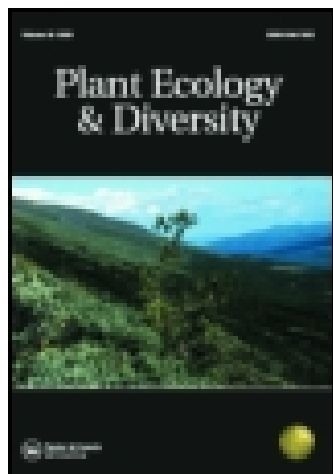


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Experiments on the Transpiration of Watery Fluid by Leaves

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21. Correspondence connected with the Introduction of the Ipecacuanha into India, 1869. Ibid. i. 307.

The following Communications were read :—

- I. *Experiments on the Transpiration of Watery Fluid by Leaves*. By W. R. M'NAB, M.D., Professor of Natural History, Royal Agricultural College, Cirencester. (Plate I.)

The experiments detailed in this paper were commenced in the month of August of this year, and have been continued during the months of September and October. The original intention was merely to repeat some of the more important experiments which had already been made on the exhalation of watery fluid by former observers. The experiments were about 100 in number, and as they were proceeded with many special points were carefully investigated. Thinking that it might not be uninteresting to give details of the various experiments tried, I venture to lay this paper before the Botanical Society of Edinburgh.

The Royal Agricultural College possesses a chemical laboratory, in which all the necessary apparatus for conducting such experiments is to be found. My very best thanks are due to my colleague Professor Church, who kindly placed the resources of the laboratory at my disposal, and aided me in very many ways, and helped me out of many difficulties. To the assistant in the laboratory, Mr Edward Kinch, I am also indebted for constant assistance and advice. In all the experiments the bay laurel (*Prunus Lauro-cerasus*) was used. As a large supply of it could be got, preference was given to it, hence the experiments made are all exactly comparable, because made on the same plant.

The experiments made may be arranged under eleven heads, each of which will be discussed separately and in detail.

1. Total quantity of water in the leaves of the bay laurel.

2. Quantity of water which can be removed from the leaves by calcium chloride, and sulphuric acid *in vacuo*.

3. Amount of transpirable fluid in the stem and leaves at a given time.

4. Rapidity of transpiration in sunlight, diffused daylight, and darkness.

5. Amount of fluid transpired in a saturated and in a dry atmosphere—in the sun, and in diffused daylight.

6. Quantity of water taken up by leaves when immersed in it.

7. Quantity of watery vapour absorbed by leaves in a saturated atmosphere.

8. Differences in the amount of fluid transpired by the upper and under sides of leaves in the sun and in diffused day-light.

9. Relation of fluid taken up to that transpired and that retained by the plant.

10. Rapidity of ascent of fluid in plants.

11. Influence of gases on transpiration.

All the experiments made can be grouped under one or other of these eleven heads, and we shall now proceed to examine each in detail.

1. Total quantity of water in the leaves of the bay laurel.

The quantity of water contained in the leaves was easily determined. Three leaves were taken and weighed, then placed in the water-oven, and dried at a temperature of about 100° C. till they ceased to lose weight. The following numbers express the results of the three experiments, with the mean and the percentage results:—

Leaves.	Weight before Drying.	Weight after Drying.	Loss.
A	1.4	0.51	0.89
B	1.33	0.49	0.84
C	1.26	0.46	0.8
	<hr/>	<hr/>	<hr/>
Mean.	1.33	0.48	0.84

This gives 63.4 per cent. as the mean percentage of water contained in the three leaves. In all cases the weights are expressed in grammes, both in this and in all the subsequent experiments.

2. Quantity of water which can be removed from the leaves by calcium chloride and sulphuric acid *in vacuo*.

As it was proposed in some cases to determine the amount of water given off by plants by means of calcium chloride, the following experiments were made:—

Three leaves were taken which had been cut off the stem at the node. The cut end of the petiole was then closed with sealing wax. The leaves were weighed and placed under a large beaker. The beaker rested on a dish containing mercury, which rendered the whole air-tight and excluded any watery vapour. A quantity of calcium chloride was then placed in the apparatus, and the whole left untouched for eighteen hours. The leaves were not exposed to the action of the sun, but only to diffused light and in darkness—

Leaves.	Weight before Experiment.	Weight after 18 Hours.	Loss.
A	0.91	0.86	0.05
B	0.66	0.62	0.04
C	0.79	0.76	0.03
	<hr/>	<hr/>	<hr/>
Mean,	0.78	0.74	0.04

equal to a loss of 5.08 per cent.

The use of sulphuric acid *in vacuo* gave nearly similar results. Three leaves were treated in the same way as in

the last experiment, but were placed over sulphuric acid *in vacuo* for eighteen hours, under the same conditions as before.

