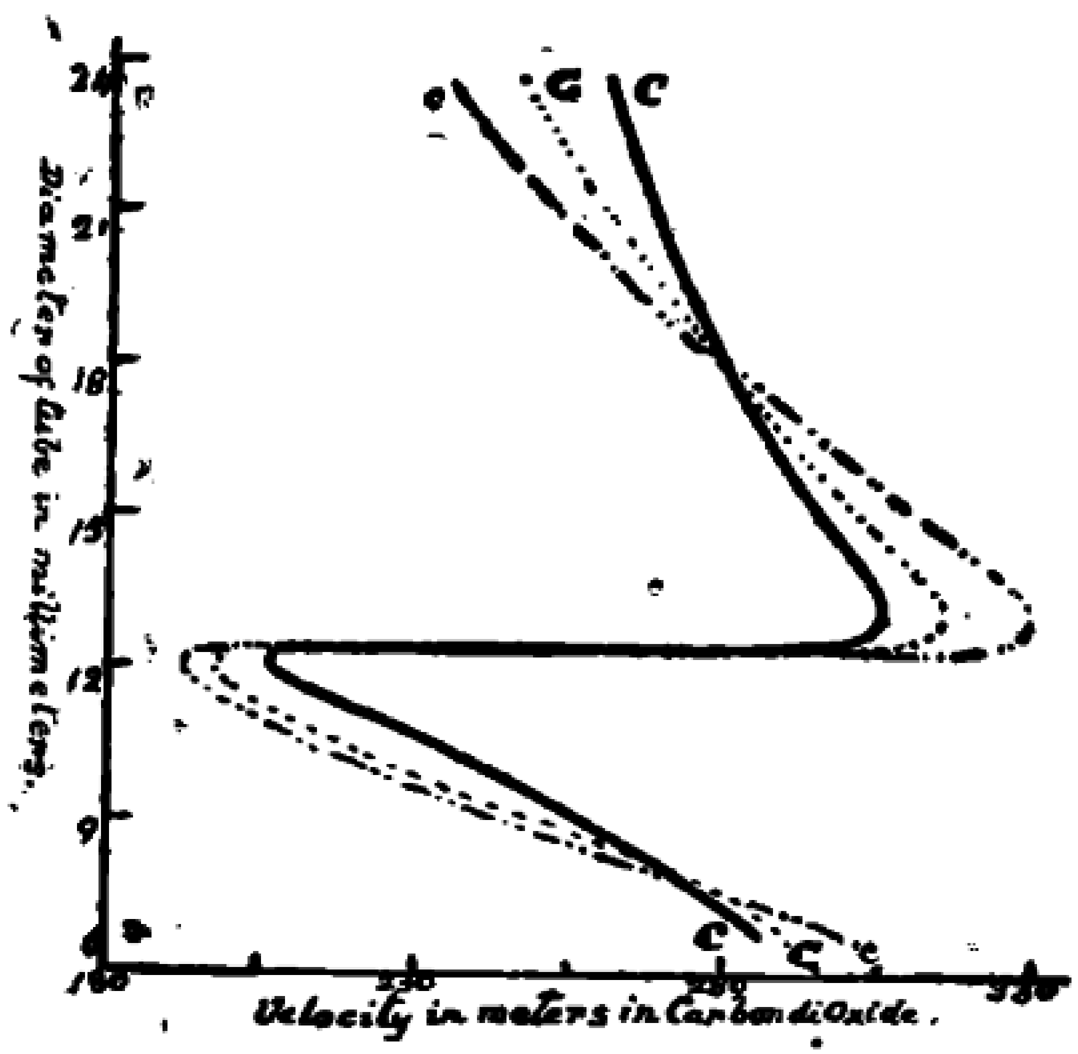
STRANGE CHANGE OF VELOCITY OF SOUND IN NARROW PIPES.

