if we here refer to a research by Blaikley.[1] He used an organ-pipe with a pear-shaped cavity just above the speaking mouth, continued into a straight cylindrical pipe with a sliding plug in it. He first made the tube sound when the plug was in a given position, and then moved the plug outwards to such a position that the pipe could give the same note as before. The added length was the distance between two nodes or $\frac{1}{2}\lambda$.

Experimenting with several tubes, he found very satisfactory agreement with the formula already given on p. 28,[2]

$$U = U_0\left(1 - \frac{c}{D\sqrt{N}}\right),$$

where U_0 is the velocity in open air, D the diameter, and N the frequency. The most satisfactory value for U_0 he found to be 331·676 m./sec.

Kundt's Dust-Tube Method.—Kundt devised a very beautiful method of showing the mode of vibration in a tube closed at both ends, and of determining the velocity of air waves in such a tube. The apparatus is represented diagrammatically in Fig. 66. The "wave-tube," which must be very dry, has a little lycopodium dust scattered along it. It is closed at one end by a tight piston, *a*, and near the other end is a loose piston, *b*, at the end of a glass or metal rod—the sounding-rod. This is clamped firmly at its middle point, *d*, and on stroking it with a wet cloth if glass, with a resined leather if metal, it vibrates like the air in an open pipe, giving its fundamental tone, *d* being a node and *b* a loop. The piston at *b* communicates motion to the air in the wave-tube, and if the piston at *a* is carefully adjusted to some particular position, exact resonance occurs and a loud clear note rings out. The lycopodium dust is caught up by the air moving at the loops, and settles down where there is no motion, that is, at the nodes *nnn*. The process may be watched, for at each stroke of the exciting rod clouds rise from the loops, and the heaps collecting at the nodes increase. The velocity of sound in the material of the sounder being many times that in air, there may be many nodes in

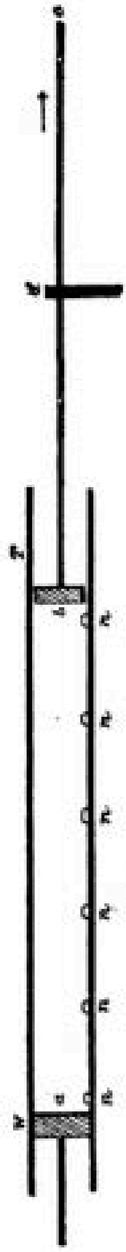


FIG. 66.—Kundt's Dust-Tube Method of determining Velocities in Tubes. WT, wave-tube closed by an adjustable tight piston at *a* and a loose piston at *b*. The loose piston is at the end of a glass or metal rod, *bc*, clamped at its centre, *d*, and excited by stroking in the direction of the arrow near *c*; *nn* are the heaps of lycopodium collecting at the nodes.

[1] *Phys. Soc.*, vol. vi. 1884–5, p. 228.
[2] Rayleigh, *Sound*, vol. ii. §§ 347–350.

the wave-tube, the first being at a and the last near b. The piston b is the source of the energy, and communicates all the motion to the air. But the amplitude of vibration in the air soon far exceeds that of the rod, so that the motion of b corresponds to that of a point much nearer a node than a loop. By measuring the average distance between the nodal heaps the half wave-length in the tube is determined with some exactness, and thence $U = n\lambda$ may be found. Replacing the air by any other gas, the velocity in that gas may be determined.

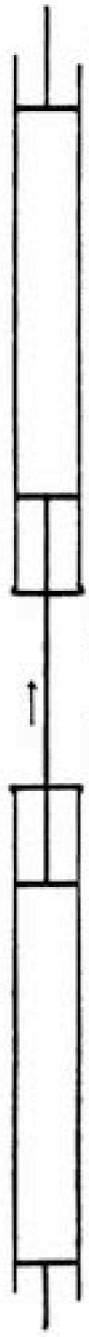


Fig. 67.—Kundt's Double Wave-Tube Apparatus, with one sounding-rod supported by india-rubber caps to the wave-tubes at the nodal points of its first overtone. The rod is excited by stroking it in the middle. The two tubes may be used for different gases.

