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The Registrar General for Ireland.

The Society adjourned over the Long Vacation to Thursday, November 17.

"On Approach caused by Vibration." By Frederick Guthrie, B.A. Communicated by Prof. G. G. Stokes, Sec. R.S. Received August 26, 1869*.

§ 1. The chain of experiments which I have to describe arose from the endeavour to explain an observation that a delicately suspended piece of cardboard moves, from a considerable distance, towards a vibrating tuning-fork. It will be preferable to detail the experiments, not in the order in which they occurred to me and were actually performed, but in the order in which I conceive them to form a logical sequence.

§ 2. The experiment of Clement shows that when a continuously renewed current of air passes between two parallel disks from the common axis towards the circumference, the disks are urged together. Consequently, in seeking to explain the fact observed in § 1, it was necessary to examine the air surrounding the resonant fork in order to ascertain whether air-currents existed in its neighbourhood; and further, to distinguish between such currents as might be found to move in closed curves forming whirlwinds in the immediate neighbourhood of the fork, and such as might radiate in unclosed paths from the fork through the air.

§ 3. In 1831 Mr. Faraday†, in tracing the cause of the accumulation of light particles on the internodal points and lines of vibrating bodies, came to the conclusion that such accumulation was due to minute whirlwinds, and not, as had been held by M. Savart‡, to the existence of secondary nodes. A general conclusion at which Mr. Faraday arrived was this: whenever the different parts of a surface are vibrated to different degrees, there is always a tendency for the air to flow along the surface of the vibrating body towards the more violently agitated portions from the less agitated.

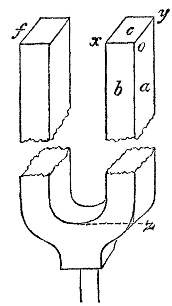
§ 4. It is clear that, before examining the possible connexion between these superficial whirlwinds and the fact mentioned in § 1, it is necessary to examine into the existence of air-currents of unclosed paths.

* Read Dec. 17, 1868. See abstract, vol. xvii. p. 106.

† Phil. Trans. 1831, p. 299.

‡ Ann. de Chim. et de Phys. t. xxxvi. pp. 187, 257.

Fig. 1.



The tuning-fork which was most employed, and which I call fork A, gave 128 complete vibrations per second, and had the following dimensions :—

mètre.

$o\,y = 0{\cdot}0230,$
$o\,x = 0{\cdot}0172,$
$o\,z = 0{\cdot}3255.$

I call the three faces intersecting in *o*, the faces *a*, *b*, and *c* respectively. Let the symbol H_c, &c. denote the position of the fork when the face *c* is horizontal, &c.

§ 5. *Experiment* 1.—The fork A was set vibrating by drawing the bow across the edge *o y*; the plane of vibration was accordingly parallel to *b*. The fork was then brought into the neighbourhood of an ascending thread of smoke. The fork and smoke had in succession the three relative positions :—

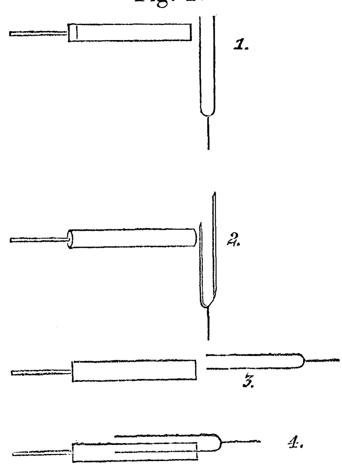
(1) H_b. The smoke passed across the face *a* parallel to *o y*.

(2) H_a. The smoke passed across the face *b* parallel to *o x*.

(3) H_a. The smoke passed across the face *c* parallel to *o x*.

In all cases the smoke clung to the surface across which it passed as though the fork were at rest.

Fig. 2.



§ 6. *Experiment* 2. — A cylindrical glass tube T, 0·4 m. long and 0·042 m. in internal diameter, was fastened (fig. 2) in a horizontal position. One end was left open, the other carried a cork, through the centre of which passed a horizontal tube *t*, 0·04 m. long and 0·0035 m. internal diameter. These tubes were filled with smoke, and the fork A, which had been set vibrating as in § 5, was brought to the open end of the wide tube. The fork and tube had in succession the four relative positions shown in fig. 2, namely :—

(1) H_c. Axis of tube perpendicular to *a*.