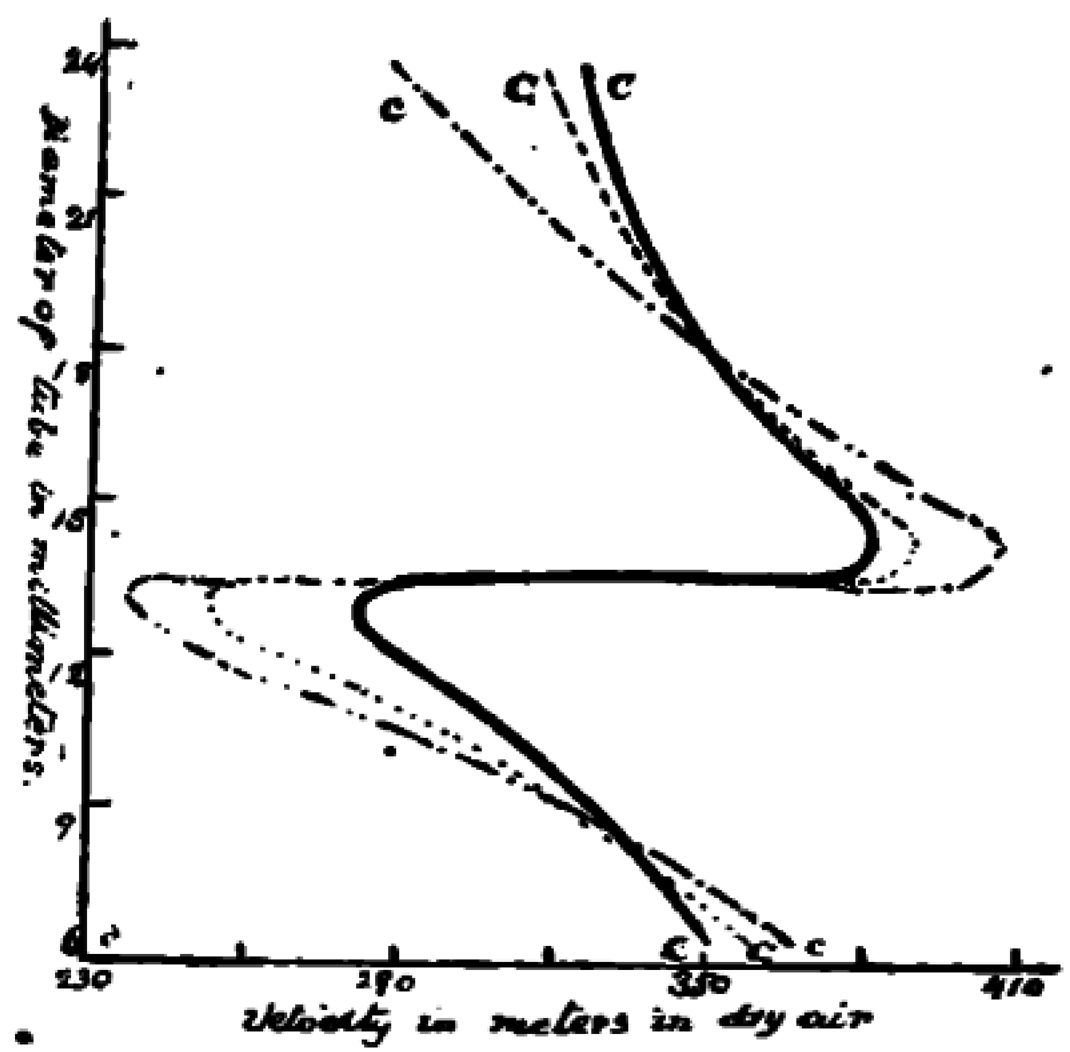
(*Original research*)

