An experimental inquiry into the cause of the ascent and descent of the sap : with some observations upon the nutrition of plants, and the cause of endosmose and exosmose / by G. Rainey.

AN

EXPERIMENTAL INQUIRY,

&c.

PREFACE.

THE series of experiments described in the following pages, were commenced as early as 1840. A short account of some of the experiments relative to the tissue occupied by the crude sap in its ascent and diffusion in plants, as well as some observations upon the descent of the elaborated fluid, were communicated to the Royal Society in 1842; but the principal part of the experiments therein recorded have been performed since that period. After the manuscript of this Essay had been placed in the hands of the printer, my attention was directed to some observations in one of the publications of the Ray Society, purporting to be an account of my views upon the ascent of the sap. These observations appear to be founded upon the abstracts of some papers read at the Royal Society, and printed in the Annals of Natural History, vol. xi, p. 383. Not having seen these abstracts, I am unable to judge how far the report given of them in the above Journal agrees with the abstracts themselves; suffice it to say, that neither the experiment of steeping thin slices of a plant in a solution of the Bichloride of Mercury, and then decomposing this substance by the Iodide of Potassium, nor the opinions therein attributed to me, as to the cause of the ascent of the sap, form any part of the original papers. My mode of experimenting being now detailed in this Essay, as well as the opinions which I have deduced from them, any further remarks upon the subject of these abstracts must be unnecessary.

As some of the experiments required a long time for their completion, portions of the plants upon which experiments were made have been preserved, in order that any one who may feel desirous to examine them might have the opportunity of so doing, and thereby of satisfying himself of the reality of many of the facts which I have mentioned. In conclusion, I have to acknowledge my thanks to my friend, Mr. Ralph, for his assistance on various occasions, connected with the publication of this Essay, and for the trouble he has taken in verifying some of my experiments; also to Mr. John Bristowe, an intelligent Student at St. Thomas's Hospital, for having made the greater part of the Drawings.

Langton Place, Kennington,
September 14, 1847.

CONTENTS.

The Nos. refer to the several Paragraphs.

EXPERIMENTAL INQUIRY Etc.

1. The fluid, which vegetables imbibe from the soil on which they grow, is generally called the *ascending*, or *crude* sap.

2. The crude sap, after having been elaborated in the vessels of a plant, and fitted for the development and production of new parts, is called the *elaborated* sap.

3. The direction taken by the crude sap is always from the root towards the branches, whilst that of the elaborated sap may be either upwards, or downwards, according as the process of elaboration is most active in the vessels of the roots, or in those of the leaves.

4. Besides the movement of these fluids, there is a distinct, and separate motion of that within the cells, denominated "Cyclosis," in which case the contents of one cell move independently of those in the adjoining cells: this phenomenon, being a local, and not a general operation, does not come under the consideration of the ascent, and descent of the sap.

5. Before a precise explanation can be given, or a correct notion obtained, of the cause of the ascent of the crude sap; or of the ascent and descent of the elaborated fluid, the structures which each of these fluids traverses in its passage from one extremity of a plant to another, must be accurately determined, and clearly demonstrated.

6. The following experiments have been instituted and performed for the purpose of satisfactorily determining these points, of showing first, that the crude sap ascends along a tissue which chiefly exists *between* the cells, but which enters also into the structure of the more solid, and permanent parts of a plant, and secondly, that the elaborated fluid, both in its descent, and ascent, passes along the ducts, and spiral vessels.

Experiment to show the structure occupied by the crude sap in its ascent and diffusion through all parts of a plant.

7. The inferior extremity of a long branch of the Valeriana rubra was placed in an aqueous solution of the Bichloride of Mercury, a short time after it had been removed from the plant, and its leaves had slightly shrunken from the evaporation of their water; and it was found, that, in the course of a few hours, it had absorbed a considerable quantity of the solution, and its leaves had recovered their former freshness, and state of distension. Next day, this branch absorbed less of the solution than on the preceding one, and the poisonous effects of the Bichloride were now visible some way up the stem, also the lower leaves were partially attacked, having become discoloured, and shrunken, but the un-

affected parts of these leaves, and of the other portions of the branch retained their natural freshness, and appeared quite healthy. Thus the Bichloride of Mercury continued to destroy successive portions of the branch from day to day; those parts of it to which the influence of the poison had not extended always remaining to all appearance sound, and in some cases distinguishable from the affected ones by a line of demarcation more or less defined.

8. After the solution had ascended into that part of the stem which was soft, and contained but little ligneous matter, its diameter became very much contracted, from the collapsed state of its vessels and cells, and was rendered so flexible as to be incapable of supporting the sound parts above it, which, notwithstanding this altered and contracted state of the inferior portion of the branch, seemed perfectly healthy, and continued to receive an abundant supply of fluid. The upper parts of this branch remained vegetating in the solution during a fortnight, although the lower ones were completely deprived of every trace of vitality, shewing that the passage of the fluid along the latter into the former, is wholly independent of any vital contraction of the sap vessels, as was formerly supposed by the older physiologists.

9. But in order to remove any doubt as to the correctness of this conclusion, a stem of Valerian was obtained, from which grew two long parallel branches of equal size, and a portion, fifteen inches in length of one of them, was exposed to the action of boiling water during quarter of an hour, after which the inferior extremity of the parent stem was placed in a weak solution of the Bichloride of Mercury for a fortnight. During this time the process of vegetation was found to be quite as active

in the upper part of the branch which had been acted upon by the boiling water, as in that which had been carefully protected from the action of the heat.

10. On repeating the first of these experiments upon a great number of other plants, it was found, that some do not vegetate at all after they have been separated from their stems, the process of vegetation ceasing immediately after their separation; but, that, others vegetate very well after their separation at one period of the year, and not at another period. It may be observed, that in all cases where a plant refuses to vegetate in a solution of the Bichloride of Mercury, it will not vegetate under similar circumstances in common water.

11. In case a slip of any plant will not vegetate in a solution of the Bichloride of Mercury, or in water, its leaves gradually droop, and wither from the evaporation of their moisture, without the plant having the power of absorbing any more fluid, shewing that mere evaporation from the leaves is not sufficient to cause the ascent of the sap. Besides, in those plants which do retain their vitality when separated from their stems, and placed in a solution of the Bichloride, the quantity absorbed by the same species of plant is found to be in proportion to the healthy condition of their leaves, and the apparent vigour with which they perform their functions; clearly proving that the ascent of the sap, in these instances, depends upon some vital operation going on in these organs.

12. If the part of any branch which had vegetated in a solution of the Bichloride of Mercury situated above the junction of the dead with the living part, be chemically examined, no Bichloride of Mercury can be discovered in it, whilst the stem and the leaves below this part contain

an abundance of that substance; hence, as all the water which went to the supply of the living part of a plant, was derived from the solution, (and in some experiments this quantity amounted to two or three ounces) a process of decomposition of the Bichloride must have been continually going on at the union of the dead with the living part of the branch all the time it was vegetating in the solution, by which the Bichloride is converted into the pro-chloride and chlorine, the former, being insoluble, remains in the vegetable tissue, whilst the latter, being set free, is indicated by the change which it produces in the colour of the plant; the water of this portion of the solution, being thus freed of all its Bichloride, ascends into the living parts of the branch to nourish them, and in this manner they receive their supply of water from this poisonous solution the same as if the extremity of the branch had been kept in water, or the entire plant had been deriving it from the soil on which it grew: so that a plant, whilst vegetating in a solution of the Bichloride of Mercury, may be distinguished into three parts, the living, the dying, and the part completely dead; the first contains the water of the solution deprived of all its Bichloride, the second the portion of solution in which the Bichloride is in the act of being decomposed, and the third the solution unchanged.

13. Now, as in the plants thus treated, the water of the solution, which had been taken up into, and nourished the living part of each branch, was in *reality* its crude sap; and as the same passages which conveyed this water, now deprived of its Bichloride, must have contained the solution whilst this substance was undergoing decomposition, and therefore whilst it contained some of the

Bichloride unchanged; to determine the *part* along which the crude sap ascends, we have only to ascertain the precise situation of the Bichloride of Mercury, and the tissue in which it is lodged.

14. This can be done by examining, with the microscope, sections of any plant which had been made first to vegetate in a solution of the Bichloride of Mercury; and in which this substance had afterwards been entirely converted into an insoluble bisulphuret by the action of Hydrosulphate of Ammonia,* employed either in a gaseous or a liquid state. In the employment of this means to advantage, the part of the stem containing the Bichloride of Mercury must be allowed to get dry before the sections are made, otherwise the solution would be pressed during the operation of cutting into the surrounding parts, and the result of the experiment rendered inconclusive.

15. Plate 1 Fig. 1 represents a portion of a very thin transverse section of a branch of the vine, which had vegetated in a solution of the Bichloride of Mercury, and afterwards been exposed to the action of the Hydrosulphate of Ammonia, by which all the Bichloride of Mercury is decomposed, and converted into a black Hydrated Bisulphuret. Plate 1 Fig. 2 represents a very thin transverse section of a portion of a branch of the Pinus Sylvestris treated in the same manner.

