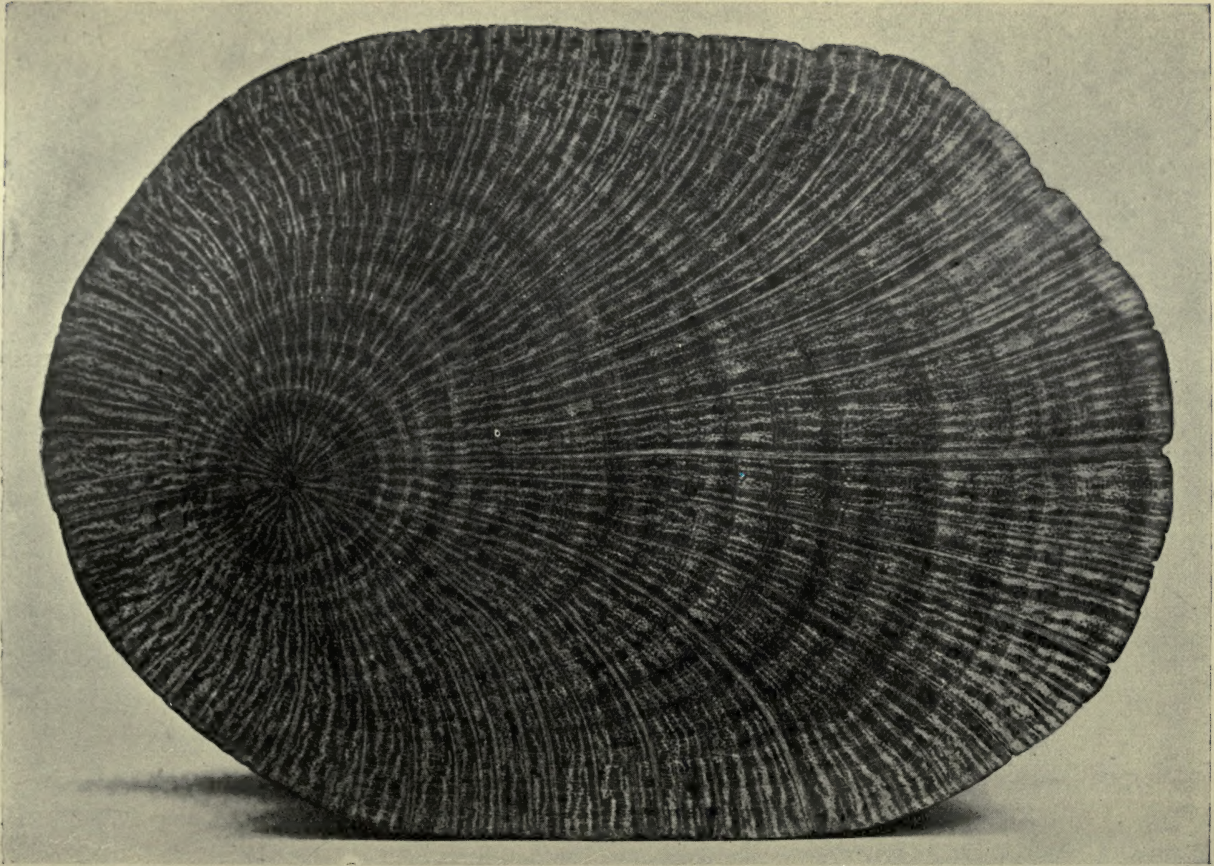
A TEXT-BOOK OF WOOD

FRONTISPIECE.

Cross-section of a branch of the Evergreen Oak (*Quercus Ilex*), magnified about 2½ times. The rays on the faster-grown side are very much wider than those on the opposite side of the pith. Note the straggling radial streams of pores and the absence of a pore-ring, indeed the limits of the annual layers are very indefinite. The fine concentric lines in the Summer zones are of parenchyma or soft-tissue. The notches on the exterior of the section indicate the spindle-shaped grooves, at the bottom of which the rays terminate (cf. Figs. 1 and 2, Plate XIV.). This photograph was taken direct from the wood, the surface of which was prepared by scraping with broken glass. (The minute small or uniseriate rays were visible in the original photo, but do not come out in the reproduction.) Photo by M. F.



Cross section of a branch of the Evergreen Oak (*Quercus Ilex*) magnified about $2\frac{1}{2}$ times

A
TEXT-BOOK OF WOOD

BY

HERBERT STONE

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"A Guide to the Identification of our More Useful Timbers"
and "Les Bois utiles de la Guyane Française"

WITH FORTY-ONE PLATES

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PREFACE

THE object of this undertaking is to provide a class-book for advanced students and to gather in a condensed form under one title all the many scattered morsels of information about wood which are to be found in works which treat of it as a secondary matter, as in botanical works, or if it be the subject in chief, then its treatment is not suitable for class-work.

Let me therefore commence by acknowledging my indebtedness to other authors, of whom there are some 1,500 that I have consulted, about 300 being those on whom I have drawn. I am a compiler, and I am not ashamed of the name, albeit it is often thrown carelessly at a writer who, if only for his "immoderate pains and extraordinary studies," deserves his hire. In my case I claim especial tenderness from the critics, inasmuch as I have travelled much on the Continent to consult books in obscure and remote libraries and to see specimens in Museums. In saving them this trouble and in sifting many a heap of millet-seed in which there was after all, no pearl, I have done the English reader good service.

In the Introduction it has not been possible to cite the name of every author of the details which make up our general knowledge of the subject; otherwise it would be necessary to recapitulate the history of Botany. Let me therefore set the matter at rest by saying that I claim no originality for that portion; it is simply "common form" arranged for the benefit of the learner. Elsewhere I have cited the originator of any detail of information, notwithstanding that it could have been gathered from a specimen lying at hand. When any fact has been borrowed from a brother compiler I acknowledge my debt both to him and to the original author, for example:—(Malonet *ex* Nouvion, 1750, Vol. I, p. 50); which means that being unable to run down the work of Malonet, I have availed myself of Nouvion, who quotes him and who no doubt was at some trouble in extracting the information. It is not fair to rob him of his labour.

The more solid matter is varied by the expression of many unorthodox views upon which the critic is welcome to fall. These heresies have been borne in upon me from contact with the wood itself. Finding that the current dogmas do not accord with my material, I have not hesitated to disagree. In a subject such as that of wood, which has so long been the Cinderella of the Sciences, those who have dealt with it from the botanical side have shown too much the bias of the laboratory, whilst, on the other hand, the practical writer has too often ignored the scientific aspect and has not seldom continued to repeat absurdities that sometimes date from Pliny.

My endeavour has always been to reconcile these two views by the union of the scientific method with the common-sense of the practical user of wood, who obtains his knowledge from the material that he daily handles.

As regards the arrangement of the matter, I have thought it well to divide it into two parts which run parallel. All that portion upon which a student for a degree should be prepared to be examined, and that may also interest the casual reader, is printed in large type. The remainder, intended for the use of those who wish to make a more profound study of the subject, is in smaller characters; hence it will be found that many things referred to in this latter portion call for a more advanced acquaintance with Botany than the first, and may sometimes seem to anticipate explanations given later.

Lastly, it is my agreeable duty to thank those of my friends from whom I have received specimens and communications either written or verbal.

First comes Joseph Chamberlain, my fellow-townsman, to whose enlightened conduct of Colonial affairs we owe so much. To him is due the greater part of my collection which is now the property of the School of Forestry, Cambridge.

Next in order of their services come the Forest Officers and Colonial Botanists, amongst whom special mention should be made of Messrs. F. Manson Bailey, Walter Gill, R. T. Baker and A. W. Foxworthy, who accompanied their specimens with information of the most valuable character. Then no less kind have been Sir Wm. Thistleton Dyer, Sir Frederick Abel, Sir Benjamin Stone, the Hon. A. G. Bell, the Rev. J. Aiken, Messrs. Samuel Robinson, A. H. Berkhout, N. Brune, Victor Davin, Gardner and Sons, R. S. Troup and Dr. Georges Beauvisage.

For facilities in their various laboratories and the use of their libraries and collections I thank Professors Victor Loret, Gérard and Chifflöt of the University of Lyons, and Professor Henri Jumelle of Marseilles.

For the superb collection of material at the School of Forestry, Cambridge, of which I have liberally availed myself, I thank Dr. Augustin Henry and Mr. E. Russell Burdon, and above all the donor of so many specimens, Mr. H. J. Elwes of Colesborne. To the latter I am indebted also for much kindness and information.

Finally, to my friends and colleagues, Miss N. M. Simmonds, Messrs. H. A. Cox, Arthur Deane, and E. A. Ketteringham, I tender thanks for their assistance so freely rendered, and which has greatly facilitated my task. Mr. Cox has added to my obligations by reading my proofs.

Certain branches of the subject are purposely omitted from the scope of this book and have been left for treatment by other and more competent authors who will, I understand, write the remaining volumes of a series of Text-books of Forestry.

HERBERT STONE.

68 Jesus Lane, Cambridge,
September, 1920.

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PART I

Introduction—Details of the Grosser Structure of Wood —Colour — Surface — Smell—Taste — The Extract and Contents of the Wood.

CHAPTER I

INTRODUCTION

A TREE may be defined as a long-lived woody plant of upright habit and single stem, having a capacity for indefinite growth.

Unlike animals, trees have no adult stage. They may reach a maturity beyond which decline sets in, but so long as they live they continue to grow.

Shrubs and indeed herbaceous plants produce wood: the former do so in precisely the same manner as trees, but they are excluded from our definition by having more than one stem, while the latter are short-lived. There seems to be some intimate association between longevity and the single upright woody stem. The only naturally prostrate trees known to me are the Vine Maple (*Acer circinnatum*) and the Sappan (*Cæsalpinia Sappan*).

It was the custom amongst botanists to divide trees into three classes according to their supposed mode of growth in bulk, as implied by the names "Acrogens," in which the addition is at the top (Tree-ferns, etc.); "Endogens," that increase from within, the first formed and oldest wood being outside (Palms, Bamboos and the like); and "Exogens," which grow by successive layers on the exterior, the oldest wood being within (Angiosperms, Conifers and some other Gymnosperms).

These terms being considered insufficiently accurate have been replaced by others which better satisfy the demands of modern Botany, viz.:—Pteridophytes, Monocotyledons and Dicotyledons. Unfortunately these latter are less convenient to the student of wood. The word "Exogen," against which no exception can be taken, is now to be rendered by the phrase "Dicotyledons and Gymnosperms" (the latter having many cotyledons or seed-leaves), which is cumbrous. As the systematic classification is a secondary matter for our purpose, I shall adhere to the older terminology, which, after all, misleads no one.

In the Exogens, which comprise those with which we have chiefly to do in this book, a part once completely formed grows no longer, but is covered by new wood that in its turn becomes passive at the end of the growing season and is enveloped by another layer or coat, and so on in succession.

One may speak of an exogenous tree as being of a certain age, but that is exact only for the original seedling that lies hidden within the heart somewhere near the root, surrounded and overtopped by all the subsequent layers, the outermost being the product of the present year.

The ancient fragments of old Oaks preserved for their historical associations, do not by any means represent the trees which stood in their places, may-be several centuries ago. Inasmuch as they are for the most part hollow, the existing shells of bark and wood are the product of recent years only, the wood previously formed having decayed away. If the original tree of say, fifty years of age could be restored, it would stand at some distance in the middle of the hollow trunk, and there would be a circular space between the two corresponding to the growth during the intervening centuries.

The vital processes that constitute the physiology of plant life are beyond the scope of this work, but we cannot proceed with the study of the substance resulting from those activities without some generalities upon the manner in which it may be produced.

A tree-seed which germinates in the ground presents at first a little root, two or more seed-leaves which nourish the young plant for a short time, and a little stem bearing a few leaves that are different from the seed-leaves but are characteristic of the species. Unlike the seeds of herbaceous plants, the tree-seed produces a stem composed of a substance that persists during many following seasons. This stem bears at its upper end a bud and others in the axils of its leaves. The leaves fall in the Autumn if the tree be of deciduous habit, or remain for two or more seasons if it be an evergreen. In the Spring the buds expand, the embryo-twigs within them lengthen, each bearing a fresh series of leaves, and we have at the end of the second year a compound stem consisting of a continuation in a vertical direction of that of the first year (the leader), and several lateral branches differing from the leader only in position.

The lower portion of the main stem has become developed in a manner which is not externally apparent except by a slight augmentation of its bulk, but if it be examined in section, this increase will be seen to consist of an additional coat of wood enveloping the stem of the first year. The latter has remained unaltered in every respect, save that the rind, epidermis or elementary bark that at first clothed it has retreated from the one-year stem and now covers the exterior of that of the second year.

If one could by any means withdraw the first-year's tree from its new sheath of wood, it would present the appearance of a twig stripped of its skin. Under certain circumstances this can be done, and it sometimes happens that in felling a tree not cut right to the centre, a young naked sapling is drawn out and stands erect and quivering upon the stump. In a less striking manner, the same thing occurs in splitting wood, when a fragment resembling a peeled branch, separates out from the middle. This experiment is worth doing in a better fashion on account of the graphic idea that will be obtained of the composition of the trunk of a tree. Select a thickish plank that shows the pith in the centre of both ends, grip it horizontally in a vice at a place a little below the pith-line and crack off the upper part of the plank with a sharp blow of the mallet, and you will see there exposed a portion of one of the trees long lost and unsuspected. If you are lucky,the little tree will appear with its branches as well, as these in their turn draw out of the holes in which they reposed.

Planks of Coniferous wood cut so as to contain the pith frequently show the traces of the insertions of the short shoots as diagonal lines of dots indicating the spiral arrangement of these shoots on the branches (Fig. 1, Pl. VIII, *Pinus laricio*); Swift (*Archiv. C.F.A.*, 1919, p. 7). Noerdlinger says: "It occasionally happens that the stumps of Coniferous trees left to rot in the forest may have the few centre sheaths of wood more heavily charged with resin than the rest. These being rendered more durable, remain after those external to them have fallen into touchwood, and stand up in the form of the lower part of a young tree, as though growing from the centre of the decaying mass."

The leader of the second year being a new extension, has only a single layer of wood enclosing the pith and is similar in structure in all respects to that of the first year, except that its connection with the root is by means of the new, second layer of wood. In every succeeding growing season, the same vertical prolongation takes place, resulting in a series of leaders superposed one above the other, each being as before, connected with the roots by its particular sheath of wood.

The resulting complex is then a series of much elongated cones or tapering tubes, each containing a pith at the upper end, the whole being enclosed by the rind or bark. Hence if this be cut transversely (horizontally as the tree stands), a series of concentric rings corresponding with the various sheaths will appear. If the cut be taken in a vertical direction (following the line of the pith), we shall see instead of rings, a number of long-drawn-out triangles, the sides of which are so gently inclined as to seem almost parallel. If again, as is more often the case, in sawing trees into planks, the cut passes parallel with the pith but at some distance from it, the course of the saw passes successively from one sheath of wood to another, so that the upper part of each appears as a loop of hyperbolic outline, that is to say, the sides of the loop recede more and more from each other as they approach the root.

In a large number of European species, the limits of these woody sheaths or cones are sharply marked owing to the contrast of the wood produced in the Summer with that of the Spring of the next year which immediately surrounds it (Fig. 4, Pl. XVI). Many others, on the contrary, present but little difference, perhaps nothing more than a narrow line of tissue, and there is often some difficulty in observing the exact boundary of the seasons' increase (Frontispiece). The seasons in the tropics not being so sharply marked, the variation in the wood corresponding to the alternating wet and dry periods (of which there may be as many as four during the year), are small or even absent altogether.

It may happen that a species which renews its foliage without immediately shedding its old leaves (*i.e.*, an evergreen), may in a climate of uniform temperature, such as that of Guiana, produce wood showing no indication whatever of the limits of the successive sheaths. This is the case with the Greenheart (Fig. 4, Pl. XXVIII), but inasmuch as nearly allied species growing along with it under the same conditions, may show definite boundaries to their layers of wood, we must not regard the difference as due to season or climate, but rather to the specific nature inherent in the plant. The Vinhatico (Persea) from Brazil and *Sesbania œgyptica* are similar instances to the Greenheart.

Even among our European deciduous trees such as the Sycamore, Birch, Willow, Poplar and Plane-tree, the limiting zone may be very inconspicuous, and its distinctness may vary, as is evident from the differing opinions of observers. Professor Boulger (1902, p. 172) says that the rings of the Boxwood are not distinct, whereas I have always found them quite clear and definite.

It is generally assumed that the wood produced in the Spring is composed of larger and laxer elements, because of the need of a more copious water-supply during the leafing of the tree. If this supposition were valid, then all deciduous trees should have lax tissue in the Spring wood and dense tissue in the Summer, as in the Oak, Ash, Elm, etc., whereas we find that many deciduous trees show but little variation, as in the species cited above, and, on the other hand, in the evergreens, such as the Pines, the difference is perhaps the most pronounced of any.

Perhaps the best argument proving that this alternating production of hard and soft layers of wood is independent of deciduous or evergreen habit, of water-supply or of nourishment, is afforded by the Coniferous trees of temperate climates. The deciduous Larch produces alternate hard and soft zones of wood precisely as do the evergreen Pines, whilst other evergreen Conifers (Podocarpus, etc.) show only just sufficient difference between one zone and another whereby to count the annual layers. All such differences in structure are characteristic of, and inherent in, the species and have nothing to do with external influences or needs.

The varying densities of the layers of the same tree or in different trees of the same species may be influenced by the conditions of growth. R. Hartig (1880, vol. I, p. 147), says that the Spring wood is lax because the nourishment available at that season is absorbed by the new shoots, and (1901, p. 10) that the dense wood of the Summer is produced in consequence of the better nourishment of the tree at that season, the leaves sending down rich supplies. In support of this he cites the fact that wood grown on good soils is the heavier.

In addition to the competition for food by the lengthening shoots we must add the comparative poverty of the nutriment itself. The store remaining over Winter in the wood is almost exclusively starch, whereas that received later when the leaves are in full activity is more complex and richer.

The first rising of the sap has nothing to do with the commencement of the activity of the shoots, but is due to root action following the warming of the ground, as witness the sap-flow of the Sugar Maple and other trees, which ceases on the putting forth of the leaves. The sap again rises as the leaves expand, because new roots are produced simultaneously.

In the Summer the rich food stimulates the production of the thickening which is laid upon the walls of the cells or chambers, of which the wood is built up, and this seems to arrest their growth—the cell, as it were, has not sufficient time to reach its full size before it is fixed by the cell-thickening. In the Spring, on the contrary, the materials which promote thickening are rare and the cells continue to enlarge, but their walls are thin and delicate.

The *quantity* of wood (*i.e.*, the thickness of the layer) produced during the growth of a season is certainly dependent upon external conditions as it is a question of the duration and intensity of the vital activity of the tree.

Local variation in the amount of wood put on (as between top and butt) may arise from the fact that as the height of the tree increases, the nourishment has farther to travel down the trunk, and if it be not in sufficient abundance, the cells of the top will rob those of the butt of their share. To this is due, according to Mathieu (1897, p. 319), the change in the form of the Beech-tree, which, at first tapering, gradually tends to become cylindrical.

Again, the awakening of the growing layer of the wood occurs several weeks later in the butt than in the top (R. Hartig, II, p. 33, 1882), so that everything is in favour of the upper cells.

Any cause which tends to arrest the production of nourishment by the leaves will close a ring or sheath, as though it had arrived at its natural seasonal termination, quite apart from the time of year. The leaf-fall, a phenomenon intimately associated in our minds with the diminishing warmth of the sun's rays, is the cause in deciduous trees, but the closing of the ring will take place just the same in a climate having no Winter such as we know in England. This is proved by our Common Oak, which, when grown in Java, produces the same sort of rings of wood as with us (Holtermann, p. 663).

This author mentions two species of Fig-tree (*Ficus religiosa* and *F. Trimerii*) at the Peradenya Gardens of Ceylon, which shed their leaves first on one side of the tree and then, after the lapse of fourteen days, on the other. During this period the first side had again come into leaf.

Sagot (p. 377) cites an instance in Guiana, where an enormous Couratari-tree remained for more than a year without leaves as though dead, and then suddenly came into leaf.

It is not stated whether the effect of the leaf-fall was reflected in the wood of these trees. It would probably be hardly perceptible in the case of the two Fig-trees and very evident in that of the Couratari.

The Common Oak grows alongside the Evergreen or Holm Oak in the South of Europe, yet the one produces a prominent lax-zone of pores in the Spring, whereas the other shows no indication of such. In some situations the Common Oak retains its leaves all the year round until the new ones "push them off," as the peasants say, and as I have seen them in the warm crater of the Solfatara, near Naples. The same thing happens in St. Vincent, where, however, the tree becomes a mere shrub (Stevenson, p. 15).

Pliny writes of Evergreen Plane-trees, and in Greece individuals of this species retain their leaves all the year round, as does the Elder at Poti on the Black Sea (Kerner, I., p. 331).

The Peach-tree retains its leaves all the year round in some places in the north African desert (Kerner, I, p. 331).

This author (I, p. 452) says that leaf-fall is due to the arrest of the water-supply consequent upon the low temperature of the ground in the late Autumn which in northern climates paralyses the roots, and in hot countries the proximate cause is drought, but the result is the same. I disagree entirely, as large trees contain enough water to last them for months or even years. Kerner's theory may apply to small woody plants.

The Cotton-tree (*Bombax malabaricum*) is said to have branches which drop their leaves at different periods as though they were independent trees.

The Angico (*Piptadenia Angico*), a deciduous tree of Brazil, shows no distinct limits to its rings, but the size of its pores diminishes from the inner to the outer side of each ring, much as in our own deciduous trees.

The cells of which wood is composed are excessively small chambers, visible only with the aid of the microscope, but of which a general idea may be gained from our figures on Plates XXX to XXXIII. The study of their several forms belongs to vegetable histology, and space does not permit of their treatment here. Any good text-book of Botany will supply such details where needed. Suffice it to say, that in wood the elements are all more or less elongated and fibre-like, the iso-diametric cells so abundant in the soft parts of plants, being entirely absent.

The Cambium or Growing Layer.—Ignoring the production of tissue in the apical region of new shoots, we may say that the wood which forms the increase in bulk of trees is produced in an exceedingly thin layer lying between the rind and the outermost layer of wood already formed. This growing layer, distinguished as the "Cambium" by Duhamel de Monceau, who first pointed it out, is so delicate that it escaped the attention of very keen observers before his time, who were expressly endeavouring to ascertain whether the wood is produced from the bark or from the woody-body itself. Hence it may and does escape the attention of most. It is manifested by a sticky substance that can be felt upon the surface of a peeled green stick and which is composed of the débris of the cambium destroyed by the forcible separation of the bark.

This growing layer is made up of thin-walled living cells or fibres which during the active period subdivide and multiply. Though the component fibres may at first be uniform in shape, they become very diverse in the course of their development and form tissues of quite different appearance and nature. New wood cells are produced on the side of the growing layer on the side towards the wood and an equally complex series of bast-cells on the outside in less quantity. All these are arranged in definite order.

This order has much to do with the identification of species. One would think that the Cambium were endowed with the power of selection and that it weaves a pattern as in a loom by the use of a limited number of different fibres. Just as the Jacquard loom once set for a determined design, will go on repeating it to the end of the warp, so the Cambium repeats the grouping of its cells so long as the tree lives. As in the one case, one design being finished, the same is recommenced, so the Cambium having completed one annual layer or ring of wood having a certain arrangement of elements, recommences with a copy of the same in the following season. For this reason each ring must be regarded as an individual woven design, and for the identification of a species by means of the structure, the examination of a single ring (if it be properly developed), suffices. This reservation must be made. The weaver takes care that his shuttles are always full of weft, but the Cambium, being dependent upon its nourishment, which may fail, will sometimes leave a pattern unfinished from lack of material.

Interruptions in the food supply may occur in a natural way by the leaf-fall, as already stated, or by the destruction of the leaves by the "locust, the caterpillar and the palmer-worm," by frost, hail or drought, or by the stripping of the leaves by the hand of man, as in the case of the Mulberry. The wood product may then be reduced to as little as two rows of cells, as I have seen it in the wood of the Giant Red-wood of California (Fig. 6, Pl. XIX), one of the greatest among wood-producers :

there was no evidence to show how this extraordinary thinness of the rings was brought about.

When no such accidents occur, the woody ring displays an arrangement of its elements which in many cases enables us to recognise, if not the precise species, then at least the Genus or Family to which a wood may belong. A glance at our figures Pls. XX to XXIX will demonstrate abundantly how characteristic are many of the designs and how recognition becomes possible. [As each photograph includes a portion of several rings (transverse section), indicated by the arcs passing from side to side of the figures, the reader is recommended to pay attention chiefly to those which are widest (highest), in a vertical direction, as shown. The pith side of the section is always below, but the strict orientation of the sections has not been possible in some cases.]

The pattern or arrangement of the elements has been termed very happily "le plan ligneux" by Perrot. I very much prefer this to the term word "topography" and think that if we must employ strange words for new ideas, it is as well to adopt one that has no other connotation in our own language. Hence I shall use the word "plan."

The idea that the ring is the basis of the method of identification is attributed to Noerdlinger (1852), who entered into much detail and who may be regarded as the author who first worked out the conception in a comprehensive manner. It was not, however, by any means new in his day, and to give credit where it is due we should not overlook the claim of Varenne de Fenille, an almost forgotten forest-botanist who wrote in 1807 and who was the first to employ the lens for the examination of the transverse section for the purpose of determination. Varenne was Professor at the Forest School of Nancy, and I believe that Noerdlinger's father, also a writer upon wood, was a student there. Varenne's work was no doubt better known a generation or two ago. His descriptions of the structure seem a little antiquated, as his phraseology is different, but they are exceedingly full and accurate, indeed far more so than those of most modern authors.

Des Étangs, in 1843–44, also employed the lens and the structure as displayed upon the transverse section, to distinguish the Oak from the Chestnut and both from the Elm, apropos of the much-debated question of the use of Chestnut in Ecclesiastical architecture.

Guibourt (1869, III, p. 505), was fully aware of the signification of the annual ring, though apparently not of the work of his predecessors. He pointed out the family likeness of the structure of certain allied species (Sapotaceæ and Cæsalpineæ), and hence he may be regarded as the founder of the method of using the structure as an aid to classification.

That the number of rings shown upon the cross section of a tree corresponds with the age of the latter was first indicated by Leonardo da Vinci about the year 1505. It was not his only contribution to the subject of wood, as he was a pioneer in the art of testing materials of construction, in this anticipating Galileo.

This counting of the rings, much employed by foresters, is not a certain indication of age, quite apart from the fact that the level at which the tree is severed from its stump will surely pass above the top of the first year's growth if not more, and the higher the cut the more of the centre rings will be lacking. According to W. J. Bean (p. 234), a ring may fail to be produced in a given year. I think that this must be exceedingly seldom and appears difficult of proof, except in such cases as the Couratari already mentioned, where no leaves were produced during a whole season. On the other hand, if the tree be of a species capable of putting forth a second generation of shoots during the same period of growth after the Spring crop has been destroyed by insects, as is our Common Oak, then a fresh ring will be formed, following the one prematurely closed. There will be two for that year, even if they be narrow and imperfect. In the Oak such a ring will be commenced by the characteristic porous zone.

This question was very thoroughly investigated by Kuhns (1910, p. 53). He found that double rings occurred in all trees experimented upon. The chief indication of such rings appears to be a zone of abnormally thin-walled cells closing the old ring and due, as he avers, to bad nourishment.

Lutz (p. 186) says: "Young Beech-trees prevented from leafing (by removing the buds), for a year, usually made no wood, but in such cases where it was exceptionally made, the vessels were entirely suppressed, and only woody fibres were produced. Amongst the Conifers the Scots Fir (*Pinus sylvestris*) produced Spring wood, when the needles were stripped off.

Here we see, by the way, that dense wood was made by the broad-leaved tree and lax wood by the Conifer. The author's conclusion is, that the production of Spring and Autumn (Summer) wood depends upon the quantity of water present in the bark and young wood, which thus stimulates the growth of the new cells in a radial direction.

R. Hartig (1901, p. 16) states that Beeches kept from leafing by the removal of the branches and new growth, made rings of wood notwithstanding, and that, in quantity proportionate to their ages, *i.e.*, a 50-year tree made 5 per cent. of the amount produced during the preceding season, a 100-year tree 15 per cent., and a 150-year tree 22·3 per cent. The same author (p. 39) discusses the cause of double-rings in Spruce. The frost produces an ice-film between the Cambium and the wood. After thawing, the Cambium makes a parenchymatous layer. Of such imperfect layers or frost-rings, he counted on one occasion no less than ten in wood of a 20-year Spruce.

Noerdlinger (1859, p. 18) says that secondary zones of the ring are regularly and normally formed in the wood of the Privet and often in that of the Bird-Cherry (*Prunus avium*), and the Hackberry (*Prunus Padus*). Mathieu (1897, p. 423) states that the suckers (*réjéts*) of the Alder (*Alnus glutinosa*) produce each year two generations of branches, from which we may conclude that a double ring is formed correspondingly in the wood.

These secondary zones are referred to later under the heading of the "Boundary of the Ring" page 19, and in a certain form are characteristic of Cypresses, Junipers and *Callitris quadrivalvis*, so that prudence, as advised by Mathieu, is necessary in estimating the age of Conifers by means of the number of rings.

The cause of this duplication is by no means satisfactorily ascertained and may possibly be due to the easing of the pressure of the bark by cracking of the latter, in consequence of a fresh rush of sap during rain after a prolonged drought.

It must be understood that double rings are not produced in those trees which put forth two series of shoots per annum, unless the first crop of leaves has been destroyed (Gayer, 1903, p. 102).

Examples of wood from the Tropics, in which the number of rings exceeds two per year, are not uncommon. From a MS. communication from Mr. P. J. Anderson, who caused a Mahogany-tree of a known age to be felled expressly to ascertain the fact, we learn that as many as five rings may be formed in one year. On the other hand, Holtermann (p. 663) cites a Cocoa-tree at Aden that made only five to six rings during thirty years. As it rains but once in from one and a half to three years at that place, the fact seems to show that the showers are sometimes insufficient to promote growth.

The age of big trees such as those of California (*Sequoia gigantea*) has been much exaggerated. The actual count of the rings exposed upon the stump of the tree upon which the so-called "dancing pavilion" is erected, made by Prof. C. E. Bessy, was 1,147 years, and this observer doubts whether any of the existing trees approaches the age of 2,000 years. There is a section of the wood of this tree in the Collection at the School of Forestry at Cambridge, made by Hough. Its radial width is $2\frac{9}{10}$ inches and the number of rings shown is 170. The finest specimen of slowly-grown wood that we have in the collection is one of Sitka Spruce, which exhibits 166 layers in the radial distance of 5·35 inches, so that it is hard to persuade oneself that every layer of the Sequoia last mentioned represents a year's increment.

The history of a tree may in some measure be read upon the transverse section, especially when it has been forest-grown. In the early part of its life the young tree generally has plenty of root and air-space, so that the centre rings are wide. As it grows taller so do its neighbours, all spreading out their crowns, which eventually touch and form canopy, thus mutually interfering with each other's development, so that the succeeding rings become progressively narrower, indicating the increasing severity of competition. Thinning may now take place and the growth in the width of the rings recommences, gradually diminishing as canopy is again formed. This may be repeated as often as the forest is thinned though eventually, when the tree has passed its optimum, it is no longer able to make growth equal to that of its prime and the rings at length become narrower. If, on the other hand, the tree is a park or hedge-row specimen, the rings, though diminishing slightly after the first period of youth, may then remain approximately constant until the decline of the tree. Bad seasons, defoliation by caterpillars, frost, etc., may often be traced and the date of the year when they occurred may be ascertained by counting back from the bark inwards.

Noerdlinger (1859, p. 383) says that the reduction in the width of the rings towards the exterior of the trunk and therefore towards the top, has as a result an improvement in the quality of the wood. This is not quite clear; in the butt wide-ringed inner wood would be surrounded by narrow-ringed outer wood, and in the top there would be narrow-ringed wood only. He therefore may be supposed to mean that the average value of the wood of the tree is raised, but the top will remain always the better.

The quantity of wood that may be added annually to the trunk of a tree is of great interest to Foresters, but to the user of wood it is of less importance; he is more interested in the relation of the amount of growth to the quality of the product. I may, however, cite a few instances in passing to show that growth may be prodigious. The reader who wishes to obtain an idea of the width of ring attainable should look at the beautiful sections of wood published by Hough, amongst which he will find one of the Bead-tree (*Melia Azedarach*) (Part V., No. 105), with a ring 1 inch wide, *i.e.*, two inches of growth in the diameter of the tree; the Willow (*Salix alba*), (Part II., No. 46), is equally fine. We have another specimen of the Sitka Spruce which is the reverse of the one mentioned on page 11; it has seven rings in 6 inches. Noerdlinger mentions (1859, p. 21) a Common Spruce with rings 25 m/m or an inch wide.

The fastest-grown timber tree of which I have heard is that of the Pawlownia mentioned by Marsh (p. 395), which during a season from April to November made a shoot from 4–5 inches in diameter by 20 feet long. Mr. R. Fyffe tells me that in Uganda the Blue Gum will attain 25 feet from seed, in the first year.

Laslett (1894, p. 44, table) gives instances of 1¼ and 1½ inch rings in the Oak and of 1½ inch in the Elm and states that they were of wood the first quality. "In the same kind of tree the width of the ring may vary as much as fifty-fold" (Mathieu, 1897, p. 680).

The growth of trees upon mountains in the temperate zone must not be compared with that of others in northerly latitudes because of the cumulative effect of the midnight sun. The light on mountains with a southern aspect is far more intense, but it may not be translated into wood-production, as we know that the chlorophyll-corpuscles tend to arrange themselves in a manner which permits them to escape the too powerful rays of the sun, whereas a feebler insolation for a shorter period, but *uninterrupted day and night*, may have a greater productive effect. The cold of Alpine nights induces a sort of torpor in the living cells, which must take time to pass after the sun has risen, whereas in the north the activity of the leaves and cambium never slackens, though it is feebler and of shorter duration. The prodigious growth of cereals at places within the arctic circle is well known and it would be interesting to learn whether the same actually applies to trees.

Noerdlinger (1859, p. 25) says that the discrimination of the north and south side of trees by inspection of the log when felled, is an assumption not borne out in the forest.

There is much confusion caused by the use of the terms "young" and "old" wood when speaking of the inner and outer portions of a tree. The innermost ring represents the oldest part of the tree in point of age, but the outer wood is that which is most visible and characteristic of an old tree. I shall make a practice of using the words 'early' for the wood produced when the tree was young and "late" for that which is made when it is old. These words have been used by others in another sense (that of the inner and outer zones of the same ring), but as this has not yet become current, I trust that my suggestion will find favour as making for precision of expression.

The ring or sheath of wood of the first-year's tree or of the leader and one-year twigs differs from those produced later. Houlbert, in 1893, pointed out that it frequently happens that the rings do not arrive at their perfect "plan ligneux" for five or six years. He goes on to say: "I have remarked that the wood acquires its definite characters slowly and progressively and that many woods when young resemble each other in structure, and that for certain groups it is extremely difficult, even if possible, to distinguish species by the examination of the rings of the first, second or even the third year." This is all the more important, inasmuch as much labour has been expended upon twigs (sometimes taken from herbarium specimens), by histologists who have drawn from them the conclusion that the wood seldom displays sufficient definite characters to be of systematic value.

The early wood of the *Vouacapoua americana* resembles in its "plan ligneux" that which is normal in the mature wood of species in quite another tribe of the same family, and one is inclined to ask whether it may not be an ancestral form repeated in the embryonic stage, as is the case with animals. In this species the pores (or groups of pores) are surrounded by soft-tissue (parenchyma), which extends laterally in the form of short wings, an indication of a concentric arrangement, as were the wings extended still further they would form concentric zones of soft-tissue. In the wood remote from the pith, the pores are also sheathed, but have no wings: on the contrary the soft-tissue joins up the pores into oblique lines, thus suggesting a change in the plan of structure. I have seen the converse of this in a wood called Parcouri of French Guiana, the continuous concentric layers of soft-tissue being in the later wood.

Dr. Georges Beauvisage ("*Cerceuils pharaoniques*," p. 3) says that in the Yew, the wood of which is characterized by fibres (tracheids), having a double spiral-thickening of their walls, he rarely found these thickenings in the young wood where they were annular only.

The woods of the endogens have already been ruled outside the scope of this work. With the exception of a few Palms that in tropical countries serve as building materials and are used whole, they are too soft in the centre of the trunk and cannot be cut up into boards. There are, however, one or two which are hard right to the centre, for example, *Rhopalostylis* (Fig. 4, Pl. XVI). Smaller plants, Bamboos, canes and the like are also used entire, or if cut up, it is chiefly with a view to make baskets and similar small articles from them. The only European Monocotyledon that is so used is the Great Reed (*Arundo donax*). The very hard stem is slit into four pieces and then used for making the shiny, cane-like baskets in which flowers and fruit are exported from the Riviera and elsewhere.

The quality of the wood of Palms may vary with their sex. The male Palmyra (*Borossus*) produces a hard black wood, very resistent to wet, especially to sea-water, whereas the female yields a wood composed of a mass of soft fibres (Chevalier).

Endogenous woods are made up of stands of fibres and vessels, but unlike those of the Broad-leaved trees, these elements are dispersed uniformly throughout a mass of soft-tissue apparently without order. These endogenous woods are easily recognized by the absence of the concentric structure of the exogens. There are a few Monocotyledons which make concentric growth, but their rings or sheaths of wood are generated outside the bast and are called extra-liberian. Examples of these may be seen in the Yuccas, Aloes and Dracænas. Extra-liberian wood is also found in several families of the Dicotyledons (Nyctaginaceæ, Chenopodiaceæ and Amarantaceæ), but as these are herbaceous they do not concern us here. The Wistaria (*Glycine chinensis*) occasionally makes this type of wood, but it seems hardly normal, the bast or liber being included at long intervals only. In one of my specimens this had happened only five times in forty years.

Climbers are nearly always aberrant in their structure, and differ widely (at least in their "plan ligneux") from nearly related self-supporting plants. They have very large pores for the most part, and these being crowded, make any special arrangement obscure. I believe that were the pores smaller, most of the climbers would agree in plan with that characteristic of the genus, but there is no means of proving this at present. Certain Lianes, such as *Serjania* (*see* Fig. 152, Strasburger, 1898, p. 138), are figured as instances of aberrant structure, and indeed they have every appearance of being a congeries of small stems that have become inarched or, as it were, soldered together.

The climbers that come within our purview and that make a hard, woody body as the result of the soldering together of many stems, arrive at this end in a slightly different manner. They entwine themselves around the trunk of a tree in all directions, making a lattice-work which becomes closer and closer as each individual stem increases in diameter, until finally a tube enclosing the support results. The tree within dies, whilst the climber persists and may become a large tree and produce good timber. This is the case with the Ratas of New Zealand (*Metrosideros*), the wood of which is excellent, being very hard, and moreover its structure, judging from specimens of three species in our collection, suggests nothing whatever abnormal. *Clusia alba* is another of these climbers. It will make a continuous tube up to 10 metres in height, according to Kerner. The wood of the Vine is used in many places for timber. The doors of the ancient Cathedral of Ravenna were made of it, from wood said to have come from the Red Sea. The planks were 15 inches wide by 12 feet long (J. G. Marsh, p. 62).

Other climbers have a partially aberrant structure, inasmuch as the annual sheath of wood is imperfect and does not pass completely round the stem : the growing wood is added in sectors, one outside the other (*see* Fig. 5, Pl. XXIX). As the first year's stem is concentric in plan, I attribute the one-sided growth to the influence of the pressure of the supporting plant around which the climber twines. *Cadaba farinosa* and *Menispermum fenestratum* make wood in sectors, arranged concentrically but separated from each other by bast. Then of a somewhat more regular character are climbers that seem to have a defective ray-system, which causes the stem to break up into a star-shaped form, as in *Bignonia glabrata, H.B.K.*, or into four quarters as in *B. apurense, H.B.K.* and *B. capreolata, L.* Other arborescent species of the same family are quite normal (*e.g.*, *Catalpa* and some *Tecomas*). *Cadaba farinosa* has a great superficial resemblance to the wood of the Gnetaceæ, a family distantly related to the Conifers. In the genus *Gnetum* (Fig. 4. Pl. XXVIII) the wood is seen to be arranged in a ring of wedge-shaped bundles of fibres and vessels separated from each other by soft-tissue radially disposed. The radial plates of soft-tissue are not continuous from one ring to another. As in the case of *Cadaba*, those of one ring are not opposite to those of another, but are short independent plates of tissue. The wood of *Gnetum* may be distinguished from that of *Cadaba*, *Ephedra* and all genera of the Dicotyledonous Broad-leaved trees by the fact that the pores are larger on the *outer* side of the ring. In all the Broad-leaved trees the contrary is the case, albeit the diminution in the size of the pores from within outwards at times is little, as is also the case in *Ephedra*.

Another group of trees included with the Gnetaceæ and Coniferæ under the term "Gymnosperms," are the Cycads. Their wood is quite different from either, being more of the type of that of the Yucca, Aloe and Dracæna. Cycads possess rays and wood-fibres but no vessels.

When the conclusion of the season's growth arrives, the deciduous tree reposes throughout the Winter and reawakens to new activity in the Spring. The last formed sheath inherits from its predecessors a growing point or bud on the end of its twigs and leader, and also the cambium mantle for the production of another layer of wood. In this respect we may consider each sheath of wood with the leaves which are contemporary to it, as an individual and a member of a fresh generation. These titles would not be denied to a young tree which is produced from a sucker, or even to the sucker itself, for it has inherited a cambium mantle, root and terminal bud. Two difficulties stand in the way of regarding the outer sheath of wood of a tree as a new individual overlaying and concealing its predecessors. Firstly, there are the rays which are common to the whole series of layers as they proceed from the centre of the tree to the bark in all directions. This may be explained away, as notwithstanding an apparent continuity of the rays, the latter may be only occupants of radial channels and not one of the primary constituent tissues, as we shall see later.

Secondly, there are the evergreen trees, especially those of tropical regions, where the activity of the tree appears to go on without complete interruption during the whole life of the plant, so that we cannot think of separate and successive generations here, as we can when contemplating the growth of a coral reef with its polyps. The tree is more comparable to a city which increases in size indefinitely while its citizens, like the leaves of the tree, pass away.

Van Tieghem, who is never content to use the same terms as any one else, calls the collective product of the Cambium the "Pachyte." This conception embraces both wood and bast. As the wood and bast of the first year are separated from one another by those of the second year and of all subsequent growth, the two members of the pachyte get further and further apart until it becomes impossible to ascertain which belongs to which. This conception, therefore, stands for a thing which cannot be located. Further, he refers continually to the "compartments" of the "pachyte," meaning the wedge of wood between two adjacent rays as seen on a transverse section. Such "compartments" are, however, a figment of imagination, as the examination of the tangential section will prove. The rays do not divide the stem into wedge-shaped segments, they simply penetrate the woody body, and were the transverse section taken at a different height, the original "compartments" would be no longer there, others having taken their places.