Leaves.	Weight before Experiment.	Weight after 18 Hours.	Loss.
A	2.22	2.08	0.14
B	1.65	1.55	0.1
C	1.54	1.45	0.09
Mean,	1.8	1.69	0.11

equal to a loss of 6.09 per cent., or 1 per cent. more than that obtained by calcium chloride. The difference in amount is probably due to the difference in atmospheric pressure in the two cases; but the experiments show that the quantity of water removable from the leaves, without destroying the leaf in any way, is but small in quantity—only from 6 to 7 per cent. of the total weight of the leaves experimented on.

3. Amount of transpirable fluid in the stem and leaves at a given time.

From the experiments already detailed, it will be seen that although 63.4 per cent. of water is contained in the leaf of the cherry laurel, only about 6 per cent. can be easily removed, or, in other words, only one-eleventh part of the total water contained in the plant at any one time is transpirable. In both the cases in which fluid was removed from the leaf by calcium chloride and sulphuric acid *in vacuo*, the leaf did not become in the least brown. By exposure to the sun a leaf will also give off a certain quantity of watery fluid without showing any signs of alteration of colour, or withering. The amount corresponds closely to that which can be removed by calcium chloride or sulphuric acid *in vacuo*, as will be seen from the following experiment. The leaves were exposed to the sun at first for 2½ hours, and then again for 3 hours.

Leaves.	Weight before Experiment.	Weight after 2½ Hours Exposure to Sun.	Loss.	Weight after 3 Hours Additional Exposure to Sun.	Further Loss.	Total loss in 5½ Hours Exposure to Sun.
A	1.95	1.87	0.08	1.83	0.04	0.12
B	1.55	1.5	0.05	1.48	0.02	0.07
C	0.98	0.93	0.05	0.91	0.02	0.07
Mean,	1.49	1.43	0.06	1.40	0.02	0.08

This experiment is instructive. It shows that in $2\frac{1}{4}$ hours in sunlight the leaves lost 4.01 per cent. of their weight, while 3 hours' additional exposure to the sun only caused a further loss of 1.86 per cent. This gives a total of 5.8 per cent. of fluid transpired,—a quantity nearly the same as that removed by the action of calcium chloride. Watery fluid would thus seem to exist in plants in two distinct states, or under two conditions:—1st, As transpirable fluid; and 2d, As fluid in relation to the cell-sap of the tissues. A branch, therefore, which contains altogether about $63\frac{1}{2}$ per cent. of water, only parts with about 6 per cent. of it by transpiration, anything above this quantity given off by the leaves being at the expense of the water in relation to the cell-sap. In plants in which the tissues are very delicate, the loss of the transpirable fluid will immediately cause the plant to become flaccid by the diminution of the tension of the tissues. This process will precede that of withering, and will at once occur if the quantity of fluid transpired by the leaves is in excess of the quantity supplied through the root. The smallness of the quantity required to be removed accounts for the rapidity with which the leaves of some plants become flaccid even when supplied with water through the cut end of the stem. To test the accuracy of this the following experiments were made:—A branch of laurel was fixed in a test-tube containing water, and placed in the sun for an hour. At the end of the hour it was found to have lost 7.5 per cent. of water. Another branch was taken and placed in a test tube containing a solution of lithium citrate,* and exposed to the light for 70 minutes, the sun shining brightly during 60 minutes. By this means it was expected that the fluid transpired by the leaves would be replaced by the water containing the lithium citrate, and that its course through the plant could be easily detected. If the quantity of fluid in a transpirable condition in the plant was less than 7.5 per cent. of the weight of the branch, then the lithium would be found in all the fibro-vascular bundles. This was tested, and the lithium citrate found at the midrib of the uppermost leaf, at the very apex.

This experiment, then, afforded conclusive evidence of the

* *Nature*, No. 52, page 515.

fact that the quantity of transpirable fluid in a plant at a given time is very small, and that when a large quantity is given off, the fluid must be in rapid motion from the root upward to supply fluid for transpiration. Full details of the lithium experiment will be given under No. 10.

4. Rapidity of transpiration in sunlight, diffused daylight, and darkness.

This experiment was conducted in the following manner:—Six leaves were taken and weighed; two were then placed in the sun, two in diffused daylight, and two in darkness. At the end of one hour they were again weighed, with the following results:—

Leaves Exposed to Sunlight for One Hour.

Leaves.	Weight before Experiment.	Weight after Experiment.	Loss.
A	2·005	1·953	0·052
B	2·34	2·26	0·08
Mean,	2·172	2·106	0·066

Leaves Exposed to Diffused Daylight for One Hour.

Leaves.	Weight before Experiment.	Weight after Experiment.	Loss.
C	1·825	1·815	0·01
D	2·22	2·205	0·015
Mean,	2·022	2·01	0·012

Leaves Placed in Darkness for One Hour.

