EXPERIMENTAL RESEARCHES

ON THE

MOVEMENT OF ATMOSPHERIC AIR IN TUBES.

By W. D. CHOWNE, M.D.

BEING AN ABSTRACT OF A PAPER READ BEFORE THE ROYAL SOCIETY JUNE 21, 1855.

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r the year 1847, the author of this paper made numerous expe-ments for the purpose of ascertaining what are the conditions under hich atmospheric air is placed with regard to motion or rest, when ithin a vertical tube having one extremity communicating within e interior of a building, and the other in the open atmosphere.

The paper now submitted to the Royal Society contains the results investigations undertaken in the year 1853 and continued to the esent time, to ascertain whether the ordinary state of atmospheric contained in a vertical cylindrical tube, open at both ends, and aced in the still atmosphere of a closed room, is one of rest or of otion; and if of motion, to investigate the influences of certain anges in the condition of the atmosphere which either produce, omote, retard, or arrest the movement.

He demonstrates, by a series of experiments, that when a tube, en at both ends, is placed in a vertical position, every precaution ing taken to exclude all extraneous causes of movement in the surrounding atmosphere, an upward current of air is almost immediately established, and continued so long as these conditions are maintained.

The experiments were made in a room 12 feet square by 8 feet 6 inches high; the window and chimney being carefully secured, and all crevices closed, by pasting paper over them, the floor carpeted, the door double, and the inner door surrounded with list. The outer wall, having a north aspect, was so sheltered by surrounding buildings that the direct rays of the sun never fell upon the window. Discs of delicate tissue-paper were suspended in several parts of the room, to indicate currents of air, if any existed, and observations were taken only when these were perfectly quiescent.

Mason's hygrometer was first employed in these experiments, to test the presence of a current of air in the tube; on the principle that as evaporation produces cold, and as evaporation is increased by a current of air, the wet-bulb thermometer would show a greater depression if any current existed, than if the air were perfectly quiescent within the tube. The tube (fig. 1) was placed in the middle of the room, and isolated from the floor by a cylinder of thick glass laid under it.

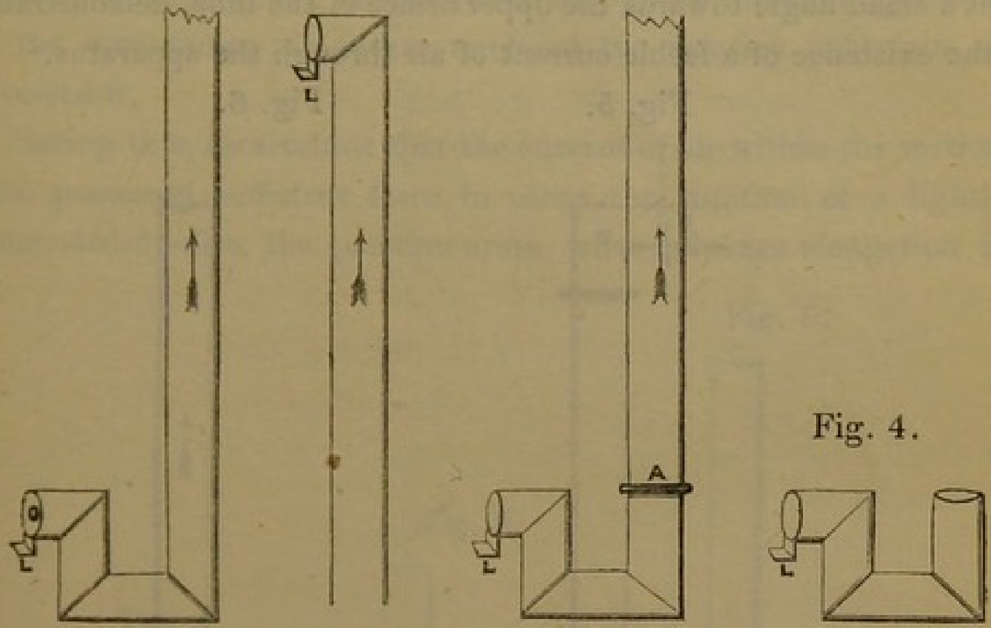
It was found that in ninety-one observations of the hygrometer, suspended in the free air of the room, the mean depression of the wet-bulb thermometer was 3°·9 Fahr., while in ninety corresponding observations, with the hygrometer at the lower aperture, O, of the tube, the mean depression was increased to 4°·9 Fahr., clearly indicating the existence of a current of air within the tube.

