

The Plant Commonwealth and its Mode of Government.¹

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THE plant commonwealth lies within the contours of an individual plant—rose, lily, grass, oak tree or any other. The physical features of the commonwealth have been surveyed and are well known. Notwithstanding their differences in outward aspect, all the members of the commonwealth—root, stem, leaves, and flowers—own a common plan of organisation. As the human being is the unit of a commonwealth of nations, so is the cell or protoplast the unit of the plant commonwealth. Just as certain men have the appearance of simplicity, so has the plant cell—a minute mass of nucleated cytoplasm, bounded by a solid wall of cell-wall substance, of such small dimensions that one thousand cells might lie comfortably side by side along the diameter of a penny piece. Yet, as is the case with man, the simplicity of the cell is illusory. The cell lives, feeds, respire, grows, and does many different kinds of work. Nor does it live unto itself alone. In all its manifold activities the cell influences and is influenced by other of the well-nigh innumerable cell units of the commonwealth. Indeed, the messages which by word of mouth, by post and telephone, telegraph and wireless, pass between members of our own commonwealth and leave us but little peace, are rare by comparison with those sent and received by the living cells of plants. Throughout life they are always “listening in.” In the simplest plants of all—the unicellular plants—the cell is the commonwealth. So is it in the highest (multicellular) plant at the moment of the rebirth of the individual within the ovary of the flower of the mother-plant. All plants begin life each as a single, minute mass of semi-fluid nucleated protoplasm. Every activity evinced by this living particle shows alike the diversity of its unrecognisable parts and the integrity, that is, the individuality of the whole, and throughout life diversity of activity and oneness or individuality alike persist.

From simple raw materials the cell-protoplasm restores and augments itself, and gradually stage by stage the plant carves out its body from this increasing mass of living substance. The primal cell grows and divides to form two daughter cells, each, like the mother cell, consisting of nucleated protoplasm invested by a wall or coat of cell-wall substance. Yet though a solid wall divides them, the daughter cells are not isolated from, but remain in communication with one another. For, in the first place, the separating wall is very thin and soluble substances may pass across it readily, and, in the second place, fine strands of cytoplasm radiating from the central mass penetrate into pits in the cell wall and, joining or all but joining with corresponding strands from a neighbouring protoplast, maintain vital touch between the cells. So in like manner the daughter cells divide, and the cells to which they give rise maintain vital contact by their protoplasmic connecting fibres, until after many divisions the embryo is recognisable within the swelling seed. If by some magical liquor the cell walls and all the non-living contents could be dissolved away and the transparent semi-fluid protoplasm made hard and visible, the contours of the plant would still be recognisable.

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Not all of the cells which compose the body of the embryo plant remain unchanged. Some, it is true, appear to do nothing else but grow and divide. They are the producer or embryonic cells destined throughout the life of the plant to carry on the work of cell formation. Groups of them are to be found at all ages of the plant in the growing point of the root and in the buds on the stem. In long-lived plants, after a thousand years and many thousands of divisions, these embryonic cells still retain their powers of cell-formation. Theirs is the gift of perennial youth; they never grow up. Once established, a growing point exercises a dominating influence over the broods of cells which it throws off by the division of its component embryonic cells. In some way, as yet unknown, it influences or perhaps determines the morphological fate of its offspring. For, as has been shown recently, a minute fragment of a root tip $\frac{1}{5}$ in. in thickness, if cut off and fed with mineral salts and suitable proteins, grows, divides, and in the cells which it produces, the same differentiation appears as in the normal root.

