"PRODUCTION OF SOUND BY THE APPLICATION OF HEAT"

(Experimental)

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(Abstract of Retiring President's Address)

That a tone of considerable intensity may be produced by heat is not new. Lord Rayleigh in his treatise on "Sound" describes several experiments dating back as far as 1875, in one of which a sonorous sound was obtained by placing a small flame within and near one end of a glass tube. This experiment, which is referred to in all text books on physics, is known as Rijke's experiment and was possibly the best example of the production of sound by the application of heat until recently. Another example is the glass blower's bulb in which a freshly blown small glass bulb while still hot emits a clear tone as the stem is removed from the lips. Both of these instances are fully discussed by Rayleigh, yet the true explanation of the cause of the tone, especially in the latter case, is not clearly understood.

Several years ago the writer chanced to be working with Pyrex glass (the new refractory glass from which baking dishes are made) and while blowing a tube to serve as a mercury vapor trap, it, quite by accident, began to emit a clear and apparently pure tone. The emission of the note was unlooked for and came as a complete surprise. The phenomenon was as unusual as it was novel and it at once suggested a fruitful field for research. It proved to be intensely interesting and many striking and unusual phenomena were recorded.

While the "singing tube", as it came to be known, seems to be primarily of scientific and educational value, yet there is also a practical aspect. The following experiments and observations have been made:

1. The tube may have a variety of forms; however, the underlying principle of sound production is the same in all.

2. The tube under normal conditions emits a pure tone which is the fundamental, as shown by photographs of the wave form.

3. The vibrating air column is accurately one quarter of the wave-length of the tone emitted.

4. The pitch may be varied over a wide range by extending or shortening the length of the vibrating air column.

5. The air within the tube is set in violent stationary vibration.

6. Because of the purity of the tones emitted two singing tubes sounded simultaneously are well adapted for the production and study of beats.

7. This vibration results in there being a considerable back pressure at the inner end of the vibrating column.

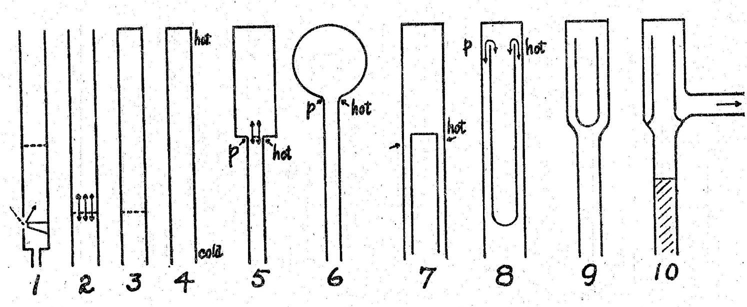
8. If the tube is lengthened indefinitely the fundamental dies out and overtones appear instead. At times the two may be heard simultaneously.

9. The intensity of the tone emitted may be increased many fold by attaching a horn.

10. Each tube has a particular point at which the heat must be applied in order that maximum intensity of sound may be attained.

11. The pitch is practically unaffected by changes in the heating temperature, while the intensity is very much increased with increase of heat.

12. The tube may be used as a standard of sound to the extent that the energy (heat) supplied can be kept



Figures 1-10
A Physical Explanation of the Action of the New Singing Tube.
By Chas. T. Knipp and Jacob Kunz, November, 1921.

constant. The best means of supplying heat is by electric current.

13. The dimensions of the various diameters of the tube are critical; however, as stated above, the various lengths are not.

14. The open end of the tube forms practically a point source of sound,—little or no sound coming from the other portions of the tube.

15. The tube when the open end is sealed is, on heating, set in violent vibration, yet it emits no sound. This vibration may be converted into sound by placing closed end on a proper resonating body.

16. The temperature difference between the cold portion and hot tip when the tune is sounding is about 400°C or 750°F.

17. The tube may be made to sing by cooling the body of tube to the temperature of liquid air, i. e. to —180°C or about—300°F, and leaving the tip (that is ordinarily heated) at room temperatures.