Partial closure of the upper orifice of the tube, by placing a piece of fine muslin upon it, produced a sensible influence on the hygrometer. In seventeen observations with the tube thus partially obstructed, the mean depression was 2°·5 Fahr.; but in an equal number of comparative observations, with the tube perfectly free, the mean depression was increased to 3°·12 Fahr.; showing a considerable diminution of the force of the current within the tube, as a result of the partial obstruction of its upper aperture.

Similar comparative observations, with the hygrometer placed at the upper aperture of the tube (fig. 2), yielded similar results.

In these experiments the lower extremity of the vertical tube was bent thrice at right angles*, for convenience in making the observations, and it appeared desirable to ascertain what influence the long branch of the siphon-like tube had in the production of the cur-

Fig. 1. Fig. 2. Fig. 3.



L. A ledge or step to place the hygrometer upon.
O. Orifice against which the bulbs were placed.

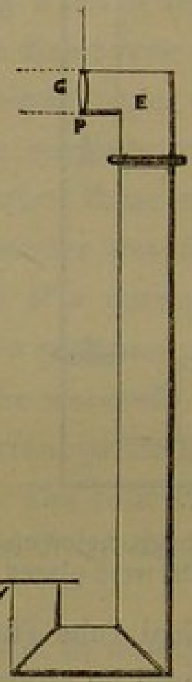
rent. For this purpose the long vertical tube (fig. 3) was made moveable at A, so that the apparatus could be alternately converted into a siphon with equal limbs 4 inches in length (fig. 4), or one with a short leg of 4 inches, and a long one of 96 inches (fig. 3). In twelve observations, when the long leg was inserted, the mean depression of the hygrometer was $2^{\circ}\cdot5$ Fahr.; when the limbs were of equal length, $2^{\circ}\cdot25$ Fahr.

Considering it possible that the current of air existing in the tube might have sufficient force to move a light body delicately suspended in its track, an elbow, E (fig. 5), was inserted into the upper orifice of the tube, to which a piece of glass tube, G, of the same diameter, was adapted, 6 inches in length, and a disc of tissue-paper, weighing one grain, which nearly occupied the area of the tube, was delicately suspended by a hair, at right angles to the axis of the tube. A slide valve was so adapted to the lower orifice, that this aperture could be opened or closed without entering the room. The air of the room being qui-

* The tubes used in these experiments were bent either at their lower or upper extremities for convenience merely.

escent, it was found that when the slide valve closed the lower orifice of the tube, the disc of tissue paper remained perfectly quiescent; but that when the slide valve was withdrawn, leaving the lower orifice open, oscillations of the paper occurred, and it was projected at a small angle towards the upper orifice of the tube, demonstrating the existence of a feeble current of air through the apparatus.

Fig. 5.



V. Slide valve.

Fig. 6.

D. A disc which occupies nearly the whole area of the tube.

The preceding experiment having proved the existence of a current of air within the tube, of sufficient force to move a light body, the author next proceeded to ascertain the velocity of the current by means of an anemometer, in the form of a horizontal fly-disc, D, suspended within the lower orifice of a tube (fig. 6), bent twice at right angles below. The revolving disc was made of a circular piece of stout writing-paper, cut into twenty-four equal segments, from the circumference to near the centre, each of the segments being afterwards inclined at an angle of twenty-five degrees*, like the vanes of a windmill; so that when properly suspended, a current of air entering the lower orifice of the tube would cause the disc to revolve from right to left. The disc was suspended in the same manner as the needle of the mariner's compass, and by the same means.

