The Respiration of Wounded Plants.

BY

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With Woodcuts 2 and 3.

WHILE it has been known for some time that, when wounded, plants respire with greater activity than under normal conditions, a more precise knowledge of the phenomena connected with this increased respiration and the causes thereof has been lacking. Böhm¹ called attention to a considerable rise in the amount of CO₂ produced by potatoes which had been injured by cutting in various ways; but the question was not further investigated until Stich², in connexion with other researches, published a more extended account of this phenomenon in the same and other plants. He established the fact of the increased respiration more clearly than Böhm had done; but, as the period of his experiments was short, he did not determine the ultimate effect of the injury on the CO₂-production as compared with normal conditions. One of the most interesting facts recorded is that when the cut surfaces of the potatoes were so fixed together with neutral gelatin as to exclude the access of air the amount of respiration in excess of the normal was markedly less. More remains to be said concerning this point, and it will be taken up later, after a discussion of experiments made by the

¹ Botanische Zeitung, Vol. xlv, p. 671, 1887.

² Die Athmung der Pflanzen bei verminderter Sauerstoffspannung und bei Verletzungen, Flora, Vol. xlix, p. 1, 1891.

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writer. Since his first paper¹ Böhm has published a short note, in which he gives, as the most probable explanation of the increased respiration, a traumatic action of the wound itself not depending upon the action of the atmospheric oxygen on the tissue exposed by wounding. To arrive, if possible, at some definite conclusion regarding these points was the object of this research. The work was undertaken at the suggestion and under the direction of Prof. Pfeffer, to whom the writer's best thanks are due for his advice, and for the opportunities offered for carrying on the research.

After a preamble concerning the methods employed and the apparatus used, there is a discussion of the various experiments, after which follows a record of the experiments in tabular form. The latter are referred to in the text by number or letter.

APPARATUS AND METHODS.

By far the larger amount of the work was done with the Pfeffer-Pettenkofer apparatus for determining the respiration of plants, and with a modified form of Stich's apparatus for finding the $\frac{\text{CO}_2}{\text{O}_2}$ -equation. A few experiments were also made to obtain some idea of the amount of CO_2 contained in living tissues, which will be mentioned in passing.

A Pettenkofer apparatus of the form as improved by Pfeffer² was employed; the apparatus is so well known that it is unnecessary to dwell on it, and in the reference given a full description of it will be found. It is also scarcely necessary to rehearse the sources of error to be avoided and the various precautions which must be taken to ensure accuracy, as all of these have been described with care by earlier writers. It suffices to say that every care was taken to observe the necessary precautions; that the apparatus was tested from time to time to make sure that there were no leaks; that the KOH

¹ Bot. Centralblatt, Vol. 1, p. 200, 1892.

² Ueber intramolekulare Athmung: Untersuch. aus dem Bot. Inst. zu Tübingen, I. 636.

in the U-tubes for washing the air from CO_2 was frequently renewed; that care was taken that the air supplied to the plants in the receiver should be sufficiently moist, and so forth. All the manipulations of the experiments and analyses were carried on each time in as nearly a similar manner as possible to ensure equality in the results. For the analyses the same burette and pipettes were used throughout the whole course of the work. The titrations were made with a solution of hydrochloric acid of such a strength that 1 cc. equalled 1 mg. of CO_2 , and for an indicator phenol-phthalein was employed.

The constant flow of air or gas through the apparatus was obtained by means of a Stainer's drop-aspirator regulated with a gas-meter (Experimentir-Gas-Messer of Elster), by which means no difficulty was found in keeping the current within 50 cc. per hour of the amount desired. The rapidity of the current was nearly 3.5 litres per hour, an amount to which the apparatus held with surprising constancy throughout the time it was used. When gases other than air were run through the apparatus, it was necessary to be somewhat careful to regulate the pressure from the gasometer so as to avoid an increase in the gas-stream. Even in such cases, however, no difficulty was found in keeping the flow at the desired rate. The hydrogen and oxygen used were first washed roughly at the time of preparation with KMnO_4 and KOH , and again, when being used, by means of U-tubes containing KMnO_4 , KOH , and HgCl_2 interpolated between the gasometer and the receiver containing the plants.

In every case the receiver containing the plants was immersed in a large vessel of water, and thereby kept at an approximately constant temperature, which usually varied but little more than half a degree during the day, the average temperature being about 20.5° .

For the determination of the relative amounts of CO_2 produced and of O_2 absorbed, or, as it is usually expressed, the equation $\frac{\text{CO}_2}{\text{O}_2}$, a form of apparatus somewhat different from

both that of Godlewski¹ and of Stich² was employed. In this case the O₂ absorbed was not measured by the diminished gas-volume in the receiver, but samples of the air in it were taken and analyzed directly for the CO₂ and O₂ which they contained. The apparatus was exceedingly simple, and thereby the sources of error arising from its use the more

WOODCUT 2.

Diagram of $\frac{\text{CO}_2}{\text{O}_2}$ apparatus.

A, Large vessel filled with water. *B*, Receiver for plants. *C*, Rubber-balloon. *D*, Capillary-tube leading to mercury bath. *E*, Tube leading to air-pump. Rubber indicated by shading; iron by heavy lines; all else glass.

easily eliminated. A bottle of some 750 cc. capacity was selected, the neck of which was not shallow, and preferably ground, and to this a deep stopper of soft rubber, perforated with two holes, was fitted. Through one of the holes was passed a capillary barometer-tube, one end of which reached almost to the bottom of the vessel, the other end leading off under a mercury-bath, being closed, however, near to the

¹ Pring's Jahrb., Vol. xiii, p. 491, 1882.

² l. c., p. 7.

bottle by means of a cock. Through the other hole in the stopper was passed a piece of ordinary tubing, which projected a short distance down into the bottle. To this end was attached a rubber-balloon with very stout walls capable of considerable expansion; while the other end, bent at a short distance above the stopper, led off to a bottle filled with water, to which was attached an air-pump. When a few strokes were given to the air-pump, the water in the bottle referred to was forced into the balloon, thus expanding it to three or four times its original capacity, by which an appreciable pressure was produced in the receiver. Reference to the figure (woodcut 2) will explain the details of this apparatus. The whole receiver was immersed under water until the stopper was well covered, to ensure both perfect closing and a tolerably constant temperature. As the temperature of the laboratory was fairly regular, it was possible to keep the receiver within at most one degree of the same temperature with comparative ease.

The mode of operating was as follows. The samples of plants under investigation were put into the receiver, and after a current of air had been passed through it the stopper was fixed tightly in place and the whole clamped in position under the water. The cock leading to the delivery-tube was closed, and the glass tube from the rubber-balloon connected with the air-pump. Two or three strokes of the air-pump were given, and the balloon so expanded was allowed to collapse to drive out the air which it contained. The apparatus was then allowed to stand until the time for the experiment had expired, upon which a sample of the contained air was taken as follows. The balloon was first filled and emptied three or four times to procure a thorough admixture of the gases in the receiver; this was found by actual experiment with smoke to be thoroughly accomplished in three repeated fillings and emptyings. Finally the balloon was once more distended, the end of the capillary-tube thrust under the mercury, and the cock at once opened. A very considerable stream of gas was thus forced out, of which the first few cc. were rejected to

make quite sure of a pure sample of the gas in the receiver. The samples of gas for analysis were collected in little tubes over dry mercury. After each experiment the air was renewed, either by running a strong current of air through the receiver, or by removing the plants from the bottle and filling it with water.

As a control for the method, experiments were made with samples of air containing a known quantity of CO_2 . This was analyzed at the beginning of the experiment, and again two days later, after the apparatus had been under water as described. As will be seen below in the three analyses given, the percentage of CO_2 does not vary appreciably between the beginning and end of the experiments :—

No. of experiment	I.	II.	III.
% CO_2 at beginning	5.94	11.35	8.42
% CO_2 48 hours afterwards	5.92	11.37	8.38

The danger of leakage as a source of error having been shown to play no part, the only other errors to be considered are those possibly arising from change of temperature during the course of the experiment, or from the danger of the air in the capillary delivery-tube vitiating the sample taken ; but these were guarded against in the manner described. While the plants under experiment were plentifully supplied with moisture, care was taken to allow no considerable amount of water to remain in the receiver, as a source of error due to the absorption of CO_2 thereby might arise. The agreement of the results among themselves speaks for the accuracy of the methods employed.

For the analysis of the air one of the improved Bonnier and Magnin apparatuses was used, such as is described by Aubert¹. By observing all the precautions against errors described by the above writers, it is possible to obtain results of more than sufficient accuracy for this work, and a similarity of manipulation tends to equalize any other remaining sources of error. Repeated analyses of the air in the laboratory showed that, as far as the purposes of this research are concerned, the amount of CO_2 contained in it need not be

¹ Rev. Gén. de Botanique, Vol. iii, p. 97, 1891.

regarded, being a scarcely perceptible fraction of one per cent. In all cases the percentage of O_2 in air was taken as 20.8, being the average amount shown by repeated analyses with this apparatus, and agreeing well enough with the already known percentage.

For certain determinations of the amount of CO_2 contained in thick bulky tissues such as potatoes, carrots, &c., a method was employed for driving the gas off with boiling water. A large flask, in which the potatoes or carrots were placed along with a considerable amount of water, was connected by means of a Liebig-condenser in reversed position with the Pettenkofer apparatus. The water was brought to the boiling-point as rapidly as possible, care being taken that no gas could escape from the flask, except through the tubes containing the BaO_2H_2 , and also that no water passed over from the condenser into the tubes. The CO_2 evolved was estimated in the usual way by titrating the remaining BaO_2H_2 . Almost all of the CO_2 thus driven off came over in the first ten minutes after boiling. The method is open to the objection that the high temperature required might bring about the decomposition of organic substances in the tissue, and thus give an excess of CO_2 ; but the fact that the gas comes off so suddenly would seem to point to its being merely absorbed or enclosed. The results were only accepted as approximate at best, and, as will be seen, no very great stress is laid on them.

All the material experimented with, with the exception of the leaves from the green-houses, was brought into the laboratory at least four days before using, to allow it to become accustomed to the temperature of the room. In almost all cases the respiration of the uninjured condition was first ascertained, the only exceptions being a few cases with potatoes, in which it was known that the respiration was practically none from experiments made previously with similar potatoes. The character of the plants and tissues employed for experimentation was various: bulky tissues like potato-tubers (*Solanum tuberosum*), carrots (*Daucus Carota*), &c.; thin, well-aerated tissues such as various leaves;

young growing tissues as found in seedlings (*Vicia Faba*, *Cucurbita Pepo*); and lastly, as with *Salix* twigs, tissue of an entirely different kind. The large majority of the experiments, however, were performed with potatoes, which lend themselves more readily to manipulation, and which react, as far as respiration goes, more markedly to injury than any of the other tissues tried.

The injury to which the plants were subjected consisted of cutting in various ways. Potatoes and carrots were usually cut into four with a sharp knife; leaves were slit longitudinally; while with seedlings the hypocotyl was split, or the tip of the root cut off. Immediately after injury, the tissues were always washed and only somewhat dried, both to rid them so far as possible from the cells killed in the process of cutting, and to ensure entire turgidity of the neighbouring parts. As Stich¹ has pointed out, the amount of CO₂ contained in the small quantity of liquid exuded from the cut surfaces is even in the case of potatoes practically imperceptible. In those experiments where it was desired to protect the wounded parts, Stich's method of sealing the pieces together with neutral gelatin was necessarily avoided, as the gelatin affords too good a basis for the growth of Bacteria when experiments lasting several days are to be undertaken. For this purpose clay was substituted. The clay employed was tested and found to be quite neutral. It was applied to the cut surfaces, which were then stuck together in their original position so that the oxygen of the air had no opportunity to act on them. After one day it was possible to remove the clay in large pieces without injury to the tissue beneath, after which the wound was washed in a stream of water, which, as shown below, does not cause any new increase in the amount of CO₂ produced.