Leaves.	Weight before Experiment.	Weight after Experiment.	Loss.
E	1·525	1·525	0
F	2·22	2·21	0·01
Mean,	1·872	1·867	0·01

The loss in sunlight was, therefore, equal to 3·03 per cent. of the weight of the leaves. In diffused daylight the loss in the same time was only 0·59 per cent., while in darkness the loss was, in one experiment nothing, and in the other equal to 0·45 per cent. In order to test still further the effect of darkness, two branches, each with three leaves, were placed in a dark box for 48 hours. The following method* was adopted in this and in most of the other ex-

* Fig. 7, in the Plate accompanying the present paper, represents the arrangement described in the text

periments:—A small terminal shoot of laurel, with either three or four leaves attached, was taken and carefully weighed. It was then passed through a hole in a small cork which fitted into a short test-tube containing water. The cork and part of the branch was then covered with melted paraffin. This fixed the branch quite firmly into the cork and prevented any escape of water, while, at the same time, the plant could take up a sufficient supply, and no loss of water from the tube could occur. In short, no water could be removed from the test-tube except by the plant.

Two branches of laurel fixed in tubes placed in darkness for 48 hours gave the following results:—

	Weight of Branch.	Weight of Branch, Test-Tube, &c., be- fore Experiment.	Weight of Branch, Test-Tube, &c., after Experiment.	Loss.
A	4.975	25.8	25.1	0.7
B	4.81	23.545	22.925	0.62
	<hr/>	<hr/>	<hr/>	<hr/>
Mean,	4.892	24.672	24.012	0.66

This is equal to a mean of 13.47 per cent. on the two experiments.

5. Amount of fluid transpired in a saturated and in a dry atmosphere, in the sun and in diffused daylight.

There seems to be a good deal of obscurity in the statements in the different text-books regarding the transpiration of leaves in wet and dry atmospheres. It is generally admitted that the stomata close when dry, and open when moist,*—the object of this, evidently, being to diminish the quantity of fluid transpired in a dry atmosphere and prevent too great loss. But again, we find it stated in the text-books that plants in a room cannot live long, because the dry atmosphere causes too great transpiration, the loss from the leaves being greater than the plant can take up by the roots.† The healthy condition of plants grown in

* “ These openings (stomata) are bounded by two (sometimes three or four) cells of a delicate nature, which have the power of opening or closing the orifice. When moist, these cells become swollen, and, while they lengthen, curve outwardly in the middle, so as to leave a free opening; when dry they are shortened and straightened, and thus their sides are applied to each other so as to close the orifice.”—*Balfour's Class-Book of Botany*, p. 43.

† *Balfour's Class-Book of Botany*, p. 482.

a Wardian case in a room is attributed to the case preventing the too great transpiration. It is difficult to understand how the closing of the stomata in a dry atmosphere should tend to increase the transpiration, as is alleged to take place in an ordinary room, while in the damp atmosphere of a Wardian case the stomata will be open, and in a condition to admit of more fluid being transpired. Four experiments, detailed below, show that in a saturated atmosphere in the sun a larger quantity of fluid is transpired, but in a dry atmosphere in the sun a smaller quantity. In the shade, or in diffused daylight, the conditions are reversed, and in a saturated atmosphere no transpiration occurs, while a small amount goes on in a dry atmosphere. In the sun plants transpire most in a saturated atmosphere, in the shade transpiration ceases when the atmosphere is loaded with watery vapour.

To obtain a saturated atmosphere the following method was adopted:—A large beaker was taken, and a broad strip of filter-paper, the height of the vessel, attached by means of marine glue to one side. This strip was wetted thoroughly with water, and the beaker inserted in a dish containing water. The filter-paper was in contact with the water in the dish, and remained constantly wet. The experiment with a dry atmosphere was conducted in a different manner. A bell-jar,* with an opening at the top, *through which two glass tubes passed, was employed.* To one of the glass tubes a U-tube containing sulphuric acid was attached. Another tube (straight), containing sulphuric acid, was then joined to the other. With the straight tube an aspirator was connected. The glass bell-jar stood in a dish containing mercury. All the air entering the bell-jar was rendered perfectly dry by passing through the U-tube, while all moisture was prevented reaching the bell-jar from the aspirator by the second sulphuric acid tube. Air was kept continually passing through the apparatus, the whole being placed in the sun at a temperature of about 21° C.

A branch of laurel was fixed in the test-tube in the manner already described, then introduced into the beaker or bell-jar, and allowed to remain for one hour.

* See fig. 1 in the Plate accompanying the present paper.

Influence of a Saturated Atmosphere on Transpiration in the Sun for One Hour.

Weight of Leaves.	Weight of Leaves, Tube, &c., before Experiment.	Weight of Leaves, &c., after Experiment.	Loss.
4.39	30.935	29.795	1.14

In one hour, in a saturated atmosphere, a branch, weighing 4.39 grammes, transpired 1.14 gramme of water, or 25.96 per cent. of its weight, very nearly 26 per cent.

Influence of a Dry Atmosphere on Transpiration in the Sun.

