I. Transpiration as a Function of Living Protoplasm; II. Transpiration, and III. Evaporation, in a Saturated Atmosphere.
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I. TRANSPIRATION AS A FUNCTION OF LIVING PROTOPLASM.

Introductory.—That green leaves and other parts of plants transpire vapour of water from their surfaces has long been known; that this transpiration is greater by day than at night, and that it is augmented by heat, has been equally well ascertained; that it is chiefly induced by the absorption of the red and violet, and to a less extent by some other of the rays of the solar spectrum, when white light impinges upon organs containing chlorophyll, has been satisfactorily demonstrated. That it is *not*, however, strictly speaking a function of chlorophyll, *per se*, but rather one of living protoplasm generally, whether green or colourless, seemed to require confirmation, and is one of the results of the experiments herein to be described.

My object has been to find out, if possible, how far transpiration is effected by light, both white as well as coloured, and by temperature without the aid of chlorophyll; and if under this condition it could be compared with the purely physical property of evaporation which takes place from all moist substances.

MM. Bonnier and Mangin, in their experiments upon the respiration and transpiration of Fungi, arrived at the following conclusions* :—

“1. La transpiration est augmentée par l’élévation de la température.

“2. La transpiration diminue quand l’état hygrométrique de l’air augmente.

“3. La lumière diffuse augmente la transpiration des Champignons.”

With reference to the differences between Transpiration and Evaporation, M. Leclerc has arrived at the following results† :—

“1°. La transpiration est indépendante de la lumière.

* Ann. des Sci. Nat. 6 sér. tome xvii. p. 302.

† Ibid. 6 sér. tome xvi. p. 274.

"2°. Elle est nulle dans une atmosphère saturée.

"3°. Elle est fonction de l'état hygrométrique de l'air.

"Cette fonction est représentée assez exactement par l'équation $E = a(F - f) + c$, dans laquelle a est un coefficient variable avec chaque plante et chaque expérience ; F , la tension de la vapeur d'eau correspondant à la température de l'atmosphère dans chaque expérience ; f , la tension de la vapeur d'eau contenue dans l'atmosphère au même moment ; c , une constante, positive ou négative.

"Dalton a trouvé que la quantité d'eau qu'évapore une surface d'eau située dans une atmosphère partiellement saturée, peut s'exprimer par une équation identique.

"4°. Si la transpiration est plus active dans la plante exposée au soliel que dans la plante à l'ombre, cela tient :—(a) Aux rayons calorifiques qui, accompagnent toujours les rayons lumineux, échauffent les tissus ; (b) aux fonctions d'assimilation des feuilles."

M. Leclerc gives a short notice of the investigators of Transpiration, from Woodward in the 17th century to Wiesner in 1876. The paper of the last-mentioned writer appeared subsequently to M. Leclerc's experiments, and he only briefly notices it to observe that Wiesner reduces the function to a form of evaporation ; so that :—"Le phénomène de la transpiration devient un phénomène entièrement physique et une fonction de la température de la plante ; mais il ne semble pas avoir cherché s'il n'y aurait pas une relation entre la transpiration et l'état hygrométrique de l'air."

M. Masure, however, arrives at a different conclusion*, viz., that transpiration is not at all a phenomenon of simple evaporation, since he found from his experiments that it is four times greater than the evaporation of pure water from the same amount of surface†. It is a function of vegetation, which continues at night, being then about one-tenth of that by day ; and

* "Recherches sur l'Evaporation de l'eau libre, de l'eau contenue dans les terres arables, et sur la Transpiration des Plantes." *Annales Agronomiques*, 1880, tome vi. (cf. pp. 451 and 490).

† If this result be correct, it does not seem to agree with those obtained by comparing the transpiration of a living plant with the evaporation from the same plant when killed, as will be seen hereafter.

he attributes this relaxation to the absence of solar radiations ; finally observing :—" La Transpiration des plantes est un phénomène complexe qui subit, d'une part les mêmes influences physiques que l'évaporation de l'eau pure et qui, d'autre part, s'effectuant sous l'empire des forces, physiologiques de la vie végétative, s'écarte nécessairement de ces lois suivant les besoins de la plante. Ce n'est que par des observations de toutes les heures et plus souvent répétées encore si c'était possible, qu'on peut espérer découvrir les raisons de ces écarts."

One great objection amongst others to the idea that transpiration is referable to evaporation, which in turn is regulated by temperature and the hygrometric state of the air, is that a living leaf loses water more slowly than when it is dead*. I have proved this repeatedly in the following manner. Taking a variety of leaves and dividing them longitudinally, I suddenly killed one half by scalding. I then weighed them, and again at short intervals till the two halves of each leaf had dried up and lost no more weight. The killed half dried up faster, the loss per hour being greater than from the living half.

As another remarkable difference, it will be seen from the tables given below that while living parts of plants can *absorb vapour at night* in a saturated atmosphere, wet cotton-wool never does so.

For further details upon the effects of temperature, and of different hours of the day and of month of the year, upon Transpiration as compared with Evaporation, the reader is referred to M. Masure's interesting paper.

EXPERIMENTS WITH MUSHROOMS.