CHAPTER II

DETAILS OF THE GROSSER STRUCTURE

HAVING sketched in a general way the manner in which the wood is produced, it is necessary for our purpose to enter into some detail concerning the different aspects under which it may present itself.

For the sake of brevity I shall use the word "rings" without the qualification of "annual," it being understood that this term is meant to include the sheaths or hollow cones of wood produced during a season of whatever kind. The word "layers" would be convenient and more appropriate (it is so used by French authors in the phrase "couches saisonnaires"), but it would be pedantic to attempt to replace so well established a term as "ring" by another.

The words "Spring and Autumn-wood," or as it is the fashion to say at present "Spring and Summer-wood," as indicating the inner and outer zones of the rings, imply that there is no wood produced in the Summer on the one hand or none in the Autumn on the other. Then they are in no way applicable to exotic woods of hot climates, and with the exception of some Conifers with densely resinous outer zones, it is rarely possible to say where one ends and the other begins. I shall use the word "zone" for the different parts of the ring, qualifying it with the words "inner, middle and outer" as the case demands.

The Rings.

DENSITY OF THE SUCCESSIVE ZONES.—The rule that the wood produced at the close of the season is denser than that of the beginning, is almost invariable, though the difference may be reduced to a minimum.

Houlbert (p. 159) says, however, that in the Butternut (*Carya cinerea*) the order is reversed. My specimens certainly show dense wood in the outer zone, but the laxest wood is in the middle of the ring, as in the Common Walnut, its near ally. In the Almond, the wood is certainly darker on the outside and may be denser: probably other exceptions will be found after proper search, but they will be rare. Mathieu (1897, p. 248), cites Lilac, Evergreen Oak, Olive and Hornbeam.

CONTOUR OF THE RING.—The rings are usually regular in contour, *i.e.*, circular in transverse section, unless disturbed by accidents of growth, such as abnormal development on one side due to the tree being situated on a slope, or receiving the sunlight from one side only.

The easing of the pressure of the bark upon the cambium mantle may cause a regular variation in the formation of the wood and produce undulations in the contour of the trunk that may be characteristic of certain species. Mathieu (1897, p. 679) relies upon this circumstance to distinguish the Alisiers (Whitethorns) and the Sorbiers (*Pyrus Sorbus*, etc.) which have entire bark, from the Pears and Apples where it is fissured. This, of course, cannot apply to young trees, and our old specimens by no means confirm this.

Branches generally display irregular shape, the pith being excentric and the growth on one side very much greater than that on the other. I have seen this lop-sided growth cited as a character of one of the varieties of Lignum-vitæ (*Guiacum officinale*), of which we have a specimen of an oval section that has scarcely an inch of wood on one side of the pith, whereas there is more than seven inches on the other. Our plate of the Evergreen Oak (*Quercus Ilex*, Frontispiece) is a good illustration of this excentric growth.

The chief irregularity in contour which is at the same time normal s that caused by the form of the pith. In the Oak this is five-lobed; the succeeding rings follow its outline for a few years and then gradually become regular. The undulating or fluted trunk of the Hornbeam is also said to derive its form from the same cause, but on examination of the transverse section the number of waves in the outline of the rings will be found to be too great.

A third modification is found in the Wacapou (*Vouacapoua americana*), which again has a five-lobed pith that affects both the contour of the rings and that of the trunk and eventually produces five flutes in the latter, that, according to Saldanha da Gama, may attain a depth of 3–4 feet, forming buttresses between which wild beasts take shelter. A still more curious fact is that these buttresses do not rise much above 6–8 feet up the stem from the roots. Above that height the trunk becomes more or less round, even though the section may still show the lobed shape of the pith in a less degree. These buttresses are called "Arcabas" in Guiana and "Sacopembas, Sapopembas, Palombras or Raizes" in Brazil, and may occur in members of widely separated families. They are ecorded for the Panacoco (*Swartzia tomentosa*) and several species of the same genus; n the Red Santal (*Pterocarpus santalinus*), the Padouk (*P. indicus*; Greshoff, p. 107); n *Copaifera*, in the Angico (*Piptadenia angico*), of the Leguminosæ; in a species of *Cedrela* and the Mahogany tree, of the Meliaceæ; in *Loreya arborescens*, of the Malpighiaceæ; in *Mimusops elata* (Saldanha, 1865, p. 53); in *Sideroxylon imbricarioides* and *S. cinereum* of the Sapotaceæ, and in the Laingbooe variety of the teak. A tree probably of this last order, the outline of which suggests a skeleton, goes in the Isle of Bourbon by the name of "Malbrouk" (Marlborough), out of compliment to our great General. Then there is *Myristica officinalis* of the Myristicaceæ and *Echirospermum sp., dub*, and, lastly, the Gutta-percha-tree. I have not had the opportunity of verifying the shape of the pith in these cases.

Kerner (p. 650) gives a drawing of a curious example of a tree with Arcabas. The alient ribs are very narrow and of equal thickness throughout, *i.e.*, they do not widen owards the trunk, but stand out like flat plates: in addition, they are of diverse heights on the same tree. When these ribs are thin, they are split off and used by the natives or oars or paddles, more especially those of the Panacoco: I have seen specimens labelled with this name that are white, whereas the wood is usually nearly black, so it appears hat the heart-wood does not penetrate into the buttresses. I imagine that some of the beautifully-figured Amboyna wood that used to come to market must have been from uch structures, and Arcabas from *Tetrameles nudiflora*, the "Thitpok" of Burma, are often used for single-piece rudders, and those of *Carapa obovata*, or "Pinleon," for rudders of maller craft (Hamilton, 1920).

A specimen of a Lime-tree presented by Downing College to the School of Forestry s developed in such a lop-sided fashion as to appear flat. Its width is 3 inches, and its depth 15¼ inches. The growth on one side of the pith is only 2 inches, while that on the other is 13¼ inches, the sides of the log being approximately parallel. The cause of this ccentricity is unfortunately unknown (*Archives C.F.A.*, No. 3, 1920).

It appears to me that, in at least some cases, we must look for external causes to explain he formation of arcabas. In the Logwood (*Hæmatoxylon campechianum*) the trunk is hannelled deeply in the most irregular manner, often to the depth of 6 inches. The sides f the ribs are roughly parallel in transverse section, but here the coloured heartwood uns into them in finger-like extensions, no way in harmony with the true contour of the ings. The depth of the channels varies very much in different specimens. In many that have examined there are traces of wounds resembling the so-called "pith-flecks" *see* Part III), caused by insects. The production of new wood takes place only in the ntervals between the wounds, and in time forms the ribs. There is this contrast to the ordinary pith-fleck, the wound is not completely healed over by callus, thus indicating njury to the bark as well as to the cambium. I suspect that those trees not having a lobed pith and which produce arcabas may be subject to similar injuries. This may possibly have an industrial application if my conjecture be justified. There are two kind of Logwood-trees quite indistinguishable by their botanical characters, one of whic produces the commercial wood, and the other wood of a bad colour that is called "Bastar Logwood." This latter is not cut by the woodmen, hence it remains to seed and i therefore displacing the more valuable species. We know that trees that have bee wounded produce heartwood (wound-heart) of a dark colour even when the species is no normally a heartwood tree, and my view is that both true and bastard Logwood-trees ar the same, but the latter has been wounded in its early life, while the other has escaped If this be so, then a timely wounding of supposed bastard trees may result in the productio of better-coloured wood fit for export (*see* Drabble, 1907).

Experiments made by Prael 1888, p. 11, on hot-house specimens of Logwood prove that in young plants consisting as yet of sap-wood only, developed the true dye-woo as a result of wounding.

Care should be taken to avoid confusing the lobed contour of th rings caused by the proximity of branches and roots which may distor a regular and sometimes truly-lobed form. In one of our specimen of the Wacapou there are, for this reason, only three lobes, whereas as already said, there should be five. Then in the Lombardy Popla there are frequently low buttresses at the foot of the tree which ca hardly be accounted arcabas, yet would lend a lobed form to the ring on a section from the stump.

Another type of undulating contour is presented by the Gimle Gum-tree of Australia (*Eucalyptus salubris*), that derives its name fro the spirally-fluted shape of its trunk. The whole tree is on the twist Our specimen is three-lobed.

In a specimen of an undetermined wood called "Chêne vert," from French Guiana, observed that the waves forming the outline of the rings did not tally, but on the contrar the crests of the waves of one ring met the hollows of those of the next within, so tha the boundaries alternately approached and receded from one another.

In a much larger number of woods, the contour, while being regula as a whole, may yet be broken up into fine undulations (transverse section) the most frequent type being that known to botanists as "crenate, *i.e.*, consisting of a series of small arcs whose crests are turned toward the bark. Each crenation or arc extends from one large ray to anothe and in such woods as the Oak or Beech, between the larger secondar rays also. This outline is very characteristic of the Black Alder whe large rays are present. In the Green Alder, where rays are of ver irregular occurrence, the contour is more regular. An outline of th contrary form, *i.e.*, "dentate," or that composed of a similar series of arc with their crests turned towards the pith, is less common, but may b found amongst the woods of the Proteaceæ. As some of these wood may be confounded with others of the Casuarineæ where the crenat contour prevails, this feature may provide a point of distinction betwee the two. The dentate form is seen very well in the Lace-bark-tree o Hui, of New Zealand (*Plagianthus betulinus*, Fig. 5, Pl. XXI).

A further warning must be given against taking abnormal undulations of the outline of the ring for specific characters, the more so as th attacks of insects may disturb it to such an extent as to change th appearance of the wood entirely as in the Bird's-eye Maple. Suc aberrations give a commercial value to the wood on account of thei beauty. This will be dealt with later under the head of "Figure. Suffice it for the moment to say, that it is only in small pieces that th student is likely to be deceived, as the markings in question do not, as a rule, recur with the regularity which belongs to the normal types of undulating rings.

The pressure of the bark and its retarding influence upon the growth of the Cambium have already been alluded to, but their effect upon the rings may be considerable, and if the cracking of the bark be according to any regular plan, the woody body will reflect this. Mathieu (1897, p. 679), says : " When the bark is slit, a pronounced salient will be found within, hence smooth, entire barks are accompanied by regularly concentric woody rings, whilst fissured barks tend to show swellings that correspond." This we see in the stem of the Birch, where the upper portion clothed as it is in the natural, smooth bark, is beautifully cylindrical and the rings regular, but below, at the foot of the tree, the stem is often covered with a thick, fissured, corky bark, and the stem and its rings show large crenations corresponding with the fissures. The Hornbeam is an apparent exception to this rule, if it be a rule, as the stem is fluted whilst the bark is smoother than most ; still we find that the bark is thick and thin in places, and hence may exert varying amounts of pressure upon the cambium. On a transverse section, the thick strips of bark are seen to be in the hollows and the thin ones along the ridges.

THE BOUNDARY OF THE RING.—As already said, the limit of the ring may be more or less vague (a sin *Podocarpus*, Fig. 4, Pl. XIX), or even untraceable (Greenheart, Fig 3, Pl. XXVIII), still the varying colour of successive rings is generally sufficient to indicate the general contour.

The absence of a definite ring-boundary is often cited as a character of *Araucaria*, but I have specimens in which the limits of the ring are as clear as in the Spruce.

Noerdlinger has employed the sharpness of the boundary as a means of identification, basing his analytical keys more or less upon this feature, but it is very unreliable even in the same piece of wood. In the Plane-tree, for instance, within a few inches one may observe very clearly marked rings and again considerable spaces where there is no indication of their limits.

The boundary may be a line of soft-tissue (parenchyma), as in the Poplar and Cigar-box Cedar : a pore-ring (Oak, Elm, Ash, Chestnut), or formed simply by the contrast in density of the tissue of the outer zone of one ring against that of the inner side of the next exterior to it. For this latter type I use the term " line of contrast." Most Conifers of the Pine family fall under this head (Fig. 1, Pl. XIX).

Moll and Janssonius (1906, I, p. 36, and Index, Vol. III, 1911), mention seventeen cases where the boundary has no precise limit and say that Reiche, Ursprung and Gamble cite others. Petrucci has met with frequent cases amongst the woods of Borneo. False boundary-like lines which terminate abruptly without completing the circuit of the ring are characteristic of *Calophyllum*.

Narrow rings that suggest a false start in the commencement of the season's growth occur so frequently in the Cypresses that these woods may be recognized at a glance. This may, however, be a character due to situation and climate, so that too much reliance should not be placed upon it. I have seen something similar in *Picea excelsa*.

Rings of pores are, according to Hartig (1891, p. 83), restricted to the *heartwood-trees* of our indigenous species. In this case we must consider the Ash as a heart-wood-tree. A perfectly continuous pore-ring of small pores frequently occurs in the Horse Chestnut, which is certainly a sap-wood tree.

Heartwood.

The young wood produced by the activity of the cambium-mantle may remain practically unchanged throughout the life of the tree and also after felling, as in the Sycamore, Lime-tree, European Birch, and Spruce, or it may undergo a transformation which, while leaving the structure unchanged, alters the nature of the wood profoundly, so that in the place of a pale-coloured, light, weak, perishable Sapwood, we have a dark, heavy, durable Heartwood more resistant to strains of all kinds and to the attacks of insects and decay. In species such as the Beech, where the change is gradual, there is little that is remarkable, but in others (Oak, Elm) it is sudden ; the sapwood of one year becomes changed into heart in the course of a season, so there must be a corresponding change in the physiological condition of that part of the tree at that period which does not extend to the ring immediately exterior to it. This change is ascribed to the death of the vessels or pores and the opening of their lumina to the access of air, frequently accompanied by the appearance of tyloses, or little bubble-like cells, which may be seen obstructing the pores of many woods.

These tyloses do not occur in all woods; for instance, it is said that the Red Oak of America (*Quercus rubra*) is devoid of them. Certainly they are rare in this wood, but their complete absence must not be assumed, as our specimens of English grown wood certainly show some. Further, the frequently repeated statement that there are no tyloses in the sapwood is incorrect, as shown by Eloise Gerry (1914, p. 451), who reports them in the sapwood of many species.

That the change is contemporaneous with the disappearance of starch seems certain, and the definition of "Sapwood" as that portion of the tree which still maintains some of its vital activity may be provisionally accepted. The fact that the cells may be still living is no real proof that the wood is sap-wood, as Penhallow (1904, p. 343) says : "in girdled Pines, the heart-wood may resume its activity long since lost and take upon itself once more the function of the sap-wood, as also to some extent the function of the bark."

The tyloses arise from the forcing of the delicate membranes which close certain perforations in the walls of the vessels, into the cavities of the latter. These perforations, called "pits," correspond with others in the walls of contiguous cells from which some of the living contents pass with the bulging pit-membrane into the vessel and may there be capable of further growth and division. In certain species, such as the False Acacia (*Robinia*), the tyloses are so densely packed that they completely block the fair-way of the vessel and from mutual compression assume a more or less angular or polygonal form. This may be seen under a microscope of low power and the mass of tyloses is visible even to the naked eye.

It is the custom amongst Foresters to divide their trees empirically into "Sap-wood trees," or those which preserve the primitive character of their wood, and "Heart-wood trees," in which by a process of ripening as it were, their wood acquires new qualities that are valuable from a technical point of view.

I use the word "empirical," inasmuch as this classification does not harmonize with the natural affinity of species. For instance, the European Birch is a sap-wood tree, whereas its near relatives the American Birches (*Betula lenta* and *B. papyrifera*) have distinct dark-coloured heartwoods. It must be admitted that, except in point of colour, weight and hardness, this heartwood is inferior to the sapwood of the same tree, but the White Poplar (*Populus alba*) has a distinct and excellent heartwood: its allies, which include the rest of the species of the genus *Populus*, have no heartwood whatever. Again, many trees have wood of a dark colour throughout and some have sapwood of a still darker colour than the centre. A third class, that of "ripewood trees," is sometimes made. Into this category fall woods similar to the Beech, where the transition is not sudden, no sharp line of demarkation between sap- and heart-wood being visible.

Noerdlinger (1859, p. 39) makes four classes, adding to the three foregoing another which he calls "Ripewood-heart-trees," of which he gives the Elm and the Berry-bearing Alder (*Rhamnus frangula*) as examples. These woods exhibit a zone between the true sap- and heart-woods. In the Elm this is reddish; it contains less water than the sapwood and is not of so dark a brown colour as the heart. As regards species of the same genus, the same author succeeds in placing the Maples in three different classes, as follows:—Sap-wood-trees, *Acer Pseudo-Platanus, platanoides, saccharinum* and *Negundo*; Ripe-wood-tree, *A. campestre*; and Heart-wood-tree, *A. dasycarpum*. Further, he says (1859, p. 528) that the Scots Fir (*Pinus sylvestris*), a heart-wood-tree, becomes a Ripe-wood-tree on very spongy soil and (p. 516) that the Dogwood (*Cornus mascula*) is a heart-wood-tree, but there is also ripe-wood in the branches. R. Hartig cannot always make up his mind as to which term to use, for he says (1878) of *Populus tremula* (Aspen), on page 34, "no heart," but on page 42 of the same brochure, "Heart lightbrown." The following extract from Mathieu (1897, p. 674) is worth quoting in extenso. He says: "Amongst other species, the White Poplar and the White Willow, for example, one may distinguish two regions in the woody body—the external region white, as is usual, which represents the sap-wood; the internal, light reddish, which does not merit the name of heart-wood except from its colour, by no means from its qualities. Then a modification more real although little apparent, occurs in some other species such as the Silver Fir and the Spruce. Notwithstanding that in their wood no coloration presents itself, and that the fluid sap rises through the whole woody body so long as the tree remains alive, yet there exists in their wood two different regions, of which the internal, once dried, loses all permeability and resists all injection. To sum up, there are then certain woods in which one recognizes neither sap-wood nor heart-wood: others where these two regions are more or less differentiated not only by their character, but also and above all by their qualities. In the latter case one perceives that in a certain species the sap-wood is as bad as the heart-wood is good: that the sap-wood of Oaks and Pines, of which the heart has excellent qualities, is detestable as wood for working up and should be rejected without pity; that the sap-wood of the Silver Fir, the Spruce, and the Poplars very nearly equals their heart-wood and may be employed for the same uses indiscriminately, and lastly, from the point of view of durability at least, the sap-wood of these is superior to that of the Oaks and Pines. Conclusion: *the value of the sap-wood* as wood for use is inversely as that of the heart-wood." On page 531 Mathieu says that the property of resisting injection possessed by the heart-wood of the Silver Fir is shared by the Spruces, Larches, Cedars and Pines (the contrary being so with the sap-wood).

The usual reagent for distinguishing sap- from heart-wood is Iodine, the resulting blue coloration indicating the presence of starch, showing that the portion of wood tested is of the former. But this method must be taken with reservations, as R. Hartig (1882, II, p. 33), says that old Beech-trees (130 years), contain no starch in the sap-wood (splint) of the butt. This, by the way, may be the reason why the cambial activity commences later in the Spring in the butt than in the top of such trees, because there is no reserve of nourishment.

The classification of Mer appeals to me more than any of the foregoing, apart from the fact that careful examination with the microscope is necessary. All these classifications are useful to the Forester, if only they are ready and can be applied without hesitation in the open; for scientific purposes I fail to see the need for a classification at all, especially if it runs counter to the affinities of species. Mer makes three classes: (*a*) where the tannin is deposited *upon* the walls of the cells and the difference between sap-wood and heart-wood is great (Oak, Elm, etc.); (*b*) where the differentiation is less, the tannin being likewise in the form of cell-thickening (Hornbeam, Beech, Spruce); (*c*) where the tannin is accumulated in the *cavities* of the cells (Whitebeam, Willow, Silver Fir). The author regards the third class as having false-heart-wood and says that all Broad-leaved trees should be considered as heart-wood producers, inasmuch as in the centre of the tree there is no starch remaining, all having been converted into tannin, which is there present in greater quantity than towards the exterior of the trunk.

None of these divisions correspond very well with our rough classification. As a matter of fact, in practice we employ the wood of the Sapwood and Ripe-wood trees just as though it were heartwood, thus tacitly denying the value of these distinctions. The Scots Pine does not show its heart-wood until it has been felled and dried (R. Hartig, 1882, p. 5), so that one might almost call it an artificial product resulting from exposure to the air.

The gradual passing over of the sapwood into the heart-wood as in the Beech is not common.

The heart-wood is not found in the roots of trees; it terminates in a conical form a short distance below ground (Mer, 1897, p. 6, footnote).

HEART-SUBSTANCE.—Before passing to the peculiarities of the Heart-wood it is necessary to know something of that substance which is changed in or added to, the sap-wood in order that it may accomplish its metamorphosis into heart. This substance is *Tannin*, which is at first in a free and soluble condition, but later becomes deposited in or upon the cells, and becomes insoluble in all reagents commonly employed to dissolve it when in a free state (Mer, p. 94). The tannin has become oxidised and may be regarded as a new form of matter and should therefore receive a new name, for to say that the durability of wood is due to tannin, itself an unstable compound, is illogical unless we can attribute to it an antiseptic action, which it does not appear to possess. That tannin may convert perishable skins into durable leather is an analogy of no value, because in such a case a chemical action takes place whereby the animal substance is converted into gelatine, the tannin disappearing in the process. No action of the kind goes on between tannin and cellulose or lignin; the first must therefore be changed either into a resistant compound or into an antiseptic.

R. Hartig appears to assume that this former alternative is right and that the new compound is Phlobaphene. Czapek says it is Hadromal, Fremy and Urbain (*ex* Petit, p. 42) say Vasculose, and others in the past called it "duramen," a stop-gap word. I think Hartig is near the truth, for Phlobaphene, or as it is commonly termed "Oak-red," is used by fishermen to tan the sails of their boats, and it presents us, by the way, with some exquisite colour-schemes at sunset on the water. The Oak-red has certainly a preservative effect upon the vegetable matter of which the canvas is made; may it not afford the same protection upon the cellulose of wood? (*see* chapter on Durability). For the present, as nothing is definitely known of the exact process of heart-production, I prefer to use the non-committal word "heart-substance."

The whole of the tannin contained in the wood may not be converted nto Phlobaphene, etc.; an iron salt will generally demonstrate its presence by turning the wood black, *i.e.*, forming an ink (*see* under head "The Extract").

The heart of the Wych Elm (*Ulmus montana*), as in the case of the Scots Pine, does not appear before felling (Wiesner, II, p. 901), and the same may be said of the Weymouth Pine (*Pinus Strobus*). Guibourt (III, p. 33) says of the Padouk (*Pterocarpus* [*Derris*] *Dalbergioides, Bak*): "I have seen a piece of this wood freshly felled that was almost white in the nterior, but which has since become completely red."

R. Hartig (1882, II, p. 49) says: "The youngest heart-ring of an Oak just after felling was coloured like the sap-wood, but after admission of the air it became dark coloured, indeed deeper than that of the old heart-wood. The change took place within a few days."

Benson and Jones (1915) state that the tannin-content of Douglas Fir slab-wood increased after storing for one year, from 5·92 per cent. to 7·5 per cent., while the total solids increased 0·9 per cent., evidently at the expense of the non-tannins, which decreased by the same amount.

As the change appears to be caused by the oxidation of tannin or one of its derivatives, the exposure to the air of any part of the living wood (as by a wound) will cause a local production of heart-wood. There is in the Cambridge collection a specimen of Horse Chestnut, a normally white wood, that has this wound-heart very well developed: the whole of the interior of a branch, except a very sharply defined outer zone which suggests a layer of sap-wood, is of the colour of good Walnut.

The careful experiments of Buffon (XII, p. 47), supported by those of Knowles (p. 270), and others, show that the sap-wood of the Oak-trees stripped of their bark while still standing, acquires many of the good qualities of the heart, more especially hardness. The sap-wood of Buffon's Oaks became hard enough to turn the edge of the axe. It seems that the process can go on so long as the wood remains saturated by the fluid sap, and perhaps the seasoning of logs under water may derive its virtue in part from the preservation of the wood in a wet condition, during which conversion may continue for a long time.

Certain experiments of the Commission of Brest, a body which tested Dumonteil's woods from French Guiana, showed that those pieces which had been exposed to the weather for two years in the open acquired a resistance to strain in a greater measure than others (cut from the same logs) that were seasoned under cover. As their report is very inaccessible, the details of a few cases are given below. The figures represent the maximum and minimum loads borne at the first indication of rupture to a transverse load by bars one metre between supports by 5 c/m side. The load is expressed in kilogrammes.

Name of Wood.	Pieces Seasoned under Cover.	Pieces Seasoned in the Open.
St. Martin Rouge	800 to 1,260	1,010 to 1,410
Maho Couratari	730 „ 800	830 „ 880
Genipa	610 „ 860	780 „ 860
Saouari	720 „ 920	860 „ 940
Oak (from the Seine watershed, as control)	600 „ 710	750 „ 810

There is nothing here to prove that heart-production continues, but the results certainly indicate that the qualities associated with the heart are intensified by avoiding too rapid drying.

Burying wood, which amounts to the same thing as seasoning in water, as it conserves the moisture, frequently enhances the characters of the heart-wood. I have seen a portion of a Chinese coffin made of the wood of a Conifer (*Cunninghamia sinensis*), which having lain in the ground for many years had become exceedingly hard, without being in any way silicified. The wood of the Merisier Cherry, so familiar in the stems of Cherry pipes, is buried by the pipe-makers of Sainte Lucie (Lorraine), and its depth of colour and aroma are thus augmented (Petit-Thouars, p. 99). The deepening of the colour of worked-up timber may be regarded as a post-mortem production of heart-substance. We return to this subject later.

Colour.

The difference between the heart-wood and the sap-wood that most attracts our attention is the deeper colour of the former: that most familiar being some shade of brown or reddish-brown, but examples of the whole scale of colours can be cited, from black to white. A few of the most remarkable are the following:—

Black. The various Ebonies (*Diospyros*), and the allied genus *Maba* ; the African Blackwood (*Dalbergia melanoxylon*), and a species of *Acacia* from Arabia (*A. mellifera*).

Chocolate-brown. The Portia-tree (*Thespesia populnea*) and one of the so-called African Oaks (*Lophira alata*).

Red, deep. Padouk, Red Santal.

„ light. Pencil Cedar (*Juniperus virginiana*).

Brown. A great variety of species, including several of our most familiar hard woods, such as the Elm, Oak, Chestnut, Mahoganies, etc.

Pink. The Pink or Red Ivory from Rhodesia, the most beautiful of all woods of a uniform colour. It really resembles ivory in texture and almost in density. It is pink when freshly cut, but afterwards becomes red.

Green. There are several shades, the darkest, a blackish-olive, is exemplified by the Lignum-vitæ (*Guaiacum officinale*) ; the lightest by the Japanese Barberry (*Mahonia japonica*). Then there is the metallic green characteristic of the genus *Rhus*, by which nearly all the species may be recognized. The genus *Nectandra* is another that contains several green woods, of which the best known is the Greenheart (*N. Rodioei*). The wood of the Tulip-tree (*Liriodendron tulipifera*), when light-coloured, often has a canary tinge of green and so has the Horse Chestnut, but the former darkens to a pronounced green colour. The False Acacia and the Mulberry frequently have distinctly green shades.

Golden or reddish-yellow. The Opepe from the Gold Coast and the Jak-tree.

Blue. The Blue Mahoe (*Hibiscus elatus*), and its ally, the Jamaica Cork-wood (*H. tiliaceus*).

Purple. The Purple-hearts.

Grey or greyish-brown. The White Pear of the Cape (*Apodytes dimidiata* and the Saouari of Guiana (*Caryocar sp.*).

Pale citron. The Orange and Lemon woods.

Yellow. The Boxwoods, Satinwoods, and most of the woods of the Rutaceæ.

White. The Sycamore, Lime and Poplar but the colour is rarely pure. The Bitter-woods (*Picræna* and *Quassia*) are the nearest to paper-white, though Horse Chestnut and Holly may be very near to it.

The commercial Quassia of the present day (*Picræna*) has a canary-colour, especially on the transverse section, the dust produced by sand-papering being distinctly of that tint.

The lighter colours mentioned are nearly all of sap-wood trees, and do not properly belong here.

It is probable that the blue colour of the Mahoe is not natural, as Leman (*Hortus jamacensis*), says that the wood becomes purplish when cut with iron. The colour of our specimen seems fairly deep-seated and gives no reaction with iron salts, but conditions may differ when the wood is full of sap. The same applies to the Jamaica Cork-wood, which has rather a purplish tinge in patches. Other species of *Hibiscus* of a light colour give a slightly bluish reaction. If names go for anything, the "Bois de cœur bleu" (*Goniostoma borbonica*) furnishes another instance of this rare colour, but the only specimens that I have seen were of sap-wood, and, lastly, there is the *Macrolobium Simira*, described by Aublet as "bleuâtre."

A black reaction is common with woods containing much tannin as is well known to every woodman who fells Oak. The Chestnut and Hornbeam behave in the same manner according to Noerdlinger (1859, p. 47), not only in the Spring, as stated by Th. Hartig, but at all times of the year. As regards the Chestnut, this is in direct contradiction to Knowles, who relates that it was the practice at Woolwich to sprinkle the saws whenever they wished to prove whether a log was of Oak or of Chestnut. If no reaction was observed, the log was regarded as being of the latter. I think that Noerdlinger is correct, as shavings of Chestnut when moistened in water give an inky reaction, although not so intense as would those of Oak.

Purple is recorded for several species of Leguminous woods of the genera *Peltogyne* and *Copaifera*, but all specimens reputed to be the latter that I have had the opportunity of seeing have proved to be of the former genus. Authors do not agree in their descriptions nor do they say whether the colour is natural or subsequent. That of the Purple hearts is abnormal in so far as it does not exist in the living tree, though produced naturally when the tree is cut up. At first quite superficial, the colour may eventually penetrate into the interior, perhaps only after the lapse of years. When the log is very wet with fluid sap, the dark-brown wood turns magenta before one's eyes.

An analogous phenomenon is the rapid change from white to deep orange-brown in freshly-felled Alder-trees, but here it is the fluid sap that turns colour; the wood itself when dry remains light coloured when cut. Hough (1897, VII, p. 40, and 1902, II, p. 48) mentions *Alnus oregona* and *A. rhombifolia* as behaving in the same way. The Bird Cherry similarly becomes a vivid red (Mathieu, p. 137), and the same author (p. 322) says that the Beech is white when freshly felled, turning reddish on exposure, and finally becoming of an uniform light reddish colour. The Ash colours light-violet on the transverse section, and the Nettle-tree (*Celtis*) grey (Noerdlinger, 1859, p. 47). Hough says of the Californian Walnut that "the sapwood is yellowish-white when fresh, but soon assumes a markedly green hue and finally changes to brownish-white" (1899, VIII, p. 46, and 1895, VI, p. 48), and of *Taxus brevifolia*, "soon after being felled it turns from a pinkish-brown to bright blood-red, this being, as in the case of the Alder, quite superficial."

R. Hartig (1901), writing of the "Rothholz" of the Spruce, which is produced in such parts as are subjected to frequent or continued stresses, owes its name to its red colour. This disappears on drying, but may be recovered on moistening.

These cases, where the fluid sap comes into question, may be compared to that of apples when bruised or cut, or to the discoloration of some woods during the pulping process in the manufacture of paper or again to the change of colour caused by steaming, as in the Beech. Steaming has often a profound effect upon the colour. H. S. Betts (1917, p. 26) says that a pressure slightly above the atmospheric for twenty-four hours will slightly darken the colour of 2-inch Maple right through and a pressure of 40 lb. will turn Oak and probably other hardwoods almost black. The Red Gum sapwood is changed to that of the heartwood by the same means.

The Brazil, when freshly opened, is of a dark yellow colour, but after exposure to light for two or three days, especially to the direct rays of the sun, becomes, according to Tolbecque (p. 251), a beautiful red.

Arnaudan (1858) insists that the turning of the Purpleheart is due to light and not to oxidation, as it may take place in wood enclosed in glass tubes filled with hydrogen. Inasmuch as already stated the colour may penetrate deeply into the wood, and as the tissues have a limited transparency, it may be doubted whether light be the only cause, indeed the change is immediately brought about by heating. We may still assume that light is a factor in the deepening of the colour to which nearly all woods are subject. This is brought home to e in handling specimens exposed in Museums. The side towards the light always darker than that turned to the wall. Returning to my llection, after the absence of some eight years, I found that those and-specimens which projected a little in advance of others were so uch darkened that there was a sharp line of contrast between the exosed ends and those which were shielded from the light by other blocks. his was most marked amongst the white-wooded Conifers, some which had darkened to the colour of Mahogany.

The wood of the Tulip-tree (*Liriodendron*) is remarkably sensitive. is not only difficult to keep a specimen white, but if an object such as a hotographic negative be placed on a board of it, and the whole exposed direct sunlight, a sort of positive will be obtained. In Museums e planks of this wood rapidly darken to a deep green or brown: there a specimen at Kew which is black. Even when planed, the wood found to be discoloured, so that the penetration is considerable. carcely less remarkable is the Mulberry, a greenish-white wood that rns to a deep chocolate.

Other instances, not always very clear, may be cited. The Plane-tree wood is fleshnk when fresh, but pale-yellow, inclining to red, later (Stevenson, p. 143). The *Amanoa ianensis* (Aublet, I, p. 256) is a white wood which turns russet.' It is one of the woods puted as a source of the Letterwood of commerce, and this character enables us to exclude The Sugar Maple (Stevenson, p. 114) is white also when fresh, becoming rosy. The olly (Noerdlinger, 1859, p. 47) passes from greenish to greenish-blue, apparently when esh, for the wood, as already stated, is ivory white. The Hercules-Club-tree (*Zanthoxylon ava-Herculis*), another white wood, becomes a beautiful, brilliant golden colour, as does so in a less degree the true Quassia (*Q. amara*).

The greatest contrast that I have met with, excepting the Tulip-wood, is the *Olea ncea* of Bourbon, The interior of old specimens is as nearly as possible white, but the rface deepens to dark Walnut-colour or dark olive-brown. Specimen No. 145, Mus. Col., arseilles, is partly polished, and this portion resembles Mahogany. I may say in parenesis, that spirit-polishes nearly always alter colours considerably, more especially ese superficial patinas. The Purpleheart when polished loses its striking effect entirely d becomes brown, like the interior of the wood. Of two authors writing of the American ack Walnut (*Juglans nigra*), one (Buffon : Suites, p. 407), says that it is at first violet, coming black, which is the common view, and the other (Roussel, p. 306), that it takes osy tint with age. Other instances are *Bellucia Aubletii* and *Loreya arborescens* of Guiana, th white, then russet; *Cedrela guiaensis*, white, then red; and the Couliboulíroua (Préfonine, p. 150) apparently becomes green.

The black colour of old Oak furniture so much admired by amateurs ems to be the product of the method of polishing or cleaning employed our English ancestors. It is rarely seen abroad : the old Oak fittings churches, even when dark, are never black. I remarked this especially the old Church of St. Michel, at Sospel, near Mentone, where there ay be seen a very beautiful, antique episcopal chair in Oak, still of a mparatively light colour, and not far from it the massive cover of e font in Walnut, which is, on the contrary, as black as charcoal. gain, the oaken image of the Virgin in the crypt of the Church of St. ctor at Marseilles, the origin of which is lost in antiquity (it is said date from Roman times), is by no means black, notwithstanding popular name of "La bonne mère noire."

Everyone knows how quickly Oak blackens in stables from the ect of the ammonia vapour (which, by the way, is used at the present y to counterfeit old furniture), and I suggest that there was some bstance containing ammonia used in the making of the old polish.

The colour of bog Oak may possibly be attributed to a similar cause, *i.e.*, the ammonia produced by the decomposition of animal matter. If it were simply due to staining by the peat-water the peat itself should be black, not brown.

A similar result is obtained by the natives of certain parts of Africa by throwing Mangrove logs (which are brown) into bogs, where they become according to Antran (p. 571) as black as Ebony and are passed off on traders as such. The tree is often as much as forty metres high, whereas the true Ebony, in these days at least, is generally very small. When buying logs of large size this should be borne in mind. It has long been said that Ebony is seasoned in marshes, but as good qualities should be, and are really black when felled, the story may have arisen from the above-mentioned practice.

Barringtonia acutangula (Pearson, 1912, p. 24) turns from nearly white to black when buried in mud. Amongst the white woods which become superficially darker in tone are many Conifers, for example: *Taxodium distichum, Chamæcyparis Lawsoniana, Podocarpus dacrydioides, Cedrus Libani* and *Picea sitchensis.* Less so, but still pronounced, are *Picea alba, Phyllocladus trichomanoides* and *Podocarpus ferruginea*; and still less, though quite distinctly darkened, the common Spruce (*Picea excelsa*). *Cupania venulosa* and *alternifolia* from Bourbon, both white or écru-coloured woods, turn distinctly red when moistened. The former becomes white again on drying, but the latter does not: the outside of the log under the bark shows stains of red.

Roth (1895, p. 24) says that Pine wood becomes dark grey after prolonged immersion.

Yellow woods, if pale in colour, do not deepen much as a rule. The Boxwoods, the Orange and Lemon woods and a great number of the family Rutaceæ are more inclined to fade. On the contrary, dark yellow woods deepen exceedingly, for instance, the Fustic (*Maclura tinctoria*), the Osage Orange (*M. aurantiaca*), the Bread-fruit tree and the Jak tree (*Artocarpus incisa* and *integrifolia*), all of which are dye-woods. Weathered logs of these species are very dark on the exterior.

Weathering profoundly affects the colour of many woods. The Oak, when used as palings or for barrel ends, acquires a beautiful silvery-grey tint, and something similar is seen on the shingles of Larch used for the roofs of châlets in Switzerland. The latter when viewed from above in the sunshine look as though covered with fish-scales.

For the most part, colour-change is only skin-deep; the slightest cut will again expose the natural and original colour. The exceptions where the change is profound are few.

The loss of colour, except in the instances cited above, is less frequent. Amongst those woods which become paler with age and exposure are the Plum-tree and its allies. In the Sapotaceæ this character is fairly constant. The beautiful red Andaman Padouk has this defect and the almost equally beautiful Redwood (*Sequoia*) fades to a dull brown, as does also the rich blood-coloured African Oak or Eki (*Lophira procera*). The case of the Pencil Cedar is familiar to all. Boulger (1902, p. 269) says that the Osage Orange fades to greyish, but my specimens have turned, as stated above, to dark brown.

The Bastard Logwood is a curious case; Drabble (1907, p. 185) says that this variety fades, whereas the true Logwood produces wood which deepens very much in colour.

A change may take place in a single tissue, the surrounding parts remaining unaffected. In the Pencil Cedar, while the tracheids (woody fibres) fade, the parenchyma (resin-cells) become darker, no doubt on account of the concentration of red resin. The parenchyma of the Brigalow (*Acacia harpophylla*) turns brown in a very short time after it has been exposed by a fresh cut.

Distribution of Colour.—The colour may be uniform or as is more usual, disposed in stripes of different shades (longitudinal section). In the Pines such difference is chiefly due to the greater density of the Summer wood, often augmented by the accumulation of resin. In most broad-leaved trees it is brought about by the greater concentration of heart-substance, otherwise the higher oxidation of the tannins.

The stripes in rarer cases may be of different colours, e.g. crimson and white in the Tulip-wood of Central America (*Physocallyma scaberrimum*); orange and black in the Cocobola-wood (sp. undetermined); light brown and black in the Letter-wood (*Brosimum Aubletii*), where they are strikingly contrasted. Again, the colour may be more or less uniform as regards its general effect, but on examination it is seen to be composed of fibres of various hues. The fibres, if prominent, will produce a striated appearance (Elm, *Acacia*, *Mora*, and the old-fashioned Partridge wood, *Andira*); if small, they will blend to produce a mixed effect, as do the dots of a three-colour print. The different effects of the silver-grain will be treated under the heading of "Rays."

Many woods are striped by a pigment that is deposited irregularly and quite independently of the structure. These stripes may easily be mistaken for the boundaries of the rings or zones, unless examined with the lens. The most common is a dusky stripe, very characteristic of the Olives, indeed they are the chief beauty of the souvenirs of the Holy Land made at Nice. The stripes straggle all over the cross-section, sometimes in such quantity as to suggest heart-wood, whereas it may be all sap-wood. I have seen similar markings in *Olea Cunninghamii*, *lanceolata* and *lancea*, but they are by no means confined to this genus, being found in the most diverse families, as follows:—The Rosewoods (*Dalbergia nigra* and *latifolia*); Walnut (*Juglans regia*), and in the genera *Liquidambar*, *Nuxia*, *Celastrus*, *Zanthoxylon*, *Thespesia*, *Weinmannia*, *Dombeya*, and *Patagonula*.

R. Hartig (1892, p. 61) asserts that in the case of the Olive, the discoloration is caused by wounds higher up in the tree. In all specimens of the European Olive-wood that I have seen, this seems to be so; one may often trace each stripe to a wound or to callus. In one specimen on a transverse section, it was possible to follow the stripes from a callus-cushion right round the ring and back again to the wound, each line being concentric with and independent of the others. On the other hand, they sometimes melt together, or die away. This seems to indicate that the infiltration is seasonal and not constant, as we should expect from a decaying branch or wound.

A most extraordinary development of such stains is found in a wood from Guiana called by the French "Cassie" or Bois Serpent (*Stryphnodendron guianense*), and nearly always confused with the "Hooboobali" from the British Colony. (Indeed, I have made this error myself in my "Timbers of Commerce," but I have since seen the former wood from

French Guiana, and there is really no resemblance between them. I have had the advantage of being able to use the herbarium material at the Mus. Col., Marseilles.) The Bois Serpent is marked with broad purplish-brown streaks, sometimes half an inch wide, and of so great a contrast to the white ground of the wood that they can be seen distinctly fifty yards away. In the Hoobooballi they are equally curious, but they are narrow, dusky and by no means so prominent. This latter wood is a species of *Lecythis*.

These capricious dusky zones would provide an interesting subject of research. Being independent of the structure, they are easily recognised. From the examination of many specimens I am inclined to think that Hartig's explanation, which is good for the Olive and the Walnut, is doubtfully applicable to some of the others cited.

It frequently happens that the limits of a decaying area in unsound wood is indicated by dusky lines much resembling those just described; indeed one author, in his description of the Quassia, has taken them to be normal characters. One must be on one's guard, for decaying wood may assume strange hues, even deep blue and green, as in Oak attacked by the fungus *Chlorosplenium*. Tunbridge-ware makers sometimes take advantage of this when the wood is not too far gone. Many such woods are figured in colours in the "Icones Lignorum," a most beautiful work, the hand-painted figures being very well done and true to nature.

The chocolate-brown of old Evergreen Oaks, the red-brown in the heart of most of the Apple tribe, the brown and reddish marbling of old Beeches, the brown shades that appear in the centre of Ash trees and the blackish, curved lines of many soft whitish woods are indications of incipient unsoundness. Mathieu (1857, pp. 275, 678), says that the canary-colour frequently seen in the wood of the Nettle-tree (*Celtis australis*) is of this nature, as may be the green stripes in Sycamore also.