* A nearer approach to an angle of 45 would have crippled the paper, so that it would not have preserved the horizontal position.

When the apparatus was arranged, the door of the room closed, and the atmosphere in a quiescent state, it was found that a constant regular rotation of the disc was established, and kept up by the upward current of air through the apparatus, and continued so long as the atmosphere of the room was quiet; but that agitations of the surrounding air either rendered the rotation uncertain, or reversed it.

Having thus ascertained that the current of air within the vertical tube possessed sufficient force to cause the rotation of a lightly suspended fly-disc, the question arose, what influence elongation or

Fig. 7.

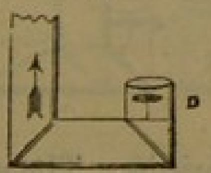


Fig. 8.

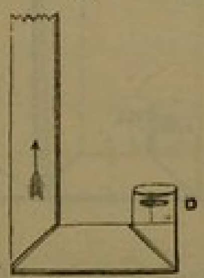
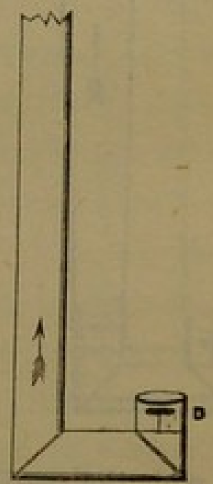


Fig. 9.



shortening of the tube would exert on the velocity of the current. For this purpose three tubes (figs. 7, 8, 9) of precisely similar construction, but with long limbs of 12, 24, and 48 inches respectively, were fitted as before with fly-discs, D, D, D, and placed near each other in the centre of the room.

In nineteen observations, the number of revolutions in the tube, with a long limb of 12 inches, varied from 0·75 to 4·5 per minute; in that with a long limb of 24 inches, from 1·5 to 9·0, and in that with the long limb of 48 inches, from 3·75 to 14·0 per minute. The gross number of revolutions in the three tubes, in the nineteen observations, were respectively 51·25, 111·25, and 199·75; and the mean revolutions per minute, 2·697, 5·855, 10·513, which, allowing for errors of observation, yield the ratios 1, 2, 4 nearly; so that it may be said that the velocity of the revolutions is in a direct ratio to the lengths of the vertical tubes.

The influence of the conoidal form of the tube being suggested by Dr. Roget as worthy of investigation, a tube (fig. 10), 96 inches long by 3 inches diameter below and 6 inches above, was fitted to a rectangular tube containing the rotating disc D. Another tube (fig. 11) of the same length, 3 inches in diameter throughout, was

Fig. 10.

Fig. 11.