(2) H_c. Axis of tube perpendicular to *b*.

(3) H_a or H_b. Axis of tube perpendicular to *c*.

(4) The same as (3), but having one prong of the fork thrust as far as possible into the tube T. In none of the cases did the smoke show any tendency to escape through the tube *t*, nor was fresh air drawn in.

§ 7. *Experiment* 3.—The cork and tube *t* of experiment 2 were with-

drawn and replaced by a film-bubble of glycerine-soap-water. The combinations of position of experiment 2 were repeated. In none of the cases did the bubble show any variation from the vertical plane.

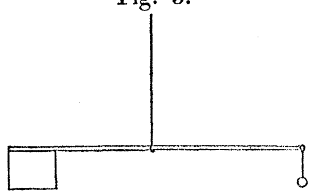
§ 8. Hence I conclude that when a tuning-fork is in a state of plane vibration, no permanent true air-currents are formed; that is, no air-currents could be detected departing from any side of the fork and penetrating the surrounding air in unclosed paths.

§ 9. The superficial whirlwinds examined by Mr. Faraday may be supposed to be greatly modified when they are excited in the immediate neighbourhood of a solid body; and as the "attraction" which formed the starting-point of the present examination (§ 1) is exerted upon a solid body in the neighbourhood of the resonant fork, some experiments, supplementary to those of Mr. Faraday, were found necessary.

§ 10. Numerous experiments, which need not be here detailed, showed (1) that Mr. Faraday's surface-currents, as exhibited on a freely vibrating fork, are very much modified when the fork vibrates in the immediate neighbourhood of a rigid plane, and (2) that the effects of any currents produced by vibration do not extend sensibly beyond 0·006 m. from the fork's face, and only even to this extent near the *a* face.

§ 11. We shall see that the existence of such air-circuits, confined as they are to the immediate vicinity of the fork, are quite insufficient to account for the class of phenomena which have to be described, and which are similar to the fundamental fact mentioned in § 1.

Fig. 3.



§ 12. *Experiment* 4.—To one end of a splinter of wood, 0·5 m. long, a card 0·08 m. square was fastened in such a way that the plane of the card was vertical, and contained the line of the splinter. The whole was hung from a fibre of unspun silk (fig. 3) and counterpoised. The tuning-fork A was set in vibration as before, and was brought towards the card in the three relative positions corresponding to those of § 6, namely:—

(1) (H_c). The face *a* parallel to the card.

(2) (H_c). The face *b* parallel to the card.

(3) (H_a or H_b). The face *c* parallel to the card.

In all three cases the card moved towards the fork. The rate at which the card moved was greatest when the fork was sounding loudest. In all three cases it was possible to draw the card from a distance of 0·05 m. at least,—a distance quite beyond the direct influence of the superficial whirls which exist in position (1) (on face *a*).

§ 13. There is perhaps nothing essentially contrary to reason in the conception of two bodies in space free to move, so related to one another that while the first has no tendency to move towards the second, the second has a tendency to move towards the first. But if the tendency of the one

to move be caused by the condition of the medium between the two, it seems inevitable that the tendency shall be mutual. Thus, if that tendency result from a general diminution in the tension of an elastic medium between the two, they will be urged towards one another. To test the reciprocity of the motive tendency in the case under consideration the following experiment was tried.

§ 14. *Experiment 5.*—The tuning-fork A was fastened to the end of a rod 1·0 m. long; the other end of the rod was counterpoised, and the whole was hung from a silk tape. If the vertical plane passing through the rod be called V, then the rod and fork received in succession the relative positions,—

(1) (H_c). V parallel to *a*.

(2) (H_c). V parallel to *b*.

(3) (H_a or H_b). V parallel to *c*.

In (1) and (2) the fork was simply hung from the suspended rod; in (3) it was fastened to an iron rod in the direction of its axis, and the two were then attached to the suspended rod at their common centre of gravity. The fork was sounded by the bow as before, and a piece of card 0·05 m. square was brought near the face *a* (in 1), *b* (in 2), and *c* (in 3). In all cases the suspended fork approached the card; but, owing to the great inertia of the suspended fork and counterpoise, the motion was much slower and less striking than was the case when the card was hung.