Root-wood is frequently variegated and is sought after by makers of marquetry. The lower end of the stem of the Hazel is used in Germany by turners, as it is marked with violet (Martin p. 167).

The difference in the shade of the same colour, exhibited by the various cuts of the same piece of wood, is not infrequently considerable and may be an indication of value. The rule is, that the transverse section is darker and duller than the vertical sections. If, however, the soft-tissue (*parenchyma*), which is generally lighter in shade than the woody fibres, be exceptionally developed, the transverse section may be the lighter, as in the case of many Sapotaceæ. This affords a good character in identification.

The contrast in the shade of the sections does not strike one when a block is held in the hand; the play of the light and shade prevents this feature from being appreciated, but if the reader will examine the veneers published by Hough, already alluded to, he will find amongst the Pines (*Pinus Strobus* is a good instance) contrasts that are so pronounced that one can scarcely believe one's eyes.

In the wood of the Peroba amarella (sp. undetermined), the cross-section is rich orange and the plank face yellow, resembling Boxwood.

With the exception of white and most light yellow woods up to a certain point depth of colour indicates good quality. Even amongst these, freshness and brightness are important features.

The colour of the ends of freshly-felled logs is used as a criterion of quality by some. Haering (ex Noerdlinger, 1859, p. 40) discusses this point at length, without, however, arriving at anything conclusive.

Testart (p. 559) says that the bluish or lilac colour at the ends of freshly-felled logs of Oak is evidence of second quality and that the tint disappears on drying, when the first and second qualities become indistinguishable. The cross-section of fresh Elm is distinctly purple. Exner (1903, p. 107) says that freshly-felled Ash also becomes violet on the cross-section, the Nettle-tree grey, and the Holly a beautiful greenish blue. Boppe (1887, p. 23) says that the Merisier Cherry turns a vivid ochreous-brown as does the Horse Chestnut.

It may here be stated that all the desirable qualities of wood that depend upon heart-substance vary together, and that richness of colour, heavy weight, resistance to strains, hardness, durability and even the smell may be predicted, mutually one from the other, with the reservation that the colour be not due to decline and incipient decay. Inasmuch as excessive weight may be a disadvantage, it may not always be prudent to choose the darkest timber of a given species, still the carpenter relies upon the colour in his estimation of woods.

The colours cited by various authors for the same species are often very different and indeed the range is great, the Tulip-wood (*Liriodendron*), as we have seen, may be either white, canary-colour, brown or black. The False Acacia is, according to Hough, called "Red, Yellow, Black, Green and White Locust." The French Colonists of tropical Africa go still further with their names of *Albizzia Lebbek*, which they call, according to its colour (corresponding in naming to as many commercial varieties), "Bois noir rouge, Bois noir blanc and Bois noir noir." It will be understood from these examples that anything like precision in the description of a wood from its colour is impossible, and it is necessary to make oneself acquainted with all variations and the range within which good material may be expected to lie. Nevertheless, colour must always be one of the most important elements in our impressions and we cannot ignore it. Some people have a marvellous capacity for recognizing woods at a glance, and colour certainly must make up the greater part of their impressions.

I hold out the suggestion to some writer of practical experience, handling large quantities of timber, that he should furnish us with a list of our common woods, giving the colour and its range according to a colour-scale, of good merchantable stuff only. It is of little practical use to record extremes and "freaks." What we want to know is the colour of serviceable qualities.

Knots in Coniferous wood are generally of a much deeper colour, as is well known, but in *Pinus Cembra*, according to Exner, they show much less contrast and this may be used as a means of identifying the wood.

In the same tree (excepting those producing light-coloured woods) the colour is the deeper the nearer the first year's cone or ring; in other words, it intensifies inwards and downwards towards the point where the heart-formation first began and has longest been in operation. Hence we find the darkest wood near the roots.

The varieties of a species may sometimes be distinguished from the parent stock. The variety "Juliana" of the Cherry has an olive-green wood, whereas that of the parent species is brown, sometimes inclining to red. The Bastard Logwood has already been mentioned, but its variations are truly remarkable—from red through chocolate to deep blue, pale pink, yellow and white, according to Drabble (1907, p. 185). The deep blue variety when chipped develops a deep, rich bronze colour.

Again a hybrid may exhibit similar divergence, as in the Willow, used for cricket-bats. The colour is perhaps not very different to the lay eye, but according to W. J. Bean, it is relied upon by the makers in their choice of timber.

Colour of the Sapwood.—Though in the vast majority of cases the sapwood of Heartwood-trees is lighter than the heart and varies from white to light brown (écru or oatmeal-colour), it may display certain striking exceptions.

The *whole* of the wood of the trunk may be of a dark colour, as in the Mangrove and several woods with odd names from Guiana:—Hoorihee, Kokeeru, Fukadie and *Mimusops Kaki*, *Myristica Mouchigot* and *Mouriria sp.* The Grenadille bâtard de Cayenne (mentioned by Varenne de Fenille) is of the same dark colour throughout, but as the author tested the weight and found that of the exterior wood to be 25 per cent. lighter than the centre, we have perhaps a true sapwood in this case.

Specimens of the Balata or Massaranduba (*Mimusops elata* [?] which I have seen, are uniformly dark throughout, but Saldanha (1865, p. 47) says that some individuals have an almost imperceptible amount of sapwood of a less intense colour, or sometimes purplish-red. Possibly in my specimens this zone had passed over into heartwood during the seasoning. As regards most of the foregoing, one does not know how to classify them, they are really "sap-wood-less" trees.

Another series of exceptions is that in which the sapwood is dark but *different* from the heart, as in the African Oak (*Lophira*), the Howadanni from Guiana and a Conifer, the Celery Pine of New Zealand (?) The most singular is the Opepe from West Africa, that has a deep brown sapwood much darker than the golden-yellow heart. The Pequia branco of Brazil (*Aspidospermum eburneum*) has a sapwood of a more intensely yellow colour that is sharply defined from the lighter heart.

A further alternative is the sapwood which may be coloured but not darker than the heart. Amongst these are:—the Ratas of New Zealand, where it is red; the Ceylon Ebony (*Diospyros melanoxylon*), where it is pink; and the Barberry, hardly a timber by-the-way, where it is yellow; and *Marlea vitiensis*, which has a beautiful greenish-golden sapwood that forms a handsome contrast with the brown heart traversed by dusky stripes. Boulger (1902, p. 199) says that the sapwood of the American Rock Elm (*Ulmus racemosa*) is greenish. The heart is brownish.

Limit of the Sapwood.—The sap- and heart-wood may be sharply defined, the one enclosing the other as though they were separate substances (Laburnum, Ebonies, Oak, etc.), or they may merge one into the other so gradually that one cannot say precisely at what point the heart commences (Pear, Apple, Evergreen Oak). In the third place, notwithstanding the widest contrast in colour, the line of demarcation may be somewhat vague. All these are good items in the identification of woods. A fourth case is that where the heart may be sharply defined, yet certain tissues of the sap-wood acquire colour in advance of others. In the Lignum-vitæ it is the pores that take precedence, as they do also in the Almond, in the Mahoganies, and in *Cassia fistula*, and according to Noerdlinger (1859, p. 32), the Young Fustic (*Rhus cotinus*).

A curious instance hardly germane to this section is the Olive from the Cape (*Olea Cunninghamii*), the dusky stripes of which have already been touched upon. These stripes in the sap-wood are pink.

A fifth form of limit is exemplified in the Oak, where there is an intermediate zone of ripe-wood as it has been termed, by which the sap-wood passes over into the condition of heart. In this species it is not distinguishable except by use of the Iodine-test for starch, but in other very rare cases this ripe-wood zone may have a distinct colour. In *Rhus integrifolia* it is green. According to Grisard (1894, II, p. 80), the Lebbek-tree has "double aubier" but he does not describe it further. My specimens show nothing unusual. Janssonius (1914, p. 41), describing the "Êbène verte" of French Guiana, says that it has an intermediate greenish-yellow zone between the yellowish-white sap-wood and the reddish-brown heart-wood, and it is in this zone that the greatest quantity of yellow dust, characteristic of this species, is found. Schneider (1916, p. 19) says that this ripe-wood is often observed, especially in species having a very dark heart-wood, and is notable in Camagon and the other species of *Diospyros*. As I have always failed to see it in these species, I imagine that in seasoning it passes into heart-wood and disappears in old specimens.

Noerdlinger (1859, p. 528), writing of the Willow (*Salix alba*), says that sap and heart merge gradually one into the other and that there is ripe-wood of a light-red present, the heart being brownish-yellow and the sap-wood reddish-white.

WIDTH OF THE SAP-WOOD IN HEART-WOOD TREES.—The sap-wood comprises a number of the outermost rings of the tree from as few as one (sometimes) in the Laburnum. Boulger (1902, p. 197) says that the sap-wood of the Laburnum is broad, but I have always used it as an example of the narrowest. It is at times as narrow as two rings in the False Acacia or as few as seven in several species of the Bixaceæ (Stone 1904, Nos 3, 4, and 5) to as many as one hundred in the Letter-wood (*Brosimum*) and some exotic Leguminosæ. Des Etangs (p. 13) says that the Chestnut has two to three rings, but as a rule the sap-wood runs rather wider, though always narrower than that of the Oak, and this fact serves very well to distinguish logs of the two species when in the round. I have measured the sap-wood in a Tamarind-tree from Madagascar, in which it was six inches wide, so that the tree would have been twelve inches in diameter before heart-wood commenced to form. This example shows the range in the family Leguminosæ being a great contrast to the narrow sap-wood of the Laburnum. The Courbaril of British Guiana has a sap-wood so wide that museum and even commercial specimens frequently exhibit nothing but sap-wood: the heart is of a very rich red colour. Both this species and the Tamarind are sometimes wrongly described for this reason. Aublet says of the Washiba of Guiana that "it has two feet of sap-wood to one of heart."

Many Conifers have a wide sap-wood—a specimen of the Scots Pine in the Cambridge collection has seven inches on one side and the narrowest is 2¼ inches. On the other hand, the Larch has a proportionately narrow sap-wood (our widest being two inches). Here, again, this feature is useful in discriminating between the Larch and the Scots Pine when in the round.

The double sap-wood of the Oak (Fr. Double aubier; Ger. Mondring) is a defect that will be referred to in its proper place (*see* p. 199).

The period at which the heart-formation commences may vary in the same species or in different parts of the same tree. The Oak, according to Buffon (XII, p. 47), begins to produce heart as early as the seventh year or may postpone its appearance for as much as twenty-five years and there may be as many as seven years' difference in heart production between one side of the tree and the other, and this quite apart from the actual measured-width, for that on the side with fewer annual rings may yet be the broader. Buffon concludes that such inequality is due to the presence of large branches or roots above and below, which carries with it as a consequence a greater abundance of nourishment. The stream of nutrient sap travels vertically and a large branch will feed the wood immediately beneath it more freely than elsewhere, hence not only will the favoured rings be broader, but they will ripen earlier.

In the Spruce, according to Hartig (1891, p. 28), the number of sap-rings decreases from below upwards and may fall below half the number of those at the foot and indeed sections close above one another may show great differences. In an old Oak of 400 years' growth, he observed (p. 30) no less than 100 rings, but their width was diminished in proportion.

Noerdlinger says (1859, p. 301) that in the Weymouth Pine the sap-wood may be as narrow as six to seven rings in the trunk and as broad as twenty rings in the branches. Mathieu states (1897, p. 351) that *Quercus pedunculata* may postpone heart-production for thirty-six years. In the case he cites, the thirty-six rings measured only 16 cm., while in another, where the rings were no more than seven in number, they measured 76 cm. Further (p. 67), "In old trees that are on the decline the number of rings of sap-wood often augments in a remarkable manner, notwithstanding that the total width that they build up, may diminish, as in *Pinus Laricio* and *P. Pinaster*." On p. 584 he states that Scots Pine may have as few as twenty-seven rings of sap-wood or as many as eighty. On p. 673 he sums up the question of Heart-wood and sap-wood generally, and avers that the expressions are synonymous in spite of all attempts to attribute to them different meanings.

It is well known amongst Foresters that certain species make heart-wood more rapidly on certain soils, a consideration which in importance may outweigh the rapidity of growth of the tree.

Von Schrenk (*ex* A. Deane) says that eight, ten or even more years' growth (*i.e.*, rings) may ripen in one year. It would be interesting to know how the author arrived at this conclusion. How could he know that the heart-wood present at one moment was sap-wood the year before?

As time is assumed to be an essential element in the production of Heart-substance, this point seems to need further investigation. "Time" is meant no doubt to imply accumulation of nourishment, but if Buffon's assertion holds good, the time factor becomes of less importance, for heart-formation may take place at different rates at different periods: at one time it may exceed the growth of the wood, and at others lag behind it. Kirk (1887, p. 30), writing of the New Zealand Birch (*Fagus ferruginea*), says that the heartwood encroaches upon the sap-wood more and more as the tree ages. On the other hand, if oxidation be the predominant factor, then the rapid production of heart may imply that the sap-wood in some cases dies earlier, and gives access to the air. Notwithstanding all this, it is the rule that the sap-wood maintains its width all round the trunk equally. Even in the lop-sided specimen of the Lignum-vitæ, previously mentioned, although the rings of one side average seven times the width of those on the other, yet the sap-wood is approximately uniformly broad. Step by step with the production of a new ring on the outside of the tree, another nearest the heart passes over into it. Certainly the rule has many exceptions apart from those cited, indeed the change may affect a *portion* of a ring only or while neglecting it in one place may encroach upon two or more rings in another. Irregular heart seems to be normal in the Pencil Cedar, the Ebonies, and the Logwood described above, where it runs out in finger-like extensions. This seems to occur in the Red Maple (*Acer rubrum*) which, according to Stevenson (p. 116), has a heart of a star-like section, with points 1–3 inches in length.

It may happen that the sap-wood of certain species may be nearly as or even more serviceable than the heart, as in the Ash and Hickory or the elastic woods used for long-bows, where the belly is made from the sap-wood and the back from the heart (*see* 137). Again, in the Persimmon (*Diospyros virginiana*) and Cornel (*Cornus florida*), used for shuttle-making, and the New Zealand Birch (Kirk, *loc. cit.*) the sap-wood is recorded as being the tougher, and in the American Birches (*B. lenta* and *papyrifera*) it is the less perishable. In the last mentioned the heart is rejected, but as *B. lenta* is valued rather for its appearance as a furniture wood, the heart-wood is the part used. The resistance to fission and shock, of the sap-wood of the Lignum-vitæ makes it invaluable for the outer portions of pulley-blocks and dead-eyes and for the manufacture of policemen's bâtons. The same may be said of the Elm, the heart being sometimes rejected by millwrights as being inferior in strength and durability to the sap-wood; on the contrary, the sap-wood of the American Elm (*U. racemosa*) is the more perishable (Stevenson, p. 34).

The question of the difference in quality of first and "second-growth" would provide an interesting subject for investigation, as the latter is indubitably of better quality than the former, a fact which is in harmony with its more rapid growth, or in other words with the greater width of the less-porous zones of the ring. It should be borne in mind, however, that there are two kinds of second-growth, *i.e.*, that which arises from the stools or stumps of trees after felling or pollarding, which is a callus production, and that which comes from the roots, when the tree is still living, as in the case of the White Poplar.

CHAPTER III

THE SURFACE, SMELL, TASTE AND CONTENTS

Surface

THE surface may be regarded from three different points of view: firstly, the manner in which it reflects the light; secondly, its uniformity, or evenness; thirdly, as regards its effect upon the sense of touch.

LUSTRE.—The surface may vary from dull to brilliant, according to the transparency of the cells, which act as tiny prisms or bubbles and reflect and refract the light. This action is often modified by the cell-contents, which may be more or less opaque or may have a lustre of their own. In the resinous Pines the general appearance of the wood is due rather to the resin than to the cells that hold it. On the contrary, the Spruce, having but little resin, is very brilliant, a quality that will be better appreciated when the wood is viewed with the aid of a lens on a smooth, freshly-cut surface or in a very thin veneer.

That refracted light must take a great part in causing our impressions of both lustre and colour will be evident from experiments made to ascertain the transparency of wood. I have obtained light through a disc of Spruce one inch thick (cross section) and through Lignum-vitæ, the densest of all woods, of ⅛ inch, notwithstanding the fact that the colour of this latter wood was a very deep brown. The light passed by all species of wood so far tried is the same, *i.e.*, red, of that tint familiar in the windows of photographic dark-rooms. It is therefore an absorption phenomenon, all rays but the red being absorbed. This experiment was first performed by Noerdlinger, but on much thinner pieces. Light is transmitted in this manner in a direction at right-angles to the fibres in a very slight degree only; still in very resinous woods it may be observed, as in the case of Larch shingles, of which Gayer (1903, p. 491) says: "they are split so thin on the inner edge that light may be seen through them." The edges of blocks of Pitch Pine and of Lignum-vitæ are somewhat translucent, and I have seen cupboards made of the former which were quite light within when the sun shone on the exterior, the presence of much resin rendering the wood more translucent.

Inasmuch as the cells of the rays in radial section (silver-grain, flower, felt, clash or chink, as it is variously termed), run at right angles to the woody fibres, either of the two sorts of cell may appear brilliant or dull by turns according to the incidence of the light. If a piece of well-smoothed wood cut on the quarter (radial section) be turned about in the hand, shadow-like patches will come and go as the light is reflected, now by the rays and now by the fibres. In consequence, some people say that the rays of a certain wood are bright and others that they are dull. Both may be right; it is a question of the point of view.

Again, one tissue may reflect while another may be really dull. This character may be made use of in identification. Noerdlinger (1859, p. 50) says that the rays are bright in the Elder (*Sambucus nigra*) and dull in the Aspen, in the Cotton-wood (*Populus monilifera*), and in various species of *Pyrus* and *Amelanchier*. In our specimens of the first two, the lustre depends on the way they are held to the light, and in some of the species of *Pyrus* also, but in the latter the rays are coloured and hence much more visible. Boulger (1902, p. 324) states that the Sycamore may be distinguished from the Lime by the greater lustre of the rays of the former. This is true, but it must not be understood that the rays of the Lime are by any means dull; they are quite lustrous in a certain light.

In many cases the rays are not visible on a radial section except by the play of light, so that a specimen should be turned every way before coming to a decision.

As regards the fibres apart from the rays, we may have any range of lustre and much of the beauty of wood is derived from this feature. Almost all the woods of the Lauraceæ are particularly lustrous, the brilliance being due to the fibres. The most striking silky and satiny effects may be found in this family. The Stinkwood (*Ocotea bullata*), the most beautiful of the dark-coloured lustrous woods that I have met with, exhibits a reflection known by carpenters as "fire," *i.e.*, the wood looks as though it were alight within, the glow coming and going with every movement. This fire may be produced in another way, as we shall see. It is remarkable in another species of Ocotea (*O. cupularis*, le Bois canelle), in *Acacia heterophylla*, and the Judas-tree (*Cercis siliquastrum*).

If the course of the woody fibres be undulating, they will reflect the light in waves, producing the impression that the surface is more or less transparent. The wood often found in the neighbourhood of large branches or roots called "Ram's-horn or Ripple" is of this nature, but it belongs rather to our chapter on "Figure," where it will be discussed.

For the sake of clearness of description, the various lustres may be roughly classified as follows: Satiny, *e.g.* the Lauraceæ just cited and the Satinwoods, both the yellow and the red; silky, *e.g. Celastrus acuminatus*, the Seidebast, a beautiful wood from the Cape, and the Sycamore; metallic, *e.g.* species of *Artocarpus*, for instance, the Jak-tree and the Del, several species of *Rhus*, the Young Fustic and others, and some specimens of the False Acacia; horny, as in the Hornbeam and the transverse sections of Poplar and Birch; flinty, as in the Lignum-vitæ when freshly cut only, as it soon becomes obscured by the green, gummy resinous exudation; micaceous, *e.g.* Red Gum or Satin Walnut and in some specimens of the Douglas Fir in tangential section; waxy, *e.g.* the Old Fustic, *Maclura*, and Osage Orange; greasy, *e.g.* the Teak and the Turnip-wood of Australia; and resinous, *e.g.* the Pitch Pine.

Cross-grained wood in a longitudinal section reflects the light in alternate stripes, corresponding to the way in which the fibres crop out on the surface. Inasmuch as their cross-section is generally dull or of a different lustre, the ends of the cut fibres show up dull, while those more parallel to the plank face appear bright.

We still need terms for the woods which cannot be called lustrous: the lowest grade of these may be called "bright," but between "bright" and "dull" there are a number of woods, of which the Walnut is an instance, that cannot properly be described as either. For want of a better term I shall call such surfaces "clean."

Dull surfaces soil readily and this character is common to many white woods (Birch, Lime, Poplar, Canary White-wood); the distinction between these and the clean woods has therefore a practical significance. The American Elm wears clean and white, according to Stevenson (p. 39), and the Sycamore is chosen for this property for kitchen utensils; it belongs, however, to the silky woods.

The Giant Fir (*Thuja gigantea*), when darkened by exposure, shows a distinctly iridescent, bronze-like lustre on the hard Summer wood. I have seen a similar iridescence on the cross-section of old Santal-wood (*Pterocarpus santalinus*) when scraped, but this was deep green, whereas the wood was nearly black, from age no doubt, but the scrapings were of a brilliant orange. I imagine that this peculiar phenomenon has something to do with the fluorescence displayed by extracts of the wood.

UNIFORMITY OF THE SURFACE.—The surface may or may not be channelled by the pores (vessels, in longitudinal section). These latter, in the woods of the broad-leaved trees, usually form small grooves or scratches. According to the size and visibility of these latter we classify wood as coarse and fine-grained. It must be remarked that these terms are differently applied to Coniferous woods where the width of the rings is meant, wide-ringed species being coarse-grained, etc. In order to avoid ambiguity I shall refer to the broad-leaved woods as coarse-pored, or fine-pored, as the case may be.

There are various grades of coarseness amongst the woody fibres, but as these are scarcely visible to the naked eye under any circumstances, and we cannot in practice form an estimate, it is better to exclude them from the classification. Still, woods are constantly referred to as "short" or "long" in the grain, but this is a real error, as the user has no knowledge whatever of the length of the fibres; indeed, on the histological side of the question, comparatively few measurements are recorded. Further, we need a word to describe those woods which may have pores, large or small, but which may be filled by resin, as is often the case in the Rosewoods. These may be called "close pored," in contradistinction to empty "open-pored" woods.

A wood may be coarse pored in one part (in the later wood), and fine in another (near the pith), so that it cannot be accurately described as either; still there may be a general difference. In any circumstances, the Maple, the Sycamore, the Horse Chestnut and Willow are fine, open-pored woods, and the Oak, Elm and Ash coarse, open-pored woods. It is only necessary, however, to examine a wide plank of Oak cut on the quarter to convince oneself that the difference in size of the pores on the two sides of the plank is very considerable (*see* later under "Vessels").

EFFECT UPON THE SENSE OF TOUCH.—This may be of three kinds:

firstly, the greasy, as in the examples already given, to which may be added the Jamaica Satin-wood, the Sandal-wood, the New Zealand Black Pine, the Common Ash and the Tuart (*Eucalyptus gomphocephala*): secondly, those which are either smooth or offer resistance to rubbing; and lastly, woods that convey a sense of coldness or the contrary.

Sticky surfaces do not fall into this scheme of classification, inasmuch as the freshly-cut surface may be clean, but may afterwards be covered by an exudation. The Lignum-vitæ has been cited before, and some of the Pines which bleed may come under this head, then several *Acacias*, like the Myalls of Australia and, the stickiest of all, the Wallaba (*Eperua falcata*), of Guiana, which is impossible to keep clean, as it collects the dust and becomes very dirty. A curious case of stickiness in a somewhat different form is the Monkey-pot-tree (*Lecythis*). The shavings of this wood may be squeezed together in the hand and the mass will retain the shape of the palm. The Lignum-vitæ (*Guaiacum officinale*), at first smooth, becomes sticky from the exudation of resin, as does also the Maracaibo variety (*G. arboreum*), but this latter rapidly becomes dry, while the other always feels like French chalk. A piece of Jamaica Satin-wood that I have had in my collection for thirty-eight years (it was my first specimen) is still sticky and other specimens that I have seen are as though soaked in oil, but these came from the Bahamas and showed a certain difference in structure from the ordinary Jamaica wood.

Some Coniferous woods contain sufficient resin to glue boards together, as in the case of the Larch. Châlets made of Larch logs, roughly squared, will become quite weather-proof from the soldering together of the timbers by the abundant resin. The ancient Romans were careful not to use Coniferous wood for doors; they employed Oak for this purpose (Thucydides, II, 34, 3).

The property of taking glue is an allied phenomenon. The Oak refuses glue, whereas the Silver Fir and the Mahogany will break in the solid wood rather than at the joint. The Brazil, an exceptionally hard wood, glues very well. This indicates some special quality of surfaces which is worth investigation. Alberti (p. 28) was the first to point this out in connection with the Silver Fir (if the "Anet," a name now entirely extinct, refers to this species). Tiffany (1904, p. 316) avers that the Padouk will not take glue. Tredgold (p. 70) says that the Honduras Mahogany holds glue better than any other wood.

The resistance to friction is dealt with later (*see* p. 143) and that to cutting tools is a subject of which I know nothing, though it is brought to my mind every time that I pick up a plane. The manner in which woods "work" is a constant preoccupation of the carpenter, but beyond the fact that a wood works well or ill, the literature of the craft is dumb, and I confess that I do not know how anything more can be put upon paper.

Certain woods have the defect of dulling edge-tools, but this is generally due to the presence of gritty matter in the pores; still, one species, the Poplar, is said to have this property without any apparent reason being given. Its surface always remains stringy (Martin and S., p. 242). The Willow cannot be turned smooth with the sharpest of tools (*ibid.*,

p. 244); it is used for brake-blocks of railway-wagons, as it affords much friction without taking fire (Laslett, p. 165). The sap-wood of the Walnut is also stringy and cannot be smoothed by turning, whereas the heart-wood turns very sweetly (Noerdlinger, 1859, p. 522). The surface of the Redwood (*Sequoia*) wears smoother by the friction of water (Hall, 1911, p. 51). The Beech, says Planat (II, p. 371) has the valuable property of being "washable and scrapeable." I believe that butchers'-blocks are made of it for this reason. The American Elms wear clean and white and the Sycamore is well known as a washable wood. The surface of the Kauri Pine (*Agathis australis*) when used for paving does not become slippery in greasy weather, hence it does not need sprinkling with sand (Hemming).

That the transverse surface is generally of a different nature to the other cuts goes without saying, as it is, as a rule, denser if not hornier, but some woods are woolly and cannot be smoothed across-grain. Many Conifers defy all efforts to smooth the cross-section, as has been borne in upon me during the preparation of the specimens for the use of students when a clean surface showing the structure is essential. A badly-finished section will mislead the beginner. The Jamaica Satin-wood, after the most careful smoothing, seems as though covered with a silky pile, and the Dalli from Guiana though very soft is so woolly that it offers an astonishing resistance to the saw.

The sensation experienced when the wood is touched, depends for the most part upon its conductivity for heat; still there are some woods that feel softer than others, as one realizes when walking upon different kinds of wood-pavement. The sensation of cold or warmth is difficult to estimate, but it is none the less useful as an aid in distinguishing certain woods. As a rule, the heavier the wood, the colder it feels, so that its conductivity for heat may be said to vary as the density. The Lignum-vitæ, the Letter-wood, the Panacocô (*Swartzia tomentosa*) are stone-cold, while the Birch, the Alder and the Willow are warm. This property is exploited in the choice of Alder for the making of sabots and clog-soles, which keep the feet warm even when wet. Other species used for this purpose are Lime, Beech, Birch and Poplar.

Those who have lived in towns in Switzerland and the north of France have no doubt noticed in Winter how unpleasantly cold to the feet are the "parquets" or uncarpeted floors of polished Oak, of which the housewives are so proud, whereas the Spruce floors of the Alpine châlets are comparatively comfortable.

Smell

Amongst the more obvious characters of woods are the smell and the taste, which may or may not be equally perceptible in the same species. Though most woods are odourless, yet many are fragrant and some offensive.

When the sap-wood is distinct from the heart, the smell is usually restricted to the latter, so that it is a heart-wood character. This is familiar in the Sandal-wood (*Santalum album*), but as a rule the sap-wood is absent from commercial specimens. The smell may be so strong in this case as to be most offensive, though after a time it becomes very delicate. A nearly related wood, the Australian Sandal (*Fusanus spicatus*) has an overpowering and sickly odour when worked, which, however, is less persistent.

In the so-called sap-wood trees the smell is evident in all parts of the woody body, as in the Bois de Rose de Cayenne (*Licaria guianensis*), from which the delicious " Essence de Licari," which reminds one of Lemon and Bergamot, is distilled. In some other species of the same family (Lauraceæ) it is the same : they are mostly sap-wood trees and remarkable for their perfume.

If the smell be due to turpentine it may impregnate both sap- and heart-wood, but the former, having most of its turpentine still unchanged, may smell very much more strongly and differently from the heart. Nearly all the Pine tribe (Abietineæ) are characterized by this terebinthine odour. I fail to find it in the Silver Fir when dry or wetted, but Duhamel de Monceau (p. 62) says that bridge-piles of this wood that had been submerged for a century still smelt strongly.

The aroma of a forest when the trees have been felled may arise from the resin of the bark, so it is as well to premise that in dealing with this subject, only wood in the dry condition is meant, unless otherwise specified.

Pine, even if very dry, smells strongly of resin when worked ; Larch and Douglas Fir do not.

A very useful expedient is the moistening of the wood to recall the smell. If not effective in every case, the fact of its absence may be a point in identification. The powerful, fishy smell of the Canella preta of Brazil is not evident until the wood is wetted ; even the piece of the Chinese coffin already mentioned, needed moistening to revive the smell.

A useful classification as an aid in the diagnosis of woods may be made on this basis : (*a*) woods that smell more when wetted, *e.g.* many Pines, as witness the familiar and agreeable aroma of freshly-washed Pine flooring ; (*b*) woods unaffected by moisture in this way ; (*c*) those which change the character of their odour on wetting ; the sweet-scented Myall (*Acacia homolophylla*), deliciously fragrant of violets when worked, is rather unpleasant when wetted, and the Rosewood (*Dalbergia nigra*), of a somewhat similar aroma, rather reminds one of decayed tan when moistened.

The aromatic Conifers, in contrast to the resinous species, seem unaffected by water, excepting perhaps the Clanwilliam Cedar (*Callitris arborea*).

A curious case is that of a species of *Cynometra* from Uganda, which is odourless wet or dry, but when sawn, gives off a strong smell recalling that of a smouldering candle-wick. The Stinkwood (*Ocotea*) belies its name when dry, worked or wetted ; possibly it is active only in the green state. Laslett (1894, p. 303) says that it is strong and peculiar when worked. Noerdlinger (1859, p. 522) says that the Black Walnut, when green, recalls plaster (" Pflaster "), and when drier, green nutshells. The Simaruba (*S. amara*) is very unpleasant when fresh, but is odourless when dry. Warming and boiling the wood will often recall the smell.

In many Conifers the smell is caused by aromatic essential oils, and is often delicate and agreeable. One needs only to be reminded of the Pencil Cedar, the fragrance of which is accompanied by a sweetish taste. The Bermuda Cedar (*Juniperus bermudiana*), once used for the making of pencils, is, according to Varenne de Fenille (p. 164), strong smelling and does not please everyone; the taste is bitter. The Bermuda Cedar is, however, according to Sargent, the same as the common Pencil Cedar (*J. virginiana*). The Juniper (*J. communis*), the Cedar of Lebanon so-called (*Cedrus Libani*), and the Atlas Cedar (*C. atlantica*), are all very much alike. Mathieu says (1897, p. 568) that the odour of the Cedar of Lebanon often becomes insupportable when worked, but in our specimens it is very faint and scarcely perceptible. Perhaps he refers to fresh wood, in which I have remarked a much more powerful odour. When dry the Common Yew has no smell, but the Californian and Florida species, according to Hough (1895, VI, p. 50), have a somewhat terebinthine odour. Opinions differ much on this subject. I have never noticed any perfume in the Quassia (*Picræna*), but Holzapfel (p. 103) says it is agreeable. The Thujas and their allies, especially *Callitris*, are fragrant. One of the last mentioned from the Cape (*C. arborea*) is most delicious, resembling Lemon somewhat, and the Thuya or Thyine wood, so much prized by the Romans, is similar and is still aromatic when dug up from the ruins of their cities. The Geneva Pine is said by Varenne to be very fatiguing when worked. As it is a variety of the Scots Pine, it is evident that the same wood may differ in this respect according to locality.

Amongst the broad-leaved trees, after the Sandal the Rosewood is the popular favourite, and as its name implies, smells of roses, this property running practically through the entire genus of *Dalbergia*. The same may be said of several species of *Acacia*, the most remarkable being the Myalls, which smell of violets, and the Raspberry-jam-wood (*Acacia acuminata*), which has an aroma very like, but vastly more powerful than the delicacy from which it takes its name. All gradations of the Rose-Violet series of perfumes may be found, all evidently due to the same principle, as is also that of a species of *Bowdichia*, said to recall the Tuberose.

The Merisier Cherry or Bois de Sainte Lucie, of which the stems of cherry pipes are made, is very sweet in smell and taste, as all pipe-smokers know. Its near relative, the Bird Cherry (*Prunus Padus*), on the contrary, is offensive. It improves with time, losing its disagreeable odour, while that of the Merisier augments. This is fortunate, as the Bird Cherry is a most excellent wood, much used by the cabinet-makers about the period of Louis XIV (Grisard, 1894, II, p. 550).

A curious but still pleasant smell, resembling that of Cocoa-nut, is characteristic of the Jamaica Satin-wood (*Zanthoxylum flavum*), the Ceylon Satin-wood (*Chloroxylon Swietenia*), and a wood from Brazil, the Cabriuna (*Myrocarpus frondosus*). Descourtilz and other authors say that Orange-wood is fragrant. I have never found it so, and believe that only the bark is aromatic when fresh. The American Birch (*Betula lenta*) is very sweet when worked, but is otherwise odourless. The English Birch has an aromatic principle in the bark, familiar to all in the smell of Russia leather, in the tanning of which it is used, but the wood has none. In cutting Birch poles this perfume is often remarked.

Amongst the odours that are indifferent, being neither pleasant nor objectionable, is the tan-smell of the Oak, a little vinegary when fresh. Testart (p. 539) maintains that the stronger the vinegar smell, the sounder the wood. This smell is also characteristic of many Eucalypts (Gums), especially the Blue Gum. Gayer states (1903, p. 4) that the Olive-wood recalls rubber. I have not succeeded in noting this, but M. Blanc, who has experience of that wood, tells me that it is "un peu rance!" The Oleastrum of the Romans mentioned by Pliny was so offensive that it could not be used for any purpose whatever. This name has been assumed to refer to the wild variety of the Common Olive (*Olea europea*), which I believe to be a mythical tree. When in Provence I made particular inquiries as to the existence of a wild Olive, and I could find no one who had ever seen a specimen. MM. Blanc and Davin, of Marseilles, both competent systematic Botanists, assured me of their disbelief in its existence. That a variety should differ in so marked a degree in smell from the parent stock seems to me improbable, and I consider that the Oleaster of Pliny is still unidentified.

The unpleasant smells are more uncommon, that taking first rank being the Goupy of Guiana (*Goupia tomentosa*), its repugnant odour, like that of cheese in an advanced state of decomposition, being so powerful that a small hand specimen was banished from my laboratory until it had calmed down. It is too strong even for wood paving, and its use in Brazil has been abandoned in consequence, and indeed it is rarely used except for rough timbering in the open air. Teak has sometimes the odour of old shoe-leather, though said to be agreeable by some. I have been taken to task by the *Indian Forester*, which journal maintains that it is fragrant. It may be different when fresh, and some varieties are almost scentless, but when worked in quantity I have known workmen become sick with the smell. It is called "Bois puant" by the French, who evidently agree with me. The Red Birch of New Zealand (*Fagus Solandri*) has a somewhat similar smell. There are many "bois puants, bois cacas and bois merdes," terms which will not bear translation: amongst these are *Sterculia fœtida*, *Prunus Padus*, *Anagyris fœtida*, *Fœtida borbonica*, *Theobroma cacao*, *Pirigara hexapetala*, *Bysonima crassifolia*, *Cassia alata* and *planisiliqua* (Duchesne, E. A.), and a "Bois catinga"—this latter word signifying the peculiar smell of negroes—was raised to generic rank by Aublet, but Baillon reduced it to a synonym for *Eugenia Catinga*. Wiesner says that the wood of the Plane-tree smells of "Rossdunger," but I have never detected any smell in this wood either fresh or dry. Noerdlinger says the Mulberry smells of stables and *Prunus virginiana* of matches (1859, p. 526). I have noted neither. There is another wood that recalls bad cheese—the Celery Pine of New Zealand, and two of bad fish, the Canella preta, already mentioned, and the Mocitayba preta, both of Brazil.

Intensity has much to do with our impressions, for a wood declared agreeable by one may be objectionable to another who has worked it in quantity. Charpentier (p. 75) says that the *Thuya occidentalis* is insupportable, whereas I cannot detect any aroma at all in a small hand specimen, either wet or dry. The Cypress is generally regarded as pleasant, but in the quarter where furniture is made at Constantinople (Rue de Galata) the air is redolent of it for some distance around (Garraud, p. 168). The Sassafras in small pieces is very sweet, smelling of Anise, but Pomet states (p. 43) that in his day the forests of this wood could be smelt at sea at a distance of two leagues from the coast.

As a rule smell eventually passes off, the time varying considerably. Sandal seems to retain it longest (twenty-five years if not longer according to my own experience). In most cases a cut or even rubbing with glass-paper will revive it, providing that it be not a character of the green wood only. A piece of a species of *Juniperus* taken from a tomb of the ancient Egyptians, regained its sweet smell when cut.

A phenomenon allied to smell—that of provoking sneezing—is displayed by several woods, of which the Sneeze-wood of the Cape (*Pteroxylon utile*) is one. It is excessively violent and breath-catching: it attacks the eyes and is altogether insupportable to work. In a note to the *Timber Trades Journal* (1917, p. 525) a writer says that he failed to remark this action: it may therefore pass off. On one occasion, when opening a log by means of a circular saw, the emanation was carried by the driving belts all over the workshops, and in less time than it took to get through the first cut, all my people had stampeded into the open air. Other woods of a less virulent nature are the Blue Mahoe (*Hibiscus elatus*), Macassar Ebony, the Iroko of W. Africa (*Chlorophora excelsa*). According to Guibourt, the Lignum-vitæ is called "Pique-nez" by the French workmen, and Laslett (1894, p. 226) says that the Pyengadu of Burmah (*Inga xylocarpa*) has a similar effect. Camwood is said to be snuffy and pungent by Holzapfel (p. 78). The Mahoe is quite mild, and I have never noticed anything specially irritating in the Lignum-vitæ. The Ipe tabaco, cited by Saldanha, derives its name from its snuffy dust.

The emanation or sublimation of aromatic substances that obviously takes place in the case of the Camphor resin probably occurs in all. Once liberated, it apparently remains suspended in the air, but must eventually be deposited. It is related that cabinets made of Pencil Cedar for the storing of sea-shells proved a failure because in the course of time the specimens became covered with a sort of varnish. Camphor has, however, no such effect, as it is commonly used in cabinets employed by Entomologists, yet it is sublimed by heat in the process of extracting the resin from the shavings of Camphor-wood. Old specimens of Pencil Cedar kept for a long time without being moved will become covered with a deposit on the under surface.

The smell given off during burning is often that of the wood intensified by the heat which seems to imply a more active sublimation at higher temperatures. The familiar Joss-sticks are good examples of this and also the many incense woods, of which the Red Gum (*Liquidambar stryraciflua*) was used by the missionaries in the early days of American colonization, and the frequency of the occurrence of the name "Bois d'encens" amongst the French Colonial woods is evidence that the fragrance of burning wood was much utilized. Joss-sticks "are made of sandal-wood and swines'-dung." *Quel bouquet!*

Taste

The taste most commonly met with is naturally that of tannin, which is astringent. It is noticed chiefly in those woods having no colouring matter beyond that of the heart-substance, that is to say, in the brown or brownish woods, but even here, if the tannin has been entirely converted, it may not be detected, as in the Elm. In the Oak, where there is abundance of unconverted tannin, it is very marked.

Next in order of frequency is the terebinthine taste of the Pines, recalling turpentine. The less resinous Conifers, such as the Spruce, are insipid and flat. Then come special tastes, of which there are a variety, for instance the sweet taste of the Pencil Cedar, the nauseous taste of the Goupy (this latter, however, being nothing like that expected from the smell), and the acrid taste of the Tulip-wood (*Physocallyma*: Guibourt, III, p. 348). The sweetish taste of the Logwood is more evident in the extract than in the wood itself (Fluckiger).

The only group in which this property is commercially useful is that of the bitter woods. The Surinam Quassia, the original and true species (*Quassia amara*), is now rarely seen, the Jamaica Quassia (*Picrœna excelsa*) having displaced it in the Pharmacopœia. This latter is familiar to all who use insecticides to destroy green fly, and medicinally as a tonic. It is still employed in France in the form of "bitter-cups," which are filled with water over-night and afford an excellent bitter-tonic in the morning. A pinch of the sawdust is as much as most care to try. Another wood of the same family, the Simaruba, has a much feebler taste, and old specimens are almost tasteless. It is said to be used for the adulteration of the other two species. Bitter woods of no industrial application are the Mora, Sabicu and Aracui of Brazil, the last being, according to Saldanha (1865, p. 119) quite insupportable. The taste of Cigar-box Cedar is well known. The Carapa of Guiana is said to resist the attacks of insects on account of its bitterness.

The complete absence of taste is a virtue made use of in the Elm, used for well-linings and pump-bodies. The White Pine (*P. Strobus*) is insisted upon by manufacturers of cheese-boxes, as it imparts no taste to the goods (Hall, 1911, p. 48), and the wood of *Abies concolor* is used for butter tubs, for the same reason (Hough, 1897, III, p. 34). The Bitter-sweet (*Solanum dulcamara*), unknown to most as a woody plant, is remarkable for the sweet and persistent taste of its wood and the bitterness of its bark (Mathieu, 1897, p. 259). Thenius (p. 114) relates that the wood of *Cupressus sempervirens* was formerly used as a febrifuge.

The Extract and Contents of Wood

The multitude of reactions that may be obtained from the use of the many tests employed by dyers' chemists is too great to permit me to enter deeply into this otherwise most interesting subject. Apart from the possibility of finding new dye-woods, the great importance of the extract for the identification of species will, I believe, be one of the chief "points d'appui" in this respect in the future.