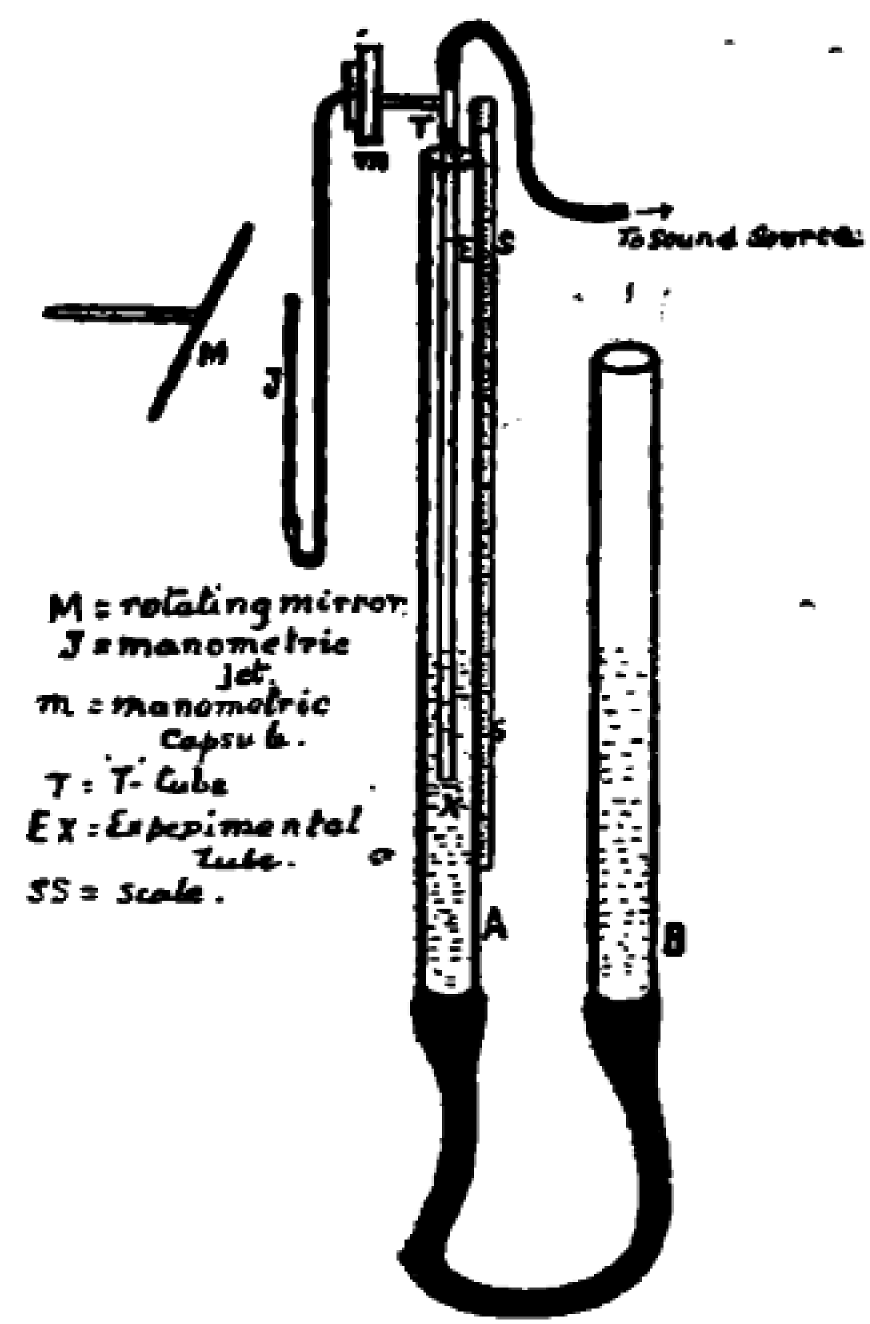
(By Professor Rajkumar Banerjee M. A.)

1. The velocity of sound is determined with the help of a wide mouthed glass tube closed at one end. When stationary waves are produced within the tube, *nodes* and *antinodes* are formed. The distance between a *node* and an *antinode* gives us data to determine the velocity. This is a well-known fact. But how to determine this distance exactly whatever be the diameter of the tube and the temperature is a problem which the experimentalist must try to solve.

Sound waves travel in *open air*, when the temperature is 0°C, at the rate of about 331 meters per second and this is called by Helmholtz the *open air velocity*. This velocity increases with temperature according to a certain law. But when sound waves travel through a pipe, the velocity varies not only with temperature but with the diameter of the pipe as well as with the nature, *i. e.*, the pitch, of the sound waves passing through. Thus by the interference of two sets of progressive waves (Quinck's method), Schulz found that the velocity of sound varied from 195 meters to 290 meters when the diameter of the tube through which the waves were transmitted, varied from ·99 *mm.* to 1·51 *mm.* Schulz used his ear as the detector of the maximum or minimum position of sound. But in the method described here I have employed a manometric capsule instead of the ear, as the detector of maximum or minimum position of sound. The coal gas flame (or the acetylene gas flame which is necessary for purposes of photographing the flame) which burns at the end of a tube connected with the manometric capsule strongly vibrates at the maximum position of sound and remains stationary at the minimum position. These vibrations of the flame are very beautifully shown by a single rotating mirror. If a small mirror is fixed with its plane normal to the rotating axis, then a single image of the flame will be seen within the mirror, whether the mirror rotates or not. But if the plane of the mirror be a little oblique to the rotating axis, then a bright circular band of light will be seen within the mirror when the latter rotates. If now the flame vibrates ever so little, the above mentioned circular band is resolved into separated 'tongues' or 'beads' called *serrations*. The presence of serrations proves the maximum position







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of sound or, in the present case, the maximum change of density, and the absence of serrations, the minimum change of density.