In the first form of the apparatus the sounding-rod was clamped at its centre by the cork closing the end of the wave-tube. The vibrations were thus communicated to the solid walls of that tube, and not only were the appearances complicated, but the note was rendered slightly variable. Kundt finally adopted a form, represented in Fig. 67, with two wave-tubes containing different gases and a single sounding-rod. This was supported at $\frac{1}{4}$ and $\frac{3}{4}$ of its length, the nodal points for its first overtone, by passing it through india-rubber sheets covering the ends of the wave-tubes, and it was sounded by stroking it in the middle. The same note was of necessity sounded in the two tubes, and the india-rubber connection between sounder and wave-tube did not carry much vibration from one to the other.

Kundt found that for a given gas the velocity increased with the diameter of the tube and the wave-length, while it decreased with the roughness of the tube and an excess of lycopodium. He showed that the velocity was independent of the pressure and proportional to the square root of the absolute temperature. He also found relative values of the velocity in different gases, taking that in air as 1. Wüllner, using Kundt's method, and applying to his results Kirchoff's modification of Helmholtz's formula for the velocity in tubes, calculated the following velocities at 0° in free gas:—

	m./sec.
Air	331·90
Carbon monoxide	337·13
Carbon dioxide	259·38
Nitrous oxide	259·64
Ammonia	415·99
Ethylene	315·90

Kundt and Warburg have used the double wave-tube to determine the ratio of the specific heats or γ in mercury vapour.[1]

[1] *Pogg. Ann.*, clvii., 1876, p. 353.

One tube contained air, and the other, which was sealed, contained mercury vapour maintained at a high temperature in an oven. As dust to show the nodes quartz sand was used, and from the experiments the velocity U was determined. But (p. 20) $U^2 = \gamma P/\rho$. The temperature and the molecular weight of mercury gave P/ρ, and hence γ could be determined. It was found to be 1·66.

Kundt's single tube method has been used by Rayleigh and Ramsay (*Phil. Trans.*, 186A, 1895, p. 187) to determine γ for Argon, and by Ramsay (*Proc. Roy. Soc.*, viii. p. 86) to determine it for Helium. In each case the value found was 1·66.

Experiments on Pressure-Change and Motion in Organ-Pipes.—Kundt[1] devised a water manometer, provided with a valve which could be fixed at any point in the walls of a pipe. The valve opened outwards, and allowed a little air to escape into the manometer at each compression, until the pressure in the manometer was equal to the maximum pressure occurring within the tube at the point. The valve consisted of an india-rubber or gutta-percha membrane over a narrow slit in a metal plate. It was stretched so as not to be very different in tone, when blown as a reed, from the organ-pipe to which it was attached. This ensured its quick response to variations of pressure. By making the valve open inwards, the minimum pressure could be measured. In a closed pipe 30 cm. long Kundt found differences of pressure amounting to 30 cm. of water on each side of the normal pressure, say 1/34th of an atmosphere. From this we may calculate the amplitude of the vibration, for the stationary wave in the pipe may be regarded as made up of two equal and opposite progressive waves, to which we may apply the investigation of Chapter II.

Let the amplitude in one of these waves be a, the maximum velocity of a particle in the wave u, the frequency n, and the variation of pressure p, while the velocity of sound-wave is U and the normal pressure is P. Then, if the particle moved round in a circle on its actual path as diameter with a uniform velocity equal to the maximum u, it would go round the circle in the time of vibration in the actual path. In one second it would travel

$$u = 2\pi n a$$

But (Chapter II. p. 18)

$$\frac{u}{U} = \frac{p}{E} = \frac{p}{\gamma P}.$$

Then eliminating u

$$a = \frac{U}{2\pi n} \cdot \frac{p}{\gamma P} = \frac{4nl}{2\pi n} \cdot \frac{p}{\gamma P} = \frac{2lp}{\pi \gamma P},$$

where l is the length of the pipe.

