Transpiration And The Ascent Of Sap In Plants

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BY

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PREFACE

The Ascent of Sap is a problem of old standing. As was the case with several other biological problems, a peculiar alternation may be observed in the hypotheses formed to explain the phenomena. At first the process of the ascent of water in trees was, almost without serious thought, assigned to the vital activities of the plant, and, in general with other vital processes, put outside the domain of physical investigation. Later, advances in physics and chemistry, introducing rationality into observation, emboldened hardy spirits to assign the whole process to various physical forces or to combinations of them. Doubtless these philosophers somewhat transgressed legitimate deduction, and their daring met its punishment in the overthrow of their successive physical theories. It was then again the turn of the Vitalists, and during the latter part of the last century they enjoyed their heyday of dogma. However, the leaven of rationality still worked on in even their theories, and several physiologists must have felt what Strasburger stated, that the physical forces developed in, and the physical configuration exhibited by, the water tracts would supply a complete explanation when properly understood.

In the present monograph, an account is given of a
physical explanation of the rise of water in trees. This theory rests on the knowledge of a property of liquids, which, although discovered in the middle of the last century, was little recognised and seldom referred to in physical literature. It now appears that a full appreciation of this property is essential for the realisation of the manner in which water is raised in plants and of the meaning of the structure of trees as a mechanism for lifting water.

In the formation of the theory and in much of the earlier work carried out to test its validity and to illustrate its applicability, Dr. J. Joly and the author worked in collaboration. The work on the cryoscopy of sap was carried out with the help of Mr. W. R. G. Atkins, to whom the author is further indebted for his help in reading the proofs and for his useful criticisms. Prof. R. A. Gregory—the editor of this series of monographs—has also kindly supplied several valuable emendations and suggestions.

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TRANSPERSION AND THE ASCENT OF SAP IN PLANTS.

CHAPTER I

THE NATURE OF TRANSPERSION

Transpiration and evaporation.—Comparison of the transpiration from the upper side and of that from the under side of hypostomatous leaves has shown that transpiration is principally effected through the stomata. The total area of the stomata, however, bears but a very small proportion to that of the whole leaf. For example, in a leaf of Catalpa bignonioides it is but 0·9 per cent. of the total leaf surface. In a leaf of Helianthus annuus the area of the stomata appears to be about 3 per cent. of the whole leaf surface.

Many years ago, Unger showed that under similar conditions the amount of water evaporated from a free surface was 2·8 to 13·8 times that transpired from an equal leaf surface. If we take the lower limit, this means that 35 sq. cm. of water surface will give off as much water vapour as 100 sq. cm. of leaf surface under similar conditions. Of this 100 sq. cm. as much as 3 sq. cm. may be represented as stomata. So we arrive at the surprising result that the combined area of the stomata is at least ten times as efficient in giving off water vapour as a free water surface of equal area.
Diffusion through stomata.—The beautiful researches of Brown and Escombe on diffusion through perforated septa have satisfactorily cleared up this difficulty. They showed experimentally that the amount of vapour which diffuses through a perforation in a septum does not diminish proportionally as the cross section diminishes, but only in proportion as its diameter decreases. This result, which is at first sight by no means obvious, has been mathematically explained by both Stephan and Larmor. Brown and Escombe quote both writers; but as their methods may not be easily followed by all botanists the following simple explanation may be of interest.

When diffusion, undisturbed by convection currents, is taking place from a perforation which is kept filled with water vapour, or from a surface of water, into a space less rich in water vapour, it is evident that after a time a certain gradient of concentration will establish itself over the aperture. The concentration will be greatest near the perforation and less more remote from it, whilst shells of uniform concentration will be found over-arching the perforation. At a little distance from the aperture, say when the diameter of the shells is about four times that of the perforation, these shells will be approximately hemispheres.

To possess any given concentration $\rho$ a shell must have an area bearing a definite proportion to the area of the perforation; because the supply maintaining its concentration is derived from the water molecules leaving the aperture, and the number of these will be proportional to its area.

Let $R$ and $A$ denote the radius and area respectively of the shell having a concentration $\rho$, and $r$ and $a$ the radius and area of the perforation. Let $\rho_1$ indicate the concentration of water vapour in the perforation.

$$A = ka \text{ or } R^2 = kr^2.$$