On the Nature of the Galvanotropic Irritability of Roots.

By Alfred J. Ewart, D.Sc., Ph.D., F.L.S., and Jessie S. Bayliss, B.Sc.

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After the contradictory statements of Elfving* that roots curve towards the positive electrode (anodotropic), and of Muller-Hettlingen,† that they were kathodotropic, Brunchhorst‡ apparently reconciled these contradictory observations by finding that strong currents, like those used by Elfving, produced a curvature to the positive electrode, weak ones a curvature to the negative electrode. The former curvature Brunchhorst considered to be traumatropic in character, on the ground that it was shown by decapitated roots, whereas the negative curvature was not. The proof that the galvanotropic irritability resides solely in the root tip, is, however, quite insufficient, and hence Brunchhorst's conclusion does not appear to be justified by the facts. The methods of the first two investigators leave much to be desired, and although Brunchhorst's experiments were, in part, carried out on a klinostat, they are by no means perfect. Thus the roots were immersed in water in a closed vessel, through which the current was passed by means of carbon electrodes. Apart from the effects due to the gases occluded by the electrodes, and to the deficiency of oxygen in the water, there would always be a tendency for the current to run obliquely or longitudinally through the roots, whose tissues form better conducting media than the surrounding water. This tendency will be especially pronounced when the roots are not exactly at right angles to the current, as is practically always the case, and when, as in Brunchhorst's experiments, numerous roots are examined at the same time. Finally, although Brunchhorst gives some data as to the total amount of current flowing in the circuit, these data afford no evidence as to the actual amount of current passing through the individual roots. Evidently, therefore, the supposed positive and negative parallelo-galvanotropism of roots is by no means satisfactorily established, and accordingly Miss Bayliss undertook to reinvestigate this subject, under more well-defined and controllable conditions, and with the results given in brief below.§

The strength of constant current required to produce a curvature is incredibly small, for using a voltage of approximately 1·3 volts, a resistance

* 'Bot. Zeit.,' 1882, p. 257.
† Müller-Hettlingen, 'Pflüger's Archiv,' vol. 31, 1883, p. 193.
‡ Brunchhorst, 'Ber. d. D. Bot. Ges.,' 1884, vol. 2, p. 204.
§ Full details will be given by Miss Bayliss in a later paper.

of 100,000 to 150,000 ohms was required in the circuit, so that the current passing through the 1 to 3 sq. mm. of cross-section lay between 0·0000135 and 0·000009 of an ampère. Even then it was difficult to produce a curvature without serious injury, or even fatal effects in the case of sensitive roots. When the platinum electrodes were on opposite sides of the apex, the curvature was always towards the positive electrode. If, however, one electrode was placed on the non-irritable base of the root and the other to one side of the apex, the curvature always took place towards the current side, independently of which electrode was on the apex. These results were obtained upon a klinostat into which the current was led by mercury contacts, and transmitted by platinum electrodes to the stimulated region of the root. The seedling and wires within the rotating glass cylinder were insulated on a slab of paraffin wax.

The facts observed suggested that the curvatures were not the result of any parallelo-galvanotropic irritability, but were due to the accumulation of the products of electrolysis at the points of application of the electrodes. Confirmation was obtained by exposing the roots to strong currents (voltage 1 to 4) for short periods (five to eight minutes), and then rotating on a klinostat, when exactly similar results to the above were given. Furthermore, if the anodal region was cut out of an electrolysed root and applied to one side of the apex of another, a curvature was shown to this side. In addition, the application of minute squares of absorbent paper, moistened with decinormal acid or alkali, caused curvatures towards the stimulated side, whereas ordinary neutral paper produced no effect in air saturated with moisture. When the acid and alkali were applied simultaneously on opposite sides, the curvature always took place towards the acid side. This corresponds to the curvature towards the positive (acid) electrode produced by moderately strong currents. The weakest currents used produced similar positive curvatures, and hence Brunchhorst's negative curvatures cannot be explained by Weber's law, as being due to the normal acidity of the root tissues preventing the stronger stimulating action of the acid coming fully into play until it accumulates beyond a certain limit.

The curvatures are usually completed in from 6 to 24 hours after exposure to the current, but they may be distinctly perceptible within four to six hours, and may begin in one to two hours, under optimal conditions. Hence it is not surprising that if the roots are fixed in a plaster cast after stimulation, and rotated on a klinostat for one or two days, a rapid sharp curvature is produced on freeing the root from the cast, whereas after two to four days the effect of the stimulation has passed away. All of these curvatures can be produced without any of the cells of the root being killed, and even when an

injury is produced, the curvature is usually towards the injured side, instead of away from it, as in a true traumatropic curvature.