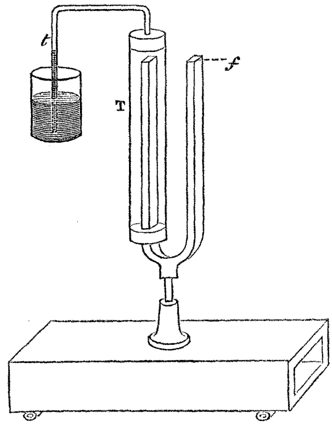
§ 15. *Experiment 6.*—Further, instead of a card, a second fork, B (sounding A), was set in vibration, and brought into the neighbourhood of the vibrating suspended fork A. The three faces *a'*, *b'*, *c'* of the fork B were held in succession parallel to the three faces *a*, *b*, *c* of the fork A, that is parallel to V when the faces *a*, *b*, *c* were in each of the three positions described in § 14. There were thus nine combinations effected. In every case the suspended fork approached the stationary one. Hence, to whatever cause the approach is due, the action is mutual.

§ 16. The next question, the solution of which promised to throw light upon our problem, was this: What is the general or mean condition as to tension of a medium in which undulations are generated? Though this question has received very great attention from theoretical physicists, it has not been approached, as far as I am aware, from the side of experiment in the manner to be described.

§ 17. *Experiment 7.*—The fork A was fixed in an upright position in its sounding-box (fig. 4). One of its prongs was enclosed in a glass tube T, 0·4 m. long, and 0·042 m. internal diameter, carrying a cork through which the prong passed. The upper end of T also carried a cork, through which passed a narrow tube *t*, bent twice at right angles, and dipping into water. The internal diameter of *t* was 0·0035 m. The corks of the tube T were made tight with wax, and a little air was expelled from the tube T by warming it with the hand, so that when the atmospheric temperature was regained, the water stood at some distance up the tube *t*. The tube *t*

was firmly clamped in several places to prevent vibration, and consequent centrifugal effect. On passing the bow across *f*, the enclosed prong was also set in vibration. When the amplitude of the vibration was as great as possible, the water had sunk in the tube *t* to the amount of 0·003 m. The moment both prongs were suddenly stopped the level of the water in *t* was restored. The depression of the water in *t* cannot be due to increased temperature; for, if it were so, the increase of volume would be gradual and accumulative, and, on stopping the vibration, the contraction due to cooling would be also gradual; whereas the attainment of maximum depression and the restoration to normal volume are practically instantaneous.

Fig. 4.



§ 18. We have here accordingly an experimental proof that the rapid motion (in this instance vibration) of a body in a medium produces on the whole an effect similar to that which would be produced by the expansion of the body, namely, a displacement of the medium. If air were perfectly elastic and had no inertia, no such total displacement could ensue, and I think I may safely predict that the apparent expansion of the medium will be found, in the case of hydrogen less, and in the case of carbonic acid greater than in that of air*.

§ 19. Though we know the dimensions of the fork and its rate of vibration, and though we can measure with tolerable accuracy the amplitude of its vibrations, we can only calculate from this the mean velocity of any given point, because in the middle of a vibration the fork is moving very much faster than towards the commencement or termination. Hence this vibratory displacement cannot, with our present data, be connected with the known rate at which air enters a vacuum.

§20. The fundamental experiment of §§ 1, 12 next suggested for its explanation the following question. Let there be two equal and opposite forces, P and Q, producing equilibrium upon a body having inertia; let one of them, P, be increased and diminished by a series of equal increments and decrements following one another in rapid succession. Will the continually varying force, whose mean is P, maintain average equilibrium with the unaltered force Q? The plane of the cardboard in § 1 and § 12 is the seat of two opposing forces, namely the pressure of the atmosphere on both sides. When the sounding-fork is held on one side, the pressure on that side undergoes successive equal increments and decrements. Accordingly, if the question just proposed be answered in the negative, a suffi-

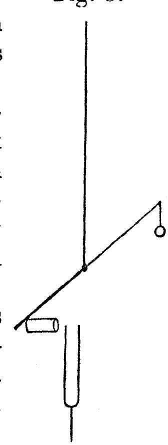
* Compare the sighing of an organ pipe after it has been sounded.

cient ground would be at hand for the approach of the cardboard to the fork.