The first series of experiments were made with Mushrooms transplanted separately from a bed into small pots about two inches deep. The latter were entirely enveloped in guttapercha sheeting, cotton-wool being wrapped round the stipes to protect it from injury, where the sheeting was carefully and somewhat tightly fastened, so that no moisture could escape otherwise than by transpiration from the plant itself.

The following table gives the results of observations upon three

* Dr. Vines also mentions this fact, 'Phys. of Plants,' p. 105.

examples, from December the 28th, 1885, and of a fourth from Jan. 23rd, 1886.

Results of Experiments.

	No. of hours.	Loss per hour, No. I.	Loss per hour, No. II.	Loss per hour, No. III.		Min.	Max.
1885.							
Dec. 28	6	R. .030	Y. .021	V. .043	Dull.	42	45
	18	D. .026	D. .020	D. .037		39	41
" 29	6	Y. .016	R. .020	G. .040	Fine, bright.	39	44
	18	D. .024	D. .020	D. .035		35	42
" 30	6	G. .013	V. .015	R. .035	Fine.	40	42
	16.5	D. .018	D. .015	D. .020		42	42
" 31	8	V. .022	G. .022	Y. .030	Very dull.	40	47
	18	D. .011	D. .011	D. .032		40	48
1886.							
Jan. 1	6	Cl. .043	Cl. .035	Cl. .045	Very dull.	51	53
	16	D. .022	D. ?	D. .031		51	53
" 2	6.5	R. .021	Y. .018	V. .042	Fine.	50	52
	16	D. .020	D. .022	D. .034		51	56
" 3	7.5	Y. .030	R. .022	G. .034	Fine.	49	56
	17.5	D. .019	D. .013	D. .031		49	52
" 4	6.5	G. .027	V. .024	R. .035	Dull, rain.	51	52
	17	D. .024	D. .025	D. .034		42	51
" 5	8	V. .032	*G. .031	Y. .032	Very fine.	44	47
	15.75	D. .026	D. .027	D. .042		38	46
" 6	7	Cl. .030	*Cl. .031	Cl. .063	Heavy snow.	38	40
	17.5	D. .028	D. .023	D. .036		36	42
" 7	7	R. .010	*Y. .034	V. .046	Fine.	36	40
	17	D. .020	D. .020	D. .030		35	41
" 8	7	Y. .029	[decayed]	G. .036	Fine.	36	40
	14	D. .019	.....	D. .028		35	42
" 9	7	G. .020	.....	R. .033	Dull.	36	39
	18.75	D. .016	.....	D. .024		36	40
" 10	5	V. .016	.....	Y. .023	Foggy.	38	41
	17.75	D. .017	.....	D. .023		38	43
" 11	7	Cl. .037	.....	Cl. .033	Very fine.	39	41
	17	D. .015	.....	D. .023		38	43
" 12	7.25	R. .022	.....	V. .027	Overcast.	39	42
	18.25	D. .015	.....	D. .019		39	44
" 13	5.75	Y. .031	.....	G. .043	Fine.	40	44
	17.25	D. .015	.....	D. .020		40	43
" 14	24	G. .015	.....	R. .030	Dull.	39	45
" 15	6.25	V. .010	.....	Y. .020	Fine.	42	44
	16.25	D. .014	.....	D. .024		39	45
" 16	7.25	Cl. .022	.....	Cl. .023	Fine.	42	43
	16.25	D. .016	.....	D. .018		40	44

* See below, p. 295.

	No. of hours.	Loss per hour, No. IV.		Min.	Max.
1886.					
Jan. 23	5.5	R. .049	Snow, dull.	40	40
	14.5	D. .042		39.5	44
" 24	8	Y. .036	Snow, sunshine.	40	42
	15.5	D. .034		40	42
" 25	10.5	G. .024	Very dull.	42	46
	13.5	D. .032		44	48
" 26	10.5	V. .036	Very fine.	42	46
	13.5	D. .038		42	48
" 27	10	R. .047	Very fine.	42	45
	14	D. .038		42	48
" 28	9.5	Y. .035	Foggy, then fine.	42	44
	14.5	D. .039		42	48
" 29	9	G. .039	Dull.	42	44
	15	D. .036		42	47
" 31	9	V. .046*	Very fine.	42	45
	15	D. .049		42	46
Feb. 1	10	Cl. .041	A.M. dull, P.M. fine.	42	46
	14	D. .045		44	50
" 2	8.5	R. .044	Fine.	44	46
	15.5	D. .040		44	48
" 3	9.5	Y. .042	Dull.	42	46
		[dying]			

Effects of Light.

Arranging the preceding results under the different colourst, they give the following mean losses per hour :—

No. I.

(Dec. 28, 1885, to Jan. 16, 1886.)

Range of mean Min. and Max. Temps. }	R. 41° 7'—44° 7'	Y. 44° 0'—46° 0'	G. 41° 5'—44° 5'	V. 41° 14'—47° 0'	Cl. 42° 5'—44° 2'	D. 40° 43'—48° 0'
	.030	.016	.013	.022	.043	Mean of nineteen observations:
	.021	.030	.027	.032	.030	
	.010	.029	.020	.016	.037	
	.022	.031	.015	.010	.022	
Means	.021	.026	.019	.020	.033	.020

† The glasses used were the same as described in my former paper :—"A Contribution to the Study of the Relative Effects of Different Parts of the Solar Spectrum on the Transpiration of Plants," Journ. Linn. Soc. Bot. vol. xxiii. p. 81.

