XIII. *On the Action of Light upon Plants, and of Plants upon the Atmosphere. By* CHARLES DAUBENY, *M.D. F.R.S., Professor of Chemistry and of Botany in the University of Oxford.*

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THE researches of PRIESTLEY, INGENHOUSZ, SENEBIER, ELLIS, and above all of the younger SAUSSURE, have long put us in possession of the leading facts appertaining to the influence of light upon the green parts of plants; and Professor DECANDOLLE has embodied the substance of all that had been ascertained on this subject, up to the year 1831, in his admirable work on Vegetable Physiology. But there appear, by the confession of this latter naturalist, to remain certain subordinate questions respecting this same function, which, though perhaps occasionally touched upon by the above-cited experimentalists and by others, can scarcely be said to have as yet obtained a satisfactory reply.

The first of these questions relates to the *nature* of the influence which, in the cases alluded to, is assignable to light. As this agent often produces chemical changes by its direct action upon inorganic bodies, decomposing saline solutions, discolouring oils, and reducing metallic oxides, so it may be supposed to operate directly upon the air, and to possess the power of decomposing carbonic acid, when this substance is presented to it within the pores of the vegetable tissue. And, on the other hand, as light appears to be a specific stimulus to the vital functions of animals, so it may be imagined to act in a similar manner on those of plants, thus enabling them to secrete from the carbonic acid presented to them the carbon required for their nutrition.

Another point as yet undecided relates to the *extent* of the influence it exerts over the vegetable kingdom; or, in other words, the degree in which certain processes attributed to its presence are capable of counteracting others that are going on at all times, whether light be absent or not. Thus, although it may be conceded, as a fact already well established, that plants purify the air in the sunshine, it still remained to be proved by more decided experiments than had hitherto been instituted, whether the quantity of oxygen given out by them during the day exceeded that absorbed during the night; and moreover, supposing this latter question answered in the affirmative, whether the probable excess was likely to be such, as would

afford a counterpoise to the effects produced by animal respiration, combustion, and the like*.

After considering therefore the *mode* in which light appears to affect the functions of plants, I shall naturally proceed to examine the *extent* of the changes produced by the latter upon the air through its influence.

Part I.—*On the Influence of Light upon Plants.*

If of the two modes of considering the operation of light above noticed we adopt the second, that is, if light be supposed to affect plants by a specific stimulus, such as it exerts on animals, and not in the first instance the air as a chemical agent, it ought to follow, that those portions of the spectrum which possess the strongest illuminating power, should exercise upon them the most powerful influence, and produce the most decided effects.

Senebier, however, has stated, that the green colour of leaves, which is supposed to be connected with the decomposition of carbonic acid and the evolution of oxygen, is produced most rapidly under the action of the violet ray†; and as the latter, from the feeble light and heat it communicates, seems almost inert, with reference to the functions *of animals*, such a circumstance, if substantiated, would seem strongly to favour the contrary hypothesis.

This latter view of the mode in which carbonic acid is decomposed within the vessels of the plant, would likewise be somewhat confirmed, if it should appear, that whilst the above process was most favoured by violet light, other functions, which are affected by the presence of this agent, but which evidently depend upon a process taking place in the vessels of the plant, are influenced in proportion to the luminousness of the ray; whilst, if the same law were found to prevail in both these cases, and if all the processes alluded to could be proved to go on most rapidly under the influence of the darkest and most refrangible portion of the solar spectrum, a curious difference between the *mode* of its operation upon the vegetable and animal kingdoms might then be suggested.

* I am aware it may be urged, that the quantity, of carbonic acid added, and of oxygen subtracted by these latter means within any moderate period of time, is in itself so small compared with the entire bulk of the atmosphere, that we must not argue, because the constitution of the latter has appeared to continue uniform ever since accurate methods have been devised for determining it, therefore that no change can be taking place insensibly in the proportions of its ingredients.

Still, however, when we recollect, how many ages have elapsed since the present races of animals were created, and how many more since the existence of others, which, although extinct, appear from the analogies of their structure to have carried on the same respiratory process which those now in existence fulfill, and therefore could not have endured an atmosphere much more highly charged with oxygen than the present one, we cannot help feeling, that nature must have some means at her disposal, by which the purity of the atmosphere is restored, and its constitution thus maintained without alteration.

† Mém. de Phys. Chim., tom. ii. p. 55.

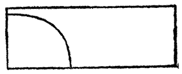
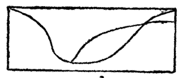
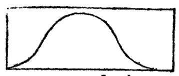
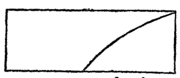
I felt therefore desirous of putting to the test of experiment the two following questions: 1st, whether the several solar rays act upon plants with equal or with different degrees of energy; and secondly, whether all the functions of plants that seem dependent on the presence of light are affected in the same ratio by similar rays.

Now the following functions are found to depend in great measure on the influence of light.

1. The decomposition of carbonic acid, and the consequent evolution of oxygen, already spoken of.
2. The green colour of leaves, and other analogous parts.
3. The expansion or unfolding of the leaves in certain species, the folding of which on the close of day constitutes what has been called "the sleep of plants."
4. The irritability belonging to certain other plants, such as the *Mimosa pudica*.
5. The exhalation of water from the leaves.
6. The absorption of the same by the roots.

The difficulty, however, of comparing the relative intensity of the light transmitted by the various coloured media, which were employed in my experiments, induced me to content myself with showing, that the effect of light upon plants corresponds with its illuminating, rather than with its chemical, or its calorific influence; and to wave the more difficult inquiry, whether its operation upon the vegetable kingdom exactly keeps pace with the increase in its own intensity. And in order to show that the former is the case, I will in the first place set down the order of sequence of the several media, with reference one to the other, in respect to their illuminating, their calorific, and their chemical power; stating at the same time, by means of a diagram, the rays intercepted and transmitted by each, as was determined for me by Professor Powell; and afterwards proceed to a statement of their respective influence upon plants.

With regard to the means adopted for estimating these points, I need perhaps only remark, that the relative illuminating power of the several media was ascertained by the number of thicknesses of wire gauze, which produced a certain definite degree of obscurity or indistinctness when interposed; their relative calorific power, by the number of degrees which a thermometer with a blackened bulb was raised in a given time by the light transmitted through each; their relative chemical influence, by the time required to reduce paper moistened with a solution of nitrate of silver to a certain standard point of discoloration. The figures in the annexed Table therefore must be understood to express nothing more than the *order of sequence*, and not to indicate the ratio between the several media in any of the above respects.

Nature of the media.	Its type.	Its illuminating influence.	Its calorific influence.	Its chemical influence.
Transparent glass	....	7	7	7
Orange, No. 5.	 *r y g b*	6	6	4
Red, No. 4.	 *r y g*	4	5	0
Blue, No. 3.	 *r y g*	4	3	6
Purple, No. 2.	 *r y g b v*	3	4	6
Green, No. 1.	 *r o y g b i v*	5	2	3
Bottle containing a solution of ammonio-sulphate of copper, No. 6.	 *r o y g b i v*	2	1	5
Bottle containing port wine, No. 7	 *r*	1	3	0

Now it remained to be seen, with which of the above scales the power of occasioning a decomposition of carbonic acid in the vessels of the plant, and of forwarding those other functions of vegetable life which depend upon light, most nearly corresponded.

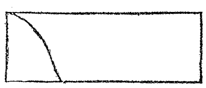
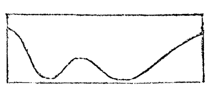
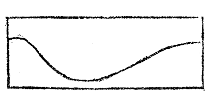
For this purpose, a certain number of fresh leaves, which presented in each case an extent of surface as nearly as possible equal, and had been previously ascertained to give out equal quantities of oxygen, were introduced severally into jars, filled with water impregnated with carbonic acid gas, placed on the surface of a pneumatic trough, and exposed for a certain time to the influence of the solar rays.

The jars, in which the leaves thus selected stood, were severally covered over by a wooden screen, which intercepted all light from the included jar, excepting in front, where a frame was fitted to it of a nature calculated to support, either a circular pane of glass, or a flat bottle of corresponding dimensions.

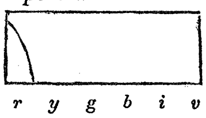
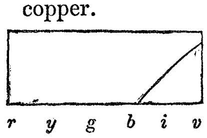
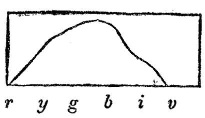
By fixing into the frame the various coloured media with which it was intended to operate, I was enabled to ascertain the influence which the light transmitted through each might exert upon the plant included.