16. In these sections the black bisulphuret is seen completely filling up the intervals between the cells

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* To secure the full effect of this experiment, the Hydrosulphate of Ammonia must have been recently prepared, otherwise it will not decompose the whole of the Bichloride of Mercury.

without being contained in the cells themselves; or, in the section of the vine, in the vessels. If these sections be compared with similar ones of the same plant in its natural condition, the intervals between the cells (seen to contain in the sections represented by Fig. 1 and Fig. 2, the Bisulphuret of Mercury) will here be observed to be filled up by a solid substance, which, from its situation, is called Inter-cellular Tissue. From these facts, and from what has been stated, it will now be obvious, that this is the tissue along which the solution of the Bichloride ascends in a plant whilst made to vegetate in it, and therefore that it is the structure which conveys the crude sap when a plant is growing in its natural soil. To shew the relation of this tissue to the cells, and how completely it is filled with the Bisulphuret of Mercury after the decomposition of the Bichloride, let a very thin section of any herbaceous plant, the Valerian for example, which has vegetated in a solution of the Bichloride of Mercury, be put into a solution of the Hydrosulphate of Ammonia, and examined by the microscope whilst the decomposition of the Bichloride is taking place, and the intercellular tissue will be seen to become instantly blackened whilst but little, or no Bisulphuret will be seen to form in the cells or in the vessels: or let a similar section be exposed merely to the vapour of the Hydrosulphate of Ammonia until it is completely black, and then examined in water under the microscope, and the collapsed cells and vessels will be seen to open from the imbibition of water, without having within them any of the Bisulphuret, whilst the intervening tissue will remain permanently blackened. It may be observed that this intercellular tissue, besides completely filling up the intervals between the cells, is blended with, and enters into the structure of the cell-walls, which become discoloured; but, that the Bisulphuret is not confined to this portion of the tissue, nor is situated on the side of it next to the cells, that is within the cells, is certain from the Bisulphuret not taking the form of the cells, and leaving the intercellular intervals uncoloured, but on the contrary from its taking the form of the intercellular intervals, and leaving the spaces surrounded by the cell walls unoccupied.*

17. If, however, any solid granular matter be contained within the cells, the solution of the Bichloride enters them, and the Bisulphuret of Mercury may be seen to be mixed with it.

18. The quantity of intercellular tissue contained in different parts of the same plant varies very considerably; there is scarcely any between the cells of the pith, or between those containing the starch in cotyledons, but it exists abundantly between all the cells of wood, and also between some of the cells in the bark. In some situations its thickness, when occupied by the Bisulphuret of Mercury, is equal to the diameter of the cells between which it is placed. It exists very sparingly in submerged vegetables.

19. The intercellular tissue appears to be of extreme tenuity, almost transparent, and without any definite

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* This fact is particularly observable near to the conflux of three or four cells, as in the position *a a*. See Plate 1, Fig. 1 and 2, where, instead of there being a colourless interval left in the centre of this space, (which must have been the case had the Bisulphurate been confined to the walls of the cells enclosing it, or situated only on the inner surface of the cells themselves,) it will be seen that the whole of the space is occupied by the Bisulphuret, and, that its centre is equally as much blackened as the other parts

structural arrangement. To the highest powers of the microscope it presents no appearance whatever of pores; and, notwithstanding its actual porosity, as shown by its easy permiability by water, and aqueous solutions, it will not allow the most finely pulverized substances to pass through it.

The cause of the ascent of the Crude Sap.

20. Having now shown that the crude sap ascends in a porous tissue, universally diffused through all parts of a plant, and occupying in greater or less abundance the intervals between the cells, there will be but little difficulty in comprehending the mode of its ascent, and general diffusion.

If it be admitted that the crude sap is of less density, than the fluid contained within the cells; and, as the former is derived directly from the earth, whilst the latter is mixed with various soluble substances, elaborated within the cells, doubtless must be so, it will then be apparent, that the position of the crude sap, in a tissue situated all around the cells, is the best possible one for favouring its passage, by endosmose through their walls into their interior, and for causing the intercellular tissue in the immediate vicinity of these cells thus to be exhausted of its fluid.

21. The intercellular tissue being porous, and generally continuous, must of nècessity, if deprived of its fluid in any one part, attract, in consequence of its capillarity, that which is contained in the tissue of the surrounding parts, and thereby cause the crude sap to move successively from one situation to another in a direction dependent upon the position of that portion of the inter-

cellular tissue, which is being most rapidly exhausted: so that when the tissue situated between the cells in the leaves is rapidly being deprived of its crude sap, in consequence of the passage of this fluid, by endosmose from the exterior to the interior of the cells; this portion of tissue will attract the water from that situated around the cells in the petioles of these leaves, which becoming more or less exhausted, will attract in like manner the water from the intercellular tissue of the stem, and thus the crude sap will be drawn up successively from one part of the stem to another, until the intercellular tissue in the root, becoming deprived of a part of its water, will re-fill itself by attracting the water from the earth through the POROUS cuticle which covers the radicles: or, if it be a branch vegetating with its extremity placed in a solution of the Bichloride of Mercury, as in the experiment first related, the intercellular tissue at its cut extremity will attract the solution from the vessel in which it is placed.

22. The intercellular tissue, besides serving for the ascent of the sap, will, from its universal existence, and general continuity, be the means also of its lateral diffusion, and thus remove a difficulty upon this subject complained of by the author of the article Botany in the Library of Useful Knowledge, who observes, "How we are to account for the lateral transfusion of the sap through the medullary rays is still unknown." The medullary rays are composed of cells longest generally in their horizontal diameter, and like the cells of wood in other parts, surrounded by intercellular tissues.

Undue distension of the cells is prevented by the constant evaporation which takes place from the leaves, and a larger quantity of fluid is by this means caused to pass through a plant to furnish it with a sufficient supply of those substances which it requires to obtain from the soil. This process, being thus accessory to the function of nutrition, is aided by the stomata, and also by the abundant pubescence present on most leaves, and especially on young leaf-buds. Although this evaporation, called sometimes transpiration, must aid indirectly the ascent of the sap, yet of itself it is altogether insufficient to cause it to ascend; the sap ceasing to ascend as soon as the cells lose their power of elaborating their contents, and thereby keeping up the physical conditions necessary for the continuance of endosmose. (See 11.)*

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* It may at first sight seem improbable that the mere cessation of the process of elaboration in the cells of the leaves should be attended with so sudden an arrest of the ascent of the sap. The evaporation itself might have been considered as favourable to the production of endosmose, by causing the inspissation of the contents of the cells. This impression arises from a too close comparison of the circumstances under which endosmose is ordinarily exhibited in experiments, with those under which it takes place in nature. In the former case the fluids are prepared apart from the membrane intended to be interposed; and, to secure the fullest effect, one fluid is generally made very much denser than the other. In the latter case the difference of density of the two fluids situated on each side of the interposed membrane, as for instance, that within the cells, and that in the tissue around them, is produced at the time that both of the fluids are in contact with this membrane: so that the instant a minute portion of soluble matter is formed in a cell, and the density of the fluid within it thereby augmented, at that same instant the water present in the tissue external to this cell is ready to pass through its walls to dilute this solution, and to render its density the same as that of the fluid in the intercellular tissue. Hence, under such circumstances, it is impossible that these fluids can ever differ much in their degree of density, as almost immediately the process of elaboration ceases within the cells from a suspension, or destruction of the chemico-vital action, the mechanical conditions required for maintaining the continuance of endosmose must cease also: nor will the inspissation of the fluid within the cells from evaporation keep up these conditions, since the inspissation is taking place equally in the fluid external to them.

23. In order to see how this explanation of the cause of the ascent of the sap just given, accords with experiments performed upon living plants, while placed in fluids of different degrees of density, three portions of Anthriscus vulgaris, as nearly as possible, of an equal size, and all taken from the same plant, were placed in fluids of different densities; the extremity of one branch in a solution of gum arabic, one drachm to the ounce, that of another in a solution of the same gum half the strength, and that of the third in common water. The last one absorbed at least ten times as much as the second, and the second rather more than the first—the one which was in the strongest solution. The two which had been placed in the solution of gum, ceased taking up any more fluid after about three days, and gradually faded, whilst that which had been kept in water continued to absorb it for more than a week, and retained, in a great measure, its natural freshness.

24. A similar experiment was next performed upon two portions of the Lapsana communis; in this instance the plant, which had been put into water, absorbed a much larger quantity than that which was kept in the solution of gum, the former continuing to absorb for more than a fortnight, the latter for about five days. That part of some vegetables (whose stems are very soft) which was kept in the mucilage, became very visibly shrunken, from the partial exhaustion of the cells, in consequence doubtless of the operation of *exosmose* going on between the contents of the cells, and the solution of gum.

25. A solution of sugar acts differently to that of gum. If transparent vegetables, when placed in a solution of sugar, be examined by the microscope, the effect is seen

to be very remarkable. No plant, which I have seen, exhibits this effect better than the Nitella. Almost the instant a piece of this plant, in which the cyclosis is active, is brought into contact with the solution, its internal membrane becomes partially and suddenly torn from the enclosing cell-wall, its contents escape, and the cyclosis ceases.