	I.	II.
	mg. CO ₂ per hour.	mg. CO ₂ per hour.
Potato three days after injury . . .	6.30	7.45
Same after washing and drying . . .	6.15	7.50

¹ l. c., p. 15.

Care must be taken, however, or portions of the corky layer which heals the wound will come off, and the fresh surfaces thus laid bare cause an increase in respiration.

During the night-time, or other times when determinations were not being made, the receivers containing the plants were placed in an inverted position to allow for the escape of the CO_2 formed; or, as was more often the case, connected with the aspirator, so that no abnormal conditions could occur owing to the lack of O_2 or the accumulation of CO_2 in the receivers. Throughout the course of the experiments the plants used were kept well supplied with moisture to keep them turgid, but no excess of water was allowed to stand in the receiver. A careful watch was kept for the growth of Fungi or Bacteria on the plants, but no difficulty was experienced from this cause, even in the experiments which were continued for a week or more.

DISCUSSION OF RESULTS.

Concerning the ordinary course of the respiratory activity of an injured plant, it may be said in general that there is an increase, varying very much in point of time and extent with the character of the plant and the conditions to which it is subjected, followed by a subsequent decrease to the normal or almost normal respiration as the wound heals. Reference to any of the experiments will afford evidence of this; for it will be seen that an increase of more than 100 per cent. was often found during the period of maximum respiration. In the case of potatoes, carrots, and other bulky tissues, it will be observed that in almost every case there is, during the first two hours, a very sudden and marked increase, which, however, falls again rapidly, although to a point still considerably above the normal respiration, to rise more slowly later to the maximum production of CO_2 . The causes of the first sudden increase will be discussed later; at present the general effect of the injury demands attention. The respiratory activity in these plants is at its height on the beginning of the second day, or

more precisely from twenty-four to thirty hours, after the injury has been inflicted, provided that the healing of the wound has been in no way retarded otherwise than by keeping the plants in a moist atmosphere. The course of this curve is fairly constant, and a decrease to a nearly normal rate of respiration, although much more gradual than the increase, is to be expected in from seven to eight days. In the case of the potatoes experimented with, the respiration never reaches quite so low a point as the normal, but this amount is in the first place so exceedingly small that hardly anything else could be expected when taking into consideration the increase of temperature and moisture to which the specimens were subjected. The amount of CO_2 evolved in comparison to the normal production is somewhat variable, but it will be noticed that it usually corresponds to about twice the amount found at the time when the plant is at its lowest respiratory condition after injury.

In potatoes the percentage increase of the respiration of the injured over the uninjured condition is far greater than in any other of the plants examined. It was with potato-tubers that Boehm¹ first observed the phenomena attending injury, and he also records a maximum on the second day, but in one instance only. Stich² in two cases gives a maximum at a somewhat earlier period, but that is a point which might readily vary with the conditions of the experiment. With carrots the maximum period (Expts. 14 and 15) was found not to be reached in some cases until the beginning of the third day. The first strong evolution of CO_2 during the first few hours is very well marked in carrots (Expts. 14 and 15), and is almost as great as the maximum reached later. In the same way sugar-beets and the ordinary red beet showed a similar respiration-curve after injury, although, weight for weight, the evolution of CO_2 is by no means so great as with carrots. As regards the $\frac{\text{CO}_2}{\text{O}_2}$ -equation, it will be seen in general that, although between the uninjured and

¹ Bot. Zeit., Bd. xlv, p. 671, 1887.

² l. c., p. 53, Versuche, 11 and 12.

injured conditions there is an appreciable rise in the fraction, there is no other marked change in the relations except during the first few hours after injury. The absorption of O_2 is always greater than the production of CO_2 , except at the time already referred to, when the latter gas almost equals or slightly exceeds the former in quantity (Expts. 37, 41). There is a slight tendency to an increase of the CO_2 in relation to the O_2 at the time of the maximum respiration, which, however, falls off again somewhat as the respiration decreases.

In the experiments with more active tissues, for which seedlings of *Vicia Faba* were taken, results of a less constant nature were obtained. But in most cases a distinct increase in the respiration was found, rising to a maximum at a somewhat variable time after injury, and falling again to approximately the original amount as before injury. Necessarily, owing to the changes taking place in the seedlings during the course of the experiment, the reaction to injury was at times dwarfed by other causes. Stich, who experimented with a considerable range of seedlings, found a great diversity in the amount of respiration, but usually he records a distinct increase after wounding. One fact to be noted in the experiments with seedlings is that no sudden evolution of CO_2 is to be found directly after injury. This is also true of leaves, which show, however, a rise and fall in the respiration, as do other injured plants, although, necessarily from their short life after separation from the plants on which they grow, it is not for long.

Such, then, are the general facts connected with the phenomena of the respiration, which raise a number of questions that require a more detailed discussion of some of the experiments to answer. The first question is of course what, on the whole, is the cause of the increased respiration. As has already been said, Böhm¹ concludes there is no doubt that the cause of it is alone the irritation of the wound itself, and not the increased opportunity for the action of the oxygen of

¹ Bot. Centralblatt, Bd. 1, p. 200.

the air. He cites the results of some experiments with potatoes which had been hollowed out in the centre, the cavities being filled with water, and again sealed from the air, under which conditions their respiration still continued very strong. But on the other hand must be considered Stich's¹ results already referred to, which point to another explanation. Experiments similar to those of Stich's with gelatin were tried, but of longer duration, so that it was necessary to use clay for the covering of the wounded surfaces. In Experiment 7, with potatoes the quarters of which had been covered with clay at once after cutting, the four determinations taken on the day of the injury did not show the expected increase. On the next day, when the ordinary maximum for a similar quantity of potatoes should have been about 15 mg., it was only 7.60 mg.; while after the lapse of seven days the amount was practically nothing. After the removal of the clay there was a sudden and marked increase of the CO₂-production. The cut surfaces of the potatoes which had been protected by the clay were not absolutely fresh, being covered with a thin layer of corky material, which, by the way it may be mentioned, was not disturbed in the removal of the covering. This is shown even more clearly in the case of Experiment 13, where the clay was not applied until the time of the maximum respiration. Immediately there followed a decrease, which again gave place to an increase when about twenty-four hours afterwards the clay was removed. The carrots (Expts. 16 and 17) treated in a similar manner exhibited much the same effect; in both the cases cited the application of the clay hindered the usual increase of CO₂, and, when after some time the clay was taken off, the respiration at once rose to a very considerably higher point, where it remained, with only a slight decrease, for several hours. A similar result was also obtained in another series with potatoes, in which case the tubers were simply deeply incised, not actually cut through, and were then at once very tightly bound with soft string. At first a slight rise in the respiration

¹ l. c., Versuche, 13-15.

was noted, which, however, increased very suddenly on removal of the binding, at which time the cuts gaped widely open and so allowed free access of air to the injured parts. These experiments show that there can be hardly a doubt that the oxygen of the air plays an important part in the reaction of the respiratory functions of the plant towards injury.

Experiments made in atmospheres of hydrogen or of diminished percentage of oxygen substantiated those already described, and also showed some other facts. In Experiment 11 it will be seen that even in 6% oxygen the potatoes ceased to show the ordinary increase, but when finally exposed to air there was a gradual rising of the respiration-curve. In other experiments the percentage of O_2 was reduced to as low as four, which Stich¹ has shown may be safely used without complicating the results with intramolecular respiration. The decrease shown in Experiments 11 and 21 after exposure to an atmosphere of this composition for six hours is not the normal decrease due to the healing of the wounds, as the considerable increase after remaining over night in a current of air demonstrates. Corresponding experiments were made with carrots, but, although much the same phenomena were noted, they were not quite so clearly marked as in the former cases. In pure hydrogen it is shown that the intramolecular respiration is not so largely increased by injury (Expts. 9 and 10). After nine hours' exposure to hydrogen, the amount of CO_2 evolved was scarcely greater than the normal intramolecular respiration. In considering these experiments one must always remember the necessary accommodation which the functions of the plant have to undergo to the diminished pressure of the artificial atmosphere. On the other hand, it is shown by the experiments carried on with pure oxygen that a surplus of this gas produces no effect in yet further increasing the production of CO_2 , from which fact it would seem that simply the action of oxygen on the tissues is not alone responsible for the

¹ l. c., p. 11.

increased respiration. Experiments 8, 21 a, and 39 illustrate this point.

The employment of well-aerated tissues, which, either from their small size or looseness of structure, afford free access of oxygen to their parts, threw yet more light on the subject. As has already been mentioned, seedlings of *Vicia Faba*, in spite of the irregularities in respiration associated with their rapid growth, showed an increase of CO_2 upon injury. But better still for this purpose are leaves, of which, as will be seen, a number of different kinds were tried. In all cases there was a distinct increase, the maximum being reached a few hours after, or at least during the same day as, the injury; while by the next day, if the leaf still lived, the respiration returned to about the normal (Expts. 28 and 32). It will be noted in all the experiments, both with seedlings and with leaves, that there was no sudden increase during the first few hours after wounding. It is, then, apparent that the shock of the injury itself must also play a part in the rise of the respiration of injured plants, since these parts of plants, which are already well supplied with O_2 , or from their nature cannot contain any considerable quantity of oxidizable substances, also react when wounded.

As regards the sudden evolution of CO_2 that is noticed immediately after injury, the numerous experiments which were made to clear up this point seem to show that the phenomenon is due to the escape of this gas, already absorbed or held in the tissue, in a physical rather than a chemical manner. As has already been stated, thin and loosely constructed tissues, and also small masses of a more compact nature, such as the hypocotyls of seedlings, showed no evidence of this temporary increase. It was only with bulkier tissues like potatoes and carrots where this was found: in tissues, that is, where their size made it possible that CO_2 might be contained in them. But this point is more conclusively demonstrated in Experiments 12 and 19, in which the plants were exposed to a vacuum at once after injury. If there were any CO_2 present, as such, in the tissue,

it would naturally come off under the reduced pressure, and such was found to have been the case: for, although determinations were made but half an hour after injury, the sudden increase and subsequent fall found under ordinary atmospheric pressure were not observed. When injured potatoes are transferred to hydrogen, there is at first a considerably greater evolution of CO_2 than some hours later; which, as Stich has pointed out, is due to a process of accommodation which the plant undergoes, but which may also partly be due to the cause mentioned above. In the relation of the CO_2 produced and O_2 absorbed during the first few hours after injury, further support is found for the opinion here expressed regarding the source of the excess of CO_2 . It will be seen that, whilst the CO_2 -production is very large, the absorption of O_2 during the first two hours is less than later, when the CO_2 evolved has greatly decreased. Reference to Experiment 37 will show this, where with potatoes the amount of CO_2 given off during the first two hours after injury was 2.19% of the air in the receiver, while but 2% of O_2 had been absorbed. Further, during the next two hours 1.83% of CO_2 was evolved to 2.5% of O_2 absorbed; whereas on the next day, when the CO_2 -production was again above 2% , the figures stood: CO_2 produced 2.56% ; O_2 absorbed 3.2% . In the experiments with carrots the same result was also obtained; first two hours, CO_2 3.71% to O_2 3.80% ; second two hours, CO_2 2.35% to O_2 3.6% ; third two hours, CO_2 3.7% to O_2 5.3% (Expt. 4).