Other cells of the plant body soon cease to divide, but undergo no very great change of form. They become the general working cells of the body. Others assume curious and characteristic forms and, grouped together, constitute gangs of cells—skilled cellular artisans—to each of which some special task is assigned. Yet other cells or groups of cells undergo greater change of size and shape. For example: those destined to give rise to the woody vessels along which sap passes from root to stem grow wide and very long, join above and below in single file with cells like themselves, build thick and woody longitudinal walls, often beautifully sculptured, and, losing their contents and dissolving away their cross walls, form long uninterrupted tubes—mere aqueducts. It requires but little imagination to realise how imperative must be the constraint brought to bear on those wood-forming cells to induce them thus to immolate themselves for the benefit of the plant commonwealth. Their fate suggests that as the commonwealth develops the cellular units suffer more and more curtailment of liberty. Each is constrained to endure a limitation of freedom, and each imposes a limitation on that of other units of the plant body. In this compromise between liberty and social obligation a new and higher unit is fashioned—the individual plant, that is, the plant commonwealth. If this way of regarding the individual be correct, it must be of interest to explore the nature of the messages which, passing between members of the plant body, bind them together and determine the subordination of the cells and their integration into an individual. On these trifles, “light as air but strong as iron,” the existence of the commonwealth is based. It is to the origin, nature, and effects of these messages that I propose now to refer.

I know of no better way of approach to this task than by describing—at the risk of the smile it may evoke—the strange things that happen when a potato is peeled. An immediate effect of the operation is the setting up of a state of fever. During this wound fever the temperature of the tissues near the cut rises

rapidly as a result of increased cell respiration. The wounded cells die; those of the layer next to them, no longer hemmed in on all sides, find some relief from the bondage which held their activities in subjection. They grow out to form bladder-like or tubular projections. In the welter and confusion due to loss of touch with other cells, these cells break rank and become a law unto themselves. Their growth is, however, limited and aimless, and presently withering and turning brown, their dead remains form a thin dry skin over the wound. Behind the broken ranks the orderliness of behaviour of the cell layers is maintained; but it is a new order which these cells obey. They form a new front. Dividing rapidly and in a regular manner, these cells come to present the appearance of rows of microscopic bricks. When the originally single layer of dividing cells has given rise to several layers, the cells of the outermost form thick corky walls, lose their living contents, and come to consist of mere empty shells fitting as hollow bricks might fit closely one with another. Thus by the formation of wound tissue is the wound healed. Until recently, nothing was known of the provenance of the new orders which stir the cork-forming cells to activity and, releasing them from obedience to previous orders, cause these cells to renew their youth and reassume the power of division. But it is now known as a result of investigations made by Prof. Haberlandt that the renewed activity is called forth by messages from the stricken and dying cells.

The origin and nature of these messages may be determined by very simple experiments. For example: if the bulbous stem of a kohlrabi (turnip-stemmed cabbage) be cut across, all the changes just described may be observed to take place. But if the cut surface be rapidly and thoroughly washed with a stream of water, little or no cork formation occurs; the wound does not heal. When, however, the washed surface is covered with a layer of brayed-up cells of kohlrabi tissue, cork formation proceeds even more vigorously than it does in the unwashed wound. Whence it is to be concluded that messages are sent by the wounded cells and that the messages are of a chemical nature. As they die, these cells liberate some substance which, diffusing into the living cells, quickens them to activity and provokes their division. This stimulator of specific change may be spoken of as a wound hormone. Its presence may be demonstrated experimentally in many different kinds of wounded tissue, and in none better than in the succulent leaves of *sempervivum* and *sedum*. Leaves of these plants may be readily torn asunder without mechanical destruction of their cells; for the cell walls between the cells give and split so that the protoplasm of the cells remains intact. Now it may be shown that whereas by cutting a leaf and thereby destroying numerous cells the cell division provoking hormone is produced, by tearing it the hormone is not produced. The wound hormone, this message of healing, is sent out by the dying cells. Thus may plants rise by stepping-stones of their dead cells to higher things.