As regards new dye-woods, I am convinced that a careful search amongst our Colonial woods, of which exceedingly little is known, will furnish good results. It is the fashion to decry vegetable dye-stuffs, but two things should be kept in view, firstly, that for the best work they are still indispensable, the aniline dyes being for the most part employed for the "schlecht und billig"; secondly, no synthetic dye will ever displace the Logwood, because it is so cheap and its yield of colouring matter so abundant. I cannot believe that the Logwood is the only such wood in the vegetable kingdom. Chemists who have, during the war, tried to copy the German methods, are still dependent upon foreign countries for certain ingredients, without which their efforts are in great part thrown away.

In a German commercial magazine entitled the *Export and Import Review*, printed in English and distributed broadcast in England (date Feb., 1920, p. 95), in an article on "The Cry for German Aniline Dyes" is the following passage: "All the Industrial countries participating in the war have, while it lasted, made assiduous efforts to reproduce the manufactures of the German Dye Industries, but neither in the belligerent nor in the neutral overseas countries has the cry for German dyes been silenced by these efforts."

As a matter of historical interest, it may be useful to mention a few of the dyes obtained in the past from familiar trees. The Common Plum formerly yielded red, maroon, coffee-colour, orange and grey, several of which dyes are good and stable; Laburnum, various colours from all parts of the tree; Ash bark, black, blue and brown; Cornel wood and bark, brownish-yellow; Poplar, a yellow stain with alum; Lime-tree, a rose-red lake; Holly, various colours; Horse Chestnut, Isabelle-yellow (fawn) with alum and blackish-grey with sulphate of iron; Sycamore, red; Apple (bark), yellow, olive-green, chamois and orange (wood) green; Mountain Ash, black; Elder, olive and yellowish-brown. The durable and brilliant colours of the Highland tartans are all made with vegetable dyes, and the best black cloth still requires the woad with which our British ancestors painted their bodies. Some of the above mentioned may be bad, or dear, or procurable with difficulty in quantity, but when we think that in India alone there are some 1,100 species of wood in common use, surely there is room for hope that something at present unknown may be found amongst these, to say nothing of the many hundreds of species from the Colonies.

The wood of the Sweet Chestnut, reduced to a coarse powder and boiled for a long time in water, yields a substance sold under the improper name of "gallic acid," which serves for dyeing silks black (Mathieu, 1897, p. 331).

The shavings of the Minquar (*Minquartia guianensis*) of Guiana, when boiled in water, yield a black colour which takes very well on cotton (Aublet, II, p. 4).

In the matter of the identification of woods, little has been done outside the few well-known dyewoods, the Logwood, Brazil, Sappan-wood, Yellow-wood, Red Santal-wood, Young and Old Fustic, Camwood, and Barwood.

The chief work on this subject is that of Maiden on the Australian Eucalypts, who divides them into three groups, according to the behaviour of their gums (*Critical Review of the Eucalypts*, Vol. I), as follows:

I. Ruby group. Ruby coloured Kinos soluble in water and alcohol, in all proportions. (Includes all the sub-genus *Renanthera*, except *E. microcorys*.)

II. Gummy group. Kinos soluble in water, but insoluble in alcohol, owing to the gum they contain. (The Ironbarks.)

III. Turbid group. Kinos soluble in hot water or hot alcohol, but which deposit sediments on cooling. (Most of the *Parallelantheræ*, but also many species little allied.)

A brochure by Lauterer contains not only much information of interest, but gives analytical Keys for the identification of the gums and resins of Queensland woods. As small quantities of such secretions are contained in the woods of these trees, many details may prove useful in our department. His classification of gums and resins (p. 35) is worth citing :—

1. Resins, unaltered by and insoluble in water.
2. Gums, swelling up in or entirely dissolved by water.
3. Gum-resins, composed in the fresh state of an inspissated emulsion of a resinous body insoluble in water, derived from an essential oil, and held in suspension by a watery solution of a kind of Arabin.
4. Tan-resins. Partly soluble in water, leaving an insoluble residue which is derived from a tannin and which residue is soluble in caustic potash and sometimes in alcohol.

Inasmuch as the Mahogany sometimes presents the contents of its pores in two colours, ruby (deepening to black) and green, to say nothing of a white deposit of a compound of lime, we must avoid the conclusion that the extract is of a simple substance. It would seem scarcely possible that the same compound should assume such different colours, yet it is hardly less difficult to believe that two gums or resins, or a gum and a resin unmixed, exist together in the same wood. Again, we have rays with red contents in a brown or yellow wood, and in the Yellow-wood of commerce (*Maclura tinctoria*), there are red streaks which are considered by some to indicate good quality, while others say that the red substance interferes with the purity of the extract.

In addition to the coloured gums and resins which may be accumulated in the pores or cell-cavities, we have pigments which impregnate the cell-walls.

Some instances of the colours obtainable from various woods with nothing more than water or alcohol may be of interest : Logwood and Brazil, including Sappan-wood, red or crimson (water), rich orange (alcohol); Red Santal, colourless, or at most a pale rose (water), port-wine colour (alcohol); Wallaba (*Eperua falcata*), pale yellow (water), crimson (alcohol), *i.e.*, the opposite of the first mentioned ; Ébène verte (reputed to be *Tecoma leucoxylon*), a green wood, if its name goes for anything, gives a yellow extract which turns bright red with alkalies. The Washiba is said to do the same ; when washing the hands after working it, the alkali of the soap turns the dust red (Holzapfel). These reactions are with potable water, which always contains a small quantity of lime that brings out the colour. Logwood is said to give a colourless solution with distilled water, but with the greatest care I have never succeeded in obtaining it. Logwood may be distinguished from Brazil by the lighter colour of the extract of the Brazil and by its red precipitate with lime, baryta and protochloride of tin, whilst these reagents give a blue precipitate with Logwood (Charpentier, p. 583). Another method is to keep the extract for twelve hours, when the rich red extract of Logwood will turn the colour of Rum, while that of a Brazil takes several days to decolorize. The true Ebonies (*Diospyros*) may be distinguished from the African Blackwood (*Dalbergia melanoxylon*) by the very copious sepia tincture yielded by the latter; the former give a faint coloration only. The Pear may readily be known from the Apple-wood by the beautiful rich red extract of the former, that from the latter being pale brown: Mountain Ash extract resembles that of Apple, but is nearly colourless, while on the other hand, the Whitethorn extract is nearly identical with that of the Pear. The Red American Oak gives a pale extract, turning greenish, the White American Oak and the English Oaks a deep brown. Perchloride of iron with the watery extract of Scots Fir yields no reaction: with Larch and Douglas Fir an ink is produced.

Coloured woods do not always give up their pigments to water or alcohol, and in such cases we may conclude that we are not dealing with either gums or resins. The Tulip-wood (*Physocallyma*), so remarkable for its crimson stripes, yields no more than a brownish-yellow colour to prolonged boiling (Prael, p. 27). A very obdurate colouring matter is cited by Vogl (p. 277), who says that *Ferreira spectabilis* is intractable to boiling water, alcohol, ether, chloroform or benzine.

Hall (1911, p. 50) says of the Red-wood (*Sequoia*): " When first used for holding or conducting water, the fluid is stained by the colouring matter leached from the wood, and the same result is seen when water flows from a new Red-wood roof. In a short time the water clears."

Steam produces a reaction by deepening the colour. Beech used for spinning-bobbins and bent-furniture turns pinkish or brownish; the sapwood of the Red Gum (*Liquidambar*) becomes the same colour as the heart; Oak and some hardwoods become nearly black. This change has some analogy with the post-mortem formation of heart-substance already discussed.

While studying a collection of ancient Egyptian woods kindly placed at my disposal by Prof. Victor Loret and Dr. Georges Beauvisage of Lyons, I remarked that all those that had been found scattered about the tombs, whatever the species, had acquired some shade of yellowish-brown, while those that had been taken from mummy-cases had retained their original colour, indeed some specimems of the Sycamore Fig were perfectly white, contrasting vividly with others of the first category that were a dark brown. Prof. Loret suggests that the change is due to the action of essences such as the Egyptians were accustomed to place in little earthen pots covered with linen. The linen perished and the aromatic substance volatilized and disappeared, the pots being found empty. An alternative explanation is the possible emanation of sulphur from the bitumen used in embalming.

Amongst the common reagents mentioned by authors is hydrochloric acid which, according to Berteau (p. 265), when applied to the surface of the Bois de Licari, turns the wood a brilliant rose-carmine. Saliva and soap, both containing alkalies, are ready means of bringing out colours (Fluckiger: Holzapfel).

The reaction of tannin with iron salts or the absence of such reaction, may frequently aid in the determination of a species, as in the cases of the Larch and Scots Pine. Any iron salt will serve, but different kinds give special tints and are used by chemists to identify the various kinds of tannin. Even the rust upon a tool will produce the characteristic ink-marks upon Oak, Hazel, and other woods containing this substance. Degame-wood (reputed to be *Calycophyllum candidissimum*), owing to its freedom from tannin, is used for dyers'-sticks. For the same reason, Walnut is suitable for gun-stocks (Tredgold, p. 70), though it has other virtues that make it serviceable for this purpose.

The maximum amount of tannin is found in the Quebracho (*Aspidosperma Quebracho*), of Brazil. It is imported for the tanning of leather. All woods that are tanniferous used in construction must be secured with copper bolts or wooden trenails. The Larch is said by Knowles to be very tannin-free, although it gives, as already stated, a strong inky reaction with iron salts. He relates (p. 25) that a trough made of this wood that had been in service for twenty-three years contained nails which had kept as clean as when new. Lunan says that the Blue Mahoe does not corrode nails. Mr. Holmes, of the Pharmaceutical Society informs me that there is a Chinese Conifer (sp. unknown) which is said to *prevent* the rusting of iron. Guijo, a Philippine wood (*Shorea guiso*, Bl.) has a marked corrosive action on metal fastenings, and about 0·2 per cent. of acetic and formic acids can be leached out from the sawdust with cold water (Schorger, 1917).

Equally important is the tannin-content in woods destined to be employed for wine casks, as the flavour of the wine may be impaired thereby. In this case the kind of tannin appears to be of greater significance than the presence of that compound itself. Faure (in Mulder's *Chemie des Weines*, p. 20, and in *l'Agriculteur praticien*, 1852, p. 145) says: "The Stettin and Danzig varieties of Oak did not affect the colour of white wine, but imparted to it a slightly balsamic and agreeable taste. Memel, Lubeck, and Riga wood colour it and give it an astringent taste. There was no result with American Oak (species unknown), when tested by means of large pieces, *i.e.*, not in the form of powder. Bosnian Oak (probably *Q. cerris*) turned the white wine black. Burgundy Oak (d'Angoumois) had rather less effect. The colour of red wines which contain tannin are not so much affected, though the taste may be." The American Oak referred to above is probably *Q. alba*, as Stevenson says (p. 19) that west of the Mississippi it is considered good for cask-staves; the Red Oak (*Q. rubra*) contains vastly less tannin, as the reaction shows. My specimens of *Q. cerris* give no tannin reaction whatever.

Shavings of Hazel, Hornbeam, and Beech (preferably the first mentioned) are used, after the removal of all colouring matter, for the clearing of beer and vinegar (Gayer, 1903, p. 494).

Ash casks are preferred for holding colourless liquids. Beech is used by glass-blowers on account of its freedom from substances that would interfere with the welding process (Holzapfel, p. 74), and Elm for the troughs or "bosches" for the rinsing of brass after dipping in nitric acid, as it resists its action longer than any other wood. Boxwood shavings were or are used as a substitute for hops (Johns, p. 73), and the Yew has the property of turning wine into vinegar (Duchesne). In addition to the Bitter-woods already mentioned, the roots of the Tulip-tree (*Liriodendron tulipifera*) are credited with the properties of Quinine. Chips of Beech are used for the clarifying of wine and beer (Boppe, 1887, p. 17).

The Gum Guaiacum from the Lignum-vitæ is well known for its medicinal properties and the same may be said of the Sandal-wood (*Santalum album*). Gurjun-oil from the wood of *Dipterocarpus turbinatus* is used medicinally as a substitute for Copaiva Balsam (Smith, p. 442). An oil is distilled from the wood of Juniper that is employed as a remedy for ulcers in veterinary practice.

Several woods are distilled for essential oils used as perfumes or incense. Amongst these are the Bois de Licari de Cayenne (*Licaria guianensis*) and the Lign Aloes (*Aquilaria Agallocha*), which latter is the source of Agar-agar, well known as a culture medium for bacteria and fungi.

Sugary exudations and sugar-pockets are common on fresh timber of *Pinus Lambertiana*. (*Record*, 1919, p. 75.) Tar oils are yielded by *Cedrus Deodara*, *Tectona grandis*, *Pinus longifolia*, and *excelsa* (Pearson, 1912, p. 122).

Poisonous principles are not rare in woods. The False Acacia (*Robinia*) is said by Thil (1900, p. 82) to be protected from insects by an alkaloid called Robinine. It is well known, however, that the cultivation of the tree was threatened in the United States by the ravages of a wood borer. The Cocobola-wood (sp. undetermined) produces an itching irritation amongst workpeople (Nestler, 1912, p. 121). The sap of the Rengas (*Gluta Rengas*) burns the skin ; the wood-cutters who fell it work naked, having first covered themselves with oil (Bilborough MS.), and the same irritation is caused by the Simaruba, that is said to produce the " gale," a sort of blistering on the skin (Préfontaine, p. 208). The Bois à gratter (Scratch-wood) (*Psiloxylon mauritianum*) is so called because the dust from the crumbling bark causes itching. The Quassia (*Picræna*), according to Kurz (*ex* Bowerbank), (*The Technologist*, II, p. 252), causes paralysis. On washing the ulcers on the hinder extremities of a dog with a decoction of this wood, complete paralysis set in, which, however, disappeared in seven hours. Though prohibited by law, it is frequently used as a substitute for hops. It is evidently for internal application only, and I regret that elsewhere I have recommended it as a protection against mosquitoes. The Manchinel (*Hippomane Mancinella*) and the Upas-tree (*Antiaris toxicaria*) are familiar subjects of more or less extravagant stories about the virulence of their juices. Several cases of poisoning from the splinters of Teak are recorded (Roussel, p. 34). It also causes nose-bleeding (E. Kett). The " Eye-blinding-tree " of India (*Excœcaria Agallocha*) contains an extremely acrid gum which is very irritant and may cause blindness. It is said by Foxworthy (1909, p. 431) that coolies who work this wood for charcoal suffer a great deal from the fumes. Poisoning by " Tonquin-wood " from the Philippines was reported from Cambridge, Mass., where twenty-six men were affected (T. T. J., 1906, p. 860). The Tamil Satin-wood (*Chloroxylon Swietenia*) has been accused of causing itching and pimples amongst workmen. This wood was investigated by Nestler, who could find nothing poisonous. He concludes that the offending wood was some spurious Satin-wood. He also tested the Satin-Walnut (*Liquidambar*) by means of an extract of ether, and succeeded in causing eruptions under his arm-pits, though he was unsuccessful in obtaining any effect by any ordinary contact with the wood. The crystals which impart to this species its satiny (micaceous) lustre are insoluble in anything but ether, hence they cannot act as a poison (Nestler, 1911, p. 672). I suggest that the crystals act by mechanical irritation by entering the pores of the skin. As the complaint is rare, it is probable that only wood in a certain condition will produce it. Indian Rosewood (*Dalbergia latifolia* [?]) is said to cause trouble, by Sternberg (*ex* Nestler), and Padouk produces swelling and redness of the eyes (Nestler, 1911, p. 672). *Cassia spinosa* contains a whitish juice which causes an erysipelatous inflammation of the skin (Aublet, p. 908). The Assapookoo, an undetermined Sapotaceous wood from Guiana, is said by Barham (p. 150) to be very poisonous.

The diuretic properties of the wood of the Lawson Cypress are so potent that in the saw mills where it is cut up the men are obliged from time to time to change to other work (Hough, 1904, X, p. 42).

More innocuous contents of the wood include the ordinary constituents of the ash: potash, soda, lime, magnesia, silica, and sulphuric and phosphoric acids, but this is a branch of the subject outside our purview. Soap, which is familiar enough in the Quillaia-bark or root, used for washing printed goods, silks and delicate-coloured fabrics and even as a hair-restorer (Smith, p. 343), was, I believe, unknown in any wood until discovered in my laboratory by Major C. W. Scott, R.A.F., who found it in *Bassia latifolia* and several other Sapotaceous woods. If this wood be rubbed with water applied by the finger, a copious lather will form. Crystals of oxalate of lime are common in wood, as in the herbaceous parts of plants. They are very characteristic of the Ebonies, where they may be seen with the lens on a vertical section like little strings of pearls. I have found them in large quantities also in the Sapotaceæ. In *Mimusops Elengi* they are so abundant as to give a peculiar lustre to the rays in radial section. On a transverse section in this species, and also in *M. hexandra*, the rays may be traced by these white beads, even when they are so thin that they are not visible otherwise. When the wood is scraped, the crystals come out and strew the surface as with grains of silver-sand, and it is the same with the Ebonies, in a smaller measure.

A fire of wood will not deposit soot, but keeps the chimney clean. I have known cases where chimneys that had not been swept for thirty years were clean and bright. The wood of the Aspen is reputed to be of special virtue and is used for chimney-cleaning in some parts of Russia, according to Held (*ex* Noerdlinger, 1859, p. 131).

Under abnormal conditions the tissues of the wood may degenerate, deliquesce and leave large cavities in which considerable quantities of resins or gums may collect. This is a well known feature in Coniferous trees; for instance, the Spruce, which normally contains very little resin, will bleed copiously from certain places and cause boards to adhere. Pockets of turpentine containing as much as a gallon are sometimes met with in the Larch (Chartres, *verb. com.*). Other Conifers which have no resin-canals, but have resin-cells, will bleed profusely, *e.g.*, the Deodar: a citron-coloured resin exudes from the surface of planks freshly cut, the more freely at the limits of the sap- and heart-wood.

The Kino gum-resins may be found in large pockets in many of the Eucalypts, and even the apatite or phosphate of lime, characteristic of the Teak, occurs in pieces weighing as much as an ounce. In the Eucalypts the beginning of the gum-gall takes the form of vertical tubes side by side, frequently running all round the ring. This is a serious defect, which affects not only this genus, but the allied genera of *Lecythis* and *Melaleuca*. In one species of *Lecythis* mentioned by Saldanha these galls apparently communicate with the exterior, as they are often occupied by a very small species of bee which builds in the tubes. In the Cedar of Lebanon resin-galls are very small and have been taken for vertical resin-canals, but since their true nature has been recognised, they have received the name of "traumatic ducts." The Swamp Cypress (*Taxodium distichum*), most of the Cypresses, Thujas and Yews exhibit these traumatic ducts at times, and it seems probable that all species normally devoid of vertical canals may show them. The Pinho (*Araucaria brasiliana*) may have resin-cells in such quantity as to be a defect.

The much-disputed question whether true resin-canals are present in the Silver Fir may perhaps be solved by assuming that certain observers have mistaken traumatic for normal vertical resin-canals. Thil's section, No. 88, of *Abies pinsapo* shows three rows of traumatic canals in a single ring. See also his sections of *Taxus baccata*, *Juniperus communis* and *Cedrus Libani*. They are exceedingly frequent in the last-mentioned species and form dark-coloured lines on both transverse and vertical sections that are visible at a distance.

Fluorescence

Occasionally we meet with this beautiful phenomenon, which is well known as a property of the principles extracted from the bark of the Horse Chestnut, the Ash and the Quinine. To the uninitiated, I may say that the curious bluish colour seen in paraffin oil is due to fluorescence, the term meaning that different colours are displayed by a liquid when viewed in different lights. Further, if some dried leaves are crumbled and soaked for a few days in spirits of wine, the resulting tincture will be green by transmitted and port-wine-red by reflected light.

Amongst the woods yielding a fluorescent extract, the Bois Nephrétique or Palo dolce of Mexico (*Eysenhardtia amorphoides, H.B.K.*), is the most remarkable. A pinch of the shavings of the heartwood placed in a glass, with water poured upon them, will produce instantaneously a beautiful, limpid solution which when viewed by transmitted light is golden-yellow and by reflected light, sky-blue. When placed near to a window and regarded from behind, the yellow fluid appears to be covered by a stratum of blue, but when removed into the shade or seen by the electric light (Osram lamp), the latter colour is not apparent. The blue is not always developed immediately (it may require half an hour) and acquires intensity with time. Certain authors record the play of other colours, even red, according to the incident light, but I have not succeeded in observing them. Again, many of the older writers, including Hernandez, speak of a *colourless* extract that afterwards becomes blue: only Guibourt mentions the yellow colour. I conclude that they were either experimenting with another species or with the sap-wood only, as the heart-wood of *Eysenhardtia* yields the yellow solution so abundantly and quickly, that it cannot possibly be overlooked. Professor Chifflot, of Lyons, who gave me my material and who is investigating the nature of the principle contained in the wood, tells me that it is very closely allied to the Fraxinine extracted from the bark of the Ash tree. The history of this wood has been worked out in a most admirable manner by Safford, whose brochure (1915) is worthy of all praise. The author adds certain species, notably the Red Santal, the Red Andaman Padauk, and the African Padauk, all species of *Pterocarpus*, which are hardly less striking than the Palo dolce. They are more effective when a strong ray of light (as from an optical lantern, for instance) is sent through the solution. The colour develops more slowly in the last two mentioned, and they may not be at their best until some hours have elapsed. The best way of showing the fluorescence is to throw the light on a screen and hold a test-tube full of the solution against it, when the fluid will appear yellow. If the test-tube be now carried towards the lantern, keeping it always in the ray of light, the colour will change to an intense blue. Fluorescence is cited as being exhibited by *Calophyllum tomentosum* (Lauterer, pp. 3–5), the Logwood (Guibourt) and Quassia, but the phenomenon is so feeble in all these cases, according to my experience, as hardly to be worth mention. No doubt many other woods will be found to have this property as research progresses.

Opalescence is another though less striking manifestation of the extract. It appears as a slight disturbance of the limpidity of the solution and usually indicates that a precipitate is forming.

PART II

The Macroscopic Study of the Tissues, with Histological Details—The Fibres—The Rays—The Pores or Vessels—The Resin-Canals of Conifers—The Soft Tissue or Parenchyma—The Pith.

CHAPTER IV

THE TISSUES

IT is not my intention to enter deeply into the histology of wood, as it is already sufficiently dealt with elsewhere. Any good textbook of Botany will afford such information as the student of wood may require, and I do not feel justified in occupying space for matter that can be but a repetition of facts that have been many times published and are readily accessible to all. When the occasion demands, any histological detail will be explained.

Except amongst Coniferous woods, I have seldom found the study of the minute characters needing high powers of magnification, of much service in the identification of species, and though others, notably Janssonius, have entered into great detail, I consider that they confuse rather than enlighten us. Of much greater importance is the grouping of the elements into tissues. Perhaps, in the whole sphere of histological research, no part has been so well worked as the Coniferous woods, yet Mathieu (1897, p. 661) says: "Without underrating the interest and attraction of this study, I leave it on one side, as it has for the most part no practical application." Without going quite so far as this, I am inclined to say that histological details have claimed a greater share of the attention of Botanists than they deserve, and this has led to the accumulation of a mass of unimportant and petty detail which encumbers the literature of the subject. The structure of wood and its significance in respect to mechanical properties and natural affinities can be perfectly comprehended by the use of a magnification of twenty diameters. This falls under the term "macroscopic." I do not wish to imply that certain minute details may not be occasionally useful, quite the contrary, but when they are accompanied by characters that are obvious to the naked eye or to the hand lens, it is superfluous to call in the aid of high powers.

The fibres of Coniferous woods are of a different nature from those of the broad-leaved trees and are given the special name of "tracheids." The sculpture of their walls is one of the few "points d'appui" that we have amongst the very uniform woods of the Coniferæ. The bordered pits which appear as circles (the borders) with a central point (the pit with its closing-membrane and torus), and the regularity or ruggedness of the walls of the ray-tracheids and the size, shape and numbers of the simple pits on the walls of the ray-cells are all critical details. The last named especially are of great utility in discriminating between certain species of Pines, and between the Pines and other tribes of the Coniferæ.

The two-leaved Pines show one large pit (rarely two) which occupies the greater part of the cross-field and the five-leaved Pines not less than two and frequently three or more. But there are exceptions. *Pinus Strobus* (five leaves) more resembles *P. sylvestris* in this respect, though two large pits are more frequent, especially in the wide cross-fields of the Spring wood. In the Silver Fir and most of the remaining Conifers the pits are relatively much smaller, more numerous and occupy only a small proportion of the area of the cross-field. *Podocarpus andina* and *Sciadopitys verticillata* have, according to Piccioli (1919, p. 229), only one large pit. Our figure (No. 3, Pl. XXXVI) shows the cross-fields of the Larch, in which there are as many as seven pits, and others on a smaller scale may just be discerned in our figures of Coniferous woods in radial section (Nos. 3 and 4, Pl. XXXI). "In the Abietineæ the walls of the ray-cells are pitted; in most other Conifers the pits belong to the tracheids only" (Seward, 1919, IV, p. 138).

Conifers that present two kinds of rays (those enclosing resin-canals and those that have none) show two kinds of cell in the ray. The upper and lower edge-cells called "ray-tracheids" exhibit differences in the thickness of their walls. Those of the Pitch Pine have exceedingly rugged thickenings that on a radial section appear as irregular projections into the interior of the tracheids and occupy much space. In the Weymouth Pine, on the contrary, the walls in question are comparatively smooth.

The thickness of the walls of the so-called "epithelial-cells" which form the linings of the vertical resin-canals, may serve as a guide to the species: in the Spruce they are thick, but in the Larch and in the Scots Pine thin. Both vertical and horizontal resin-canals may be filled with tyloses.

The excessively minute discs, or "tori," which perform the function of "clack-valves" to the apertures of the bordered pits above referred to, may also be utilized for identification. In most species they are round, but in *Cedrus* they have the outline of a tiny circular saw (Wiesner, 1903, p. 8). The shape of the pits of the tracheids and their relation to the borders and the number of vertical rows of pits on each tracheid are also of diagnostic value. In the Araucarineæ the pits are hexagonal and frequently in two or sometimes more rows.

Moeller (p. 300) regards the tracheids as imperforate vessels and says that all stages of transition may be traced between them. Van Tieghem (1906, p. 220) consistently uses the term "vaisseau" instead of "tracheid." Schwartz (1892, p. 93) says: "The separation of these groups is not always satisfactory, as it is difficult, from the transition of tracheæ to tracheids, from tracheids to libriform-cells, to make sure which we have before us."

Spiral thickenings running round the interior of the walls of the vertical tracheids, like a spiral spring, are found in the Douglas Fir, the Yew and its allies, in the Cypress, in the Pencil Cedar and in young stems of the Larch. Bertrand (*ex* Beauvisage) mentions them in *Torreya*, though in a much less marked manner than in *Taxus*, and still more feebly in *Cephalotaxus*. Jones (1912, p. 121) says that all grades of spiral thickening may be found in the Douglas Fir and in the Spruce and that their presence is not an infallible guide in distinguishing the former from the latter. Beauvisage (1896, p. 8) again says that there are two, three or four spiral threads in *Taxus*, rarely a single one, but he failed to find any in young wood. The parenchyma, generally referred to as being absent in *Taxus*, may be observed in small quantity in some specimens.

Burgerstein (1907, pp. 101–112), who seems to have a most complete knowledge of the structure of the Conifers, never attempts to distinguish separate species, but only groups of species and genera. His " Key " would doubtless be ideal if accompanied step by step by diagrams or photographs showing what he really means ; but he uses expressions such as " thin or medium thick," which are only intelligible to himself, besides which he uses more than one figure for an average, *e.g.*, " rays averaging 10–19 microns high." Extreme figures may be a guide as limits beyond which an element cannot go, but the mean taken from two or three specimens is of little value. Further, no account seems to be taken of the fact that the cells increase in size as the tree ages. Keys based on the examinations of two specimens per species (he examined 250 specimens of 175 species) cannot be final. His remarks on the utility of the minute character for the determination of Conifers may, however, be worth quoting ; he says (p. 101) : " The following genera are characteristic and relatively easily recognized by the structure : *Araucaria, Cedrus, Dacrydium, Torreya, Taxus, Cephalotaxus, Tsuga, Pseudo-Tsuga* and *Sciadopitys*. Of the species of *Pinus*, those are easily known that have ray-tracheids with rugged walls (Zackenzellen) well developed, and those having smooth-walled ray-tracheids and only one pit in the cross-field. These latter comprise the vast majority (nearly seventy species) of the genus. However, there are species of *Pinus*, for example, *P. Pinea*, where the ray-parenchyma-cells remind one distinctly of *Abies* or *Picea*, in respect to their pitting. For other genera of the Conifers, histological characters as diagnostic ' Merkmale ' are difficult to find. On the one hand, *Abies, Keteleeria* and *Pseudo-Larix* show such identical structure of the wood, and on the other, *Picea* and *Larix*, and finally *Cupressus, Biota* and *Thuja*, that, according to my experience, the determination of the genus of a specimen in most cases is either very difficult or actually impossible." Burgerstein gives a list of authors who have made contributions to this subject and criticizes the confidence of some of them (p. 101), hazarding the conjecture that many errors have been due to improperly-determined material (p. 103).

Boulger (1902, Key, p. 51) classes the Scots Pine amongst those having three to six pits in the cross-field. J. Line (*ex* Stone, 1920, p. 32) believes that he can utilize the pits in the cross-field (made by the walls of the *vessels* with those of the ray-cells) to distinguish *Populus, Salix* and *Æsculus* from each other. If his distinctions prove to be constant they will provide a much needed aid. *Record* (1919, p. 25) makes a distinction between rays consisting wholly of procumbent cells (" homogeneous ") and those which contain both upright and procumbent cells (" heterogeneous "). This difference, long since utilized for Coniferous woods, is applied by *Record* to the broad-leaved trees, *Salix* coming into the first category and *Populus* into the second. I trust that this also will be found to be constant.

The perforations of the septa, or end-walls of the vessels, present differences which help us to separate the Birch from the other woods resembling it. In this wood on a radial section these septa are seen to be still in position, but the greater part of their substance has disappeared, leaving a ladder or grid of thin bars of cellulose (scalariform perforation) (cf. Fig. 2, Pl. XXXI). When torn by the razor in cutting the section they simulate tiny rakes, and in tangential section the ends of the bars of the grids appear as a row of beads. Similar grids are found in many species of the Fagaceæ and in *Liriodendron*. The number of bars to the grid may sometimes afford a minor point of distinction. In the Lime and Poplar the septa are entirely absorbed, leaving a clean-edged perforation.

The wood-fibres are usually simple, thick-walled, fusiform cells, but occasionally they present division-walls and are then termed "septate." Such fibres are found in the Mahogany and most of the members of the same family (Dixon, 1918), and also in the Teak.

CHAPTER V

THE PORES OR VESSELS

THE vessels are familiar to all as the little tubes which when cut vertically appear as minute grooves on the sides of a plank of any broad-leaved wood or on the cross section as tiny perforations or pores. In discussing the vessels we part company for the moment with the Conifers, which have none except in the primary wood. Their presence is therefore a good point in deciding whether we are dealing with a Coniferous or Broad-leaved wood. On the other hand, they occur in the endogens and in some of the Gymnosperms related to the Conifers, namely, the Gnetaceæ (*see* p. 14). The endogens, however, present no difficulty, as their wood is not formed sheath by sheath, their vessels or groups of vessels being scattered irregularly throughout the tissue of the stem, so that on once seeing a cross-section of an endogen, such as a Palm, no difficulty will be experienced in recognizing woods of that nature (cf. Fig. 4, Pl. XVI).

Some Conifers have pores which, however, are not vessels, but resin-canals. They may be mistaken by the beginner for vessels, but as they never occur in the inner zone of the rings, this single fact will rule them out. Many authors express this somewhat differently by saying that the resin-canals occur in the outer or Summer zone only or very occasionally in the middle zone. As this latter alternative occurs in nearly every piece of Coniferous wood, it is apt to mislead, but the fact that they are never present in the inner or Spring zone, is categorical. The resin-canals will be dealt with later (*see* p. 71). The genus *Gnetum*, which, as stated above, has vessels, may be known by the fact that these are larger in the *outer* side of the ring than in the inner, but this does not apply to the allied genus *Ephedra*, *E. fragilis* having them slightly larger in the inner zone.

True vessels arise from the fusion of elongated, cell-like elements called by the inappropriate name of "Tracheæ," a term invented by Nehemiah Grew, who flourished at the end of the seventeenth century, when the fondness for analogy was the fashion. Observing that there was a distant resemblance between these tubes and those of the human lungs, he gave them the same name.

The dividing walls of the cells composing the vessels become wholly or partially absorbed and long continuous tubes are formed. They run from one end of the annual sheath of wood to the other, connecting the roots with the leaves.

This continuity is still much disputed, but I have pumped water, air and mercury through the whole length of a pole of ash, 14 feet 4 inches long, and I can see no reason why the same result may not be obtained with any greater length. Certain observers, who consider that they have proved the contrary, do not seem to have gone about the task in the proper manner; indeed, Prof. Ewart, of Melbourne, the strongest opponent of the theory of the continuity of the vessels (propounded first by Hales), does not state his method, but from internal evidence it would appear that they were such as to prevent him discovering the truth. This is hardly the place to discuss this matter, so I refer the reader who may be interested to my article in the *Proc. Econ. Biol.*, 1905, I, p. 12, contenting myself by saying that the experiment is of the simplest. Take a pole of any broad-leaved tree, the vessels of which are not too much obstructed by tyloses, and blow through it with the mouth into water. The air will be seen to come out of those rings only, which are exposed at the upper end, that is to say, the outer rings. On a small scale, but in a less convincing manner, the experiment may be performed with a short stick, soaped on the lower end. When blown through, bubbles will be formed. Duhamel made similar tests upon short pieces, and he says that he never found it to fail. I have myself pumped *water* through a stick of American Birch, 2 feet long by 1 inch diameter, out of which it flowed in a continuous stream as freely as from a ¼-inch tap. Duhamel (*Physique des Arbres*, p. 59) mentions the practice of passing oil through canes to make them supple, but this applies to endogenous woods and hardly affects the present case.

We cannot enter here into the much disputed question of the function of the vessels. It certainly cannot be very important, inasmuch as the Conifers do very well without them, and even in broad-leaved trees their number may be indifferently great or small and an annual ring may be either wide with many vessels or exceedingly narrow with very few, yet the life of the tree goes on. All trees have the same need of air and water if the vessels be the channel for either. That the vessels contain nothing but air is an idea that seems to have descended to us from Malpighi. It suffices to say, that excessively fine tubes whose walls are saturated, cannot do otherwise than contain some water, if there be any free water present. True, the walls of the vessels and cells may exert an attraction for water (the "Imbibition" of Sachs), greater than that of the capillarity of the tube, but when this force is satisfied, the surplus water is free to move in any direction. That there is surplus water is abundantly proved by the tapping of Maple and Birch trees and by the fact that water will flow copiously from the trunk of a tree when severed from its root and held in an upright position (Duhamel, *Phys.*, p. 67).

It is certain that experiments with capillary tubes having impermeable walls are beside the question. Capillarity, which manifests itself in the attraction of fluids by those surfaces that are wetted by them (water against glass, for example), or their repulsion by surfaces not so wetted (mercury against glass), has nothing in common with the phenomenon presented by the vessels of plants. There the water does not circulate in tubes with impermeable walls, the walls are saturated and the water circulates, as it were, in tubes of water in which neither attraction nor repulsion can exist. That such tubes can be empty is only possible when the quantity of water in the wood falls below saturation point, *i.e.*, when there is no free water to ascend to the leaves, which implies the death of the tree.

The Arrangement of the Vessels or Pores

If the end of a plank be examined, the pores (which term I prefer in this connection) appear as minute perforations, often visible to the naked eye. They are most familiar in the Oak, Ash and Elm, where the large ones are arranged in a zone or pore-ring on the inner side of each annual layer (*i.e.*, in the Spring wood), and smaller ones that decrease in size towards the Autumn boundary. These smaller pores are disposed in a tree-like or radial stream in the Oak (Fig. 4, Pl. II), in festoons in the Elm (Fig. 5, Pl. III), and in tiny angles and arcs in the Ash. Let it be clearly understood that the pore-ring is an unusual feature, has less importance and is of less significance than the plan of the smaller pores : it is confined to a few species only, but as these are very common in the temperate zone, the pore-ring has acquired an importance in the identification of species to which it is hardly entitled ; still it is very useful amongst the limited number of European woods. In exotic woods a pore-ring worthy of the name is rare : as instances may be cited, the *Cedrelas* (Cigar-box Cedars and their allies), the Teak (Fig. 6, Pl. III), and the Bead-tree or Persian Lilac (*Melia Azedarach*). The pore-ring is found in the woods of widely separated families, being present in the Elms, Mulberries and Nettle-trees (*Celtis*), but not in the Fustic (*Chlorophora tinctoria*), of the Moraceæ. In the Fagaceæ, it occurs in some deciduous Oaks, but not in the evergreen species (Fig. 2, Pl. II), in the Chestnut (Fig. 3, Pl. II), but not in the Beech. In the Oleaceæ it is met with in the Ash, but not in any other genus, and in the Leguminosæ in the False Acacia, the Tree of Heaven and the Laburnum, but in few others.

The White Mulberry grown in Bourbon (Réunion) has no pore-ring whatever, but all the wood of South Europe, from trees stripped annually of their leaves, consists of little more than a succession of pore-rings.

The rings of pores may be so numerous and close in slowly-grown branches of old Oaks, says Noerdlinger (1859, p. 23), that the annual layers cannot be distinguished one from another, and in well-grown wood they may be so wide as to outweigh the better quality of the wide Autumn wood. Hartig (1891, p. 85) says that the pore-ring is restricted to the indigenous (German, understood) heart-wood trees.

In a species of *Lecythis* (sp. dub.), I have seen a remarkable and unique example of a continuous ring of linear, radial *groups* of small pores, that are so crowded as to appear " en palisade." The other species of the same genus have no pore-ring whatever.

Feeble pore-rings, having the pores more or less widely spaced, may be seen in many woods, but they do not afford the same contrast nor the abrupt diminution in size of the smaller pores immediately external to them (*e.g.*, the Walnut). A wood, normally without a pore-ring, may occasionally produce one, as in the Horse Chestnut, where, as a rule, the boundary of the ring is only perceptible in a transparent section. This seems to indicate the influence of external conditions, but as already stated (p. 7), the temperate species planted in a tropical climate sometimes continue to make wood of the usual normal structure. The Elms (*Ulmus integrifolia* and *Wallichiana*) and the deciduous Oaks of India agree with our own in having the pore-ring. Still, when all is said, the latter is nothing more than a zone of vessels of exaggerated size which, being crowded, cannot exhibit their true plan. Were they small, no doubt they would share the same arrangement as the smaller pores in the Autumn wood, as they do in the Evergreen Oak. An analogous case is that of the climbers, the pores of which are so large and so closely crowded that such woods have the appearance of being all of the same structure to whatever family they may belong, whereas their true "plans" may be very different one from another.

A special form of pore-ring is seen in many woods of the Proteaceæ, such as *Grevillea robusta* (Fig. 2, Pl. XXI.), where all the vessels of the ring are collected into one zone. These are generally crenate in contour, sagging between each large ray, like the rungs of a rope-ladder, and are somewhat characteristic of this family.

The disposition of the smaller pores in the outer wood of the ring is, on the contrary, extremely important and significant of the genus or family. Not only do all Oaks present radial streams of pores, but all Elms show them united into festoons. This may be stated as the rule, though the exceptions be many.

From the examination of not less than 7,000 species, I have arrived at the conclusion that however obscure may be the "plan ligneux," there exists a rhythm in the production of the pores in all species. It is certainly difficult if not impossible to discern this when the crowding of the pores arises either from great size, as in the climbers, or great numbers, as in the Horse Chestnut. Still, whenever the pores are sufficiently wide apart, they present a certain order, even if it be of the simplest.

Let us imagine a zone of cambium at work producing pores at *regular intervals* (Fig. 1, Pl. XXXIX), beginning with the point A. With the increase in circumference the file of pores will gradually become oblique. To produce radial files, the generating point in the cambium must shift its position. We find that the oblique distribution is the prevailing one. Our diagram is, however, purely conventional, as in a circle there is no starting point "A"; still, for the sake of finding a peg on which to hang our thoughts, let us assume that there is another starting point, B, diametrically opposite, from which to work in a contrary direction. The two series of oblique files would then meet in the middle and cross one another like the waves on a pond generated by two stones that have been thrown in at the same time. The lines in the outer zones will form angles and eventually flatten out, which is precisely what we find in the Ash, the Elm, the Fustic, and many other woods. Wherever two such oblique files cross each other there will of course be two pores at that point, and if we have a number of starting points in addition to A and B, we shall have considerable groups of pores. This again we find in the above-named species and many others. Another alternative is the suppression of one or more of the pores which meet in this manner. This is all purely imaginary, but it would explain many of the complicated patterns in which pores are arranged. If the pores are scattered over the transverse surface in all directions and are equally distant from each other, they may be described as "scattered" or "crowded," as the case may be. If alternate pores are suppressed, we have the arrangement known as "quincunx," in which lines may be traced in all directions, radial, tangential and oblique (right and left), as on the squares of a chess-board. If from the quincunx we imagine alternate oblique lines or files of pores to be suppressed, those remaining will become more evident. The oblique lines may lean all the same way in the same ring or may be directed alternately to right and left. In the latter case they are commonly united more or less intimately by one or both ends. If by the one end only, angles and arcs are produced, as in the Ash, and when both ends are joined they give rise to festoons, as in the Elms. Many Eucalypts exhibit a modification in the form of a long-drawn-out S, which may be interpreted either as an oblique line that reverses its direction twice, or each section of the S belongs to a different ring, the boundary of which is not clear (Fig. 3, Pl. XXII).

Phyllanthus sp., from Bourbon, shows oblique lines of pores that sometimes extend uninterruptedly over as many as four rings. In other places, the lines are reversed in their orientation from ring to ring.

Again, the lines may cross each other and may then be termed cruciform, as in the Gorse, the Laburnum, and *Rhamnus cartharticus* and *virgatus* (Fig. 5, Pl. XXV). This arrangement is, by the way, entirely lost in *R. frangula, vitiensis, Jujuba* and *latifolia.* Simple lines being files of single pores are usual, but compound lines or streams of small pores crowded together are sometimes met with, as in the Oak and the Chestnut. As already stated, the oblique arrangement in transverse section seems to be always accompanied by cross-grain (spiral fibres, *see* p. 76). When the lines in the one section run all to the left, as in the Chestnut, the spiral grain also runs one way throughout the whole tree. When they are reversed from ring to ring, the spiral reverses in sympathy and double cross-grain occurs. The case of the Eucalypts is more difficult to explain, as the grain is undulating. The angle of inclination of the oblique lines is occasionally a good point. It is very high in the Sabicu and the Chestnut, very low in *Chlorophora*, and very variable in *Sophora* (Fig. 6, Pl. XXVII). Inasmuch as the angle is not constant even in the same ring, it is a character which is useful only when extreme.

