observations on some of the other plants, *e.g.*, Plum "Belgian Purple." On the other hand, many species of both evergreen and deciduous plants do not admit of the water conductivity results being grouped in so satisfactory a frequency curve as that of the Privet.

The Evergreen Oak (*Quercus Ilex*) also stands high, at about 28. Its wood is far less close than that of most evergreens, and contains wide vessels resembling those of the common Oak. It shares with the latter species a considerable degree of plasticity, and in this respect it also departs from the evergreen type.

The relatively freely transpiring evergreen Portugal Laurel (*Prunus lusitanica*) has a specific conductivity of about 18·5; of 14 specimens examined 10 were within ± 4 of this amount. The Common Laurel (*P. Laurocerasus*), as might have been expected, ranks much lower, and of 9 specimens 6 fell within the limits of 10 ± 2.

A number of other evergreens were examined, but those here mentioned will suffice to indicate the general character of the group. The preceding Table will, however, sufficiently indicate the range of the investigation on evergreens; it will be more fully referred to in a second paper dealing with the deciduous species of trees and shrubs.

On the Quantitative Differences in the Water-Conductivity of the Wood in Trees and Shrubs. Part II.—*The Deciduous Plants.*

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If the broad-leaved deciduous trees and shrubs be contrasted with the evergreens, it is found that they are marked by a specific conductivity which in the free-growing and foliage-bearing shoots is far greater than in the class hitherto considered.

This is well brought out by contrasting the results obtained on comparing an evergreen with a deciduous species of the same genus. The subjoined Table (I) for *Euonymus japonica* (evergreen) and *E. europæus* (deciduous) will serve to illustrate the point. It will presently become apparent, however, that there are certain exceptions to be reckoned with amongst the deciduous trees, especially in the case of young sapling trees and coppice stool-shoots (*e.g.* of ash or hazel).

Table I.

Euonymus japonica (Evergreen). *Euonymus europæus* (Deciduous).

Age in years.	Absolute vol. in c.c. per ¼ hour.	Specific vol. in c.c. per ¼ hour.	Age in years.	Absolute vol. in c.c. per ¼ hour.	Specific vol. in c.c. per ¼ hour.
1	0·6	12·5	2	10·6	29·7
1	0·5	7·5	5	6·0	31·0
1	0·5	10·2	2	16·0	38·0
2	1·4	9·0	6	12·2	46·3
2	1·0	8·9	4	16·4	48·3
1	0·6	9·5	6	8·6	51·0
1	0·4	8·6	5	13·8	45·5
1	1·4	13·4	3	7·8	47·3
2	0·7	11·6	5	11·4	45·0
2	0·8	11·3	3	5·2	39·5
1	0·8	13·4	4	21·0	53·0
1	0·6	10·9	5	4·8	26·7
1	0·3	9·8	2	9·8	37·0
2	5·2	19·1	4	8·8	40·0
3	4·2	17·0	2	9·0	29·7
2	3·9	17·1	2	14·4	37·0
3	3·1	14·9	2	10·2	33·0
1	1·5	13·7	3	8·8	45·5
Total		218·4	Total		723·5
Average		=12·1	Average		=40·2

A second feature which is brought out in the Table is that the range of actual values is larger in the deciduous trees. This is largely owing to the fact that the *proportional* range is not very dissimilar as between the two classes as a whole. But the relatively high mean in the deciduous plants makes the fluctuation more noticeable, and its absolute extent is, of course, much greater. This feature is evidently bound up with the water supplies at the disposal of the more rapidly transpiring leaves, but the inter-relations of water supply and transpiration are very complex, and will not be further discussed here, especially as they are forming the subject of separate research at the present time.

Nevertheless, the opinion may safely be hazarded that the relatively efficient character of their wood, together with its plasticity in relation to requirements, constitute, at any rate, two of the factors which have co-operated to enable the deciduous trees to assume the dominant position they enjoy in the ordinary environment within the temperate zones. Even within the tropics deciduous species are not uncommon, especially where there is an alternation of dry and rainy seasons.

The plasticity in wood-structure is borne out even within the limits of individual shoots, especially in the free-growing "extension" branches. The specific conductivity is often lower at the base than higher up, in which

region the lateral leaf-bearing shoots are chiefly produced. A relatively larger proportion of the wood at the base is devoted to mechanical construction, and less to conductive purposes. It may easily happen, and, indeed, commonly does, that the absolute volume of transmitted water is greatest at the base, owing to its greater cross-sectional area. Hence, in endeavouring to get an idea of the specific conductivity of the wood as a whole, and for comparative purposes, it is best to test consecutive lengths of such branches, and then to average the lot for each shoot. The averages thus obtained coincide with one another more closely than was anticipated, and the resultant figures agree nearly with those which best express the character for a given species. In the earlier stages of the work, before this had been recognised, the figures, though obviously grouping themselves more or less round a mean, appeared to be broken up into puzzling sub-groups. This was largely due to the chance positions in a branch from which the specimens to be tested had been selected. This plasticity of the wood is a matter of great importance, which the forester cannot too clearly recognise, for, by understanding the limits of variability and the conditions that affect them, he is obviously in a better position to produce the largest yield of the most desired kind of timber. It becomes plain that, while the deciduous trees are far more plastic in respect of the quantitative distribution of the tissues composing their wood than are the evergreens, they also differ a good deal amongst each other in respect of this plasticity.