From a variety of experiments, which it seems unnecessary to detail, in as much as they merely tend to confirm the statements of preceding observers, it appeared, that the kind of leaf selected made but little difference in the result. I therefore contented myself with selecting such, as could be procured most readily, and in the freshest condition.

The first plant operated on was the common Cabbage (*Brassica oleracea*); and as some of the results obtained in this instance appeared anomalous, in as much as they indicated an evolution of pure nitrogen, which I have detected in none of my other experiments, three or more trials with each kind of glass were in this instance had recourse to. The following were the results obtained.

Media through which the light was transmitted.	State of the weather.	Proportion between the whole quantity of gas obtained in the two jars.	Proportion per cent. between the oxygen and nitrogen in the two jars.	Proportion between the oxygen in the two jars.	Proportion between the nitrogen in the two jars.
Jar 1. Transparent window-glass Jar 2. Glass No. 5. (Orange.) Type 	*Exp.* 1. Bright sunshine.	Jar 1. 100 Jar 2. 80	O. 44 N. 56 O. 40 N. 60	100 77·5	100 86
	Exp. 2. Bright sunshine.	Jar 1. 100 Jar 2. 82	O. 33 N. 66 O. 33·4 N. 66·6	100 80	100 83
	Exp. 3.* Bright sunshine.	Jar 1. 100 Jar 2. 83	O. 0 N. 100 O. 0 N. 83		
Jar 1. Same as before. Jar 2. Glass No. 4. (Crimson-coloured.) Type 	*Exp.* 1. Bright sunshine with a few fleecy clouds.	Jar 1. 100 Jar 2. 45	O. 37·5 N. 62·5 O. 33·3 N. 66·6	100 40	100 48
	Exp. 2. Strong bright sunshine.	Jar 1. 100 Jar 2. 54	O. 39 N. 61 O. 38 N. 62	100 52·5	100 55
Jar 1. Same as before. Jar 2. Glass No. 3. (Dark blue.) Type 	*Exp.* 1. Sunshine with partial clouds.	Jar 1. 100 Jar 2. 57·5	O. 33 N. 66 O. 34·6 N. 65·4	100 56	100 56·5
	Exp. 2. Bright sunshine without clouds.	Jar 1. 100 Jar 2. 57·5	O. 33·3 N. 66·6 O. 30·2 N. 69·8	100 70·5	100 53·5
Jar 1. Same as before. Jar 2. Glass No. 2. (Purple.) Type 	*Exp.* 1. Sunshine without clouds.	Jar 1. 100 Jar 2. 47	O. 38·4 N. 61·6 O. 30 N. 70	100 35·4	100 51
	Exp. 2. Sunshine more obscured than in Exp. 1.	Jar 1. 100 Jar 2. 31·4	O. 25 N. 75 O. 22 N. 78	100 27·7	100 26·6

* N.B. The leaves in this latter case were quite fresh, and had not been previously immersed in water.

Media through which the light was transmitted.	State of the weather.	Proportion between the whole quantity of gas obtained in the two jars.	Proportion per cent. between the oxygen and nitrogen in the two jars.	Proportion between the oxygen in the two jars.	Proportion between the nitrogen in the two jars.
Jar. 1. Same as before. Jar. 2. Bottle No. 7. Filled with port wine. Type 	*Exp.* 1&2. Sunshine of different degrees of brightness.	Jar 1. 100 Jar 2. No Gas.			
Jar 1. Same as before. Jar 2. Bottle No. 6. Filled with the ammonio-sulphate of copper. Type 	*Exp.* 1. Sunshine of feeble intensity, though without dense clouds.	Jar 1. 100 Jar 2. 18	O. 47 N. 53 O. 37·8 N. 62·2	100 14·5	100 20·6
	Exp. 2. Bright and cloudless sunshine.	Jar 1. 100 Jar 2. 49	O. 32·7 N. 67·3 O. 37 N. 63	100 55	100 46
Jar 1. Same as before. Jar 2. Glass No. 1. (Green.) Type 	*Exp.* 1. Bright sunshine with occasional clouds.	Jar 1. 100 Jar 2. 32·8	O. 44 N. 56 O. 34·7 N. 65·3	100 26	100 38
	Exp. 2. Sunshine, for the most part bright.	Jar 1. 100 Jar 2. 25	O. 34 N. 66 O. 26·7 N. 73·3	100 18	100 25·6
	Exp. 3. Sunshine feeble and intermitting.	Jar 1. 100 Jar 2. no gas collected.			

The *second series* of experiments undertaken was with the leaves of the *Salicornia herbacea*, and the following were the results obtained. Temperature 65° FAHR.

Media through which the light was transmitted.	State of the weather.	Proportion between the whole quantity of gas obtained in the two jars.	Proportion per cent. between the oxygen and nitrogen in the two jars.	Proportion between the oxygen in the two jars.	Proportion between the nitrogen in the two jars.
Jar 1. Transparent glass .... Jar 2. No. 5. Glass (Orange)..	Feeble sunshine.	Jar 1. 100 Jar 2. 67	O. 25 N. 75 O. 16·4 N. 83·6	100 44	100 75
Jar 1. Transparent.......... Jar 2. No. 4. (Red)..........	Feeble sunshine.	Jar 1. 100 Jar 2. 60	O. 10 N. 90 O. 0 N. 60	100 0	100 66·5
Jar 1. Transparent.......... Jar 2. No. 3. (Blue)	Feeble sunshine.	Jar 1. 100 Jar 2. 20	O. 25 N. 75 O. 0 N. 20	100 0	100 26·7

Media through which the light was transmitted.	State of the weather.	Proportion between the whole quantity of gas obtained in the two jars.	Proportion per cent. between the oxygen and nitrogen in the two jars.	Proportion between the oxygen in the two jars.	Proportion between the nitrogen in the two jars.
Jar 1. Transparent .... Jar 2. No. 2. (Purple)........	Bright sunshine, with a few clouds.	Jar 1. 100 Jar 2. 16	O. 46 N. 64 O. 15 N. 85	100 5·25	100 21·4
Jar 1. Transparent .... Jar 2. No. 7. Bottle filled with port wine........	Bright sunshine.	Jar 1. 100 Jar 2. 0			
Jar 1. Transparent .... Jar 2. No. 6. Bottle (with ammonio-sulphate of copper)	Bright sun, though with a few clouds.	Jar 1. 100 Jar 2. 42	O. 33 N. 66 O. 0 N. 42	100 0	100 63
Jar 1. Transparent .... Jar 2. No. 1. Glass (Green) ..	Bright sunshine.	Jar 1. 100 Jar 2. 43	O. 46 N. 64 O. 0 N. 43	100 0	100 67

The *third series* undertaken was with common Sea Wrack (*Fucus digitatus*), immersed in water of temperature 65°, and the following were the results obtained.

Media through which the light was transmitted.	State of the weather.	Proportion between the whole quantity of gas obtained in the two jars.	Proportion per cent. between the oxygen and nitrogen in the two jars.	Proportion between the oxygen in the two jars.	Proportion between the nitrogen in the two jars.
Jar 1. Transparent glass .... Jar 2. No. 5. (Orange)	*Exp.* 1. Feeble sunshine.	Jar 1. 100 Jar 2. 31	O. 55·5 N. 44·5 O. 14·2 N. 85·8	100 7·9	100 59
	Exp. 2. Bright sunshine.	Jar 1. 100 Jar 2. 19·2	O. 60 N. 40 O. 44 N. 56	100 14	100 27
Jar 1. Transparent .... Jar 2. No. 4. (Red)	Bright sunshine.	Jar 1. 100 Jar 2. 10·8	O. 75 N. 25 O. 46 N. 54	100 6·65	100 23
Jar 1. Transparent .... Jar 2. No. 3. Glass (Blue)....	*Exp.* 1. Bright sunshine.	Jar 1. 100 Jar 2. 13	O. 69 N. 31 O. 31·5 N. 68·5	100 6	100 28·7
	Dull day.	Jar 1. 100 Jar 2. 7·3	O. not determined. O. 0 N. 7·3		
Jar 1. Transparent .... Jar 2. No. 2. Glass (Purple) ..	Feeble sunshine.	Jar 1. 100 Jar 2. 12·5	O. 60 N. 40 O. 8·8 N. 91·2	100 1·8	100 28·5
Jar 1. Transparent .... Jar 2. No. 6. Bottle (containing a solution of ammonio-sulphate of copper)	Bright sunshine.	Jar 1. 100 Jar 2. 8	O. 70 N. 30 O. 19 N. 81	100 2	100 21·7
Jar 1. Transparent .... Jar 2. No. 1. (Green)	*Exp.* 1. Weak sunshine.	Jar 1. 100 Jar 2. 7·6	O. 40 N. 60	100	100 7·6
	Exp. 2. Strong sunshine.	Jar 1. 100 Jar 2. 5·2	O. 65 N. 35	100	100 5·2

Bottle No. 7 with port wine tried without effect.