Weight of Leaves.	Weight of Leaves, Tube, &c., before Experiment.	Weight of Leaves, Tube, &c., after Experiment.	Loss.
4.92	18.885	17.875	1.01

The experiment was made at the same time as the other in a saturated atmosphere, the exposure was for the same time, and a gallon of dry air was passed through the apparatus during the experiment,—the amount of fluid transpired being equal to 20.52 per cent. of the weight of the leaves. These experiments were made on September 20, the sun being very bright, and the temperature from 20° to 22° C.

In the shade the conditions are reversed, more fluid being transpired in a dry than in a saturated atmosphere. The time given in each case was one hour; the temperature was, however, much lower, being only from 10° to 13° C.

Influence of a Saturated Atmosphere on Transpiration in the Shade.

Weight of Leaves.	Weight of Leaves, Tube, &c., before Experiment.	Weight of Leaves, Tube, &c., after Experiment.	Loss.
4.92	17.69	17.69	0

In a saturated atmosphere in the shade, the leaves neither lost nor gained weight; in a dry atmosphere, however, the results were slightly different.

Influence of a Dry Atmosphere on Transpiration in the Shade.

Weight of Leaves.	Weight of Leaves, Tube, &c., before Experiment.	Weight of Leaves, Tube, &c., after Experiment.	Loss.
5.322	25.59	25.5	0.09

In this experiment the loss is equal to 1·69 per cent. of the weight of the leaves. These observations must have an important bearing on the treatment of plants in hot-houses. Plants in the warm, moist air of a hot-house will give off very large quantities of fluid by transpiration, unless this is moderated and regulated by proper shading.

6. Quantity of water taken up by leaves when immersed in it.

Detached leaves, when immersed in water, took up a considerable quantity. The results were, however, variable and unsatisfactory. One leaf, for example, would gain 7 per cent. of weight, while another, under the same circumstances, would only gain $1\frac{1}{2}$ per cent., the mean being 4·37 per cent.

Three leaves were taken and the cut end of the petiole closed with sealing-wax. They were next weighed and then immersed in water for $1\frac{1}{2}$ hour.

Leaves.	Weight before Experiment.	Weight after Experiment.	Gain.	Percentage.
A	1·435	1·51	0·075	5·15
B	0·901	0·915	0·014	1·55
C	0·68	0·73	0·05	7·35
Mean,	1·005	1·052	0·046	4·37

7. Quantity of watery vapour absorbed by plants in a saturated atmosphere.

Two experiments, already detailed, show that plants do not absorb watery vapour from the atmosphere, as far as can be detected by the use of the balance, either in the sun or in the shade. Detached leaves placed in a moist atmosphere do not lose or gain weight. Three leaves were taken and placed under a beaker with water—blotting-paper being also introduced to make the air as moist as possible. At the end of 18 hours, when the leaves were removed, the balance failed to detect the slightest change in the weight.

Leaves.	Weight of Leaves before Experiment.	Weight of Leaves after Experiment.
A	1·87	1·87
B	1·5	1·5
C	0·93	0·93

8. Differences in the amount of fluid transpired by the upper and under sides of leaves in the sun and in diffused daylight.

In order to discover the different amount of fluid transpired by the two surfaces of the leaves, a very simple expedient was adopted. The surface or surfaces of the leaf were covered with plastic collodion. The collodion adhered firmly to the surface of the leaf, and enabled the observations to be made with the greatest ease.

Three experiments were made in the sun, and three in the shade. In the first the under surface of the leaf was covered with collodion, thus preventing any transpiration except from the upper surface, and the petioles and stalks. In the second the upper surface was collodionised; and in the third both sides were covered with plastic collodion.

Under Surface of Leaves Coated with Collodion. Transpiration from Upper Surface.

Weight of Branch.	Weight of Tube and Branch Collodionised before Experiment.	Weight of Tube and Branch Collodionised after Experiment.	Loss.
6·825	21·345	21·253	0·092

In one hour in the sun the loss from the upper surface was 1·34 per cent.

Upper Surface of Leaves Coated with Collodion. Transpiration from Under Surface.

Weight of Branch.	Weight of Tube and Branch Collodionised before Experiment.	Weight of Tube and Branch Collodionised after Experiment.	Loss.
6·123	25·925	25·17	0·755

The amount given off by the under surface was therefore 12·33 per cent.

Transpiration with both Sides of the Leaf Collodionised.

Weight of Branch.	Weight of Tube, Branch, &c., Collodionised before Experiment.	Weight of Tube, Branch, &c., Collodionised after Experiment.	Loss.
6·235	26·605	26·545	0·06

In one hour the loss, when exposed to sunlight, with both sides collodionised, was thus equal to 0·96 per cent. only.

After 48 hours exposure in diffused daylight the results

were found to be very much the same as those obtained in sunlight.

Weight of Branch.	Weight of Tube, &c., before Experiment.	Weight of Tube, &c., after Experiment.	Loss.
6·825	21·253	21·06	0·193

The under side coated with collodion. Loss after 48 hours' exposure to action of diffused daylight equal to 2·82 per cent.