After examining the stems of Birch, Hazel, Ash, and Sycamore in sufficiently large numbers (from 100 to 300 for a single species), and plotting the results as curves, it became evident that several independent factors were concerned in producing the irregularities observed. The water conductivity was found, generally speaking, to be lower in young plants and stool-shoots, and to be often very much higher, and also far more variable (*i.e.* the wood is much more plastic), in rapidly-growing older trees. In the shoots formed on adult trees, however, the value again sank, and a closer approximation to a particular mean was obtained, in other words, individual variation became more restricted. The leading shoots, in spite of their wider average diameter, were commonly of lower specific conductivity than the laterals. This is very marked by the case when, as in the Ash, the leader commonly becomes more or less abortive, its function being assumed by one or more of the lateral branches below it. But, in any event, the laterals usually produce the bulk of the leaves, either directly or by further branching, and it is these leafy branches which always display the highest specific conductivity, at any rate, in young trees.

The methods employed in dealing with the experimental data acquired

during this investigation were mainly statistical. This appeared, in the present lack of accurate knowledge on the subject, to be the most promising way to attack the subject, and to offer the best chance of clearly formulating further problems. But the conclusions drawn from the data themselves must be cautiously and critically drawn. The nature of the material, especially in the case of deciduous trees, often shows rather wide fluctuations. When there is reason to believe that these fluctuations arise owing to the lack of real homogeneity in the material, it is obvious that nothing is gained by determining the arithmetic mean and the probable error. The curves drawn from a large series of observations sufficiently indicate the interaction of different factors, and increase of the observations does not lead to a smoothing of a single curve for the total results. A frequency-grouping of values at different intervals is what is obtained, and in this way one arrives at a clearer recognition of the existence of the several influences which affect the general result.

The observations made of the Birch afford an illustration of the foregoing remarks. They show that a smooth curve cannot be obtained, nor is it likely that a very large increase in the experiments would bring this about. Even if it did the results would be misleading, because in collecting data from an indiscriminately selected lot of Birch twigs one is dealing with really heterogeneous material. The leading shoots are worse water-conductors (per unit area of wood) than the laterals, and the presence of the two maxima leads to a flattening of the curve in the intervening values. At the same time, as the subjoined Tables show, a few unusually high or low figures may seriously disturb the position of the arithmetic mean of the result if taken from such a relatively small number of specimens as 28 sets of laterals and terminals here presented.

The shoots were obtained from a lot of trees all about five to six years old, and as much care as possible was taken to secure as fairly average a set as possible both of terminals and laterals. The results show that by taking the mean of each series, it would be concluded that there was but little difference (at most only 2·8) between them—too small to be regarded as significant. But the numerical average for the terminals is really too high, and this is due to a small detached group standing at about 67. The *density* average for the terminals lies about 40, whilst that of the laterals is at about 52. The Tables give the areas as well as the absolute specific volumes, and the close agreement between the average specific volume, as recorded at the bottom of the last column, with that obtained from the sum of the areas and absolute volumes at the foot of the third column, affords a ready check on the calculations as a whole.

Table II.—Twenty-seven Birch Twigs. Leading (or Terminal) Shoots.

Age in years.	Area in inches (× 10).	Absolute vol. of water passed in ¼ hour.	Specific vol. of water per ¼ hour.
1	2·46	7·6	48·0
1	2·26	7·2	49·0
1	2·30	7·2	48·5
1	1·95	8·4	67·0
1	3·18	13·0	67·0
1	2·25	5·4	37·0
1	3·33	11·2	53·5
1	3·00	12·3	65·0
1	2·60	7·7	45·5
1	2·03	5·5	42·5
1	3·98	8·2	32·0
2	2·65	7·0	41·0
1	2·16	6·0	43·0
1	1·34	3·0	34·7
1	2·46	6·5	41·0
1	2·09	4·4	32·5
1	1·75	4·6	40·7
1	2·46	6·2	39·0
1	2·29	6·6	44·5
1	1·88	6·1	50·0
1	1·96	6·0	55·0
1	2·58	8·4	50·0
1	2·36	8·0	53·0
1	1·81	4·2	36·0
1	1·98	8·6	67·0
1	2·33	5·4	36·0
2	2·32	5·8	39·0
	63·76 sq. in. (at × 10)	190·5	1257·9
	=4·12 sq. cm. (actual size)	$\frac{190 \cdot 5}{4 \cdot 12} = 46 \cdot 2\ldots$	Average = 46·6...

With the results obtained from these young trees it is useful to compare those taken from branches cut from a tree of 14 years of age, and about 22 feet in height, felled in July, 1917.

The mean value of the position of greatest density of the numerical results both fall somewhat below that of the young laterals, but above that for the young terminal shoots.

The main average range for the Birch extends from about 38 to 58, with very distinct maximal densities round 42 and 52. This result was arrived at as the result of investigating 164 stems chosen at random. The annexed figure, in which these are shown plotted on squared paper, shows that it is hopeless to expect to get any single significant average. It will be noted that there is a small but fairly well-defined group about 63. These exceptionally high numbers may occur in twigs of any age and any diameter. They are more frequent in the Birch than in most other species examined by me, but they occur occasionally in most deciduous trees.

Table III.—Twenty-seven Birch Twigs, Lateral Branches.