Using the values of the quantities given above, viz.—

$$l = 30, \; p/P = 1/68,$$

and putting $\gamma = 1{\cdot}4$, we find that at the open end of the tube

$$a = 0{\cdot}2 \text{ cm.}$$

[1] *Pogg. Ann.*, cxxxiv., 1868, p. 163.

We must double this for the stationary wave, and again for the whole swing. Thus the extent of vibration is nearly 1 cm.

Another method of investigating the range of pressure has been devised by Töpler and Boltzmann. This depends on the lengthening and shortening of the path of one of two interfering beams of light, and the consequent shifting of the interference fringes by the compression and rarefaction of the air in the pipe. In a particular case, they deduced an amplitude of 0·25 cm.[1]

Mach[2] investigated the excursion directly by the following method. An organ-pipe was fixed horizontally, and along the top wall on the inside ran a platinum wire previously wetted with sulphuric acid. When the wire was heated by an electric current, a fine line of vapour descended from each drop. The pipe was closed by a membrane at the centre to prevent any through draught of air, and when it was blown, the lines of vapour were carried to and fro; one of the side walls was of glass, so that the lines of vapour could be seen, and their extent of excursion measured by a stroboscopic method. The excursion at the end of an open pipe 125 cm. long was 0·4 cm.

A very simple method of showing the vibrations in the air just outside the end of an organ pipe has been devised by Prof. C. V. Boys. The pipe, preferably a large one, is fixed in a horizontal position, with a Bunsen burner close to the open end. When the pipe is blown, the longitudinal vibrations of the air are manifested by the sinusoidal motions of the ascending incandescent dust particles in the flame.