26. The experiments first described shew that the ascending sap is attracted, and not propelled; and therefore, the explanation of the cause of the ascent of the sap given by Dutrochet, as the consequence of the passage of fluid from the earth into the roots by endosmose, must, in these instances, fail. Nor is the explanation advanced by some Physiologists, by whom it is supposed, that the crude sap ascends from cell to cell by endosmose, assuming that the contents of the cell above are always more dense than those of the cell below, less at variance with the facts shewn by these experiments. As in the stems whose vitality had been destroyed by the Bichloride of Mercury, along which the sap, or rather the fluid which furnishes the sap, has been shown to ascend with perfect facility, there could not possibly exist that difference in the density of the contents of the cells at different parts of the stem, necessary to ensure the continued passage of the fluid of one cell into another by endosmose during a period of a fortnight or three weeks. For this imaginary state of progressive inspissation of the contents of the cells, according to their relative distance from the roots, could only be the result of a vital process; and therefore, if the ascent of the sap depended upon it, that ascent must immediately cease in any part of a stem, as soon as its vitality is destroyed.

27. The preceding explanation of the cause of the ascent of the sap, being made to depend upon the foliaceous organs, pre-supposes that they exist before the sap can begin to ascend. This without doubt is true, although in some cases it may seem not to be so, as these organs appear, at some seasons, from their minuteness and imperfect state of development, to be entirely absent; yet, notwithstanding, their existence is unquestionable, and their function similar to that of the matured leaves. These parts, before they acquire the general characters of leaves, are more or less concealed, and denominated leaf-buds: Their form is conical, they consist of a central axis composed of cells and a few vessels continuous with those around the pith of the branch on which they are situated, and surrounded by rudimentary leaves. The cells resemble those of the pith, in having very thin cell-walls, and but little intercellular tissue; and, in the external cells generally, containing starch granules, or some other solid matter. Now, as these germinating bodies (the leaf-buds) require a supply of water the instant their germination commences, and the solid material within their cells becomes elaborated, and a solution formed, that is the instant the conditions required for endosmose are set up, it is necessary that they should be situated near to a reservoir of that fluid: this is effected by their connection with, and their proximity to the pith; so that the office of the pith is most probably to contain between, and within its cells, that portion of water which the leaf-buds require the moment their transformation into leaves commences, and before their development is sufficiently advanced to enable them, by the absorbing power of their own intercellular tissue, to absorb it from

the surrounding tissue, in the manner described when treating of the ascent of the sap into the matured leaves. Hence the reason why the pith is so universally connected with leaf-buds, and why it occupies the central portion of the ascending axis, and those parts derived from it, and is absent in the roots.

DESCENT OF THE ELABORATED SAP, &c.

28. Having shewn by experiment, that the crude sap ascends in a tissue situated around the cells, as well as entering into the structure of their walls, thus occupying a position the most favourable for the supply of these organs, both individually and collectively—See Plate 1, Fig. 1 and 2, the cause of the descent and ascent of the elaborated sap may now be considered; and, first, it will be necessary to shew by what parts it is conducted.

Experiments performed upon living plants, with a view to determine the passages which convey the Elaborated Sap.

29. In the winter of 1844, three suckers of Lilac, of two years' growth, all springing from the same root, were severally girt with a piece of copper wire, drawn as tight as it would admit of, without cutting into the bark, and the effect was carefully watched until the spring of 1847.

30. In the spring of 1845, it was observed that the budding commenced at the same time in these suckers as in some others growing from the same root; and that, during the summer and early part of the autumn, no difference could be distinguished in the state of the

vegetation of these shoots, the girt always appearing as healthy as the ungirt ones.

In the winter, one of the girt suckers was cut for the purpose of examination. The other two were allowed to remain.

The part of this sucker above the ligature had received a layer of new wood of the ordinary thickness, also an addition to the bark: that included in it retained of course its former diameter, but had undergone an alteration, a thin layer of wood having been added to that of last year, and the bark having become thinner than it was before, in consequence of being compressed between the new wood and the ligature: the part below the ligature was smaller than that above, and had received a new layer both of wood and of bark, but both *much thinner* than those above the ligature. In the immediate vicinity of the wire the shoot was swollen both above and below, but more so above than below it.

31. In the spring of 1846, the two constricted suckers which remained were observed to begin budding at the same time as some other suckers growing from the same root; and, during the spring, and summer, no very material difference could be distinguished in their states of vegetation. The leaves of the constricted suckers appearing perhaps a little yellower than those of the unconstricted ones, but in all other respects they had the same aspect. The part of the stem close to the ligature was swollen both above and below it: and although, the stem above the wire had increased considerably in diameter, the part below it had undergone no increase in thickness.

In the early part of the summer, one of these suckers was cut and examined with the microscope, but the other was allowed to remain for future observation. The part of this sucker above the ligature had received a layer of new wood, also an addition to its bark: that included in it had undergone a change similar to the one mentioned in the last experiment; but the part below the ligature had undergone no change whatever: not the slightest addition had been made either to the wood or to the bark.

32. The sucker which was left, the only remaining one, still continued to grow, increasing in size above the ligature, but not in the least below it. Its leaves were as large, and with the exception of a slight yellowish tint, appeared as healthy, and remained as long attached to the plant as those of the suckers which sprang from the same root, but had not been experimented upon.

33. In the spring of the next year, (1847) at the period when all the leaf-buds of the unconstricted suckers began to swell and develope themselves, those of the constricted one rapidly withered. Up to this time they were as large, and appeared as healthy as those of the other suckers.

At the commencement of June (1847) this sucker was cut, and examined. The part of the stem above the ligature had received a layer of wood, and an addition of bark to that of the preceding year: the part included in the ligature it was not considered necessary to examine: the part below the ligature had received no addition whatever to the wood of the last year, and the whole thickness of the stem had lost its natural aspect, appearing brown, and destitute of vitality, whilst the part above the ligature was of a greenish colour, and had a healthy appearance.

34. It appears from these experiments, that the part of a stem thus constricted allows the crude sap to ascend freely through it, although it does not permit the elaborated sap to pass below it; and consequently that the formation of new wood and new bark goes on above the ligature after it has completely ceased below it. From this fact it seems obvious that the ascending and descending fluids do not pass through the same channels, and hence that the elaborated sap does not descend along the intercellular tissue.

35. It is also evident, from what has been stated concerning the last of these suckers, that, when the layer of new wood extends no further down than the constriction, and consequently has no direct communication with the roots, the process of vegetation ceases in the entire shoot, first below, and then above the ligature, shewing the independence of one layer of wood of another, and the necessity of each layer having a separate connection with the roots.

36. Now, the only parts which connect the leaves of an exogenous plant with its branches, are cells, vessels, and intercellular tissue; and, it has been shewn that the descending sap does not pass along the last of these, *i. e.*, the intercellular tissue, it must therefore be conducted either by the cells or by the vessels. The cells being distinct one from another, surrounded by intercellular tissue, and having no openings of communication one with another, can scarcely be supposed to serve as conductors of a fluid. Besides, had the cells been capable of conducting the elaborated sap, it would not probably have been detained so completely by the ligature after its second year's application, for the cells of the new layer of

wood formed above the constricted part being closely applied to those of the last year's layer, and this layer not being at all compressed by the wire, the descending sap, if conducted by cells, would readily find its way from the wood above into that below the ligature; (see 33) and therefore the function of conducting the elaborated sap may fairly be inferred to be performed by vessels. Moreover, vessels are continuous passages extending from the leaves all along the branches and stem down into the roots, and have large and extremely well defined openings of communication one with another, and therefore possess all the necessary anatomical characters of tubes designed for the transmission of a fluid. See Plate 1, Figs. 3, 4, 5, and 6.*

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* Some Botanists attempt to distinguish true spiral vessels from ducts, by the former having no openings of communication one with another; this is however an error, I have in my possession preparations of true spiral vessels of the most perfect kind, with large well defined openings in them, and find but little difficulty in preparing specimens of this description of vessel. Plate 1 Fig. 3 is an accurate representation of one of these vessels, taken from the common Rhubarb. Fig. 4 is also an accurate representation of two of these vessels, taken from the Elaterium. In one of these vessels, a full view of the opening is obtained, surrounded by a distinct ring: in the other, the opening is seen only in profile; but, in the preparation, it can be seen much more distinctly on the other side. While these two vessels were in their natural situation, the opening in one was applied to that in the other, but now they have become partially separated. In some spirals, especially in those of parts which have not attained their full size, the opening is not so distinct, nor is it surrounded by a border. Plate 1 Fig. 5 is the representation of a spiral vessel, taken from the upper part of a young stem of the Solanum tuberosum. In this specimen the portion of spiral fibre, situated at the part where an opening is being formed, is partially absorbed. Some of the coils of fibre opposite the middle of this opening are completely divided, others are very much thinned, and widely separated from one another, so that, when vessels of this kind are in contact, a free communication exists between them. Spiral vessels sometimes terminate in conical extremities, at other times in

37. Before endeavouring to show the manner in which vessels obtain their supply of fluid in the leaves, and conduct it into the branches, stem, and roots, it will be necessary to premise some observations *upon* the formation, and general distribution of vessels, and the connection of the petioles of leaves with the branches on which they grow.