18. The temperature difference necessary when liquid air is used is about 200°C.

19. By extrapolation this means a temperature difference of only 80°C when the body of the tube is cooled to absolute zero.

20. Recent experiments show that the energy necessary to maintain the sound is from 2 to 3% of that supplied to the tube.

Experiments illustrating most of the above items were performed.

The following physical explanation of the action of the new singing tube is offered:*

In the organ pipe, energy is supplied by a stream of air which encourages the vibrations in a one-sided way, so that the vibrating column receives an impulse each time when the air moves upward towards the node in the middle of the pipe, Fig. 1, and receives no impulse in the opposite motion. It looks as if a pendulum were kept in oscillation by receiving at one end of its path an impulse always in the same direction. If we would apply

* In collaboration with Dr. Jakob Kunz, University of Illinois.

the momentum of the air jet at the center of the tube, vibrations of the column would be discouraged.

We can communicate momentum to a vertical open air column by heating it. If we heat the air in a tube, 2, by a wire net placed in the lower half of the tube, we will obtain a uniform current of air upwards. If the air is vibrating then as it is moving inward its vibration is increased by the momentum of the upward stream of air, but not increased by moving downward. When we place the hot wire net in the middle of the tube it will tend to increase the pressure of the gas when it is a minimum, i. e., it will discourage oscillations. The same will happen when we place the hot net above the middle. In order to encourage oscillations we have to add momentum in a position and at a moment such that the pressure in the node increases more than it would do because of the oscillations alone. If we put the hot wire net at the lower end of the tube, i. e., in a loop, the effect will be very small, or zero. The transfer of heat will depend upon the temperature of the air in contact with the wire net, being greatest when the temperature is lowest. But the temperature in the loop at the lower end does not vary; therefore, the transfer of heat in this position of the gauze does not give rise to oscillations. It tends only to raise the temperature of the gas uniformly. *Heat must therefore be applied between a loop and a node.*

If we cover the upper end of the tube, Fig. 3, with the hot net in the most favorable position, the sound ceases, and if we heat by means of a Bunsen burner the outside at the top, as in 4, we get no sound. This was considered by Rayleigh** as possible. But if we change the cross section of the tube as in 5, and heat at p, then the tube will emit a sound. The pressure in the upper half of the tube will increase, partly because the air is heated, partly because of the condensations of the air in the node on the top. The air will expand, and now the expansion in the narrow neck is aided by the air being heated by the wall. Here the oscillations are encouraged because each time when the air is expanding by the oscillation the expansion is increased by the heat. In each cycle the vibrating

** Theory of Sound, Vol. II, p. 231.

particle receives one push in the right direction. It is this one-sidedness of the action which encourages the oscillations. Moreover, as the heat here has the tendency to increase the pressure near the node, the oscillations will start very readly. A slight modification of this experment is the glass blower's bulb, 6, which emits a sound when heated round about the neck, p. Instead of making the lower part of the tube narrower, as in 5, we might proceed as in 7, where the annular area takes the place of the narrow tube, in 6. A modification of this tube is the tube of Fig. 8, which will sound when heated at p, and which is much more sensitive. It is evident from the explanation that this tube will not sing when the lower end of the inner tube is open, because the one-sidedness of the action is destroyed. Slight modifications of 8 are the tubes represented by 9 and 10. If we place a hot wire net inside the tubes 5, 6, 7, 8, 9, 10, where the hot flame was out-side, the tubes will produce a sound. In all cases, in the organ pipe, in Rijke's experiment (tube 2) and in the tubes 5-10, the oscillations of a column of air are maintained by a one-sided addition of momentum at the right moment and in the right place.

These experiments belong to a large variety of phenomena in which a direct motion is transformed into a periodic motion, or, electrically speaking, where direct current is transformed into an alternating current.