

On a Method of Mechanically Reinforcing Sounds

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1903 Proc. Phys. Soc. London 19 31

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standard wire, the masses being expressed in any single unit of mass whatever. For routine testing, where large quantities of copper have to be dealt with, the average time of a test for a long series of tests has by this instrument been reduced to 18 seconds, with the *diameter* method. The theory and the mechanical details of the instrument are fully described in the 'Proceedings of the Institution of Civil Engineers,' vol. cliv. Session 1902-1903, part iv. It is clear that the principle above described for compensating for differences of diameter can be applied to potentiometer work generally. If conductivity is assumed constant, the instrument can be used as a very sensitive micrometer.

IV. *On a Method of Mechanically Reinforcing Sounds.*

By T. C. PORTER, M.A.*

[Plate III.]

It is now about ten years since a friend, Mr. A. J. Jex-Blake, first drew my attention to the fact that if a small tuning-fork be struck and then held in the flame of a bunsen-burner the loudness of its note is very materially increased; at that time the explanation, though simple, did not occur to me, and although I mentioned the fact to two or three physicists, they did not suggest the cause.

That the phenomenon is not a case of ordinary resonance is proved by the fact that no increase in the loudness of the note is observed if the fork is held over the burner, either with or without the gas turned on; nor when the length of the tube of the burner is altered so that it would naturally respond, when filled with the mixture of gas and air, to the pitch of the fork employed. There is, in this case, some resonance, but it is very much fainter than the reinforcement we are considering.

Further, if the fork be held in the luminous flame from the same burner, caused by stopping up its holes, the sound is slightly louder, so that it is the action of the rarefactions and condensations of the sound-waves in the *burning* mixture

* Read December 11, 1903.

FIG. 3.

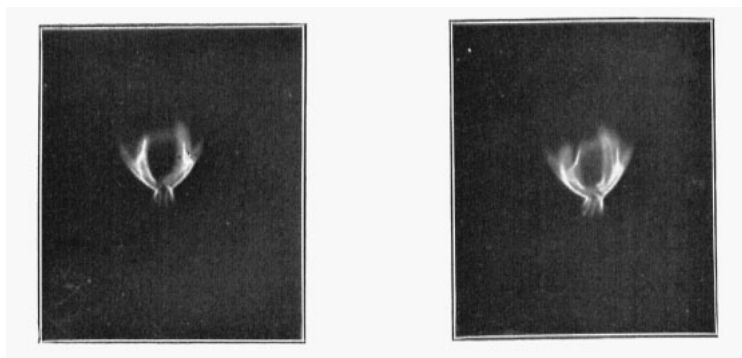
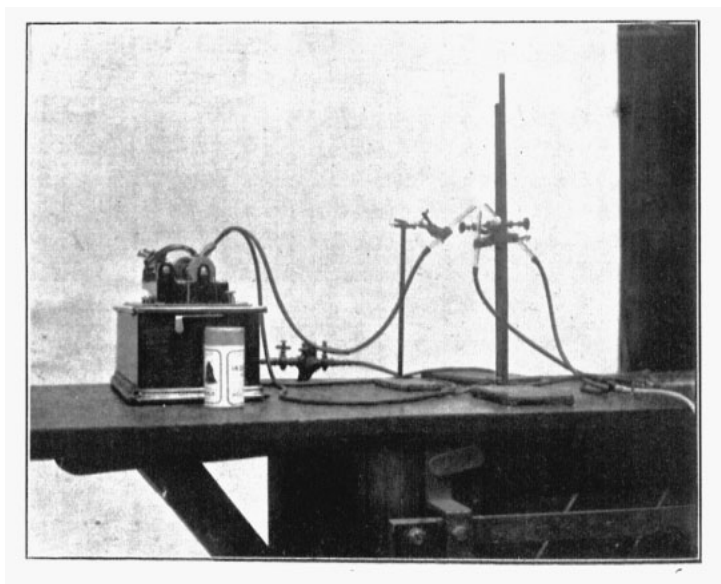


FIG. 4.



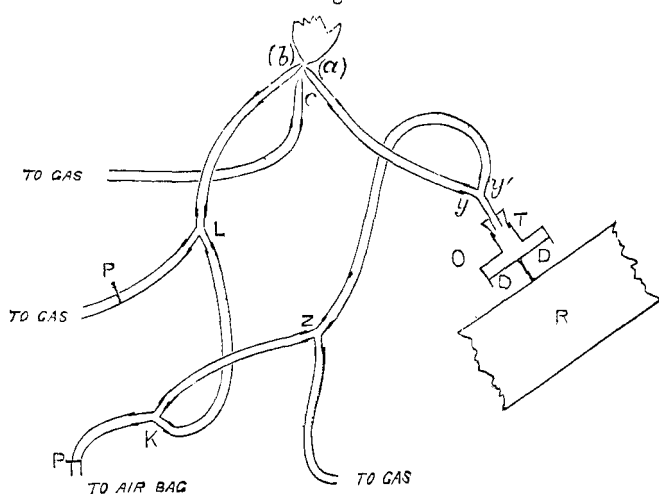
of gas and air which gives rise to the increased loudness. The following experiment shows this admirably. A piece of wire gauze is supported about three-quarters of an inch above the bunsen, and the issuing mixture of gases ignited above the gauze, and the supply of gas and air so adjusted that the flame is all blue, and nearly quiet; if the fork be then held in the flame there is a very marked increase of loudness, whilst if it be held, as it easily can with a little care, between the gauze and the top of the burner, there is scarcely any augmentation of the sound.