To obtain some idea of the amount of CO_2 which may be contained in such a large mass of tissue as a potato or a carrot, a number of experiments were made by which the contained gas was driven off by boiling water. The amount of CO_2 thus obtained was about 5 mg. to every gram of substance (Expts. A—G). The method is open to the objection that perhaps some of the CO_2 driven off may have been formed by the decomposition by the heat of organic compounds in the plant; but without much doubt a large portion of the gas was simply the contained or absorbed CO_2 .

in the tissues, as is indicated by the fact that practically all of it came off at once on warming. It was only desired to determine in a general way if there was much or little CO_2 , as such, in the tissues, and not to arrive at a definite quantitative result. That there appears to be a considerable amount agrees with the other experiments discussed, and supports the view, already expressed, of the source of the first rush of CO_2 immediately after injury.

It was also desired to find if an increase of injury brought about a corresponding increase of respiration. As is shown in Experiments 6 and 18, there is a certain increase when the plant is further wounded, both in the case of potatoes and carrots, but one that does not bear any distinct relation to the amount of injury done. As before, leaves give an opportunity of more or less eliminating the question of aeration, and allowing a better means of observing the effect of the irritation alone. The leaves of *Veronica* and *Acacia* (Expt. 32) were experimented with from this standpoint. The latter was the better, although the former also served to show the reaction to some extent. With the *Acacia* the large compound leaves were taken from the plant, and determinations were made until it was found that the injury caused by the cutting of the petioles had passed its maximum. The pinnae were then cut off, and the main stalks once or twice cut across; as a result, the respiration rose a second time to a slightly higher point. When the evolution of CO_2 was once more on the wane, the leaves were injured for a third time, and more severely than before, by stripping off the pinnules and longitudinally slitting all the stalks. On this occasion the increase was much more strongly marked, and finally stopped on the gradual death of the leaves. This experiment shows then quite plainly that a certain effect is produced by increase of injury, although it must be remembered that in this case it was not possible to wash away the injured cells as was always done with longer tissues.

An examination of the results obtained with the apparatus already described for the comparison of the amount of CO_2

produced and of O_2 absorbed shows that the ratio of $\frac{CO_2}{O_2}$ does not change to any very great extent after injury, always excepting the first two hours, concerning which an explanation has already been given. The average ratio with uninjured potatoes is almost .50, from which after the first sudden rise a second slower ascent is found, which corresponds to the curve of respiration as found in the Pfeffer-Pettenkofer apparatus. At the time of the greatest evolution of CO_2 it is about .75 or .80, falling again as the respiration decreases. In other words, somewhat more CO_2 is given off in proportion to the O_2 absorbed in the injured than in the uninjured condition. With the carrots experimented upon, even less change was found in three of the experiments (Expts. 40, 41, 42); it remained almost the same, while in a fourth it was slightly lower. In the analyses of respiration from seedlings, in two cases there was at first a rise in the ratio to which it kept during the entire experiment (Expts. 44 and 46), while in one case there was an appreciable fall to an amount equalling the respiration in the uninjured condition (Expt. 45). In the case of leaves, those of *Veronica speciosa* showed a distinct increase of the ratio at the time when the respiratory activity is at its maximum. In no case was there observed such a marked increase of the amount of oxygen absorbed as is indicated by the results of Stich's experiments.

It is apparent that the amount of CO_2 produced bears a close relationship to the amount of O_2 absorbed, the latter always, with the one exception already noted, being in excess of the former, but to no very great extent. It will be noticed in the following table that the amount of oxygen absorbed after injury, over and above that theoretically required for the amount of CO_2 produced, is somewhat more than in the uninjured condition, being at its highest when the respiration is strongest. It is, however, proportionally to the CO_2 formed, far less than before injury. It may possibly be due to the fact that the processes, involving the absorption of oxygen, which go on in the plants under normal conditions are simply somewhat

hastened by the freer access of the air to the tissues. The following table is calculated out from three of the experiments given in detail at the end of this paper. With the temperature and the ordinary pressure under which these experiments were carried out, 1 cc. of CO_2 may be called 1.8 mg. in weight, while the same amount of O_2 would be 1.3 mg., this being accurate within the limits of error of the methods employed and within the purposes of the table. In Experiments 37 and 42, where determinations were made immediately after injury, the amount of O_2 required for the CO_2 given off was not estimated for these two hours; for, as has already been explained, the relation between the two gases is then not normal. The object of this table is twofold: both to bring more clearly before the eye the exact amount of the gases interchanged, and to show that this method coincides as to the production of CO_2 with the direct determinations made with BaO_2H_2 . Taking weight for weight, it will be seen that the two methods agree well as to the amount of CO_2 produced per hour. All the other experiments of the kind may be calculated out in a similar way from the data given.

	No. of Det.	Duration of Expt.	cc CO_2 produced.	cc O_2 absorbed.	mg. CO_2 produced.	mg. O_2 absorbed.	Amount in mg. O_2 required theoretically for CO_2 produced.	Amount in mg. O_2 absorbed not used in respiration.
Expt. 36 8 potatoes 195 grams	a	2 hours	2.27	4.92	4.10	6.40	3.00	3.40
	b	"	11.00	11.72	19.80	19.20	14.40	4.80
	c	"	13.96	18.45	25.20	24.00	18.35	5.65
	d	"	15.74	19.68	28.30	25.60	20.60	5.00
	e	"	12.61	16.50	22.70	21.20	16.50	4.70
Expt. 37 8 potatoes 200 grams	a	2 hours	2.55	5.61	4.60	7.30	3.35	3.95
	b	"	11.77	10.20	20.10	13.30	...	...
	c	"	9.33	13.77	16.80	18.00	12.70	6.30
	d	"	13.06	16.36	23.40	21.20	17.00	4.20
	e	"	11.48	15.05	20.35	19.60	14.40	5.20
Expt. 42 2 carrots 165 grams	a	2 hours	9.10	12.84	16.40	16.70	11.95	4.75
	b	"	19.85	20.33	35.70	26.40	...	...
	c	"	12.57	19.26	22.60	25.00	16.45	8.55
	d	"	19.80	28.35	35.60	36.80	25.90	10.90
	e	"	25.68	34.24	46.20	44.50	33.60	10.90
	f	"	15.78	22.47	28.40	29.20	20.70	8.50

GENERAL CONSIDERATIONS.

Considering the increased respiration attending the injury of plants as an indication of stimulated activity on the part of the tissues, its significance is understood at once. In common with the general tendency of living organisms, plants endeavour to tide over the critical period following an injury by exerting an unusual effort to overcome the same. If the unfavourable conditions be too severe or too long-continued, death will naturally result; but until vitality is so far weakened that even ordinary activity is diminished, or until the crisis is past and recovery assured, evidences of an acceleration of the ordinary functions of life will pretty surely be found in almost any living organism. In the case of plants, so far as the kind of injuries produced by cutting are concerned, a far greater amount can be suffered without fatal effects than in even fairly lowly organized animals, so that a direct comparison between the two is not to be instituted. Nevertheless, even in such organs as leaves, where death of the parts follows comparatively rapidly on any severe injury, a distinct increase in the rate of respiration was found. But it is not necessary to be limited to only this type of abnormal conditions, for numerous authors have shown that plants respond by increased respiration, and hence, it is to be understood, increased activity in general, to other unnatural conditions. Elfving¹, experimenting with various plants under the influence of chloroform and ether, found that respiration was very considerably accelerated, although he did not determine the curve from the point of view of time. Johannsen's² work on the influence of an increased pressure of oxygen on seedlings shows a similar result even more plainly. He found that at first in almost every case the respiration was increased, falling again until finally death ensued. As has already been referred to, Stich³

¹ Öfversigt af Finska Vetensk.-Soc.'s Förh., Bd. xxviii, 1886.

² Untersuch. aus dem Bot. Inst. zu Tübingen, Bd. i, 716, 1885.

³ l. c.

also discovered that, in a diminished quantity of oxygen, plants require a period of accommodation to the new conditions, during which time the respiration rises perceptibly. All of these results show, in common with what has been described here, that, under conditions which are unnatural, plants strive to rid themselves of, or surmount, the irritating influences of this unnatural state by a temporary increase of their vital energy.

In considering respiration as a measure of such increased activity, it must be remembered that in all these cases, and in the case of the work herein described, the methods necessarily employed show only the total effect of the injury upon the plants concerned. That is to say, it is impossible to locate the active region, to say whether it really is the whole potato, for instance, or only the part near the wound, which is affected, and which therefore respire more rapidly. In considering other effects of injury, Hauptfleisch¹ has shown that the movement of the protoplasmic contents of the cells is greatly increased in the neighbourhood of a wound, and that the activity so produced is transmitted to other cells after the lapse of a certain time. That this stimulation is carried to all the cells of the entire plant would hardly be supposed, nor does it seem to be the case from what Hauptfleisch records. In some comparatively delicate water-plants, as *Elodea* and *Vallisneria*, it was indeed seen to be propagated for a considerable distance; but in examples of hardier tissues, such as those of *Zea Mais* or *Triticum*, it seems to be much more restricted. In the experiments recorded here, indications of a more or less restricted zone of activity are suggested by the ever-increasing rate of respiration which followed successively severer injuries. That there may be a connexion between the phenomena which Hauptfleisch describes as 'secondary streaming' and the increased rate of respiration after injury is not at all improbable, in that they are all but part and parcel of the general stimulation of the normal functions of the plant.

¹ Pring's Jahrb., Bd. xxiv, p. 191 et seq., 1892.

That there are yet other forms of irritation to which plants respond by increased activity goes without saying. The familiar examples of the effect of many plant-parasites on their hosts show that this may become evident from even a morphological standpoint; and in other cases, where no direct atrophy or hypertrophy results, it would no doubt be found that the host-plant endeavours to counteract the effect of the parasite in such a way. Böhm¹ mentions the fact that the respiration of potatoes affected with *Phytophthora* is above the normal. Of course in such cases the period of stimulation is more prolonged than by simple wounding, for the source of irritation is always present, and also increasing; but before the plant succumbs there must be a time when the effect of the stimulus given by the parasite has reached a maximum.

Different as they may be, these examples all serve to illustrate the power of reaction against untoward and abnormal conditions which plants possess in common with other living organisms.

STATEMENT OF CONCLUSIONS.

To recapitulate in brief the conclusions arrived at from the experiments here recorded, as far as they can be judged from the plants employed, they may be stated as follows:—

1. That after injury to plant-tissue there results a greatly increased respiration, varying in intensity and duration with the character of the tissue involved and with the extent of the wounding. This increased activity of respiration, after reaching—usually within two days—a maximum, falls gradually, as the wounds heal over, to a normal or to an almost normal rate.

2. That this increased respiration may be ascribed to an effort on the part of the plant to recover from the injury by which the ordinary functions of the plant are stimulated, thereby demanding and necessitating an increased supply of oxygen.

¹ Bot. Centralblatt, Bd. 1, p. 202, 1892.

3. That in large bulky tissues there is in the natural condition a certain amount of enclosed or absorbed CO_2 , some of which is given off very suddenly during the first two or three hours after injury, thereby indicating a seemingly higher respiratory activity than in the hours which immediately follow.

4. That, in the plants experimented with, the ratio of the absorption of O_2 and production of CO_2 does not vary within very wide limits before and after injury, though there is a distinct, if small, increase in the proportion of CO_2 given off in the latter case. Also, that the amount of O_2 absorbed is always in excess of the amount theoretically required for the quantity of evolved CO_2 .

BOTANISCHES INSTITUT, LEIPZIG,
June, 1896.

TABLES OF EXPERIMENTAL RESULTS.

A.