No. II.
(Same period.)

Range of mean Min. and Max. Temps. }	R. 44°-50°.	Y. 46°-48°·5.	G. 42°-47°.	V. 45°·5'-47°.	Cl. 44°·5'-46°·5'	D. 40°·7'-46°.
	·020 ·022	·021 ·018	·022 ·031	·015 ·024	·035 ·031	Mean of ten observations:
Means	·021	·019	·026	·019	·033	·020

No. III.
(Same period.)

Range of mean Min. and Max. Temps. }	R. 41°·5'-44°.	Y. 41°-44°·5.	G. 41°-46°.	V. 41°·7'-45°.	Cl. 42°·5'-44°·5'	D. 40°·5'-45°·1.
	·035 ·035 ·033 ·030	·030 ·032 ·023 ·020	·040 ·034 ·036 ·043	·043 ·042 ·046 ·027	·045 ·063 ·033 ·023	Mean of nineteen observations:
Means	·033	·026	·038	·040	·041	·028

No. IV.
(Jan. 23 to Feb. 3, 1885.)

Range of mean Min. and Max. Temps. }	R. 41°·8'-45°.	Y. 41°·3'-44°.	G. 42°-45°.	V. 42°-45°·5.	Cl. 42°-46°.	D. 42°·1'-47°.
	·049 ·047 ·044	·036 ·035 ·042	·024 ·039	·036 ·046	·041	Mean of ten observations:
Means	·047	·038	·031	·041	·041	·039

The means of all four specimens will therefore be as follows:—

R.	Y.	G.	V.	Cl.	Dk.
·0305	·0267	·0285	·0300	·0370	·0267.

These may be practically represented:—

·030	·027	·028	·030	·037	·027.
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These results agree with those obtained from plants possessing chlorophyll, so far as the maxima occur under red, violet, and clear glasses, while yellow, green, and total darkness give minima. This result is almost as obvious in the means for each specimen respectively.

If, however, we neglect third places of decimals, we may write the above thus:—

·03	·03	·03	·03	·04	·03.
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This result shows that the differences between the effects of any particular colour is really almost inappreciable; whereas the augmentation under clear light is more pronounced. This last result, as mentioned above, was obtained by MM. Bonnier and Mangin. It should be observed that, taking high places of decimals (as the third or fourth), one runs the risk of appearing to emphasize what may be fictitious results. So far as they go, however, it is at least somewhat remarkable that they should so completely tally with the results obtained from green plants, where the differences are more manifest.

Effects of Temperature.

The mean temperatures from December 28, 1885, to January 15, 1886, during which period the observations were made upon the specimens Nos. I., II., and III., rose during the first four days, fluctuated from Jan. 1st to the 4th, and then fell again. Grouping the total amount of losses per hour during these three successive periods, the results are as follows:—

	Mean Max.	No. I.	No. II.	No. III.
Dec. 28 to 31	43°·5	·018	·020	·034
Jan. 1 to 4	53°·5	·026	·023	·036
Jan. 5 to Feb. 15 ...	43°·0	·020	[decayed]	·031

Comparing the losses per hour under the lowest minimum temperature with those under the highest maximum, the effect under each glass is shown as follows:—

	Lowest Min. No. I.	Highest Max. No. I.	Lowest Min. No. II.	Highest Max. No. II.	Lowest Min. No. III.	Highest Max. No. III.
R...	36° ... '010	52° ... '021	39° ... '020	52° ... '021	36° ... '033	52° ... '035
Y...	36 ... '029	56 ... '030	36 .. '034*	56 ... '030	38 ... '023	47 ... '041†
G...	36 ... '020	52 ... '027	40 ... '022	52 ... '027	36 ... '036	56 ... '036
V...	38 ... '016	47 ... '027†	40 ... '015	47 ... '027	36 ... '046	52 ... '042
Cl...	38 ... '030	53 ... '043	38 ... '031	53 ... '043	38 ... '063	53 ... '045

These results are sufficient to show that temperature has a marked effect upon the transpiration, when no account is taken of any difference between light and darkness. The effect, however, becomes much more pronounced when Mushrooms are transferred from a warm room to a cool one, and allowed to remain in each for definite periods and of the same duration.

Three Mushrooms were grown in separate pots and protected as before. They were placed for twenty-four hours alternately in a cool room with no fire in it, and in a warm one where a fire burned every day. They were always in total darkness, being enclosed in a cardboard box. The following are the total losses in twenty-four hours :—

		I.	II.	III.	Min.	Max.
1886.		grms.	grms.	grms.	°	°
Dec. 6- 7...	Cool room	1·50	·82	1·16	50	56
" 7- 8...	Warm "	3·38	1·68	2·73	52	68
" 8- 9...	Cool "	2·18	1·19	1·81	44	59
" 9-10...	Warm "	3·57	2·61	2·90	48	76
" 10-11...	Cool "	2·67	·85	1·15	44	56
" 11-12...	Warm "	3·15	1·45	1·93	50	62
" 12-13...	Cool "	·99	·92	1·02	47	56
" 13-14...	Warm "	2·27	1·37	1·71	48	61

Transpiration from Living Mushrooms compared with Evaporation from Saturated Dead Specimens.