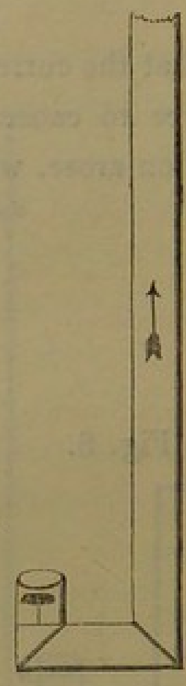


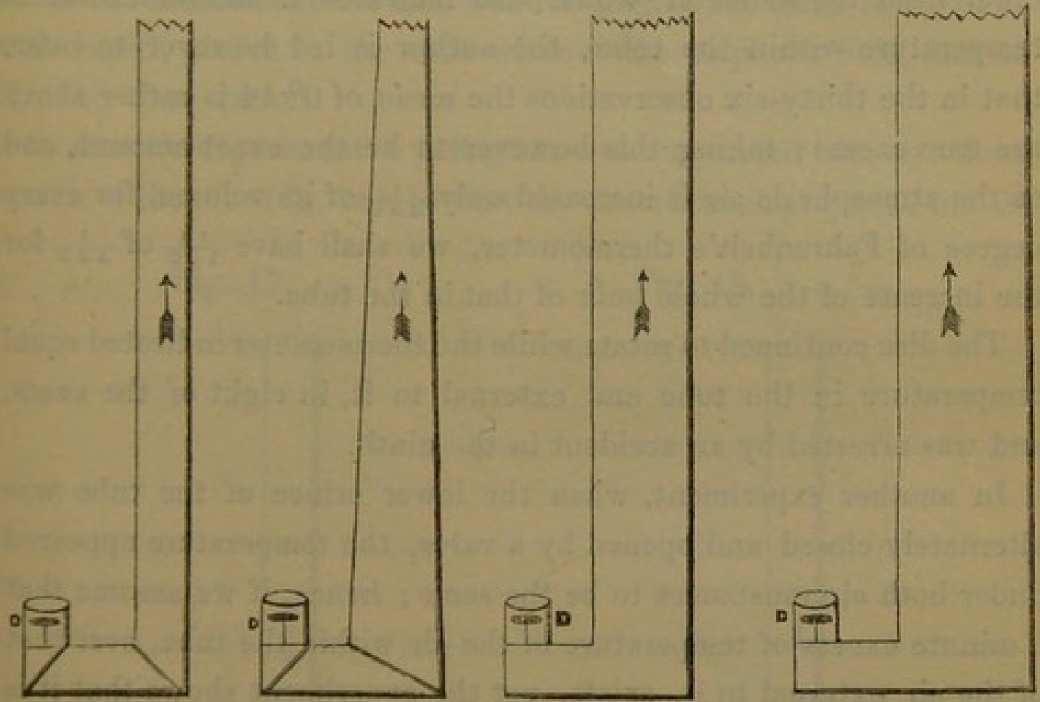
Fig. 12.

placed near the conical tube as a term of comparison. The revolutions of the disc in the conical tube were more rapid than in that of uniform diameter, in the proportion of 8·8 to 3·0. When the position of the cone was reversed (fig. 12), and the entrance and exit orifices were equal, the revolutions still continued more rapid than in the tube of uniform diameter.

To determine the influence of the area of the tube on the velocity of the current, four tubes (figs. 13, 14, 15, 16), 96 inches in length in the long, and 4 inches in the short branch, but varying in diameter, were placed in the room near each other and simultaneously observed.

In a tube of 3 inches uniform diameter (fig. 13), the revolutions were 3·0 per minute; in one of 5 inches (fig. 15) 9·15, and in one of 6·75 inches (fig. 16) 13·15; their respective areas being 7·065, 15·708, and 21·205. In the conical tube (fig. 14) on its base, whose area was 14·529, the revolutions were 8·8 per minute. It would seem, then, that the velocity has relation rather to the mean area of the tube than to that of the entrance and exit orifices, as the latter were the same in the tube of 3 inches uniform diameter, and in the conical tube on its base, while the revolutions of the disc were 3·0 per minute in the former, and 8·8 per minute in the latter.

Fig. 13. Fig. 14. Fig. 15. Fig. 16.



When the exit orifice of the tube of 6·75 inches diameter was reduced to 3·5 inches, the rapidity of the revolutions was reduced only about 10 per cent.

The influence of temperature in accelerating or retarding the currents through the tubes next engaged the author's attention; but before entering into direct experiments, he found by very numerous observations, that on some occasions no appreciable difference could be observed in the temperature of the atmosphere of the room near the floor and the ceiling, while on others there was a mean excess of $0^{\circ}\cdot17$ Fahr. near the ceiling without causing any perceptible difference in the velocity of the revolutions of the discs. In forty comparative observations of the temperature of the external surface of the tube (fig. 13) and of the surrounding air, that of the tube was 0·09 higher; in twenty-three it was equal, but in only five was it lower than the surrounding air.

Of thirty-six comparative observations of the temperature of the air within, and external to the tube, by a delicate mercurial thermometer, it was found to be slightly higher within the tube in twenty-seven, and in the remaining nine it was equal, but never lower than that of the external air. The greatest excess was $0^{\circ}.4$ Fahr., and the mean excess $0^{\circ}.14$ Fahr.