To summarize the different arrangements of the pores in the ring, let us again adopt the simile of the chess-board. We shall then have :—

Crowded pores	All squares occupied.
Quincunx	All squares of one colour occupied.
Oblique	Bishop's move in one line.
Festoons	Bishop's move in advancing and retreating one square at a time.
Cruciform	Bishop's move in all directions.
Concentric or tangential	Rook's move horizontally.
Radial	Rook's move vertically.
Échelonné	Knight's move.

The concentric is the equivalent of the pore-ring, but occurs also in many woods that have none, as in many Leguminosæ. The form "en échelon" is rare and almost confined to the Sapotaceæ and *Calophyllum* (Figs. 4, Pl. XXV and Fig. 3, Pl. XXVI), where it is practically a decisive feature. It consists of short radial groups, each succeeding other a little higher and a little to one side, and may be regarded as an oblique line of groups.

The unit may be a group, *i.e.*, not a single pore. These groups seem to arise from the successive subdivision of the same mother-pore. They may form irregular nests or radial series (Fig. 4, Pl. XXIV). Such mother-and-daughter groups may consist of from two to seventy-six pores in close contact with each other, *i.e.*, their adjacent sides are more or less flattened. The extreme number of seventy-six is found only in the Maracaibo Lignum-vitæ, in which the long strings are readily visible ; indeed, Varenne de Fenille pointed out this feature as characteristic of this wood as early as 1807. I doubt whether they are true mother-and-daughter pores ; they are more probably independent of each other, though in close apposition. This is important, because we have here a difference in kind ; it must be clearly understood that rounded pores which may be united into groups by sheaths of soft-tissue (parenchyma) do not fall into this category, the flattening of the sides being the critical test.

The mother-and-daughter groups may consist of equally large pores or of a large pore followed by successively smaller ones; or, again, the first and the last may be larger than the rest (*Albizzia odoratissima* and *Dicorynia paraense*). It is not unusual to find one of the long radial groups passing across the boundary of one ring into the next. I have seen this in the Cottonwood (*Populus monilifera*) and in the Mango (*Mangifera indica*). Moll and Janssonius (1906, I and III, see their Index) mention several examples among woods from Java, notably *Zizyphus Jujuba* (well shown in their Fig. 115, Vol. III). This running across the boundary may indicate that the pores are salient on the outside of the log, as may occur sometimes, as pointed out by Hartig. In *Calophyllum inophyllum* they form strong ribs.

The radial groups may at times be double, *i.e.*, two parallel rows of mother-and-daughter pores (*Bois Préfontaine*), and in such cases they greatly affect the appearance of the various sections, because, when the wood is cut radially, many pores are exposed side by side, causing the surface to appear coarse-grained. This also happens with the single, radial groups in a less degree. These, on a tangential surface, will show one or two pores only, so that it appears less channelled. The presence of twinned groups serves as a distinction between certain species.

A similar effect to that just described is produced on the different cuts by oval pores. The grooves presented by quartered wood (radial section) are wider than those on a tangential section. In the Orham-wood this difference is very marked. Again, as already said, the wood made during the early life of the tree has much smaller pores than the later rings (Fig. 2, Pl. XX), and a wide board cut on the quarter will have fine grain on the edge near the pith and coarse grain on the distal side near the bark. This elementary fact is nearly always overlooked by Histologists, who give micrometric measurements of the vessels and other elements as though they were constant. A glance at our illustration of a young branch of the Evergreen Oak (*see* Frontispiece), or any piece of wood of a like nature, shows how great the variation may be. The best way to compare the size of the pores is to cut a piece from both edges of a wide quartered plank, place them side by side, and examine with a lens.

R. Hartig (1901, p. 13, Figs. 1 and 2) figures macerated vessels of Beech from five- to six-year rings, and again others from the hundred-and-fortieth ring of the same tree, in which the difference is immense (*see* also transverse sections, Figs. 3 and 4, p. 14 of his edition of 1888). He further demonstrates the fact that when the production of wood is greater in the upper part of the stem, the pores are also larger above. To this he attributes the greater weight of the wood of the butt. The maximum and minimum size for a given species may be useful to show the range of variation, but descriptions based on sections from small twigs, sometimes even from herbarium specimens, are of no use whatever.

The general range of the size of the pores, in any but very well-worked species, will long remain unknown, so the rough method adopted of saying that the pores are visible to the unaided eye, with the lens (× 3), or with a higher power (× 10), conveys an impression which is less misleading than precise measurements. The wood which has the smallest pores is the common Horse Chestnut, or possibly its near ally, *Æsculus rubicunda*.

The pores are exceedingly numerous in both species. The largest pores, apart from certain climbers (Lianes) that do not produce useful wood, are found in that of the Silk-cotton-tree.

Independently of the increase in size with the age of the tree, there is frequently much variation within the limits of the individual ring, but here it is in the converse order—the pores become less in diameter as they approach the outer side of the ring. This is the rule, quite apart from the abrupt diminution in size when a pore-ring is present. A very great and sudden reduction immediately outside the pore-ring is seen in the Hickory and in the Toon (*Cedrela Toona* Royle, syn. *C. serrata* Roxb.). The exceptions to this rule so far recorded are few, but, as in other matters, investigation brings more to light. In the Blackthorn and Bullace the largest pores are found towards the middle of the ring, the smallest in the outer zone, and an intermediate size in the Spring (inner) wood. So is it in the Sea-Buckthorn, according to Moeller (p. 300), and Moll and Janssonius also cite many cases. Thil (1900, p. 4) says that the pores are smaller in the inner zone in the Poplar, Maple and Hazel, and suggests that the circumstance is correlated with the habit of flowering before the leaves appear. Pores which are larger in the middle of the ring may be seen in the Walnut. In most cases a few small pores may be seen mixed with the large ones in the inner zone.

The diminution in size is seldom very marked in tropical woods, and in such cases as are known the tree is generally deciduous, as, for instance, the Teak (Fig. 6, Pl. XXIII) and the Angico of Brazil. For the most part pores of all sizes may be observed scattered in any part of the ring, or they may be all much of the same size, as in the Balata and the Greenheart (Fig. 3, Pl. XXVIII). In some of my specimens of *Hibiscus tiliaceus*, from Madagascar and Queensland, the size of the pores increases instead of decreasing outwards to the boundary of the ring. The normal diminution in size conveys the impression that there are fewer pores in the Autumn wood, but this is usually an illusion, though there are instances, for example, the Tulip-tree (*Liriodendron*). As regards the influence of external conditions, I found, while examining an interesting collection put at my disposal by Prof. Henri Jumelle of Marseilles, that altitude does not seem to be an important factor. The smallest pores of all, in the specimens of Beech, were from a tree from 150 metres altitude only. Of a number of the Alder, one from 1,500 metres altitude had pores of approximately the same size as our home-grown wood, whereas in others from above and below (1,700 and 1,200 metres respectively), the pores were abnormally small. No doubt soil and aspect outweighed the influence of the height above the sea.

Perrot (p. 16) says that the largest vessels accompany the largest elements (fibres, etc.), and that we have therefore a definite means of classifying woods according to the coarseness of their grain. Certainly the fibres and other cells increase in size as the tree ages "pari passu" with the vessels, but this is only in the same individual. To different species this cannot apply, for woods like the Rosewood (Fig. 4, Pl. XXVII), the Padauk and the Opepe have fine fibres and excessively coarse pores, and one may say the same of the bulk of the harder Leguminous woods.

The size of the pores has little technical importance except to the polisher, who has to produce an even surface. I, however, throw out a hint to the manufacturers of matches not to use a too porous wood for that purpose. The French matches, so atrocious in all respects (I have heard them termed "ignifuge") are made of Poplar, and it has frequently happened that when the match has burned some distance, the flame has run down the pores and spurted out at the end; moreover, the matches break more easily. I mention these facts, as I once received several specimens of wood from Brazil, expressly recommended for matches, that were unusually large-pored. Spigots are made of Oak because the pores admit the air to the cask as the fluid is withdrawn.

The pores may have an indirect influence upon the use to which wood is put when they are present in too great a proportion, for it is solid matter, not cavities, that we need for most purposes: the more porous the timber the less use it will be in construction, but badly-grown Oak (*i.e.*, slowly-grown), consisting of little but a succession of pore-rings, may be the more elastic, and is preferred (at least in France) for beams, on account of its greater elasticity. The better-grown wood is reserved for fittings, being the more beautiful. The White Mulberry, the leaves of which are stripped for the feeding of silkworms, is useless for timber on account of its close pore-rings, whereas the wood of the Black Mulberry, cultivated only for its fruit, may furnish excellent timber, especially for cask staves.

The branches of broad-leaved trees are more porous than the wood of the trunk, and, according to Mathieu (1897, p. 68), they yield less heat while burning. As branches afford the better charcoal, perhaps the greater porosity is the reason why it remains smouldering until consumed, whereas that from the trunk ceases to burn.

Few woods amongst the Exogens are without vessels. There are none at all in *Drymis chilensis* (Fig. 2, Pl. XXIX), nor in *Zygogynum* of the Magnoliaceæ and *Tetracentron* and *Trochodendron* of the Trochodendraceæ (Solereder, 1908, II, p. 1136). *Drymis Winteri* may have a few. All these woods have distinct Coniferous characters. In *Acacia juniperina* (Fig. 6, Pl. XXIX) pores may be wanting over considerable areas. The small number shown in the wood of the Silk-Cotton-tree is naturally due to the great size of the pores: in the Boco (*Swartzia sp.*) it is due to their scarcity (about 1 per sq. mm.), and indeed the tropical Leguminosæ have as a rule very few; for example, *Cassia* (Fig. 2, Pl. XXVI). In the wood of the broad-leaved trees of temperate climates, the vessels are usually numerous, rising to as many as 200 per sq. mm. in that of the Horse Chestnut, where they are very small, though they occupy the greater part of the wood. When the vessels are large, the number may fall as low as seven per sq. mm., as is sometimes seen in the pore-ring of the Elm. In some exotic Leguminous woods such as certain species of *Pterocarpus*, and *Swartzia* there may be only one vessel in an area of three sq. mm. The number of the vessels may vary with the age of the tree, and according to Hartig (1901, p. 34) they may occupy 3 per cent. only of the tissue in wood produced when the tree is young, while at a later age the proportion may rise to 30 per cent.

Once more, the variation within the limits of a single ring may be considerable, *e.g.*, the Elm already mentioned as having few vessels in the pore-ring may present as many as 160 per sq. mm. in the Summer wood. In other species (*e.g.*, the Ash) the great diminution in size of the vessels gives one the impression that they diminish in number also, whereas the contrary is the case.

These differences may be constant in certain genera, and are invaluable when using a Key to the species, otherwise I would not inflict such petty detail upon the reader.

N. J. C. Moeller states that the wood of the Bead-tree (*Melia Azedarach*) has no pores in the Autumn wood. This statement is probably due to the use of small specimens, inasmuch as the tree produces so much wood during the season that probably the author was working upon a young piece that had not yet developed its first Autumn zone. In the specimen in Hough's collection, which is accessible to most, the Autumn pores can be seen from the distance of a yard. Hartig says (*Unterscheidungsmerkmale*, 1896, p. 18) that the vessels of the Cork Elm [*Ulmus suberosa* (*campestris*)] in the Autumn wood are in single rows of pores, not in broad bands, as in *U. effusa*. I would this were true, as I have long sought a definite character to distinguish these Elms, but I have never found it as Hartig says. These characters are too variable to rely upon.

Shape of the Pores

As a rule the pores are somewhat oval in section, the longer axis being in a radial direction. The nearest to the round shape are found in the Boxwood and Satinwood, and after these come those of the False Acacia and the Laburnum. I have seen a specimen of the latter in which they were elongated in the tangential direction, but this being such an exceptional circumstance, I ascribe it to shrinkage. When in mother-and-daughter groups, the sides of the pores are, of course, more or less flattened, and again the proximity of a ray or of another pore may have a similar effect.

In a disc (cross-section) of Oak, one half of which has been soaked while the other remained dry, I imagine that I can discern a difference in the general shape of the pores in either half, the round ones being in the wetted portion. If I am right, then it is possible that the oval shape is due to shrinkage, and the impression that all pores are oval has been gained from the examination of dried specimens.

It will generally be found that the pores are in contact with a ray at least on one side, but whether there is any communication of fluid between them is not clear, though probable. Occasionally a pore or two may be found within a ray when the latter is broad. I have seen them in *Macadamia tenuifolia*, in *Exocarpus* and some species of *Casuarina*. In all these cases the presence of the pores indicated the splitting of the ray, hence the pore is not really within it, but between the two new halves, the separation of which is not yet apparent on the transverse section.

Hartig (1880, I, p. 147) seems to consider that there is some relation between the production of vessels and the pressure of the bark. He says that vessels are absent when this pressure is relieved. If this be true, then the pore-ring might be accounted for as being produced in the early Spring, before the ascending sap has fissured or stretched the bark. If all ring-porous woods had fissured bark, the case would be simple, but in such trees as the Ash and the Nettle-tree and in the smooth branches and young saplings of some of the trees with cracked bark, the pore-ring is very marked and we must assume that the creation of minute fissures, which usually pass unnoticed, occurs. I incline to the latter view, as on the first, second and sometimes the third years' twigs of the Copper Beech (a smooth-barked tree), I observed that the young smooth epidermis was fissured all over. Later it became quite even, as though the fissures had been filled up. On the contrary Van Tieghem (*Traité de Botanique*, p. 833) states that experiments of slitting the bark made in July, when the formation of Autumn wood had already commenced, showed not only a sudden increase in the width of the annual rings near the slits, but from the moment the bark was cut, the wood exhibited larger vessels than before along with fibres that were not flattened tangentially—in other words, it produced elements which resembled those of the Spring wood.

The Contents of the Pores

The little grooves seen upon the surface of a plank (vertical section) appear to be divided into lengths at regular intervals. Each of these lengths represents a cell (trachea), and the constrictions, its end walls that have been partly absorbed. The tube resulting from this arrangement may be said to be " throttled " at intervals, and it is at such points that resins, gums, etc., are most apt to accumulate. In certain species the whole of the tube may be filled (*e.g.*, in Rosewood, in the blacker bands), but usually these contents are in the form of beads or drops. The nature of these has been dealt with under the heading of the " Extract " (p. 45). In the Teak the beads are white and hard ; they constitute the " grit " which spoils the edges of the carpenter's tools. This grit will also accumulate in cracks, and may form considerable masses. Similar white specks are common in the Cuban Mahogany, and when present they are considered to be a point of difference between this species and the Honduras and Tabasco Mahoganies. In Baywood, an inferior quality of the same wood, the contents of the " bait " are usually black (Tiffany, 1904, p. 312). In the Teak the white deposit is usually confined to the larger vessels of the pore-ring. In a specimen of the the True Mahogany (*Swietenia Mahagoni*), I have seen not only white and red-black, but also green beads in the bait. Wilhelm (1905, II, p. 916) says that in the Greenheart (*Nectandra Rodiœi*) some of the beads are greenish-yellow, while others are reddish, and Schacht has noticed others in the Rosewood (*Dalbergia nigra*) that were yellow to brown and blue to green.

Of single colours, we have white in the Mulberry (*Morus alba*), green in the Lignum-vitæ (*Guaiacum officinale*), but red in the Maracaibo variety (*G. arboreum*) ; bright yellow like sulphur in a wood sent to me as Sabicu from Tunas de Zazas. This latter colour is very rare for a solid deposit, but as one for tyloses it may occur in several species of *Bignonia* (*B. xylocarpa* and others). Tyloses may readily be seen in any section of the Common Oak, the False Acacia, and many other woods. In the Ash and the Red Oak of America (*Q. rubra*) they are rare, but not altogether absent. The Honey Locust (*Gledischia triacanthos*), which often has a remarkable resemblance to the False Acacia (also called Locust), may be distinguished by the absence of tyloses from the former.

Though usually thin-walled and delicate objects, the tyloses may become lignified to such an extent as to be almost half-filled up and very hard, as in the Letter-wood (*Brosimum Aubletii*), where they were found by Wilhelm, who figures them (1903, II, p. 285). Woody tyloses have been seen by Foxworthy (1909, pp. 557–8) in *Heterophragma* and *Paganella*, where they were yellow in the vessels of the heart-wood and white in those of the sap-wood, and in *Stereospermum*, where they were white in both. I have observed them in the Ébène verte of French Guiana (reputed to be *Tecoma*) and in the Taigu (sp. undetermined) all of the Bignoniaceæ, so that we may regard them as being a character useful in identifying woods of that family. Another wood frequently confused with the Ébène verte has its pores full of a yellow dust which may be taken for tyloses on a superficial examination, but according to some authors (*see* p. 33), this yellow dust is crystalline. Molisch (Vol. LXXXIV p. 7) mentions carbonate of lime in the vessels (and in the fibres) of the "wound-heart" of the Beech. The casts of the vessels obtained by burning this wood are perfect, even to the impressions of the pits upon the cell-walls. The Couratari of French Guiana is reported by the Commission of Brest to have considerable accumulations of red matter in the cracks of the wood, with which one may write as with red chalk. When large accumulations of any substance occur, smaller quantities are generally found in the pores also, as in the Camphor-tree (*Cinnamomum Camphora* and *pedunculatum*). Other contents of the pores of unknown composition are the red juices of the Wallaba and the Umiry of British Guiana (*Eperua falcata* and *Humiria balsamifera*), which run when a fresh cut is made in the wood. The former wood bleeds so copiously as to become unpleasant and collect the dust. That of the latter solidifies, and then each pore shines like a tiny mirror when seen by the aid of the lens. Laslett (1894, p. 212) says that the Pyengadu (*Xylia dolabriformis*) exudes a thick glutinous or oily substance, which leaves a clamminess on the surface that is long in drying.

Vertical Resin-Canals of Conifers

The pores which are to be seen in Coniferous woods allied to the Pines are of quite a different nature from the vessels of the broad-leaved trees. If the transverse section of the wood of a Pine or Spruce be examined, minute whitish dots will be seen at irregular intervals and, for the most part, singly or in very loose concentric arcs (Fig. 1, Pl. XIX). The genera *Pinus*, *Picea*, *Pseudo-Tsuga* and *Larix* are characterized by these vertical resin-canals, which, by the way, are invariably accompanied by horizontal canals in the rays. The other Conifers, such as *Abies*, the Araucarineæ, the Taxodinæ, the Cupressineæ, and the Taxoideæ, have none. Certain canals of a pathological origin called "traumatic ducts" may however be present (Fig. 2, Pl. XXVIII). The existence of resin-canals in the Silver Fir (*Abies pectinata*) has been much disputed, but all that I have ever seen were undoubtedly traumatic. Baillon (*Dict. Bot.*, III, p. 588) figures the transverse section of a twig of three-years' growth which shows apparently true vertical resin-canals. Possibly they occur in the young wood only, which may be regarded as being in an embryonic condition. Traumatic canals, as pointed out by Tscirsch (*ex* Gayer, 1903, p. 576), are so frequent in many Conifers that they may at times be useful in the determination of the species; this is the case with the Cedar of Lebanon (*Cedrus Libani*) and in *C. Deodara*, to which my attention was called many years ago by the late Prof. Fisher. The figures given by Prof. Boulger (1902) of *Sequoia gigantea* (his Fig. 49) and *Picea sitchensis* (his Fig. 64), show arcs of ducts, which are undoubtedly traumatic.

Some authors regard all vertical resin-canals as being due to a degeneration of the tissues, but the prevailing view is that they are normal. I have observed in the wood of the Douglas Fir that the rays in passing them spread out, avoiding them as it were. I cannot imagine that a cavity formed later than the rays could push them aside in this way. Hartig (1891, p. 105) has shown that both horizontal and vertical resin-ducts are in open communication with each other. At the point of junction the lining-cells separate, forming large inter-cellular spaces by which the fluid contents can readily pass from one system to the other. [This junction is figured in R. Hartig, 1891, p. 106, Fig. 66, but can be seen in the works of most subsequent authors.]

Resin-canals of both kinds will bleed and stain the wood in proportion to the abundance and state of liquefaction of the resin. Those of the Douglas Fir will exude their contents on a freshly-cut surface, as the resin for a long time remains fluid. Other species that bleed but little from the heart-wood, will do so copiously from the sap-wood, for example, *Cedrus Deodara*. On the other hand, the Pitch Pine (*Pinus palustris*) retains a large quantity of resin, but as the latter soon solidifies, the dry wood does not bleed, hence this feature may be made use of as a minor character in identification. An alternative reason why some species do not exhibit this exudation may be that the resin, being very fluid, deserts the wood early. Of such are, according to Mathieu (1897, p. 572), *Pinus Strobus*, *Cembra* and *montana*. He says that the resin is viscous in the Scots Fir, the Austrian Pine, and the maritime Pine (*P. sylvestris*, *laricio* and *maritima*), hence the dry wood is heavily charged with it. The bleeding of resin aids in the showing up of the canals on a vertical section. In Spruce and the feebly resinous Pines the canals are often extremely obscure and difficult to see, being hardly visible unless the wood is slightly soiled or when viewed with one's back to the light. The wood of the Silver Fir when dry is almost free from resin, but it accumulates in the knots and in cracks (Mathieu, p. 525).

CHAPTER VI

THE WOOD-FIBRES AND THE RAYS

DURING the growth of the tree the addition of sheath upon sheath of wood produces an extension of the circumference that will need more or larger cells to occupy the space. In many, if not in all species, the number of rows of cells produced in a radial direction during one season remains practically the same, as does also the tangential width of the individual cells in each row. The cells, as it were, keep step in rank and file, hence lacking sufficient width to occupy the increasing periphery, they separate here and there, leaving spaces between them.

These spaces are afterwards filled by another kind of tissue that is familiar as the radial lines on a transverse section, mimicking the threads of a spider's web and well known to all who have examined a stump left after the felling of an Oak tree. These radial lines have been called "Medullary rays," but the adjective is inapt and cumbrous and should be dropped.

The woody-fibres and other elements composing the wood (apart from the rays) when seen in tangential section, may be compared to the meshes of a net which, when hanging loosely, are closed, but when stretched in order to occupy a wider space, will open. A better analogy is the structure of a "Loofah," as it is a vegetable substance and is developed in the same manner as wood. If one imagines the meshes of the Loofah to be filled with a tissue (as indeed they are before the fruit is ripe), such tissue will represent the rays.

In a Cactus (*Cereus peruvianus, see* Fig. 1, Pl. XII) the mesh-work, greatly resembling that of a Loofah, is a true woody plexus from which the rays and concentric layers of soft-tissue (parenchyma) have rotted away, leaving alternate layers of fibres in the form of cylindrical nets. A similar structure may be seen in the more accessible cabbage-stalk, in a state of decay. Our figures No. 1 to 6, Pl. XXXII (highly magnified) shows the same thing as it really exists in wood with the rays *in situ*.

Sachs figures *Cereus* (1887, his Fig. 126), and refers to the mesh-work as being of "Holzbundeln" (woody vascular bundles), but in another figure illustrating a similar case in *Carica papaya* (Fig. 130, p. 172), he uses the term "Bastfaserbundeln" (bast-fibre bundles).

An excellent idea of the mesh-like structure may be gained from the examination of Oak charcoal. The heat destroys the rays, leaving the structure of the rest of the wood undisturbed; moreover, the ray-spaces are caused to gape widely, by which it is clearly seen that the woody body hangs together as a mass of plates which are continuous in a radial direction, but interrupted by ray-spaces in a tangential direction, a very important point to keep in view, as it has much to do with the resistance to strains and also to shrinkage, as will be seen later. The charcoal, moreover, shows how the rays become divided by strands of fibres which are pulled across them in the process of the extension of the periphery of the stem.

Although the sheath or ring of wood produced each season is an individual, as it were, and stands by itself, it is not isolated from its neighbours, for the ray-space or ray itself provides a means of transference of fluids in a horizontal-radial direction.

The term "individual" applied to living things cannot be defined, it is a stop-gap word, for every creature is or was a portion of another of a previous generation. The portion that the parent may pass on to the offspring may be small, but nevertheless the latter remains a part of the former. A sucker, already provided with roots of its own, arising from the root of a tree, starts life a perfect tree already equipped with all its members, yet who would deny it the title of individual?

It may be asked—"Where does the increase in the number of radial rows of cells take place?" It is clear that the quantity needed to occupy the periphery of a tiny twig will not, in spite of an unlimited number of slits, suffice to encircle a large tree. As a matter of fact, the number of slits keeps proportionally the same, in all rings of whatever age. I have few data upon this point, but I believe that the increase in number of the rows of cells takes place at the commencement of each season's growth, and during the widening of the ring, only so many new slits or ray-spaces are produced as may suffice to compensate the increase in circumference of that particular ring. The increase in the width of the large rays in such species as possess them, take part in the general filling up.

Supposing that we have a sector of wood having two cells at its pith end. If these multiply in a radial direction without increase of width, we shall have on the bark side two rows of cells separated by a wide gap. If they subdivide by means of radial septa, every cell giving rise to two daughter-cells, and they in their turn subdividing in the same manner, in thirty rows (ranks) they will number over a million. If, again, the original two cells increase in width without subdivision, they will eventually reach an enormous width. Lastly, if they subdivide only when needed to fill up the increasing space, we shall have large and small cells without order, or like the "stretchers and headers" in a brick wall. The three first suppositions may be ruled out as being absurd, and the latter as not being according to the observed facts. Such subdivision in a radial direction has certainly been observed, but any one may convince himself that it is exceedingly rare by the examination of the transverse section of any wood. We can, therefore, conclude that the increase which may take place does so once for each ring, and this can be only at the point where one ring is closed and the next begins. Examination of the transverse section will show that any further increase in circumference during the year is compensated for by the cracks, which are immediately filled with the tissue called "rays.'

If the rays be simply filling material, as I contend, it will follow that the strength of wood will be due to the cohesion of the woody-fibres at the points where they meet above and below the meshes. All other tissues form strata (cylinders or patches) of less strength. The vessels or pores may have walls as strong as those of the woody-fibres, but owing to the size of their cavities they present so much less solid matter per unit mass, as is proved by the fact that so many ring-porous woods split more easily in the plane of the pore-ring than elsewhere. The parenchyma of the rays and that which is either dispersed amongst the other elements or arranged in zones or in tubular sheaths around the vessels, have cells of so fragile a nature as to be negligible from the point of view of strength, though they may contribute to the elasticity of the material. As they are very bibulous, no doubt they exert much force during the swelling of the wood, just as will a pneumatic tyre when distended with air, but in the contrary process of shrinking their collapse on losing water may permit other elements to close in, but of themselves they cannot exert much contractile force.

The great bulk of the wood amongst species with which we are familiar is composed of woody-fibres. (Exceptions where the parenchyma outweighs them in bulk will be enumerated later under the chapter on "Parenchyma or Soft-tissue.") It follows that the major part of our impressions are gained from the characters of the fibres whose colour, weight, hardness, etc., are those of which we are sensible and which enable persons who have no knowledge of the structure of wood to recognize and even to classify the greater number. Singularly enough, it is just on this point where our scientific knowledge serves us least. We can describe the distribution of the vessels, rays, and parenchyma amongst the groundwork of woody-fibres, but when we come to deal with the latter, which are by far the most important in every way, we have no better means of doing so than has the intelligent carpenter. For this reason the determination of the species of woods must, in part, always remain an art, as that of tea- and wine-tasting and the assessment of the value of grain. In describing the structure of woods, we really concentrate our attention on the points where the woody-fibres are absent, *i.e.*, where their place is taken by vessels and parenchyma, hence very little is said about the great mass of the tissues. This fact is brought home to one on reading histological descriptions.

Janssonius, the most careful author that has dealt with the minute structure of wood to any great extent and whose descriptions are fuller than any others that I have met with, almost entirely ignores all the evidence of his unaided senses, and but rarely gives either colour, weight, hardness, smell, etc., as though they were of no value. In consequence, his work is of very little use except to prove that he is a remarkably able and patient observer; moreover, his details are useful in proportion as his magnification is low. The object of Janssonius and other histologists is, however, not so much to provide means of identification as to describe the structure for its own sake. I do not offer these remarks by way of criticism, but simply to point out that the utility of a description for the purpose of determination usually decreases as the magnification increases.

Returning to the subject of the woody-fibres, we have learnt that when seen on a tangential section, or on the outside of a log that has been stripped of its bark (Fig. 2, Pl. XVI), they appear as a mesh-work, while on a radial section (quarter-cut) they are continuous sheets extending from the pith to the bark. Certain interruptions in a radial direction may occur according to the species. In many broad-leaved trees there may be one or more zones of pores or of parenchyma, and in all species an interruption of some kind is presented by the boundary of the annual sheath. This is reduced to a minimum in some Coniferous woods, the Willows and Poplars, the Greenheart and many exotic woods.

The course of the woody-fibres in a vertical direction is parallel to the pith or long axis, slightly modified by the presence of rays which cause the fibres to bend away on either side in passing them. In the Oak (Figs. 1 and 2, Pl. XIV) this bending is pronounced, but in Coniferous woods, where the proportion of rays to fibres is vastly smaller and the rays themselves minute, little disturbance of the straight, vertical course takes place.

Sinuous or wavy grain, uninfluenced by the rays and of a very marked character, is found in the woods of many Gum-trees (Eucalypts). In all the species of this genus having deciduous bark which reproduces the grain of the naked wood, the wavy course is conspicuous on the exterior of the bark. Sinuous grain has been recorded for the False Acacia, the Ash and the Alder (Noerdlinger, 1859, p. 17), but his cases seem to me to be abnormal, as I cannot find any indication in any of the numerous specimens at the School of Forestry.

The direction of the grain may be complicated by a general twist, making a long-drawn-out spiral, as may be sometimes seen in the Sweet Chestnut. This has been attributed by many (even by recent authors, *see* Harder, 1910, p. 328, in Krais' *Gewerbliche Materialkunde*) to the action of the wind. Harder says "the whole tree gives the impression that it has been turned with great force, which is what actually happens. It is again the wind that by its continued action has called forth the spiral growth." That this is absurd needs but a moment's consideration, for weather-beaten trees lose their branches on the windward side at a comparatively early age, and once they are lop-sided they will certainly turn no more. Only a half-turn will be possible, whereas we find in certain species, such as the Pomegranate (Braun, p. 434), the inclination of the fibres is as much as 45° and they take several turns round the trunk. Further, the twist should decrease downwards, as the top will turn further than the butt, where the twist will be practically nil, which again is not the case. Thirdly, we find that the twist is frequently greater on the exterior of large trees and disappears gradually inwards.

Take a piece of paper, draw a line diagonally from corner to corner and roll it up to represent the trunk of a tree. You will then see that the line will take the more turns the smaller the tube made with the paper; hence if the inclination of the grain be constant in the tree (as it is on the paper) the number of turns will decrease as the diameter increases, which puts the "weather-beaten" theory out of court. If, on the contrary, the inclination be variable and the number of turns constant, the angle must continually increase and the fibres gradually pass from vertical to horizontal, which is unthinkable. As far as my observations go, the inclination is approximately constant in all rings from the same tree, which implies that there will be more turns when the tree is young and fewer when it is old. Stevenson (1918, *T. T. J.*, p. 753) says, "The deeper the River (splitter) cuts into the tree for his layer of wood, the more he is in trouble, as the twist tends towards disappearance"; this points to the contrary. Thil (1900, p. 71) holds a third view, and says that in the case of the Lime of Tonkin (*Baryoxylon inerme*) the fibres are at first strongly inclined, but afterwards become nearly vertical. There are evidently several manifestations of the phenomenon.

Hartig (1891, III, p. 136) mentions 167 species as showing spiral grain, but I have met with it so often amongst the exotic woods, especially those of the Leguminosæ and Urticaceæ, that I have come to regard it as the normal rather than the straight grain. A distinction must be made between such twisted grain, which may always be observed in a definite species, and that which is only occasional, occurring in isolated individuals only. Noerdlinger says (1859, p. 499) that as regards Firs and Oaks the spiral grain reaches right into the thinnest twigs.

According to R. Hartig (1901, p. 41, etc.) the twist is due to the creeping of the cambium cells. These, as has long been known (Trecul, 1852), increase in length after being cut off from the mother cell, and insinuate their ends between those of the rows immediately above and below them. In so doing their transverse septa become more and more oblique until they appear as the one side of a long point (*see* Hartig's Fig. 8, 1901, p. 41, and compare our Fig. 3, Pl. XXXI). If the slope of these septa inclines all one way, a spiral course of the fibres results. In normal tissue, the septa are inclined as often one way as the other and the course of the grain remains straight.

This theory, due to Hartig, does not seem to be altogether satisfactory, for if the cambium-creep takes place as regularly as is supposed, then on a transverse section we shall have large cell-lumina representing the middle-height of the fibres, alternating with pairs of small cells representing points, which is only the case here and there. Indeed, I do not believe in the cambium-creep at all, except in so far as the extreme ends of the fibres may mutually accommodate each other, becoming thinner and longer. On the other hand, the extension of the cambium-cell, without creeping, will result in a general lengthening of the whole cambium-mantle, which lengthening must be compensated by the whole taking a spiral direction, as in the twisted grain, or by simple undulations on a large scale, as in the Eucalypts, or on a small scale, as in those smaller waves which pass around the rays. Spiral-grain as an individual aberration may be defined if not explained, as the result of excessive activity of the cambium in the direction of the length of the tree.

When discussing the question of "Cambium-creep," it should be borne in mind that the Cambium forms a complete mantle over the whole of the woody-cylinder, and that the daughter-cells of the cambium are halves of the mother-cells and hence form a corresponding cylinder within the first, both being indissolubly bound together. It is inconceivable that any change can take place in the cells of the daughter-cylinder that will entail more than a slight change of form in the individual cells. Anything beyond this must lead to a rupture of the bond between the two sheaths, or else a corresponding alteration in the size of the mother-sheath. This last alternative leads us to an absurdity, as if the mother sheath be altered, the next generation of daughter-cells will be after the likeness of the altered mother-cells, so that the "cambium-creep" will hold good for one generation of cells only, or a continual change in the form and size of the mother-cells must take place. Cells are not like the wool-fibres in the process of being felted, they cannot creep freely about the mass of tissue; the movement of one cell is strictly limited, so that it is hard to believe stories of cambium-cells which become "a metre long."

The cleaving of a log on the twist or the familiar cracking of telegraph-poles, is not of necessity an indication of a spiral course of the fibres. It results from the gradual shifting of the lines of weakness formed by the rays (as in Fig. 4, Pl. XXXVI of *Casuarina*). As the rays split up radially into smaller rays they tend to take an oblique course and, when shrinking, the wood will open spirally, although the grain may be quite straight. If the oblique shifting and the resulting cracks are indifferently to right and left, as in Fig. 1, Pl. XXXV of the Beech, the effect will be neutralized and the wood will appear more or less straight-grained. This shifting of the plane of fission and the splitting up of the rays was first pointed out by Jost. The discovery of ordinary spiral grain has been attributed by Braun to the poet Goethe, but it has been common knowledge from time immemorial, as witness Pliny (XVI, 76, 3), who says: "Publicum omnium vilium vocant spires ubi convolvere se venæ atque nodi."

Spiral-grained woods are spoken of as "cross-grained" because when converted into boards, the saw cuts across the inclined fibres, whose ends are thereby exposed to the plane, making smoothing troublesome. I have already referred to the stripy effect of cross-grain on the colour and lustre. Inasmuch as the stripes alternately expose the vertical and transverse sections, and as these sections vary considerably in shade of colour and amount of lustre, they contrast strongly. For this reason they are prized for their appearance, in spite of the difficulty of working. In certain species the direction of the spiral may be reversed from time to time, if not from year to year, and a layer (or series of layers), winding to the right, may be followed by another running to the left, as in most Eucalypti, the Logwood, the Lignum-vitæ and many others. This double-cross-grain is well shown in Fig. 4, Pl. IX of the last-mentioned wood, being a photograph from a specimen in the collection of the Faculté des Sciences of Lyons, which had been most ingeniously split into successive half-cylinders by some lignologist whose name has not been preserved. The split surfaces show the double spiral admirably, the extent of the interlacing of the fibres being remarkable. Not only is the grain reversed from N.E. to N.W. and back again within the thickness of an eighth of an inch, but certain individual layers alter their course. Hartig (1891, p. 136) mentions only one case of the double spiral, *i.e.*, the Italian Poplar. Thil (1900, p. 70) cites it for the Spruce and the Scots Fir: it is undoubtedly rare amongst species of temperate climates.

When wood is worked up, the spiral is more difficult to trace on the tangential section (plankwise), but it may be made out on the radial section (quarter) when examined by the lens.

I have remarked that spiral grain, either single or double, is generally accompanied by a decided obliquity of the lines of pores, as seen on a transverse section.

The statement sometimes met with (*see* Roth, 1895, p. 23) that the fibres run into a branch from below, but not from above, thus making splitting difficult, is not precise. The proper way to express the fact is that the nature of the fibres changes in the upper angle of the fork. Here they become lax, have little coherence, and hence offer less resistance than those which remain strong and tough below the crotch: the tissue, however, is quite continuous (Fig. 2, Pl. XV).

The Rays

In discussing the course of the fibres we have to some extent decided the distribution of the rays, as the latter occupy slits in the woody stem. Regarding them as separate bodies, the rays are strips or ribbons of tissue running radially amongst the fibres and consisting for the most part of thin-walled, cylindrical cells, which are generally extended in a horizontal direction, *i.e.*, contrary to that of the fibres, which have their longer axes in a vertical direction. Unlike the other elements of the wood which occur in zones, strips, or tubes of tissue that may be continuous throughout the whole length of a sheath of wood, the rays are simply *islands of tissue.*

As the isolation of a complete ray is a difficult operation, its shape must be judged by means of sections taken in three directions. On the transverse section of an Oak, we note that they are wedge-shaped bodies, very gradually widening outwards, having their points turned towards the pith, and terminating at the exterior of the log (Frontispiece). The largest of all arise in the first ring of wood and have been termed "primary rays," but they do not differ in appearance from the others arising later. In other species, as in the Beech, the rays may be pointed at both ends: R. Hartig says that some end blindly outwards in this wood. This is, however, an illusion caused by the section, the ray instead of dying away, is split by a strand of fibres which has been drawn obliquely across its mouth and the apparent end is only the thin, upper edge of one of the two halves resulting. This process is well shown in a tangential section in our figure No. 4, Pl. XXXVI. In this section the ray appears as a spindle-shaped body which is regular or otherwise, according to species. On a radial section the ray should look like a ribbon or strip of shining tissue the edges of which are quite straight. We have now obtained all the material necessary to form a mental picture of the complete ray, except the extreme proximal ends which we never see quite clearly, so we may say that the shape resembles that of a double-edged blade of fusiform section, having parallel sides and gradually tapering at one or both ends. For the shape of the end the reader is referred to Fig. 1, Pl. XXXVII.

Mathieu says that the rays do not taper to a point as they appear to do on a transverse section, but that they curve downwards below the surface, hence the cut traversing the upper edge where there is but one row of cells, causes the apparent tapering. This is true, but only of the extreme end where a ray may be split up into two, as explained by Zijlstra:—"After the splitting up, the upper part of the ray may overlap that of the lower, causing a bending in a vertical sense. The fluctuation of rays in height is also irregular." This is obvious on a tangential section where subdivided rays are shown, as they may be split into many superposed sections, but otherwise, to the naked eye, the edges of the rays are remarkably straight.

The effect of the splitting up on the "figure" in quartered wood is well exemplified in Fig. 2, Pl. XI of the Turkey Oak (*Quercus cerris*), in which case it imparts a specially flakey appearance to the silver-grain. The subdivision of the rays may be seen in many woods besides the Oak and the Beech. All members of the families Casuarineæ and Proteaceæ show this feature well and it is seen wherever there are very large rays. I have observed splitting and forking in both directions (towards and away from the pith) in the same ray, so that on a transverse surface, two rays running side by side appeared to be connected by a third like the switches of a railway. I have also seen a ray split up into four branches in the wood of the Coffee-tree. In a turned cylinder of Beech, the rays running from the pith outwards may be traced down the side for several inches in a vertical direction, sometimes winding as much as an inch out of the straight, but preserving their identity in spite of the splitting, whereas others arising further from the pith become dispersed and lost amongst the mass of secondary rays, or in other words, a primary ray may be said to have become subdivided into hundreds of small ones.

Tschirch (*ex* Jost, 1901, p. 15) says that the primary rays are of the same height as the internode and that on a tangential section they are distinguishable from the secondary with ease, as only the latter are spindle-shaped. This is less than the truth, as the large rays can be traced, as already said, for the length of several internodes. Moll and Janssonius (1906, I, p. 77, Fig. 2) figure some curiously split and branched rays in *Dillenia aurea*; they also enumerate (1906, I, Index) seventeen species of Javanese woods where they split and three where they fuse into one another.

True secondary rays should arise independently of the primary and probably do so from the opening of new ray-slits. They are independent of each other, whereas the primary rays form a continuous, radial plexus or brush, all being gathered together near the pith into a long, single, vertically-extended ray. In most species the subdivision begins very early, and it is necessary to examine the inner zone of the first ring, in order to find the rays in their original entirety, which accounts for the fact that they have, for the most part, been overlooked. The splitting may be retarded for a time, as in the Beech, or postponed indefinitely, as in *Carallia calycina* of Ceylon, which has undivided rays of six or more inches high. From this it will be seen that Hartig's statement that many rays end outwards in the solid wood, is not the proper way of expressing the fact—they all arrive at the bark, but in a subdivided condition. This accounts also for the difficulty in describing the shape of their ends.

The height of the rays of *Clematis*, according to Noerdlinger (1859, p. 9), is about 160 mm., and in *Alnus glutinosa* from 160 mm. to a foot high: in the Oak 50 mm. and the Beech 5 mm. De Bary gives 100–200 mm. (about 4–8 inches) for the rays of the *Clematis*, but it must be understood that the measurements in this case are for the full height of the undivided ray, and perhaps this applies to the Alder also, but for the Oak and the Beech it is evidently the size of the subdivisions that is referred to by these authors.

In a specimen of the Tamarisk (*Tamarix gallica*), at Lyons (No. 123, Ser. I), there are many wide rays, which are not normal. Amongst these is one very large one equalling ten to twelve of the others in breadth. It commences to split up in the third annual ring and at the tenth consists of a brush of two fine, two wide, four excessively fine and two normal rays.

The familiar examples of the Oaks, Beech, Hornbeam, Plane-tree, Hazel and Alder are apt to convey the impression that large rays are a common occurrence or even normal. On the contrary: they are confined to a very few families indeed, and might more properly be regarded as abnormal, for some species, the Black Alder, for example, may have them, while its near relative, the White Alder, shows them sparingly or not at all.