Two of the three specimens, viz. Nos. I. and III., together with No. IV., were scalded after the above experiments were

* Exceptionally increased loss by dying and drying up rapidly.

† Means of two observations.

completed. All superficial moisture being carefully removed by slight pressure between sheets of blotting-paper, they were submitted for four and three days and nights respectively to diffused sunlight and total darkness respectively, with the following results :—

Loss per hour by Day, No. I. No. III.		Min.	Max.	Loss per hour by Night, No. I. No. III.		Min.	Max.
·023	·044	39 ⁰ ·5	41 ⁰	·017	·023	39 ⁰ ·5	41 ⁰
·028	·041	38	40	·014	·012	38	42
·017	·020	40	40	·013	·017	39·5	44
·016	·022	40	42	·014	·022	40	42
Means	·021 ·032	39·4	40·7	·014	·018	39·2	42·2

Loss per hour by Day, No. IV.		Min.	Max.	Loss per hour by Night, No. IV.		Min.	Max.
·043		42 ⁰	42 ⁰ ·5	·035		41 ⁰	44 ⁰
·025		38	42	·020		40	44
·017		41	45	·014		46	50
Means.....	·028	40	43	·023		42	44

Total mean
loss by Day.

·027

Min. Max.

40° 42°

Total mean
loss by Night.

·018

Min. Max.

40° 43°

Comparing these results with the mean losses by transpiration under clear diffused light and total darkness, the latter were as follows :—

Total mean
loss by Day.

·036

Min. Max.

42°·3 45°

Total mean
loss by Night.

·029

Min. Max.

41° 45°

In both cases the loss is greater by transpiration than from an artificially saturated condition, and whether the loss be by transpiration or evaporation, it is greater by day than by night.

This may appear strange with regard to evaporation, but it is a well-known fact that dark bodies especially, such as a dead mushroom, can absorb radiant energy and convert it into heat. This is well illustrated by small objects, such as dead leaves, pieces of bark, small stones, dead insects, &c., which when lying on ice gradually sink into it, sometimes to a depth of several inches. This is frequently observable on the glaciers of Switzerland, and that, too, when the temperature of the air in contact with the ice must be close upon the freezing-point of water.

That a mushroom with blackened gills absorbs much light is further proved by making an alcoholic solution. If this be examined with a spectroscope, it will be found that the only light which is transmitted is a very dull red and green, showing how much of the spectrum is arrested.

There is another point illustrated in the above experiments, namely, that a living organism transpires *ceteris paribus* less than when dying or dead, *i. e.* when it is replaced by evaporation. Thus specimen No. II. will be seen to have transpired more largely from Jan. 5 to 7 (indicated by * p. 289), when decay had set in, though there was no special rise of temperature to account for it. It was also more pronounced by day than at night.

Similarly, specimen No. IV. was beginning to dry up about Jan. 31 (* p. 290). From that date to the 3rd, the loss per hour was markedly greater than it had been previously.

EXPERIMENTS WITH ETIOLATED SEAKALE.

The following experiments were made with plants of Seakale which had at first been grown in a dark cellar. One had a rhizome 3 inches in length, and foliage consisting of white petioles with purplish arrested blades. The other had a rhizome about 5 inches in length, with long petioles varying from 6 to 12 inches in length. The rhizomes, with a few rootlets attached, were wrapped up in saturated cotton-wool, and the whole enveloped in guttapercha sheeting, so that no moisture could possibly escape except from the exposed petioles. The plants were subjected to light transmitted through coloured glasses successively by day, and placed in total darkness at night. They were carefully weighed every morning and evening, and the losses by day and by night reduced to losses per hour for each period respectively, as in the case of the Mushrooms described above.

The following are the results obtained :—

	No. of hours.		Loss per hour, No. I.	Loss per hour, No. II.		Min.	Max.
1886.							
March 15	13·5	Dark.	·036	·067		41°	46°
" 16	10	R.	·041	·070	Dull.	39	42
" 16	14	D.	·032	·062		38	43
" 17	10	Y.	·034	·065	Fine.	40	40
" 17	14	D.	·032	·063		41	44
" 18	10	V.	·034	·070	Dull.	40	44
" 18	9·5	D.	·031	·073		42	46
" 19	10	G.	·030	·083	A.M. dull ;	44	52
" 19	14·5	D.	·029	·080	[P.M. fine.	49	52
" 20	10	Cl.	·031	·079	Fine.	50	54
" 20	14	D.	·032	·070		53	56
" 21	9·5	R.	·026	·076	Dull.	53	56
" 21	15	D.	·030	·111		53	57
" 22	9·5	Y.	·028	·026	Dull.	52	58
" 22	14·5	D.	·028	·070		54	57
" 23	10	G.	·031	·089	A.M. dull ;	54	56
" 23	14	D.	·043	·085	[P.M. fine.	55	60
" 24	9·5	V.	·053	·087	Fine.	55	59
" 24	15	D.	·044	·088		56	57
" 25	9·5	Cl.	·051	·090	Dull.	56	59
" 25	14	D.	·039	·073		56	59
" 26	10	R.	·051	·084	Dull.	55	59
" 26	14	D.	·044	·077		56	58
" 27	10	Y.	·043	·066	Dull.	56	56
" 27	14·5	D.	·035	·065		56	58
" 29*	9·5	G.	·042	·072	Dull, rain.	54	56
" 29*	14	D.	·037	·069		50	55
" 30	9·5	V.	·040	·070	Fine.	52	54
" 30	14·5	D.	·037	·072		51	54
" 31	10·5	Cl.	·044	·067	Fine.	50	54
" 31	13·5	D.	·037	·054		49	52