Determinations with Pettenkofer-apparatus. Air washed with potassic hydrate U-tubes. Hydrogen or oxygen when used washed also with potassic permanganate and mercuric chloride tubes. Air-current regulated by aspirator and gasometer in all experiments being 3.500 or a few cc. over per hour. When new experiments were begun, or a change made in the gases run through the receiver, the apparatus was always run at least a half-hour, and often longer, before a determination was made. Temperature of receiver and plants therein kept constant within $.5$ to 1° by immersion in water. The first two or three determinations, unless it is stated otherwise in the description of experiment, were taken in the uninjured condition.

EXPERIMENT 1.

24 small potato-tubers, weight 200 grams. Air-current, 3.5 litres per hour. Ran thirty minutes before first determination.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xi. 10. '95	9.45 - 10.45 a.m.	21°	2.00
"	10.45 - 11.45 "	21°	1.70
Potatoes cut in two pieces lengthwise.			
xi. 10. '95	12.15 - 1.15 p.m.	21°	10.20
"	1.15 - 2.15 "	21°	4.00
"	2.15 - 3.15 "	20°.8	4.20
"	3.15 - 4.15 "	20°.8	3.60
"	4.15 - 5.15 "	20°.7	7.40
xi. 11. '95	9.25 - 10.25 a.m.	21°	10.00
"	10.25 - 11.25 "	21°	10.60
"	11.25 - 12.25 p.m.	20°.7	12.10
"	12.25 - 2.25 "	20°.6	14.60*
"	2.25 - 3.25 "	21°.1	14.50
"	3.25 - 4.25 "	21°	16.30
"	4.25 - 5.25 "	21°	14.70
xi. 12. '95	10.10 - 11.10 a.m.	20°.5	13.20
"	11.10 - 12.10 p.m.	20°.7	13.30
"	12.10 - 1.10 "	20°.7	11.10
"	1.10 - 3.10 "	20°.6	11.00*
"	3.10 - 4.10 "	20°.8	10.90
xi. 13. '95	10.00 - 11.00 a.m.	20°.9	10.70
xi. 14. '95	9.15 - 10.15 "	21°	7.70
xi. 18. '95	8.15 - 9.15 "	21°	4.20

* Reduced to value of 1 hour.

EXPERIMENT 2.

26 small potato-tubers, 200 grams. Respiration, uninjured, practically nothing. Sliced in half. Ran apparatus of half-hour. Air-current, 3.5 litres.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xi. 15. '95	10.15 - 11.15 a.m.	20°	8.80
"	11.15 - 12.15 p.m.	20°.5	8.10
"	12.15 - 1.15 "	20°.5	6.90
"	1.15 - 2.15 "	20°.7	6.90
"	2.15 - 3.15 "	21°	6.50
"	3.15 - 4.15 "	21°	6.70
"	4.15 - 5.15 "	21°	7.70
"	5.15 - 6.15 "	20°.8	7.70
"	6.15 - 7.15 "	20°.8	6.30
"	7.15 - 9.15 "	20°.6	8.85
xi. 16. '95	12.00 - 1.00 "	21°	11.70
"	1.00 - 3.00 "	21°	10.25*
"	3.00 - 4.00 "	21°.1	10.10
"	4.00 - 5.00 "	21°.1	8.25
xi. 17. '95	10.30 - 11.30 a.m.	20°.5	9.10
"	11.30 - 12.30 p.m.	20°.5	9.00
xi. 18. '95	9.30 - 10.30 "	20°.5	7.30
xi. 19. '95	9.20 - 10.20 "	20°.7	6.70
xi. 20. '95	3.50 - 4.50 p.m.	20°.8	5.70
xi. 21. '95	12.00 - 1.00 "	20°.4	4.50

* Reduced to value of 1 hour.

EXPERIMENT 3.

9 potato-tubers, 300 grams. Ran for two hours in uninjured condition, but only found a trace of CO_2 evolved. Air-current, 3.5 litres. Tubers quartered, washed, and dried, and at once tied together again with soft string.

Date.	Time.	Temperature.	mg. CO_2 produced per hour.
xi. 18. '95	1.45 - 2.45 p.m.	21°	16.50
"	2.45 - 4.15 "	21°	13.20*
"	4.15 - 5.15 "	20° .5	13.30
"	5.15 - 6.15 "	20° .5	14.30
"	6.15 - 7.15 "	20° .5	15.10
"	7.15 - 9.15 "	20° .8	16.25*
xi. 19. '95	10.30 - 11.30 a.m.	20° .5	2.50
"	11.30 - 12.30 p.m.	20° .3	20.50
"	12.30 - 2.30 "	20° .5	16.10*
"	2.30 - 3.30 "	21°	16.10
"	3.30 - 4.30 p.m.	21°	16.30
"	4.30 - 5.30 "	20° .8	16.50
"	5.30 - 6.30 "	20° .5	17.30
xi. 20. '95	8.20 - 10.20 a.m.	20° .8	17.30
"	10.20 - 11.20 "	20° .8	16.90
Removed bindings and separated the cut quarters.			
xi. 20. '95	11.40 - 12.40 p.m.	20° .9	22.00
"	12.40 - 2.40 "	20° .9	20.00*
"	2.40 - 3.40 "	20° .8	20.90
"	5.00 - 6.00 "	20° .5	17.90
"	6.00 - 7.00 "	20° .2	17.30
xi. 21. '95	10.00 - 11.00 a.m.	21°	14.10
xi. 29. '95	3.05 - 4.05 p.m.	21°	9.40
"	4.05 - 5.05 "	20° .8	7.40
xi. 30. '95	4.00 - 6.00 "	21°	6.30*

* Reduced to value of 1 hour.

EXPERIMENT 4.

8 potato-tubers, 300 grams. Give only a trace of respiration in uninjured condition. Tubers quartered, washed, and dried. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xi. 22. '95	9.15 - 10.15 a.m.	20°	13.40
"	10.15 - 11.15 "	20°	9.00
"	11.15 - 12.15 p.m.	20°.5	11.60
"	12.15 - 1.15 "	20°.5	11.80
"	1.15 - 3.15 "	20°.7	14.40*
"	3.15 - 4.15 "	20°.6	14.80
"	4.15 - 5.15 "	20°.8	15.70
"	5.15 - 6.15 "	20°.6	16.00
"	6.15 - 7.15 "	20°.5	16.80
xi. 23. '95	9.15 - 10.15 a.m.	20°.8	15.60
"	10.15 - 11.15 "	20°.6	15.60
"	11.15 - 12.15 p.m.	20°.8	16.00
"	12.15 - 1.15 "	21°.0	18.60
"	1.15 - 3.15 "	20°.7	18.40*
xi. 24. '95	11.30 - 12.30 "	20°.5	13.60
xi. 29. '95	6.15 - 7.15 "	21°	7.40
xii. 3. '95	8.15 - 9.15 a.m.	20°.8	3.20
xii. 4. '95	8.15 - 9.15 "	20°.8	1.60

EXPERIMENT 5.

11 potatoes, 300 grams. Cut into eight pieces. The object of this experiment was to verify the previous observations regarding the production of CO₂ during the first few hours after injury. Air-current, 3.5 litres.

Date.	Time.	Temp.	mg CO ₂ produced per hour.
ii. 20. '96	9.40 - 10.40 a.m.	20°.8	51.20
"	10.40 - 11.40 "	20°.7	36.00
"	11.40 - 12.40 p.m.	20°.7	23.00
"	12.40 - 2.10 "	20°.6	21.40*
"	2.10 - 3.10 "	20°.4	21.80
"	3.10 - 4.10 "	21°.0	21.60
"	4.10 - 5.10 "	20°.8	23.40
"	5.10 - 6.10 "	20°.8	23.60
ii. 21. '96	9.00 - 10.00 a.m.	20°.7	30.00
"	10.00 - 11.00 "	20°.7	33.60

* Reduced to value of 1 hour.

EXPERIMENT 6.

8 potatoes, 300 grams. Halved, washed, and dried. Experiment to determine if there is any increase of respiration with increase of injury. Air-current, 3.5 litres.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xii. 11. '95	8.20 - 9.20 a.m.	21°	6.20
"	9.20 - 11.20 "	20°.8	8.60*
"	11.20 - 12.20 p.m.	20°.7	8.50
Cut each half into six pieces, washed and dried. Time, 12.30.			
xii. 11. '95	2.20 - 3.20 p.m.	20°.7	21.70
"	3.20 - 4.20 "	20°.6	20.70
"	4.20 - 5.20 "	21°	27.40
xii. 12. '95	9.30 - 10.30 a.m.	21°	27.60

EXPERIMENT 7.

7 potatoes, 225 grams. Respiration in uninjured condition less than 1 mg. per hour. Quartered, washed, and dried, and then at once fastened the quarters together with clay. Air-current, 3.5 litres.

Date.	Time.	Temperature.	mg. Co ₂ produced per hour.
xi. 28. '95	9.15 - 11.15 a.m.	20°.6	3.60*
"	11.15 - 1.15 p.m.	20°.5	4.20*
"	1.15 - 3.15 "	20°.5	6.60*
"	3.15 - 5.15 "	20°.5	7.30*
xi. 29. '95	9.25 - 11.25 a.m.	21°	7.60*
xii. 2. '95	2.35 - 4.35 p.m.	20°.4	2.50*
Clay removed.			
xii. 2. '95	5.05 - 6.05 p.m.	20°	24.60
"	6.05 - 7.05 "	20°	25.40
"	7.15 - 9.15 "	20°.3	20.40*
xii. 3. '95	6.10 - 7.10 "	20°.4	13.00
xii. 6. '95	9.20 - 10.20 a.m.	20°.3	12.00
xii. 12. '95	11.45 - 12.45 p.m.	20°.6	11.60

* Reduced to value of 1 hour.

EXPERIMENT 8.

6 potatoes, 310 grams. To determine effect of oxygen. Oxygen from gasometer 94 %. Before taking determinations with O a strong current was run through the apparatus until practically pure O came off. Current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.	Medium.
xii. 8. '95	9.00 - 11.00 a.m.	20°.4	2.10*	Air
"	3.00 - 5.00 p.m.	20°.5	2.40*	Oxygen
Potatoes quartered, washed, and dried. First determination, 1½ hours after injury.				
xii. 9. '95	10.00 - 11.00 a.m.	20°.5	10.60	Air
"	11.00 - 12.00 m.	20°.5	13.80	Air
"	12.00 - 1.00 p.m.	20°.3	13.60	Air
"	1.00 - 3.00 "	20°.8	13.50*	Air
"	3.40 - 4.40 "	20°.5	16.60	Oxygen
"	4.40 - 5.40 "	20°.5	19.80	Oxygen
xii. 10. '95	9.30 - 10.30 a.m.	20°	21.40	Air
"	11.00 - 12.00 m.	20°.8	23.40	Oxygen
"	12.00 - 1.00 p.m.	20°.6	21.40	Oxygen
"	1.20 - 3.20 "	20°.5	21.35	Air
"	3.20 - 5.20 "	20°.4	22.00	Air*

* Reduced to value of 1 hour.

EXPERIMENT 9.

8 potatoes, 260 grams. Air- and hydrogen-current as before, 3.5 litres per hour.