As a component part of the wood, the rays may occupy as much as half the transverse section, as in the Apple and Pear, where they are so small as to be scarcely visible to the naked eye. In the Silky-Oaks (Proteaceæ; Figs. 2 and 6, Pl. XXI), the Casuarinas, *Plagianthus* (Fig. 5) and *Hoheria* of the Malvaceæ they occupy much space, but they are few and large. For the most part they occupy about one-third of the transverse surface. When the size is small it is compensated by numbers (De Bary, p. 489). I say advisedly on the transverse surface, as the proportion of the whole mass is difficult to estimate. R. Hartig (1901, p. 34) puts it very low, he says that in the Oak the proportion of ray-tissue is 1 per cent. but may rise to 10 or 12 per cent. "pari passu" with the admission of light to the leafy crown of the tree, but on p. 37 he says that in the trunk of the Oak the proportion is 22 per cent., and in the root 20 per cent.

The rays of the Conifers are small and widely separated on a vertical section, and the proportion of space that they occupy is much less, as will be seen from our figures on Pl. XXXI, which are all on the same scale of magnification.

Under the somewhat loose term of Small Rays are grouped all those narrow rays of woods that have but one kind of cell whether they be of one row of cells in width or more. There is really no sharp line of demarcation between these and the large rays, inasmuch as in the Hornbeam every gradation is found from low, unicellular empty rays to the large compound form with edge- and starch-bearing cells, which are again assembled into still larger groups or bunches, called "aggregate rays," as Hartig pointed out (1859, p. 94). Noerdlinger states (1859, p. 11) that these broad rays do not occur in the branches of the Hornbeam.

The small rays are of an exceedingly simple nature, being composed of from one to five rows of cells in width, by one to about fifty in height. Their shape is linear with pointed ends, such as one would expect of a body occupying a narrow slit. In certain rare cases they may be filled with coloured matter, but for the most part they are delicate and transucent. They may often be traced over many successive rings (as many as thirty) (*cf*. Fig. 2, Pl. XXIII).

In measured height they may be from 0·2 mm. to 2 mm., but there is no rule or definite mit. In the New Zealand Birch (*Fagus fusca*) as much as three-quarters of an inch 19 mm.) may be reached, and in the Wallaba of British Guiana (*Eperua falcata*) fiveighths (16 mm.), but both of these woods are abnormal in other respects. Noerdlinger tates (1859, p. 507) that in the Common Spruce they may run to 7 mm. at the foot of the tem, but in this case also a special aberration known as "Hazel-pine" may be in question.

In number, the small rays may range from 5–40 per mm. on a transverse section. Where the thickness of rays reaches three or more rows of cells, they seem to approximate o large rays in appearance and are no longer influenced by the presence of the pores, nd ran straight without, as it were, avoiding the latter. Some small rays have a proounced serpentine course, as shown in Fig. 2, Pl. XXIII.

When large rays are present, small ones almost invariably accompany hem and may be made out by the means of a hand-lens. They are hen frequently uniseriate and resemble the extreme ends of the larger ays. Exceptions to this rule are, according to Hartig (1898, Key), he Vine and the Barberry, that have large rays only, to which may be dded *Plagianthus*, *Hoheria*, and perhaps many others may be found if looked for. *Platanus* has uniseriate rays in very small numbers. If the large rays on a transverse section be followed until they become like the small ones and then at this point the wood be cut away and the connection between the original large ray and its end lost, no one would pronounce this thin end to be other than a small ray : they continue to be traceable for too great a distance for it to be possible that the cut should pass truly along the row of " edge-cells " which form the upper margin of some large rays. Again, the practical difficulty of deciding whether a wood should be described as having one or two kinds of ray supports my contention that there is really but one, which varies in size, composition, and form. Hartig (1859, p. 74) says that there are three kinds in the Beech, but apart from the peculiar form mentioned on p. 86, I fail to see any essential difference. We cannot well avoid using the terms " large and small," but in the description of woods I am sometimes compelled to treat the large rays as the " middles " of long ones, of which the small ones are obviously the ends.

Certain authors make a separate class, under the term " false-rays," for such as those of the Hornbeam. So long as no scientific distinction is implied there is no objection to this. As has been remarked above, these false-rays are simply aggregations of small ones, or if viewed from the opposite standpoint, they arise from the subdivision of a very large ray by strands of fibres being drawn across it. This is the more correct view.

The small rays of the Hornbeam seem to be dispersed where they cross the crest of the waves in the boundary of the ring and thrown together in the hollows because the periphery tends to increase in the one case and diminish in the other. Perhaps this may account for the formation of the large rays, which are simply bunches of the smaller. The same thing is seen in the transverse section of the Bird's-eye figure of Maple (*see* Hough's section card, No. 76, Vol. I). Here the rays arise from callus, but the notch in the ring-boundary has the same effect as the hollow of the wave in the ring of the Hornbeam.

With the exception of very abnormal cases, such as that shown in Fig. 3, Pl. XVII, no exogenous wood (either Conifer or Angiosperm) is without rays, hence the presence of the latter serves to separate them from the endogens (Palms, Canes, etc.), and for a sufficient reason —the periphery of the endogens does not increase. In the exceptional cases, *e.g.*, the Aloes, the Dracænas and Yuccas, the swollen bases of which increase in diameter, rays are produced likewise. Amongst the herbaceous Dicotyledons this rule does not apply, as Solereder (1899, p. 344) enumerates twenty-three families where parenchymatous rays do not occur.

The curious wood referred to above (Fig. 2, *Acantholinum sp.* Plumbaginaceæ, after Krueger) would, if it ever becomes a tree, form a mass perforated by large spindle-shaped holes narrowing inwards towards the pith. It has ray-spaces with no rays to occupy them. Another wood, the Mincouar of British Guiana, described by Dumonteil, is, as he says, " percé à jour," but is none the less durable and makes good beams : he regrets that the holes make it useless for ship-building. We may conclude that such a structure will render the wood very elastic without in any way impairing its strength.

The only specimen of *Minquartia guianensis*, the species to which this wood is usually referred, that I have seen was, however, quite normal in structure. There may be a confusion of names—no rare occurrence, by the way, in Museums.

In point of distribution and size, the large rays may be 1 mm. or more, apart and built up of five to eighteen rows of cells, in their widest part. They are then readily visible in all sections and frequently striking, some of those of the Silky-Oaks being superb, lending the wood a magnificent lustre and figure. The lower limits are not easy to fix, but rays having edge-cells may be quite minute, as in the Iroko from West Africa, figured by Hopkinson (p. 455). (This author sketches the ray as having an integument or skin, which is not correct, as the cells lie in the ray-slit as in a sheath and do not constitute a separate body.) On a transverse section long, wide rays are straight, unless disturbed by eccentric growth. They keep, as it were, the vessels or pores within bounds, so that in species like the Oak, the pores are forced to arrange themselves in a radial direction, whereas in the Chestnut, which is closely allied to the Oak, the rays are thin and weak, and the pores take an oblique direction. The Oak will often show spaces where the large rays are far apart and then, even in this species, the obliquity of the lines of pores is to be seen. We have already observed that it is the contrary n the case of the small rays, which in their turn give way to the pores and run round as though avoiding them. This is very characteristic of many woods and is a good diagnostic feature : it is found in the small ays between the large ones in broad-rayed woods which have coarse pore-rings, but only amongst the vessels of the pore-ring ; the small pores have not the power, figuratively speaking, to push the rays aside.

If undulating rays happen to be coloured, they give a special character o a planed radial surface, as in *Vochysia guianensis*. The appearance f nodosity or swellings in the rays (tr. sec.), just at the point where hey cross the boundary of the rings, is characteristic of many woods, he Beech and Plane-tree being the most familiar examples (*see* Figs. and 4, Pl. XX), where it may be seen with the lens. This nodosity is eneral in all Conifers allied to the Pines, but it is on a very small scale. n any case, a slight irregularity in the colour of the parts on either side f the boundary is visible. The explanation of the swelling is easy. f the outside of the log after the bark has been stripped be examined, he ends of the rays will be seen to be at the bottom of fusiform grooves Frontispiece) ; in the following season this groove is filled up by a tissue f a different density and colour, so that the ray at this point not only ppears different in depth of shade, but partakes of the shape of the roove. In extreme cases these differences may have their effect upon he appearance of the silver-grain or rays in radial section.

The invagination of the ring-boundary is well shown in our figures f the Hornbeam (Fig. 1, Pl. XX), and the Beech (Fig. 2).

Thil (1900, p. 82) says that the wood from the outer surface of the em of the Beech, after the bark has been removed, has long been used for printing on silk. The re-entrant fusiform grooves of the ray-space are taken advantage of as forming a sort of design.

The distribution and number of the rays have been suggested as a means of determining the species of Conifers, but Essner (1882, *Conclusions*) says that neither the height, number per sq. mm., nor the number of the cells in tangential section are to be relied upon, as these characters are not sufficiently constant. With this I agree entirely.

A better method is to observe their relation to the diameter of the largest pores present, as these vary with them. In some woods there may be three to four, or even five rays in the space equal to the width of a pore (*Physocalymma*). In such cases some of the intermediate rays appear to be stopped short by the vessel. In the vast majority of woods there are two rays to the " pore-width " : when less, the rays are generally of three or more rows of cells, and are stout enough to dominate the vessels. A character that I have found useful, but which is difficult to convey, is the regularity or otherwise of the arrangement. If all were exactly the same in shape, we could say that they were at such and such intervals, but on a transverse section all but uniseriate rays are tapering bodies whose greatest diameters rarely if ever occur on the same horizon ; in other words, the middles are separated by many thin ends, none of which are equal either in size or length. The number of ends between two approximately opposite middles is a very indefinite character on paper, yet when seen on the wood itself, greatly aids diagnosis.

The Silver-Grain

The rays in radial section, or quarter, form a figure which is called variously " silver-grain, flower, felt, clash, or chink." It is composed of the fragments of the rays that have been spared by the saw or plane, when the wood is cut in the direction of the diameter of the tree, *i.e.*, across and parallel with the pith. It is of course more apparent in the broad-rayed woods such as the Oak, where the rays are deep and of a different appearance to that of the ground (woody-fibres). Small rays show up only when they are coloured, or by reflection, but inasmuch as all true woods have rays, they must have silver-grain also. It may happen that both large and small rays are coloured, as in the Alder, and then we have a double silver-grain, but this is rare. The Hornbeam has very large rays that come out as broad flakes on the quarter, but owing to their white colour they are very inconspicuous and require looking for. The most gorgeous effects are obtained on the radial section of the wood of the Silky-Oaks, the most beautiful being that of one of the " Native Pears " of New Zealand (*Xylomelum*). In rare cases, as in *Swartzia triphylla* of French Guiana, the rays, though minute, are so numerous as to cover practically the whole of the radial section.

The colour exhibited by the rays in this section is generally some tint of that of the woody-fibres, but lighter or darker in shade : in rarer cases they may be different. They are snow-white in the Lace-bark-trees (*Plagianthus* and *Hoheria*), the Holly, the Hornbeam and the Spruce ; flesh-coloured in the Cornel (*Cornus florida*) ; red in the native Pear above mentioned, the Red Alder of the Cape (*Elæodendron croceum*), the Salmon Gum (*Eucalyptus salmonophloia*), the Monkey-pot-tree (*Lecythis corrugata*), the Vouapa and Baradaballi of Guiana ; alternately red and yellow in some of the Silky-Oaks, and black on a brown ground, in the Letter-wood (*Brosimum Aubletii*). In *Memecylon cordatum*, the rays in transverse section are golden on a dark brown background, while in tangential section they are red against greyish-brown.

Rays which in the middle of their length are red, and white at their ends occur in *Ludia sessiliflora* Lamk., of French Guiana.

As rays that are wide on a transverse section are almost invariably deep on a radial section, the appearance of the latter may be deduced from the former so that a chip taken from a log or a smooth cut made with an axe will suffice to show an intending buyer how much figure he may expect.

The silver-grain is much better seen on a cleft surface, as the rays are less injured and appear bright, clean and free from débris of wood-fibres as they separate (at least on one side) completely from the wood. The only example of fragments of wood which I have seen where the fibres cling to the rays, is in *Psidium Guajuva*, Linn. In a specimen at Lyons the parenchyma still adhered to the surface of the rays, conveying the impression that the ray-cells were running the wrong way. Perhaps the specimen was a little decayed and abnormal, though I detected no indication of this.

When higher powers of magnification are used, the large rays of the Oak (and many other woods) are seen to consist of two kinds of cells, as they are in the Coniferæ, but the middle cells composing the greater part of the mass are round in tangential section, and procumbent or prostrate (*i.e.*, their longer axis is horizontal) and generally filled with starch. The edge-cells are empty like those of the small rays and are probably of the same origin as the latter, that is to say, the large ray is a mass of starch-bearing cells, intercalated between the upper and lower parts of a small ray. The large rays of the Conifers which are characteristic of those species which have vertical resin-canals are really very minute objects and are rarely visible to the naked eye, though when deeply coloured they may be evident enough. These rays are called "lenticular" or "multiseriate" rays and differ from the smaller in the possession of a horizontal resin-canal passing through the middle of their height. This canal may occupy nearly the whole width of the widest diameter of the ray, as in the Pines and Spruces, or it may occupy the centre only, there being one or more rows of cells between the canal and the exterior, as in the Douglas Fir. They are all of more than one row of cells wide in the part immediately adjacent to the canal, but rapidly diminish to a single row upwards and downwards. This thinning is much more abrupt in the Pines, Spruces and Larch, so that the ray appears attenuated and slender: in the Douglas Fir the reduction in width is attained much more gradually and the shape is rather like that of a boat. Jones (1912, p. 122) makes a point of the number of sides formed by the cells around the canal. In the Douglas Fir, he says that the canal hus becomes pentagonal or hexagonal, while, in the Spruce, the number f sides ranges between seven and eleven.

These large rays of the Conifers are of two kinds of cells: those orming the edges are tracheids, whose walls may be smooth internally, s in the Weymouth Pine, or irregularly thickened (appearing jagged n radial section), as in the hard Pines (Scots and Pitch Pine). Ray-racheids are not unknown even in *Abies* (*see* Thompson, *W. P. Bot. az.*, Vol. LIII, p. 53).

A peculiar form of ray is found in *Araucaria*, where it extends for a considerable height in a vertical tangential direction, but is thinned down to a single row of cells here and there, conveying the impression that several rays are connected with each other by strings of cells (De Bary, English Ed., p. 490). Another variation from the normal form consists in the presence of cells of an elongated thread-like shape (fusiform) in radial section; they resemble woody-fibres lying down, but are parenchymatous (Hartig, 1891, p. 91, Figs. 41 and 42*b*; also Schwartz, 1892, p. 921). In the *Elæodendron croceum* the rays are from two- to three-rowed in the middle, which part may be as little as five cells high, or they may have as many as seventeen edge-cells on each edge above and below and five ray-middles may be connected by such edge-cells, somewhat after the manner of Araucaria. The middle cells contain starch, while the others are empty. This species may occasionally exhibit a compound broad ray.

An important point is the distribution of the rays in tangential section. The commonest form is in alternate rows, an arrangement called by Foresters " quincunx " or like the black squares on a chess-board (Fig. 1, Pl. XXXII). It is seldom perfect and the varying sizes of the rays makes it still less evident, but the opposite form, in parallel or " en palissade," " en étages " or " stockwerkartig," as it is variously called, is very striking (Fig. 5, Pl. XXVII), and gives rise to reflection in lines or waves called " fire " that is easily observed, albeit the rays themselves are individually too small to be visible to the naked eye. My friend Mr. H. A. Cox has pointed out the parallelism of the rays in the wood of the Horse Chestnut. It is very characteristic of many of the exotic Leguminosæ, which owe much of their beauty to this feature.

The remarkable diversity in the form and structure of the rays when the wood-fibres are distorted, as in the case of the " Ripple or Ramshorn " figure, and well illustrated by Jaccard (his Fig. 10, p. 76, and Pl. V, VI), is due to the irregularity in the form of the ray-spaces, caused by the buckling of the wood-fibres in their endeavour to attain their normal length in an insufficient space.

As a rule the rays are composed of very delicate, feebly-lignified cells whose walls are very thin in proportion to their cavities. In uniseriate or single-rowed rays, this is nearly always the case, even in such woods as the Ebonies and many hard Leguminous species. Their delicacy becomes apparent when an attempt is made to cut thin sections from the cross-section, as the wood will break up into strips at the rays. When such thin slices are examined by transmitted light the rays are seen to be of laxer texture than the surrounding fibres. In large rays the cells frequently become lignified, that is to say, a layer of denser substance is deposited upon their walls, and then the hardness of the ray-cells may exceed that of the fibres. The rays of the Beech are much harder than the ground-tissue, as may be felt when the wood is scraped with a knife. In the Cork Oak, the rays, although softer than the wood, are, according to Noerdlinger (1859, p. 235), " stone-hard " in the bark. In the Kauri and Weymouth Pines, they are tough and may be drawn from a thin cross-section like so many threads. Mathieu (1897, p. 665) says that the rays of the Oak are often harder than the wood, and when the latter is subjected to wear may become salient.

Whether hard or soft, the rays shrink more in drying than the substance around them, and to this is due some of the important phenomena accompanying the drying of wood. Noerdlinger again says (p. 262) of the Cork Oak that conspicuous grooves are formed in the cross-section on drying so that it appears covered with a mass of converging channels. The same thing in a lesser degree is seen in the Common Oak, Beech, Plane and other woods. Thin sections of the Turkey Oak will appear wrinkled because the fibres cannot follow the contraction of the rays.

In point of colour it may happen that the rays are lighter, which is indeed the rule, but yet they may be more opaque in a thin section, as in the Rosewood (*Dalbergia nigra*).

Form of the Cells of the Rays.

The ray-cells are usually rectangular prisms with their longer axes extended in a horizontal, radial direction, and they resemble the cells of the vertical parenchyma, from which they are virtually indistinguishable except by their position. Some rays exhibit cells which are more or less upright and somewhat triangular in tangential section, and exceedingly irregular and malformed in radial section. These are tracheids and are called " edge-cells," as they occupy the upper and lower edges of the ray. The middle cells are more or less round in tangential section, with intercellular spaces between them which may run along the whole length of the ray and communicate with similar passages in the vertical wood-parenchyma (Schwartz, p. 921). They may thus connect the latter with the outer air by way of the lenticels while the epidermis is young, but when the bark is old and thick, the number of the rays vastly outnumber that of the lenticels, and the circulation of air would seem to be anything but free.

A certain correspondence between the rays and the fissures of the bark is to be seen in *Grevillea*, and I believe that in many other cases the early fissures have a relation to the rays. This is exhibited by the young (one to four year) shoots of *Fraxinus Ornus*, *Ailanthus glandulosus*, *Broussonettia papyrifera* and *Populus pyramidalis*. This character becomes vague as the tree ages, but the bark always retains a peculiar reticulation which recalls the original condition. Beech twigs, as already stated, show this type of fissure in the second year and sometimes on those of the third.

It should be borne in mind that all kinds of cells or elements may merge one into another. They are all daughter-cells of the cambium and at first are alike, and such changes that they undergo may, for all we know, be caused by their environment. For instance, the wood-fibres and the wood-parenchyma are widely different in their ultimate forms, yet cells are occasionally met with that have the characters of a fibre at one end and of a parenchyma-cell at the other (*Harpullia pendula*, Moll and Janssonius, III, p. 402). Again, the cells of the pith and of the rays, of callus and tyloses are frequently indistinguishable, Jeffrey finds that there are transitional states between the parenchyma- or middle-cells of the rays of Conifers and their tracheids or edge-cells. Sanio contends that if we admit the community of the elements, all our superstructure of descriptive histology breaks down, and Moll strongly supports his view. This seems to be a trivial question relating to a system of research that is far too much occupied in making petty distinctions and creating new terms for them. If the system breaks down perhaps we shall see some light.

Crystals are abundant in the ray-cells and are sometimes visible to the naked eye in the Ebony and some Sapotaceæ (*see* p. 51). I have also seen them in *Acacia mellifera*, a black or blackish wood that may be taken for Ebony. One may mistake these large crystals for small pores under a magnification of × 10. In the Ziricotti from Honduras the rays are about three cells wide and occasionally contain three crystals side by side. These, after being located with a higher power, can be seen with a lens (say × 3). Smaller crystals are of common occurrence.

CHAPTER VII

THE SOFT-TISSUE OR PARENCHYMA

THE fourth tissue to be described is composed of delicate cells, shorter and less pointed than the woody-fibres, and divided into a number of chambers, which form more or less rectangular members. They retain their living contents for a very long period and in all respects (except their vertical direction) resemble the parenchyma-cells of the rays. The term "soft-tissue," which I borrow from Gamble, is very convenient from the macroscopic point of view, but as this tissue was unknown until discovered by the histologists, there is no objection whatever to the term "parenchyma," for new conceptions demand new words. If one may take exception to the term, it is because it covers so many different types of tissue, including that of the leaves, pith, rays, etc. The word "soft-tissue" is applicable exclusively to the parenchyma of the wood and is appropriate, inasmuch as it is always softer than the fibres surrounding it. It is the name of a tissue and not of a state of a tissue, as is the case with the alternative word. The form of the cells of the soft-tissue may be gathered from our figures Nos. 2 and 3 on Pl. XXXIII. They may be grouped in four different ways :—

(*a*) The first and most conspicuous is always found in intimate connection with the vessels or pores. Most commonly it clothes them as with a thin sheath of irregular thickness, which on a transverse section, appears as a narrow aureole around the orifice of the pore (Fig. 1, Pl. XXVI), and in a vertical section as borders to them (Fig. 2, Pl. XXXIII). When further developed, the sheaths may be sufficiently wide to connect a series of pores into a chain (Fig. 5, Pl. XXVI) or stream (Fig. 1, Pl. XXIX), as in the Oaks and Chestnut, or into festoons, as in the Elms (Figs. 6, Pl. XXII.), or the pores of the pore-ring may be imbedded in it. A lateral (tangential) extension may give rise to minute wings (Fig. 2, Pl. XXVII), which may with greater development run to complete zones all round the ring. Such zones may be independent of each other (Fig. 4, Pl. XXV), or may anastomose (Fig. 6, Pl. XXVII).

The direction taken by the lines of this kind of soft-tissue (when so far developed) is nearly always that of the lines of the pores, *i.e.*, sometimes oblique, at others concentric (Rosewood), at others radial (Oaks, Sweet Chestnut). It thus aids us in tracing the plan of the pores as it compacts their lines and streams and renders them more evident. For instance, the visibility of the radial streams in the Oak is due in a great measure to the light-coloured soft-tissue in which they are imbedded. (It is sometimes indistinct in the Chestnut and is liable to betray one.)

One or two exceptions to this orientation occur in the Leguminosæ, where the soft-tissue is concentric while the pores are arranged obliquely, *e.g.*, the Padauk.

An idea of the appearance of the soft-tissue of the Elm, in radial section, may be gathered from our figure No. 3, Pl. XXXII, where some few cells are faintly shown.

This kind of soft-tissue is by some termed the "paratracheal" parenchyma, but I propose to employ the symbol P (*a*) for the sake of brevity.

The second manner of distribution which I call P (*b*) is always concentric and forms layers, sheaths or zones, which may be continuous, as in the Evergreen Oak, or interrupted (*i.e.*, in very fine bars) in the Hickory and Walnut. It frequently exists in the same wood as the P (*a*), when it is distinguishable from it by its different colour, and in a less degree by its independence of the pores. If a zone of soft-tissue be seen to be the same as that clothing the pores, it is P (*a*), if different then P (*b*). As both may form concentric zones (but not in the same wood), the idea is confusing, yet in practice it is not difficult to distinguish them, as in the great majority of cases the P (*b*) is accompanied by P (*a*), with which it can be compared. This kind of parenchyma has been termed metatracheal. It is shown in radial section, highly magnified, in our figures Nos. 2, 4 and 5, Pl. XXX. In our Frontispiece, with the aid of the lens, and in Figs. 2 and 4, Pl. XXVII, the excessively fine, wavy lines are just visible. Unfortunately in photographs there is no colour to aid us; still, any piece of well-grown Oak or, if available, the Evergreen Oak, will show both kinds of parenchyma.

This second kind of parenchyma is of somewhat different nature to the first, as one will naturally gather from the foregoing, yet Moll and Janssonius state that in certain species they gradually pass one into the other, so that such difference is not fundamental. When complete concentric zones are formed by either P (*a*) or (*b*), their contour may be regular, undulating, crenate or dentate. When the zones are repeated several times within the same ring, the boundary-line is usually indicated by an empty space where the P fails. The frequency of repetition is an important point in identification: it may be so high as to equal that of the rays, thus making a net-work with them, as in the Sapotaceæ (Fig. 3, Pl. XXV).

The lines of P (*b*) are rarely visible to the naked eye on the surface of the solid wood. They are fairly clearly shown on our frontispiece, which is taken with a magnification of 2½ times natural size.

In the Beech and Hornbeam parenchyma (*b*) is in very small quantity, though making complete sheaths of one cell wide. It is visible in a transparent section (preferably the radial) and only by the aid of the microscope.

In the genus *Calophyllum* and in *Celastrus acuminatus*, on the contrary, the parenchyma may occur in clearly visible dark-coloured lines which on a tangential section are very conspicuous and produce much of the "figure." In *Calophyllum* this line or sheath does not always make the circuit of the annual ring, but occasionally stops short abruptly. This peculiarity is rare, and, combined with the arrangement of the pores "en échelon," is a means of distinguishing woods of this genus (Fig. 3, Pl. XXVI). In *Celastrus* the bands are continuous and wider.

There can be no doubt that there is more than one kind of parenchyma (*b*), and our classification must be regarded as tentative pending further investigation.

(*c*). In certain cases where the limit of the annual ring is determined by one or more rows of parenchyma cells, as in the Poplars, the cells of this tissue may sometimes be distinguished in young wood from the wood-fibres in transverse section by the presence of nuclei, but no conclusion should be arrived at concerning parenchyma from an inspection of the transverse section alone.

The third form of soft-tissue P (*c*) occurs at the ring-boundary only, where it forms a thin zone. It may be coloured as in Mahogany (Fig. 3, Pl. I), or colourless, as in the Poplars.

(*d*). The fourth form of soft-tissue is that of isolated cells, or at most files of cells, dispersed amongst the fibres. These cells are not visible on a solid section and only by their slightly larger lumina in a transparent transverse section. To be sure whether one has to deal with parenchyma or with small vessels, it is necessary to examine a longitudinal section with a power of at least twenty diameters. We may call this type P (*d*).

Let it be thoroughly understood that these rough divisions correspond to the method of grouping and not to the nature of the cells. It is not a histological classification, but a strictly practical one of great service. After all, it is not so very empirical though intended to deal with appearances rather than with the nature of the component cells.

Unfortunately the soft-tissue is exceedingly capricious and appears to be much affected by the conditions of growth. For instance, in the Elm, the golden P (*a*), compacting the festoons of pores, is generally visible in great abundance, but by inadvertence I used a piece of wood for an illustration in my *Timbers of Commerce* Fig. 107 from which the soft-tissue was practically absent. The same applies to my Fig. 36 of the False Acacia. This is the chief difficulty in constructing a Key to the species, inasmuch as the P is very characteristic, but only when properly developed. Another good instance is the Jak-tree (*Artocarpus integrifolia*) of which there are two varieties, the wild and the cultivated trees. In the former the P (*a*) is abundant and unites the pores in wide, conspicuous patches. In the cultivated Jak it surrounds the pores as narrow aureoles only. This circumstance makes this species troublesome to deal with as it falls into two quite different divisions of a Key, and has to be taken twice over.

Great care must be used in the examination of transparent transverse sections prepared for the microscope, as the cells of the P may so much resemble the cells of the wood-fibres that confusion is easy. Certain authors have stated that there is no P in the Jamaica Quassia (*Picræna excelsa*), the Simaruba or the Orange-wood, whereas it is readily visible to the naked eye in all three. Hopkinson, who describes the Mangrove as having visible zones of parenchyma, gives a diagrammatic figure in which none is seen. This error may be due to the extraordinary optical properties of this tissue. In many woods (for instance, *Calophyllum inophyllum*), in a transparent transverse section, the parenchyma is invisible by direct transmitted light, but appears when the light is oblique and with reflected light it is very dark and almost conspicuous. Other similar examples are *Hæmatoxylon Campechianum*, *Carya tomentosa*, *Juglans regia* and *aurea*. In *Carya amara* it is neither visible by direct nor oblique transmitted light, but can be seen in the solid quite clearly. In *Xylomelum pyriforme* it is visible by oblique light in the heart-wood, and in the sap-wood by direct light only. In *Gleditschia triacanthos* the parenchyma is visible also in the solid heart-wood, but not in a transparent section, though in the sap-wood it is to be seen either way. An extreme case is that of *Fœtida mauritiana*, a wood with a very characteristic "plan" when viewed in the solid or in section by reflected light, but all this disappears in a transparent section.

This proves the necessity of controlling one's observations by the examination of the vertical sections.

On the other hand, according to Moeller, the soft-tissue may be conspicuous in transverse section and scarcely perceptible in vertical section, as in *Erythrina corallodendron*. The soft-tissue is generally more visible in the Autumn wood: even if similar in quantity, it is there more easily seen. The delicate white lines uniting the pores in the Ash are much more apparent in the outer zone of the ring.

The P may again be very little developed in the early rings near the pith, so that the structure or plan appears quite different from that of the later wood (*see* p. 13). The colour of the soft-tissue is generally that of the wood-fibres, but of a lighter tint.

One of the most beautiful woods with which I have met is a species of *Swartzia* from French Guiana. It is quite black, relieved by delicate golden lines of soft-tissue, the effect being wonderfully pleasing. Many instances occur where it shows a difference of colour from that of the fibres, yellow on brown being the commonest, as in the False Acacia and the Elm.

As regards the function of the soft-tissue, as already conjectured, it may act as a means of transference of fluids between the vessels and the rays and as a starch-reserve. From its uncertain appearance in the same species and the great variation between different species living under identical conditions, it is clear that whatever function it may perform, this cannot be of supreme importance.

The parenchyma of Coniferous woods is never visible to the naked eye unless filled with resin. Such resin-cells are found chiefly in the Cypresses and their allies, and make a good character in diagnosis, a good example being the Pencil Cedar (Fig. 5, Pl. XIX). In certain cases they may form zones of colour that are even more prominent than the boundaries of the rings which they simulate. The wood of *Cupressus Goveniana* bleeds profusely in spots from the vertical section, probably indicating groups of resin-cells. When very numerous and closely superposed, these resin-cells may be mistaken for resin-canals, and in any case care must be taken when examining vertical sections of small area, as when rare the resin-cells may easily be overlooked.

Jeffrey (1917, p. 24) says that " there is in fact no good evidence that the parenchymatous elements of the wood occur anywhere in forms not characterized by the presence of annual rings." In the most familiar wood in which the boundaries of the successive layers of wood cannot be traced, the Greenheart (*Nectandra Rodiœi*), the parenchyma surrounding the vessels is visible to the naked eye (Fig. 3, Pl. XXVIII). Other woods in which the boundaries are extremely vague and which have abundant parenchyma are *Dysoxylon* (Fig. 3, Pl.XXVI) and *Stenocarpus salignus* (Fig. 6, Pl. XXI).

CHAPTER VIII

THE PITH

THE pith which occupies the centre of the woody ring of the seedling-tree and of the leaders and lateral shoots of succeeding years is one of the least important of the tissues. Except in herbaceous plants it is little more than a stop-gap, inasmuch as it soon dies and has no further influence upon the later life of the tree. In mature wood it occupies a very subordinate place, and I do not propose to do more than touch upon it in its relation to the identification of woods.

As we frequently find the pith in knots or in planks that happen to be cut from the centre of the log, we may avail ourselves of its presence. Size is of small value in this connection, as the pith tapers, as does the twig within which it is concealed, so that it is possible to find it quite large in one place and small in another. Duhamel says that the pith of the Elder (familiar to all as being one of the largest) diminishes as the tree ages; but those that I have seen have the pith of normal size, or, to be more correct, the channel where the pith was at one time, as it is generally empty. The pith of the branches of old trees is sometimes small.

Knots are common in the European Boxwood and rare in the so-called West Indian Box, so that the presence of knots apart from the pith may be a distinguishing character.

The most usual shape of the pith is round in transverse section; all others may be regarded as rare. The oval, which may be a modification only, is mentioned by Boulger (1892, p. 29) as being characteristic of the Lime-tree, Plane-tree, Holly, Ash and the Maples.

The shape of the pith and its influence on the contour of the rings have been dealt with (p. 17). It seems that this influence is confined to those which have five lobes or angles. To the cases enumerated may be added the False Acacia, but five-lobed piths, which do not affect the rings, are found in the Poplar, Beech, *Halesia tetraptera* and *Styrax officinale* (Noerdlinger's sections and his work, 1859, p. 519).

Other shapes are:—

Three sides or lobes.—Metrosideros corymbosa, the Orange and Lemon woods, Birch, Alder (*A. glutinosa* and *viridis*), the Hazel, and the New Zealand Cedar (*Libocedrus Bidwilli*).

Four sides or lobes.—Halleria lucida and *Vismea dealbata.*

Ditto, but two of the lobes longer than the others, forming a sort of " lozenge.' —The true Boxwoods (*Buxus*).

Six lobes.—The Kamassihout (*Gonioma kamassi*), *Avicennia tomentosa*, and Courbaril.

A curious shape, something like that of an attenuated dumb-bell, is seen in *Psidium pomiferum.*

According to Mathieu (1897, p. 672) the shape of the pith appears to follow the method of insertion of the leaves, and Beauvisage says that the pith changes its form at the insertion of every leaf. This will account for the contradictory reports upon the contour that we meet with in various authors. The true shape will only be seen at that point of the twig that is below the insertion of the last or lowest leaf, and the cut in a transverse section of a log may strike any point whatever in the leader which forms the centre ring, so that we must not place too much reliance on this character. Again, if the outcrop of the pith be exactly at the insertion of a leaf, the shape of the former may be altogether distorted.

In the Boxwoods the habit of the tree certainly seems to be significant: *Buxus sempervirens* has a bilateral habit, otherwise the sprays are flat, and the pith is winged, two of the lobes being much the longer, whereas *B. balearica* is of upright habit and the pith is sub-regularly four-lobed. Here, by the way, we have another distinction between the True and the False Boxwoods, for the West Indian wood has a round pith. Out of fourteen specimens that I saw at the École de Pharmacie at Lyons, twelve exhibited a pith. All were labelled "Buis," but one had a large, soft, round pith which declared it immediately to be Elder, and another a small, round, pith of some unknown wood: the rest had the characteristic "lozenge" of Buxus. In point of size the Elder leads with about ¾ inch diameter. The Sappan, *Cæsalpinia Sappan*, one of the Brazils (indeed, the species that went by that name before the country Brazil was discovered and named after it), comes next, and this serves to distinguish it from other Brazils which have very small piths. At the other end of the scale are the Larch and Juniper, in which, according to Noerdlinger (1859, p. 523), there is scarcely any pith. The pith in *Lophira alata* may run to as much as ½ inch in diameter.

The course of the pith is usually straight but in some species it is crooked, according to Thil, who figures it (1890, p. 60, *Quercus pedunculata*). I have never been fortunate enough to see this, but it occurs to me that this zigzag form is due to the continual destruction of the leader by the gall-insects that produce the Oak "Apples," thus forcing the next lowest shoot to become leader. Thil attributes the loss of the leader to frosts, others to lack of nourishment. Noerdlinger says that the tortuous course of the pith is the rule in the Elm, the Nettle-tree (*Celtis*), in *Robinia tortuosa* and others.

The structure of the pith in a vertical direction is very uniformly cellular except in the Walnuts and their allies, not including *Carya*. These have a remarkable chambered pith consisting of numerous transverse, horny diaphragms, a feature which renders identification easy. It also occurs in Paulownia (Braid, *verb. com.*) and in Magnolia, Liriodendron, Nyssa, Asimina and Anona (*Record*, 1919, p. 8). Jaccard (p. 69) gives instances of sclerenchymatous, chambered piths in herbaceous plants, and Mathieu cites it in *Laurus*. Solereder says (1885, p. 30) that the pith is not septate in *Carya*, and that it is not sclerotic in *Juglans*. They are, however, hard and horny, as any one may see on cutting a twig of a Walnut-tree. Pterocarya has a soft and septate pith.

The colour of the pith may occasionally be utilized in the diagnosis of species.

The presence of vascular bundles may also be of service. In *Piper aduncum* they are arranged in two concentric circles. The Blue Gum, which has a star-shaped pith, shows a row of very large vessels on the outer edge.

The pith does not die in every case. It may remain active in part. Boulger (1902, p. 31) says that in the Elm the inner portion of the pith loses its protoplasm, whilst the outer becomes thick-walled and retains its cell-contents. Readers who are interested in the histology of the pith should consult Jaccard and Gris.

PART III

The Mechanical Properties of Wood—Weight—Hardness—Resistance to Strain—Acoustic Properties—Absorption and Shrinkage—Seasoning.

CHAPTER IX

THE MECHANICAL PROPERTIES OF WOOD

THE specific gravity or density of woody substance was found by Rumford to be from 1·460 to 1·532 (that of water being unity). Other observers, notably Hofmeister, Sachs and R. Hartig, have repeated his experiments with slightly varying results, which do not go much beyond Rumford's. Hartig (1882, II, p. 14) found the true density of resinous Pine to be 1·52 and (1901, p. 32) the wall-substance of the heartwood of Oak as high as 1·62.

Wood, however, consists of other substances than cellulose or even than ligno-cellulose, and the specific gravity of either is of theoretical interest only; from our point of view, it is of much greater importance to know that wood is made up of tissues which contain much air, and the weight per cubic foot or per cubic metre depends upon the amount of air entangled amongst the tissues (the very small differences in the true specific gravity excepted). All woods sink when "water-logged," the expression meaning that the air has been driven out of the cavities directly accessible to the water, and dissolved from those that are closed. A shaving taken from the transverse section of the *lightest* wood will sink in water immediately because the pores being opened by the cut, the air is readily displaced. The term "specific gravity" as applied to wood in the literature of the subject is utterly unscientific and should be given up. The word "density" may pass in the popular sense, but it has much the same fault. The only way to express *the fact* is by the use of such terms as "weight per cubic foot or per cubic metre." The density or specific gravity of a body shows the relation of its weight to that of a corresponding bulk of water, and to understand this we must first find how much water weighs. Kemp's *Engineer's Year Book* (1902, p. 383) gives 62·348 lb., but on p. 384 (Table) we find 62 lb., rain-water being the same. I assume that potable water weighs very nearly 62½ lb. at ordinary temperatures on account of the small quantities of lime and other mineral substances always present, so that we cannot go far wrong in reckoning 1,000 ounces to the cubic foot of water. If not exact enough to satisfy physicists, it is sufficiently accurate for the lignologist, as we shall see. Moreover, this round number represents the "specific gravity" when three places are pointed off. We can easily convert the "sp. gr." frequently cited in books upon the subject into lbs. per cubic foot by treating them as whole numbers and dividing by 16. If a piece of wood be accurately weighed and its "specific gravity" taken, and then the wood be divided into two or more equal pieces and these again weighed and the "specific gravities" of all taken separately, they will all furnish different results. No two parts of a tree will give the same specific gravity, whether the wood be taken from the inside, outside, top or butt. No two trees of the same species will yield the same figures except by accident, indeed, were any one compelled to find two pieces of wood of the same weight per cubic foot, he would have no easy task. Hence the compilation of tables giving single numbers pretending to be the specific gravity of a species is a kind of pseudo-science which does no credit to the authors guilty of it. It generally proves that they have copied from others without a thought of trying for themselves, for a single experiment, showing, as it must inevitably do, a difference from the figures copied, should have raised a doubt and enforced enquiry. Many others, more correctly, quote maxima and minima, but such figures do not convey much useful knowledge, for extreme cases amongst woods are usually "freaks," and, further, great inequality in the maxima and minima generally indicates not that the wood in question is particularly variable, but that it is a favourite species amongst investigators and has been worked more completely than others. A small inequality which, on the contrary, implies a species rarely dealt with, gives the impression that such a wood fluctuates in weight within narrow limits only. Averages, indulged in by another class of author, are the most misleading of all, as the reader believes that they indicate a medium quality, whereas it is only the result of trials upon a series of odd specimens collected at haphazard. These averages may be the mean of 30 lb. and 50 lb. per cubic foot, or 39 lb. and 41 lb. I confess that I myself have been often in default in quoting single numbers, when I have had but one specimen to test, and in other cases I quote maximum and minimum figures collected from all sources which though interesting to the lignologist, as showing the range of a species, are not really of any use. What we need to know is the range of weight per cubic foot of good, ordinary, merchantable wood, leaving all freaks aside. Then the user would know that above or below these figures the wood is more or less undesirable. The weight of the very best quality should be stated in addition, as the quality of the wood may not increase or decrease in the same proportion upwards and downwards. Furniture-woods that owe their value to depth of colour are generally of better quality in the heavier grades until there comes a point where extra weight and hardness are undesirable on account of brittleness and the difficulty of working. Oak augments in strength with the increase in weight, but the wood may, in extreme cases, be too ponderous for construction and will certainly be lacking in elasticity. Below the "best-quality-line" any decrease in weight will indicate a falling off in all desirable features, and below a certain weight, any further diminution will indicate unsoundness.

The amount of water still remaining in the wood naturally affects the weight, and it is usual to make tests in the "air-dry" condition, this expression meaning that the wood has ceased to lose moisture indoors at ordinary temperatures. This vitiates all comparisons between woods weighed in England and in Canada or Australia, where the dryness of the air is greater. Such tests, to be accurate, should be accompanied by the simultaneous readings of the barometer and wet- and dry-bulb thermometers if one wishes to pile up absurdities. It is the fashion now-a-days to dry the wood until it has lost its hygroscopic moisture and to wait till it has re-absorbed a definite percentage from the air. This point is more or less fixed for the same species, but for comparisons between species it is useless, as it is only a few which will content themselves with the amount of moisture prescribed, the rest persisting in imbibing more, which they will do with astonishing rapidity. Exner truly says (1903, p. 119) that the specific gravity found by experiment is good only for the test-piece itself, and then only for the moment of weighing.

Experiments cannot be too carefully carried out, but figures which lead one to conclude that they are of general application should not be used in connection with wood. "While striving to cleave the pin, we sometimes miss the butt," hence I contend that weights of wood should not be given nearer than to a quarter of a pound per cubic foot and the odd quarter would not be missed.

The kiln-drying of specimens was adopted by Prof. S. P. Sharples, who calculated the specific gravity of the American woods for Prof. Sargent. He dried the blocks at 100° Centigrade until they ceased to lose weight, and did not consider it necessary to wait until they came back to the air-dry condition. His figures cannot therefore be compared with those of other observers who have used the air-dry method. Hough and others have repeated his figures, to the great confusion of all who are not aware of this unusual method, and it is much more serious when it is employed in transverse breaking tests where the factor of moisture is all important.

By Buffon's law the density of wood increases in the tree from without inwards and from above downwards. His experiments were performed almost exclusively upon the Oak, and for that species may hold good in part. Mathieu (1897, p. 551) says that Oak, having an average width of annual ring of 1·360 mm. worked out at sp. gr. 0·647, but another having an average width of 4·736 mm. gave sp. gr. 0·906. As rings of these various widths may often be found in any part of the same tree, it will be seen that the position of the test piece in relation to the trunk is not the only condition.