Age in years.	Area in inches (× 10).	Absolute vol. per ¼ hour.	Specific vol. per ¼ hour.
2	2·34	8·2	54·0
1	1·90	6·4	52·3
1	2·30	5·0	33·5
1	2·10	7·2	53·0
2	2·95	10·0	52·5
1	2·17	6·9	49·0
2	2·44	9·2	58·0
2	2·46	8·2	52·0
1	2·53	8·4	51·5
2	2·90	7·0	37·5
1	2·78	7·2	40·0
2	2·60	7·0	47·7
1	1·64	5·8	55·0
2	1·76	5·9	51·8
1	1·30	3·4	40·5
1	1·90	7·1	58·0
1	1·80	5·2	55·0
2	1·87	5·0	41·5
2	1·60	5·0	48·5
2	2·54	8·8	53·5
2	1·40	3·6	40·0
2	2·22	5·7	39·8
2	2·06	3·6	28·0
2	3·42	12·8	58·0
2	2·57	12·0	73·0
2	1·50	4·0	41·3
2	1·30	4·8	57·0
	58·35 ins. (at × 10) = 3·76 sq. cm. actual size	184·4 $\frac{184\cdot4}{3\cdot76} = 49\ldots$	1311·9 average = 48·6

As another instance of variation, it will be convenient next to consider the behaviour of young sapling trees, as compared with that of the branches and terminal twigs of an adult individual belonging to the same species.

The Sycamore furnishes a good example, and I have found the same conditions that exist in it to apply more or less entirely to all other trees I have been able to examine. If well grown young trees of from four to five years of age be cut up and tested from base to apex, it becomes apparent that the wood in the upper (younger) part of the vertically growing stem is a better conductor of water per unit area than that nearer the base. But although the specific conductivity shows relatively little change, there is a great falling off in the amount of water absolutely transmitted, owing to the narrowing of the diameter of the stem towards the apex. This becomes intelligible when one reflects that saplings, until they begin to branch, commonly possess a relatively small leaf surface. The absolute amount of water transmissible

Table IV.—Sixteen Birch Twigs from 14-year-old tree felled July, 1917. All are Lateral Branches.

Age in years.	Area in inches (× 10).	Absolute vol. per ¼ hour.	Specific vol. per ¼ hour.
2	2·72	7·6	43·5
2	2·56	9·3	56·0
3	5·56	15·8	44·0
2	4·72	14·4	47·0
2	6·87	22·2	48·0
3	6·84	22·0	50·2
3	8·17	21·2	40·0
3	4·42	16·0	56·0
3	3·23	8·0	38·5
3	3·35	13·4	64·0
3	5·20	14·6	43·5
4	6·20	23·8	59·5
3	4·24	10·8	39·5
3	3·33	10·0	47·0
3	3·50	13·0	57·5
3	3·64	9·4	33·3
	74·55 sq. ins. (× 10) = 4·81 cm. (actual size)	230·5 $\frac{230\cdot5}{4\cdot81} = 47\cdot9\ldots$	767·5 average = 47·9...

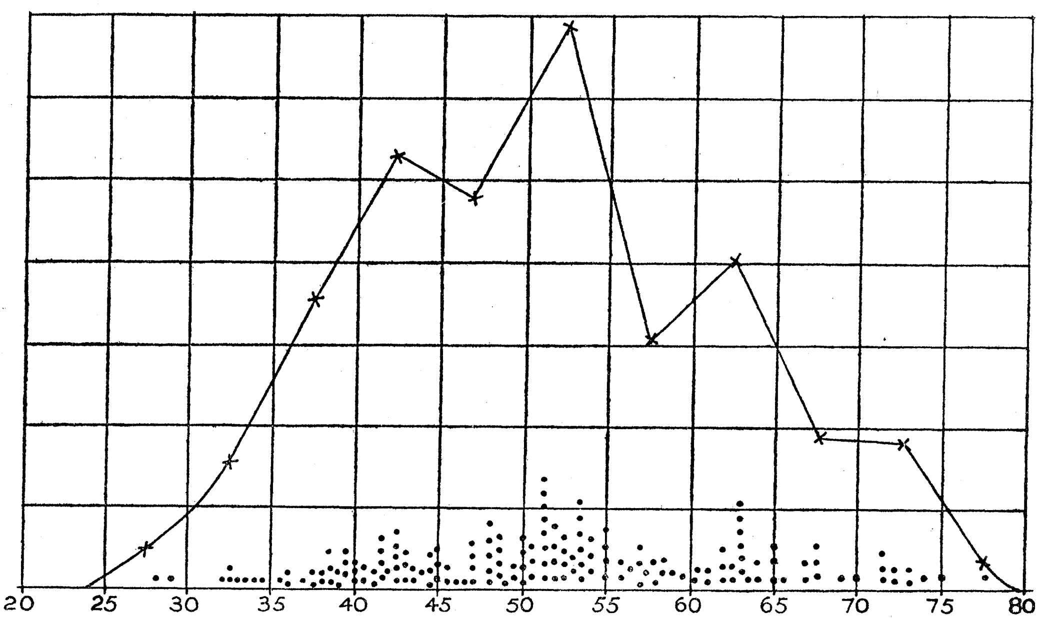

Fig. 1.—Results of haphazard mixing of Birch laterals and terminals of young trees with branches of older trees.