2. Instead of transmitting two independent trains of waves by different paths like Schulz, interference is also produced by the direct reflection of a train of incident waves. The following arrangement is adopted to determine the velocity of sound in any gas and at any temperature through *narrow* tubes.

It may be mentioned at the outset, that the velocity of sound in narrow pipes does not vary according to the empirical law of Kirchhoff and Helmholtz but in a very strange manner not detected before. I shall now describe briefly the method by which this strange behaviour has been detected.

3. Two glass tubes are taken ; one of which is at least 1 meter long, and 3 or 4 *cm.* in diameter, the other, half a meter in length but wider than the former tube. Let me call these tubes, A and B respectively. These are connected by a suitable rubber tubing capable to stand the pressure of mercury when necessary. The tube A is kept vertically fixed, attached to a long stand such that it may be raised or lowered within wide limits. Mercury or any *non-volatile* oil is poured into B, until the level of the liquid poured into reaches to the middle of the tube B. By raising or lowering this tube, the level of the liquid may be raised or lowered to any extent in A.

The experimental tubes are to be hung, one at a time, inside A. A suitable 'T-tube' is attached at the upper end of the experimental tube. The lower opening of the tube is now dipped into the liquid ; the upper opening of the T-tube is connected to the source of sound by means of a long rubber tubing, and the lateral opening of the 'T' is directly connected with the manometric capsule. The source of sound may be a heavy tuning-fork or an organ pipe. I have taken three separate forks, *C*, *G*, and *c* fixed on their sound boxes.

4. The experimental tube may now be filled with any gas, dry air, moist air, carbon di-oxide, ammonia, &c. I shall not explain this part of the operation in detail, but this should be mentioned that the gas, dry air, or carbon di-oxide or anything else, through which sound waves shall travel, shall pass through the long rubber tubing and filling up the experimental tube must bubble through the liquid for a certain time, while all along the side opening of the 'T' must be kept closed by a pinch-cock. The passing of the gas is now stopped, the side-opening is

connected with the manometric capsule and the upper end joined to the source of sound (tuning-fork in the present case).

When the tuning-fork is bowed, strong stationary waves are produced in the experimental tube, and nodes and antinodes are formed. The tube B is now raised or lowered so that the level of the liquid within the experimental tube is raised or lowered to the same extent. By this adjustment the position of an antinode is exactly brought before the side opening of the 'T,' *i.e.* at the manommetric capsule. When this happens, the flame does not vibrate and the image-circle does not show any serrations. The distance between this point and the level of the liquid is measured by a scale attached to the 'T-tube'; this gives one quarter of the wave passing through. The absence of serrations shows the exact point for the antinode, for a variation of the air column within the tube by half a millimeter produces distinct serrations. (This does not happen when the experimental tube is sufficiently wide, the cause of which is mentioned later on). By increasing the length of the experimental tube three quarter waves can be obtained, but this not only makes the arrangement cumbrous but diminishes the sensitiveness of the flame.

5. To determine the velocity of sound in different tubes, a number of 'T-tubes' must be kept ready to fit into the mouths of different tubes—different experimental tubes are to be carefully selected, the bore should be as uniform as possible. As no tube is found exactly uniform throughout deviations in the results follow.

6. In the two following Tables I give the velocities of sound in different tubes in dry air and dry carbon-di-oxide at 29°6 *C.*, the sources of sound being *C. G.* and *c* forks. See Tables I. and II.

7. When curves are drawn on a graph paper with the velocities and the diameters of the tube recorded in Tables I. and II., very marked deviations are observed at some points. These are mainly due to the non-uniformity of the bore. But the peculiar point to be noticed is the abrupt change of velocity from minimum to maximum at some particular value of the diameter of the tube. Thus when the diameter of the bore is 13*mm.* the velocity in air is 273*m.*, whereas at 14*mm.* it is suddenly changed to 384 *m.* This change is the same in the same medium, but not in another medium. (Compare Tables I. and II.)