The accuracy of these results was tested by an extremely delicate differential thermometer, which also indicated a minute excess of temperature within the tube; the author is led however to infer, that in the thirty-six observations the mean of $0^{\circ}.14$ is rather above the true excess; taking this however to be the exact amount, and as the atmospheric air is increased only $\frac{1}{480}$ of its volume, for every degree of Fahrenheit's thermometer, we shall have $\frac{14}{100}$ of $\frac{1}{480}$ for the increase of the whole bulk of that in the tube.

The disc continued to rotate while the thermometer indicated equal temperature in the tube and external to it, in eight of the cases, and was arrested by an accident in the ninth.

In another experiment, when the lower orifice of the tube was alternately closed and opened by a valve, the temperature appeared under both circumstances to be the same; hence, if we assume that a minute excess of temperature of the air within the tube, over that of the air external to it, exists, yet the experiment shows that it is not attributable to any heat being disengaged by the movement of the air itself.

Increase and decrease of the temperature of the room exercised a considerable influence on the velocity of the rotations of the discs, which increased as the day advanced, and declined as the temperature fell towards evening, although the direct rays of the sun never fell upon the window of the room.

Partial exclusion of light, by a blind covering the whole window, produced a considerable reduction in the velocity of the rotations of the discs, but a screen of a foot in breadth, interposed between the window and an individual tube (fig. 13), merely reduced the velocity of the rotations from 12·5 to 11·0 per minute.

The influence of reduction of temperature of the long branch of the tube, by placing around it two coils of wet tape*, reduced the revolutions of the disc from 4·0 to 1·75 per minute; a third reduced the revolutions to 1·0; a fourth to 0·5; and a fifth caused complete cessation.

* Half an inch broad, and not so wet that any of the water ran away from it.

To ascertain the influence of the abstraction of aqueous vapour on the rotation of the discs, a shallow vessel, containing strong sulphuric acid, was placed, at the suggestion of the Rev. Dr. Booth, immediately below the disc (D), in the short branch of the tube (fig. 17). After the lapse of thirty minutes, the rotation had ceased altogether; at the commencement the disc was rotating at the usual rate. The same vessel, placed in the tube without the sulphuric acid, had no effect on the rotation.

In another experiment a bell-glass was suspended over the short branch of the tube (fig. 18), so that the short branch projected into it,

Fig. 17.

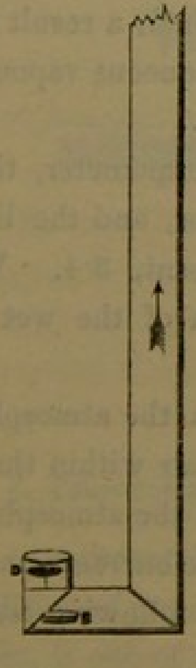
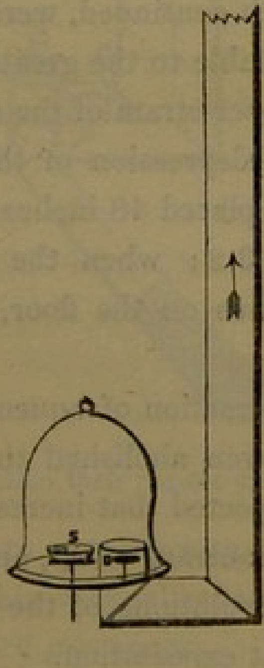


Fig. 18.



and a saucer (*s*), containing concentrated sulphuric acid, was also placed under the bell-glass, on a level with the orifice of the tube. The rotations of the disc were accelerated by placing the warm hand for a few seconds in contact with the long branch of the tube; but at the end of five minutes after it was withdrawn, and the room left and closed, the disc had ceased to rotate.