Upper Side Coated with Collodion.

Weight of Branch.	Weight of Tube, &c., before Experiment.	Weight of Tube, &c., after Experiment.	Loss.
6·123	25·17	24·185	0·985

In 48 hours the loss in diffused daylight was equal to 16·08 per cent. of the weight of the branch and leaves.

Both Sides Coated with Collodion.

Weight of Branch.	Weight of Tube, &c., before Experiment.	Weight of Tube, &c., after Experiment.	Loss.
6·235	26·545	26·385	0·16

The loss in this case is nearly the same as in the experiment with the under surface collodionised; the loss in 48 hours in diffused daylight being 2·56 per cent.

In the bay laurel, therefore, the transpiration is nearly all from the under side,—the under surface giving off 12·33 per cent., while the upper, under the influence of sunlight for one hour, gave off only 1·34 per cent. of its weight of fluid.

9. Relation of fluid taken up to that transpired and that retained by the plant.

In these experiments a branch of laurel was taken and weighed. It was then fixed in the ordinary way in a test-tube containing a known weight of water. The branch and tube were then placed under a beaker over mercury, and the fluid transpired was taken up by calcium chloride.

	Weight of Branch.	Weight of Tube and Water.	Weight of Branch, Tube, &c.	Weight of Calcium Chloride.
Before,	8·442	19·585	31·035	9·48
After,	8·84	18·484	30·395	10·084

Gain,	0·398	Loss,	1·101	Loss,	0·64	Gain,	0·604
Deduct weight re- moved by cork, &c., 0·013							

1·088

The loss by transpiration was 0·64 gramme, while the branch gained 0·398 gramme in weight. Of the amount transpired 0·604 gramme was taken up by the calcium chloride. Adding the amount gained by the branch to the amount transpired, we get 1·038 gramme. If we deduct this from the quantity of water removed from the tube, we get a remainder of 0·05 gramme unaccounted for. Also by deducting the amount taken up by the calcium chloride from the quantity transpired we get an error of 0·036 gramme.

The mean of two experiments gives somewhat similar results,—

Weight of Branch.		Weight of Tube and Water.	Weight of Branch, Tube, &c.	Weight of Calcium Chloride.
Before,	6·811	20·03	29·912	9·18
After,	7·121	19·074	29·345	9·749
<hr/>		<hr/>	<hr/>	<hr/>
Gain,	0·31	Loss, 0·956	Loss, 0·567	Gain, 0·569
Error to be deducted,		0·053		
		<hr/>		
		0·903		

The branches in these experiments, of which the mean is given, transpired 0·567 gramme of fluid. The calcium chloride gained 0·569 gramme in weight, being 0·002 gramme in excess, while the branch gained 0·31 gramme. Adding the amount transpired to the amount gained by the branch, we get 0·877 gramme. This deducted from 0·903 gramme, the amount lost in the tube, we have a difference of 0·026 gramme. In the one case we have 0·031 of an English grain too much ; in the other, 0·406 of an English grain too little.

In these and other experiments the branch experimented on was always found to have gained weight. A larger quantity of water was taken up than that transpired. How far this gain is to be attributed to the fixation of carbon from the minute quantity of carbon dioxide in the air in the jar, has yet to be determined. This action was not altered by placing portions of plants in a saturated atmosphere, but was reduced greatly by placing the branches in darkness. The following experiments, continued for 48 hours, show the difference between saturated and an ordinary atmosphere in diffused daylight, and an ordinary atmosphere in darkness.

Increase of Weight of Branch in a Saturated Atmosphere for 48 Hours in Diffused Daylight.

Weight of Branch before Experiment.	Weight of Branch after Experiment.	Gain.
6.47	6.955	0.485

Increase of Weight of Branch in Ordinary Atmosphere for 48 Hours in Diffused Daylight.

Weight of Branch before Experiment.	Weight of Branch after Experiment.	Gain.
5.875	6.295	0.42

Increase of Weight of Branch in Ordinary Atmosphere for 48 Hours in Darkness.

Weight of Branch before Experiment.	Weight of Branch after Experiment.	Gain.
4.975	5.135	0.15

In the first experiment in a saturated atmosphere the gain was 7.34 per cent. In the second, in ordinary atmosphere, the gain in weight was equal to 7.14 per cent., while in darkness the gain was only equal to 3.01 per cent. In a saturated atmosphere, where the transpiration would be checked in diffused daylight, the tendency of the plant would be to become dropsical, unless the fluid was more rapidly transpired in sunlight.