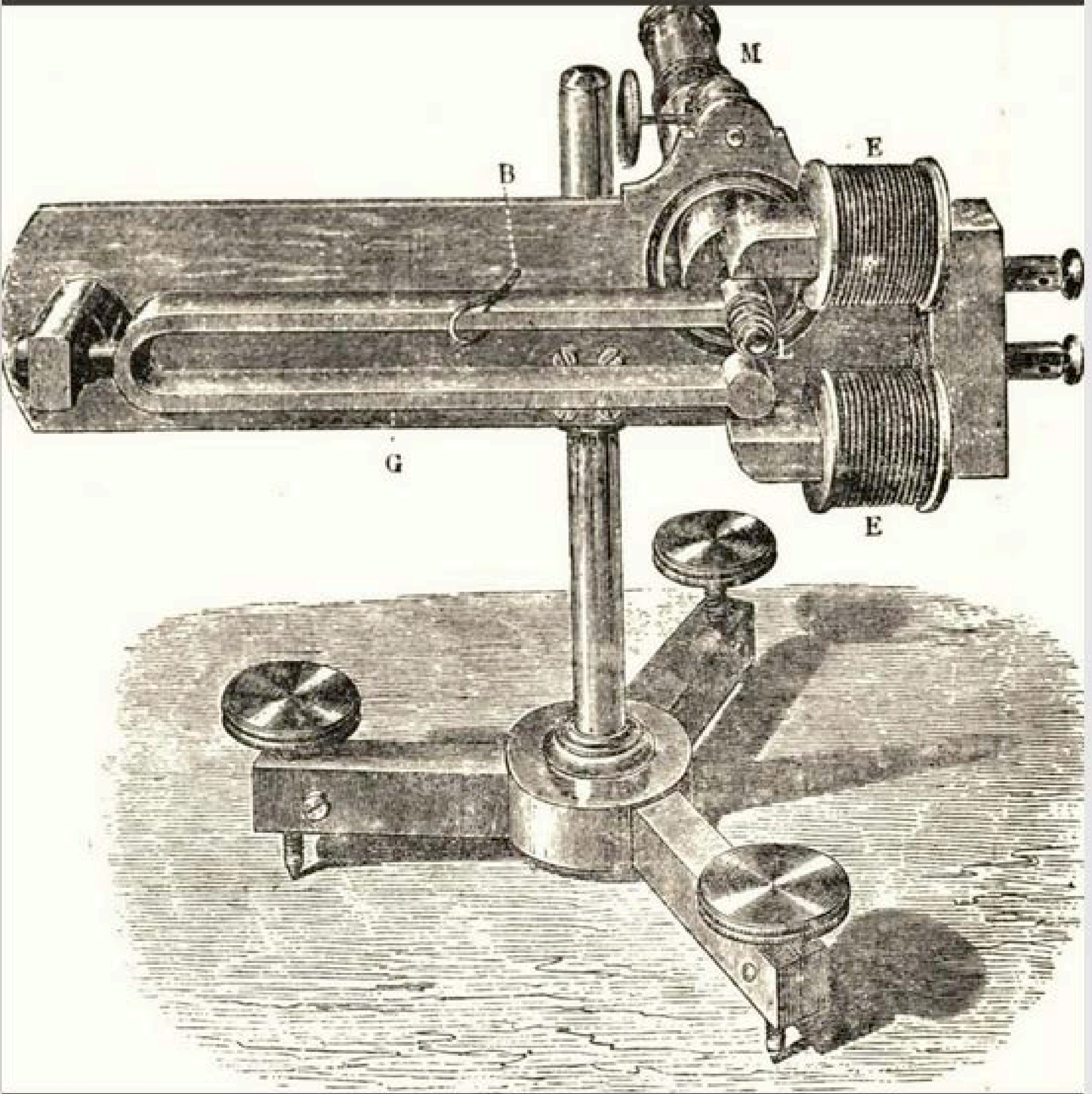
Extent of Excursion in Waves necessary for Audibility.—Lord Rayleigh[3] made an experiment on the amplitude of vibration in a sound just audible. The sound was produced by a whistle, of frequency 2730, blown by a measured current of air at observed pressure, the rate of working in producing the blast being W = 1850000 ergs/sec. nearly, and it was certainly audible at a distance of 820 metres.

Now if v is the maximum velocity of a particle in a wave, it is easy to show that the average energy, kinetic and potential, per cubic centimetre, is $\frac{\rho v^2}{2}$.

If, then, it is assumed that the energy travels out in a hemisphere in the form of sound-waves, and that v is the maximum velocity of a particle 82,000 cm. from the source, the energy passing per second through the hemisphere of that radius is $W = \pi \times 82{,}002^2 \times 34{,}100 \times \cdot 0013 \times v^2$, where 34,100 is the velocity of sound at the observed density of the air, ·0013.

This gives $v = \cdot 0014$ cm./sec. But $2\pi na = v$ where a is the amplitude and n is 2730.

[1] *Pogg. Ann.*, cxli.; Rayleigh, § 322*d*, 2nd ed. [2] *Optisch-akustischen Versuche.*
[3] *Proc. Roy. Soc.*, xxvi. 1877, p. 248; *Sound*, ii. § 384, 2nd ed.



A textbook of physics

John Henry Poynting, Joseph John Thomson

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BY

J. H. POYNTING, Sc.D., F.R.S.;

Hon. Sc.D., Victoria University;

Late Fellow of Trinity College, Cambridge; Mason Professor of Physics in the University of Birmingham.

AND

J. J. THOMSON, M.A., F.R.S., Hon. Sc.D., Dublin;

Hon. D.L., Princetown; Hon. Sc.D., Victoria;
Hon. LL.D., Glasgow; Hon. Ph.D., Cracow.

Fellow of Trinity College, Cambridge; Cavendish Professor of Experimental Physics in the University of Cambridge.

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CHARLES GRIFFIN AND COMPANY, Limited;
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