The *fourth series*, with leaves of *Tussilago hybrida*, in water of temp. 70°, gave the following results.

Media through which the light was transmitted.	State of the weather.	Proportion between the whole quantity of gas obtained in the two jars.	Proportion per cent. between the oxygen and nitrogen in the two jars.	Proportion be tween the oxygen in the two jars.	Proportion between the nitrogen in the two jars.
Jar 1. Transparent glass. Jar 2. Glass No 5. (Orange.)	Sultry day.	100 56	O. 45 N. 55 O. 41 N. 59	100 51	100 60
Jar 1. Transparent. Jar 2. Glass No. 4. (Red.)	Ditto.	100 49	O. 44·5 N. 55·5 O. 61 N. 59	100 67·5	100 39
Jar 1. Transparent. Jar 2. Glass No. 3. (Blue.)	Ditto.	100 41	O. 62 N. 38 O. 33 N. 66	100 22	100 72
Jar 1. Transparent. Jar 2. Glass No. 2. (Purple.)	Ditto.	100 10·7	O. 54 N. 46		
Jar 1. Transparent. Jar 2. No. 1. (Green.)	Ditto.	100 14	O. 53 N. 47 O. none, or barely any.		
Jar 1. Transparent. Jar 2. Bottle No. 6. containing the copper solution.	Ditto.	100 21	O. 50 N. 50 O. 13 N. 87	100 5·5	100 20·5

Fifth Series, with leaves of *Cochlearea Armoracia* immersed in water having a temperature of 72°, gave the following results.

Media through which the light was transmitted.	State of the weather.	Proportion between the whole quantity of gas obtained in the two jars.	Proportion per cent. between the oxygen and nitrogen in the two jars.	Proportion between the oxygen in the two jars.	Proportion between the nitrogen in the two jars.
Jar 1. Transparent glass .... Jar 2. No. 5. (Orange)	Bright sunshine. Th. 80°.	100 75	O. 57 N. 43 O. 54 N. 46	100 71	100 80
Jar 1. Transparent .... Jar 2. No. 2. (Blue)	Ditto.	100 24	O. 57 N. 43 O. 27 N. 73	100 11·4	100 40
Jar 1. Transparent .... Jar 2. No. 5. (Green)........	Ditto.	100 14·5	O. 57 N. 43 O. 20 N. 80	100 5·25	100 26·8
Jar 1. Transparent .... Jar 2. No. 4. (Red)..........	Ditto.	100 15	Not measured. O. 31 N. 69		
Jar 1. Transparent .... Jar 2. No. 3. (Purple) ...... Jar 3. No. 1. (Green)........ Jar 4. No. 6. (Bottle with copper solution) ..	Ditto.	100 36 20 12	O. 52 N. 48 O. 35 N. 65 O. 16 N. 84 O. 5 N. 95	100·0 24·2 6·2 1·2	100 48 35·2 22·5

N.B. In another experiment with No. 6. no gas at all was collected.

Sixth series, with sprigs of *Mentha viridis* immersed in water of the temperature of 74° Fahr.

Media through which the light was transmitted.	State of the weather.	Proportion between the whole quantity of gas obtained in the two jars.	Proportion per cent. between the oxygen and nitrogen in the two jars.	Proportion between the oxygen in the two jars.	Proportion between the nitrogen in the two jars.
Jar 1. Transparent glass	Cloudless sky. Thermometer 80°.	100	O. 59 N. 41	100	100
Jar 2. No. 5. (Orange)		70	O. 37 N. 63	44	108
Jar 3. No. 2. (Blue)		22·5	O. 8 N. 92	30	50·5
Jar 4. No. 6. (Bottle with copper solution)		20·0	O. 4 N. 96	13·5	47·0
Jar 1. Transparent glass	Ditto.	100	O. 47 N. 53	100	100
Jar 2. No. 1. (Green)........		20	O. 7 N. 93	3	34
Jar 3. No. 3. (Purple)		20	O. 0 N. 100	0	40
Jar 4. No. 4. (Red)		30	O. 12 N. 88	7·7	49

Similar experiments made upon leaves of *Rheum Rhaponticum*, of *Allium ursinum*, and of various species of Meadow-grass, corroborated the same conclusions; as likewise did some on plants confined in atmospheric air, containing about six per cent. of carbonic acid, and exposed to these several media.

In the above experiments the proportion of oxygen was ascertained, by heating the air in a bent graduated tube with phosphorus, and observing the diminution of capacity thereby occasioned; two per cent. being allowed for the expansion caused in nitrogen by phosphorous vapour. This method, which I have always found to give very uniform results, I adopted in preference to that of exploding the gas with hydrogen, as being less troublesome and more expeditious, in a climate so damp as ours, than a process requiring the aid of electricity.

The constant presence of more or less nitrogen in the air emitted by the plant, is a circumstance which, although often before observed, deserves, nevertheless, here to be briefly adverted to.

Its quantity appeared to be relatively smaller in proportion to the intensity of the solar influence, being always least under transparent glass; and where the light transmitted was not energetic enough to cause any emission of oxygen at all, still some portion of nitrogen would frequently be given out. Perhaps this circumstance may admit of explanation, by considering the emission of gas from leaves, when exposed to light under water, as derived from two sources; the first, the disengagement of a portion of atmospheric air which it had previously absorbed, and whose place within the tissue of the plant is probably supplied, either by the water with which it is surrounded, or by the carbonic acid with which this water is impregnated; the latter, the emission of pure oxygen, derived from a decomposition of the carbonic acid in contact with it.

Hence in Experiment 1. with cabbage-leaves, where we obtained 100 parts of a gas consisting of oxygen 44, and nitrogen 56 parts, we may suppose that the leaves had emitted,

Of atmospheric air which had been previously absorbed	68 parts: consisting of	nitrogen	56
		oxygen	12
together with excess of oxygen ..	32	Excess of oxygen ..	32
Total of gas obtained	100	Total of oxygen ..	44

whereas, when orange-coloured glass No. 5. was employed, we obtained,

Of atmospheric air	60·5	Oxygen	12·6
Excess of oxygen	19·4	Excess of oxygen .	19·4
Total of gas ..	79·9	Total of oxygen .	32·0

The two most difficult cases to explain seem to be, first, the evolution of pure nitrogen, and secondly, that of the same gas accompanied with a smaller proportion of oxygen than that present in the atmosphere.

In the instance in which the former was observed, no incipient putrefaction could be suspected by way of accounting for its occurrence, for the plants were fresh and healthy; and the circumstance that gas is not disengaged at all in the dark, proves the evolution of nitrogen to be in both cases a process connected with the same kind of action as that to which the emission of oxygen is to be ascribed.

Perhaps the phenomenon may be better understood by reference to the experiments of the younger Saussure, which go to prove; that oxygen becomes fixed in the plant in a condition, such as renders it incapable of being withdrawn from the vegetable tissue by the air-pump, or by other mechanical means; that it there unites with the carbon, so as to bring the latter into a fit state for the plant to assimilate it; and that it is then again disengaged from its combination, by a process not unaptly compared by the late Professor Burnett to the digestion of animals.

Now for this latter function to be discharged, the stimulus of the more luminous rays may be requisite, whilst that of the duller portions of the spectrum may suffice for the mere respiration of the plant, or for the elimination of the residuary air. Hence when rays of the latter description are alone transmitted, the composition of the gas evolved may even indicate a smaller amount of oxygen than that present in atmospheric air, because a portion of this element had become combined with certain of the carbonaceous principles present in the vegetable tissue, or been fixed in some manner within the plant.

The other processes, enumerated as under the influence of solar light, appear to be subjected to the same law, as that by which we have seen the decomposition of carbonic acid in the green parts of plants to be regulated.