10. Rapidity of ascent of fluid in plants.

At the early part of this paper, when discussing the amount of transpirable fluid in the plant at a given time, the use of lithium citrate was mentioned. When experimenting on the amount of fluid transpired, it occurred to me to use the spectroscope for the purpose, as being much more delicate than any other method. This method was suggested to me by Mr Church in connection with another series of experiments, and I determined to try it in the present researches. Lithium and thallium were employed because they give very characteristic bright lines in the spectrum. Only one experiment was made with thallium, its green line being very evanescent. Lithium, on the other hand, gave most admirable results, and was very easily managed. The solution employed was a dilute aqueous solution of lithium citrate. The citrate was used in preference to any other salt, on account of its being the salt of an organic acid, and less likely to offer any obstruction to the ab-

sorptive power of the tissues. The solution was placed in a short test-tube, the branch placed in it, and fixed by means of a cork. It was then placed in sunshine for a given time, varying from 70 minutes to 10 minutes. Immediately on being removed, the stem was cut in pieces directly above each node, a leaf and internode being in this way separated. They were then numbered and carefully measured. The next operation consisted in drying the portions of stem and leaf thoroughly in the water-oven at a temperature of 100° C. When quite dry, the pieces were taken, and a small portion for examination was placed in a watch-glass with dilute hydrochloric acid. A piece of platinum wire was bent so as to form a support, and fixed in such a position that it could be easily examined by means of the spectroscope fixed at a short distance from the wire. A colourless Bunsen flame placed under the platinum wire completed the arrangement. The wire was first examined for lithium, then the portion of plant placed on the wire and reduced to ashes. The ashes were then wetted with a small quantity of dilute hydrochloric acid, and the flame again applied. The spectroscope generally showed first the characteristic red and green calcium bands, then the red potassium band, and, at the same time, the characteristic lithium band, if any was present in the portion of stem or leaf under examination. When the experiment was finished, the platinum wire was strongly heated, cleaned with acid, and tested for lithium; then a new portion of stem or leaf was taken and treated with fresh hydrochloric acid, the same process being repeated over and over again, as often as required. The red lithium band was not to be confounded with the calcium or potassium band, and always appeared after the calcium bands, and when the temperature was very high. With thallium it was found that the green band was very evanescent, and appeared very early. As it was liable to be confounded with the green calcium bands the use of thallium was abandoned, and only lithium employed.

Five experiments were made in all—four with lithium citrate, and one with thallium citrate. In one experiment 70 minutes' exposure was given, 60 of them being in sunlight. In three others 30 minutes, and in one 10 minutes' exposure to sunlight was tried.

1st, Branch of laurel allowed to absorb solution of lithium citrate for 70 minutes.

The branch was allowed to absorb, and then cut in pieces and dried in the water-bath. The spectroscope showed that the lithium had penetrated the whole branch, and it was detected without any difficulty in every internode and petiole. It was also found in the midrib at the apex of the terminal leaf (see fig. 2). The branch had four leaves. The terminal leaf was 3 inches long. It will thus be seen that the whole length of fibro-vascular tissue through which the lithium citrate had passed was $8\frac{1}{2}$ inches. The quantity of fluid given off by another laurel branch showed that the amount of transpiration was equal to 7.58 per cent. per hour.

Branch Weighed.	Weight of Branch, Tube, &c., before Experiment.	Weight of Branch, Tube, &c., after Experiment.	Loss.
8.442	31.035	30.395	0.64

2d, Branch in lithium citrate for 30 minutes (October 4, 1870).

In this case a branch with five leaves was allowed to absorb solution of lithium for 30 minutes in the sun. When dried and examined by the spectroscope, lithium was detected along the branch, even to the apex of the terminal leaf—the total distance traversed being $9\frac{1}{2}$ inches in 30 minutes (see fig. 3).

3d, Branch in thallium citrate for 30 minutes (October 4, 1870).

An experiment with thallium was made at the same time as the preceding one with lithium. A branch with four leaves was placed in the sun for 30 minutes. On examination with the spectroscope, it was found that the thallium could be detected in all the internodes and petioles, but not in any of the leaves, the midrib of the lowest leaf failing to show it. The distance through which the thallium passed was $5\frac{3}{4}$ inches in 30 minutes (see fig. 4).

4th, Experiment with lithium citrate for 30 minutes in sun (October 10, 1870).

A branch of laurel with five leaves was placed in sun for 30 minutes. When examined with the spectroscope in the usual way it was found that the lithium had only passed two leaves. No lithium could be detected in the petioles

or internodes above the two leaves. The branch was 8 inches long, and the lithium had ascended $6\frac{5}{12}$ inches in 30 minutes. It was also found in the midrib at the centre of the lowest leaf, the apex and parenchyma failing to show even a trace (see fig. 5).

5th, Experiment with lithium citrate for 10 minutes in sun (October 10, 1870).

The branch employed in this experiment had four leaves, and measured 6 inches in length. When tested with the spectroscope the lithium was found to have ascended $4\frac{9}{12}$ inches in 10 minutes, but it could not be detected in the midrib or leaf (see fig. 6).

At the same time that the last two experiments were being made, a branch was placed in the sun to measure the amount of transpiration.