(at whatever the pressure) represents the relative water supply available for them. The apparently unnecessarily large surplus conductivity (absolute) in the lower and leafless parts of the stem is, nevertheless, important, inasmuch as, by lowering the resistance to movement, it enables the full supply to be maintained.

Table V.—Five Sycamore Sapling Trees cut into Lengths and Tested from Base to Apex.

No. of tree.	Order of Length.	Age in years.	Absolute vol. in c.c. per ¼ hour.	Specific vol. in c.c. per ¼ hour.	Average of specific vol. per tree.
A	basal	3	18·8	29·0	36·95
	2	2	24·6	42·0	
	3	2	17·6	38·5	
	apical	1	6·8	38·3	
B	basal	2	21·0	27·0	29·22
	2	2	21·8	35·5	
	3	1	17·4	37·4	
	apical	1	6·8	17·0*	
C	basal	2	15·6	40·3	29·22
	2	2	12·4	48·0	
	3	1	4·2	33·0	
	apical	1	1·3	26·5	
D	basal	3	16·6	31·7	36·57
	2	2	16·6	32·0	
	apical	1	11·6	46·0	
E	basal	2	15·4	39·5	41·17
	2	1	11·2	42·5	
	apical	1	4·4	41·5	

The general average of the specific volumes given in the last column = 34·63; all but one of the five sets of averages fall within ±5·5 of this number.

* This apex contained immature wood, hence its exceptionally low value.

The slightly lower specific conductivity observed at the base finds an explanation in the circumstance that a relatively larger proportion of the whole wood in this region is modified to subserve mechanical requirements at the expense of its water-conducting function. The same thing also occurs, but to a very much larger extent, in the stems of young climbing plants during the period that elapses between germination and the formation of the foliage-bearing shoots. It is, of course, difficult to decide as to which is cause and which is effect in these cases, but it appears likely that the relatively ill-conducting wood which is first formed, both in climbers and in many trees, encourages the rapid upward growth of the shoot by stopping down exuberant leaf production and reducing the tendency to early lateral branching. The higher absolute conductivity noticed at the base of the young sycamore trees is largely due to the quality of the secondary wood, in which water-conducting tissue is more abundant. But the steadiness of the figures

indicating specific (or relative) conductivity further emphasises the uniformity of the secondary wood in this respect, when regarded from the point of view of its composition per unit area. The Table (VI), which gives the results of comparing two lengths from the main stems of 10 young sycamores, illustrates the above points, and serves further to indicate the amount of variability that may be expected to occur in such material.

Table VI.—Ten Sycamore Sapling Trees with Sample Lengths (15 cm.) tested at the Base and near the Apex respectively.

No.	Position.	Age in years.	Absolute vol. in c.c. per ¼ hour.	Specific vol. in c.c. per ¼ hour.	Average of specific vol.
1	basal	3	4·6	20·2	24·25
	apical	1	5·2	28·3	
2	basal	3	8·4	20·3	27·40
	apical	3	9·0	34·5	
3	basal	3	10·8	34·3	36·40
	apical	2	10·2	38·5	
4	basal	3	5·0	25·8	28·65
	apical	2	4·6	32·5	
5	basal	3	4·6	20·7	28·35
	apical	2	5·0	36·0	
6	basal	4	4·6	17·8	22·55
	apical	3	5·2	28·3	
7	basal	2	6·0	25·2	25·95
	apical	1	4·8	26·7	
8	basal	3	6·8	26·2	27·10
	apical	2	5·4	28·0	
9	basal	3	10·8	34·3	36·40
	apical	2	10·2	38·5	
10	basal	3	7·2	26·6	31·05
	apical	2	7·2	35·5	

The general average of the specific volumes given in the last column = 28·81, and seven of the ten sets of averages fall within ±5·5 of this number.

The wood of the adult tree is always higher than that of the saplings, so far as my observations have extended. This is borne out by comparing the results given in Table VII with those contained in the two preceding Tables. It will be seen that the numbers for this tree vary within small limits, although the age and thickness of the twigs differed considerably. Corresponding to this difference between the basal and upper parts of sapling trees, a lowering of specific conductivity also distinguishes stool-shoots which spring from coppiced stems. This is well seen in all the instances I have investigated, *e.g.* Oak, Ash, Sycamore, Hazel, etc.

The last-named plant, the Hazel, may be taken as typical of these, and the wand-like rods that arise when the bush has been cut down very well illustrate certain characteristically recurring features in this class of stems, and in this they repeat the peculiarities of the young sapling trees as

Table VII.—Eleven Twigs from Topmost Branches of a large Sycamore Tree blown down in November, 1917. All the twigs had borne flowers.

