mental impression too faint for complete identification, now that attention is directed to it, nevertheless rose into consciousness with the semblance of a spontaneous idea, and gave rise to a distinctly plagiaristic publication.

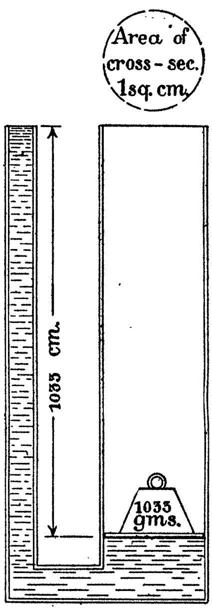
G. K. Gilbert.

San Francisco,
June 28, 1904.

SPECIAL ARTICLES.

THE ASCENT OF WATER IN TREES.

Recent discoveries by Vesque and E. B. Copeland and others have brought us very near the solution of this inveterate problem; but botanists seem agreed to halt at the last



Hydrostatic Paradox.

step, awaiting some occult signal from the physicists. The old toy of the 'hydrostatic paradox' ought to teach them that water pressed upwards by the atmosphere has no divine right to call a halt at 1,033 centimeters. One fluid may support and also elevate another fluid to any required height. Thus the supported weight in the annexed diagram may be represented by a column of water raised a mile high or more. The condition is that there shall be no immediate continuity of mass between the fluid to which the atmospheric pressure is applied, and that which is to be lifted. This condition is secured in the tree by the numerous transverse septa on its water-ducts, which prevent the transmission of air or water in mass, but permit a very free molecular diffusion of water, and of everything dissolved in it.

Assuming the diameter of a water-duct to be half a millimeter, it is easy to estimate the weight supportable by a septum at its base; seeing that its upward parts are protected from other atmospheric pressure. The area of the cross-section of the basal part, in centimeters, if multiplied by 1,033 (the height in centimeters of a column of water equaling the atmospheric pressure), gives 2.028 cubic centimeters, or the same number of grams, as the load which the basal septum can support. This load may be a column of water filling the whole duct for a height of 34 feet, or it might be a column or stream of water twelve times as high and only one twelfth as large in cross-section. If the duct were filled with one part of water and eleven parts of air, the water and air together should be supported by the atmospheric pressure at the base to a height of about 403 feet. Assuming that there were in this course about 90 cross-septa, approximately equidistant, we should have a fall of pressure with each succeeding stage, equivalent to about one third of an inch of the mercurial barometer, reaching zero at the summit.

The mechanism in the xylem-ducts, however, can not be of this kind; because not only would the gas-bubbles obstruct the current if they came between it and the walls, but the spreading out of the pressure of the ascending current over the septa would cause the 'hydrostatic paradox' to work backwards with greatly increased force. This compels us to favor the view of interning the gas-bubbles within the water. Dr. MacDougal states that 'the cavity of a wood-cell contains a bubble of gas' ('Plant-Physiology,' p. 29). And Strasburger describes the water as freely streaming round the gas bubbles, or between them and the walls. This arrangement of water surrounding gas-bubbles constitutes what is known as foam; not, indeed, of the rough kind, but 'dressed' so as to be in unison with the shape of the duct through which it must pass. It would take a great many hundreds of meters of such foam to weigh a kilogram to the square centimeter. Thus the atmospheric pressure at the base proves to be sufficient for the work to be done. Every change of equilibrium will cause a movement upwards of the water which is the only movable ingredient of the mixture.

If we are correct in accepting the observations that the water thus surrounds and encloses the continuous or beaded air-globules (which must also have much vapor of water) not only is the streaming of the water accounted for, but also such phenomena as capillarity and diffusion, and occasional stasis reminding one of the phenomena of capillary circulation of blood. Also the correlation which Strasburger, Vesque and others have observed between the state of the barometer and the streaming within the xylem-ducts is explained; and possibly the pulsation of gas-bubbles which MacDougal regarded as helping to raise the water upwards.