From a few experiments I have made on the secretion of green matter in the leaves, I should be led to infer, in contradiction to the results of Senebier, that the most luminous rays were most influential; the orange glass, whose chemical influence was as 4, whilst its illuminating power was as 6, quickly imparting to the primordial leaves of beans which had just appeared above ground a bright green hue, whereas

under the ammonio-sulphate, whose illuminating power was as 2, whilst its chemical influence was as 5, they continued of a pale yellow, scarcely indeed of a shade darker than in another case where light was completely excluded.

I have made some experiments with similar results on the colours of flowers, the intensity or depth of which appeared also to depend on the brightness of the kind of light that had been allowed admission to them.

The irritability of the Sensitive Plant was likewise found to be dependent on the influence of bright rays, and not of those which act chemically. Six healthy sensitive plants were introduced in the beginning of August into an oblong box, with partitions so arranged, that each pot was in contact with a differently coloured light. In five weeks' time, that which had been exposed to the full light of the sun, transmitted through transparent glass, was still excitable, as was the one covered with the orange-coloured; but those which had received merely the portions of light transmitted through the copper solution, through port wine, and through a solution of green muriate of copper, as well as one which had been kept in entire darkness, lost all their irritability. Yet in each case the temperature was kept up to the same point by means of a hot-bed.

The exhalation of moisture from the leaves, and the absorption of it by the roots, are the last processes dependent on the action of light to which my attention has been directed. The results of my experiments on these two points confirm the same general inference as that to which the foregoing ones point; but having met with some apparent anomalies, I shall forbear at present to report the numerical results of the respective trials made with various glasses. It will be sufficient to lay before the Society a statement of the plan on which the experiments were conducted, and to particularize one or two which tend to show, that the processes above alluded to are probably dependent on the combined action of heat and light, coupled with those mechanical influences, which operate upon dead, as well as upon living organic matter.

The method whereby I proposed to estimate the degree, in which the exhalation of moisture depended on the quality of the light admitted to the plant, was in itself sufficiently simple. It consisted, in placing some plant growing in a pot, in a square tin vessel, the margin of which received in a groove a cucumber frame of sufficiently large dimensions to inclose it. All communication with the external air was cut off, by means of a little oil introduced into the groove into which the edges of the frame dipped, and the moisture exhaled was absorbed by concentrated sulphuric acid, placed in shallow earthen pots, along with the plant, in the interior of the tin vessel.

By weighing these vessels, just before the plant was introduced, and immediately after it had been taken out, I hoped to ascertain the amount of water that had been evolved, and after deducting from the sum total the quantity which had been previously found to be given off by the plant in the dark, I concluded that the remainder ought to represent the quantity to be set down to the action of light. But as it was impos-

sible to command an uniform intensity of solar radiation during the whole period occupied by any one series of experiments, another plant of the same kind and size was placed under transparent glass; and from the comparative amount of moisture emitted by it, I calculated what might be the difference in the amount of solar influence during the period at which the experiments were carried on.

Now although the experiments conducted on the above plan in general tended to show, that the extrication of moisture, *cœteris paribus*, was most abundant in proportion to the intensity of the light admitted, (orange glass in general causing more moisture to be exhaled than red or green,) yet in some instances blue and purple glasses, and still more remarkably, bottles filled with the cupreous solution, would cause a more abundant exhalation than orange or even transparent glass. Here, however, another principle seems to come into play, namely, the influence of heat radiated from the surface of the screen. This I infer, first, because the quantity of water exhaled under the influence of the copper solution became greatest, when the state of the weather was such as to elevate the temperature of the liquid considerably above that of the surrounding atmosphere; and, secondly, because a bottle filled with water blackened with ink to such a degree, as to transmit just as much light, so far as could be measured by the eye, as that filled with the copper solution was found to do, caused an equally considerable amount of water to be evolved by the plant.

Thus I selected two plants of the Tree Mallow (*Lavatera arborea*), which, by a previous experiment, had been found to exhale in the open air equal quantities of moisture, and placed the one under a frame, into which were inserted the bottles of ink and water, and the other under one with the solution of ammonio-sulphate of copper. Both fluids soon acquired in the sun a temperature from 110° to 120° FAHR.; and at the end of two hours the sulphuric acid in connexion with each of the plants was successively weighed, and the increase found to be nearly uniform; that under the ink and water having gained 150 grains per hour, that under the cupreous solution 162 grains in the same time.

Now as water with the addition of a little ink is known to absorb the rays proceeding from all parts of the spectrum in an equal ratio, it follows, that the effect produced in either instance must be ascribed to the heat radiated, and not to any peculiar virtue of the violet extremity in stimulating the vegetative functions.

Yet it is curious that the presence of some light seems essential to the due continuance of this process. The same plants which had been employed in the preceding experiment were placed out in the sun on a bright day; one, as before, under the influence of the light transmitted through the cupreous solution, the other under a frame covered over with blue tiles, which, together with the liquid, soon became heated by the sun's rays to the temperature of 110° or 120° of FAHRENHEIT. At the end of a certain time the sulphuric acid contained in the tin vessel which had inclosed the plant exposed to the action of the violet end of the spectrum had gained at the rate of 159 grains in the hour, (which is within 3 grains of the amount ob-

tained in the previous experiment,) whilst that in connexion with the one covered with the tiles had only increased by 32 grains.

Thus it would appear, that although heat assists the process, some degree of light is essential to its activity.

I was desirous, likewise, of ascertaining whether the brightest kind of light attainable by artificial means contributed in any degree to the process under consideration; Professor DECANDOLLE having found that the leaves of plants placed in a cellar became green on exposure to a strong light from lamps, and that their flowers even reversed their natural periods of opening, when the cellar was illuminated by night, and kept dark during the day.

In my own experiments, the light employed was that produced by a jet of mixed oxygen and hydrogen directed upon a ball of quick-lime, a kind of light, which I have found capable, like that from the sun, of passing through, and being concentrated by, a lens. Nevertheless, in two or three experiments, each lasting nearly an hour, in which the rays proceeding from the incandescent lime were directed towards, and thrown back upon the plant, by concave metallic reflectors, no increase in the quantity of moisture exhaled could be detected, beyond what the same individual had given out whilst in the dark.

The last function which it was left for me to consider, namely, the absorption of water by the roots, is so related to the preceding one, that it might almost be inferred *à priori* to be subject to the same laws.

It seems indeed evident, that, *cæteris paribus*, in proportion to the velocity with which the sap ascends, will the extremities of the roots absorb moisture from the ground; since, unless the former operation continued, the latter organs would very soon become fully charged with humidity, and thus the absorption be put a stop to.

In order to ascertain the quantity of water absorbed under different circumstances by the roots of plants, I made the following experiments.

Two small plants of *Helianthus annuus*, in pots marked A and B, were immersed in tin vessels nearly full of water, the height of which within was measured by glass tubes cemented into them below, and rising on the outside nearly to the top. These vessels were severally provided with tin covers, each of which had a circular aperture at its centre, through which the stem of the plant passed, and another small one at the side, through which water might be introduced. Being elsewhere closely attached to the vessel, little or no evaporation could take place from the surface of the included water.

Things being thus prepared, the two plants were placed for twenty-four hours in the open air, part of the time exposed to a bright sun, with the thermometer at 75° in the shade.

At the expiration of that time it was found that the vessels had lost, as nearly as could be ascertained, the same quantity of water, which amounted in each case to four ounces.

The next day, the thermometer being as on the preceding occasion, and the sun bright, sunflower A was placed under a frame glazed with orange-coloured glass the same as No. 5, and sunflower B under one glazed with blue glass as No. 2.

In the evening it was found, that the tin vessel containing plant A had lost three ounces of water, and that containing B one ounce. Now in another experiment with the same plants, the tin containing A, placed under a frame glazed with blue glass No. 2, had lost six ounces; that containing B, under one glazed with orange, No. 5, had lost $9\frac{1}{2}$. So that although the ratio between the two was very different (being in the one case as 1 to 3, in the second as 1 to $1\frac{1}{2}$), still in both there was a manifest superiority in the orange over the blue glass with respect to its power of producing absorption. Now orange-coloured glass seemed to act with about half the energy which belonged to transparent; for in another experiment upon the same plants, whilst the *former* had caused an absorption of four ounces, the *latter* had occasioned one of only two.

The same plants being next tried, one with a covering of transparent, the other with one of red glass, it was found that the former had absorbed $4\frac{1}{2}$, the latter 2 ounces, in equal times, the ratio being as 2·00 to ·89.