A very distinct view of vessels in their natural situation may be obtained, by placing a thin leaf or petal (provided

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rounded ones, in both cases inosculating with the vessel above and the one below.—See Plate 1 Fig. 6. *c*. Porous vessels (Bothrenchyma) have the same forms of termination, and anastomose in the same manner as do spirals. Indeed, these kinds of vessels in many parts resemble one another, so as not to be distinguishable by any individual anatomical character; and, I have several specimens of vessels, in which one extremity of the vessel is a perfect spiral, and the other a dotted or barred duct, whilst the intermediate portion shews the gradual passage of the one kind of vessel into the other. Sometimes also a barred duct inosculates with a spiral.—See Plate 1 Fig. 6, which is the representation of a vessel, with one extremity resembling a duct, anastomosing with two others, and the other extremity a true spiral vessel. With resemblances so decided, there can be no question as to their function being the same. It is supposed by many Physiologists, that spiral vessels are for the conveyance of air; and, that they correspond to the respiratory organs in insects. If these vessels be dissected, and examined under water, they will generally be found to be full of fluid: sometimes they contain air, also mixed with water. But the most satisfactory manner of examining them is in the living unmutilated part, this can be done in the stipules of the Hydrocharis, where they can be seen very distinctly, but without the slightest appearance of air within them, although air may be observed very distinctly in many of the spaces between the cells. Besides, true spiral vessels, especially when young, are frequently found, containing solid matter of various kinds. I have some preparations, in which many of these vessels are completely filled with a greenish substance,—Chlorophylle. With these facts, and the resemblance between *true* spiral and ducts beforementioned, there can be no doubt but that if the one convey a fluid, the other does also, for it seems to be the last degree of probability that parts resembling each other so closely in their structure should differ so widely in their office, as that one should be a respiratory organ, and the other a conduit for the sap.

the latter be not of a yellow colour) upon a microscope slide, with a piece of thin glass over it, and after having introduced some *pure* acetic acid sufficient completely to cover the piece of plant, to hold them above the flame of a candle, so as gently to boil the acid. The introduction of the acid, and the boiling, must be repeated until the petal becomes almost transparent. When this operation is properly performed, all the cellular portion of the petal becomes clear, and almost invisible, whilst the vessels are rendered quite distinct. By this mode of preparation, the existence of vessels, their relations, and manner of termination, can be made out more satisfactorily than could be done without it. To facilitate the examination of detached vessels, maceration, and various other modes of preparation may be resorted to, all known to microscopic observers.

38. A thin leaf or petal, when thus treated, is observed to consist of bundles of vessels, disposed in an arborescent manner, and inclosing cells in the spaces formed by the anastomoses of their minuter ramifications. These bundles, as well as many of the vessels composing them, decrease in size as they approach the margins of a leaf, a short distance from which they terminate, some by joining the nearest ramifications and forming arches, others in free extremities which are impervious, and have no communication with the stomata or intercellular spaces, as some Botanists have imagined. These vessels are all spirals, consisting of several joints, having for the most part conical extremities, the extremity of one joint lying in contact with that of another. In parts imperfectly developed, the cavities of the contiguous joints do not

communicate, some of the joints are even isolated from the rest, but at a later period, their parietes, where they lie in contact, become removed by a process of absorption, and a free communication is established between them. Sometimes the openings by which they communicate are circular, with a distinct border, at others the coils of spiral fibre are partially absorbed, and separated as shewn in Plate 1, Figs. 3, 4, 5, and 6.

39. The vascular bundles of a leaf are continued into its petiole, and from thence they pass into the stem, where they become dispersed, some are continuous with the spiral vessels situated around the pith, and others with the vessels of the layer of wood last formed. These vessels, in their passage through the bark, are contained in large canals, situated between the liber and the cuticle, in which they appear to lie naked—See Plate 1, Fig. 7. Some of the vessels in the petiole do not pass directly into the stem, but either become intermixed with a quantity of loosely connected cells, see Plate ii. Fig. 8, or anastomose with the vessels of the adjacent bundles. These can be very well seen in the Fig-tree, by making a vertical section through the petiole at its insertion into the stem. The canals which transmit the vessels appear to be continuous with spaces of various sizes, continued all along the bark of the stem, and situated at different distances from the surface. Their walls, or immediate boundaries consist of rows of cells piled one row upon another; sometimes they are smooth, and at others they are covered with small whitish granules. Many of the passages seem to become filled up more or less completely with clusters of new cells, which have a pale greyish tint,

and resemble *wood cells* in their form and general characters; they are also acted upon in a manner similar to such cells by the Tincture of Iodine. In order to trace distinctly the passage of the vessels of the petiole into those of the wood, thin vertical and horizontal sections must be made through the attachment of the petiole with the stem, and afterwards treated with acetic acid in the manner described in (37). As the vessels descend from the attachment of the petiole into the wood, they lose somewhat the character of true spirals, and become more like barred ducts. Probably a difference in the mechanical conditions under which vessels are placed in the leaves and in the stem, renders it necessary that the former should be more perfect spirals than the latter.

40. The manner in which vessels are formed from cells can be very well seen, by examining plants during their growth, and contrasting the same structures at different periods of their development. The petals of the Potatoe, taken a little before the flowers have expanded, and previously rendered transparent by the employment of acetic acid, shew well the manner in which vessels increase in length. In the colourless parts of these petals, bundles of long, but very narrow cells, may be observed marking out the place for the future vessels; and, at the part where these cells are continuous with the vessels, extremely minute dark points are visible in the walls of the former. These points coalescing, form a number of lines, indicating the spaces between the coils of the spiral fibre in the perfect vessel. After several of these cells have been thus transformed into vessels, a new joint is formed, which at first lies merely in contact with the extremity of

a previously finished joint, but afterwards communicates with it in the manner before described, and thus a vessel is increased in length by the successive addition of new joints. At first, the marking of many of the recently formed vessels is so faint, as not to be distinguishable, excepting by the best lenses of a high magnifying power, but it gradually increases in distinctness as the spiral fibre becomes developed.

In petals, and in the expansions of thin leaves, such as admit of being rendered transparent by acetic acid, the cells and vessels are too small to shew distinctly the manner in which the larger vessels acquire their diameter; this can be best seen in the soft immature stems of herbaceous vegetables. Plate ii. Fig. 10 is the representation of a very thin transverse section of the stem of the Solanum Tuberosum dried, and preserved in Canada Balsam, showing that the wall of a vessel is formed by the union of the external thickened wall of the surrounding cells. Plate ii. Fig. 12 exhibits vessels seen lengthwise in different states of development, taken from the Solanum Tuberosum, shewing how they acquire their diameter by the union of cells (called cambium cells). The walls of these cells are seen first to unite longitudinally, forming vessels of various sizes, the diameter of each depending upon the number of cells thus united: next the spiral fibre can be observed to become developed in the walls of the cells; prior to which, these walls are remarkably thin and diaphonous. The formation of this fibre seldom commences simultaneously in all the cells occupying the entire circumference of a vessel, but on the contrary, its development is seen to be much more advanced on some cells than on others, and even more on one part of a cell than on another part. The first indication of the formation of the spiral fibre is a very minute oval spot, slightly elevated, so that when viewed by reflected light, especially in a dried longitudinal section, it seems to be vesicular, in the centre of this spot a thinning soon appears to take place, which keeps increasing in a direction more or less transverse to the axis of the vessel, until a narrow line is formed, after a time this line joins an adjacent one, (formed in the same manner,) producing a bar. A series of such bars frequently occupy the breadth only of one cell, without extending at all to the collateral cells. A vessel marked by a number of these lines is called a "reticulated" vessel.* But when the transverse lines, or thinning between the bars, at first occupying only the individual cells, become continuous with those of the collateral cells, and extend uninterruptedly around a vessel several times, a spiral fibre is the result, and the vessel is then called a spiral vessel. See Plate 1 Fig. 6.

41. Besides the transverse markings of vessels, there are longitudinal ones. These are seen more or less distinctly upon all spiral vessels, as well as upon ducts; they indicate the situation where the cambium cells became united prior to the production of the spiral fibre.

42. As during the transformation of cells into vessels, a thinning is taking place in the parts of the cell-walls,

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* By some Physiologists these bars are supposed to result from the breaking up of a spiral fibre. There are some spiral vessels, (probably those of an early formation) in which elongation appears to have taken place after they have been completely formed, and in which the spiral thread has the appearance of being broken up into separate rings. If this has been the case, the spiral fibre of these vessels was doubtless formed in the same manner as in other spirals.

corresponding to the space between the coils of spiral fibre, so a thickening is taking place in the parts between the lines constituting the spiral fibre itself; hence, when a vessel is completely formed, that side of each cell which enters into its formation is much thicker than the sides which lie in contact with the surrounding cells. See Plate ii. Fig. 10.

