With the stopcock closed the arc voltage is 54 to 125 volts, corresponding to 23–30 volts/cm gradient, the current being 0.6–1.95 amp.

The advantages of the lamps described above are (1) simplicity of construction, (2) extremely low cost, (3) adjustable length of arc and (4) various pressures may be used.

The small quartz tubes can be blown very easily by means of an oxygen-gas blast burner, the gas being enriched by passing through casing head gasoline or petroleum ether.

T. Hashimoto
C. C. Wu

Chemistry Laboratory,
Stanford University

SPECIAL ARTICLES

SAP FLOW AND PRESSURE IN TREES

The authors having been engaged in the study of movements of solutions in plants for several years arranged to collaborate in a series of experiments at the Desert Laboratory and at the Coastal Laboratory of the Carnegie Institution of Washington for a period of eight months in 1926. Professor Gilbert Smith joined us in some supplementary and anatomical studies for a few weeks. It seems advisable to present some of the results already obtained.

These support the theory of the upward movement of sap in trees in a cohesive column extending from the menisci in the walls of transpiring cells in leaves extending downward through dead wood cells and vessels and outward through the living cells of the root into the soil. The upward movement of water through such a system may continue at a diminished rate after the living cells at the upper and lower ends of the system are killed if the colloidal remains of the killed cells are not disturbed mechanically.

An examination of the assertions of Sir J. C. Bose that sap is pumped upward by pulsating action of living cortical cells has been made. Bose's claims as to the rate and mechanism of sap movements ignore well-established anatomical and mechanical facts, and are based upon imagined but impossible hydrostatic action of living cells. No single direct observation nor any measure of pulsatory action has ever been made, by Bose or any one else, yet his explanation of the ascent of sap is based on such an idea. It seems to be plainly evident to most beginners in botany that the drop of water applied to one smoothed end of a saturated branch is not identical with the drop appearing at the other end almost instantly, or that when water under pressure is turned into a hundred feet of filled garden hose the instantly resulting stream from the nozzle was made up of water that had traversed the length of the hose, yet Bose's estimates of sap-flow are based on preposterous assumptions that erection of flagging leaves is due to water passing from the base of stems to these organs at rates of 70 mm per second or as much as 70 meters per hour.[1]

Bose's conclusion that the wood serves as a reservoir from which living cells draw water and pump it by pulsating action not through wood, but from protoplast to protoplast at the rates given would imply transfer through two to four hundred living cells per second is too fantastic to be the subject of any serious comment.

To ascribe rhythmic variations in galvanometer readings connected with probes pushed into cortical layers[2] as due to hydrostatic pulsations is to throw aside all the safeguards of research. With Bose's suggestion that these pulsations may be the result of stimulation by friction of the roots with soil particles it is realized that the passage from pseudo-research to infantile fancies is an easy one. A sympathetic exposition of the Bose Institution and of the work of its director reprinted in *The Garland* (Calcutta) for May, 1926 (edited by S. M. Swaminathaiyer) includes the following passage: "For the mysteries of nature are probed in Sir Jagadish's institute not by study of libraries or by mechanical experiments, but primarily by communion with the unseen and the unknown. Inspiration, imagination, intuition, vision, this is an even more romantic touch."

The correctness of this characterization is attested by every page of Bose's book on the ascent of sap, which is utterly lacking in scientific significance. Such books appearing on the lists of scientific publications constitute a menace and danger to sound science.

Since the acceptance of Bose's work in America and since it has been widely proclaimed in the popular press of Great Britain, we are led to say that such recognition of Bose's work on ascent of sap and the nervous mechanism of plants has been confined to persons of non-scientific training, political propagandists and literary reviewers, whose capacity for judgment, motives and purposes may not be adequately discussed here.

Much attention has been given in our experiments of the past three years to the path of the upward movement of liquid in different types of woody stems and to the analysis of varying pressures which may be detected in the cortex, water-filled wood and gas mesh-work in the older wood. A comprehensive

[1] Bose, J. C. "The Physiology of the Ascent of Sap." London, 1923.