Effects of Light.

Arranging the preceding results under the different colours, they give the following mean results of the losses per hour :—

No. I. (March 16–32, 1886.)

	R.	Y.	G.	V.	Cl.	D.
	·041	·034	·030	·034	·031	Mean of fourteen observations :
	·026	·028	·031	·053	·051	
	·051	·043	·042	·040	·044	
Means	·039	·035	·034	·042	·042	·034

* Observations not taken on March 28.

No. II.

	R.	Y.	G.	V.	Cl.	D.
	·070	·065	·083	·070	·079	Mean of fourteen observations:
	·076	·026	·089	·087	·090	
	·084	·066	·072	·070	·067	
Means ...	·077	·052	·081	·076	·079	·073

Taking the means again of the above, the results are as follows:—

R.	Y.	G.	V.	Cl.	D.
·058	·043	·058	·059	·060	·053 ;

or, practically,

·06	·04	·06	·06	·06	·05.
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It will be seen that these means agree very closely with what is experienced with green plants; in so far as red, violet, and clear light furnish maxima, yellow, and generally green as well as total darkness, minima. These results, moreover, agree with those obtained by Wiesner, who found that etiolated plants absorbed the same rays, but in a lessened degree. Temperature, however, bears so important a part that apparently exceptional results may easily mark the general law.

A somewhat conspicuous difference will be observed between the effects of green light on the two specimens: thus, while No. I. has the most decided minimum, No. II. has the most decided maximum. I met with a similar experience when experimenting with green plants; thus, while one batch of Lettuces gave a mean under green the next lowest to that under yellow light, both a second and a third batch gave the mean under green next highest after red, violet, and clear glass. On the other hand, Palms gave the mean under green as the lowest minimum.

The green glass used transmitted the absorption-bands III. to vi. Hence there seems to be some peculiarity about the effect of green glass which requires further investigation.

The lowest minimum is most constantly under yellow glass; and the results with colourless glass agree therefore with those obtained with green plants, in which I have pointed out that yellow light must have a *retarding* effect on transpiration, since the glass used transmits all the red as well, whereas the red glass is absolutely pure without a trace of any other colour. It

is a remarkable coincidence that MM. Bonnier and Mangin found that the luminous rays, especially red and yellow, retarded respiration, other conditions being equal*.

Effects of Temperature.

Comparing the losses per hour under the lowest minimum temperature with those under the highest maximum, the effect under each glass is shown as follows :—

	Lowest min.	No. I.	No. II.	Highest max.	No. I.	No. II.
R.	39	·041	·070	59	·051	·084
Y.	40	·034	·065	58	·028	·026
G.	44	·030	·083	56	·036†	·080†
V.	40	·034	·070	59	·053	·087
Cl.	50	·031	·079	59	·051	·090

By comparing these results, it will be seen that increments of temperature *generally* increase markedly the transpiration. A curious exception is noticeable with yellow light, in which an increase of 18° is accompanied by a decreased power of transpiring. Somewhat similar results seem noticeable with Mushrooms ‡.

With regard to the effects of temperature apart from light, if we group the means in successive increments as follows, the effect is clearly seen.

The following figures represent the loss per hour at night in total darkness :—

		I.	II.
March 16.....	40·5	} 03	} 06
" 17.....	42·5		
" 15.....	43·5	} 03	} 07
" 18.....	44·0		
" 19.....	50·5	} 03	} 07
" 31.....	50·5		
" 29.....	52·5	} 04	} 07
" 30.....	52·5		
" 20.....	54·5	} 03	} 08
" 21.....	55·0		
" 22.....	55·5	} 04	} 09
" 24.....	56·5		
" 26.....	57·0	} 04	} 08
" 27.....	57·0		
" 23.....	57·5		
" 25.....	57·5		

* "La Fonction Respiratoire chez les Végétaux." Ann. des Sci. Nat. tome ii. p. 877.

† Means of two observations.

‡ See the corresponding table p. 293, especially Nos. I. and II.

This indicates a gradual increase of transpiration in accordance with slight increments of temperature.