Date.	Time.	Temperature.	Medium.	mg. CO ₂ produced per hour.
i. 6. '96	4.00 - 5.00 p.m.	20°·6	Air	2.80
"	5.00 - 7.00 "	20°·6	Hydrogen	3.10
"	7.00 - 9.00 "	20°·4	"	2.00
The potatoes were cut in half, washed as usual, and placed as quickly as possible in an atmosphere of hydrogen. Hydrogen run through apparatus in a strong stream until practically pure.				
i. 7. '96	10.00 - 11.00 a.m.	20°·8	Hydrogen	16.80
"	11.00 - 1.00 p.m.	20°·6	"	13.20*
"	1.00 - 3.15 "	20°·7	"	10.00*
"	3.15 - 4.15 "	20°·5	"	9.00
"	4.15 - 5.15 "	20°·3	"	8.90
"	5.15 - 6.15 "	20°·2	"	8.20
"	6.15 - 7.15 "	20°·7	"	7.90
"	7.15 - 9.15 "	20°·7	"	7.80*
The determinations of Jan. 7 are all in hydrogen, of the following day in air.				
i. 8. '96	10.07 - 12.07 p.m.	20°·8	Air	12.80
"	12.07 - 1.07 "	20°·6	"	14.80
"	1.07 - 3.07 "	20°·4	"	15.80*
"	3.07 - 5.07 "	20°·3	"	15.70
i. 9. '96	10.00 - 11.00 a.m.	20°·4	"	18.30
"	11.00 - 12.00 m.	20°·5	"	20.00
"	12.00 - 1.00 p.m.	20°·4	"	20.40
"	1.00 - 3.00 "	20°·2	"	18.80
"	3.00 - 5.00 "	20°·5	"	18.40*
"	5.00 - 7.00 "	20°·5	"	18.60*
i. 10. '96	11.00 - 1.00 "	20°·4	"	10.30*
"	1.00 - 3.00 "	20°·3	"	11.00*
"	3.00 - 5.00 "	20°·7	"	10.60*
"	5.00 - 7.00 "	20°·5	"	8.40*

* Reduced to value of 1 hour.

EXPERIMENT 10.

8 potatoes, 250 grams. Quartered, washed, and dried. Evacuated under air-pump for half an hour, ran hydrogen in. Current, 3.5 litres per hour.

Date.	Time.	Temperature.	Medium.	mg. CO ₂ produced per hour.
ii. 28. '96	8.20 - 9.20 a.m.	20°.8	Hydrogen	3.60
"	9.20 - 10.20 "	20°.8	"	3.80
"	10.20 - 11.20 "	20°.7	"	3.10
"	11.20 - 12.20 p.m.	20°.5	"	4.20
"	12.20 - 1.20 "	20°.3	"	5.40
"	1.20 - 2.20 "	21°	"	4.60
"	2.20 - 3.30 "	20°.9	"	4.10
"	3.30 - 4.20 "	20°.7	"	3.90
"	4.20 - 5.20 "	20°.7	"	3.20
"	5.20 - 6.20 "	20°.4	Air	4.20
"	6.20 - 7.20 "	20°.3	"	4.50
"	7.20 - 9.20 "	20°.3	"	4.10*
ii. 29. '96	9.10 - 10.10 a.m.	20°.8	Hydrogen †	8.00
"	10.10 - 11.10 "	20°.8	"	8.20
"	11.10 - 12.10 p.m.	20°.7	"	6.00
"	12.10 - 1.10 "	20°.6	"	4.40
"	1.10 - 2.10 "	20°.7	"	4.20
"	2.10 - 3.10 "	20°.7	"	3.80
"	3.10 - 4.10 "	20°.5	"	3.80
"	4.10 - 5.10 "	20°.5	"	4.00
"	5.10 - 6.10 "	20°.4	"	3.60
"	6.10 - 7.10 "	20°.6	Air	5.90
"	7.10 - 9.20 "	20°.3	"	8.70*
iii. 1. '96	8.20 - 9.20 a.m.	20°.8	"	19.20
"	9.20 - 10.20 "	20°.7	"	22.40
"	10.45 - 11.45 "	20°.7	Hydrogen †	10.00
"	11.45 - 12.45 p.m.	20°.4	"	8.10
"	12.45 - 1.45 "	20°.4	"	8.30
"	1.45 - 2.45 "	20°.7	"	7.60
"	2.45 - 3.45 "	20°.6	"	6.30
iii. 2. '96	9.00 - 10.00 a.m.	20°.9	Air	24.60
"	10.00 - 11.00 "	20°.8	"	23.10

* Reduced to value of 1 hour.

† In replacing air by hydrogen the receiver was evacuated under the air-pump several times, and a strong stream of hydrogen run in.

EXPERIMENT 11.

9 potatoes, 300 grams. Respiration in normal condition both in air and 60% oxygen very slight. Quartered, washed, &c. Air 6%, and 4% oxygen, used in this experiment. Current, 3.5 litres per hour.

Date.	Time.	Temperature.	Medium.	mg. CO ₂ produced per hour.
ii. 10. '96	9.10 - 10.10 a.m.	20°·5	6 % Oxygen	24.30
"	10.10 - 11.10 "	20°·5	"	17.60
"	11.10 - 12.10 p.m.	20°·4	"	15.40
"	12.10 - 1.10 "	20°·3	"	12.00
"	1.10 - 2.10 "	20°·6	"	13.00
"	2.10 - 3.10 "	20°·6	"	12.80
"	3.10 - 4.10 "	20°·5	"	12.70
"	4.10 - 5.10 "	20°·3	"	16.00
"	5.10 - 7.10 "	20°·3	"	15.80
"	7.10 - 9.10 "	20°·1	"	18.40*
ii. 11. '96	10.00 - 11.00 a.m.	20°·7	Air	22.40
"	11.00 - 12.00 "	20°·6	"	21.60
"	12.15 - 1.15 p.m.	20°·6	4 % Oxygen†	21.20
"	1.15 - 2.15 "	20°·5	"	22.00
"	2.15 - 3.15 "	20°·5	"	22.40
"	3.15 - 4.15 "	20°·4	"	15.40
"	4.15 - 5.15 "	20°·5	"	15.00
"	5.15 - 6.15 "	20°·3	"	14.80
ii. 12. '96	9.00 - 10.00 a.m.	20°·8	Air	32.80
"	10.00 - 11.00 "	20°·8	"	29.80

* Reduced to value of 1 hour.

† Receiver exhausted three times with 4% oxygen.

EXPERIMENT 12.

5 potatoes, 180 grams. Quartered and washed. Exhausted under air-pump for half an hour; from thence attached receiver at once to Pettenkofer apparatus.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
ii. 13. '96	4.00 – 5.00 p.m.	20°	8.40
"	5.00 – 6.00 "	20°	9.00
"	6.00 – 7.00 "	20°·4	9.25
"	7.00 – 9.00 "	20°·3	9.40
ii. 14. '96	8.20 – 9.20 a.m.	20°·3	9.60
"	6.00 – 7.00 p.m.	20°·6	14.20

EXPERIMENT 13.

7 potatoes, 200 grams. Cut into quarters Feb. 11, 10 a.m.; allowed to stand over a day until the respiration had about reached its maximum. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
ii. 12. '96	8.00 – 9.00 a.m.	20°·8	17.60
"	9.00 – 10.00 "	20°·7	18.00
Cut quarters covered with clay and stuck together.			
ii. 12. '96	12.30 – 1.00 p.m.	20°·4	10.40*
"	1.00 – 3.00 "	20°·4	10.50*
"	3.00 – 4.00 "	20°·9	12.00
"	4.00 – 5.00 "	20°·7	13.40
ii. 13. '96	9.20 – 10.20 a.m.	21°	9.20
"	10.20 – 11.20 "	21°	8.80
Clay removed.			
ii. 13. '96	11.45 – 12.45 p.m.	20°·8	23.20
"	12.45 – 1.45 "	20°·6	19.84
"	1.45 – 2.45 "	20°·5	15.90
"	2.45 – 5.00 "	20°·5	16.20*

* Reduced to value of 1 hour.

EXPERIMENT 14.

5 carrots, 320 grams. Respiration in uninjured condition first determined. The wounds caused by the original gathering of the carrots had completely healed, and to accustom them to the conditions of the laboratory they had in this, as in all subsequent classes, been kept in the room for at least three days before use. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xi. 25. '95	8.25 - 9.25 a.m.	20°·5	18.40
"	9.25 - 10.25 "	20°·5	18.20
Cut carrots into quarters longitudinally. Washed and dried the cut surfaces.			
xi. 55. '95	10.38 - 11.38 a.m.	21°	64.60
"	11.38 - 12.38 p.m.	21°	46.40
"	12.38 - 2.38 "	20°·8	38.95*
The quarters tightly bound together again with soft string.			
xi. 25. '95	3.10 - 4.10 p.m.	20°·6	27.60
"	4.10 - 5.10 "	20°·5	34.20
"	5.10 - 6.10 "	20°·9	42.10
"	6.10 - 7.10 "	20°·7	43.00
xi. 26. '95	9.20 - 10.20 a.m.	20°·9	42.65
"	10.20 - 11.20 "	21°·0	46.10
"	11.20 - 12.20 p.m.	21°·0	51.40
"	12.20 - 1.20 "	20°·8	52.30
"	1.20 - 2.50 "	20°·7	51.90*
"	2.50 - 3.50 "	20°·4	50.10
"	3.50 - 4.50 "	20°·2	45.50
"	4.50 - 5.50 "	20°·8	50.00
"	5.50 - 6.50 "	20°·5	52.80
xi. 27. '95	9.38 - 10.38 a.m.	21°·0	51.40
"	10.38 - 11.38 "	20°·8	50.60
"	12.15 - 1.15 p.m.	20°·7	53.20
"	1.15 - 3.15 "	20°·5	55.00*
"	3.15 - 4.15 "	21°·0	54.10
"	4.15 - 5.15 "	21°·0	52.40
"	5.15 - 6.15 "	20°·8	45.40
xi. 29. '95	11.30 - 12.30 "	20°·6	29.40
"	12.30 - 2.30 "	20°·3	29.20*
xii. 2. '95	12.35 - 2.35 "	21°·0	23.70*

* Reduced to value of 1 hour.

EXPERIMENT 15.

4 carrots, 280 grams. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xii. 30. '95	3.00 - 4.00 p.m.	21°	17.40
"	4.00 - 5.00 "	22°	18.20
"	5.00 - 6.00 "	20°.8	17.30
Each carrot cut in quarters longitudinally. Washed and dried.			
xii. 31. '95	8.00 - 9.00 a.m.	21°	56.60
"	9.00 - 10.00 "	20°.7	43.40
"	10.00 - 11.00 "	20°.6	33.70
"	11.00 - 12.00 m.	20°.6	34.10
"	12.00 - 1.00 p.m.	20°.5	36.50
"	1.00 - 2.00 "	20°.4	34.40
"	2.00 - 3.00 "	21°.0	38.20
"	3.00 - 4.00 "	20°.8	38.40
"	4.00 - 5.00 "	20°.8	40.70
"	5.00 - 6.00 "	20°.7	41.00
"	6.00 - 7.00 "	20°.4	40.80
"	7.00 - 9.00 "	20°.4	42.60*
i. 1. '96	10.30 - 11.30 a.m.	21°.0	51.10
"	11.30 - 12.30 p.m.	21°.0	53.40
"	12.30 - 2.00 "	20°.7	53.80*
"	2.00 - 3.00 "	20°.7	55.30
"	3.00 - 4.00 "	20°.8	57.10
"	4.00 - 5.00 "	20°.6	57.00
"	5.00 - 6.00 "	20°.5	55.40
i. 2. '96	9.10 - 10.10 a.m.	20°.9	59.70
"	10.10 - 11.10 "	20°.8	62.40
"	11.10 - 12.10 p.m.	20°.8	58.25
"	12.10 - 1.10 "	20°.5	56.10
"	1.10 - 3.10 "	20°.3	53.70*
i. 3. '96	8.30 - 9.30 a.m.	21°	42.50
i. 4. '96	5.00 - 6.00 "	20°.7	29.70
i. 6. '96	9.15 - 10.15 "	21°	26.40
i. 10. '96	9.05 - 10.05 "	21°	21.20

* Reduced to value of 1 hour.