[2] This reaction has not been confirmed. See Dixon, H. H., "The Transpiration Stream," London, 1924.

presentation of earlier results was published in 1926.[3]

Positive or exudation pressures in latex systems and resin canals have been measured. Some positive pressures have also been found in bores driven into central or older wood which are ascribable to temperature expansions of gases. Pressures as great as 5 Atm. have been found in resin canals in pine trees, and of nearly one Atm. in other trees attributable to gas expansion in the heart wood.

These sources of positive pressure seem clearly separable from positive pressures ("root-pressures") which show on stumps of stems and of roots. For these no adequate explanation has yet been found.

The liquids used by us in tracing the movements of sap include toxic solutions of picric acid, 1 pct., which are carried along by the sap stream and diffuse into living cells; solutions of anhydrous sodium tellurite at 0.00007 to 0.00017 M which is reduced by protoplasm and gives a black precipitate not toxic at this concentration, and acid fuchsin 1–1000 in distilled water, the particles of which are so large that they may pass through microscopic openings such as the perforations in the membranes of pits in coniferous wood, and other openings left by the disintegration of plasmodesmen.

Strasburger's classical experiment of the movement of picric acid in a tree was repeated with the arroyo willow (*Salix lasiolepis*).

As a result it is concluded that conduction is strictly in the xylem and that the movement in this tract is of a different type and rate from that in the phloem. Experiments show that differences in age, amount and position of the wood affect its conducting capacity. Conduction of dyes is most rapid and to the greatest heights in tracheae with unblocked lumina, those containing tyloses, deposits of gum, or blocked with gas bubbles conducting feebly, if at all. In the willow practically all annual rings retain their capacity to conduct, but the individual elements of the xylem possesses unequal conducting capacities, the spring and summer wood not being concerned to the same extent. Conduction occurs mainly in the late summer wood of any annual ring near the terminal parenchyma. In this species tyloses develop very early and are present in all annual layers of wood, even in that of the current year's growth. Blocking of the vessels by tyloses occurs extensively in all layers except in the vessels of the late summer wood in which region conductivity is retained for years. Frequently certain later formed vessels of the summer wood do not abut upon medullary rays. As there is no wood parenchyma other than the terminal parenchyma, these vessels are not in contact with parenchymatous cells formed by the cambium. Therefore no tyloses can be formed in such vessels. Vessels of the spring and early summer wood, or the contrary, almost always lie adjacent to medullary rays, and most of these vessels are blocked by tyloses.

In the walnut, conduction is also mainly in the late summer wood, but not so sharply confined to this region as in the willow. Unlike the willow, all vessels are in contact with living parenchymatous cells, hence the possibility of the formation of tyloses in all vessels. All vessels of the spring wood usually become blocked by tyloses toward the end of the growing season, after which conduction occurs only through the unblocked vessels of the summer wood. However, these vessels of the summer wood of any annual layer develop tyloses and also become blocked, so that there is consequently no conduction through either spring or summer wood. The summer wood retains its conducting capacity for a period of four to six years, after which tyloses develop in the vessels of the summer wood and consequently there is no conduction through either spring or summer wood. Conduction is therefore confined to a certain number of superficial rings and there is no conduction through the interior heart-wood.

It appears that the presence of living cells in contact with the conducting elements of the xylem is a hindrance rather than an aid to conduction, as they may form tyloses and block the vessels. Furthermore, the conduction of a comparatively harmless dye in an untreated stem is not different in any essential particular from that in a trunk filled with picric acid. The existence of perforations in membranes of bordered pits of the wood of Monterey pine was demonstrated by pulling particles of Chinese ink, and particles of graphite from "aquadag," a lubricant made up in a watery suspension, by means of suction set up and maintained by a rotary air pump working in heavy oil, through sections of stems of the Monterey pine.

The pattern of the conductive tracts in the pine, walnut and willow have been made out. It has been found that the number of layers occupied by sap and the part of each layer serving as conduits is determined by perforations in pit-membranes, by tyloses and by apical connections with transpiratory systems in leaves.

D. T. MACDOUGAL
CARNEGIE INSTITUTION OF WASHINGTON
J. B. OVERTON
UNIVERSITY OF WISCONSIN

[3] MacDougal, D. T., "The Hydrostatic System of Trees." Publ. 373, Carnegie Inst. of Wash., 1926.