Age of twig in years.	Absolute vol. in c.c. per ½ hour.	Specific vol. in c.c. per ¼ hour.
4	12·2	41·5
1	7·2	37·9
1	10·2	34·6
1	10·0	45·6
4	11·5	47·5
3	8·2	38·5
3	12·9	43·7
2	9·6	38·6
4	11·2	47·0
3	11·4	48·0
3	11·0	47·5
Total		470·4
Average		≒42·76

illustrated by the Sycamore. The wood at the base of the shoot always, or almost always, has a lower specific conductivity than that which occurs higher up. The reason lies in the relatively small amount of real vascular, and the large amount of mechanical, non-conducting, tissue. At the same time, the large diameter at the base often causes the absolute volume of transmitted water to be actually larger than that passing through the more efficient (from the standpoint of conductivity) wood higher up in the stem. As the top of the Hazel shoots is approached, both the absolute and the specific conductivity become rapidly reduced, and this is doubtless connected with many of the peculiarities of sympodial growth and branch development near the apex of such shoots, due to the dying back of the apex of the stem, and the subsequent resumption of growth by a lateral branch. The Table (VIII) shows the general type of behaviour of Hazel wands in the respects mentioned above, and it serves to emphasise the similarity that exists between sapling trees and stool-shoots—a similarity that often extends further, and embraces the arrangement and characteristic forms of youth leaves.

The Ash affords a good example of a tree in which the wood of the sapling and the coppice shoots ("ash plants") closely resemble each other in respect of their water-conductivity system, and differ greatly in this respect from the ordinary shoots which occur on the branches of the adult tree. For whereas the conductivity is great in the latter, owing to the abundance of wide and long vessels, in the former the character of evergreens is strongly recalled; even the absolute conductivity is often low in spite of the considerable thickness of the stems, but as branching supervenes, and vigorous secondary

Table VIII.—Two Long Stool-shoots of Hazel, A and B, cut into Lengths from Base to Apex.

Shoot.	Order of length.	Age in years.	Absolute vol. in c.c. per ¼ hour.	Specific vol. in c.c. per ¼ hour.
A	Basal	3	37·6	45·0
	2	3	32·0	48·0
	3	3	22·6	48·5
	4	2	12·8	38·0
	5	1	7·8	35·5
	6	1	5·0	37·5
	Apical	1	2·2	35·5
	Total			288·0
	Average			= 41·1
B	Basal	2	27·6	44·5
	2	2	20·8	47·5
	3	2	14·2	40·5
	4	1	3·8	25·5
	Apical	1	2·4	23·7
	Total			181·7
	Average			= 36·3

thickening occurs, the absolute conductivity of course undergoes a corresponding increase.

But the absolute as well as the specific conductivity of the wood falls off very rapidly as the apical region both of the leader and the lateral branch is approached. It is, I think, a fair inference that this falling off in conducting efficiency is responsible for the very characteristic habit of growth of young Ash trees and coppice-shoots. The apex often dies back for a considerable distance each year, and the elongation of the stem is assured by one or more of the stronger lateral shoots. More or less equally forked tops are not uncommon during the late spring and early summer, but one of the branches of the fork usually obtains the lead, and it is always found that its success is correlated with superior specific conductivity. A large number of examples have been employed to test these peculiarities in the Ash, as regards water-conductivity, and no exception has been encountered. Probably the best way of rendering the position clear will be found in presenting, in semi-diagrammatic form, the results obtained in a typical instance. The diagram illustrates the mode of branching, as shown in a vigorous young Ash tree growing in a hedgerow, and cut off in the early spring of 1917. The figures enclosed in brackets represent the absolute amount of water

transmitted through 15-cm. lengths of the stems at the places indicated, under the same standard conditions of pressure, etc., as have been maintained throughout the enquiry. The figures opposite, which are not so enclosed, give the specific conductivity values. It is thus seen to be almost

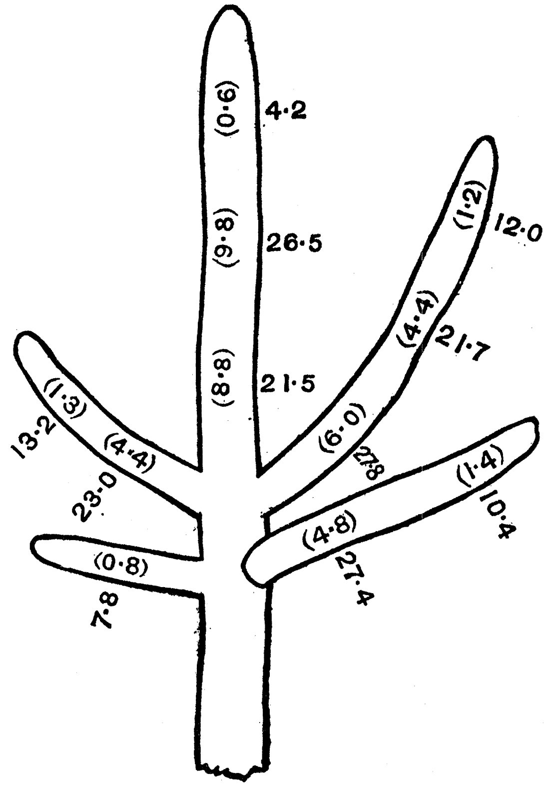

FIG. 2.—Semi-diagrammatic sketch of the top of a young Ash tree. The figures in brackets denote absolute volumes of water transmitted, those adjacent to them denote the specific volumes, at the corresponding places.

inevitable that the apex should die back, and that one or more of the stronger shoots should assume the *rôle* of leaders. The shoots further behind may grow out also, but they often fail to do so unless the stem be cut back. Of course it is not suggested that this water-conductivity factor is the only one that determines total habit; on the contrary, the final result is certainly made up of a complex of factors. But it seems clear that it does constitute an important element in determining which may and which may not become dominant shoots and branches.