Hence the following may be stated as representing the relative amount of absorption in these several cases:

Under transparent	2·00
Under orange	1·00
Under blue, varying from	{ ·33 / ·66
Under red	·89

Similar experiments were tried with Vines, and with the *Sagittaria sagittifolia*, which latter being an aquatic plant, continued for a longer period in a healthy condition when immersed in the water. But in either instance the same exception was found with respect to the influence of light on the rate of absorption, as had been observed in that of exhalation, those glasses which radiated most heat, appearing to act upon the plant with an energy quite disproportionate to their illuminating power.

The heat of the weather was very great during these experiments, the thermometer being frequently above 80°, and the liquor in the bottles often mounting as high as 105°, so that it would seem, that the heat radiated from the coloured liquid assisted in promoting absorption in the roots, as it appeared to have done in the former one in increasing the exhalation from the leaves. The same might have been the case, though in a lesser degree, when the blue or red glasses were the media employed, and thus certain irregularities observed in the results may perhaps be explained, by supposing that the joint action, of the light transmitted, and of the heat radiated from these screens, caused a greater exhalation from the leaves, and thereby produced a more abundant absorption by the roots to supply the deficiency.

Upon the whole, then, I am inclined to infer, from the general tenor of the experi-

ments I have hitherto made, that both the exhalation and the absorption of moisture by plants, so far as they depend upon the influence of light, are affected in the greatest degree by the most luminous rays, and that all the functions of the vegetable economy, which are owing to the presence of this agent, follow in that respect the same law. And this is just what we ought to expect, if we suppose that light acts upon the vegetable, as it does upon the animal kingdom, in the character of a specific stimulus; for we all are sensible, that the vivifying influence of light upon ourselves is in proportion to its brightness; nor is it uninteresting to remark, that rays of the very description which most abound in solar light, are at once the most cheering to the animal creation, and the most conducive to the growth and well-being of the vegetable.

We have already seen, that even that most intense form of artificial light which is emitted from incandescent lime, produces no sensible influence upon plants; and we are reminded, that the same holds good with respect to animals, by the fact said to have been observed by the exhibitors of the oxyhydrogen microscope, namely, that animalcules of kinds which used to be speedily destroyed by the too stimulating action of solar light, appear to suffer much less from that now substituted, provided the water in which they are immersed does not become heated thereby.

Part II. *On the Action of Plants upon the Atmosphere.*

Having now considered the mode in which light may be supposed to operate upon plants, I shall next proceed to examine the extent of the changes wrought in the constitution of the atmosphere by the latter, under the influence of this agent.

I say the extent of the changes produced, because no one denies the nature of this operation, or questions the fact, that carbonic acid is really decomposed, and oxygen given out, by the green parts of plants under certain circumstances. But between the original views of Priestley, who saw in this process a counterpoise to the effects of animal respiration and the like, and those of Ellis, who did not admit it even as an equivalent to the opposite tendency of vegetable respiration, as carried on during the absence of solar light, a wide difference exists, and hence some fresh investigations seem necessary with reference to this question.

On perusing the account, which Mr. Ellis, in the Second Part of his Researches on Air, has given of the experiments by which he attempts to establish this latter opinion, several circumstances occurred to me, of a nature calculated to throw doubts upon their conclusiveness. I may mention, for example, in the first place, the smallness of the volume of air in which his plants were confined; in the second, the length of time that was suffered to elapse before the air underwent examination, owing to which it is even stated occasionally that the leaves had begun to fade and drop off; in the third place, the removal in some cases, and the neglect of a due supply in all, of that carbonic acid, the decomposition of which would have constituted the very source of the oxygen which it was expected to discover.

Accordingly I kept constantly in view these three essential conditions, and

contrived an apparatus, in which the quantity of air should be so large, that the healthy functions of the plant might be as little as possible interfered with; in which the constitution of the air could be examined as frequently as I pleased; and in which a regular supply of carbonic acid could be kept up, without disturbing the plant, or suspending the progress of the experiment by its introduction.

The apparatus consisted of a large bell-glass jar, containing in one case 600, in the other 800 cubic inches of air*, and suspended by pulleys. Its edges dipped into quicksilver, contained in a double iron cylinder of corresponding dimensions to the jar, which being closed at bottom, constituted a well of about six inches in depth, calculated to receive a fluid, and to admit of the glass vessel moving freely in it. The inner margin of this hollow cylinder was cemented air-tight, according to circumstances, either to a plate or a pot of iron, upon which the plant operated on might be placed; and the jar was then let down upon it, until its edges were sunk a little beneath the surface of the mercury.

Thus all communication with external atmosphere was cut off, and the effect of the plant upon the air inclosed in the jar was readily measured, by simply pressing down the latter, and thus expelling a portion of its contents through a tube, communicating with its interior, and introduced at its outer extremity under a pneumatic trough, wherein the air might be collected and examined. By connecting this extremity with a vessel containing a measured quantity of carbonic acid, and raising the jar a little in the well of mercury, it was easy to draw in any proportion of that gas, with which it was thought proper that the plant should be supplied. A portion of the air was always tested, immediately after the introduction of every fresh portion of carbonic acid, and again after an interval of some hours, and the proportion of this gas and of oxygen present was carefully registered. The amount of carbonic acid was determined by a solution of potass, that of oxygen by the rapid combustion of phosphorus with a portion of it in a bent tube.

Such was the mode of procedure, when an entire plant became the subject of experiment; but some of the most satisfactory trials were with branches of certain shrubs, themselves too large to be admitted under the jar. These branches, without being detached from the parent trunk, were introduced through a hole in the centre of two corresponding semicircular plates of iron, which were cemented air-tight, to the inner margin of the iron cylinder on the one hand, and to the stem of the branch on the other. In this manner, when the jar came to be placed over them, and to dip beneath the surface of the mercury, the external air was as effectually excluded, as it had been when the whole of the plant was inclosed.

The results of several experiments conducted after this plan will be given in a tabular form; but it may be well in the first instance to specify one of the most satisfactory of those undertaken. In this case the jar itself contained about 600 cubic inches of air, and the plant experimented on was the common Lilac (*Syringa vulgaris*).

* Larger jars, containing from 1200 to 1300 cubic inches, were latterly employed.

The proportion of carbonic acid in the jar was each morning made equivalent to 5 or 6 per cent. by additions through the tube.

The first day no great alteration in the air was detected, but on the second day, by eight in the evening, the oxygen had risen to 26·5 per cent. In the morning it had sunk to 26, but by 2 P.M. it had again risen to no less than 29·75, and by sunset it had reached 30 per cent. At night it sunk one half per cent.; but the effect during the following day was not estimated, as the sickly appearance which the plant now began to assume induced me to suspend the experiment.

In a second trial, however, the branch of a healthy Lilac growing in the garden was introduced into the same jar, where it was suffered to remain until its leaves became entirely withered.

The first day the increase of oxygen in the jar was no more than 0·25 per cent., but on the second it rose to 25·0. At night it sunk to nearly 22 per cent., but the next evening it had again risen to 27 per cent. This was the maximum of its increase, for at night it sunk to 26, and in the morning exhibited signs of incipient decay. Accordingly in the evening the oxygen amounted only to 26·5; the next evening to 25·5; the following one to 24·75; and the one next succeeding it had sunk to the point at which it stood at the commencement, or to 21 per cent.

The reason of this decrease was, however, very manifest in the decay and falling off of the leaves; so that this circumstance does not invalidate the conclusion which the preceding experiments concur in establishing, namely, that in fine weather, at least so long as the plant continues healthy, it adds considerably to the oxygen of the air when carbonic acid is freely supplied.

In the last instance quoted, the exposed surface of all the leaves inclosed in the jar, which were about fifty in number, was calculated at no more than three hundred square inches, and yet there must have been added to the air of the jar as much as twenty-six cubic inches of oxygen, in consequence of the action of this quantity upon the carbonic acid introduced.

But there is reason to believe, that even under the circumstances above stated (which were more favourable to the due performance of the functions of the plant than those to which Mr. ELLIS's were subjected,) the amount of oxygen evolved was much smaller than it would have been in the open air, for by introducing several plants into the same jar of air in pretty quick succession, I have succeeded in raising the amount of oxygen contained from 21 to 39 per cent., and probably had not even then attained the limit to which the increase of this constituent might have been brought.

How great then must be the effect of an entire tree in the open air under favourable circumstances! and we must recollect that, *cœteris paribus*, the circumstances will be favourable to the exertion of the vital energies of the plant, within certain limits at least, in proportion as animal respiration and animal putrefaction furnish to it a supply of carbonic acid.