R. Hartig (1901, p. 29) says that portions of the same Spruce-tree may vary as much as between 0·33 and 0·709.

Climate may greatly influence the weight of the wood of the same species. Sargent (*Silva*, p. 251) says "the wood of the form of *Quercus rubra* peculiar to W. Texas is nearly 39 per cent. heavier than the average of all the specimens of the typical species grown in the northern States, but in *Fraxinus viridis*, *Celtis* and *Platanus* the order is reversed." It is a popular error to assume that tropical woods are heavier than those grown in temperate climates. Many tropical woods are far lighter than anything with which we are familiar, but it so happens that none of the European species attain any great density. Boulger (1918, p. 35) goes so far as to say that "none of the native woods of temperate latitudes are, when dry, as heavy as water." Boxwood however frequently works out at 1·152, to say nothing of the Pomegranate, which is one of the heaviest of all woods (1·350), and Mathieu (1897, pp. 657–9) is able to give a table enumerating no less than eleven European trees which yield wood that will sink in water.

Locality affects the weight even when in the same climate. The Scots Fir shows a range of from 19¾ lb. to 52½ lb. per cubic foot (0·316 to 0·832) for the whole of Europe. Between less distant localities such as the Isère and Hagenau in France, it may differ as much as from 0·405 and 0·799.

P. Barlow (1867, p. 6) gives a table of weights per cubic foot of various woods from both top and butt. Most of his species are difficult to recognize, but in any case, all the Conifers and the common European woods work out much the heavier in the butt. On the other hand, most of the exotic woods were heavier in the top.

The sap-wood is always lighter than the heart-wood of the same tree. and the greater the contrast in colour between the two, the greater the difference. Beech, in which the sap-wood gradually merges into the wood of the centre (by some called ripe-wood and by others heart-wood), is apparently an exception, for, according to R. Hartig (1882, II, p. 53), the sap-wood is the heavier by 1·6 per cent. He ascribes this difference to the greater quantity of the starch in the sap-wood.

When cut up wood has the property of absorbing mineral substances, which may enormously increase its weight. Trees growing near the Geysers of the Yellowstone Park become silicified so that fragments of them have the appearance of agate, the structure being beautifully retained. The wood of *Cunninghamia sinensis*, so highly prized by the Chinese for coffins, is obtained from buried trunks that have become so hard as to resemble stone. Pit-props which have lain long buried by roof-falls will sink in water. An instance of a pillar made of the wood of the Pyengadu (*Xylia dolabriformis*), mentioned by H. W. Blake (*ex* Laslett, 1894, p. 203), which returned a bullet fired from a rifle from a distance of twenty yards, belongs, I fancy, to this category, because, of the five specimens, one being Laslett's own, from different localities, which are in the collection of the School of Forestry, Cambridge, none show any such hardness or weight as this narrative implies. The fact that the pillar in question stood in a lake seems to point to induration by mineral matters contained in the water. Examples of hard and soft woods will be found under the heading of "Hardness," that quality being more or less inseparable from the one at present under discussion.

The calculation of the weight or so-called "specific gravity" of woods has been practised more than any other on account of the ease of the operation. Two methods may be employed, the wet and the dry. The wet method is that of ascertaining the weight of water displaced by the wood. Simple immersion of small pieces leads to great errors and the phial method is out of the question, not only because small pieces give no idea of the general weight of the wood of the same species, or of the tree from which it was cut, or even of the piece that lay next to it, but wood is so bibulous and the surface of a small piece so great in proportion to its mass, that the water taken up in the course of a few seconds is quite enough to vitiate the results. Bubbles will adhere to the wood also and buoy it up. Various expedients have been devised to obviate these difficulties, such as varnishing the wood, or by using mercury, etc., instead of water. If a varnish be used it must be of the same specific gravity as water and the amount applied must be measured, as some woods will absorb as much as three coats of varnish without showing any result. This will displace much air. The same objection applies to the use of paraffin used hot. Hartig's "Xylometer" is otherwise good. It consists of a vessel in which the test-piece is to be plunged, the former having a small graduated tube in which the water ascends by displacement fitted outside to the bottom of the vessel and by which the quantity can be read off. This instrument is not incapable of improvement, because the test pieces are too small and the time taken by the water to rise in the graduated tube is too long, albeit it be only a few seconds.

I use a large tank which is divided by a partition that rises to within 2½ inches of the top only, and forms a sort of weir. One of the compartments of the tank is filled with water until it overflows into the other, from which the overflow is drawn off by an outlet that is afterwards closed. The test-piece, previously weighed, is plunged into the water and displaces a quantity equal to its bulk. As the water can flow over the weir along the whole length, the displacement is instantaneous and the wood has no chance of absorbing more than an infinitesimal amount. The overflow water is then run into a measure graduated in cubic centimetres and the cubic contents of the test-piece read off. As this is equal to so many grammes, the weight of the wood per cubic metre is obtained by a simple proportion. (Weight of wood before testing divided by volume in cubic centimetres = density.)

By the dry way the test-piece is measured to find the cubic contents, but when blocks must be trimmed by hand, this method is not to be recommended, as it involves a great expenditure of time. It is not so easy as it sounds to get a block true, more especially as many of the hard, cross-grained, exotic woods rip out and leave hollows, and as fast as one hole is planed out another appears. The wet method obviates all these troubles and the most irregularly-shaped block may be used; if there be any cracks the water enters them and the true volume is obtained without trouble.

Hardness

Hardness is an ambiguous term which admits of no scientific limitation in its application to wood. It implies a resistance to penetration, to shock, and to wear, which may be manifested in many ways by the difficulty experienced in the use of tools, etc. Our impressions gained when employing the saw, chisel, plane, drill, hammer or nails are all different. The various machines used in testing steel, etc., such as the falling ball, conical point or hemisphere, record the resistance to impact or to penetration, neither of which covers the term "hardness"; then the wear of wheels or the hoofs of horses on wood pavement, of wooden cogs, of spokes against their sockets, of the soles of plane-stocks against the planks worked by the carpenter and the usage of flooring, have all some feature differing from the rest and yet the resistance of all is included under the same expression of hardness.

If the statement of Emma Olt, that the cellulose of all kinds of wood is equally hard, be true, we might consider the words density and hardness synonymous, but wood, as already said, is by no means entirely composed of cellulose; on the contrary, the cellulose may not amount to one-half of the bulk in the heavier woods. Then, the various substances which make up the tissues and the tissues themselves are distributed in so many ways in different species and in such varying proportions in the same piece of wood that, did we know the densities and hardness of each component, we should not be advanced a step.

Buffon propounded the law that the hardness and the density vary together, and Dumonteil in 1823 wrote "that without stating as a principle that the hardness is proportional to the weight, yet we may say that the one is the natural consequence of the other."

Were woods uniform in structure, this law might be accepted and our lack of means for estimating the hardness would be very conveniently supplied by the use of the balance and the "weight-hardness" could be expressed by one figure. For practical purposes I think that this method is near enough, and perfect accuracy being unattainable, as no two pieces of wood will give the same results, I think that the expression "weight-hardness" may be used with advantage within the limits of certain classes. These classes differ considerably from each other and the figures valid for one will not be good for others with different structure (otherwise of different distribution of the tissues) or various degrees of induration of the wood by accessory deposits of gum, resin, silica, lime and the like.

The influence of resin is important, as within the limits of the same species of Pine (*P. sylvestris*, for example), we may have great extremes of hardness which are independent of the structure and of the amount of woody substance present, hence it is not possible to place such a highly-resinous Pine in any precise category.

The process of "tapping" or "gemmage" of the Maritime Pine for resin, drains the upper portion of the tree, but has the curious result of causing a greater accumulation in the butt, making a difference in the dry-weight of the wood of 150 kilos. per 1,000 in favour of the latter. Although this tapped wood is rejected for pit-props and telegraph-posts on account of its supposed want of elasticity, it is better for paving-blocks, presenting special qualities of wear and durability. It has practically displaced all other woods for paving in Paris, the only precaution needed being that no "bois blanc" of the tops shall be employed, a condition somewhat difficult to fulfil, because it does not pay the producer to sell one without the other (Petsch, 1896, p. 78).

Woods containing much carbonate or phosphate of lime are rare, the quantity of these substances is generally so small that the hardness of the wood as a whole is little affected by them, but they ruin the edges of tools that are employed in working them. Silica, although to be found in the ash of most if not of all woods, is of little importance, and it is only in isolated cases where it is found in quantity, as in the Guaiacum (Lignum-vitæ). Gums are often abundant, and whether soft or brittle, do not add to the hardness of the wood, though by occupying cavities otherwise filled with air, they may materially increase the density. All these cases are exceptional and cannot be reduced to rule.

The following is a suggestion for a rough classification of woods according to their structure. The weights per cub. ft. are approximate and are given merely as a guide.

Class A. *Woods of approximately uniform structure.* Examples: Ebony, average weight per cubic foot, 72 lb.; Greenheart, 66 lb.; Box-wood, Olive-wood, 63 lb.; Lance-wood, 57 lb.; Plum, Blackthorn, Mahogany, 50 lb.; Elder, 49 lb.; Apple, 45 lb.; Maple, 44 lb.; Mountain Ash, American Birch, 42 lb.; European Birch, 40 lb.; Sycamore, 39 lb.; Satin Walnut, American Black Walnut, White Poplar, 36 lb.; Alder, 34 lb.; Canary Whitewood, 32 lb.; Lime, 31 lb.; Willow, Black Poplar, 28 lb.; Horse Chestnut, Pencil Cedar, 27 lb.

Class B. *Woods having concentric zones of unequal hardness due to three different causes:—*

(*a*) The presence of denser and laxer zones of woody-fibres (sometimes complicated by secretions of gum or resin): Yew-tree, 48 lb.; Pitch Pine, 40 lb.; Larch, Red Pine, 35 lb.; Silver Fir, 32 lb.; Spruce, 28 lb.; Sequoia, 26 lb.; American White Pine, 25 lb.

(*b*) The presence of a broad zone of open pores in the Spring wood: Hickory, 50 lb.; Ash, 48 lb.; Elm, 43 lb.; Chestnut, 39½ lb.

(*c*) The presence of a broad zone of soft tissue (parenchyma), a rare case, as in Sophora, Ficus, Eugenia and some tropical Leguminous woods.

Class C. *Woods having lines of unequal hardness in a radial direction, due to the presence of broad rays:* Holm or Evergreen Oak, 64 lb.; Hornbeam, 50 lb.; Beech, 48 lb.; Hazel, 40 lb.; Plane-tree, 36 lb.

Class D. *Woods having lines of unequal hardness in both concentric and radial directions due to the presence of pore-rings* (as in Class B*b*), *plus broad rays* (as in Class C): Oaks of numerous species (say 44 lb. average), and some few exotic woods, more especially of the Proteaceæ.

Woods of absolutely uniform structure, if it were possible to find such, would, as already said, vary together in hardness and weight. As uniformity is not conceivable in organic nature, we must content ourselves with compromise, and inasmuch as we have nothing but our senses to guide us in our estimate of the hardness of wood, we cannot afford to be too meticulous. Let us take blocks of wood showing equal amounts of the tangential and radial surfaces and another from the same tree with the same area of the transverse section (we cannot get all three of the same size from the same block). Let the surfaces be planed, first trying the transverse, because all the various layers are exposed in their true proportion, then the radial, where the various zones are also presented to the plane in true proportion, but the rays, being islands of tissue and not layers or sheaths, will crop out on the surface here and there and offer a spasmodic resistance, and lastly, the tangential section, which will show loops and lines of hard and soft wood, alternating with each other, and of which different amounts will appear at each stroke of the plane. In one direction the tool will get under the thin ends of the loops of hard wood, which then rip out, and it will be found necessary to turn the wood round to make a smooth cut. The transverse section will plane much more easily when the rings run as much as possible parallel with the flat of the board than when they pass across it. For rough tests, which may be memorized though not recorded, I recommend planing the radial section of all woods which have a very slight silver-grain (Class B), and the tangential for those which have large rays (Class C), especially when the rays are hard.

From our experience in planing these we shall learn that quite a number of different results may be obtained from the same piece of wood, and although the act of planing may not be accepted as a scientific means of testing the hardness, yet it is a very good illustration of the difficulty, nay, the impossibility of estimating exactly the hardness of woods. All the instruments which have been devised and which have met with success in their application to steel, etc., are quite useless for the testing of wood, because no two cubic inches of wood are alike, and such machines will give three or more different results for the same piece, according to the section upon which they are employed.

The hardness of the wood from the same tree may vary greatly, not only in respect to the relative amount of Spring and Summer wood, but from the change which takes place in some species where a heart-wood is formed. This change is profound and affects all those qualities for which wood is esteemed. It may occur abruptly, as in the Oak or the Acacia, when a ring on the inner side of the sap-wood passes over into heart-wood during the course of a season, or it may be gradual, when no exact line of demarcation between sap- and heart-wood is discernible, as in the Beech. But there is more than this, for years and years afterwards the heart-wood continues to ripen as it were, and to become harder, stronger, heavier, deeper in colour and more durable, so that here, again, we have a marked variation of all these qualities within a few inches of each other.

The cellulose can offer but a part of the resistance which appeals to us as hardness, because in the harder wood the amount of added matter (lignin, etc.) greatly increases, and in those woods where the cellulose predominates, the cellular structure is lax and the tissues are obviously soft. The lignin is much more probably the factor which makes for hardness, which may vary with the quantity of lignin accumulated on the walls of the cells or in their cavities, plus any induration that the lignin itself may undergo. I use the word " induration " as a stop-gap, as we know so little about the change which takes place during the ripening of the heart-wood. Examples of extreme induration are the Ebonies, the Ironwoods and, above all, the fibres of some Palms which, according to Col. G. A. Lloyd (*ex* Holzapfel, p. 98), are used in the Isthmus of Darien for nails for joinery work.

Spruce-trees, subjected to a constant strain, develop harder wood on the underside of the branches or on the leeward side of the trunk. For this reason Gayer (1903, p. 42) says that the East side of a tree is called the " hard side." This is no doubt true as regards trees grown in situations exposed to prevailing West winds, but on mountain sides, with a northerly aspect, the hard wood would be produced on the South side. Opinions differ much on this point evidently for the same reason, each person speaking from his local experience. Noerdlinger (1859, p. 54) says that the wood-cutters of Bopser, near Stuttgart, maintain that the wood from the " Summer " (South) side of large trees is noticeably more difficult to split than that on the " Winter " side. On the other hand, Chevandier found the difference so small that he considered it useless to continue his investigations in that direction.

The height of the part of the stem from which the sample is taken affects the hardness. Birch is harder at the butt than at the top, and indeed so much so that I have noticed the difference when ripping Birch with the circular saw. In this case it may, however, be due to certain changes which may hardly be normal and which are discussed elsewhere. The tops are easily riven, while the butts will often break rather than split.

The rapidity of the growth may greatly affect the hardness, and trees generally show rings which indicate fat and lean years or series of such, because the amount of light enjoyed by a tree, if in a forest, is dependent upon the growth of its neighbours. In Coniferous woods which are not heavily charged with resin, fast growth may be said to indicate softness of wood, because in this class of tree a good year tends to produce a much larger proportion of lax Spring wood than of hard Summer wood. In bad years little Summer wood may be produced, it is true, but the Summer zone suffers to a less extent, so that the narrow ring has more dense tissue, and a series of twenty-six annual rings, totalling all together but an inch in width, has twenty-six narrow but hard zones, whilst a single ring, an inch wide, has but one (though it be rather wider than any one of the first series). There are specimens of the Sitka Spruce in the collection of the School of Forestry at Cambridge corresponding to this wide variation in growth. Again, the coarse wood of Common Spruce or White Deal, and the wood from the same species used for the bellies of violins, where narrow-ringed wood is essential, are familiar examples.

Amongst the broad-leaved trees we find two classes, in one of which the Spring zone is lax, because a coarse ring or sheath of pores (vessels) is developed at that time. These vessels may diminish abruptly in size immediately outside the pore-ring, leaving the space to be occupied for the most part by the harder woody-fibres, or the pores may become gradually smaller as they approach the Summer boundary and the transition from soft to hard zones is gentle. The second class is composed of woods of very uniform structure, such as the Sycamore and the Beech, where the whole of the ring is of approximately the same density, the pores showing but little diminution in size. In the first category good years imply much solid Summer wood, and fast growth is an indication of good quality and greater density. In the second, a bad year may result in the production of a narrow ring, but as all rings are much of the same quality, the density is little affected.

Woods may vary in their hardness when grown in different climates. The Blue Gum and other Eucalypts and the Australian Blackwood (*Acacia melanoxylon*), when raised in their natural habitat in Australia, produce very hard wood indeed. When these same species are grown in Algeria, the South of Europe and at the Cape, they produce soft wood of inferior quality. According to De Noter, the Blue Gum planted in Algeria will attain as much as 30 cm. in diameter in five years (approximately 2½ inches per annum), but the timber is of very poor quality.

The influence upon the hardness exercised by the rays is of little importance, inasmuch as very few woods show any marked difference in this respect. If the transverse section of a piece of Beech be scraped with a knife, the greater resistance of the rays can be felt.

Some woods appear to become harder with time after they have been put into use. This must be due either to the unknown process of induration, implying an increase of density due to some change in the substance of the wood, or to a post-mortem formation of heart-substance. The latter raises a difficulty, as such formation could only be at the expense of other materials existing in the wood as it can no longer draw supplies from without as could the living tree.

It is generally supposed that wood grown at great altitudes is denser than that raised on the plain. From the examination of a large number of specimens in the possession of Prof. Henri Jumelle at Marseilles, I found that the densest specimen of Beech was from an altitude of 180 metres only. Of the Alder, one from 1,500 metres was in no way different from English-grown wood, whereas others from both above and below this height (1,200 and 1,700 metres) were abnormally dense and heavy. In the Spruce, height may be a consideration (the wood for violins being reported to come from considerable altitudes), but in all cases soil and aspect are probably the chief factors.

A few examples of the softer and harder woods may be of interest. The softest of all is the so-called " pith," of which helmets are made in India. This is a true wood, as may be proved by examination of the transverse section, where the real pith or the channel which it occupied will be seen in the centre. The Balsa wood of Porto Rico, according to Cook and Collinson (p. 204), has a density of 0·120, cork having one of 0·240. The Ivaniva of Madagascar (*Smithia chamæchrista*) has a density of 0·21. The lightest wood that can be employed in construction appears to be the Giant Cactus (*Cereus giganteus*), density 0·3188, said by Sargent (*Silva*, V, p. 54) to be used for rafters of adobe houses and even for bows.

In point of great hardness, the Lignum-vitæ (*Guaiacum officinale*) leads with a density of 1·39 (Wiesner, p. 481); the Cocus wood of commerce (reputed to be *Brya Ebenus*) comes closely after with 1·35. In the working of the two woods, however, the difference in hardness is markedly in favour of the former, the Cocus being not so flinty. Black Ironwood (*Condalia ferrea*) is recorded by Sharples (*ex* Hough, 1893, I, p. 22) as reaching 1·302. *Eucalyptus microthecs* is said to be very hard.

Until we come to some decision as to what we mean by the term " hardness," tests cannot be of any great service, but there is no reason why we should not continue researches upon some of the definite qualities which help to make up our sense of hardness, such as penetrability, resilience, elasticity, resistance to wear and to impact. Tests made with a point or wedge, dropped from a given height, will give different readings on every section of the wood and upon every variation of or transition between them. On a wooden sphere one should obtain a different result from every point of the surface. As wood in a commercial form is only occasionally true to any one section, and as " bastard-cuts " outweigh all others by a very large proportion, tests made upon the principal sections can be only of theoretical value. Secondly, the result will depend largely upon the angle of the wedge or point used If this be wide, then the resilience of the wood will be more active than its resistance to penetration ; if it be narrow, the tendency to split the wood will bring its fissibility into play. Thirdly, a few touches of a whetstone may cause even a wide-angled wedge to become a cutting instrument. As regards slender points, it is only necessary to think of the different resistance to the penetration of nails displayed by woods of apparently similar hardness to show how futile such experiments are. An attempt to drive a nail into the broad resinous zones of some Pines will generally result in the nail finding its way into the soft wood of the Spring zones, alternating with them. If tried upon pieces of considerable area, tests for ascertaining the amount of resilience may be useful, as in practice the shocks are rarely received upon points so small as to fall within the limits of the width of a Spring or Autumn zone of wood. In this, as in every other test, the results will vary according to the section. The Shortt Sclerometer used upon steel is too small, because it gives different readings for every point of the wood tested. With soft woods every blow of the little drop-hammer will compress the wood slightly, so that the preliminary blows relied upon to gauge the height of the rebound will not be steady. The personal equation of the observer is much too variable for such minute readings. A falling ball rebounding from an inclined surface against a self-recording scale (the wooden block being shifted between each shot) will give an average figure of the resilience, zone by zone, but as another piece of the same wood will give quite other figures, I doubt the value of experiments in this direction also. This idea, adapted from the practice of sorting the hard from the soft balls used for cycle-bearings, has the advantage of being self-recording and not dependent upon the quickness of the eye of the observer, as in the Sclerometer. The recording scale is made by laying a strip of graduated paper over another of carbon paper, both being placed upon a metal shield bent into a parabolic curve and set at a given distance from the point of impact of the ball upon the wood. At each shot the ball makes a black spot on the underside of the graduated paper. The parabolic form of the register is necessary, because the trajectory of the ball sinks very rapidly, and, indeed, with very soft spongy woods, the ball hardly rebounds at all.

The conical point, cube, or hemisphere, used by Noerdlinger, Hugueny, Jancke and others, covers too many zones of varying hardness to give a true average, and in some woods the bottom of the depression made will rise immediately after the blow, making the measurement of the depth uncertain, while in others, where the depression remains permanent, some of the fibres are probably ruptured. Noerdlinger (1859, p. 342) himself says that this test is useless, inasmuch as it is well known that letters in deep relief, produced by striking the cross-section of wood, may be planed off level, but if the wood be moistened, the letters again appear. I may add that this applies to the plank-face also.

If the tests be made by the ordinary methods used in crushing experiments, the load being eased from time to time to ascertain whether the wood regains its original form to find the limit of elasticity in a vertical direction, their bearing upon transverse strain may prove useful theoretically. I believe that the limit of elasticity under a crushing stress corresponds with the limit of elasticity under transverse loads, and that the refusal in the latter case of the wood to resume its original form is the commencement of the crushing of the upper layers of the test piece. The weight may still be borne and even augmented, but it is then taken chiefly by the extension layer. In short, the wood becomes progressively tired (*see* p. 117).

Resistance to Shock

This depends either upon the resilience of the wood or upon its fissibility, as in the case of the Willow on the one hand (hence its use for cricket-bats), or in that of the Boxwood, which is one of the best woods for the handles of tools destined to be struck with the mallet, on the other. In the first case the virtue of the wood depends upon the resilience of its radial section, in the other upon the resistance to fissibility in a longitudinal direction, the blow tending either to separate the fibres at their severed ends and causing them to "brush-over" or to split the whole lengthwise. Tests made by means of a weight dropped from a given height will be disturbed by the disposition of the annual rings, as in all other cases.

Resistance to Wear

Various experiments have been made with the view to predict the probable life of paving-blocks, by means of a grinding machine which was supposed to reproduce the effect of traffic, something similar to the machine employed for testing the wear of blue-bricks. I think that the wear of traffic is too complicated a matter to be reproduced in a machine. I once tried to imitate the shock of the hoofs of horses on the pavement by placing the blocks in a shake-barrel with blocks of iron. The wooden blocks were worn as expected, but the noise was considerable, and the machine was destroyed by a distracted neighbour, who availed himself of a dark night for the purpose. The test-blocks were threaded upon a bar, to protect two of their sides. The end blocks of each series were nearly worn away in the course of two days, but what was most surprising was the fact that the hole in which the bar fitted was worn to double its original size by the friction against the iron.

Thil recommends a machine of the nature of a grindstone, sprinkled with No. 3 emery-powder, the wooden block being held against it by a weight of 250 kilos., the number of revolutions and the amount o wear being noted. I think that a wood like the Poplar, which is used by glass-grinders for their wheels, because it has the property of retaining the emery or sand, would pick up the grinding material so well tha it would probably grind the mill. In any case, hard woods would b ground away faster than soft woods.

CHAPTER X

RESISTANCE TO STRAIN

THE resistance of wood to external forces may be considered from several points of view, such as resistance to compression, penetration, bending, tension, torsion, fission, shearing, impact and wear. These terms may be translated into words implying qualities of strength, hardness, toughness, rigidity, flexibility, elasticity, penetrability, etc., though these somewhat overlap; strength may cover resistance to compression (vertical strain) and bending (transverse strain), while toughness may include resistance to shock, fission, penetration and torsion. Then, on the other hand, resistance to compression takes a great part in resistance to penetration, bending, torsion, fission and wear.

Except in some cases of rupture by tension (where the fibres are actually torn asunder) and transverse shearing, all resistance to stress by wood must ultimately be referred to fission, for no failure can take place in wood without the separation of the fibres, hence fissibility should properly take the first place in our discussion. Wood differs from all other substances (except asbestos) in having a fibrous structure, and it is the only substance (except such as slate and talc) which is fissile. In exogenous wood the fibres are traversed by rays which convert the whole into a network, the meshes being represented by the ray-spaces and the knots by the points where the fibres meet above and below them. In other words, the continuity of the tissue is interrupted by the rays, which reduce the cohesion of the mass and thus provide lines of weakness or fission in a radial-vertical direction (*cf.* Fig. 1H. Pl. XXXVI and the tangential sections on Plates XXXII and XXXIII). Again, inasmuch as the adhesion of the annual rings or sheaths to each other is less than the cohesion of the parts of the sheaths, other lines of weakness or fission occur in a concentric direction.

Theoretically, the failure of wood under stress (except by tension and transverse shearing) is only possible when the fibres are bent, and this can occur only when they are separated, that is to say, by fission.

If lines of low resistance to fission exist in wood, it is at these points that the fibres will separate before they bend, but, as a matter of fact, the walls of the fibres are curved and the fibres themselves are also curved where they run round the ray-spaces, and there are cavities into which they may bend, viz., their own cell-cavities (and in the broad-leaved trees) the cavities of the vessels. This affords a freedom of movement which manifests itself as elasticity, and it is when this movement has reached its limit that crushing commences, and the fibres separate and collapse.

So long as they cohere, the wood can be compressed, not crushed, and if the pressure be relieved, the wood will resume its original form.

Fissibility may be advantageous to the user of wood in facilitating cleavage, as, for instance, in the making of barrel-staves, baskets and split-ware; or a defect, when wood splits under the tool or in the finished article when in use. I deal elsewhere with the splitting during drying and in the tree before felling. The favourable action of fissibility may be due to lack of cohesion in two directions, radial and concentric or tangential, as it is often wrongly termed.

If radial it follows, as the term implies, the plane of the rays. In this direction the axe meets but with little resistance. Still, it must be pointed out that a wood commonly used for cleaving may not be so much a fissile wood as one which splits with a smooth surface. The Common Oak, a stave-wood *par excellence*, is not really very fissile in a radial direction, the riving of staves being a reasonably heavy job. Further, the Common Oak is more fissible in a *concentric* direction than in the radial, because of the weakness of the large vessels of the pore-ring. Chestnut and Mulberry are riven in the direction of the pore-rings, not because they are less fissile in a radial direction (on account of their very minute rays), but because these do not afford a smooth cleavage surface. There are other Oaks, such as the Turkey Oak, which are in truth very fissile and according to Mayer, the blocks for splitting, which are about one to two feet high, need but a single blow to completely separate a shingle from the entire length, and the workman has to encircle the log with an iron ring to keep the pieces from falling about. Most Coniferous woods are as easily split in the concentric as in the radial direction. In the case of the Oaks, the parenchyma or soft-tissue which accompanies the radial streams of pores in the Summer wood must contribute to the fissibility of these woods in a radial direction. Most woods are as easily split in the one direction as the other, as shown by Troup in connection with the woods of India. This is contrary to the general impression as regards the woods of the broad-leaved trees, but the fact is well recognized in connection with the Conifers, in which the cohesion both of the annual sheaths and the fibres is very low. For this reason Spruce is much employed in Germany for split-wares such as baskets, small boxes and toys. Great economy of material is secured by this method, as nothing is lost in sawdust, the pieces being split parallel by the "through and through" method.

Fissibility may be a disadvantage when wood tends to chip out during planing, as this makes the work of smoothing difficult, and the lack of adhesion between one layer and another which renders it necessary to reverse the piece and study "the way of the grain," is well known to the carpenter. This occurs chiefly in cross-grained woods. Sometimes, during the smoothing of quartered wood, the rays which adhere feebly to the fibres chip out in a similar manner. This is particularly troublesome in turning, as the rays are always exposed somewhere on the surface of the cylinder, and the defect is not seen until the turner has stopped his lathe.

There are three modifications of the fissibility in a concentric direction corresponding to the distribution of the tissues mentioned under the head of "Hardness" (p. 105, Class B), otherwise the occurrence of a change in the tissue at the ring-boundaries. When there is not much contrast at these points, the adhesion is high, but when the size and thickness of the cell-walls present great contrast, as in the Pines, it is low, as the lax tissue of the Spring wood is easily torn from the dense ring of hard Summer wood. The Giant Fir (*Thuya plicata*) is an extreme case where the mere bending of a stick will cause it to separate into as many laths as there are rings. Another form consists of a layer of a different kind of tissue (soft-tissue or parenchyma), as in the Willow, Mahogany, etc. In *Sophora* and *Ficus* these bands may be so broad as to occupy one-third of the transverse section. Although the parenchyma-cells are very delicate, we do not know of many instances where it is of serious disadvantage in commercial timbers. Lastly, there may be sheaths of pores (pore-rings), consisting of tubes running longitudinally and whose walls offer but little resistance to rupture, especially when, as in the cases of the Oak, Ash, Elm, the pores are densely crowded and in several rows. We have a parallel instance to that of the Giant Fir in the American Black Ash, which, according to Stevenson, may be split into laths by bending, the separation taking place along the pore-sheaths.

Fissibility varies with the amount of moisture in the wood, so the makers of split-ware rend their logs wet. The moisture augments tissue-tensions, as one would naturally conclude from the swelling of wood in water. Perhaps it would be more accurate to say that tissue-tensions are normal in saturated wood and that their direction becomes reversed, or at least much slackened, during drying. The woods mentioned by Dumonteil as bursting when sawn green do not, as far as I have been able to ascertain, do so when dry. The Carapa, a case in particular (*see* p. 123), is not a very fissile wood when dry. Troup however disputes the opinion expressed by Gayer that hard woods are more fissile when wet and soft woods when dry. Of sixteen woods that he tested, all but one split more easily when dry. In Troup's experiments a wedge was used, the resistance to splitting being gauged by the number of blows necessary to rend a block of given size. This is a good method except (as he points out) when the grain is "cross," in which case the fibres are cut rather than separated.

Certain woods, such as the Boxwood, offer remarkable resistance to splitting, and will break in the cleaving. The Olive-wood is another with a similar reputation. The sap-wood of the Lignum-vitæ is exceedingly tenacious, for which reason the makers of pulley-blocks and dead-eyes endeavour to leave a ring of sap-wood around the heart-wood, to prevent splitting. In this latter case there is a very evident justification for the employment of this wood for blocks, inasmuch as the fibres have a spiral course at a very pronounced angle, the spiral being reversed from point to point or from ring to ring. Spiral grain as an occasional phenomenon or "sport," in a normally straight-grained species, is well known to wood splitters.

Fissibility as a useful quality may be illustrated by the following examples. Oak, as already mentioned, serves for the making of cask-staves and also for plasterers' laths, but as regards the difference shown by various growths and species, authors are by no means in accord. Mathieu (1897, p. 357) says that as "bois de fente," *Quercus sessiliflora* comes first, whereas Tredgold (p. 54) says that it is difficult to split, but that *Q. pedunculata* makes good plasterers' laths. Noerdlinger (1859, pp. 257, 535–6) says the Oaks are generally accounted fissile, yet the Cork Oak, with its uncommonly strong silver-grain, is very difficult to split and the cleft continually runs out (*i.e.*, leaves the plane of the rays). We have already touched upon the other extreme exhibited by the Turkey Oak (*Q. cerris*). For pieces of large dimensions the Alerce of Chile (*Libocedrus tetragona*), the Giant tree of California and the Red Beech or Birch (*Fagus fusca*) of New Zealand seem to share the honours, as they can be separated in wide planks which look as clean as though prepared in the mill. The last-named is said to split perfectly truly in lengths of as much as seventy feet (Kirk, p. 51). For smaller work, in addition to the woods of the Conifers, we have good examples in the Whitebeam, that, according to Thil (1900, p. 44), is split into thin plates for the making of ladies' fans, and the Buckthorn (*Rhamnus frangula*) and the Common Sallow (*Salix Capræa*), which are shredded into thin strings to be utilized in the weaving of fine baskets (Mathieu, 1897, p. 73).

Fissibility is a disadvantage and its absence a virtue in woods needed for use in engraving (Boxwood) and carving (Lime, Maple, Horse Chestnut, Walnut, and woods of the Apple and Pear tribe). The Lime was much used by Grinling Gibbons for his carving, and Oak and Elm are seen in Church Architecture, but not for the finer work. Even Poplars are used for this purpose, according to Boulger (1902, p. 105). Maple has the reputation of never splitting.

Elm has been long noted for its resistance to splitting, and is the best wood for holding nails; it is therefore used for the ends of packing-cases and tin-plate boxes. Its relative, the Wych Elm, is, according to Stevenson, much more fissile and may be cleft with ease, and in consequence is employed neither for naves of wheels nor for pulley-blocks, as is the Common Elm.

The Hornbeam has the reputation of being both fissile and the contrary. Cleaving it resists strongly, but when planed or turned it tends to chip out. The reason is that the course of the annual layers is undulating, as may be seen on a cross-section. When planed or turned the annual layers must be severed, and the wood in the re-entrant curves being isolated, as it were, has a very slight hold, and in consequence flakes off easily.

We have seen in the case of the two Elms that the fissibility may to a certain extent be a guide to the identification of the woods, and so it is with the Boxwoods. The European Box may be distinguished from the Cape Box (*Buxus Macowani*) by the greater ease with which the latter is split. The fissile qualities of the so-called West Indian Box enable comb-makers to make economies with their wood, which is riven in wedge-shaped strips instead of being sawn.

In a report of the U.S. Forest Products Laboratory for 1916 we learn that 3,000 nail-pulling tests have been made upon various woods. The conclusion of the authors is that the holding power of wood has a definite relation to the density. While complimenting these gentlemen on their good work, I must say that their conclusion does not accord with our impressions, for, as already said, the Common Elm is our best nail-holding wood, but its density is not sensibly different from that of the Wych Elm, which is a fissile wood and by no means a good nail-holder. The property seems to be more nearly related to the elasticity and fissibility, as stated above. Their rule may, however, apply within a given species.

Tests made with a view to ascertain the fissibility of woods are of two kinds: by one method the wood is cleft with a wedge-shaped instrument, and by the other a piece cut in the form of a clothes-peg is torn asunder by a weight suspended to one of the legs, the other being fixed to a support. The first is objectionable, because not only does the sharpness of the wedge materially affect the issue, but the elasticity of the wood enters into play, for, as will be seen in splitting some woods, the rift will run far ahead of the wedge, whereas in others the wood will hug it, and there will be much friction between the instrument and the wood. In the second, originally used by Noerdlinger, we have a means which has been criticised by his countrymen, but against which I see little objection, providing all precautions are taken, as he did, that the orientation of the test-piece is correct and that experiments are performed in at least three directions, transverse, radial and tangential. I would add also a bastard-cut, as in practice bastard-cuts are met with more frequently than any of the others. At the apex of the wedge-shaped cut in the test-piece Noerdlinger bored a hole. If his object was to obtain an extended surface at the point of fission so that the weakest layer exposed should yield first, it was good. If, on the contrary, any particular zone is to be tested, this hole should be omitted and the point of the wedge-shaped opening should be carefully directed to that zone.

Compression and its Relation to Transverse Resistance

No law, as far as I am aware, has been formulated in respect to compression, nor does its importance appear to have attracted the attention it deserves. Perhaps investigators have been baffled by the contradictory results of experiment. Thil, who used pieces of the same wood but of different sectional areas, says that a block of Oak one centimetre square supported a proportional pressure three times as great as others thirty-six times that area, whereas Hadek and Janka (*ex* Exner, 1903, p. 167) say that the area does not affect the result. This, of course, applies to very short pieces, and as far as the practical application to wood for columns is concerned, such tests are of no value, because no post ever yields from crushing in the manner manifested in short pieces. From the examination of a number of test-blocks crushed under the superintendence of Thomas Laslett, some of which are still in the collection of the School of Forestry, Cambridge, one observes that they have given way in a definite manner, which recalls that shown by similar test-pieces of iron, that is to say, the lines formed by the layers where the fibres have been bent have the outline of two opposite wedges, widening outwards (*see* Fig. 11, Pl. XXXVI.), which indicate that the two wedge-shaped pieces have been pushed outwards. In those blocks in which the rays run more or less parallel with two of the sides of the upper (transverse) surface these lines are fairly well balanced and the wedges are approximately symmetrical, but in other blocks, where the rays are more oblique to that axis, the crushing-lines shift laterally and the wedges corresponding are of different sizes (Fig. 1J.). In the first case the block may be regarded as a more or less homogeneous substance, but in the latter the manner of crushing is evidently influenced by the structure. A third alternative, where the fibres cede together in one direction, producing a horizontal plane of crushing, may present itself, especially in woods which have minute rays, and, lastly, there are certain rare cases where the block failed suddenly and was crushed into powder (cited by Laslett, 1894, p. 275, for Greenheart and Sabicu).

The most frequent cases of failure in actual use of long pieces are in pit-props, which sooner or later give way under the enormous pressure of the subsiding rock. Pit-props may break either in the middle or may "brush-over" at the ends. In the first case they split, the separated parts bulging outwards and breaking transversely. In "brushing-over" the upper- and lowermost fibres, being severed and thus supported by their neighbours on the inner side only, separate from one another. In both cases failure is by fission. Tiemann says (1908, p. 551) that the elastic limit in beams corresponds very closely to the ultimate crushing strength of the material. Noerdlinger says that "every post that is seven to eight times as long as wide, bends before it is crushed, and it is the rule amongst carpenters that the length shall never exceed ten times the thickness." The height of a post or test-piece has enormous influence on the resistance to crushing. Even so small a difference as between 2·5 and 5 centimetres will give results which differ as much as 85 : 100 (Hadek and Janka), and Thil says that pieces of a length more than six times that of the side will show such reduction in strength as to make any rule impossible. As regards vertical stress, although laboratory tests on short pieces are of no practical value, yet theoretically they may be made to assume an important rôle in the elucidation of bending and transverse breaking tests.

If a square stick of wood laid upon two supports be broken by means of a weight suspended to its middle, it will sometimes show on the upper side a pair of wedge-shaped pieces like those already described as being present in Laslett's test-blocks. These wedges have been forced outwards and demonstrate the fact that the upper layer of the stick has been in compression and has ceded in the characteristic manner. It is, of course, well known that a bar of whatever material when bent must have zones of compression on the concave, and of extension on the convex side; between these lies a neutral zone, where both kinds of strain are equalized. This may be seen very graphically on tree-stumps which remain after the felling of the tree. The last portion breaks off when the trunk is severed sufficiently to permit the weight of the tree to cause it to fall, and the resulting fracture shows a zone where the fibres have been torn apart leaving long splinters, another on the opposite side where they have been crushed, and an intermediate zone where one passes over into the other.

Now the point that most physicists overlook is that in all woods in common use as building material the resistance of the fibres to extension is far greater (at least two and a half times) than that to compression, hence the variation in the strength of the wood depends almost entirely upon the resistance to compression of the upper side of the piece. Tension tests have afforded such high figures of the resistance of wood as to appear fantastic indeed. One observer compares the tensile strength of the fibres of the Silver Fir to that of mild steel. Schneider (1916, p. 25) says, " The tensile strength of . . . yellow pine is about 17,000 lb. per square inch, a little greater than that of cast iron and about one-fifth of that of a high grade of Bessemer steel; but steel weighs about twelve times as much as this wood, so that, weight for weight, yellow pine has more than twice the tensile strength of steel." I fancy that this author has shorn the steel of a digit, and has taken six figures for five; nevertheless, one needs only to think of the great strength of ropes, which, after all, are but vegetable fibres little different in structure and composition from those of wood, to be convinced that, were the wood-fibres laid as closely side by side as those of steel, they would make a brave show. In the rope we have an instance of a mass which has little resistance to compression (because the fibres do not cohere to one another) and a great resistance to tension. The nearest that we can approach to this in wood is a green stick which we may bend and twist into a rope without separating the two parts, or woods such as cane and certain others, that cannot be said to have a breaking-point by reason of their excessive pliability, and, lastly, wood-ropes and binder-twine, that are made by planing off fine shreds of wood by means of a special toothed plane (or dissociating them by the sulphite process) and then spinning them (Gayer, 1902, p. 502).

In rigid woods when dry the coherence of the fibres must be overcome before the wood will break and the separation of the two parts takes place, because as soon as the concave surface of the beam cedes, the crushed portion becomes a fulcrum and the two halves, levers, which are able to exert sufficient force to tear the convex surface asunder. In the green stick, the cane or the withy, the concave surface offers so little resistance that no fulcrum, so to speak, is provided and no fracture is set up.

This important truth, discovered by Buffon, was well known to his contemporaries. It seems to have passed out of recollection, otherwise physicists could not have persisted in applying the law of Galileo to wood. As regards the height of the beam, this law supposes that the resistance to transverse strain varies as the square of the height, whereas the resistance to compression of the upper (concave) layers is a still more important factor and the height may be reduced and yet the beam be the stronger. This paradox becomes clear when we consider an experiment first performed by Duhamel de Monceau (" De la force des Bois," p. 427), who took a series of young Willows of equal size and humidity, which were cut up into bars and tested for transverse strain. Six of them broke under an average weight of 256,909 kilogrammes. Two others were sawn one-third of their thickness from above in the middle of their length, the nick being filled by a slip of oak. These broke under 267,718 kilogrammes, or a greater load than that supported by those that had not been slotted. Two others were sawn to half their thickness and broke under 265,312 kilogrammes, and five, sawn three-quarters of the way through, did not give way under less than 259,764 kilogrammes, an average still greater than that given by the uninjured bars.

It was the greater resistance to compression of the harder piece of wood inserted in the slot that made the difference, so that the law as to the square of the height was proved to be false. The practical application which the French builders made was in the reduction of the height of their beams, in the upper surfaces of which a piece of hard wood was likewise fitted, but in a somewhat different manner, and extending along the beam for a greater length. Such beams were called "barreaux armés," and by their use a great economy of weight was secured. Those who have noticed the mass of timbers in the roofs of some French churches (appropriately called by the carpenters "les forêts") will appreciate the value of this procedure.