In fig. 3 the top of a vigorous young Sycamore tree is represented for comparison with the Ash. It becomes at once obvious, on the basis of the

explanation advanced for the dying back of the apex of the last-mentioned tree, that the Sycamore is not likely to lose its apex. And, as a matter of

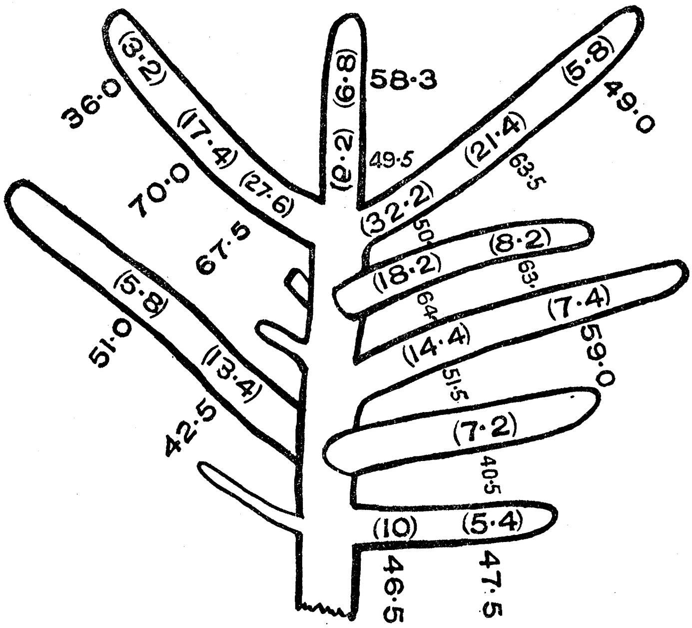

Fig. 3.—Semi-diagrammatic sketch of the top of a young Sycamore tree. The figures in brackets denote absolute volumes of water transmitted, those adjacent to them denote the specific volumes, at the corresponding places.

fact, it is very seldom that the leader in this species fails to maintain its predominance until it finally becomes merged in the formation of the crown of the maturing tree.

It is evidently unsafe to draw conclusions as to the specific conductivity of the branches of the adult tree from the behaviour of saplings or coppice-shoots of the same species. Thus, the Oak and Ash are both low in respect of the latter, but quite irregular, with very large values (from 70 to 120 or more) for the adult shoots. This great range of conductivity is by no means characteristic of all, or perhaps even of most, of the deciduous trees. Beech, Hornbeam, Elm, Sycamore, to mention only a few, are fairly regular; most Willows, on the other hand, can hardly be represented by any average number owing to their extensive fluctuation. It is just those species with wide fluctuation, however, that are likely to prove most amenable to intelligent treatment in respect of timber production, especially when it is desired to encourage the development of qualities the structural background of which is responsive to the influence of a particular environment.

A somewhat extensive series of experiments has been made on fruit trees

with the view of finding out what influence manuring and pruning might exert on the character of the wood. The results as a whole are still somewhat obscure, but it is clear that the effect of manuring is greatly to increase the amount of water-conducting tissue. This may account for the exuberant vegetative development and loss of fruitfulness which often occurs as the result of too liberally manuring fruit trees (plums, apples, pears).

The observations on the results of root-pruning were not very conclusive, though they all pointed in the direction of a lowering of the specific conductivity as a result. The actual amount of wood produced on two adjacent rows of trees respectively root-pruned (in 1916–17) and not so treated, was very striking. There was a large falling off in the absolute conductivity of the total shoots for the current year, and their feeble development was clearly a consequence of the pruning. But the *quality* of the wood in the pruned trees, as measured by its specific conductivity, was only slightly less efficient as a water-conductor than that of the unpruned set of pears and apples which were used as controls in the experiments.

During the course of the investigation it was observed that a seasonal difference in the water-contents of the wood is clearly apparent in most deciduous trees. For whereas twigs and branches cut off during the summer always float in water, those cut during the autumn and winter as regularly sink at once. This means that the air which is present in many of the water-conducting elements of the wood is got rid of soon after the fall of the leaf. In the summer, while transpiration is active and the water in the tree is under low pressure, bubbles of air are formed. As was shown by Dixon, these may be re-absorbed into solution under pressure. This is doubtless accomplished by means of root-pressure in early autumn while the soil is still warm enough to enable the roots to pump up water into the trunk and branches of the tree at a time when no corresponding amount is being lost through the leaves. In this way the lacunæ (localised in individual tracheids and vessels) in the water column within the tree are again filled up with water, and the wood is already preparing to meet the requirements of the unfolding leaves in the following spring. A few trees, however, possess branches which always float, but they are those in which, as in Willows, the pith and cortex contain considerable air spaces. Of course, it is not to be expected that branches old enough to have heart wood will sink in this way, inasmuch as the heart wood has ceased to conduct water and always contains some air. But in every example I have been able to examine personally I have found the specific gravity of lengths cut from trunks containing heart wood to be very much greater in winter than when cut from trees felled in summer. This difference is largely, but not perhaps entirely, due to relative

water-content in the sapwood, and it becomes a question whether, when the need for seasoned timber is urgent, it may not pay to fell during the summer in spite of the difficulties and disadvantages of so doing. Of course it is the deciduous trees that most clearly exhibit this kind of difference between the wood in summer and winter. The evergreens are transpiring all the time. and show to a far less extent the striking differences which are here referred to. I have endeavoured to obtain information on this subject from practical foresters and others * interested in woodland industry, but very little appears to be known, at any rate in this country, on the subject. Nevertheless, it would be easy to plan a few test experiments which would settle the matter, and they would also indicate the extent to which different species might lend themselves with advantage to summer felling, or how far the same drying out effect might be obtained by ringing the sapwood during the summer, as is sometimes done.