The curvatures produced by continuous currents appear usually to be accompanied or preceded by a temporary more or less pronounced retardation of the average rate of growth in length. Indeed the latter may be temporarily arrested for some time after strong stimulation, even when the electric current produces little or no injury. In such cases negative results may be obtained as regards curvature.

Finally, using non-polarizable electrodes moistened with cell-sap diluted with distilled water, no curvatures were produced, whereas similar stimulation, using platinum electrodes applied to the surface of the root, and with the non-polarizable electrodes still in the circuit so that the resistance was the same, gave the usual curvatures according to how and where the electrodes were applied. With stronger currents and more prolonged exposure, curvatures are induced, even when "non-polarizable" electrodes are used, since the products of electrolysis may diffuse to the surface of the root, and it is impossible to prevent the internal polarization which takes place wherever the current traverses dissimilar saline solutions separated by semi-impermeable membranes. There is, however, less tendency to injury than with platinum electrodes.

The irritable and responsive zone extends 4 to 5 mm. behind the apex of the root of *Vicia Faba* and *Phaseolus vulgaris*. When one platinum electrode was applied to the non-irritable base of a root, and the other laid flat on the extreme tip, no curvature was produced in whichever direction the current was passed. This is presumably due to the products of electrolysis diffusing evenly and stimulating the irritable regions and cells equally on all sides, for when the same current was applied transversely behind the apex, a positive curvature was shown. If the roots were either truly positively or truly negatively parallelogalvanotropic, they should curve in the above experiment so as to place the tip parallel to the current, and either against or with its direction, whenever this does not at first coincide with their tropic irritability.

The "galvanotropism" of roots is therefore due to chemotropic stimulation by the products of electrolysis, of which the acid is more effective than the alkali, the latter also being neutralised more or less by the respiratory carbon dioxide. It is indeed possible that the curvature of the roots of *Lupinus albus* in gelatine towards phosphates and carbonates observed by Lilienfeldt* may be of similar origin, since acid phosphate and alkaline carbonates were used. That the "galvanotropic" or *galvanogenic* curvatures are not trauma-

* Lilienfeldt, 'Ber. d. D. Bot. Ges.,' 1905, vol. 23, p. 91.

tropic in origin is shown by the fact that they may be produced without any cells being killed. In Brunchhorst's experiments the electrolysis presumably occurred in the superficial cells of the roots submerged in water, the tissues being sufficiently impermeable superficially to the liberated acid and alkaline ions to allow them to accumulate beyond the minimum for stimulation. Although the curvature is usually sharp and strongly localised to the point of application of the electrode, the discriminatory power of the root, as well as the relation of the rates of growth on concave and convex sides to the normal rate of growth, suffice to show that the response is a stimulatory one, and is not due to the direct action of the products of electrolysis, retarding growth on one side or accelerating it on the other.

On the Isolation of the Infecting Organism ("Zoochlorella") of Convoluta roscoffensis.

By FREDERICK KEEBLE, M.A., University College, Reading, and F. W. GAMBLE, D.Sc., University of Manchester.

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The present paper gives a preliminary account, (1) of experiments proving that the green cells ("zoochlorellæ") of *Convoluta roscoffensis* result from infection from without: (2) of the means whereby the infecting organism may be cultivated outside the body of the animal: and (3) of the nature of the infecting organism.

1. *Evidence for Infection.*—In our former papers* we reached the conclusion that though direct proof of infection was lacking, the evidence pointed most strongly to infection as the source of the green cells of *Convoluta*. We showed, moreover, that the difficulty in the way of obtaining direct proof of the origin of these green cells is due to the fact that the mucilaginous capsules that invest the clutches of eggs laid by *Convoluta* are rarely, if ever, sterile. Even when adults are washed repeatedly in sterilised sea-water and caused to lay in sterilised surroundings, their egg-capsules become covered in time with a varied flora of colourless and of green organisms.

It is therefore necessary to isolate the young at the moment of hatching. During the present summer we have done this in larger numbers than before and maintained them in carefully filtered sea-water. Such young *Convoluta*

* "The Bionomics of *Convoluta roscoffensis*," 'Roy. Soc. Proc.,' vol. 72, p. 93, and 'Quart. Journ. Micro. Sci.,' vol. 47, p. 363, 1903.