43. The part which each vessel occupies, being previously taken up by cambium cells, a number of these cells, equal to the area of the future vessel, must be removed to allow space for its interior. This is produced by the attenuation, and breaking up of the cells occupying the site of the vessel which is in progress of formation, and frequently debris of these cells can be seen in vessels after their completion.

This process can be best seen in the spring of the year, at the junction of the previous year's layer of wood with those cells which are then undergoing a transformation into vessels.

44. The facts just stated showing, that vessels are made up of cells, that the same structure is common both to the vessels and to the cells surrounding them; and that vessels contain a fluid, and in many cases a solid material, render it extremely probable that their function also is analogous to that of cells; and that they receive their contents by the passage of fluid from the adjacent intercellular tissue, and perhaps from the surrounding cells, by the operation of the same principle,—Endosmose,—and in the same manner as that described in treating of the passage of the fluid from the intercellular tissue into the interior of the cells. Plate ii. Fig. 11 is a section of the cyst, or receptacle of oil in the rind of a lemon, showing that it

is a mere cavity built up of cellular tissue, taken from Dr. Lindley's Introduction to Botany. The comparison of this representation of a secreting cell with the representation given in Plate ii. Fig. 10 of vessels, shows that a vessel, and a cavity containing a secretion, have exactly the same relation to the adjacent cells, and therefore strengthens the above conclusion.

45. Now, each cell being isolated, and without any communication with those in its vicinity, the pressure exerted upon the inner surface of its walls, in consequence of the passage of a larger quantity of fluid into it by endosmose, than can escape from it in the same time by exosmose, (to which pressure the enlargement of the cells is due,) is altogether local and limited; and thus the development of one part of the cellular system of a plant is independent of that of another part. Vessels on the contrary, being a species of cell, designed to elaborate materials, like as do the ordinary cells, but, for the production of remote parts, and afterwards being intended to convey their elaborated contents to the place of destination, require that free communications should exist between them, (these are shown in Plate i. Figs. 3, 4, 5.) in order that the fluid elaborated and accumulated more particularly in one part of the vascular system, may, by the force of distension, be propelled into all the other parts communicating with it. Hence, when the process of elaboration is most active in the vessels of the leaves, and a quantity of fluid, proportionate to the activity of this process (*i. e.* to the quantity of soluble matter which is being formed) is, by endosmose, passing into them from the adjacent intercellular tissue, this fluid cannot fail to be forced into those vessels which are receiving less fluid from the sur-

rounding parts; for instance, into those of the petioles of the leaves, and from these vessels some of the elaborated sap must pass into the vessels around the pith to furnish the material necessary for the production of starch, or other nutrient matter for the leaf-buds of the ensuing year, but the greater quantity will pass into the ducts of the wood, (these being continuous with the vessels descending from the petioles) for the production of new wood and new bark. It is possible that some part of the contents of the vessels, during their passage through the cellular spaces in the bark, may escape, and that to this is due the granular matter, or the clusters of cambium cells found in these spaces. But the most probable cause of the passage of the elaborated sap from the vessels and ducts must be looked for in the endosmic action of the surrounding cells. These cells in vegetables performing probably a function similar to that which epithelial cells perform in animal structures, especially in those structures which are but sparingly supplied with blood, such for instance, cartilage. In animals a thin membrane called *basement*, or *limitary* membrane, is generally situated between the vessels containing the nutrient fluid,—the blood-vessels,—and the epithelial cells, to which Physiologists ascribe more or less of importance. In vegetables no such membrane is present; but in the ligneous parts of a plant the walls of the ducts are provided with minute nucleated cellules generally of an hexagonal figure, and disposed in the form of a tesselated epithelium. Where the vessels of the petiole become continuous with these ducts, the spiral fibre gets more and more imperfect in proportion as this disposition of cellules makes its appearance: hence, as the vessels of wood must be confessed to have a more active function, in reference to the production of new parts, than those of the petiole of leaves, (the office of these being only to convey the fluid elaborated in the leaves to the ducts of the wood) this apparatus of cellules may be inferred to perform some function connected with the especial organization of new wood and bark, as yet unknown.

46. Perhaps the spiral fibre of the vessels of leaves, besides tending to prevent the dissipation of their fluid by evaporation, and thus keeping up a greater degree of distension than would be required in the ordinary cells, may confer also upon these vessels a resiliency and elasticity advantageous in regulating the pressure upon their contents, and the passage of the fluid along them.

47. That the vessels of the leaves do elaborate a fluid, and conduct it from thence into the branches, stem, and roots, for the production of new wood, and new bark, is proved by the fact of these structures completely ceasing to be formed, where the descent of the elaborated fluid is prevented by ligature, whilst they are produced in the ordinary quantity in the stem above the constriction; for, if the intercellular tissue, or the ordinary cells, and not the vessels, had been the elaboratories and conductors of the descending sap, these two structures, the intercellular tissue, and the cells situated above the ligature being so much, and so closely connected with the same structures below it, would still have allowed of the descent of a portion of the elaborated sap, as one of them, the intercellular tissue, allows the free ascent of the crude sap, and the growth of the stem would not have been so completely arrested below the wire whilst it was going on uninterruptedly above it, see (33). The layer of wood and

bark of the sucker, which had been cut at the end of the first year, being much thinner below than above the ligature, was the consequence of the constriction of the newly formed vessels at the girt part, by the pressure of the gradually increasing layer of new wood on one side, and the wire on the other. And the circumstance of there being, in the other sucker, no addition whatever made to the wood and bark below the ligature during the second year of its application, proceeded from the entire closure of these vessels by the continued increase of this pressure, so that now no sap could descend below the constricted part. And the fact observable in the same sucker, of the sap elaborated in the leaves of 1846 not being permitted to descend below the ligature applied in 1844, proves that there are no collateral or anastomosing channels between the layers of wood of *separate years*, capable of conducting the descending sap, although there is no interruption whatever to the passage and lateral diffusion of the ascending sap. It shows also that the descent and the ascent of the sap must take place through a very different system of parts, the descent of the elaborated sap being limited to one direction, and confined only to one part of a plant, whilst the crude sap, in addition to its passage upwards, is diffused throughout its entire substance. Now, there is no other system of organs in plants, excepting vessels, which are capable of thus limiting the passage of the elaborated sap; nor is there any one but the intercellular tissue, (that is the tissue filling up the intervals between the cavities of the cells,) which can allow the crude sap to have such an universal diffusion.

48. Now, as long as the process of elaboration is going

on most actively in the leaves, and other foliaceous organs, and the material elaborated is disposed of in the parts which are situated below them, that is, nearer the roots, the direction taken by the elaborated sap along the vessels must be downwards, and thus it ought to continue until these organs have accomplished all the purposes for which they were intended, until, after having completed their own development, they have provided for the propagation of the species by the production of seed. In this case the process of elaboration is first employed in forming cells, and afterwards in depositing within them solid matter for the nutrition of the germs at some future period. As the process of deposition advances, the conditions become less and less favourable for endosmose, and after the cells have become full, these conditions cease to exist, and no more fluid is attracted into the intercellular tissue surrounding them, that which they did contain evaporates, and the seed, as well as those parts, whose function had been subservient to its growth and maturation, become so altered in their physical characters as to unfit them for being retained any longer on the plant. Until also a provision has been made for the leaf-buds of the ensuing year, by a deposition of starch or some similar substance in the vessels and cells of the stem and roots: Hence, if the root of a vine be dug up in the winter, the cells and vessels situated in the outer layer of wood are found filled with starch granules; if in the spring, after it has ceased bleeding, as it is termed, and the leaves have appeared, the quantity of starch in these vessels and cells will have very much diminished, and at a still later period it will be found almost to have disappeared; and lastly, until a deposit has been formed of finely granular matter around the last year's wood. This deposit is contained in minute square cells, compressed in the direction of a line extending from the centre to the circumference of the stem, and forming collectively a dark coloured ring all around the last year's layer of wood, by which a thin transverse section made in the winter can be distinguished by the microscope from one cut at any other period. This deposit being formed in the autumn, may be called the *autumnal* deposit. This is one of the earliest parts in which, at the commencement of spring, a process of elaboration is seen to begin: as this process is going on, the granular matter disappears, and the cells become of an irregular figure and filled with fluid, still later these cells become broken up, and their place occupied by vessels and ligneous cells. The distension of these cells with fluid, and their consequent breaking up, is the cause of that loose connection between the wood and the bark, so remarkable in the branches of most trees at the spring of the year. The foliaceous organs having made these provisions for the future, and fulfilled all the purposes for which they were designed, now become useless, and the process of elaboration ceasing in their cells and vessels, they attract no more crude sap, become withered, and unfit to be retained on the tree, and are therefore shed; and the plant experiences a state of repose, the duration and completeness of which varies in different kinds of plants.

Ascent of the Elaborated Fluid.