Further insight into the circumstances in which wound hormones are produced may be obtained by observing the effects which follow upon mechanical injury of delicate plant-tissues, as, for example, the

multicellular hairs so often found on leaves and stems. These structures are formed each by the outgrowth and division of a single surface cell. This cell divides to form a row of cells placed end to end; after a few divisions growth ceases, and the constituent cells of the hair divide no more. If, however, the hairs on the leaf or stem of a coleus or zonal pelargonium be maltreated by cutting or pinching or by less drastic means, as, for example, rubbing gently between the fingers or brushing with a hair brush, cell division may in certain circumstances be resumed. If a hair be cut across with a sharp instrument the cell cut into dies at once, its contents dry up, and no division occurs in the remaining intact cells. But if the instrument, in removing the top of the hair, also bruises the cell beneath the one cut into, the bruised cell enclosed in its wall, though it dies ultimately, has time to prepare its message, and its last will and testament consists in wound hormone which, passing to the next-of-kin, endows that cell with renewed powers of cell division. The wound hormone, diffusing into a cell, exercises an attraction on the nucleus which moves up in the direction of the injury, and in consequence nuclear divisions and subsequent division occur in the part of the cell near the wall across which the hormone diffuses. In some plants, as, for example, the zonal pelargonium, the basal cell of the hair appears to resist injury more than the other cells, and hence it may happen that when the stem bearing the hairs is brushed not too harshly, all the cells of a hair are killed except the basal cell. If this sole surviving cell, though damaged as may be seen by a puckering of its wall, has not been mortally injured, it produces wound hormone and thereby stimulates itself to cell division.

It may, and I think it will be that these discoveries are destined to throw light on many obscure phenomena in plants. Thus it has long been known that by wounding a plant a turmoil may be set up which spreads from the seat of injury to the uttermost parts of the plant. When a branch of a tree is lopped there are repercussions in the roots buried deep underground. The turmoil is visible under the microscope. In normal circumstances the protoplasm of a plant cell presents no sign of movement; but in certain circumstances an incessant restlessness very marvellous to witness overcomes it. All its granular mass except the layer next the cell wall begins and continues long to circulate around the cell or else to stream up and down along certain lines. When tissues are injured this streaming or circulation of protoplasm begins in cells near the wound, infects the cells next to them, and so on until, like bees disturbed in a hive, the myriad protoplasts of the plant are all in active movement.

In the light of the experiments with wound hormones, it would seem probable that the propagation of the disturbance which leads to streaming is due to some chemical message passing by diffusion from cell to cell. Again, it would seem possible to ascribe the remarkable behaviour of the fertilised egg cell to the influence of a wound hormone. As is well known, the egg cell of a plant or animal remains quiescent until it is penetrated by the male reproductive cell. Soon after this event the fertilised cell begins actively to divide, and continues growth and division until the embryo has been formed. Ingenious experimenters

have shown that egg cells of the lower animals and of some plants may be caused to undergo division and to produce embryos even in the absence of fertilisation. Thus the unfertilised egg of a frog pricked by a needle has been caused to undergo division and development, and to give rise to fatherless tadpoles. Hence there would seem to be little doubt that, in normal fertilisation, the abrupt entrance into the egg cell of the male reproductive cell leads to the production of a wound hormone which acts specifically in provoking cell division.

It might be objected that such an hypothesis presupposes an almost incredible delicacy of protoplasmic organisation, but the objection has no weight with the plant physiologist who knows from long experience that disturbances of protoplasm, often so slight as to escape our own powers of perception, may suffice to produce marked and far-reaching effects in plants. The exposure of one side of the tip of the seedling leaf of oat or other grass to direct sunlight for periods of so brief a time as $\frac{1}{2000}$ th of a second suffices to interrupt the uniformity of its upright growth and make it do obeisance to the sun. The tendril of the passion flower has a receptiveness so acute that the hanging upon it of a thread weighing no more than $\frac{1}{4000}$ th of a