If the various parts of a bunsen flame be explored with a sounding fork it will be found that there is the greatest effect in the hottest part of the flame, *i. e.* in that part where the most rapid chemical action is proceeding, and if experiments are made to compare the effects of the luminous and nonluminous flames of the same bunsen-burner, it appears that the latter is the more energetic, though the reinforcement caused by the former is very considerable. The effect of the sound-pulses is probably therefore to change the continuous flame of the burner into one which is more or less discontinuous, each condensation and rarefaction being attended by a corresponding increase and diminution of the rate at which the gas and air are burning, and in many cases it is easy to convince oneself that this is really the case by viewing the flame in the rotating mirror, when the appearance of the flame is similar to that of the flame in experiments such as the chemical harmonicon or Koenig's vowel flames; indeed the explanation of the effect of the sounds upon the flames in those experiments, and in those to be described, is very similar. In the well-known experiments just mentioned, however, and in Tyndall's and Rayleigh's work on sensitive flames, the flames *themselves* do not sensibly reinforce the sounds to which they are sensitive. In the chemical harmonicon, for example, in which the flame burning in an open tube may be made to give a loud note by a weak note of the same pitch sung outside the tube, it is the vibration of the *air* in the tube to which the *loudness* is due, and the note itself is chiefly determined by the dimensions of the tube. In my experiments, however, each sound-wave determines what may be called an explosion, which

may give to the air a pulse of very much greater amplitude than that of the corresponding sound-pulse, and the succession of these explosions may thus reinforce the sound enormously. Three of the conditions for the maximum effect are obviously (*a*) that the mixture of gas and air shall be that for maximum force of explosion, (*b*) that each explosion shall consume as great a mass of the explosive mixture as possible, and (*c*) that the form of the flame during the explosion shall be such as to spread the disturbance through the air as advantageously as possible.

I have used for the source of the sounds an ordinary "Home" Edison-Bell phonograph, with the "reproducer" sold to be used with the instrument. In this, as every one knows, the roughnesses of the "record" make a rod vibrate up and down, and these vibrations are communicated purely mechanically to a thin disk of glass or mica, which in turn

Fig. 1.



transmits them to the air on the side of the disk remote from the rod; the aerial disturbances are then conducted by means of a tube, usually to a trumpet, but in the experiments here described the reinforcement of the sounds is obtained by the combustion of coal-gas and air, and the method in which I have obtained the best results will be next described. The arrangement can most easily be understood from fig. 1.

R is the "record," DD is the vibrating disk, T is the short metal tube on the upper side of the "reproducer," which is generally connected by a short piece of tubing with a trumpet. In this case, however, it is closed with a pierced cork, into which fits a "Y" connector, one branch of which, *y*, is connected by tubing to the jet "*a*," whilst the other branch, *y'*, is joined to a second Y-fork, called in the diagram Z; of the two remaining branches of this one leads to an ordinary gas-supply nozzle, whilst the other is joined to a third Y-piece, the stem of which is connected with a large gas-bag, containing air under very considerable pressure (generally a cwt. and a half being placed on the pressure-boards). The third arm of this Y-piece, namely K, leads to a fourth Y-piece "*L*," the stem of which is joined to the jet "*b*," whilst its other arm is connected to a second gas-supply nozzle. A small third jet *c* rises vertically beneath the other two, and almost touches them; this is joined by tubing to a third gas-supply nozzle. P, P, P, are screw pinch-cocks. The jets I have used have hitherto been made of

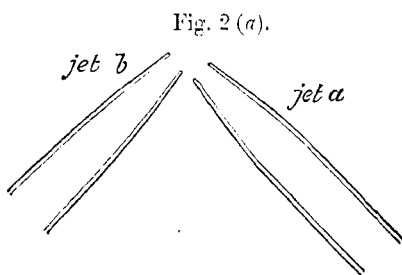


Fig. 2 (b).