Students of mathematics may try their skill in drawing the two serpentine curves lying on both sides of a line which corresponds to that of the open air velocity.

That velocities vary with tubes and with the pitch of the sound is not a new fact. It was observed by Schulz and commented on by Helmholtz. The formula empirically deduced by Helmholtz and Kirchhoff shows that the velocity curve cannot intersect the open-air line but becomes asymptotic to it. The formula therefore is only a particular case of a general law represented by the curves drawn from Tables I. and II.

It is to be remarked that in tubes the diameters of which are greater than 14·5*mm.*, no sharp antinodal plane is obtained; *i.e.* a slight change of the level of the liquid either ways, does not change much the nature of the flame. In wider tubes this anomaly is found to be greater. The nodal and antinodal planes seem to be oscillating within sufficiently large limits.

In *very* narrow tubes *progressive* sound waves can easily pass but no *stationary* waves are formed, so far as detected by a manometric flame.

The line joining the first minimum velocity and the first maximum is the *critical line*; it is independent of pitch but depends upon the medium. The diameter of the tube corresponding to this first minimum may be called the *critical* diameter.

In conclusion I state that I am much obliged to Prof. P. N. Ghose, M. A. my former colleague, who gave me much assistance and advice in setting up the apparatus and in pointing out the various sources of error.

Table of Velocities in Dry Air at 29·6 C.

Diameter of tube in millimeters.	C-fork, v. f=256.		G-fork, v. f=384.		c-fork, v. f=512.	
	Quarter wave-length in *cm.*	Velocity in meters.	Quarter wave-length in *cm.*	Velocity in meters.	Quarter wave-length in *cm.*	Velocity in meters.
6·9	34·2	350·34	23·5	360·9	18·0	368·6
7·4	34·0	348·16	23·0	353·28	17·4	356·35
7·8	33·8	346·11	22·7	348·66	16·8	343·6
8·4	33·2	339·9	22·2	341·0	16·2	331·7
9·2	32·8	335·87	21·3	327·16	15·5	317·44
9·7	32·0	327·6	20·5	314·88	15·0	307·2
11·0	30·0	307·2	18·9	290·3	13·6	278·5
12·1	27·9	285·7	17·5	268·8	11·9	243·7
13·0	26·7	273·0	16·0	245·76	11·5	235·52
13·5	27·0	276·5	16·2	248·83	11·8	241·66
14·0	37·5	384·0	25·5	391·6	20·0	409·6
14·5	37·2	380·9	25·3	388·6	19·7	407·4
15·1	36·4	372·8	24·5	376·3	19·3	395·2
16·2	35·0	358·4	23·5	360·9	18·5	378·8
17·1	34·0	348·16	22·8	350·2	17·0	348·16
18·2	33·5	343·04	22·3	342·5	16·3	333·8
23·3	32·0	327·68	20·5	314·88	14·0	286·72

Table of Velocities in Dry Carbon-di-Oxide at 29·5 C.

Diameter of tube in millimeters.	C-fork, v. f=256.		G-fork, v. f=384.		c-fork, v. f=512.	
	Quarter wave-length in *cm.*	Velocity in meters.	Quarter wave-length in *cm.*	Velocity in metres.	Quarter wave-length in *cm.*	Velocity in meters.
6·9	27·8	284·67	19·0	291·84	14·8	303·1
7·4	27·3	279·5	18·4	283·0	14·7	292·8
7·8	27·5	274·06	18·0	273·4	13·8	282·6
8·4	25·6	262·84	16·9	259·58	12·6	258·04
9·2	24·4	249·8	16·0	245·7	11·9	243·7
9·7	23·7	242·7	15·3	235·0	11·4	233·4
11·0	21·4	219·13	13·9	214·0	10·1	207·0
12·1	20·0	204·8	12·8	196·6	9·4	193·5
13·0	29·1	297·48	20·0	307·2	16·2	331·7
13·5	28·5	291·8	19·8	302·9	15·3	314·0
14·0	28·0	286·7	19·0	288·5	14·4	294·9
15·1	27·5	282·5	17·9	274·9	13·5	276·48
16·1	27·2	278·5	18·0	276·49	12·9	264·12
17·1	26·5	276·48	17·5	265·7	12·4	253·9
18·2	26·0	266·24	17·0	261·12	11·9	243·7
23·3	25·5	262·0	16·0	245·76	11·5	235·52