Neither is this influence exerted exclusively by plants of any particular kind or description. I have found it alike in the monocotyledonous and the dicotyledonous, in such as thrive in sunshine and those which prefer the shade, in aquatic as well as in terrestrial, in cryptogamous and imperfect, such as Ferns and Algæ, as well as in those of a more complicated organization. How low in the scale of vegetable life this power extends is not yet exactly ascertained, but Professor MARCET of Geneva, in a late paper, has shown that it does not prevail amongst Fungi.

The disappearance of carbonic acid in my experiments always more than kept pace with the addition to the quantity of oxygen; but the shortness of time during which the plant could be retained in a sufficiently healthy condition, prevented my ascertaining, whether after the carbonic acid had been absorbed by it, a part was not at some subsequent period given out again unchanged.

A small portion might perhaps have been taken up by a thin film of water, which I was compelled to keep continually upon the surface of the mercury, in order to prevent the latter from destroying, by a disengagement of its vapour, the plant confined underneath it. This quantity, however, must have been inconsiderable compared with the amount introduced.

I shall now conclude, by placing in a tabular form some of the principal, or the more illustrative experiments which I have carried on, appending some remarks immediately suggested by the particular phenomena observed in each.

Experiments concerning the influence of plants on atmospheric air mixed with various proportions of carbonic acid; the plants being exposed to the sun, and confined in jars containing from 600 to 800 cubic inches of air, and which rested upon mercury covered by a thin film of water.

Experiment 1.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
April 10.	12 A. M. A small Cypress in a garden-pot was introduced into the jar, its stem being cemented air-tight into the hole in the two hemispherical iron plates, that fit the inner margin of the hollow cylinder	0	0	81	2	79	21
	6 P. M. After a cloudy and gloomy day, with only occasional gleams of sunshine	0	0	81	2	79	21
April 11.	8 A. M.	0	0	79	2	77	23
	$8\frac{1}{2}$	8	8				
	5 P. M. Stormy and cloudy day, much like that preceding it	0	0	79·5	2	77·5	22·5
April 12.	12 A. M. No sun during the morning, but a settled rain throughout	0	0	81·5	2	79·5	20·5
	1 P. M.	4	4				
April 13.	8 A. M.	0	0	82	2	80	20
	12 A. M. A fine bright day, with occasional storms...............	3	3				
	4 P. M.	0	1	79	2	77	23
April 14.	The unfavourable state of the weather induced me to suspend the experiment.						

Remarks.—The circumstances most worthy of remark in this experiment appear to be, 1st, the emission of 2 per cent. of oxygen the second day, when the proportion of carbonic acid in the air of the jar was too small to be detected by my apparatus; and 2ndly, the absorption of carbonic acid afterwards when no oxygen was evolved. In the first case we must suppose that the plant had imbibed from the atmosphere, previously to its confinement, the carbonic acid, which under the influence of sunshine it decomposed within the jar; in the second, that it absorbed a large quantity of carbonic acid, which in the unfavourable state of the weather it did not decompose. This latter supposition must be adopted as applicable to most of the succeeding experiments; for my apparatus was proved to be sufficiently perfect to prevent any such escape of carbonic acid, within a corresponding period of time, introduced into the jar, when no plant was present in it, and thereby to obviate any suspicion that it might arise from a defect in the union of the joints.

Experiment 2.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
April 19.	2 P. M. A dull day, with a tendency to rain. Stem and branches of a Persian Lilac (*Syringa persica*) introduced into the jar in the manner above described	9	9	81	2	79	21
	7 P. M.	0	2·75	78	2	76	24
April 20.	8 A. M. Air examined before the sun had acquired any power	0	2·75	80	2	78	22
	11 A. M.......................	3·25	6·00				
	7 P. M. After a dull day, with occasional storms until 2 P. M., when the sun broke out.............	0	4·25	80	2	79	21
April 21.	Observed the leaves to be altered and faded, and this, together with the unfavourable state of the weather, induced me to discontinue the experiment.						

Observations.—It appears from this experiment, that when a plant is in a perfectly healthy and fresh condition, it may add considerably to the amount of oxygen even in dull weather.

Experiment 3.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
April 26.	12 A. M. Dull day, with occasional gleams of sunshine, but no rain. A (*Pelargonium*) Geranium with its pot introduced into the jar	5	5	81	2	79	21·0
	7 P. M.	0	1	79·5	2	77·5	22·5
April 27.	8 A. M. .... The unfavourable state of the weather led me to discontinue this experiment.	0	0	79·25	2	77·25	22·75

Experiment 4.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
April 29.	12 A. M. Dull and stormy day, with occasional gleams of sunshine. A Geranium with its pot introduced into the jar, occupying together a capacity of about 60 cubic inches	5	5	81	2	79	21
	6 P. M.	0	1	83·6	2	81·6	18·4
April 30.	10 A. M.	5	5	82·5	2	80·5	19·5
	5 P. M. After a bright day, with clouds and showers occurring occasionally	0	0	78·5	2	76·5	23·5
May 1.	8 A. M. Access of the morning sun prevented by an opake screen covering the jar .... A diminution in the quantity of oxygen was detected, but its amount was not registered, as the apparatus was found not to be perfectly air-tight. The experiment was therefore suspended in order to repair the defect.	0	2				

Experiment 5.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
May 8.	12 A. M. Bright day. A Geranium in a pot was introduced into the jar	5	5	81	2	79	21·00
	1½ P. M.	0	2·5	79·75	2	77·75	22·25
	2½	0	2·25	79·25	2	77·25	22·75
	3½	0	0·05	79·00	2	77·00	23·00
May 9.	8 A. M. During the morning screened from the sun................	0	0·0				
	10 A. M. Fine bright day	10	10·0				
	11 A. M.	0	9·50	82	2	80·00	20·00
	12 A. M.	0	6·25	82	2	80·00	20·00
	2 P. M.	0	6·5	80	2	78·00	22·00

Experiment 6.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
May 10.	Fine bright day. At 12 A. M. a fresh Geranium was introduced	10·5	10·5	81	2	79	21
	5½ P. M.	0	1·0	76	2	74	26

Experiment 7.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
May 11.	11 A.M. Dull and sultry day. Fresh Geranium introduced	8·5	8·5	81	2	79	21
	11 P.M.	0	1	81	2	79	21

Observations.—These two latter experiments show decidedly that the disappearance of carbonic acid is not at all in proportion to the disengagement of oxygen. In Experiment 6, in a bright sun, the Geranium, which absorbed 9·5 per cent. of carbonic acid, emitted 5 per cent. of oxygen; in Experiment 7. a similar plant, which absorbed 7·5 of the former in a dull day, seemed to have made no addition at all to the amount of oxygen in the jar.

Experiment 8.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
May 13.	2 P.M. Bright sunshine all the day. A young Lilac (*Syringa vulgaris*) had its stem introduced under the jar, its roots being in a pot outside	8	8	81	2	79	21
	7½ P.M.	0	0·05	82·5	2	80·5	19
May 14.	8 A.M.	0	6·00	not estimated.			
	8½. Day as that preceding it......	2	8				
	8 P.M.	0	2	75·5	2	73·5	26·5
May 15.	9 A.M. Jar during the preceding part of the morning covered with a screen	0	3·5	76·0	2	74	26·0
	9½ A.M.	6·5	10·0				
	2 P.M.	0	3·0	72·25	2	70·25	29·75
	8½ P.M.	0	0·0	72·00	2	70·00	30·00
May 16.	8 A.M. Jar during the former part of the morning having been covered with a screen	0	2·75	72·50	2	70·50	29·50
	The plant beginning to look unhealthy was now removed.						

Observations.—The remarkable clearness of the sky, and the warmth of the weather during these three days, was peculiarly favourable to the experiments, and will account for the large quantity of oxygen obtained, which was equal to 8·5 per cent., or 8·5 × 6 = 51 cubic inches. Owing to the longer time that the plant continued in a state of health, the quantity of carbonic acid that disappeared did not so much exceed that of the oxygen given out as in the preceding experiments.