glass, and in fig. 2 they are drawn life-size—in (a) a vertical section, in (b) as seen when viewed from a point immediately above them. In both these figures the relative positions and dimensions of the jets have been carefully depicted. The third jet *c*, fig. 1, is an ordinary glass jet, and, so far as I have seen, need not be of any special dimensions or shape, but *b* and *a* should be made as nearly as possible as drawn. Ordinary black indiarubber-tubing serves well for the connexions, and for the three-way pieces, those sold by the Edison-Bell Phonograph Co., 39 Charing Cross-road, serve

very well. In using the apparatus the gas should be turned on first, and lit at the jets (*a*) and (*b*), and these, if of glass, should be allowed a little time to grow warm before the pinch-cock admitting air from the gas-bag to the jets is unscrewed: this should be done very gradually, and the gas and air which issues at jet (*a*) adjusted until the issuing flame is quite blue. The jet *c* should then be lighted and turned down very low. Jet *b* is then brought into the position in which it gives the loudest sound, and the final adjustment of the gas and air passing through (*b*) made by very gradually opening the pinch-cock which regulates the supply of air from the bag: if the reinforcement of the sound is still unsatisfactory, the supply of gas to (*b*) should be gradually shut off. In some instances the best results are obtained when almost pure air is issuing from *b*. If the jets hiss and roar, as they are at times wont to do, *c* may be turned up a little higher, or the position of jet *b* may be very carefully shifted farther into, or away from the flame from jet *a*, or moved slightly from or towards jet *a*: in practice the adjustments are not difficult, and when all is right the reinforcement of the tones of the phonograph is very striking, being quite equivalent to the use of a small trumpet, and easily heard all over a fairly large room. Fig. 3 (Pl. III.) is the stereoscopic photograph of the flame, '37 times life-size, when it is in a condition to "play" well, and fig. 4 is a photograph of the general arrangement of the apparatus taken whilst the flame was "playing."

It will naturally be supposed that if pure oxygen is used instead of air the results will be better: I have made the experiment, with the expected result, but the difference is not so great as one would expect, and in practice the manipulation of the jets is made so much more difficult, to say nothing of the increased cost, that I do not recommend the experiment. Ethylene and acetylene in place of coal-gas I have not tried, but there is no reason for supposing that they would yield much better results than those already obtained.

It would be unnecessary and tedious to describe all the experiments which led me to adopt the above arrangement, but there are one or two of interest that it may be as well to mention. If jet (*a*) in fig. 1 is used alone, the branches of the three-way piece *Z* being put into connexion with the

air-bag and the gas supply respectively, a common blowpipe-flame can easily be obtained from (a), and this will be found to sing, but not nearly so loudly as the flame already spoken of: the blue tip of the inner cone can be seen shooting in and out as it emits the different sounds. If now a thin sheet of platinum-foil be brought into this part of the flame, the sound is very markedly reinforced, the tones given out by the hot platinum being very "round," smooth, and pleasant to the ear, though, as I have already said, they are not loud. I attribute this reinforcement to the rapid expansion and contraction of the platinum in response to the variation in the heat of the flame caused by the sound-waves from the phonograph, and not to simple reflexion of these waves from the platinum surface. The well-known surface action of the metal may also play some part in the phenomenon, although there is no reinforcement, if, whilst the platinum is in position and sounding, the blowpipe-flame is blown out: the platinum, under these circumstances, remains at a yellow heat, from the combustion of the unignited gas and air on its surface, but there is no sound until the flame is rekindled.

Finally, the action of the flame in reinforcing sounds originally of equal loudness but of different pitch deserves notice. This can be generally stated as follows:—The smaller the flame the more rapid the current of air or of gas, or of both; or the more jet (b) is made to encroach on jet (a) in fig. 2 (b), the higher is the pitch to which the flame most readily responds and reinforces, and *vice versa*: but it is very remarkable how wide a range of pitch the tones may have which are reinforced at one and the same time, so that it is possible and easy in the case of a phonograph record in which the high-pitched notes have been recorded too strongly, to lessen their loudness, or, indeed, to eliminate them altogether without seriously interfering with the other notes: on the other hand, if it is the base which is too prominent, this may be reduced, whilst additional strength is added to the treble.

I do not think that it is too much to say that these facts*

* *Note*.—Since the reading of this paper, the writer has been much indebted to Mr. Chichester Bell for calling his attention to a communication of Mr. Bell's, read before the Royal Society, and published in the 'Transactions' of that Society, 1886, Part 2, and entitled "The Sym-

place at our disposal a method of reinforcing sounds possessing some special advantages, and may prove capable of increasing faint sounds so that many can hear them at once, to a degree beyond that attained by any other method at present known.

Eton, Oct. 1903.

DISCUSSION.