EXPERIMENT 16.

4 carrots, 300 grams. From same lot as carrots used in previous experiment. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xi. 30. '95	8.15 - 9.15 a.m.	21°	20.20
„	9.15 - 10.15 „	21°	19.60
Cut in five pieces transversely.			
xi. 30. '95	10.45 - 11.45 a.m.	21°	29.4
„	11.45 - 12.45 p.m.	20°·7	23.0
Cut surfaces covered with clay.			
xi. 30. '95	2.30 - 3.30 p.m.	20°·5	20.15
„	3.30 - 4.30 „	21°	22.60
„	4.30 - 5.30 „	21°	23.80
xii. 1. '95	10.30 - 11.30 a.m.	21°	21.00
„	11.30 - 12.30 p.m.	20°·8	24.40
xii. 2. '95	8.57 - 9.57 a.m.	20°·7	18.00
Clay removed.			
xii. 2. '95	10.25 - 11.25 a.m.	20°·8	30.00
„	11.25 - 12.25 p.m.	20°·4	25.20
xii. 5. '95	6.00 - 7.00 „	20°·3	24.40
xii. 12. '95	9.30 - 10.30 a.m.	21°	17.80

EXPERIMENT 17.

4 carrots, 290 grams. As in previous experiment. Air-current, 3.5 litres per hour. Cut in five transversely, and at once covered cut surfaces with clay.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xii. 12. '95	9.30 – 10.30 a.m.	20°.8	20.30
"	10.30 – 11.30 "	20°.6	21.35
"	11.30 – 12.30 p.m.	20°.6	22.60
"	12.30 – 2.30 "	20°.4	22.10*
"	2.30 – 3.30 "	20°.5	24.00
xii. 13. '95	9.30 – 10.30 a.m.	20°.8	20.00
xii. 14. '95	4.00 – 5.00 p.m.	20°.2	19.30
Clay removed.			
xii. 14. '95	5.00 – 6.00 p.m.	20°.6	35.20
"	6.00 – 7.00 "	20°.5	32.00
"	7.00 – 9.00 "	20°.5	33.40*
xii. 15. '95	10.10 – 12.10 "	21°	25.35
xii. 18. '95	6.10 – 7.00 "	20°.7	17.50

EXPERIMENT 18.

4 carrots, 290 grams. To determine if respiration increases with increase of injury. Air-current, 3.5 litres per hour. Cut in three pieces transversely.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xi. 16. '95	1.00 – 3.00 p.m.	20°.5	20.20*
"	3.00 – 4.00 "	20°.5	21.00
"	4.00 – 5.30 "	20°.4	22.80*
Cut each piece in four longitudinally.			
xi. 17. '95	10.52 – 11.52 a.m.	20°.2	28.80
"	11.52 – 12.52 p.m.	19°.7	27.80
"	12.52 – 2.52 "	20°.6	29.50*
"	5.20 – 6.20 "	20°.5	32.40

* Reduced to value of 1 hour.

EXPERIMENT 19.

3 carrots, 200 grams. Quartered each longitudinally, placed under air-pump for three quarters of an hour. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
ii. 14. '96	3.00 - 4.00 p.m.	21°	27.30
"	4.00 - 5.00 "	20°·8	28.00
"	5.00 - 6.00 "	20°·8	29.20
"	6.00 - 7.00 "	20°·6	29.40
"	7.00 - 9.00 "	20°·5	31.90*

EXPERIMENT 20.

4 carrots, 260 grams. Mode of operation as in the experiments with potatoes in which hydrogen was employed. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	Medium.	mg. CO ₂ produced per hour.
i. 3. '96	10.10 - 11.10 a.m.	20°·0	Air	18.80
"	12.20 - 1.20 p.m.	20°·0	Hydrogen	21.00
"	1.20 - 3.20 "	19°·9	"	19.60
"	3.20 - 4.20 "	20°·6	"	19.20
"	4.20 - 5.20 "	20°·6	Air	15.80
"	5.20 - 6.20 "	20°·5	"	19.40
Each carrot cut longitudinally in quarters, Jan. 3, 6.30 p.m.				
i. 4. '96	9.22 - 10.22 a.m.	20°·8	Air	33.60
"	10.22 - 11.22 "	20°·8	Hydrogen	31.80
"	11.22 - 12.22 p.m.	20°·6	"	33.40
"	12.22 - 2.30 "	20°·5	"	32.60*
"	2.30 - 3.30 "	20°·4	"	32.80
"	3.30 - 4.30 "	20°·3	"	30.20
"	4.30 - 5.30 "	20°·9	"	24.30
"	5.30 - 6.30 "	20°·7	"	21.20

* Reduced to value of 1 hour.

EXPERIMENT 21.

3 carrots, 270 grams. Quartered each longitudinally, and put as soon as possible in an atmosphere of 4% oxygen.

Date.	Time.	Temperature.	Medium.	mg. CO ₂ produced per hour.
ii. 14. '96	9.05 – 10.05 a.m.	20°·3	4% O.	52.40
„	10.05 – 11.05 „	20°·3	„	40.80
„	11.05 – 12.05 p.m.	20°·3	„	32.00
„	12.05 – 1.05 „	20°·2	„	28.60
„	1.05 – 2.05 „	20°·1	„	27.30
„	2.05 – 3.05 „	20°·1	„	27.65
„	3.05 – 4.05 „	20°·0	„	28.30
„	4.05 – 5.05 „	19°·9	Air	29.00
„	5.05 – 6.05 „	19°·9	„	29.20
„	6.05 – 7.05 „	19°·6	„	29.20
„	7.05 – 9.05 „	19°·6	„	29.80*
ii. 15. '96	9.35 – 10.35 a.m.	20°·4	4% O.	32.00
„	10.45 – 11.15 „	20°·4	„	32.80*
„	11.15 – 12.15 p.m.	20°·4	„	34.20
„	12.15 – 1.15 „	20°·3	„	32.00
„	1.15 – 2.15 „	20°·3	„	28.40
„	2.15 – 3.15 „	20°·2	„	26.20
„	3.15 – 4.15 „	20°·6	„	28.40
„	4.15 – 5.15 „	20°·5	„	25.60
„	5.15 – 6.25 „	20°·5	„	24.00*
ii. 16. '96	10.00 – 11.00 „	20°·3	Air	34.00

* Reduced to value of 1 hour.

EXPERIMENT 21 a.

3 carrots, 330 grams. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	Medium.	mg. CO ₂ produced per hour.
xii. 6. '95	10.35 - 11.35 a.m.	20°	Air	15.2
Ran for 40 min. in oxygen current.				
xii. 6. '95	12.15 - 1.15 p.m.	20°	Oxygen	15.4
Cut carrots in quarters longitudinally.				
xii. 6. '95	1.20 - 2.20 p.m.	20°·7	Air	55.6
„	2.20 - 3.20 „	20°·6	„	32.6
„	3.20 - 4.20 „	20°·6	„	28.8
Ran for 45 min. in oxygen current.				
xii. 6. '95	5.00 - 6.00 p.m.	20°·5	Oxygen	28.4
„	6.00 - 7.00 „	20°·7	„	31.5
Ran in an air-current overnight.				
xii. 7. '95	8.45 - 9.45 p.m.	20°·5	Air	38.4
Ran for some time in oxygen.				
xii. 7. '95	10.15 - 11.15 a.m.	20°·5	Oxygen	36.4

EXPERIMENT 22.

4 red beets (*Beta vulgaris*), 250 grams. Had been in laboratory four days before use. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xii. 4. '95	9.05 - 10.05 a.m.	20°	7.80
„	10.05 - 11.05 „	20°	8.30
Quartered longitudinally. Pieces washed and dried.			
xii. 4. '95	11.35 - 12.35 p.m.	20°	18.20
„	2.35 - 3.35 „	20°·3	17.00
„	5.00 - 6.00 „	20°·5	15.10
xii. 5. '95	6.00 - 7.00 a.m.	20°·9	16.70
„	9.10 - 10.10 „	21°·0	21.50
„	10.10 - 11.40 „	21°·0	27.10*
„	11.40 - 12.40 p.m.	20°·8	22.60
„	12.40 - 2.40 „	20°·7	23.60*
„	2.40 - 3.40 „	20°·5	22.80
„	3.40 - 4.40 „	20°·5	23.40
„	4.40 - 5.40 „	20°·3	22.20
xii. 7. '95	12.10 - 1.10 „	20°·5	14.80
„	1.10 - 3.10 „	20°·3	14.60
xii. 8. '95	10.35 - 11.35 a.m.	20°·8	14.00
„	11.35 - 12.35 p.m.	20°·8	15.30
xii. 9. '95	5.35 - 7.00 „	21°	10.60*
xii. 12. '95	12.30 - 2.30 „	20°·6	10.40*

* Reduced to value of 1 hour.

EXPERIMENT 23.

2 sugar beets (*Beta vulgaris*, var.), 300 grams. Had been in laboratory three days before use. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xii. 18. '95	10.30 - 11.30 a.m.	20°·7	16.40
"	11.30 - 12.30 p.m.	20°·6	17.00
Cut each beet in four longitudinally. Washed and dried cut surfaces.			
xii. 18. '95	1.30 - 3.30 p.m.	20°·5	30.20
"	3.30 - 4.30 "	20°·5	22.16
"	4.30 - 5.30 "	20°·5	26.40
xii. 19. '95	10.30 - 11.30 a.m.	21°·0	31.20
"	11.30 - 1.00 p.m.	20°·6	28.30
"	1.00 - 2.30 "	20°·5	28.30
"	2.30 - 3.30 "	20°·3	24.60
"	3.30 - 4.30 "	20°·7	24.40
xii. 20. '95	8.30 - 9.30 a.m.	21°·0	21.00
"	9.30 - 10.30 "	20°·6	21.00
"	10.30 - 11.30 "	20°·5	21.40
xii. 22. '95	10.00 - 11.00 "	20°·3	17.40

EXPERIMENT 24.

48 young seedlings of *Vicia Faba*. Hypocotyls from 2-4 cm. long. Weight, 110 grams. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
i. 11. '96	9.35 - 10.35 a.m.	20°·5	20.00
"	10.35 - 11.35 "	20°·4	19.60
Hypocotyls split into shreds lengthwise without severing their connexion with the cotyledons.			
i. 11. '96	12.17 - 1.17 p.m.	20°·3	25.20
"	1.17 - 2.17 "	20°·3	31.00
"	2.17 - 3.17 "	20°·3	35.00
"	3.17 - 4.17 "	20°·2	36.40
"	4.17 - 5.17 "	20°·0	36.60
i. 12. '96	10.30 - 11.30 "	20°·6	39.40
"	11.30 - 12.30 p.m.	20°·6	39.60
i. 13. '96	12.00 - 1.00 "	20°·4	24.90
"	1.00 - 3.00 "	20°·9	22.80*
"	3.00 - 4.00 "	20°·6	22.20
"	4.00 - 6.00 "	20°·6	22.30*

* Reduced to value of 1 hour.

EXPERIMENT 25.

40 young seedlings of *Vicia Faba*. Hypocotyls from 1.5–3 cm. long. Weight, 80 grams. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
i. 17. '96	10.30 – 11.30 a.m.	20°·5	14.20
"	11.30 – 12.30 p.m.	20°·4	14.30
Hypocotyls split into two longitudinally without severing their connexion with the cotyledons.			
i. 17. '96	1.15 – 3.15 p.m.	20°·00	15.60
"	3.15 – 4.15 "	19°·50	15.60
"	4.15 – 5.15 "	19°·40	16.10
"	5.15 – 6.15 "	19°·40	17.30
"	6.15 – 8.15 "	19°·60	20.00*
i. 18. '96	9.05 – 10.05 a.m.	20°·50	21.00
"	10.05 – 11.05 "	20°·40	21.00
"	11.05 – 12.05 p.m.	20°·30	22.10
"	12.05 – 1.05 "	20°·80	23.20
"	1.05 – 3.05 "	20°·60	27.10*
i. 19. '96	5.00 – 6.00 "	20°·60	13.20

EXPERIMENT 26.