As with Mushrooms so with etiolated Seakale, the effect of temperature becomes more marked when the specimens are transferred from a cool room to a warm one, and *vice versâ*, as the following experiment shows :—Two specimens of Seakale of about the same size as the preceding, and carefully protected as described, were placed for twenty-four hours alternately in a cool room without a fire and in a warm one. They were not enclosed, but exposed to diffused daylight.

	No. I.	Loss in 24 hours. No. I.	Loss in 24 hours. No. II.	Min. temp.	Max. temp.
1887.		grammes.	grammes.	°	°
April 7-8	Cool room.	2·80	1·83	44	51
" 8-9	Warm "	2·24	2·34	49	61
" 9-10	Cool "	·89	·86	46	56
" 10-11	Warm "	1·46	1·55	48	69
" 11-12	Cool "	·71	·76	45	58
" 12-13	Dark "	1·20	1·13	54	64

Transpiration compared with Evaporation.

The two specimens of Seakale were scalded after the termination of the experiments on transpiration. All superficial moisture being carefully removed, they were subjected for a week to successive coloured glasses by day and to total darkness at night, with the following results :—

Colour of glass.	No. I.	No. II.	Min.	Max.
Dark	·115	·162	52°	54°
R.	·121	·201	52	56
D.	·075	·112	55	58
Y.	·117	·210	51	58
D.	·074*	·133*	50	56
G.	·060	·110	52	54
D.	·048	·070	51	56
V.	·050	·050	52	54
D.	·033	·047	54	56
CL.	·043	·048	50	58

The first observation to be made on these results is that up to (*) the losses were greater by day than by night; subsequently the evaporation steadily declined, apparently irrespective

of light. Taking the means of the above, we have as results, irrespective of colour :—

Mean loss by day.	Min.	Max.	Mean loss in darkness.	Min.	Max.
·106	51	56	·087	52	56

Comparing these results with the mean losses by transpiration irrespective of colours :—

Mean loss by day.	Min.	Max.	Mean loss in darkness.	Min.	Max.
·056	50	53·3	·049	53·3	57

In both cases, as with Mushrooms, the loss is greater under light than in darkness ; and probably the same interpretation may be given here as with the former experiments.

Again, as it was observed (on p. 294) that the transpiration of Mushrooms was greater than their evaporation, similarly is it with Seakale. In the latter case the evaporation is nearly double that of transpiration. So great a difference possibly depends upon the different natures of the cellular tissues of these two plants, though I confess at present to be quite unable to explain it. That there is some similarity, if not identity in part, between the two processes of transpiration and evaporation seems obvious, yet that the *vitality* of a living plant has an important modifying influence is equally apparent. Leclerc considers transpiration as not being due to light *per se*, but to the calorific rays which accompany it. But though the chlorophyll absorption-band No. I. coincides pretty nearly with the maximum of the calorific rays (as Langley and Abney have shown *), it is difficult to see in what way Leclerc would explain how a maximum of transpiration is obtained with violet light, as both Wiesner and myself have proved, and which we believe to be converted into heat, and thus do work.

One great point of difference between transpiration and evaporation in their final results consists in the relatively greater quantity of water lost, and that with a greater rapidity, by evaporation as compared with transpiration. Thus, for example, the mean loss by transpiration under all lights of a plant of *Echeveria* was ·033 gramme per hour ; while the same plant scalded to death evaporated ·068 gr. per hour under a very

* "The Influence of Water in the Atmosphere on the Solar Spectrum and Solar Temperature," by Capt. Abney, R.E., F.R.S., and Col. Festing. Proc. Royal Soc. xxxv. p. 328 (1883).

similar range of temperatures. The inference is, that living protoplasm has a power of controlling and regulating the loss of water which a dead organic structure does not possess.

CONCLUSIONS.

The general conclusions which the above-described experiments seem to warrant are, that plants, such as Mushrooms, which do not possess chlorophyll at all, transpire more under light than in darkness, but exhibit slight, but not very appreciable, differences under light of various colours. Transpiration, however, appears to be more sensitive to increments of temperature than to colours, and perhaps than to pure white light itself.

Etiolated plants, as Seakale, which under normal conditions would be green, still show some slight difference, due to coloured rays, such as are, however, much more pronounced with plants possessing chlorophyll.

In both cases transpiration is a function of living colourless protoplasm; this function, however, being greatly enhanced by the presence of chlorophyll, in consequence of the power possessed by the latter substance of absorbing certain rays, which then, by their conversion into heat, raise the temperature within the leaf and thereby increase the loss of the vapour of water.

Lastly, the difference in the effects of transpiration from a living organism and evaporation from a dead one can easily be seen in the usually relatively greater amount of water lost under the latter process under similar conditions and in the same space of time. A further difference will be noted hereafter; and the reader may be referred to M. Masure's paper, mentioned above, for other differences.

Since this paper was written a short communication from M. Ph. van Tieghem* has appeared, in which he also suggests that the term *transpiration* should be given to the vaporization of water from protoplasm, and which occurs independently of chlorophyll. This, he remarks, is a process common to animals as well as vegetables, or to all living beings:—"Elle croît, comme on sait, avec la température, avec la sécheresse et l'agitation de l'air. La lumière aussi s'accélère; au soleil, un organe sans chlorophylle, un pétale de Mauve ou de Lis, par exemple, transpire jusqu'à deux et trois fois plus fortement qu'à l'obscurité."

