THE RESISTANCE TO FLOW IN WOOD VESSELS.—In vessels filled with water, the resistance to flow depends upon the rate of flow, the square of the radius of the tube, the length of the vessel and the viscosity of water. Although the vessels are relatively narrow tubes, the rate of flow is not very great, so that the total viscosity resistance to flow in an ordinary tree during active transpiration is considerably less than the height of the tree¹. As air appears in the vessels, however, two new factors are introduced. In intact vessels these bubbles when large and pressed against the sides of the vessels remain approximately stationary, the water flowing past them. Under these circumstances the surface tension film around each bubble forms an additional limiting surface to the ascending stream. If the latter exercises any friction upon the sides of the bubble, and it is difficult to see how friction against a stationary surface tension film around the air-bubble can be avoided, then the bubble must be subjected to some downwardly directed force which counterbalances the frictional and gravitational upthrust upon it.

The explanation of this peculiarity seems to lie in the fact that a true Jamin's chain action is exercised in wood vessels containing air-bubbles and water-columns, in spite of the fact that the walls of the wood vessels are lined internally by a more or less continuous adherent film of water. No Jamin's chain action can be exercised when the liquid wets the smooth walls of a containing vessel equally at all points, since in this case the boundaries of the surface tension films move as readily as the central regions instead of being dragged back, so that the front boundary of each drop becomes convex, and the hinder one concave. As a matter of fact, however, a true Jamin's chain resistance does appear to be shown in vessels lined by a film of water and whose walls are wetted by water. Possibly this may be due to the internal localized thickenings of the walls, the surface tension films coming within the limit of adhesion opposite to these but moving freely between them. In this way a valvular mechanism could be maintained in the vessels, by the aid of which water could be passed from point to point in a vessel by slight local forces, without the total head of water in the tree requiring to be maintained by any pronounced pressure or tension applied at base or apex. Thus in Fig. 8 a slight pressure generated between *b b* would be prevented from acting downwards by the bubble beneath adhering at *a a*, so that the surface tension film became more convex, and would act upwards only. A wave of actions of this kind running up along the vessels would raise the water upwards.

Evidence as to the existence of a true Jamin's chain resistance in the conducting wood of actively transpiring trees is afforded by the fact that the resistance to flow is much greater than would be expected from a viscosity calculation. In addition direct evidence was obtained in the following way. Living branches of the plants previously examined (*l. c.*) were shaved down at one end until thin enough to examine the uncut vessels under the microscope. The other end was fixed to a pressure apparatus containing a coloured liquid which could be driven slowly

¹ See Ewart on the Ascent of Water in Trees. Phil. Trans. 1905, p. 44 seq.

through the wood. To retard the flow the distal end was imbedded in a mass of vaseline, and in all cases it was seen that where the vessels contained large air-bubbles the front end of each film became more convex when pressure was applied, while the hinder end became flattened or concave. These effects become extremely pronounced when the bubble is passing the constrictions where segment cells join

Fig. 8.

Fig. 10.

FIG. 8. Diagrammatic longitudinal section of a segment of a vessel. The ends of the segments at *a a*, *b b*, form the adhesion points of the surface tension films. FIG. 9. View from beneath of a surface tension film on the under side of an air-bubble at the middle of a segment, showing that water may still be able to pass the air-bubble in spite of the adhesion of the surface tension film to the inner wall of the vessel. FIG. 10. As in Fig. 8, but with less water, so that the films adhere to the inner wall, and as in the true Jamin's chain there is no internal lining of water between the water-columns.

(Fig. 8, *a a*, *b b*). The same differences were maintained as the bubble was driven slowly along the tube, so that it can be safely assumed that the differences of curvature were even more pronounced with velocities too high to permit of direct observation. At the same time the coloured solution appeared in front of the last few air-bubbles in the series¹, so that here we have what appears to be definite proof

¹ These observations can be made on the stem of the *Wistaria* with the aid of a hand lens without injuring the wood.

that the water is able to pass the air-bubbles and surface tension films in the vessels, and yet the films are able to exert a back pressure increasing the resistance to flow. Further research must determine whether the explanation given is a true one, or whether unknown factors enter into play in the vessels.

When the walls of the vessels dry, or become covered internally over the whole or parts of their length by films of oily or similar substances, a true Jamin's chain may be set up in the vessel (Fig. 10). This, when once formed, is difficult to remove and interposes a relatively enormous resistance to flow when the vessel is narrow and the air-bubbles numerous. Even then, however, the presence of longitudinal pores containing water and longer than the air-bubbles may allow water to pass slowly even when the films appear to be adherent to the internal wall. The air in dry wood vessels always tends to break into shorter or longer bubbles when the wood is soaked in water, so that the normal conductivity can only be restored by forcing in water under such pressure as either to break the adhesion of the surface tension films to the walls of the wood vessels, or to render their attachment more labile. Naturally the conductivity restored in this way will be rapidly lost again if the wood is allowed to become depleted of water, and even if the supply is maintained by suction, the presence of any films of oily or impermeable material on the interior of the vessels will tend along with the increasing air-bubbles to produce an ordinary high resistance Jamin's chain. The latter involves an interrupted column of water, rapid upward flow requiring a movement of the entire series of air-bubbles and water-columns, which is impossible in vessels with imperforate partitions across them.

On the other hand, the valvular type of Jamin's chain with a peripheral adhesion film of water, allows local feeble pumping actions to be maintained from point to point in a staircase fashion. The least resistance to flow is shown when the vessels are filled with water, and continuous water-columns may support a tension of over 200 atmospheres in the absence of air¹. The transpiring leaves cannot exert the tensions required even momentarily in the wood vessels of the tallest trees (150 metres), since these are very much greater than is usually supposed².

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ON ENDOPHYTIC ADAPTATION SHOWN BY ERYSIPIHE GRAMINIS, DC., UNDER CULTURAL CONDITIONS³.—In recent papers by the author the fact has been pointed out that certain species of the *Erysiphaceae* are able, under cultural conditions, to infect their host-plants vigorously when their conidia or ascospores are sown on the cells of the internal tissues exposed by means of a wound, although the fungi in question are confined normally to the external surface of the epidermal cells.

The present paper gives the results of investigations carried out in the laboratory of Professor Marshall Ward at Cambridge, with the object of ascertaining the details

¹ Berthelot, Ann. de Chimie, xxx, 1852.

² Ewart, loc. cit., p. 55.

³ Abstract of a paper read before the Royal Society on April 6, 1905.

Ewart, Alfred J. 1905. "The resistance to flow in wood vessels." *Annals of botany* 19, 442–444. <https://doi.org/10.1093/oxfordjournals.aob.a089011>.

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