Weight of Branch.	Weight of Branch, Tube, &c., before Experiment.	Weight of Branch, Tube, &c., after Experiment.	Loss.
4.633	24.335	24.125	0.21

This gives a loss of 4.53 per cent. per hour. When, therefore, the transpiration was 7.58 per cent. per hour, lithium could be detected in every part of the branch; but if only 4.53 per cent., it was found not to have risen very far into the leaves.

As the leaves in the experiment just detailed must have exercised a great influence on the ascent of fluid in the stem, it was considered necessary to make a few observations on the relative action of the leaves at different parts of the stem. If a branch with four leaves be taken, it is obvious that while the fluid is ascending through the first internode, the evaporating power of all the four leaves must be fully in action. When the fluid has passed the lowest leaf, and is traversing the next internode, the evaporating power of three leaves is acting on it, in the next only two, and in the last only one. It seems probable in this way that the fluid will gradually become slower and slower in motion as it passes each node. If we number the leaves, beginning at the terminal one—1, 2, 3, and 4,—we find that on an average of twenty experiments we can represent the relative relations of the leaves by the following numbers: 1 = 91; 2 = 122; 3 = 150; 4 = 240. In this case the

average *weight* is given, as the square surface and number of stomata will bear a definite relation to it. It thus follows, that when the fluid is passing from the cut end of the branch to leaf No. 4, the evaporating surfaces of the leaves acting in it will be equal to 603. After passing leaf 4, in the internode between leaves 4 and 3, the amount has diminished to 363; from leaves 3 to 2, to 213; and between leaf 2 and the terminal leaf, to 91. Or we may say that the action is at first equal to 1, then it diminishes first to $\frac{1}{2}$, next to $\frac{1}{3}$, and lastly to $\frac{1}{6}$ nearly.

11. Influence of gases on transpiration.

A large beaker was filled with the gas to be used for the experiment, and placed over water or mercury. The branch, fixed as usual in the test-tube, was then introduced into the beaker when placed over a pneumatic trough. Experiments in this way were made with atmospheric air, oxygen, nitrogen, and carbon dioxide. In all cases the percentage given is for one hour, the temperature being also noted:—

1. *Atmospheric Air in Sun for Two Hours, Temperature 12° C.*

Weight of Branch.	Weight of Tube, &c., before Experiment.	Weight of Tube, &c., after Experiment.	Loss.
10·125	30·33	28·81	1·52

or 7·5 per cent in one hour.

2. *In Nitrogen for Two Hours in the Sun, Temperature 12° C.*

Weight of Branch.	Weight of Branch, Tube, &c., before Experiment.	Weight of Branch, Tube, &c., after Experiment.	Loss.
8·29	28·373	28·045	0·328

This gives as the loss in one hour in nitrogen only 1·97 per cent.

3. *In Oxygen for One Hour in the Sun, Temperature 11° C.*

Weight of Branch.	Weight of Branch, Tube, &c., before Experiment.	Weight of Branch, Tube, &c., after Experiment.	Loss.
5·44	25·23	24·925	0·695

Equal to 12·77 per cent. of the weight of the branch.

4. In Carbon Dioxide for One Hour in the Sun, Temperature 11° C.

Weight of Branch.	Weight of Branch, Tube, &c., before Experiment.	Weight of Branch, Tube, &c., after Experiment.	Loss.
6.32	25.405	25.155	0.25

The loss in this case being equal to 4.01 per cent.

These experiments point to the conclusion that leaves transpire most in an atmosphere of oxygen, less in atmospheric air, and least of all in nitrogen. The following table shows the results :—

	Per cent.	Temperature.
Transpiration in oxygen in one hour,	12.77	11° C.
„ atmospheric air in one hour,	7.5	12° C.
„ carbon dioxide, „	4.01	11° C.
„ nitrogen, „	1.97	12° C.

The lateness of the season has rendered it advisable to stop the experiments for the present. When the weather improves, it is hoped that a much larger series of experiments may be made on this and other kindred subjects.

Recapitulation.

	Per cent.*
1. Total quantity of water in the leaves of the bay laurel,	63.4
2. Quantity of water which can be removed from the leaves by calcium chloride,	5.08
3. Quantity of water which can be removed from the leaves by sulphuric acid <i>in vacuo</i> ,	6.09
4. Quantity of water which can be removed from the leaves in the sun,	5.8
5. Amount of transpirable fluid in stem and leaves, Between 6 and 7	
6. Amount of fluid in relation to cell sap, Between 56 and 57	
7. Rapidity of transpiration in sunlight, 1 hour,	3.03
8. „ „ in diffused daylight, 1 hour,	0.59
9. „ „ in darkness, 1 hour,	0.45
10. Amount of transpiration in darkness, 48 hours (mean),	13.47
11. Amount of fluid transpired in a saturated atmosphere, in sun, 1 hour,	25.96
12. Amount of fluid transpired in a dry atmosphere, in sun, 1 hour,	20.52
13. Amount of fluid transpired in a saturated atmosphere, in shade, 1 hour,	0.00

* Percentage calculated on the total weight of leaves or branch employed.