45 young seedlings of *Vicia Faba*. Hypocotyls from 1–3 cm. long. Weight, 100 grams. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
i. 31. '96	9.10 – 10.10 a.m.	20°·7	29.00
"	10.10 – 11.10 "	20°·6	30.00
About 1–2 millimetres cut off of the growing tips of the roots.			
i. '96	12.00 – 1.00 p.m.	20°·6	32.70
"	1.00 – 3.10 "	20°·5	33.20*
"	3.10 – 4.10 "	20°·8	36.40
"	4.10 – 5.10 "	20°·7	39.20
"	5.10 – 6.10 "	20°·4	42.00
ii. 1. '96	10.00 – 11.00 a.m.	20°·4	33.20
"	11.00 – 12.00 m.	20°·7	32.80
"	12.00 – 1.00 p.m.	20°·7	32.40
"	1.00 – 2.00 "	20°·6	32.00
"	2.00 – 3.00 "	20°·4	31.20
"	3.00 – 4.00 "	20°·8	29.40
"	4.00 – 5.00 "	20°·7	30.00

* Reduced to value of 1 hour.

EXPERIMENT 27.

82 seedlings of *Cucurbita Pepo*. Hypocotyls from 2-3 cm. long. Weight, 37 grams. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
i. 19. '96	9.35 - 10.35 a.m.	20°·6	15·40
"	10.35 - 11.35 "	20°·5	16·00
The entire hypocotyl, so far as possible, split longitudinally.			
i. 19. '96	12.10 - 1.10 p.m.	20°·3	16·00
"	1.10 - 3.10 "	20°·7	16·00*
"	3.10 - 4.10 "	20°·7	16·20
"	4.10 - 5.10 "	20°·6	16·40
"	5.10 - 6.10 "	20°·6	16·80
i. 20. '96	9.55 - 11.55 "	20°·4	16·40*
"	11.55 - 12.55 "	20°·8	22·00
"	12.55 - 2.55 "	20°·8	22·20
"	2.55 - 4.55 "	20°·6	21·00
"	4.55 - 6.55 "	20°·5	26·35*
i. 21. '96	10.00 - 11.00 a.m.	21°·0	19·10
i. 22. '96	10.00 - 11.00 "	20°·7	15·70

EXPERIMENT 28.

50 young leaves of *Rhododendron calophyllum* from greenhouse. Weight, 90 grams. In dark. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
xi. 9. '95	10.15 - 11.15 a.m.	20°·6	3·20
"	11.15 - 12.15 "	20°·4	3·60
Leaves cut transversely in thin strip about .5 cm. wide.			
xi. 9. '95	3.10 - 4.10 p.m.	20°·3	6·60
"	4.10 - 5.10 "	20°·7	7·20
"	5.10 - 6.10 "	20°·5	7·10
xi. 10. '95	11.00 - 12.00 m.	20°·5	4·20

* Reduced to value of 1 hour.

EXPERIMENT 29.

7 young shoots of *Veronica speciosa* with about 80 leaves. Weight, 50 grams. Growing in green-house at temperature of 17°–20°. In dark. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
i. 27. '96	12.00 – 1.00 p.m.	20°·4	7.60
„	1.00 – 3.00 „	20°·6	8.20
Leaves split four or five times longitudinally, but still remaining on petioles.			
i. 27. '96	4.00 – 5.00 p.m.	20°·4	16.20
„	5.00 – 6.00 „	20°·4	19.00
„	6.00 – 7.00 „	20°·3	15.80
i. 28. '96	9.00 – 10.00 a.m.	20°·8	10.30

EXPERIMENT 30.

8 young shoots of *Veronica speciosa* with about 95 leaves. Weight, 53 grams. In dark. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
i. 30. '96	9.30 – 10.30 a.m.	20°·6	7.60
„	9.30 – 10.30 „	20°·5	7.80
Leaves split in four or five strips longitudinally, but still remaining on petioles.			
i. 30. '96	11.00 – 12.00 m.	20°·7	14.20
„	12.00 – 1.00 p.m.	20°·4	16.00
„	1.00 – 2.00 „	20°·3	15.00
„	2.00 – 3.00 „	20°·8	11.00
ii. 1. '96	8.30 – 9.30 „	20°·8	8.60

EXPERIMENT 31.

52 grams of young leaves of *Viburnum odoratissimum* from green-house, the temperature of which was about 18°–20°. Light excluded from receiver. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
ii. 3. '96	10.37 – 11.37 a.m.	20°.4	11.40
"	11.37 – 12.37 p.m.	20°.4	12.00
Leaves slit four or five times longitudinally, but pieces not actually separated.			
ii. 3. '96	1.10 – 2.10 p.m.	20°.2	16.00
"	2.10 – 3.10 "	20°.2	17.20
"	3.10 – 4.10 "	20°.5	15.40
"	4.10 – 5.10 "	20°.4	15.40
ii. 4. '96	11.00 – 12.00 m.	20°.6	12.00
"	4.00 – 5.00 p.m.	20°.6	12.00

EXPERIMENT 32.

50 grams of leaves of *Acacia lophocantha*, growing in green-house at temperature of about 25°. In dark. Air-current, 3.5 litres per hour. Determination first made of respiration excited by injury due to removal from stem.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
ii. 24. '96	10.00 – 11.00 a.m.	20°.3	14.00
"	11.00 – 12.00 m.	20°.3	15.60
"	12.00 – 1.00 p.m.	20°.2	15.80
"	1.00 – 2.00 "	20°.2	15.30
"	2.00 – 3.00 "	20°.5	18.00
"	3.00 – 4.00 "	20°.5	17.20
"	4.00 – 5.00 "	20°.4	16.40
"	5.00 – 6.00 "	20°.2	15.60
"	6.00 – 7.00 "	20°.2	15.40
Pinnae cut off and main stem of leaf cut in pieces.			
ii. 25. '96	10.10 – 11.10 a.m.	20°.4	17.00
"	11.10 – 12.10 p.m.	20°.4	19.00
"	12.10 – 1.10 "	20°.3	17.80
"	1.10 – 3.10 "	20°.2	16.00*
"	3.10 – 4.10 "	20°.5	14.80
Cut pinnules off and cut petioles lengthwise.			
ii. 25. '96	5.10 – 6.10 p.m.	20°.2	24.40
"	6.10 – 7.10 "	20°.0	24.80
"	7.10 – 9.10 "	20°.4	21.30*

* Reduced to value of 1 hour.

EXPERIMENT 33.

60 grams of twigs of *Salix alba* in pieces about 10 cm. long. Had been gathered in the open, and kept in laboratory nine days before the determinations were made. Air-current, 3.5 litres per hour.

Date.	Time.	Temperature.	mg. CO ₂ produced per hour.
i. 23. '96	8.55 - 9.55 a.m.	20°.8	11.40
"	9.55 - 10.55 "	20°.6	12.80
"	10.55 - 11.55 "	20°.6	12.10
Twigs split longitudinally in several pieces.			
i. 23. '96	1.30 - 2.30 p.m.	20°.4	17.30
"	2.30 - 3.30 "	20°.8	17.80
"	3.30 - 4.30 "	20°.4	17.40
"	4.30 - 5.30 "	20°.3	17.20
"	5.30 - 6.30 "	20°.2	17.20
"	6.30 - 8.00 "	20°.3	17.60*
i. 24. '96	11.07 - 12.07 "	20°.6	17.00
"	12.07 - 1.07 "	20°.5	18.10
"	1.07 - 3.07 "	20°.4	19.50*
"	3.07 - 5.07 "	20°.2	16.80*
i. 27. '96	9.15 - 11.15 a.m.	20°.2	16.90*

* Reduced to value of 1 hour.

B.

In the experiments made to determine the relation between the amount of CO₂ produced and of O₂ absorbed, the time interval was always two hours. The apparatus used and the method of analysis of the air has already been described¹. For the purpose of these experiments the air of the laboratory was perfectly pure, containing but a bare trace of CO₂. The amount of O₂ in the air is taken in the following tables at

¹ See this paper, page 534 et seq.

the round figure of 20.8 %. The amount of O_2 absorbed by the plants is calculated by the diminution in per cent. contained in the air in receiver at close of experiment, as given in the tables below.

	Capacity of receiver, cc.	Temp.	Volume of air taken.	CO_2 absorbed by KOH.	O_2 absorbed by Pyrogallol.	% CO_2 produced.	% O_2 absorbed by plants.	CO_2 O_2
EXPERIMENT 34.								
4 potatoes, 150 grms. 130 cc. } Uninjured. i. 18. '96, 8.45-10.45 a.m. }	700	19°·6	53·30	·30	10·65	·60	·80	·75
Same, i. 18. '96, 10.45-12.45 p.m. }	„	19°·4	58·50	·40	11·60	·70	1·00	·70
Same, quartered at 1 p.m. } i. 18. '96, 3-5 p.m. }	„	19°·6	55·20	1·05	10·20	1·95	2·40	·81
Same, i. 19. '96, 9.30-11.30 a.m. }	„	19°·7	51·30	1·20	9·25	2·35	2·75	·85
EXPERIMENT 35.								
8 potatoes, 200 grms. 190 cc. } Uninjured. i. 24. '96, 10-12 m. }	700	19°·8	53·40	·20	10·50	·40	1·10	·36
Same, i. 24. '96, 1-3 p.m. }	„	19°·6	53·80	·30	10·60	·56	1·10	·50
Same, quartered, washed, &c. } i. 24. '96, 5.15-7.15 p.m. }	„	19°·2	51·30	·80	9·40	1·55	2·50	·62
Same, i. 25. '96, 1-3 p.m. }	„	19°·7	54·30	1·40	9·60	2·60	3·10	·84
Same, i. 25. '96, 3.05-5.05 p.m. }	„	20°	54·80	1·30	9·90	2·35	2·70	·87
EXPERIMENT 36.								
(a) 8 potatoes, 195 grms. 180 cc. } Uninjured. i. 30. '96, 9.30-11.30 a.m. }	800	20°.	54·40	·20	10·90	·37	·80	·46
(b) Quartered at 12 m. First determination, i. 30. '96, } 3.10-5.10 p.m. }	„	20°	50·30	·90	9·30	1·8	2·40	·75
(c) Same, i. 3. '96, 9.30-11.30 a.m. }	„	20°·2	52·90	1·20	9·40	2·27	3·00	·76
(d) Same, i. 31. '96, 1-3 p.m. }	„	20°·1	53·80	1·50	9·30	2·8	3·50	·80
(e) Same, ii. 3. '96, 1-3 p.m. }	„	20°	54·10	1·10	9·80	2·05	2·65	·77
EXPERIMENT 37.								
(a) 8 potatoes, 200 grms. 190 cc. } Uninjured. ii. 3. '96, 8.50-9.50 a.m. }	700	20°·3	52·50	·25	10·35	·50	1·10	·45
(b) Same, quartered; determina- tion made at once; ii. 3. '96, } 11-1 p.m. }	„	20°·1	54·90	1·20	10·10	2·20	2·00	1·10
(c) Same, ii. 3. '96, 3.20-5.20 p.m. }	„	20°·3	54·50	1·00	9·85	1·83	2·70	·68
(d) Same, ii. 4. '96, 11-1 p.m. }	„	20°·2	54·60	1·40	9·60	2·56	3·20	·80
(e) Same, ii. 6. '96, 11-1 p.m. }	„	20°·0	54·20	1·20	9·65	2·20	2·95	·75