* Bull. de la Soc. Bot. de France, 1886, p. 152.

To this general property of transpiration the "chloroleucites," or chlorophyll-grains, add their quota by means of the particular rays absorbed by them in sunlight. This second phenomenon, be it observed, is much more intense than the former, and Tieghem proposes the term "chlorovaporisation" to represent the "transpiration chlorophyllien."

II. TRANSPIRATION IN A SATURATED ATMOSPHERE.

M. Dehérain states * that transpiration continues indefinitely in a saturated atmosphere from living leaves undetached from the plant; whereas (he says) a cotton wick dipped in water after two hours lost .076 gramme, after three hours' exposure to sunlight .086 gr., but after four hours there was no further loss. Wiesner also remarks that plants can transpire in a saturated atmosphere, but only under the influence of light, inasmuch as the temperature within the leaf must be warmer than without, and this increase is produced by the conversion into heat of the rays which are absorbed.

On the other hand, M. Leclerc, in his paper alluded to above, states that transpiration does *not* take place in a saturated atmosphere.

Lastly Knop (Veg. Stat. vi. 255) found that a moist piece of paper or wood lost weight when kept for some time in a confined space over water.

The following experiments were made for the purpose of testing these results, and, as far as they go, they certainly seem to corroborate Dehérain and Wiesner with regard to transpiration, and Knop in that a dead substance will continue to evaporate for many days in an apparently saturated atmosphere.

The experiments were conducted in a large glass jar constructed like a hat with a broad rim. A thick piece of plate glass was well luted to the rim by a band of putty about two inches broad and a quarter of an inch thick. A small hole, about half a line in diameter, was bored in the centre of the plate, through which a fine platinum wire was passed, and upon which was suspended the leaf or cotton-wool &c. The wire was attached to one of the pans of a delicate balance, and, except when the specimen was required to be weighed, the hole was plugged with putty. The latter was removed at intervals, so that the

* Ann. des Sci. Nat. 5 sér. tome xii. 1869, p. 5.

leaf &c. could be weighed while still remaining within the glass jar. A layer of water covered the bottom of the jar; and a wet- and a dry-bulb thermometer were suspended within it; the mercury was always exactly at the same height in both of them.

The jar was either exposed to diffused light, or else entirely excluded from light by means of oiled cloth.

The following is a selection of experiments to represent three types of foliage.

In the following cases, selected out of several, it will be observed that as long as the plants were exposed to diffused daylight, they continued to lose weight, although the atmosphere was apparently perfectly saturated all the time*.

Buxus sempervirens.

	Weight in grammes.	Loss per cent.	Temp. (W. & D.).
July 9th.			
8 A.M.	3.240	.....	67°
3 P.M.	3.155	.973	71
5 "	3.085	.221	73
10 "	3.035	1.626	69
July 10th.			
8 A.M.	3.045	† .032	67.5
1 P.M.	3.035	.032	71
10 "	3.005	.098	71
July 11th.			
8 A.M.	3.115	† .366	70
6 P.M.	2.950	5.296	75
July 12th.			
8 A.M.	2.965	† .050	71
1 P.M.	2.965	.000	71
6 "	2.945	.067	72
10 "	2.955	† .033	70
July 13th.			
8 A.M.	2.980	† .084	69
2 P.M.	2.955	.083	71
5.30 P.M.	2.905	.016	76.5
10 P.M.	2.920	† .051	67
July 14th.			
8 A.M.	2.940	† 1.369	66
6 P.M.	2.925	5.102	69
July 15th.			
8 A.M.	2.960	† 1.196	67
6 P.M.	2.950	.034	68
July 16th.			
8 A.M.	2.960	† .036	67

* The reader's attention is called to the instances of no loss by a * and a † represents a gain. In all other instances the numbers represent a loss per cent. of the entire weight of the leaves under examination.

Ligustrum vulgare.

	Weight in grammes.	Loss per cent.	Temp. (W. & D.).
August 4th.			
8 A.M.	2.965	.....	71°
10 P.M.	2.795	.576	66
August 5th.			
8 A.M.	2.795	* .000	63
1 P.M.	2.765	.106	68.5
6 "	2.760	.017	67
12 "	2.770	† .036	64
August 6th.			
8 A.M.	2.770	* .000	64
4.30 P.M.	2.615	5.595	68
12 P.M.	2.625	† .015	63
August 7th.			
8 A.M.	2.630	† .019	63
1 P.M.	2.610	.076	65.5
6 "	2.585	.095	64
12 "	2.600	† .057	63
August 8th.			
8 A.M.	2.605	† .019	64.6
6 P.M.	2.565	.153	65
11 "	2.675	† .039	64
August 9th.			
8 A.M.	2.590	† .059	62

Epilobium hirsutum.