49. It was observed at the commencement of this paper, that the direction in which the elaborated sap

moves, is either upwards or downwards, according as the process of elaboration is most active in the leaves or in the roots. So far this process has been spoken of only in the leaves, and therefore the explanation has been confined to the cause of the descent of the elaborated sap. It now remains to treat of that process of elaboration which takes place in the roots, in the early part of the year, before the leaves appear; and to shew in what manner the ascent of the elaborated sap depends upon it. The roots having been shown to be one of the parts in which starch is deposited whilst the leaves are in active operation; and this deposit being undoubtedly for the supply of the leaf-buds, more especially when they first begin to be developed, two things are necessary; first, such a change in the physical properties of the deposit as will enable it, or the elements which enter into its composition, to be brought into contact with the parts which it has to nourish; and, secondly, its propulsion into these parts. Now, as the starch deposited in the vessels cannot be supposed to escape from them, and to diffuse itself through a plant whilst in a solid state, it must, by some process of elaboration, pass from the state of an insoluble to a soluble substance, and then become dissolved in the water contained in the vessels. It was shown at (48) that the starch deposited in the vessels of the root of the vine gradually disappeared as the leaf-buds became developed, and the fact of starch in seed becoming converted into sugar and gum during the process of germination, render it almost certain that the same change is produced in the starch contained in the vessels of roots during the development of the leaf-buds: Hence, in the early part of the year, these vessels may fairly be supposed to contain a solution of sugar, gum, and perhaps some other soluble material; and being in contact by their external surface, with a certain quantity of intercellular tissue, loaded with water imbibed from the earth by capillary attraction, their contents are placed under the same circumstances, as it respects the operation of endosmose, as the vessels of the leaves were in summer, consequently they will receive the water from the cellular tissue between the cells of the roots, first to dissolve the soluble matter elaborated within them, and secondly, to dilute the solution thus formed, and an addition of fresh fluid being made to their contents, that already contained in their interior will be pressed upwards into the vessels of the stem, and from thence into those of the branches, and lastly into the vessels of the developing leaf-buds; the water, or crude sap, on the exterior of these vessels, being at this period derived from the pith, as before explained when treating of the use of the pith (27).

50. From this explanation, the reason is apparent why the leaf-buds on the constricted sucker, see (33) began rapidly to wither in the spring of the year; although, up to this time they had appeared healthy. The vessels of the layer of wood, and bark connected with these buds, not extending further than the ligature, and being therefore cut off completely from the roots, there could have been no deposit of nutritious matter stored up in the roots for these buds, and consequently after they had passed from a dormant into an active state, they were compelled to die from inanition.

51. Before the leaves are at all expanded, and consequently the vascular system of a plant is unprovided with the means of getting rid, by transpiration, of the excess

of water taken in by the roots, the vessels will become generally distended, and if the tree be wounded in any part, fluid escapes, and so continues flowing until the leaves, or at least that pubescence, with which their buds are for the most part liberally provided, be sufficiently formed to carry off the superfluous water, this is well seen by wounding the vine at different seasons of the year. As the leaves become matured, the ascent of the elaborated sap keeps diminishing, but its motion upwards continues until all the nutritious matter which had been deposited in the vessels of the stem, but more particularly in those of the roots, has been made available in supplying the developing leaf or flower buds, when it will cease, (a tree, if wounded at this period, will not bleed;) but, instead of remaining quiescent, the elaborated sap must soon take a reversed movement, in order that the leaves now in progress of development, may perform for their successors the same service which their predecessors performed for them.

52. This part of the explanation of the cause of the ascent of the elaborated sap is the same in principle as Dutrochet's, but as this Philosopher, to whom so much honour is due, in being the first to make known the facts of endosmose and exosmose, denies that the crude sap ascends external to the vessels and cells, there is nothing in common in our mode of accounting for the ascent of the crude sap. On carefully reading Dutrochet's observations upon the ascent and descent of the sap, my impression is, that his notions are exceedingly confused, and his mode of applying the facts of endosmose and exosmose in explanation of these phenomena unsatisfactory.

Nutrition of Plants.

53. As the movement of the sap in plants is a part of the function of nutrition, and altogether subservient to it, I shall make a few remarks upon the probable manner in which nutritious matter is introduced into them along with the crude sap.

Although starch is found in vessels, especially in those of the roots, yet its principal depository is the cellular system, and as it exists most abundantly in seed, and in the vicinity of leaf-buds, and disappears as their development advances, it may be fairly inferred to contribute something to these parts which stands in the same physiological relation to them, that alimentary matter does to animals. With a view to determine this point experimentally, some of the buds or eyes were removed from a potato with as little as possible of the surrounding substance, and placed in the earth. After some weeks they sprang up, and grew rapidly for nearly a month, but they were so long and slender as to be incapable of supporting their own weight, consequently they soon withered away. After that an entire potato was planted in the earth, and after its sprouts had shot up about six inches above the surface, it was taken up, and half of the sprouts having been carefully detached from the potato, whilst the other half were allowed to remain connected with it, they were all replanted in the same soil, and were found to grow very well; but those which remained connected with the potato, grew stronger, and higher than the separated ones. Next two kidney beans were set near together, and after they had grown to the height of about half a foot, they were dug up; and the colyledons being removed from one of them, but left connected with the other, they were replanted near together, and it was found that the latter grew stronger than the former. It is a curious fact, bearing upon this subject, that of two species of kidney bean, the dwarf, and the scarlet runner, the cotyledons of the latter remain under ground to be exhausted, whilst those of the former came up with the plumula. From all these experiments, it appears evident that the starch deposited in plants has some share in nourishing their developing buds.

54. The next question to determine is, the passages by which the nutritious matter is conducted from the part where it was deposited to that which it nourishes. When a seed is placed under circumstances favourable for its germination, a quantity of water soon penetrates through its coverings, enters the spaces between the starch cells, and lastly, passes into the cells themselves, becoming mixed with the granules of starch; thus far the imbibition of water is due to capillary attraction, and takes place the same in a dead as in a living seed. Next the seed begins to germinate, and some of the starch in the cells nearest to the embryo becomes converted into sugar, gum, &c., which being dissolved in the water imbibed from the earth, form in these cells a solution more dense of course than the water in the intercellular spaces, and the conditions necessary for endosmose and exosmose are now set up; when some of the water must pass from the intercellular spaces into the cells by endosmose, and a portion of soluble matter out of the cells into the same spaces by exosmose. (It has been already observed, that but very little intercellular tissue exists between the starch

cells in cotyledons, and that the intervals between these cells are actually spaces,) but as (at this time) the plumula is being developed, and a process of elaboration is going on in its cells, as well as in those of the cotyledons; the tissue situated between the cells of the plumula will attract fluid from the tissue between the cells of the peduncule, or process connecting the plumula with the cotyledons, and this intercellular tissue will imbibe the solution from the intercellular spaces of the cotyledons themselves, and thus the nutritious matter, deposited between the cells of the cotyledon, will arrive at the plumula. But it must be recollected that the plumula has roots like an ordinary plant, therefore its intercellular tissue, at the same time that it is attracting the solution of nutritious matter from the intercellular spaces of the cotyledons, will attract water from the earth by its roots in the manner described in treating of the ascent of the crude sap (21), which water, at the junction of the peduncule of the cotyledon with the plumula, must mix with the fluid attracted from the spaces between the starch cells. Hence a plant, at this period of its existence, derives one part of its nutriment from the cotyledons, and the other from the soil in which it is germinating. It may be observed, that the entire surface of cotyledons, like the cuticular covering of roots, is permeable by fluids.

55. In order to see how far this explanation agrees with the results of experiment, some kidney beans were set in the earth, and after they had grown about four inches above the surface, they were taken up, and one of the cotyledons was removed from some of them, whilst the inferior extremity of the remaining one was allowed

just to dip into a solution of the Bichloride of Mercury. They were in this state put into a dark place to vegetate, (for under such circumstances they preserve their vitality longest in a dark place). About the fourth day, the discoloration of the stem for the distance of an inch, rendered it evident that they had imbibed some of the solution, which being decomposed by the Hydrosulphate of Ammonia. The Bisulphuret of Mercury was found in the intercellular tissue of the plumula, the peduncle connecting it with the cotyledon, and between the starch cells of the cotyledon.

56. During the operation of endosmose and exosmose in plants, the quantity of fluid which enters the vegetable cells is always greater than that which escapes from them into the intercellular spaces or tissue, hence the cells are kept always in a state of distension. Whilst they are being developed, this distension is necessary to cause their gradual enlargement. After they have acquired their full size, the excess of water is got rid of in those parts of a plant which are exposed to the air, by transpiration, but in the cells of cotyledons, and in those of roots, and of deeply seated parts of a stem, a portion of water is doubtless decomposed to assist in forming those various substances which remain permanent in the cells of these parts: Hence, as the starch disappears from cotyledons, and roots, a quantity of fibrous matter is formed, causing these parts to become hard and woody as they get older; and as wood increases in age, an accumulation of ligneous matter takes place in the cells, rendering the old wood harder, and generally of a darker colour than that of a more recent growth. The preceding observations upon the function of cotyledons refer

only to such as become exhausted underground; but it is probable that the function of those which come out of the earth, and afterwards assume the form of leaves, is, at first, and as long as they remain in the soil, the same as that of those which never appear above the surface; that is, that the starch in the cells nearest to the germ becomes converted into a soluble substance, and thereby causes a part of the water which had been absorbed from the earth to enter them by endosmose, and some of the dissolved vegetable matter to escape from them by exosmose; this solution mixing in the intercellular spaces with the water attracted from the earth, both by the cotyledons, and by the roots, serves to nourish the developing embryo until the cotyledons are fit to appear above the surface, when they become green, and probably afterwards perform the same function as leaves.