In such trees as Birches, Plums, and probably in others as well, it is possible to follow the autumnal filling up of the wood by the water. The lower branches are found to be filled first, and they sink when cut off and thrown on to water whilst those higher up still float. In a well-grown Plum-tree of about 12 years of age more than a week was required from the date at which the lower branches were first observed to sink, before the topmost twigs also ceased to float. The topmost twigs of a large Sycamore which was blown down early in November, 1917, still barely floated, while those formed lower down sank at once.

Naturally, as the soil becomes colder, the root action falls off, and it is not until the following spring that renewed activity supervenes, often to such an extent as to produce an abundant flow of sap from the stumps of trees felled at that season. It is perhaps to this latter circumstance that the widely spread idea of the wood being comparatively free from water in winter, and that the filling up of the water-conducting tissues is a concomitant of spring, is to be attributed.

In Central Europe, where the winter is more severe than in this country, R. Hartig† found the Birch to contain the lowest proportion of water at the end of September. From that time a slight rise was observed, which lasted till the middle of February, when a rapid increase occurs, and the curve indicating water-content rose sharply until the latter end of March,

* In this connection I desire to record my thanks to Mr. Duchesne for his information given from the point of view of a practical forester, and especially to Prof. Augustine Henry, who has most kindly placed me in possession of the chief statements in the literature, the extremely conflicting character of which indicates how little actual knowledge on the subject we at present possess.

† 'Unters. a. d. forstbotan. Inst. z. München,' II.

when it began to fall again. Doubtless the difference between Hartig's observations and my own in this respect finds its explanation in the relative severity of the German winter, which checks root absorption during that period in the situations in which Birch is prevalent. This view seems to be borne out by Hartig's statements concerning the Beech. He found that the period of maximum water-content in this tree coincides with the month of December, and not with March as in the Birch. The Beech grows in less exposed situations, and its close canopy likewise serves to mitigate the effects of freezing winds on the soil. It is also of interest to note that the Scots Pine in the Central European forests behaves like the Beech, although, as might have been expected, the seasonal fluctuations in the water-content are less marked than in the deciduous tree. It is evident, however, that it is unjustifiable to assume that the results obtained under the influence of a continental climate (*e.g.*, of Central Europe, or many parts of North America) must necessarily be identical with those yielded under such widely different climatic conditions as prevail over the greater part of the British Isles.

In the subjoined Table a summary is given of the investigations on the greater number of deciduous species which have been studied in connection with this research. I have not included a number of results on fruit trees, because they form a special part of the general enquiry which is not yet sufficiently ripe for publication. No attempt has been made in this, or the preceding paper on the Evergreens, to deal with the range of fluctuation in accordance with any fixed statistical principles, but a rather arbitrarily limited range for each species has been adopted where experience seemed to indicate the limits of normal fluctuation should be drawn. It might be argued that it is useless to attempt to fix any limits other than those afforded by the actual figures, on such a variable structure as that concerned in water-conduction. But at least it is useful to recognise the relative density or frequency of occurrence of the values within the extreme limits of variability, and it is obvious that there is in most cases a genuine average value which can be assigned for each species. It is equally evident, however, that the proportional fluctuation is by no means identical for the different species. Sometimes a reason for such fluctuation can be assigned, as when heavily shaded (and consequently starved) shoots have been included in the averages.

It is not proposed at the present time to attempt a detailed discussion of the results presented in the foregoing pages. To do so adequately would require much space, and, moreover, there still remain many points on which further information is desirable, before attempting to review the whole subject. It may, however, not be out of place to state that there are good

Summary of Observations on Deciduous Trees and Shrubs, etc.