	Per cent.
14. Amount of fluid transpired in a dry atmosphere, in shade, 1 hour,	1·69
15. Quantity of water taken up by leaves when immersed in it, $1\frac{1}{2}$ hour (mean),	4·37
16. Quantity of watery vapour absorbed by leaves in a saturated atmosphere, 18 hours,	0·00
17. Amount of fluid transpired by upper surface of leaf, in sun, 1 hour,	1·34
18. Amount of fluid transpired by under surface of leaf, in sun, 1 hour,	12·33
19. Amount of fluid transpired, both sides coated with collodion, in sun, 1 hour,	0·96
20. Amount of fluid transpired by upper surface of leaf, 48 hours in diffused light,	2·82
21. Amount of fluid transpired by under surface of leaf, 48 hours in diffused light,	16·08
22. Amount of fluid transpired, both sides coated with collodion, 48 hours in diffused light,	2·56
23. Relation of fluid taken up to that transpired, and that retained by plant in 1 hour sunlight—	

	Grammes.
Total amount taken up,	1·088
Deduct,	1·038
	<hr/>
Difference,	0·05
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Amount transpired,	0·64
Gain of weight of branch,	0·398
	<hr/>
Total,	1·038

24. Increase of weight of branch in saturated atmosphere, diffused daylight, 48 hours,	7·34
25. Increase of weight of branch in ordinary atmosphere, diffused daylight, 48 hours,	7·14
26. Increase of weight of branch in ordinary atmosphere, darkness, 48 hours,	3·01
27. Rapidity of ascent of fluid in plants (<i>a</i>) $8\frac{7}{8}$ inches in 70 minutes, in sun. Lithium citrate. Transpiration equal to 7·58 per cent. per hour, in sun. Lithium all through branch.	
28. Rapidity of ascent of fluid (<i>b</i>) $9\frac{4}{8}$ inches in 30 minutes. Lithium citrate.	
29. Rapidity of ascent of fluid (<i>c</i>) $5\frac{3}{8}$ inches in 30 minutes. Thallium citrate.	
30. Rapidity of ascent of fluid (<i>d</i>) $6\frac{5}{8}$ inches in 30 minutes. Lithium citrate.	

	Per cent.
31. Rapidity of ascent of fluid (<i>e</i>) $4\frac{2}{3}$ inches in 10 minutes. Lithium citrate. Transpiration equal to 4.53 per cent. per hour in sun, during <i>d</i> and <i>e</i> . Lithium not all through branch.	
32. Transpiration of fluid in oxygen, one hour, sun,	12.77
33. " " atmospheric air in one hour,	7.5
34. " " carbon dioxide, "	4.01
35. " " nitrogen, "	1.97

DESCRIPTION OF PLATE I.

Fig. 1. Apparatus for obtaining a dry atmosphere. A. U-tube, filled with sulphuric acid and fragments of pumice stone. B. Bell-jar, in which the leaves to be experimented on are placed. C. Straight tube, containing sulphuric acid and pumice. D. Aspirator. The air enters at E, is dried in the tube A, passes into the bell-jar B, then through C, which prevents moist air entering from the aspirator. The water contained in the aspirator is removed by the siphon, and escapes at P. The arrows show the direction of the current of air.

Fig. 2. Branch of laurel, showing course of lithium citrate in 70 minutes in the sun. 1st Oct. 1870.

Fig. 3. Branch of laurel, showing course of lithium citrate in 30 minutes in the sun. 4th Oct. 1870.

Fig. 4. Branch of laurel, showing course of thallium citrate in 30 minutes in the sun. 4th Oct. 1870.

Fig. 5. Branch of laurel, showing course of lithium citrate in 30 minutes in the sun. 10th Oct. 1870.

Fig. 6. Branch of laurel, showing course of lithium citrate in 10 minutes in the sun. 10th Oct. 1870.

Red line—lithium. Green line—thallium. Black line—portion of branch in which no lithium or thallium could be detected. Thick lines indicate stems and petioles. Dotted lines—leaves. Scale for figs. 2 to 6, $\frac{1}{2}$ inch to 1 inch.

Fig. 7. Test-tube, with cork, through which the branch of laurel was passed into the fluid in the test-tube. The cork covered with melted paraffin. The whole was supported by being fixed in a large piece of india rubber.

II. *On the Law of Growth in Plants.* By Col. T. B. COLLINSON, R.E. Communicated by Dr CLEGHORN.

III. *Miscellaneous Communications.*

A letter was read from M. Adolph Ernst, Caracas, transmitting specimens of *Wolffia Welwitschii*, Heg., a species which he had described in the "Journal of Botany" 1865, page 114. He also sent seeds of *Pontederia paradoxa*, Mart., an interesting aquatic plant.

Mr Carruthers, British Museum, presented a specimen

