood suggested as an explanation of the spacing that a sound-shadow is formed on the two sides of the cylinders at each half vibration, alternately. These shadows, being regions of less motion, press so to speak against the cylinders. When there are two rows the shadows between the cylinders press them apart until the force just equals that pressing against the outside or nodal sides of the two cylinders. This also explains their rapid movement from the nodes toward the loop. The average velocity on the side nearest a node is less, and hence the pressure greater than on the side nearest a loop, where the velocity is greater. The behavior of the capsule-cylinders illustrates the distribution of the forces acting upon rigid bodies in moving fluids, the mathematical analysis of which has been so fully developed by W. Koenig.\*

The effect here described can be easily reproduced as a lecture experiment. The ordinary stopped organ-pipe found in lecture cabinets will suffice for the purpose. The smaller capsules will perhaps be found to give the effect more strongly in case the pipe is not a powerful one.

Physical Laboratory of Columbia University, June 1, 1901.

\* Wied. Ann., xlii, pp. 353, 549, 1891.