Name of Plant.	Range within which fluctuation is probably normal.		Results falling outside range. Highest and lowest deviations are included in brackets.				Ratio of number falling within normal range to those outside it.	Totals.
	Range.	Number included.	Below normal range.		Above normal range.			
Common Oak	75±15	12	11	(19)	10	(240)	12 : 21	33
Beech	65±10	20	3	(35)	6	(91)	20 : 9	29
Birch	51±13	129	16	(18)	26	(42)	129 : 42	171
Hornbeam and stools	26±6	17	1	(18)	—	—	17 : 1	45
Ordinary branches	43±8	22	—	—	5	(71)	22 : 5	
Ash and stools and young trees	14±10	100	7	(1)	7	(30)	100 : 14	114
Older trees	The range too wide to admit of conclusions being drawn.							
Hazel and stool shoots	31±9	81	5	(16)	12	(50)	81 : 17	122
Ordinary branches	60±10	26	7	(40)	1	(75)	26 : 8	
Mountain Ash and stool shoots	30±10	7	—	—	—	—	7 : 0	25
Ordinary branches	63±9	13	—	—	5	(79)	13 : 5	
Wych Elm stool and coppice	22±7	10	2	(6)	—	—	10 : 2	12
Plum, "Belgium Purple"	45±15	58	5	(20)	10	(75)	58 : 15	73
,, "Czar"	Variation very wide, correlated with excessive manuring.							
Pear, Doyenné du Comice	60±20	45	9	(22)	11	(104)	45 : 20	65
Crab	70±15	29	5	(32)	8	(104)	29 : 13	42
Lime	85±20	22	2	(52)	4	(131)	22 : 6	28
Sycamore, young coppice shoots	25±5	27	—	—	—	—	27 : 0	97
Stool shoots	42±13	55	—	—	—	—	55 : 0	
Shoots from adult	65±5	15	—	—	—	—	15 : 0	
Spindle tree (*Euonymus europæus*)	47±8	9	1	(23)	—	—	9 : 1	10
Hawthorn	44±5	8	1	(23)	1	(53)	8 : 2	10
Blackthorn	51±12	10	1	(41)	1	(82)	10 : 2	12
Aspen	81±11	10	—	—	2	(103)	12 : 2	12
Goat Willow	65±15	22	3	(28)	9	(113)	22 : 12	34
Osier	95±20	59	10	(43)	8	(157)	59 : 18	77
Apple, Cox	45±15	54	9	(18)	6	(73)	54 : 15	69
,, Lane's Prince Albert	40±10	21	—	—	2	(54)	21 : 2	23
Maple (*Acer campestre*)	45±15	25	2	(19)	—	—	25 : 2	27
Laburnum	42±10	18	3	(25)	3	(80)	18 : 6	24
Philadelphus grandiflorus, shoot from roots	20±5	10	3	(9)	—	—	10 : 3	13

grounds for believing that one of the principal sources of the differences between the evergreen and deciduous trees, with their very different transpiration values, depends largely upon the smaller bore, and especially on the shorter length, of the vessels in the wood of the former group. The short length of vessels obviously involves more resistance to the passage of water. The Holly may be cited as an example. It was not possible to force clean mercury* through more than 2·5 cm. of one well-grown specimen, even at a pressure of 90 cm. of mercury continuously applied for 18 hours. On passing water in which Indian ink was suspended through another stem, the Indian ink only emerged through three vessels in a length of 6·5 cm., while at 3 cm. it had filled up 20 vessels in 18 hours at 90 cm. of mercury pressure.

Shoots of coppice Ash are also resistant, though not so effectively, the passage of mercury and Indian ink through 15 cm. length being almost entirely limited to the vessels situated close to the pith. But, as the ash sapling grows, of course the new wood is more vascular, and that of adult trees is very porous. Strasburger found he could force mercury at a pressure of 40 cm. through the wood of Oak branches to a length of 3–4 metres. The vessels of this tree are of rather exceptional length and width for a timber tree. It is possible that Indian ink or sepia suspended in water might give even higher values, as the resistance offered to the passage of mercury must obviously be considerable, unless it turns out that the mercury actually burst the thin cross walls in the vessels.

The principal results incorporated in this and the preceding communication may be summarised as follows:—

1. A quantitative method has been described for estimating the water conductivity of trees, shrubs, and herbaceous plants. The method depends on measuring the volume transmitted through 15 cm. (in length) of the stem (or root) delivered at a pressure of 30 cm. of mercury for a period of 15 minutes. The amount so transmitted is called the absolute volume. By ascertaining with precision the area in cross-section of the wood, it is practicable to reduce the absolute volume to a specific volume, which is the ratio of water volume transmitted through the stem under the foregoing pressure for 15 minutes, and an area of wood, the cross-sectional area of which is 1 sq. cm. This ratio, or specific volume, can be used as a basis for

* Mercury, which has been used by Strasburger and others for injecting the vessels, is open to objections from an experimental point of view. I obtained far more reliable results with a specially fine sample of Indian ink, which my colleague and friend, Prof. H. G. Plimmer, was good enough to place at my disposal.

comparison between different stems, whether of the same or different species of plants.

2. The results obtained throw light on the habit of many "Xerophilous" plants.

3. The specific conductivity of evergreens is relatively low, with correspondingly small absolute fluctuation; that of the deciduous species (with certain special exceptions) is relatively high, with a fluctuation sometimes relatively high.

4. Some of the deciduous trees are markedly more plastic and are more easily influenced by environmental conditions than are others. Although this feature occurs in evergreens also, it is far less widespread.

5. A considerable difference exists between the normal adult wood of the tree and that of "leaders" of young trees, and especially of coppice-shoots. This difference, which is in the direction of a lowering of conductivity, occurs to an exaggerated extent in the main shoot of most climbers.

6. The wood of arborescent and frutescent monocotyledons is defective as regards water-conductivity, and this is to be regarded as a factor in determining their special habit of growth.

7. The wood especially of deciduous trees becomes filled up with water during the early autumn, owing to the activity of root pressure which persists after the functional activity of the leaves has ceased. It is suggested that this circumstance may have a practical application in shortening the time normally required for the seasoning of felled timber.

8. There are grounds for attributing the lower conductivity of evergreens, at least in great part, to the narrow and short vessels which are present in their wood.

I desire to acknowledge the assistance received from the Department of Scientific and Industrial Research, which has enabled me to secure the services of an assistant, without whose help the work, owing to other demands on my time, could not have been carried on. I also wish to thank my assistant, Mr. H. Tooley, for the conscientious manner in which he has carried out much of the laborious experimental work.