Experiment 9.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
May 20	4 P.M. Day dull, but free from rain: in the evening a little sunshine. Branch of a Lilac, having on it about fifty healthy leaves, each leaf on an average presenting a surface of about six square inches (50 × 6 = 300 square inches to the whole)	5	5	81	2	79	21
	7 P.M.	0	3·3	80·75	2	78·75	21·25
May 21.	7½ A.M. Jar during the former part of the morning covered by an opake screen	0	2·25	80	2	78	22
	11½ A.M. Bright sunny day. Thermometer 65°................	0	2·25	79·5	2	77·5	22·5
	3½	0	0·00	77	2	75·0	25·0

Experiment 9.—Continued.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
May 22.	8 A. M. Before uncovering the jar..	0	0·5	79·75	2	77·75	22·25
	9 A. M. Fine bright cloudless day. Thermometer 68°..............	8·5	9·0	....	....	....	....
	$1\frac{1}{2}$ P. M.........................	0	6·0	75·75	2	73·75	26·25
	5 P. M.	0	3·0	74·5	2	72·5	27·5
May 23.	8 A. M. Before the screen had been removed	0	2	75	2	73	27
	8 P. M. After a fine bright day	0	0	76	2	74	26
May 24.	8 A. M. Before removing the screen..	0	0	75·5	2	73·5	26·5
	4 P. M. After a fine bright day	0	0	76·5	2	74·5	25·5
May 25.	8 A. M. Before removing the screen..	0	2	76·75	2	74·75	25·25
	6 P. M. Fine bright day, like yesterday	0	0	77·25	2	75·25	24·75
May 27.	10 A. M........................	0	1	80·75	2	78·75	21·25
	Experiment discontinued, as most of the leaves had dropped off, and the remainder looked decayed and withered. The decay of the leaves began to date from the 24th, at which time the amount of oxygen will be seen to have begun to diminish.						

Observations.—This experiment shows how erroneous a conclusion we might deduce, if we contented ourselves with examining the air after an interval of some days, and how soon, even under the most favourable circumstances, confinement interferes with the healthy functions of a plant.

Experiment 10.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
Aug. 20.	12 A. M. Day dull and cloudy, with a few occasional gleams of sunshine. Therm. 70°. A young Cedar with its pot was introduced under a jar having a capacity of about 800 cubic inches	7·5	7·5	81	2	79	21
	10 P. M........................	....	2·75	80	2	78	22
Aug. 21.	10 A. M. Day overcast, but with occasional gleams of sunshine. Thermometer 70°.................	0	2·0	82·5	2	80·5	19·5
	$10\frac{1}{2}$	7·5	9·5	....	....	....	....
	7 P. M.	0	5·0	80	2	78	22·0
Aug. 22.	11 A. M. Windy day, but with a bright sun till about 4 P. M. Thermometer 70°.................	0	4·0	80	2	78	22·0
	7 P. M.	0	0·0	78·75	2	76·75	23·25
Aug. 23.	8 A. M. Windy and cloudy day, with occasional showers, and few gleams of sunshine. Therm. 64°	0	2·0	80	2	78	22
	10 A. M.	7·5	9·5	80	2	78	22
	7 P. M.	0	4·0	78·50	2	76·50	23·50
Aug. 24.	10 A. M. Cloudy day, without sun. Therm. 66°	0	1	77·25	2	75·25	24·75
	12 A. M.	7·5	....	....	....	....	....
	7 P. M.	0	5	78·20	2	76·20	23·80
	Experiment discontinued.						

Experiment 11.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of nitrogen.	Calculated amount per cent. of oxygen.
Aug. 20.	12 A. M. Bright day, with occasional clouds. Therm. 72°. Another Cedar like the former, with its pot, was introduced into a jar containing about 1300 cubic inches of air; size of the plant being 8 inches in diameter, branches and all, and 16 inches from the pot to the topmost branch	7·50	7·50	....	....	79	21
	10 P. M.	....	2·00	80	2	78	22
Aug. 21.	10 A. M. Windy day, often overcast	....	1·75	79·50	2	77·50	22·50
	10½ A. M.	7·50	9·25	....	....	....	....
	7 P. M.	....	5·00	79·50	2	77·50	22·50
Aug. 22.	11 A. M. Windy day, but with a bright sun	....	2·50	77·0	2	75·00	25·00
	7 P. M.	0	1·0	75·5	2	73·5	26·5
Aug. 23.	8 A. M. Windy and cloudy day, as above stated	0	1·0	78·0	2	76	24·0
	10 A. M.	7·5	....	....	....	....	....
	7 P. M.	0	6·0	75·25	2	73·25	26·75
Aug. 24.	10 A. M. Cloudy day, without sun	0	5·0	77·25	2	75·25	24·75
	12 A. M.	2·5	7·5	....	....	....	....
	7 P. M.	0	6·0	75·25	2	73·25	26·75
	Experiment was here discontinued.						

Observations.—These two latter experiments tend to show that the leaves of evergreens purify the air as well as those of deciduous plants, although they may not act upon the carbonic acid with the same energy as the latter do.

Experiment 12.

May 27.	Bright sunny day. Therm. 60°. *Crassula lactea* with its pot introduced into the jar at 12 A. M.	11	11	....	....	79	21
	6 P. M.	0	6·5	81·25	2	79·25	20·75
May 28.	8 A. M. Jar previously covered with a screen	0	6·0	81·25	2	79·25	20·75
	5 P. M. After a bright day	0	6·5	80·00	2	78·00	20·00

Observations.—This experiment, and another made on another species of Crassula, show that these succulent plants do not act with much energy on the air, at least under confinement; but the following experiment evinces that even this tribe act in the same manner, though not with the same intensity.

Experiment 13.

June 30.	12 A. M. Plant of *Mesembryanthemum verrucosum* introduced into jar. (N.B. No record of the weather: probably it was fine)	6·6	....	....	....	79	21
	8 P. M.	....	4·9	78·6	2	76·6	23·4
July 1.	10 A. M.	....	2·0	....	....	....	....
	10½ A. M.	4·5	6·5	....	....	....	....

EXPERIMENT 13.—Continued.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	Calculated amount per cent. of	
						nitrogen.	oxygen.
July 1.	5 P.M.	0	5·0	82·5	2	80·5	19·5
July 2.	1 P.M.	0	5·0	79·5	2	77·5	22·5
July 3.	12 A.M.	0	2·0	80·75	2	78·75	21·25
July 4.	12 A.M.	3·25	2·25	81·75	2	79·75	20·25
	8 P.M.	....	5·00	81·5	2	79·5	20·50
July 5.	1 P.M.	....	2·00	81·25	2	79·25	20·75
July 7.	12 A.M.	....	1·00	83·75	2	81·75	18·25

Observations.—Before the experiment was brought to a close, the plant had assumed an unhealthy appearance; yet the length of time during which it was confined, and the smallness of the change it produced upon the included air, show the more languid manner in which the functions of vegetable life are carried on through the medium of the metamorphosed leaves of this tribe of plants. A similar experiment was tried with a specimen of *Aloe mitræformis*, in which case also 2 per cent. was added to the amount of oxygen by its presence.

EXPERIMENT 14.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	nitrogen.	oxygen.
Aug. 30.	12 A.M. Healthy Dahlia in a pot, containing one full-blown flower and twenty leaves, were introduced into the jar	7·5	....	....	....	79	21
	8 P.M. After a day, bright till 3 P.M. afterwards overcast	....	3·0	79·25	2	77·25	22·75
Aug. 31.	10 P.M. Bleak and boisterous weather throughout the day, with much rain. Therm. 65°	0	2·0	77·25	2	75·25	24·75
Sept. 1.	Weather cold, stormy, and bleak, but a bright sun occasionally. Thermometer 55° at 9 A.M.	7·5	....	....	....	....	....
	At 10 P.M.	....	2·0	78·25	2	76·25	23·75
Sept. 2.	Fine day but cloudy: sun at intervals bright. Therm. 62° at 10 P.M.	0	1·0	79·25	2	77·25	22·75
Sept. 3.	Dull stormy day at 9 A.M.	7·5	....	....	....	....	....
	At 4 P.M.	....	4·0	77·25	2	75·25	24·75
Sept. 4.	Fine day at 1 P.M.	....	0·0	75·50	2	73·50	26·50
	Experiment suspended, though the plant seemed to have suffered but very little from its confinement.						

EXPERIMENT 15.