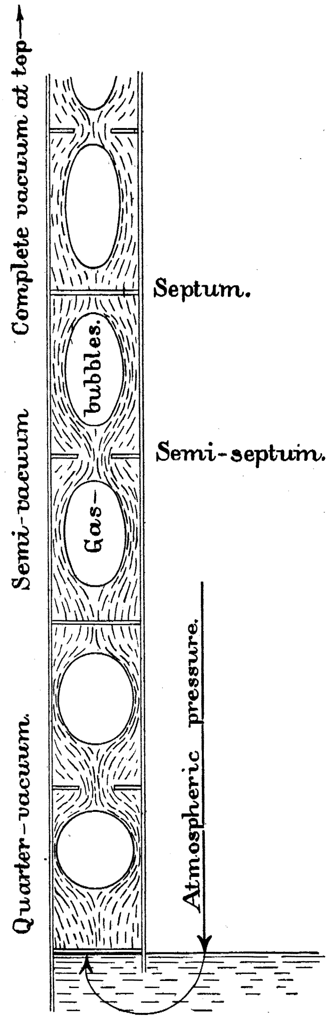
The condition of low apical pressure is secured by the activity of the leaves correlated with the structure of the ducts. The leaves are not known to actively attract the water, but they always remove it as it arrives, turning it into starch, and transpiring it in great quantity. When they die or are stripped, the ascent of water ceases (though at lower parts of the stem bleeding may be thereby induced). Also in the leaves and downwards the water-ducts are protected from direct atmospheric pressure by their structure, having spiral threads, and bars and thick walls to prevent compression, and having their very tips roofed over by domes. Their pits with thin membranes permit diffusion sideways, into other ducts or into parenchyma; and thus interchange is secured among the different elements. The machine will not work if the walls are torn, but if they are whole, their being dead does not obstruct their action. The fact that trees become stag-headed from a loss of water proves a delicate adjustment, especially as the different species have their differences of height and other idiosyncrasies relatively to the phenomenon.

The transverse septa of the water-ducts appear to us to play a leading part in the process. Transmitting the water by diffusion and intercepting the gases, they constitute a series of chambers each having a number of immobile air-bubbles, and permitting the water to flow between these by the only channel which it can take. We do not know how thick is the stream, otherwise than by the deductive method given above, but it probably varies in thickness and rapidity relatively to the height and leafage of the tree; very lofty trees having little leafage, and yet having many water-ducts. We think that the dynamical part of the problem is explainable mainly by the *vis a tergo* of the atmospheric pressure at the base.

The tracheids of the giant conifers exhibit the same principle, by their bordered pits with a torus which is centrally thickened and is overarched by diaphragms. The torus is a relatively large flexible membrane, which transmits the whole pressure, and at the same time limits the quantum of water that can find a passage upwards.

The air drops are not only obstructed by the septa, but they seem to keep apart within a section, as if we had a combination of the Jamin-theory with the osmotic functions of the septa. Each air-drop seems to have a shell which prevents its fusing with its neighbors, and thus the system becomes a sort of emulsion, like the fat-globules in milk. My colleague, Professor E. H. Loomis, who has aided me by criticizing the physical points, furnishes me with a striking illustration of this phenomenon. A bubble of air having got into one of his barometers, and being imprisoned between the mercury and the glass, he let in other bubbles. But these carefully avoided it; and when their course seemed to indicate collision and fusion, they turned aside and passed round it, escaping contact. Another colleague tells me of a case in Kansas where the lives of a community were saved during a drouth by a rotten pump which admitted air as well as water and raised the mixture about 40 feet after the other pumps had given out.

The second diagram represents the air-bubbles as gradually narrowing upwards. This accords with the theorem of Schwendener and Steinbrink, who held that the ducts are ex-



Xylem-duct.
(diagrammatic)

ceedingly narrow at their tips. The same result is given from observations on the red beech by Hartig and Weber. Strasburger had previously shown that narrow ducts contain very little air, and have streaming water; whilst large ducts in tall stems have much air and usually little water. If we accept these data we find an extraordinary correlation. Through the length of a lofty stem are wide tubes, whose contents are a column of froth of the lightest kind, having a maximum of air in a very thin shell of water. In the region of the leafy spray the conditions are reversed, narrow ducts and a relatively heavy load; and hence the need of a high vacuum, which is secured by the curious structure and the proximity of the leaves.

I am obliged to Professor MacDougal for referring me to Steinbrink's paper, and to Mr. Earle Anderson for drawing the diagrams.

George Macloskie.
Princeton University,
June 25, 1904.

BOTANICAL NOTES.

THE NUMBER AND WEIGHT OF COTTONWOOD SEEDS.

At my suggestion, one of my students, Mr. B. R. H. d'Allemand, made careful counts and estimates as to the number and weight of the seeds of the cottonwood (*Populus deltoides*). Selecting a well-grown pistillate tree about forty feet in height with a trunk two feet in diameter, and a spreading top fully forty-five feet from side to side, he carefully divided it by an imaginary vertical plane into two equal parts. One of these halves he divided again in the same manner, and continued the process until he reached a branch small enough to enable him to count the number of catkins which it bore. It was found in this way that the tree bore about 32,400 catkins. Then a number of careful counts were made of the seed pods in the catkins, by which it was found that the average number is about twenty-seven. The average number of seeds in the pods was easily determined by a series of counts to be thirty-two. From this it appears that this particular tree produced the enormous number of nearly twenty-eight millions of seeds.

One hundred seeds with their cottony fibers attached were then weighed upon a chemical balance. The result was .065 gram. So the weight of a single seed is .00065 gram, and the total weight of all the seeds on the tree 18.2 kilograms, or almost exactly forty pounds.