MR. CHICHESTER A. BELL, in a letter to the Secretaries, expressed his interest in the subject of the paper and pointed out that the literature dealing with the vibrations of jets and flames was very extensive. He believed that all the phenomena described by various writers, including the author, were referable to the simple fact that any impulse communicated in any way whatsoever to a jet at the orifice from which it escapes, produces a disturbance which tends to increase as the jet travels onwards until finally it causes complete disintegration. He had investigated the matter at length in a paper on "The Sympathetic Vibrations of Jets," published in the Phil. Trans. for 1886, and shown that jets or flames or combinations of them may be made to reproduce sounds of all kinds and of a wide range of period. He felt

pathetic Vibrations of Jets." It appears that as early as 1866 Kundt obtained musical tones by the impact of two flames, and of an air-jet against a flame. Barrett and Tyndall were apparently the first to notice that a sensitive flame sometimes reproduces the tones by which it is affected. In 1875 Decharme found that carbon dioxide blown through a jet against a flame gave a feeble effect, and attributed this to the decomposition of the CO_2 —a chemical explanation. He also found that pure oxygen gave only a feeble effect in comparison with air, and that nitrogen gave no effect at all. Mr. Bell himself, by boring a small hole in a telephone-plate, and forcing through it, at a gentle pressure, a stream of air which impinged on a small flame, *reinforced* the otherwise inaudible sounds of the telephone till they could be distinctly heard over a small room. The explanation of the reinforcement,—founded by Mr. Bell on a long series of delicate and beautiful experiments, including the measurement of the relative pressures at different points in and near the jets,—seems to be a purely physical one. The actual experiments as described in the present paper are, however, new, so far as the author can ascertain—though Mr. Bell has experimented on the use of flames in connexion with the graphophone, and took out a patent thereon in 1886.

assured, however, that Mr. Porter had worked the matter out for himself *ab initio*.

Mr. W. DUDELL suggested that the flame was in a condition of instability, so that any disturbance created in it tended to increase in amplitude. If the energy for the increased sound came from the tuning-fork, and the flame simply acted as a trumpet, then the fork would be rapidly damped; but if the flame was unstable the tuning-fork would not be so rapidly damped. He asked the author if he had tried experiments on this point.

Prof. A. S. HERSCHEL referred to the ways in which energy could be transmitted by a gas (1) by a flow, and (2) by the passage of undulations. The second method was concerned in the experiments shown by the author. In reply to a question by Prof. Ayrton, he said he did not think that the increased sound was due to an increase in the amplitude of vibration of the tuning-fork.

Mr. D. J. BLAILEY asked if the flame could be so adjusted or used as to restore to its original form a compound wave which in passing from the phonograph had suffered distortion by strengthening of the upper partials through unequal resonance; and further, if the flame had any such power, did its action go so far as to reduce the wave-form to that of a pure tone? (The Chairman pointed out that in the experiments shown with the phonograph the distinctive character of the notes emitted by the various instruments could be easily recognized.)

Prof. H. L. CALLENDAR referred to Prof. Dixon's experiments on the propagation of explosive waves through gases. These waves had been photographed, and proved that the passage of a detonation-wave through an explosive mixture caused a local heating, shown by a corresponding brilliance in the photograph. Complicated effects were produced by the meeting of a detonation- and a retonation-wave, but in every case there was an increase of chemical action in the flame. He suggested that the behaviour of the platinum foil in the blowpipe-jet might be ascribed to the meeting of such waves.

Mr. PORTER, replying to Mr. Duddell, said a tuning-fork was unquestionably rapidly damped when placed in a flame.

With regard to Prof. Callender's observations, he said he had looked in vain for anything corresponding to the existence of loops or nodes in the flame. Referring to Mr. Blaikley's remarks, he said that a small flame reinforced the high notes better than the lower ones and *vice versa*.

V. *The Simmance-Abady "Flicker" Photometer.*
By Messrs. SIMMANCE & ABADY *.

[Plate IV.]

THIS photometer is of the alternating-light type, recently called in France "scintillation-photometer," but more generally known in America and England as "flicker."

A very long experience with all the known variations of "flicker" photometers, and the construction of many others of different patterns, resulted in the design of the present instrument, and enabled actual rules to be laid down, which when adhered to produce a photometer which is most sensitive to degrees of lights of the same colour, and also enable the intensities of the most violently contrasted tints to be compared and balanced.

These rules are as follows:—The light effects must be in juxtaposition without any apparent division line, and must move, oscillate, or rotate so that the point of juncture of the rays of the two lights passes and returns entirely across the vision-field. Any hiatus, or longer exhibition of one light than the other, biases the result. The observation surface or surfaces upon which the light rays fall, must be at exactly the same distance from the eye, at exactly the same angle in relation to the line of sight, and must be of pure white such as is afforded, for example, by a clean chalk, plaster of Paris, magnesium carbonate, or barium sulphate; any tint affects the accuracy of the result. The observation surfaces must also themselves in turn occupy the field of vision; an apparent movement or optical illusion does not afford accurate results.

* Read December 11, 1903.