To determine the influence of partial abstraction of aqueous vapour from the entire atmosphere of the room on the velocity of the rotations, the three tubes (figs. 7, 8, 9), with long limbs of 12, 24, and 48 inches, employed in a previous experiment, were placed near each other, and three bushels of quicklime were spread in shallow vessels on the floor and other parts of the room. Before the lime was placed, the disc in the 12-inch tube was revolving at the rate of 0·75 per minute; that in the 24-inch tube at 2·0; and that in the 48-inch tube at 4·0 per minute. At the end of fifty minutes the rotation had ceased in the 12-inch tube, and was reduced to 1·75, and 3·5 in the 24- and 48-inch tubes. After seventy minutes, rotation had ceased in the 24-inch tube, and was reduced to 3·75 in the 48-inch tube. Finally, after ninety minutes, the rotations in the 48-inch tube were reduced to 2·75 per minute.

Similar reductions in velocity were observed after the removal and reintroduction of the quicklime in a second and third series of observations. Thus in all these experiments the rotations in the 12- and 24-inch tubes entirely ceased; and those in the 48-inch tube, although continued, were much diminished; a result most probably attributable to the greater quantity of aqueous vapour remaining in the upper strata of the air in the room.

The mean depression of the wet-bulb thermometer, the hygrometer being placed 48 inches above the floor, and the lime being absent, was 3·2; when the lime was present, 3·4. When the hygrometer was on the floor, the depression of the wet bulb was 3·5.

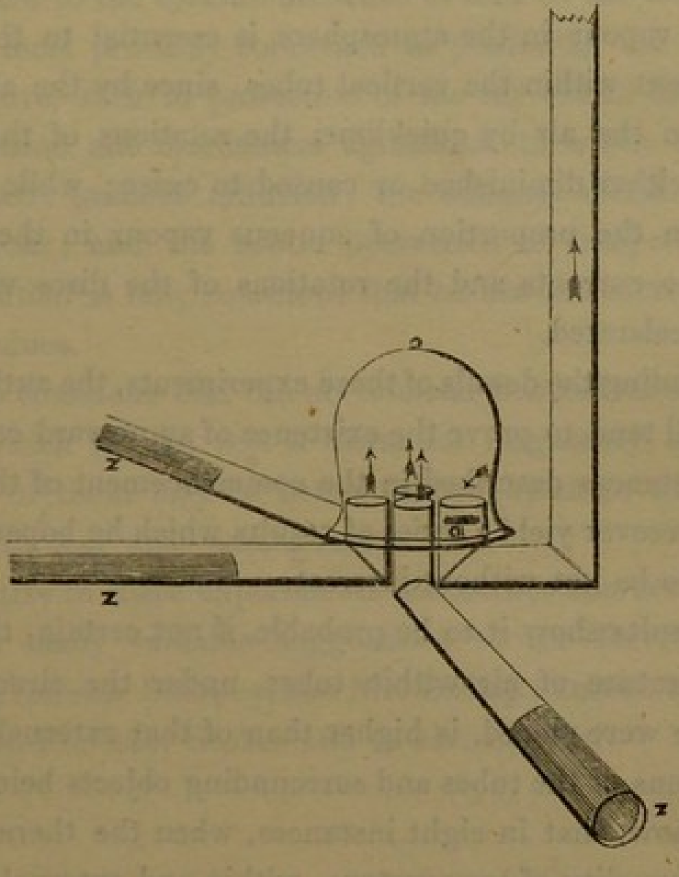
As the abstraction of aqueous vapour from the atmosphere diminished and even abolished the currents of air within the tubes, it was to be expected that increase of vapour in the atmosphere would produce the contrary effect, and accelerate the currents and the corresponding revolutions of the discs, and the following results coincide with that expectation.

In the first experiment, the tube and bell-glass previously described (fig. 18) were employed, but substituting folds of damp linen for the saucer of sulphuric acid, so as fully to charge the air in the bell-glass with vapour, the rotations rapidly rose from 4·0 to 17 or 18 per minute.