	Weight in grammes.	Loss per cent.	Temp. (W. & D.).
July 17th.			°
9 A.M.	3.625		
11 "	3.585	1.1	65
1 P.M.	3.565	.55	64.5
5 "	3.510	1.51	64.5
10.30 P.M.	3.510	* 0.00	64
July 18th.			
8 A.M.	3.510	* 0.00	64
2 P.M.	2.860	18.51	67
10.30 P.M.	2.700	5.59	65
July 19th.			
8 A.M.	2.700	* 0.00	65
12 (noon)	2.660	1.44	67
6 P.M.	2.585	2.81	67
July 20th.			
8 A.M.	2.610	† .09	64
4.30 P.M.	2.530	3.06	67
10 P.M.	2.530	* 0.00	67

Epilobium hirsutum (continued).

	Weight in grammes.	Loss per cent.	Temp. (W. & D.).
July 21st.			
8 A.M.	2.480	1.98	61.5
3 P.M.	2.460	0.79	62
10.30 P.M.	2.460	* 0.00	62
July 22nd.			
5.30 P.M.	2.350	4.47	63
July 23rd.			
9 A.M.	2.350	* 0.00	62
2 P.M.	2.300	2.12	64

Between 6 P.M. one day and 8 A.M. on the following day, the plants very frequently either lost nothing (*), or else they gained weight (†).

The author of 'How Plants Feed' says:—"Knop found in one instance that a *Portulaca*, standing overnight in a bell-glass with moistened sides, did not lose, but gained weight, some dew having gathered on the foliage" (p. 37). That plants, especially when at all "wilted," to use the American term, can absorb dew and rain has been abundantly proved by Boucicault* and by myself†.

In carefully examining the specimens, of course through the glass jar, I could not detect that the gain was in consequence of any visible dew upon the surface. Indeed, the amount gained in each case is so minute, that it could only be detected by very careful weighing; but the fact that the gains all occurred during the evenings and nights, when the temperature fell, while the losses only occurred by day, are sufficient to indicate the occurrence as an undoubted fact; and while Knop only recorded it as an isolated instance, the above table establishes the property of gain as a law.

* Annales de Chimie et de Physique, Mars 1878.

† Journ. Linn. Soc., Bot. vol. xvii. p. 313.

III. EVAPORATION IN A SATURATED ATMOSPHERE.

Some cotton-wool, saturated with distilled water, and weighing 9·715 grammes, was suspended in the glass jar as described. The losses in weight were as follows :—

	Weight in grammes.	Loss per cent.	Temp. (W. & D.).
November 9th.			
8 A.M.	9·716	.....	53
6.30 P.M.	9·710	·005	53
November 10th.			
8 A.M.	9·700	·010	56
6 P.M.	9·695	·005	56·5
November 11th.			
8 A.M.	9·670	·025	52
6 P.M.	9·660	·010	52·5
November 12th.			
8 A.M.	9·645	·015	51
5.30 P.M.	9·630	·015	49
November 13th.			
9 A.M.	9·615	·015	49
7 P.M.	9·600	·015	47
November 14th.			
8 A.M.	9·585	·015	44
5 P.M.	9·580	·005	46
November 15th.			
8 A.M.	9·565	·015	43
November 16th.			
8 A.M.	9·540	·025	40
November 17th.			
9 A.M.	9·525	·015	45

The total loss was ·255 gramme, or on an average ·0232 gr. per day.

From Nov. 17th to Dec. 1st, or a fortnight, the cotton-wool was kept in the jar, which was completely closed during the whole time. On Dec. 1st it weighed 9·235 grammes, so that it had lost ·0217 gr. per day.

A piece of sponge weighing 18·005 grammes and saturated with distilled water was suspended in the same manner, and lost weight as follows :—

	Weight in grammes.	Loss per cent.	Temp. (W. & D.).
May 9th.	18.005		°
„ 10th.	17.980	.025	56
„ 11th.	17.940	.034	57.5
„ 12th.	17.930	.016	?
„ 13th.	17.890	.040	59
„ 14th.	17.855	.035	59
„ 15th.	17.840	.015	63
„ 16th.	17.785	.055	65
„ 17th.	17.713	.072	62
„ 18th.	17.705	.008	59

The total loss was therefore .390 gramme, and the mean loss per day .035 gramme.

These two cases, several times repeated and corroborated by others which I need not quote, fully prove that dead saturated substances continue to evaporate, notwithstanding that the atmosphere in which they are suspended is apparently saturated; we can only conclude with Knop that it is impossible to maintain the air saturated with vapour.

Since the temperatures within the jar are constantly changing, the capacity of absorption must vary accordingly, and when the temperature rises, one can understand that the air can absorb more vapour, and may extract it from the substance or leaf experimented with as well as from the water at the bottom of the jar. But when the temperature falls, it is not so easy to see why cotton-wool or a sponge should still lose moisture. Such, however, is evidently the case.

A point to notice in these experiments is that while living specimens *gained* weight at night, dead substances never did so, but *lost* weight under all circumstances. Thus, when the glass jar was entirely excluded from light, and a piece of cotton-wool saturated with distilled water, weighing 8.670 grammes, was suspended within it for seven days, it lost .165 gramme, or .022 gr. per day. It would seem, therefore, that the power to absorb the vapour of water must be regarded as a property of living protoplasm, since dead cellular tissue (as cotton-wool) entirely failed to do so; and this furnishes an additional difference between living and dead organic structures.