Date.	Circumstances of the experiment.	Proportion per cent. of carbonic acid added.	Absorption per cent. caused by solution of potash.	Residuum per cent. after burning phosphorus in a portion of the air.	Allowance for phosphorus vapour.	nitrogen.	oxygen.
Aug. 30.	Weather reported above. Healthy Dahlia, with about as many leaves as the former one, but without any flower, was introduced into the jar at 12 A.M.	7·5	....	....	....	79	21
	8 P.M.	0	3·75	....	....	....	....
Aug. 31.	10 A.M.	0	3·75	82·25	2	80·25	20·75
	10 P.M.	0	2·00	82·75	2	80·75	19·25
Sept. 1.	10 A.M.	7·5	9·50	....	....	....	....
	10 P.M.	....	7·50	78·00	2	76·00	24·00
Sept. 2.	10 P.M.	....	5·00	79·00	2	77·00	23·00
Sept. 3.	4 P.M.	....	4·00	78·25	2	76·25	23·75
Sept. 4.	1 P.M.	....	1·00	78·00	2	76·00	24·00
	Experiment was here suspended, as I was on the point of leaving home.						

Observations.—These two last experiments show that even plants which are in flower may purify the atmosphere, the influence of the accompanying leaves more than counterbalancing that of the parts of fructification: and, indeed, a comparison of the results of the first experiment with those of the second seems to indicate, that the presence or absence of a flower does not make so great a difference as might have been anticipated.

The same experiment was tried with a plant of *Helianthus annuus* in full flower, and an increase of 1 per cent. of oxygen was detected.

In the following experiments a succession of different plants were introduced at intervals of from four to twelve hours, into a jar containing about 240 cubic inches of common air, together with generally about ten cubic inches of carbonic acid. The following Table will show the increase of oxygen caused.

Experiment 16.

Date.	Circumstances of the experiment.	Oxygen.	
		Proportion per cent.	Calculated number of cubic inches.
May 23.	Before any plant was introduced	21	50
	After a pot of *Sinapis alba* had continued in contact with the air during six hours of bright sunshine	25	60
	After a pot containing *Hydrangea hortensis*, only in leaf, had continued in contact with the air during twelve hours of bright sunshine	26·5	63·5
May 24.	After a pot, containing a *Crassula lactea*, had continued in contact with the air during four hours of bright sunshine	32·75	77
	After a pot of *Lepidium sativum* had continued in contact with the air during four hours of bright sunshine	33·5	80·5
May 25.	After a pot containing a Geranium (Pelargonium) had continued in contact with the air during four hours' bright sunshine	36·5	87·0
	After the same Hydrangea as before had continued in contact with the air during five hours' bright sunshine	33·25	80·0
May 27.	After a Geranium had continued in contact with the air during five hours' bright sunshine	37·0	88·0
	After a healthy Myrtle had continued in contact with the air during four hours' bright sun	39·0	93
May 28.	After a young but apparently healthy plant of the Sweet Pea (*Lathyrus odoratus*) had continued in contact with the air for four hours	33	78·5
May 30.	After a Geranium had continued in contact with the air for five hours	36·5	87·0

Observations.—Here, owing to an accident, the experiment was suspended; but it was carried far enough to show how much oxygen may be added to the air during the day by plants in a healthy condition. The increase was progressive until I employed the same plant a second time: it probably had suffered from its previous confinement, or from being passed backwards and forwards through the water of the pneumatic trough on which the jar rested. The only other plant which diminished the amount of oxygen was the Sweet Pea; all the others added somewhat to its quantity.

Experiment 17.

Capacity of jar 620 cubic inches (600 atmospheric air, 20 carbonic acid).

Date.	Circumstances of the experiment.	Proportion per cent.	Calculated number of cubic inches.
August 7.	Before any plant was introduced	21	126
	6 P.M. After a Geranium had continued in contact with the air during five hours' strong sun	23	138
August 8.	10 A.M. After a second Geranium had remained in contact with the air during the previous night and morning	22	132
	5 P. M. After a Myrtle had been in contact with the air during the period since the previous experiment made	24·5	147
August 9.	11 A. M. After a second Myrtle had continued in contact with the air ever since the last experiment	26	156
	5 P. M. A common garden Lettuce growing in a pot, having continued in contact with the air since the last experiment: day fine	29	174
August 10.	11 A. M. A second Lettuce, having continued in contact with the air since the preceding experiment: day wet	30	180
	5 P.M. After a Geranium had been introduced since the preceding experiment: day wet	35	210
August 11.	11 A. M. After a second Geranium had continued in contact with the air during the interval since the last experiment	28	168
	Finding a temporary difficulty in procuring healthy plants, I here suspended the experiments.		

Observations.—This latter series of experiments was undertaken in order to show, that even when the plants were confined in the air of the jar, by night, as well as by day, the balance was still greatly in favour of their purifying influence.

With respect to the comparative influence of similar plants in direct and in diffused light, I have as yet made only a few experiments, but the results of these few seem to indicate that even under the latter circumstances an increase in the amount of oxygen will be sometimes produced by them.

	Per cent.
Thus a jar, in which a Geranium had been confined, contained, after exposure for four hours to direct light, of oxygen	25
Whilst another, in which a similar plant had been placed for the same time in diffused light, contained	19·5

On the other hand,

Two jars, containing Myrtles, after being placed in direct light for eight hours, had acquired of oxygen,	
No. 1.	23·75
No. 2.	26·00
Two similar jars with Myrtles in diffused light, exposed for the same time, contained,	
No. 1.	20·0
No. 2.	23·0
Two jars with *Polypodium dryopteris*, the one in direct, the other in diffused light, each contained of oxygen	22·0

In conclusion, it may perhaps be well to present in a tabular form the different questions which this inquiry embraces, pointing out how far each may be considered as answered, either by the experiments of preceding investigators, or by those detailed in the present memoir.

Scheme of Experiments.

Part I.—ON THE ACTION OF LIGHT UPON PLANTS.

- I. Solar light.
  - A. direct.
    - 1. In causing the leaves to emit oxygen, and to decompose carbonic acid ......
      - Immersed in water. Tried with 1. *Brassica oleracea*; 2. *Salicornia herbacea*; 3. *Fucus digitatus*; 4. *Tussilago hybrida*; 5. *Cochlearia Armoracia*; 6. *Mentha viridis*; 7. *Rheum rhaponticum*; 8. *Allium ursinum*; and several species of *Gramineæ*.
      - In atmospheric air. Tried with Geraniums.
    - 2. To become green when etiolated.... Tried with Beans.
    - 3. To maintain their irritability .... Tried with the Sensitive Plant (*Mimosa pudica*).
    - 4. To exhale water by their leaves ...... Tried with Vines, Dahlias, Helianthuses, *Lavatera arborea*, &c.
    - 5. To absorb the same by their roots .... Tried with plants of *Helianthus annuus*, *Sagittaria sagittifolia*, Vines, &c.
  - B. diffused or reflected.
    - Its influence compared with that of direct solar light in the above particulars. Tried with the Geranium, Myrtle, and Polypodium, so far as regards its relative influence in causing the emission of oxygen.
- II. Artificial light, obtained
  - A. from lamps. Tried by Professor Decandolle.
  - B. from incandescent lime. Tried by myself, but no influence detected.

Part II.—ON THE ACTION OF PLANTS UPON THE ATMOSPHERE.

- I. Proportion between the effects attributable to their action during the night and during the day.
  - 1. During fine weather, and in bright sunshine.
    - Of plants without flowers, and with leaves alone, viz.
    - Of plants with flowers and leaves.

		Maximum increase per cent. of oxygen.
Of plants without flowers, and with leaves alone, viz.	Cupressus	2
	Cedrus	3·75
	Syringa vulgaris ..	8·75
	Ditto	6·50
	Pelargonium	2·00
	Ditto	5·00
	Crassula, 2 sp.	0·00
	Mesembryanthemum	2·40
	Dahlia	3·00
Of plants with flowers and leaves.	Dahlia	3·75
	Helianthus	1·00

  - 2. During bad weather, or in diffused light.
    - *Syringa persica* 3 per cent.
    - Geranium, Myrtle, Fern, as noticed above.
- II. Proportion between the carbonic acid absorbed and oxygen evolved. My experiments show that when plants are confined the former is always greatest at first; but this may not continue to be the case after a certain interval.
- III. Greatest amount of oxygen that can be added to the air of a jar by the influence of a plant. My experiments show that at least 18 per cent. of oxygen may be so added.
- IV. At what stage in the scale of vegetable life the function of purifying air stops.
  - Probably where there cease to be leaves.—I have shown that it exists in dicotyledonous and monocotyledonous, in evergreens and deciduous, in terrestrial and aquatic plants, in the green parts of succulents as well as in ordinary leaves, in Algæ and in Ferns as well as in phanerogamous families.
  - Prof. Marcet has shown that it does not take place in Fungi.