§ 21. *Experiment* 8.—A "Cartesian diver" was made out of a test-tube, a bubble of air, and a beaker-glass of water. This was so nicely adjusted that it rose when near the surface of the water, and sank when the top of the tube was 0·05 m. below the surface. When resting on the bottom of the beaker, the top of the test-tube was 0·067 m. below the surface of the water. When the diver was resting on the bottom of the beaker, the tuning-fork A, in a state of vibration, was presented to the glass in various directions with regard to the tube. The fork was placed sometimes in contact with the water, sometimes in the neighbouring air, and sometimes in contact (towards the base of the fork) with the glass. Although the vibration of the bottom of the beaker caused the diver to leap up it invariably sank again, and showed no sign of undergoing any alteration in specific gravity. If, now, the question in § 20 were answerable in the negative, the equilibrium would have been destroyed, because the atmosperic pressure on the one hand, and the elasticity of the confined air on the other being equal and opposite forces, an alteration in one caused by its subjection to successive sonorous waves, would have altered the volume of the confined air and so destroyed the equilibrium.

§ 22. I hoped to throw light upon the fundamental experiment of § 1 and § 12, by varying the nature of the surface of the body which received the vibrations, with the view on the one hand of preserving them, and, on the other, of dispersing them as much as possible. With this view experiments 9–12 were undertaken.

Fig. 5.



§ 23. *Experiment* 9, fig. 5.—Upon one end of a splinter of wood 0·5 m. long, a cylinder of cardboard 0·03 m. in diameter and 0·04 m. deep, closed at the bottom, was fastened in such a manner that its axis was horizontal, and its bottom in the plane V. The cylinder was counterpoised, and the whole was hung from an unspun silk thread. The vibrating-fork A was brought near the open end of the cylinder in the three positions already described, and also with one prong inserted into and nearly touching the bottom of the cylinder. In all cases motion towards the fork ensued.

§ 24. *Experiment* 10.—A handful of cotton-wool was hung upon the splinter in place of the cylinder of experiment 12. The cotton-wool moved towards the fork from a distance of at least 0·05 m., when the latter was presented to it in either of the three positions, § 8.

Muslin and washleather behaved in a similar manner.

§ 25. *Experiment* 11.—A circular paper drum 0·25 m. in diameter having a rim 0·025 m. deep, was hung by a silk tape in the same manner as the cylinder of § 23. Parchment was stretched across the wide end of

a funnel 0·2 m. in diameter. The neck of the funnel was placed in the mouth, and the drum of the funnel was brought opposite and parallel to the edged face of the paper drum. Air was rapidly forced into and drawn out of the funnel. The paper drum moved towards the funnel even from a distance of 0·1 m.

§ 26. *Experiment* 12.—A sheet of cardboard 0·4 m. square was hung in the plane V from a rod 1·0 m. long. The cardboard was counterpoised, and hung from a silk tape. The paper drum of § 25 was placed 0·05 in. from the cardboard, and parallel to it, and was then thipped. The cardboard moved towards the drum.

§ 27. *Experiment* 13.—A rod of brass 1·2 m. long, provided at the ends with disks of brass perpendicular to the rod 0·26 m. in diameter, was set in longitudinal vibration by means of resined leather. One of the disks was held, during the vibration, near to the cardboard of § 26, also near the cotton-wool and muslin of § 24. In all cases the suspended body moved towards the disk. By this means it was easy to cause motion when the two were at the distance of 0·2 m.

§ 28. I have in the foregoing paragraphs sought to eliminate systematically secondary and disturbing influences from the fundamental experiment. The experimental results appear to me to point to the following conclusions.

Whenever an elastic medium is between two vibrating bodies, or between a vibrating body and one at rest, and when the vibrations are dispersed in consequence of their impact on one or both of the bodies, the bodies will be urged together.

The dispersion of a vibration produces a similar effect to that produced by the dispersion of the air-current in Clement's experiment, and, like the latter, the effect is due to the pressure exerted by the medium, which is in a state of higher mean tension on the side of the body furthest from the origin of vibration than on the side towards it.

In mechanics,—in nature there is no such thing as a pulling force—though the term attraction may have been used in the above to denote the tendency of bodies to approach, the line of conclusions here indicated tends to argue that there is no such thing as attraction in the sense of a pulling force, and that two utterly isolated bodies cannot influence one another.

If the ætherial vibrations which are supposed to constitute radiant heat resemble the aerial vibrations which constitute radiant sound, the heat which all bodies possess, and which they are all supposed to radiate in exchange, will cause all bodies to be urged towards one another.