milligram suffices to deflect the tendril from its course of growth. It curves in the direction of an incubus, the weight of which would have to be increased tenfold before we, if it were placed upon the skin, could be made aware of it by our sense of touch. The human eye is apt to distinguish small differences of light intensity. When we are young, our eyes can perceive the difference between a ninety-nine and a hundred candle-power lamp. As we grow old, acuteness of perception fails, and we are lucky if we can tell the difference between lights of one hundred and ninety-six candle-powers. A leaf can "tell the difference" between one hundred and 98.7 candle-power, so that its sensitiveness, as expressed by responsive movement, is equal to that of a fairly young eye. The trained eye is a wonderful instrument for perceiving whether or no a line be truly vertical, but I doubt whether its power is greater than that of the root of any plant. More than once a delicate experiment in plant behaviour has come to grief because the experimenter failed to notice that his table was not absolutely horizontal, and in consequence his plants not vertical. The plants themselves took heed of the displacement and set to work to rectify it to the undoing of the experiment.

(To be continued.)

Large Crystals of Iron.

THE paper by Prof. Edwards and Mr. Pfeil presented at the May meeting of the Iron and Steel Institute on "The Production of Large Crystals by Annealing Strained Iron" has now brought iron into the rapidly growing list of metals which can be obtained in the form of very large crystals. The research follows on a preliminary paper presented to the Institute by the same authors a year ago, in which they dealt with the commercial importance of coarse crystallisation in a number of defective stampings which had come into their possession. Methods of producing large metallic crystals may be classified under the following heads: (1) By slow cooling of the melt; (2) by drawing a rod slowly out of the melt; (3) by straining to a critical amount a test-piece composed of small metallic crystals, followed by heat treatment; (4) by the simultaneous application of strain and heat treatment to a metal wire. The method adopted by the authors is No. 3, which was introduced in 1921 by Carpenter and Elam in the case of the metal aluminium, and the large crystals produced are very similar in form.

It could have been predicted that iron would be more difficult to prepare by this method in the form of "single crystal" test-pieces than aluminium, for two reasons: (1) That no suitable form of commercial iron exists; and (2) that no heat treatment can be carried out above 900° C. on account of the A_3 change point at which the α to γ change occurs. Another difficulty presented itself in the course of the research to which reference will be made. The authors employed as their starting material mild steel plate 0.125 in. thick, containing 0.10 to 0.13 per cent. of carbon and the usual amounts of commercial impurities. The sheets were covered with a thin layer of scale which had to be removed by pickling in dilute sulphuric acid, leaving a dull metallic surface free

from serious defects. The test-pieces used were from 8 to 12 in. in length by 1 to 2 in. in width. Chappell's earlier work having shown that the presence of carbon in iron restricts the size of the crystals which could be developed, and the authors' investigations of the defective stampings having shown that coarse crystallisation was more pronounced where decarburisation has occurred, it was decided to remove all carbon from the test-pieces before attempting to produce large crystals. It was necessary to determine carefully the conditions of decarburisation, since the problem resolved itself into obtaining an iron of suitable crystal size free from carbon. As the result of a large number of experiments, it was found that a grain size of approximately 120 grains per square millimetre is required. This was obtained by decarburising at a temperature of 950° C. for 48 hours (*i.e.* in the γ range), followed by slow annealing (12 hours from 950° to 100° C.). The complete removal of carbon was found to be necessary. From this material large crystal test-pieces could be prepared by an elongation of 3.25 per cent. produced by tensile stress, followed by annealing just below the A_3 change point (about 880° C.) for three days. The maximum size obtained was 4 in. \times 1 $\frac{1}{4}$ in. \times $\frac{1}{8}$ in.

A complication from which aluminium is free is the presence of a surface film of very fine crystals which masks the very large crystals produced, and in order to reveal them it is necessary to remove this layer. The authors' experiments show that in general this film was just one crystal thick, and they concluded that those crystals in the original material which had a "free boundary" did not undergo the same kind of change during deformation by tensile strain as the interior crystals. They found, however, that if the elongation was produced by rolling, the surface film of fine crystals was not produced after annealing.