57. The same explanation which has been advanced to account for the disappearance of the starch from the cells of cotyledons, and its passage, in another form, into the young plant will, without doubt, equally apply to the removal of starch from the roots, (as for instance from the cells of the roots of the vine,) and its diffusion through all parts of a tree. To render that description applicable, it is only necessary to suppose, in the present instance, that the starch accumulated in the cells of the roots is converted into a soluble substance, and that water by endosmose, passes from the intercellular tissue into the cells; and, by exosmose, the nutritious matter in a state of solution, passes from the cells into the intercellular tissue, which, mixing with the water passing along this tissue, absorbed by the roots, and attracted by the developing leaves, in the manner explained in treating of the ascent

of the crude sap (21), is conveyed into the foliaceous parts of a plant for their nutrition and growth, until they have attained their maturity. This solution, arriving at its destination in the tissue occupying the intervals between the growing cells, as well as forming the cell-walls themselves, serves as their cytoblastema, or source from which their supply of alimentary matter is immediately derived. This mode of nutrition probably is not confined to vegetables. Some animal structures, such, for instance, as cartilage, seem to be made up entirely of cells and intercellular substance; this latter perhaps performing the same office in this part which its analogue does in vegetable textures.

58. Although the preceding observations upon the passage of the sap have not been made in reference to any particular class of plants, those vegetables which are composed both of cells, and vessels, have been more particularly kept in view. In plants exclusively cellular, there is no regular descending sap, no vessels being present in them for its conveyance. In these, the ascent and diffusion of the crude sap takes place in the same manner as in the most cellular parts of the more complex plants: there is however one class of plants, the coniferæ, which require especial notice. The wood of these trees is made up entirely of ligneous cells and intercellular tissue, there is no distinct system of sap vessels as in other Exogens, the channels which convey the turpentine being for the passage of a specific secretion. The intercellular tissue is as abundant in these as in any other class of trees, and the crude sap can be shown to ascend through it by means of the Bichloride of Mercury and the Hydrosulphate of Ammonia, in the manner already explained—

See Plate 1 Fig. 2. The ligneous cells are very long, tubular, and appear to communicate by oval or circular openings of various sizes, so that, by these communications, the elaborated sap can pass from one set of tubular cells into another as along the sap vessels in other trees. Mr. Henfrey observes, respecting the wood of the Coniferæ and Cycadeæ, that "it consists wholly of large prosenchymatous cells with pores; it is difficult to determine whether these should be called *vessels* or not," page 32. Some of these openings are depicted by Dr. Lindley, as seen in the Ephedra, and are considered as the places from which glands have fallen. This mode of accounting for them is, I have no doubt incorrect, for they are too regular, both in their form and situation, and their existence is too uniform to justify an idea of their being merely accidental communications. These openings are found chiefly in the horizontal tubular cells, whilst the glands, as they are called, exist most abundantly in the perpendicular ones. Dr. Mohl considers that these glands have openings through them, leading from one tube into another, but this view has been generally opposed. It is possible that these bodies have been too partially examined by these opposite parties, and only in opposite states of their development, for in some instances the central spot may be seen to be a distinct cell, and in others a distinct oval or round opening. Moreover, the existence of communications between the longitudinal cells in the coniferæ, capable of transmitting a fine powder, may be demonstrated by placing a small quantity of very finely powdered vermilion, suspended in water upon a thin longitudinal section of the common fir, (pinus sylvestris), when the water will be seen to pass through to the other side of the section, with some portion of the vermilion, as the pores in the intercellular tissue are too minute to give passage to any solid matter, the vermilion must in this instance have passed through other openings.

ON THE CAUSE OF ENDOSMOSE AND EXOSMOSE.

59. Endosmose and exosmose being frequently referred to in the preceding observations, as well as being generally regarded as the effect of a distinct principle, different to that attraction which is exerted between the particles of matter, and operating at small distances; instead of being looked upon as a consequence of this attraction, and differing only in the circumstances under which it acts, from capillary attraction, diffusion, &c. I shall conclude this paper by some remarks upon the cause of endosmose and exosmose.

The remarkable phenomena comprised under these terms were attributed by Dutrochet, the discoverer of them, to the passage of currents of electricity of unequal intensity through a membrane situated between two fluids of different densities, these currents being supposed to carry with them unequal quantities of fluid. But although the facts of endosmose, and exosmose, as described by this Philosopher, have been found to be correct, and are now universally admitted, yet his mode of accounting for them has not been generally received.

The phenomena of endosmose seem to be merely the effect of the diffusion of fluids of unequal density through a porous membrane, the pores of the membrane allowing the rarer fluid to pass through them quicker than the denser one, and thereby occasioning the fluid to accumulate on that side of the membrane on which is situated the denser solution.

60. That diffusion does take place whenever two fluids of a different density are brought into contact, although no porous membrane intervenes, is evident from the following experiment: Fill a piece of thermometer tube with water, and after closing one of its extremities, place it vertically with the other, the inferior one, in a small quantity of thick mucilage, coloured with logwood, and the coloured mucilage will gradually ascend, though contrary to gravity, and colour the water in the upper part of the tube. As in this experiment the diffusion is independent, or even opposed to, the attraction of gravitation, it is only attributable to that form of universal attraction which is exerted between the particles of matter at small distances, the attraction varying in the inverse ratio of the squares of the distances of the particles, and the direct ratio of their densities. The unequally dense particles, in this instance, moving in a medium which allows of the perfectly free motion of one particle upon another, cannot come to a state of repose until every one of them is attracted equally on all sides, that is, until the two solutions have become of one and the same density.

61. Now, when a porous membrane is situated between two fluids of different degrees of density, its porosity acting merely as a multitude of very fine capillary tubes, will allow of the intermixture of the two fluids by diffusion, as shown by experiment; when the rarer fluid passing through the interstices of the membrane in one direction, will mix with the denser fluid, making it more rare; whilst the denser fluid, passing through the same

interstices in the opposite direction, will mix with the rarer fluid, making it more dense; and thus these fluids will continue intermixing until they are both of the same density. But the characteristic property of endosmose and exosmose is the *accumulation* of fluid on the side of the membrane in contact with the denser solution. This arises from the mutual attraction existing between the two fluids, and the material of which the membrane situated between them is composed, which attraction is greater in the case of the denser than in that of the rarer fluid, as is manifest by the following fact, with which every one is familiar, namely, if solutions of the same soluble substance of different degrees of density be filtered through any membrane, the rarest fluid will pass through it most rapidly.

62. Now, if when diffusion goes on through the pores of a membrane, the quantity of fluid had remained equal on both sides of it, then the denser fluid must have passed through the intervening membrane with the same velocity as the rarer one, that is, the two fluids, though of different densities, must have been attracted by the material of which the membrane is composed, with an equal force, which is contrary to the law of attraction as well as to the fact just stated. Hence, when diffusion is going on between two fluids of different degrees of density, separated by a porous septum, there must be an accumulation of fluid on that side of the septum on which is situated the fluid, or the solution, that passes through it *most slowly*. If visible perforations be made through the interposed membrane, the solutions on each side of it intermix, but the fluid does not rise higher on one side of the membrane than on the other. This proceeds from the attraction

between the margins of the apertures, and the central particles of the columns of fluid passing through them becoming diminished in proportion as the distance between these particles and the membrane is increased; so that when these cease to attract one another with a force greater than that of gravity, the dense and the rare solutions will pass through the membrane nearly with the same velocity.

63. This explanation of the cause of endosmose and exosmose, being strictly applicable in all cases where the solutions, on each side of the interposed membrane, possess the same chemical properties, and differ only in their degree of density, will apply very generally in the endosmose of plants, and animals, as in them water is the fluid which holds the various substances in solution.

64. If the fluids on each side of the interposed membrane have different chemical properties, still the accumulation is on that side of it on which is situated the fluid passing through most slowly, although the density of this fluid may be less than the other; thus, when a bladder full of atmospheric air is surrounded with carbonic acid, the latter, the denser, enters faster than the former escapes, and the bladder becomes more distended. Now, it is found by experiment, that carbonic acid *passes by itself* through humid membrane quicker, than does atmospheric air; hence we have here an example of the effects of that form of attraction, which requires only for its operation the presence of matter, being overcome by another species of attraction, chemical attraction or affinity.