	Capacity of receiver, cc.	Temp.	Volume of air taken.	CO ₂ absorbed by KOH.	CO ₂ absorbed by Pyrogallol.	% CO ₂ produced.	% O ₂ absorbed by plants.	CO ₂ / O ₂
EXPERIMENT 38.								
6 potatoes, 200 grms. 190 cc. } Uninjured. ii. 5. '96, 8.20-10.20 a.m. }	700	20°·2	53·00	·30	10·50	·56	1·00	·56
Same, quartered; determination made at once, ii. 5. '96, 10.30-12.30 p.m. }	"	20°·3	53·90	1·20	9·60	2·22	3·00	·73
Same, ii. 5. '96, 1-3 p.m. }	"	20°·2	51·75	·75	9·40	1·45	2·65	·54
Same, ii. 5. '96, 3.10-5.10 p.m. }	"	20°·2	52·00	·90	9·20	1·80	3·10	·60
Same, ii. 6. '96, 1-3 p.m. }	"	20°·6	53·80	1·20	9·40	2·25	3·30	·68
Same, ii. 9. '96, 9-11 a.m. }	"	20°·2	51·10	1·00	9·15	1·95	2·90	·67
EXPERIMENT 39.								
7 potatoes, 205 grms. 180 cc. } Uninjured. i. 7. '96, 1-3 p.m. }	800	20°·4	53·30	·30	10·60	·56	·90	·62
Same current of O ₂ run through apparatus until almost pure. }	"							
i. 28. '96, 9.45 a.m. Analysis of gas in receiver. }	"		52·00		50·90		97·90 ¹	
i. 28. '96, 9.45-11.45 a.m. in O ₂ }	"	20°·2	54·00	·30	52·40	·55	·90	·61
Same, quartered, washed, and dried, in air, i. 28. '96, 1.30-3.30 p.m. }	"	20°·1	53·80	·90	10·00	1·68	2·20	·77
Same, ran O ₂ through. Analysis of air in receiver, i. 28. '96, 3.55 p.m. }	"		52·30		51·20		98·10 ¹	
i. 28. '96, 3.55-5.55 p.m. in O ₂ }	"	20°·2	54·60	·90	52·30	16·5	2·30	·72
Same in air, i. 29. '96, 1-3 p.m. }	"	20°·0	54·80	1·10	9·60	2·55	3·30	·77
Same, ran O ₂ through. Analysis of air in receiver, i. 29. '96, 4 p.m. }	"		57·00		49·10		86·20 ¹	
i. 29. '96, 4-6 p.m. in O ₂ }	"	20°·3	56·00	1·35	46·40	2·40	3·30	·73
EXPERIMENT 40.								
2 carrots (<i>Daucus Carota</i>), 150 grms. 150 cc. Uninjured. i. 27. '96, 9.20-11.20 a.m. }	700	20°	54·10	·70	10·30	1·30	1·75	·75
Same, at 12 m. cut longitudinally into quarters. i. 27. '96, 3.30-5.30 p.m. }	"	20°	55·00	1·00	10·00	1·80	2·60	·70
Same, i. 28. '96, 9.30-11.30 a.m. }	"	20°	53·70	1·10	9·60	2·05	2·90	·71
Same, i. 28. '96, 3.10-5.10 p.m. }	"	20°	52·50	1·30	8·90	2·48	3·80	·65
EXPERIMENT 41.								
2 carrots (<i>Daucus Carota</i>), 150 grms. 150 cc. Uninjured. ii. i. '96, 10.40-12.40 p.m. }	700	20°·3	51·10	·70	9·70	1·35	1·8	·75
Same; quartered longitudinally. Determination at once. ii. i. '96, 12.50-2.50 p.m. }	"	20°·2	56·80	1·30	10·40	2·30	2·5	·92
Same, ii. i. '96, 2.55-4.55 p.m. }	"	20°·3	50·75	·90	9·15	1·77	2·75	·65
Same, ii. i. '96, 10-12 m. }	"	20°·2	54·90	1·40	9·40	2·55	3·70	·69

¹ % O in receiver at beginning of experiment.

	Capacity of receiver, cc.	Temp.	Volume of air taken.	CO ₂ absorbed by KOH.	O ₂ absorbed by Pyrogallol.	% CO ₂ produced.	% O ₂ absorbed by plants.	CO ₂ / O ₂
EXPERIMENT 42.								
(a) 13 carrots (<i>Daucus Carota</i>), 165 grms. 160 cc. Uninjured. } ii. 14. '96, 10.50-12.50 p.m. }	700	20°.1	52.70	.90	9.70	1.70	2.40	.71
(b) Same, quartered longitudi- nally; determination at once. } ii. 14. '96, 1-3 p.m. }	"	20°.2	56.60	2.10	9.60	3.70	3.80	.97
(c) Same, ii. 14. '96, 3.05-5.05 p.m.	"	20°.2	55.10	1.30	9.50	2.35	3.60	.65
(d) Same, ii. 14. '96, 7.05-9.05 p.m.	"	20°.1	54.20	2.00	8.40	3.10	5.30	.70
(e) Same, ii. 15. '96, 3.15-5.15 p.m.	"	20°.2	51.10	2.45	7.35	4.80	6.40	.75
(f) Same, ii. 16. '96, 10-12 m.	"	20°.3	51.00	1.50	8.50	2.95	4.20	.70
EXPERIMENT 43.								
2 carrots (<i>Daucus Carota</i>), 150 grms. 150 cc. Uninjured. ii. } 18. '96, 8.45-10.45 a.m. }	700	20°.3	54.50	.70	10.30	1.25	1.90	.66
Same, quartered longitudinally; determination at once. ii. 18. } '96, 10.55-12.55 p.m. }	"	20°.2	56.40	1.60	9.90	2.85	3.25	.88
Same, ii. 18. '96, 1-3 p.m.	"	20°.2	53.50	1.10	9.40	2.05	3.25	.63
Same, ii. 18. '96, 3.05-5.05 p.m.	"	20°.1	57.10	1.50	9.80	2.65	3.30	.70
Same, ii. 19. '96, 2-4 p.m.	"	20°.4	53.50	1.20	9.60	2.24	2.90	.77
Same, ii. 20. '96, 10-12 m.	"	20°.1	52.20	.90	9.60	1.72	2.40	.72
EXPERIMENT 44.								
45 young seedlings <i>Vicia Faba</i> , hypocotyls 2-3 cm. long, 100 gm. 20 cc. Uninjured. ii. 3. } '96, 9.30-11.30 a.m. }	800	20°.4	53.60	1.00	9.20	1.86	3.60	.52
Same, root tips cut off, ii. 3. '96, } 3.25-5.25 p.m. }	"	20°.2	55.10	1.20	9.70	2.20	3.20	.69
Same, ii. 4. '96, 9.45-11.45 a.m.	"	20°	57.70	1.60	9.80	2.77	3.80	.73
Same, ii. 4. '96, 4-6 p.m.	"	20°.3	57.50	1.40	10.00	2.45	3.55	.69
EXPERIMENT 45.								
42 young seedlings <i>Vicia Faba</i> , hypocotyls 2-3 cm. long, 100 grms. 100 cc., ii. 7. '96, 8.50- 10.50 a.m. }	700	20°.2	55.80	1.20	9.40	2.15	3.95	.55
Same, root tips cut off, ii. 7. '96, } 11-1 p.m. }	"	20°.1	55.20	1.50	9.10	2.72	4.30	.63
Same, ii. 7. '96, 1.10-3.10 p.m.	"	20°.3	52.20	1.50	8.70	2.90	4.10	.71
Same, ii. 7. '96, 4.10-6.10 p.m.	"	20°.2	52.00	1.50	8.60	2.90	4.20	.70
Same, ii. 8. '96, 10.30-12.30 p.m.	"	20°.3	55.40	1.00	9.70	1.80	3.30	.55

	Capacity of receiver, cc.	Temp.	Volume of air taken.	CO ₂ absorbed by KOH.	O ₂ absorbed by pyrogallol.	% CO ₂ produced.	% O ₂ absorbed by plants.	CO ₂ / O ₂
EXPERIMENT 46.								
45 young seedlings <i>Vicia Faba</i> , hypocotyls 3-5 cm. long, 100 grms. 97 cc. Uninjured. ii. 10. '96, 10.40-12.40 p.m. }	800	20° 0	53.70	1.00	9.15	1.87	3.80	.49
Same, roots transversely cut but not completely divided, ii. 10. '96, 1-3 p.m. }	"	20° 2	50.80	1.30	8.60	2.55	3.90	.65
Same, ii. 10. '96, 4-6 p.m.	"	20° 3	53.10	1.50	8.90	2.80	4.05	.71
Same, ii. 10. '96, 7-9 p.m.	"	20° 0	57.30	1.80	9.50	3.15	4.40	.72
Same, ii. 11. '96, 1-3 p.m.	"	20° 3	54.70	1.50	9.20	2.90	3.95	.73
EXPERIMENT 47.								
7 shoots <i>Veronica speciosa</i> ; about 130 leaves, 47 grms. 50 cc. Uninjured. i. 30. '96, 11- 1 p.m. }	800	20° 0	54.40	.80	10.10	1.50	2.25	.66
Same, leaves and buds cut length- wise, i. 30. '96, 4.10-6.10 p.m. }	"	20° 0	54.20	1.20	9.70	2.20	2.90	.76
Same, i. 31. '96, 10-12 a.m.	"	20° 0	56.60	1.10	10.20	1.95	2.80	.70
EXPERIMENT 48.								
7 shoots <i>Veronica speciosa</i> ; about 140 leaves, 50 grms. 50 cc. Uninjured. ii. 12. '96, 10- 12 p.m. }	800	20° 2	55.80	.50	10.50	.90	2.00	.45
Same, ii. 12. '96, 1-3 p.m.	"	20° 1	53.00	.70	10.00	1.30	1.90	.68
Same, ii. 13. '96, 10-12 p.m.	"	20° 3	51.20	.30	10.10	.60	1.10	.55

C.

Experiments to determine amount of CO_2 contained in living potatoes and carrots. Driven off by boiling water and determined in Pfeffer-Pettenkofer apparatus.

With Potatoes.			
		Weight objects.	mg. CO_2
EXPT. A.	3 potatoes	66 grams	36.0
„ B.	3 „	56 „	32.0
„ C.	5 „	105 „	61.2
„ D.	3 „	60 „	27.8
Average CO_2 per gram 5.5 mg.			
With Carrots (<i>Daucus Carota</i>).			
EXPT. E.	2 carrots	102 grams	38.0
„ F.	1 „	95 „	34.4
„ G.	2 „	101 „	46.8
Average CO_2 per gram 3.7 mg.

Woodcut 3.

I. Respiration-curve of Potato, cut, and allowed to run its normal course. See Experiment 1. II. Same, but cut surfaces covered with clay which was removed during the fifth day. See Experiment 7. III. Normal curve of injured Carrot. See Experiment 15. IV. Curve showing result of covering cut surfaces with clay as in II. See Experiment 17. V. Normal curve of injured seedlings (*Vicia Faba*). See Experiment 24. VI. Normal curve of injured leaf (*Veronica speciosa*). See Experiment 30. On the horizontal the days are numbered, beginning from time of injury. Before Zero is given the respiration in the uninjured condition. On the perpendicular the number of mg. CO₂ per hour are given.

Richards, Herbert M. 1896. "The respiration of wounded plants." *Annals of botany* 10, 531–582. <https://doi.org/10.1093/oxfordjournals.aob.a088626>.

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