But as the cold produced by the evaporation of the water in this experiment might be a source of fallacy, an arrangement was made (fig. 19) to supply the bell-glass with air, previously charged with vapour, formed at a distance of 5 feet from the glass. The rapidity of the revolutions was however still considerably increased.

Augmentation of the quantity of aqueous vapour, in the general atmosphere of the room, by spreading wet cloths on the floor and other parts, also produced increase in the rapidity of the rotations, though to a small extent.

Fig. 19.



Z, Z, Z. Tubes containing wet linen within their remote extremities.

These experiments* would seem to demonstrate that the ordinary condition of atmospheric air within vertical tubes, open at both extremities, is one of continual upward movement.

If the atmosphere were a strictly homogeneous elastic fluid, and in a state of perfect equilibrium, any portion of it contained in a vertical tube would of course be perfectly stationary unless some adventitious cause produced disturbance of its equilibrium. But our atmosphere being a mixed fluid, and the aqueous vapour being of a much lower specific gravity at all atmospheric temperatures

* Throughout the entire series the results were carefully observed during the night, when the atmosphere of the room was free from solar influences. The dry- and the wet-bulb thermometers yielded the same relative differences, and the discs rotated with the same constancy. The night as well as the day observations were continued through all the changes of temperature, from March 1853 to the present time.

than the compound of which it forms a part, it is constantly rising within a tube, as in the free air; entering at the lower, and making its exit at the upper orifice of the tube.

The experiments appear further to demonstrate, that the presence of aqueous vapour in the atmosphere is essential to the production of the current within the vertical tubes, since by the abstraction of vapour from the air by quicklime, the rotations of the discs were invariably either diminished or caused to cease; while on the other hand, when the proportion of aqueous vapour in the air was increased, the currents and the rotations of the discs were simultaneously accelerated.

In concluding the details of these experiments, the author considers that they all tend to prove the existence of an upward current, under the circumstances described in the commencement of this paper.

They moreover yield a series of results which he hopes the Society will deem to be not without interest.

These results show it to be probable, if not certain, that the ordinary temperature of air within tubes, under the circumstances in which these were placed, is higher than of that external to them, all other relations of the tubes and surrounding objects being the same; they also show, that in eight instances, when the thermometers indicated an equality of temperature, within and external to the tube, the rotations of the discs still continued; and that when four coils of tape, moistened with water, were applied round the external surface of the tube, the rotations of the disc did not wholly cease.

They also show, that when the atmosphere of the room, in which the tubes were immersed, contained a larger or smaller proportion of aqueous vapour, all other things being equal, the discs revolved with more or less velocity; but that when the atmosphere was deprived in a great degree of aqueous vapour by the presence of quicklime, the thermometric state in all other respects remaining the same, the revolutions of the discs ceased.

Adverting to the indications cited above, of a minute excess of temperature in the interior of the tubes, and assuming that even that slight excess would be sufficient to rotate the discs, still the rotations diminished or ceased in proportion as the aqueous vapour was withdrawn.

Any increase of temperature which might have been produced by the quicklime would have had a tendency rather to increase than diminish the revolutions of the discs, but we have seen that the abstraction of the vapour entirely arrested their rotation.

With regard to the specific influence of each of the circumstances and agents most probably concerned in producing the phenomena described above, such as protection of the air within the tube from lateral expansion and mechanical agitations, to which the external air is exposed; gaseous diffusion; the unequal specific gravity of air and vapour; and the subtle operations of temperature at all times, the author is fully conscious that he has not ascertained their respective values.

He is also conscious that the phenomena themselves are the chief ground on which he can rest a claim for originality, and that the explanation of them may be better treated by those who are more accustomed to deal with similar researches.

In the course of these experiments the author has been especially indebted for many valuable suggestions to the Rev. Dr. Booth, Dr. Roget, Professor Sharpey, and Mr. Bishop; and he is also under obligations to Professor Stokes and to Mr. Brooke.

[*From the* PROCEEDINGS OF THE ROYAL SOCIETY, June 21, 1855.]

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...m the Proceedings of the Royal Society, June [illegible], 1871.]