65. Endosmose and exosmose, to which nearly all the phœnomena of vegetation are due, being simply the effect of one universal force, which never ceases for an instant

to act upon all matter, organic and inorganic, according to fixed and invariable laws, require to be modified by other forces, in order to produce that endless variety of results which are so remarkable, both in living plants and animals during their different periods of growth and development; and, as chemical attraction is the principle of them, the reason is obvious why the contents of the cells in different parts of a plant, and in the same part, at different stages of its development, should differ so much in their chemical properties. This is very well exemplified in the ripening of fruit, the germination of seed, and in the nutrition of plants: For in these processes the effects of density, that is, of that attraction which is regulated by quantity of matter, is modified by the chemical attraction of the various substances elaborated within the cells for the cell-walls themselves, as instanced in the endosmose of atmospheric air and carbonic acid, and in this manner, one simple force, universal attraction, thus modified, is made the immediate cause of an endless variety of effects. But these changes in the density and chemical properties of the contents of vegetable cells are produced no longer than a plant is possessed of vitality; therefore they must be regarded as the effects of a vital principle. So that all the processes strictly vegetative, such for instance, nutrition and growth, seem to be effected by the agency of two principles upon matter, one vital, the other physical, namely, life and universal attraction; the former, life, having the power of modifying and regulating the action of the latter, by producing different degrees of density, and various chemical changes in the substances which are subjected to its operation.

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DESCRIPTION OF

Plate I.

Fig. 1. Represents a thin transverse section of the Vine, with the intercellular tissue filled with the Bisulphuret of Mercury; (*a*) is a space existing at the conflux of three cells, filled up entirely by the Bisulphuret. See paragraph 15, and page 6.

Fig. 2. Represents a thin transverse section of the Pinus sylvestris, with the intercellular tissue filled with the Bisulphuret of Mercury; (*a*) is a space existing at the conflux of three cells, filled up entirely by the Bisulphuret. See paragraph 15, 16, and page 6.

Fig. 3. Represents a true spiral vessel taken from the petiole of the common Rhubarb, showing the opening by which it communicated with an adjoining spiral vessel. Page 19, note.

Fig. 4. Represents two spiral vessels, from the completely mature stem of the Elaterium, showing in one of them its opening of communication, surrounded by a distinct ring; and in the other, the same description of opening seen only in profile, when these vessels were in their natural position, the opening in one was accurately applied to that in the other. Page 19, note.

Fig. 5. Represents a spiral vessel from the upper part of a young stem of the Solanum Tuberosum, showing the opening of communication in progress of formation. Page 19 note, (*a*) the situation where this inosculates with another spiral vessel.

Fig. 6. Vessels taken from the Solanum Tuberosum. The largest of these vessels is at one part a barred or dotted duct, and at the other a true spiral, (*a*) the inosculating of this vessel with two barred ducts, (*b*) an opening in the larger one, similar to that in a true spiral. Page 19, note.

Fig. 7. Portion of the Sambucus Niger, showing the spiral vessels passing from the leaf-stalk into the cortical canals of the bark; (*a*) represents the spiral vessels going into a canal, (*b*) represents some of these passages as shown by a vertical section, made a little below the insertion of the petiole into the stem. To see these canals distinctly, a short time ought to elapse, half an hour, between making the section and the examination of it by the microscope, in order that some of the fluid contained within them may have had time to evaporate.

PLATE I.

Fig.1.

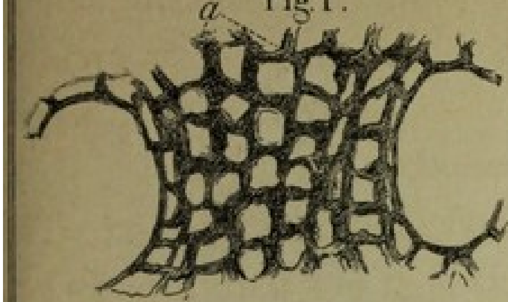

Fig. 2.

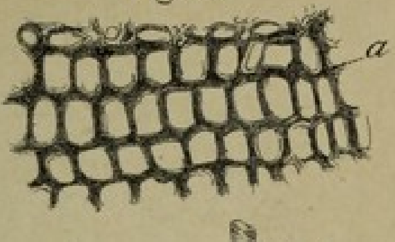

Fig. 3.

Fig.4.

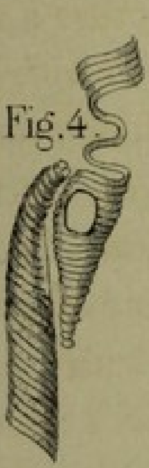

Fig 5.

Fig.6.

Fig.7.

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DESCRIPTION OF

Plate II.

FIG. 8. A horizontal section of the Sambucus made at the junction of the petiole with the stem, showing a bundle of spiral vessels running outwards into a layer of cells lying beneath the cuticle, among which the vessels become lost. Paragraph 39.

FIG. 9. A horizontal section of the Sambucus, shewing the cortical canals (*a*), some of the canals partly filled with granular matter (*b*), other canals which have become filled with new cells. As these cells become developed, the dark point in their centre increases in size, and becomes at length a distinct opening, the cavity of the cell. Page .

FIG. 10. A very thin transverse section of the upper part of a young stem of the Solanum Tuberosum, preserved in Canada Balsam, showing that vessels are formed by the union of the external thickened wall of several cells, (*a*) a vessel, (*b*) that side of a cell which enters into its composition, (*c*) those sides of the same cell lying in contact with the adjoining cells. Paragraph 40, and 42.

FIG. 11. Taken from Dr. Lindley's Introduction to Botany, is the representation of " a section of the cyst, or receptacle of oil in the rind of a Lemon, showing that it is a mere cavity built up of cellular tissue," and resembling in this respect a sap duct or spiral vessel. Paragraph 44.

FIG. 12. Representation of a vessel in progress of formation, taken from the Solanum Tuberosum, (*a*) the part of a cell wall as yet unoccupied by cellules,

(*b*) some of these cellules just coming as it were into existence, (*c*) the cellules enlarged, and joining with contiguous ones to form the spaces between the bars or coils of spiral fibre, according to the future condition of the vessel, whether it shall be a dotted duct or spiral vessel. The comparison of this figure with fig. 6. shows, that the dotted or barred appearance of a vessel is due to the non-union of the cellules (*c*), and not to the breaking up of a previously formed perfect spiral fibre. For at (*a*), fig. 12, there is no spiral figure in existence to be broken up into fragments, to furnish the bars which are present at the other parts of this vessel. According to this theory, the organization of the smaller vessels in fig. 6. is more advanced than that of the larger one with which they are connected, which is obviously not the case; and the upper part of this vessel is more perfect than the lower one, which a close inspection of the preparation from which this Drawing was taken show to be the reverse. Besides, what force can be imagined to have broken up the spiral at the upper part of this vessel, and not at the lower; this vessel being of an equal calibre, the spiral thread can not have been stretched, and thus broken, by something distending the vessel, more above than below. This opinion, besides being contrary to minute observation, is at variance with that economy which is observable in all the works of nature; for nothing can be more inconsistent with that economy than that a more complex structure must be formed first, in order that a less complex one may be made out of it, that is, that the primary form of all vessels must be first composed of a continuous spiral fibre, and then that this fibre must be broken into fragments to produce all the other forms. Paragraph 40, page 24.

PLATE 2.

Fig. 8.

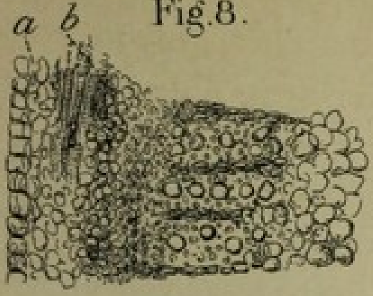


Fig. 9.

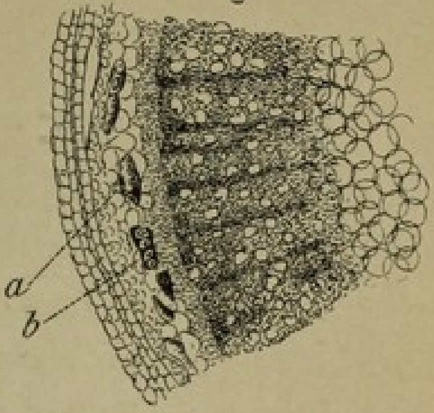


Fig. 12.

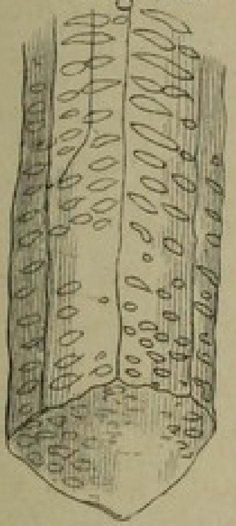
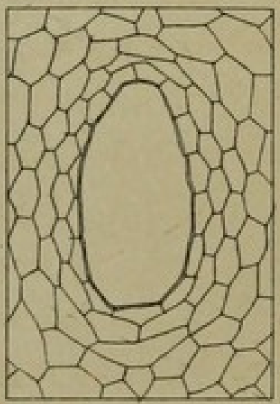


Fig. 10.

Fig. 11.



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☞ The ring which surrounds the foramen in fig. 4 is shown by the artist, and defined—much less distinctly than it is seen to be in the preparation from which the drawing was taken.—G. R.

(63) The ring which surrounds the foramen in fig. 1
own by the artist, and defined—much less distinctly
it is seen to be in the preparation from which the
ing was taken.—C. R.