The experiments of Peschel (*ex* Lardner, 1855, p. 293), which have a resemblance to those of Duhamel, may mislead. Peschel notched the upper surface of his beams and drove a wedge of iron or hard wood into the notch, by which means the two ends became inclined. The difference that he found in the strength of these is surprisingly small, for by his method he had converted a horizontal beam into an arch, the wedge being the keystone, and it would have continued to support weight even had the beam been almost entirely severed.

Moroto (1915, p. 47) holds the diametrically opposite view to Duhamel, as indeed do practically all modern investigators whose work I have consulted. He says that the rupture of wood generally begins with the strained tissues, in other words, the tissues in the under part of the beam.

The law of Galileo cannot apply to wood for many other reasons.

Wood is not a homogeneous substance such as iron. Its structure, and therefore its strength, varies from point to point. The annual rings of which woods are made up are, with few exceptions, less dense in the tissues produced in the Spring than in those produced in the Autumn (or more properly, the Summer), *i.e.*, there are zones of stronger and weaker wood alternating, their proportions varying indefinitely. Secondly, good and bad years will produce wide or narrow rings, in which either the strong or the weak zone will predominate. In good years Conifers will produce much lax Spring wood: some broad-leaved trees, having large pores in the Spring, on the contrary, make much dense wood. In bad years, the former make a less *quantity* of Spring wood, and even if they do not make more hard Autumn wood, at least its proportional share of the substance of the ring will be increased. Broad-leaved trees in bad years may show a succession of pore-rings which have but little mass, between which lies a meagre zone of Autumn wood only. Further, apart from fat and lean years, the wood of forest-grown trees shows a gradual diminution in the width of the rings as the tree ages, corresponding to the reduced amount of light enjoyed by the tree as its neighbours close in and form "canopy." Should subsequent thinning of the trees take place, light is admitted and wide rings are again produced.

Supposing that our test-piece is taken from a tree in such a manner that a series of dense rings occupies one side and a series of lax rings the other. It is clear that the same stick will break under a less load if placed on the supports with the lax rings above (in the compression-layer) than if the position be reversed, to say nothing of the third alternative of the rings being placed as it were on edge, the strongest position. Hence a law based upon the square of the height must be vicious.

The experiments at the University of Washington by Fernow, Roth, Lanza and others are conducted with large square timbers and are of real practical utility, as they show how much beams, as they are actually employed, can bear. Nevertheless, any attempt to use these results to calculate the strain that can be resisted by posts of smaller section by means of a formula is futile. For shorter posts of equal sectional area to the large test-pieces, the calculations may be safe, but for those of smaller section they are inapplicable.

The transverse test-piece varies in its resistance on account of its structure. The lines of weakness are generally the plane of the rays and the points where one annual ring ends and the next commences. If there be in addition a ring of pores or zone of soft-tissue, the ring-boundary is still further weakened, because the fibres can bend readily into the cavities of the pores or cells. Separation over long lines takes place and the wood really shears before crushing in the plane of the rays and of the ring-boundaries, these being the planes of easiest fission. With pore-rings, both shearing and bending of the fibres may take place. This explains the shifting of the lines of fracture in Laslett's specimen, already cited (see p. 115).

The transverse test-piece may vary in its resistance on account of the amount of water it contains. We have seen that the green stick doubles up without a true fracture. This same stick when dried would snap short, in fact, moisture makes the wood plastic and the upper concave surface of the bending wood is compressed more easily. This can be proved by moistening the wood, and is the base of the practice of bending sticks of Beech for furniture, Maple for the sides of violins, Willow for punt-bottoms and Oak for ships'-timbers. Heat either moist or dry also augments the plasticity, indeed it is generally applied in the form of steam, which has a double effect. Beech is generally steamed; the Maple is moulded with hot irons with occasional sprinkling; the twisted whip-stocks of Perpignan are fixed by heating in moulds or on grilles.

Hadek and Janka (*ex* Exner, 1903, p. 167) assert that the influence of moisture is double that of the density of wood. Tiemann (1909, p. 542) says that beams which will bear a certain load in dry weather may fail on absorbing moisture from the atmosphere. Inasmuch as in small pieces Oak will absorb as much as 13 per cent. of its weight from damp air in the course of two days (*see* p. 160 "Absorption"), how dangerous are calculations based on tests made with air-dry pieces or even with 10–20 per cent. moisture. If experiments are to be taken seriously as guides for the security of construction, they should be made with wood containing at least as much moisture as it is likely to absorb in situations in which it is destined to be employed. A beam that will hold in the comparatively dry atmosphere of a first floor may give way when used over a damp cellar.

On the other hand, excessive dryness is prejudicial to the strength of wood. On this Buffon, Duhamel, Chevandier and Werthheim all agree, as do some modern observers. Indeed, they maintain that if wood be artificially dried to 10 per cent. or even short of this, the wood becomes so brittle that precise experiments can be no longer performed with it (Noerdlinger, 1859, p. 386). Observers are not, however, in unison on this point, and Noerdlinger says elsewhere (*ex* Exner, 1903, p. 128) that in none of his experiments did specimens of wood dried at 60–90 degrees Celsius (= Fahr.) suffer in the least in their tensile and transverse strengths. In this he is supported by some of the American school, who maintain that kiln-dried wood loses none of its strength, but is less hygroscopic and will be stronger for that reason under ordinary atmospheric conditions. This point needs clearing up urgently, as the tendency of the commercial kiln-manufacturer is assiduously to assert the equality of kiln-dried wood to that which is naturally seasoned. Apart from the practical side, this is immaterial, for in either case it is sufficiently obvious that an absorbent substance, the strength of which depends upon its moisture-content, cannot be dealt with by means of a formula. Again, the distribution of the water in the beam is very unequal. This has been very well shown by Hatt (1907, p. 10), who gives some excellent diagrams of the water-content in the various parts of beams (*see* p. 164), from which we see that while the moisture of the exterior fell from 71 per cent. to 9 per cent., between the green and the kiln-dried conditions, that of the centre actually rose from 30 per cent. to 33 per cent., as though the heat had driven the water inwards.

All this proves that the resistance of a substance the strength of which depends upon so many conditions, cannot vary as the square of the height or of any other dimension.

Certain investigators try to avoid this difficulty by reducing the moisture of their test-pieces to 10 per cent. or thereabouts, but their results are true only for the moment at which they were obtained, and there is no means of adjusting them to meet moisture conditions which in England at least, prevail for the greater part of the year.

The structure again affects the result in tests for resistance to transverse strain but in a somewhat different manner, in which compression plays no part. As already said, the lines of weakness are either the ring-boundaries or the planes of the rays. We know but little concerning the latter in this connection. It remains to be investigated and is well worthy of attention. Of the ring-boundaries, we know that in certain woods, such as the American Black Ash and the Giant Fir, a mere bending of a stick will cause it to separate into as many slats as there are annual layers. Further, the Silver Fir, one of the very best building timbers, will separate into annular sheets or troughs, if the cylinders of wood represented by the rings be severed (as always happens in sawn timber). Thirdly, if a plank of deal, cut on the quarter, be placed lengthwise in a vice and the free portion sharply struck, the wood will crack off, leaving exposed a portion of a cylinder, that is really a portion of a tree concealed within, that may be separated even to its branches, for the latter will draw out of the holes made by the coats of wood subsequently laid upon it. Fourthly, bridge-builders avoid piles which show entire rings on their ends, as they say that they will knock out under the blows of the pile-driver. Fifthly, during tension tests the centre of the piece often draws out like a cork. Lastly, floor-boards laid the wrong way (heart-side) up will "shell out," as it is termed. By the way, Leonardo da Vinci was the first to point out that there is a right and a wrong way of laying boards.

All these instances prove that the adhesion of successive annual layers is less than the cohesion between the fibres of each layer.

A good example is seen in Plate I, Fig. 1, of McGarvey Cline and Knapp (*U.S. Bulletin*, F.S. 88), which they use as an illustration of their machine for testing large timbers. The first failure of the beam is seen to be longitudinal and the two partly-separated pieces appear of clearly different lengths.

As soon as the beam begins to bend and therefore to shorten, a longitudinal strain is set up which tends to separate the layers. Three cases may arise. Firstly, the beam may be from the centre of the tree, thus containing the pith surrounded by the rings that were formed earliest in the life of the tree. This is general in large timbers. Theoretically, this form should be the strongest, as most of the sheaths of wood are entire, and as they retain the form of tubes they should be able to bear a maximum strain. Actually, we find that the centre is generally fast-grown, with wide rings, as previously explained, but at a more advanced age passes over into slowly-grown, narrow-ringed wood. This is a great defect in Conifers, for the denser and stronger series of ring acts, towards the laxer, weaker centre as a strong tube enclosing a core from which it will separate with comparative ease, as happens in the case of the bridge-piles.

This inequality of growth is a frequent cause of ring-shake, and even in the living tree one series of sheaths will separate from the other spontaneously. Laboratory tests also prove this. "Box-heart," as it is called, makes the weakest form of beam, and Gayer (1903, p. 78), classes it 10 per cent. below the best, though I doubt whether in the event of wood grown under "canopy" from its youth, being employed, this form would not prove to be the strongest after all.

Julius (1918, p. 29) says "quartered wood worked out 12 per cent. weaker than square-cut beams."

Secondly, let us take the case of beams in which the pith is either to the one side, as it is in quartered wood, or cut away altogether (plankwise). Here we shall see the annual rings in the form of arcs, one within the other. We have again several possible cases: (*a*) pieces from a small tree or from the centre of a large one, in which the arcs will be more or less complete semicircles or semicircular troughs, for which three different positions are possible :—with the arcs with their convex sides uppermost, like so many bridge-spans, this is a resistant position, for so long as the spans are prevented from spreading by their adhesion one to another, they derive great strength from the arch-like form, and the weakest members (the arcs of smallest radius) are in the zone of extension (Fig. 1A, Pl. XXXV). (*b*) When the position is reversed and the arches become troughs and the weakest members are in the zone of compression, and lastly (*c*), when the semicircular layers are, as it were, on edge and the load is more equally divided between the hard and soft, strong and weak layers. This is the strongest of the three positions.

Next, we have beams cut from large trees, in which the periphery of the rings is so large that the curvature of the layers approaches a straight line. Here the influence of the position is very considerable, inasmuch as if the beam be laid with its layers in a horizontal position, the latter will tend to separate like a bundle of slats (Fig. 1F), but, on the contrary, if the layers be on edge (disposed vertically), we have the strongest type of all beams, as the tendency to separate is at its lowest and a greater proportion of the hard Autumn zones of wood will crop out on the upper edge in the zone of compression.

If therefore we have so many alternatives from the wood of the same tree or from the same piece, what becomes of formulæ based on the square of the height ? There are a number of the modern investigators who recognise this difficulty and take necessary precautions, but in many works, even of the most recent date, nothing is said about either structure or position. I will mention the names of a few of the more enlightened, the more gladly as they are all Foresters ; they are Thil, Noerdlinger, Hartig, R. Gayer and the American school.

Even were the grosser structure indifferent, we should be confronted with the difficulty of variation in the strength of wood from different parts of the same tree. Briefly, the inner wood is generally stronger than the outer wood, and that from the butt stronger than that from the top, so that a long beam varies in strength from point to point.

As regards the minute structure, we must not overlook the fact that the tissues such as the woody-fibres, the parenchyma and the vessels are of very different strength, as indicated by the thickness of their walls. Were they evenly distributed, this would not matter, but in many species they are grouped or in zones or patches. The parenchyma, the element with the most delicate walls, is very capricious in its appearance and may sometimes be present in great abundance and at others practically absent, even in trees of the same species. The walls of any element susceptible of lignification accumulates lignin for long periods, and at diverse epochs the same cell may be of greatly different strength. Lignin, according to Exner, contributes resistance to compression, and cellulose that to extension, which confirms the popular impression in contrasting a piece of Oak and a rope. The proportions of lignin and of the various tissues is a matter that cannot be estimated nor predicted and must therefore stultify any attempt to reduce such a protean substance as wood to rule.

Once more, time is an element, as Buffon and others after him, notably Noerdlinger (1859, p. 244), have proved, that a piece of wood that may bear a certain weight for a moment will not do so for an hour. A beam broken by Buffon bore 9,000 lb. for a day, but eventually after six months gave way under a load of only 6,000 lb. that was suspended from it. It is well recognised by investigators that the speed with which the load is applied is a factor of importance, and they specify regular increments of so many kilogrammes per sq. centimetre per minute. The interruption during the test is disadvantageous. Noerdlinger says (1859, p. 244): "Indeed from my experience, pieces that bore the first load of 30 kilogrammes, on reloading could not support 28 kilogrammes. With green wood or that which is tough rather than elastic, the continued stress acted in the same way as an augmentation of the weight."

Thil says (1900, p. 118) that the duration of the test should not exceed eight to ten minutes. Such tests seem to me to be of very little service unless controlled by others extending over many months. Buildings are not erected for ten-minute stresses and a railway train passing on to a bridge does not respect this rule. Even if theoretical conclusions can be drawn from experiments of this kind, they should not displace others which reproduce more closely the stresses met with in practice, from which indeed more valuable theoretical results may accrue.

Still, we have not finished with the obstacles to the application of Galileo's law on this count, for there are the tissue-tensions to be reckoned with. Of these we know practically nothing, a few isolated facts are all that can be indicated, which may be divided into two classes. Firstly, such as appear to be normal and in the absence of which wood would be as flexible as rope. Shavings as they leave the plane are devoid of rigidity and a log may be planed away to such shavings and its rigidity be reduced thereby to nothing. It is the pull of each layer of cells against its neighbours, combined with the resistance to compression of each individual cell that makes up the stiffness of the tree. This pull must be enormous, as an apparently sound log will sometimes split in consequence of the concussion resulting from its being thrown from a waggon. Dumonteil relates that when he was sawing green logs of Carapa and other woods of French Guiana, they would split with a loud report for as much as two to three metres in advance of the saw-gate, and not only in the direction of the cut, *but at right angles to it*, so that the tree sometimes fell into four quarters! Howard (1920) mentions a case where a log burst with such violence that one half was projected through the roof of the saw-mill. A more familiar circumstance is the bending outwards or gaping of a green stick when partly slit or the pinching of the saw by the wood which sometimes renders the use of a wedge necessary to keep the saw-gate free. Noerdlinger also mentions the fact that when sawing a trunk of Laburnum into short lengths, a crack appeared in the heart, accompanied by a loud noise. This happens with the Aspen, the Hornbeam and even with the Beech when felled in Winter, a phenomenon well known to the wood-cutters (Noerd. 1857, p. 476).

The second class of tissue-tensions is illustrated by the shakes which occur in timber either during drying after felling or before, as the amount of water in the different parts of the tree varies considerably at different periods of its life and at different times of the year. Roughly speaking, dense wood shrinks more than lax, and therefore tends to separate from it. Ring-shake and star-shake may both arise from this reason. The weakness of kiln-dried timber is probably partly due to the setting up of minute fissures caused by tissue-tensions.

All the foregoing is more or less germane to the question of the resistance to transverse strain plus crushing, which we have seen to be inseparable, and the result is fatal to the use of formulæ based on the square of the height. We now come to that part of the law relating to the length, by which the resistance is supposed to be inversely as that dimension.

I know of no author since Buffon, excepting Peter Barlow, who has not taken this supposition for granted. Buffon, in 1733 (Vol. XII of the French edition of his complete works), proved that the resistance of wood was not "inversely as the length," *but very much less.* This model investigator conducted his experiments upon 100 selected Oak-trees, which after being stripped of their sap-wood and squared, were broken by a load suspended from the middle, the ends being supported upon walls. These beams ranged from 4 × 4 inches to 8 × 8 inches in section and their length from 8 to 16 feet between supports. Buffon showed that a piece 16 feet long and of the same sectional area as another 8 feet long, which should by rule carry half the weight supported by the latter, will break at much less than half.

One or two of the modern investigators have felt that something is wrong with their results and make statements that are unintelligible, except when considered in the light of Buffon's work. Gaetano Lanza (*ex* Fernow, 1892, p. 26) says the calculated strength based on tests of small pieces (2″ × 2″ × 24″) was less than half that expected. G. A. Julius (pocket edition, 1918, p. 29) says, "small beams up to 10 inches square in section are from 10 per cent. to 16 per cent. stronger than beams of sizes between 20 and 25 square inches, whilst heavy beams 30 to 40 square inches section are from 8 to 22 per cent. weaker." This curious mixture can be explained only by the supposition that the length of these various categories of beams were not proportional to one another.

Peter Barlow (1867, p. 27) endeavoured to provide a formula to meet the case; we shall however see that no formula is possible.

Practically all of the reasons why the law of the square of the height is not applicable to wood apply in like manner to the length, but here we have, in addition, a very important point in the structure which does not touch the former problem.

When dealing with long pieces we must not regard the tree as being made up of cylinders, but of cones. The first-year's tree, a tiny object of a few inches long, is distinctly tapered; the second and subsequent ayers overlaying it, follow the same outline, and providing that the ree be grown in the open, it will maintain the tapering form for the whole of its life ; indeed, nothing is more familiar than the conical form of a tree, albeit the cone be extremely long-drawn-out.

In testing a whole tree in the round (an absurd proposition, however), we must think of it as an object made up of parts, one only of which (the latest cone, sheath or layer of wood) runs the entire length. Every one of the cones within will fall short of its successor until we come again to the tiny seedling still concealed within the butt.

If we cut off the top and use the shortened piece, we shall see that at the end we have a number of annual rings exposed (say 50 for the sake of argument), while at the butt there are many more (say 100). There are, so to speak, half of the members of the tree which, supposing t to be resting upon two supports, will fail to reach one of the latter. In practice we square the log, in which process we cut open fifty of the cones, only those in the centre of the tree being entire. The corners of the squared log will be made up of fragments of cones, which on examination will be seen to be short lengths of a hyperbolic outline, that crop out in turns on the sides. Only those cones which are perfect at the top end of the log will remain perfect and run the entire length, all the others will be severed. This holds good for logs that have the pith n the centre of the long axis ; all other pieces, such as planks, battens, etc., that may be obtained from the sawing up of a tree, will have a still greater number of imperfect cones, and small pieces may not have a single one. (It may be observed in parenthesis that this can actually be an advantage, providing the stick be posed with the boundaries of the rings on edge (Fig. 1E), where the adhesion of the layers has but ittle influence : if, on the contrary, they be arranged horizontally, the strength will be materially less).

As we have already seen, the adhesion of one cone to another is less than that of the cohesion of the fibres amongst themselves, and it is clear that the more severed cones that are presented, the more lines of weakness will occur. The longer the beam, the more severed cones or lines of weakness there will be, so that the wood is not less resistant simply in proportion to the length, but also in proportion to the number of its severed cones. We have also seen that the number, width and composition of the cones vary according to growth, and that in the same ength two beams may differ in the number of their cones by hundreds, and as a matter of fact no two beams are ever alike in this respect. Hence, unless we can assume uniformity in the composition of a substance, we can formulate no law.

The strength of tubular spars made from wood bent into various orms, now used for the construction of aeroplanes, proves the importance of retaining the sheaths of the wood uninjured as much as possible.

Applying the knowledge that we have gained as to the alternation of strong and weak series of cones, we find that the hewing or sawing of the log may leave a series of either on the surface, just in the layer where the compression is most severe, so that the strength will vary rom point to point as the density of the upper surface.

Lastly, we must consider those phenomena which are called " defects," and are such from the carpenter's point of view, though they may be quite normal to and frequently necessary to the growth of the tree, *i.e.*, the branches. These are always present in the early wood, which will be represented by the inner cones of a large tree. It is for this reason that Gayer and others consider the form, as in Fig. 1c, Pl. XXXVI, to be the weakest. I have said that it might be the strongest under certain cir-cumtances (growth in close canopy), but, in addition, the branches will be smaller. In hedgerow trees, the larger branches, when cut through, as they must be in squaring timber, are very serious defects.

But why are they defects in point of strength ? As blemishes they are obvious enough, but they are generally harder than the rest of the wood, and one might think that would add to its resistance, at least as regards compression. The longitudinal fibres (those running vertically up and down the tree) separate above, run round and close in again below the branches ; there is no loss of continuity, and as far as longitudinal strength is concerned, the branches should reduce the strength by taking from the wood so much of the substance, but nothing more. The reason why they appear to reduce the resistance is, that to a transverse strain they offer little resistance, as they will tend to draw out from the rest of the wood, as in the bridge-piles whose centres come out under blows. If the reader has performed the experiment suggested, of cracking out the trees concealed within a plank, he will probably see for himself that the little branches which belonged to the tree so exposed, will appear complete and will draw out of the sheaths of wood in which they lay concealed. I have a specimen in which a tiny twig, not the twentieth of an inch in diameter, drew out to the length of about three-eighths of an inch, and another of about one-eighth of an inch diameter to a length of one inch. If such fragile structures can leave their sheaths without injury, it is evident that the adhesion of the knots may be very slight. The application of this to the question of the evil influence of branches, as regards cross-strain, is that their line of least resistance tends to approach that of greatest traction. At the same time, it is possible that they can be so placed as to afford a certain amount of support, but in practice this is only to be thought of in connection with those that appear upon the surface. The smaller will frequently be hidden ; indeed, in some experiments made upon the transparency of wood, I have seen within a disc of wood, not more than three-eighths of an inch thick, traces of four hidden knots that were not visible upon the surface.

If knots appear in the zone of compression they are bad, because the longitudinal fibres in their passage around them are separated and already bent, so as to offer less resistance. If in the zone of extension, they reduce the strength by being so much inert substance only. If one must use a knotty piece, it is better placed with the knots sideways in the neutral zone.

Amongst defects must be mentioned the spiral grain when it occurs as a " sport " in otherwise straight-grained species. If the tree is to be used whole, this cannot be regarded as a great defect, unless it be accompanied by spiral checking or fissuring, but in squared wood t is considered bad. In species where the spiral course of the grain is normal, there is, of course, no choice, and in double-spiral species it may be regarded as a virtue, because it lends great tenacity to the wood. The eccentricity of the rings is considered a defect by Stamer (p. 370). Certainly the quality of the wood will vary more than in a well-balanced tree, but if used as a whole, the disadvantage of this form of growth is not obvious and appears to be assumed rather than proved. If used in small pieces then some will be of better quality than others, that is all, and the width of their rings will guide us in our selection.

Buffon proved that young wood is less strong than the more mature, and, which is the same thing, the wood from the exterior of the log is weaker than that from the heart. Here we have a question of a quite different nature. If this were the only point it might be neglected, because the sap-wood of heartwood-trees is carefully rejected by all good builders. There is, however, a more important matter, that is, even when sap-wood is changed into heart, the wood is but partially ripe, for the process continues for many years, the wood improving with time in all its desirable qualities (except elasticity and flexibility) until maturity.

This process of heart-wood production consists partly in the deposition of lignin upon the walls or in the cavities of the cells and partly in a change in the nature of that substance itself.

From our present point of view it is important, because it greatly augments the resistance of the wood to compression, so that a law which applies to wood which has undergone the complete process will not do so to another piece of the same species which is still unripe. Buffon propounded a law that the resistance to transverse strain varies as the density of the wood, and I see no objection to this within the limits of the same species, providing that the tree be not in its decline, in which case the excessive lignification will cause the wood to become brittle, which occurs so often in the wood of the Eucalypti. Builders always reject the centres of large Gum-trees. Outside the limits of a species the density may mislead us. Certainly the heavier woods are generally the stronger, but there are some of remarkable strength, such as the Angelique of French Guiana, which is 1⅓ times stronger than Oak, while being little, if any, heavier (*Commission of Brest*, p. 171). Then it is quite conceivable that the resistance to compression in woods, such as the Ebony, may actually outrun the tensile strength.

Sargent (Silva, V, p. 54) found that the greatest weight and strength in American White Pine lay between the pith and the outer layers of the heart-wood, also (p. 362) "that no rigid rule exists, but that a marked difference is to be found on the two sides of the tree. Stiff and rigid woods which are most resistant to transverse strain are those which are hardest and therefore heaviest." This is Buffon's view. Secondly, the elastic woods that are most resistant are also those that are most resilient and cede to compression without crushing. The Oak falls into the first category and the Silver Fir into the second. It is odd that woods of such very different hardness and strength should compete for first place amongst building materials. A recent Congress of Engineers on the Continent declared that the Silver Fir was the best building timber in the world (excepting the Pitch Pine), and in France it is preferred to Oak for beams, as witness the couplet :—

> "Chêne debout, Sapin à travers
> Porteraient l'univers."

The explanation would seem to be that the lack of rigidity in the compression layer of the Silver Fir is compensated by its elasticity; the wood bends without crushing and readily resumes its original form when the load is relieved. It would be interesting to know whether the Silver Fir would tire as easily as the Oak under repeated loads.

Thiéry (1896, p. 789) says " the bending moment (' le moment fléchissant ') which can be supported with safety by different pieces of wood of the same dimensions, but of different widths of annual rings (*i.e.*, different growth), is inversely proportional to the square root of the average thickness of the rings." His experiments were made upon the Silver Fir (*Abies pectinata*), and he assumes that the proportion of hard Autumn wood to soft Spring wood is constant, whereas the examination of any piece of that or any other wood will convince any one of the contrary.

R. Hartig (1882, p. 63) says that " quality is not indicated by the width of the rings, for wide-ringed Pine that when young could not have had more than 30 per cent. solid substance, had when converted into heartwood and filled with resin, as much as 43·1 per cent." As it is the solid substance that most resists compression, the width of the ring goes for nothing. Hartig again says (1882, p. 61), that narrow rings may be of bad quality through lack of nourishment (*i.e.*, in Coniferous woods where narrow rings are commonly regarded as being an indication of good quality). As regards the wood of broad-leaved trees, he states (1882, II, p. 62) that the narrow rings are the best, this being due to the smaller number of the vessels and less parenchyma and thicker-walled elements. I disagree with this last statement, as broad rings in Oak certainly show the greatest proportion of resistant material.

The highest strength given by Noerdlinger (1859, p. 394) is for the Robinia, 11·88; then follow the Ash, 7·16; Oak, 8·9; and Teak (after Barlow), 10·609. Stamer (p. 386, footnote) says that the results obtained from good and indifferent qualities of the same wood may vary 80–100 per cent. or more. This author also assumes (1910, p. 376) that the neutral zone of a beam under stress lies in the centre of gravity of the cross-section. It will be seen from the foregoing that it is capable of rising or falling according to the structure and orientation of the piece.

Noerdlinger (1859, p. 392) criticises Buffon's law that the strength varies as the density and cites the cases of the Pine, Birch and Beech, where the contrary is the truth : " By equal dry weight, the ripe-wood is without doubt more brittle than the sap-wood, and the same applies to the Silver Fir in heavy, resinous specimens that are rather too old, and to the heavy Australian woods." The same author (1859, p. 387) makes the somewhat astonishing statement that the strength of wood is not affected by decay unless far advanced. There is more than one kind of decay, and if there be any such that attacks the lignified cell-walls without affecting either the cellulose or the inter-cellular layer, we may believe that the tensile strength remains unimpaired, but as the lignin is the substance which is supposed to furnish the resistance to compression, Noerdlinger's statement must be regarded as not applying to bending or crushing. The disappearance of either the cellulose or the inter-cellular substance would of course reduce the wood to touchwood.

Some of the best investigators of the properties of woods have been not physicists, but dockyard men. To mention but a few, we discover a galaxy of talent—Duhamel de Monceau (the friend of Buffon), Dumonteil, Knowles and Laslett. Galileo himself conceived the idea of applying mathematics to the determination of the strength of wood during a visit to a dockyard (Dupin, p. 137). The architects come next, commencing with Leonardo da Vinci, who was the first of all to make tests of the breaking strain of materials of construction; then Leon Batista degli Alberti, who outlined the law propounded by Buffon, that the qualities associated with the heart-wood vary together (*L'Art de bien bâtir*, French ed., p. 28, left side).

The futility of using small test-pieces was long ago pointed out by Buffon and it seems extraordinary that it should need animadverting upon nearly two hundred years afterwards. Laslett, whose own bars were far too small, exclaimed at some of the experiments that had been performed in his time upon slender rods of no larger section than a French line (·0888 inch). F. A. Campbell (*ex* Boulger, 1908, p. 118) used pieces of one-sixteenth of an inch square. With small commercial sizes, not intended as bases of calculation, the question is different, and we may prescribe the precautions to be taken.

For crushing-tests the blocks must be quite flat. To obtain the necessary accuracy the upper and lower faces are best dressed in a lathe by means of a slide-rest. It is only by this means that the result can be obtained without an expenditure of time out of proportion to the needs of the case. Next, the course of the rays must be observed. They are always arranged more or less in a fan-shape. The rays which form the *middle* ribs, as it were, of the fan should be parallel with two of the sides. If the block be cylindrical, it can not only be dressed to an exact size with little trouble in the lathe, but the orientation of the rays will be indifferent. It has always appeared to me that a cubical block in which the corners are at a greater distance from the centre than are the sides, cannot be the best form; moreover, if the block be taken from the centre of the tree, a cylindrical form will have the additional advantage of severing a minimum number of rings. Jaccard (1910) has employed round pieces of young stems entire. Thirdly, the block must be air-dry. It cannot be helped if it does not provide a true comparison with wood that may be exposed to damp air, but it will be in the only possible condition in which it will not either gain or lose moisture and thus shrink or swell and become distorted. Other tests should be made with blocks containing the maximum amount of moisture that such wood may be expected to absorb in the dampest situation in the wettest weather, as in practice it may have to undergo such an extreme. Wood is exceedingly bibulous. Knots should be permitted only when it is desired to study their influence, and it then should be carefully stated in which direction they run.

When the surface parallel with the fibres (radial or tangential sections) is to be subjected to compression, it will be well to add some trials on pieces which project for some distance on either side of the plunger, so that the fibres of the part immediately under the plunger shall be supported by neighbouring fibres, as would be the case in a beam supporting a weight by a single point or as in most tests for transverse breaking. A similar practice is adopted by some experimenters for shearing tests.

Owing to the importance of the resistance of the compression layer in tests for transverse strain, it would be interesting to make experiments in crushing blocks in a manner which will reproduce the actual process that goes on in the wood. During the bending of a beam before breaking, the curvature of the upper surface varies from moment, to moment, and the nearer the two ends approach each other, the more severe becomes the pinch on the middle, so that in a bent form the particles of the wood are subjected to a greater pressure per unit of weight than when the beam is straight. In other words, the crushing strain upon a bending beam augments in a gradually increasing ratio and the deeper (higher) the beam the more intense the stress. If the strain becomes more severe as the radius of the curvature diminishes, then the unit weight at the breaking-point of a beam of a species which bends *much* will exert greater pressure than on one that bends little, so that comparisons between woods of different kinds can be approximate only.

I suggest that an iron beam or toggle be employed, having a hinge or link in the middle to permit bending (Fig. 1G), with jaws between which the test-piece is to be placed. The insertion of the test-piece between the two jaws will bring and retain it together with the toggle, into a horizontal position and the whole will form a beam which can be laid upon two supports and the load applied to the middle as in transverse strain experiments. By this means the augmenting severity of the pinch on the upper layer of the block will increase in the same way as in the bending beam and make comparisons of crushing and transverse tests more akin.

Assuming that the tensile strength of the extension layer is superfluously great, as I believe it to be in all but exceedingly dense woods, let us put it out of the case by reinforcing it by a band of spring-steel placed on the underside of the beam. Then if the compression layer fails first, it should do so under weights similar in amount to those which would break the beam were the steel band not there.

Many authors specify test-pieces from certain parts of the log only as being essential. I disagree, as the whole of the pieces, except such as show obvious defects, should be tried. These choice samples must always be above the average of ordinary commercial grades in respcet to quality and dryness, and below it in large pieces, on account of the severance of a greater number of the rings.

Laslett (1894, p. 102) showed that the wood taken from the same height in the same Oak tree varied in transverse strength as much as 42 per cent. and the tensile strength as much as 58 per cent., both being in favour of the inner wood.

The resistance to transverse strain is the form of experiment which has been one of the most popular in the past. Pieces suspended by one end and weighted on the other have not been so far of much practical use, and as Buffon pointed out, do not yield the same results as when they are laid upon two supports and weighted in the middle. Their resistance is supposed to be one-quarter of that of the latter. They may afford information regarding the bending moment, as when held by one end only they are free from friction against the supports, the error from shortening does not affect the case and the wood is injured less.

When the bar is posed upon two supports near its ends, and the load applied, the bar begins to bend and therefore to drag on the supports. The ends rise and the corners of the supports bite into the wood and hold, so that much of the load is absorbed by this biting-in and dragging. This is avoided firstly by placing a plate between the supports and the beam, with a rocker which tilts as the ends of the latter rise. This is not enough, as the shortening of the bar must be provided for. This was done by Paccinotti and Peri, by slinging the test-piece in chains instead of using rigid supports. I have used iron slings, which are less troublesome than chains. The necessity for this contrivance will be seen when one considers that a piece of Beech tested by Musschenbroek, which at the commencement of the experiment was ten inches long, bent so much that, at the conclusion, its two ends were only seven inches from one another. Had he been using an ordinary machine he would have had to provide a length of stick of more than three inches longer, or it would have slipped down between the supports, and then at the breaking-point the test-piece would have been not ten inches but thirteen inches long. Hence, all experiments that have hitherto been made with fixed supports are vitiated, because the piece changes its length during the operation.

The means of applying the load are too well known to need mention. Whether it be hydraulic pressure, lever or dead weight, is a matter of convenience and labour-saving. It is interesting to record that Leonardo da Vinci used a box of sand, the weight being estimated from the number of baskets of sand required to cause the beam to break. Buffon used weights made of stone and employed eight men to load, and some of his beams were tested to 28,000 lb. Such methods are cumbrous, and of course, need not now be used, though I have made use of a dead-weight machine myself, my chief difficulty being that of finding any workmen willing to load after the first experience. The real disadvantage is the impracticability of continually easing the load to see if the test-piece returns to its original form, which is so easily done with modern machines.

As the beam bends, the radius of the arc described by its upper and lower surfaces alters from moment to moment. Assuming that the lower surface or extension layer is inextensible, which is practically the case, the pull is borne more or less equally by the whole of the under surface, but the crushing has to be supported by the *middle only* of the upper surface, as is proved by the experiment of the slotted beam of Duhamel de Monceau and the "barreaux armés." This being the case, any injury to the centre of the beam by the shackle or plunger of the machine must be guarded against. This shackle, by which the weight is suspended to the beam (or the plunger of the press), seriously damages the upper layers. Even when an iron plate is interposed, this ill effect is not avoided, for I have seen a small bar 1½ in. wide by 2⅞ in. deep, upon which a three-inch plate was used, so much damaged, that crushing and buckling of the fibres was traceable for a distance downwards of nearly half an inch, indeed, the whole of the substance beneath the plate was slightly displaced and the upper layers of wood actually crushed. The bar in question had broken elsewhere on account of defects, so how much more the crushing would have progressed had the bar resisted until it broke in the middle is difficult to say. This is a serious matter, for if we enlarge the plate we fortify the resistance of the upper layers and distribute the load. I can see no way out of this difficulty. Perhaps wide planks of small depth and great length would meet the case, but it vitiates comparisons of the resistance between different woods, as they will depend so much upon the resistance to crushing at right angles to the course of the fibres. The test-piece held by one end suffers far less.

In the illustration of McGarvey Cline and Knapp referred to above, this enlargement of the protected upper layer is well shown. Two plungers are used to distribute the weight, which would be too severe on a single point, with the result which might be expected, that the failure of the beam takes place under one or the other of the plungers, and not at the centre of the beam, which undergoes but little crushing stress and may be regarded as a more or less neutral point.

The selection of the test-piece should be made with regard to the orientation of the rings and the rays, and other pieces broken to ascertain the different resistance of all possible positions, which should be specified. If small pieces of commercial size are used, then the disposition of the structure of both ends should be described or a photograph be taken of them, in order that conclusions may be drawn as to the position, etc., in the tree from which the bars were cut.

Further tests are needed to find out approximately how much influence the length has upon the resistance to breaking. At present we rely solely upon Buffon's experiments. No one else appears to have tested various lengths of the same sectional area.

In addition to the difficulties which are presented by the capricious nature of the wood, we are confronted with many mechanical difficulties in testing specimens. Only laboratories which are richly endowed can afford the necessary machinery, and we cast envious eyes upon the princely installations of the Universities of the United States. Still, the appliances at our own School of Engineering of the University of Cambridge are excellent, and if used with an intelligent appreciation of the structure of wood, should be able to hold their own, more particularly as most published records made up to the present are only worthy of the waste-paper basket.

The United States has had the good fortune to be able to work upon large pieces, thus avoiding many of the errors which the use of small ones must lead to, inasmuch as most of the trouble arises from the subdivision of the log.

As already stated, Buffon and Duhamel de Monceau employed whole logs or logs merely squared, so that errors arising from the severance of the rings or of the orientation of the test-piece in respect to its structure came but little into play. Then, by the use of long lengths and by basing calculations upon results obtained by such means, these investigators remained on the safe side, as every shorter length provides a greater margin of safety. If the resistance to transverse strain is not as the inverse of the length, but very much less, then data from long lengths may be safely used for shorter pieces and we run no risks even if the results are wanting in scientific accuracy. If, on the contrary, short pieces are employed, and we use the results as bases to calculate the loads that long ones will bear, we shall be guilty of a fatal stupidity that may endanger human lives. This is of little moment as regards our well-known timbers. The builder and the carpenter do not think of tests; they know their trade sufficiently well to be able to provide plenty of margin for safety. I often wonder whether practical men pay any attention whatever to the figures so far provided by physicists. I hope and believe not. They instinctively feel that there is something wrong with them, and leave them severely alone. Never was the divorce between theory and practice more justified, and the sin is on the part of the former.

When we are thinking of stimulating the introduction of Colonial and Indian woods to make up for the dearth of the timbers which we are accustomed to use, and builders and carpenters (who confess that they know nothing of the margin of safety of the new woods) apply to scientific institutions for advice, Heaven help us if we do not do better now than in the past. Much work has been done already in the Colonies, but many of the necessary precautions have been ignored and the figures will be better reserved for comparison with others obtained under identical conditions, and a fresh start made.

It may be said that it is easy for me to indulge in destructive criticism, but have I anything to suggest that will remedy matters? I have only two, which are lame enough, as I freely admit. Firstly, abandon the use of small specimens: use the largest possible and work backwards by calculation into safety; and, secondly, make the tests upon sizes in common use and of good, ordinary commercial timber, free from external defects, but not otherwise selected, and find the *least* load under which the weakest may give way. The results so found should hold good only for the sizes and lengths actually experimented upon, and if other lengths be wanted, then repeat experiments specially for them also, but abolish all calculations whatsoever. The data will be good, but calculated results must always be bad. Timber is commonly used in a limited number of sizes, and it is not too formidable a task to compile a series of results for each kind of wood in the usual sizes and lengths in which it is employed. True, the attraction which the reduction of everything to a formula provides, will be absent, but the practical value of the results should abundantly compensate the investigator, to say nothing of the possibility of practice and theory, so far divorced, being again made to kiss and be friends.

Tensile Strength

There are few data upon this head, and all are equally unsatisfactory, owing to the neglect of the structure by investigators. Tests made upon very small pieces are of no value, the proportion of severed layers being too great, though it should not be impossible to arrive at better results in the present case with small pieces than in transverse and crushing tests. On the other hand, tension-tests with whole logs or beams is at present, at least, out of the question. It has been found very difficult to hold wood by means of clamps with sufficient force to resist the pull without crushing it, so that the expedient of reducing the diameter of the middle of the piece after the manner employed for steel, etc., has been adopted. This is about the most imperfect of all the methods, as many of the rings or cones are cut into and the force is borne by zones of varying strength, much strain being thrown upon the point where the boundaries of the rings or cones provide lines of least resistance. Frequently the centre draws out like a cork. This difficulty may be avoided in some measure by using very long clamps, which will increase the length of these weak zones and augment the sum of their adhesion one to another, and at the same time distribute the pressure of the clamps over a larger surface of the wood. I think that *thin but wide* strips would give better results, as they offer much greater clamping-surface and even if crushed might still hold. They would not be more representative of the log than any other form, and we could not draw conclusions from such experiments as to the strength of any particular kind of wood, still, I think that they would throw light upon the question of transverse strain and together with results obtained from compression tests, might afford food for thought upon the distribution of strains in a bending beam. For this purpose I suggest that the strip be clamped horizontally at both ends, and a weight suspended in the middle, as an alternative to stretching in an ordinary tension machine.

Tensile tests carried out upon pieces of wood fastened to others or to a machine by means of mortice, bolt, or tenon, are not truly tension- but shearing-tests. They may have their practical value if properly carried out, but not in this connection. If we employ a wood having weak lines at the ring-boundaries, then it is clear that if these lines be parallel to the bolt-hole, the piece exterior to it will be readily sheared out; if at right angles the resistance will be greater, and all intermediate degrees of resistance will be obtained from pieces where the boundaries are more or less inclined to the axes of the holes.

To understand the resistance of wood to tension, we must have a proper idea of the real structure of wood. If the reader will examine a branch of Oak from which the bark has been stripped, he will see that the course of the fibres is vertical (as the tree stands), or shall we say longitudinal, as we are dealing with a branch. This course is not, however, straight, but undulating, *i.e.*, the fibres turn aside slightly to avoid certain fusiform depressions, and after passing them, again rejoin each other. These fusiform depressions are the ray-spaces subtending the rays that, as their name implies, run towards the centre of the tree. All woods (except those of Palm-trees) that are used in construction are traversed in the same manner by rays, though the latter may be so small as to be invisible to the naked eye. However small the rays may be, the fibres must run round them in the same way, and if we imagine the rays to be dissolved away, we shall have a mass of fibres which are connected above and below the meshes of a net-work, and, in some woods, by a comparatively small portion of their length. This net-work is of cylindrical or conically-cylindrical form, each cylinder being connected to its neighbours within and without by adhesion, the power of which may vary very much. This zone of adhesion is always a zone of weakness, which in certain extreme cases may arrive at complete separation of the cones. The point that I wish to make clear is, that all woods commonly used consist of tubular nets with rays which render the whole mass solid. The tensile strength of the wood depends almost entirely upon the cohesion of the fibres of the net-work plus the strength of each individual fibre. Compare Fig. 1, Pl. XIII, and Fig. 2, Pl. XVI.

We have, then, two cases in which the strength may vary, that in which the cohesion of the fibres is the greater, and that in which it is less, than the strength of the individual fibres. Illustrations of both may be seen in the fractures of wood, where an examination with a lens will demonstrate that in some the fibres are *torn apart* from each other and in others they are evidently *broken across* and show their sections. The former are called "long-fibrous" and the latter "short-fibrous," without, it must be said, much regard having been paid to the actual length of the cells themselves.

When the wood is first formed, the cells of the mother cambium or growing layer divide into two by the formation of a plate or septum, so that the cohesion of the two daughter cells should be just as great as that of the walls of either, being all of the same substance. Later, however, a layer in the middle of the wall newly made, is changed in its chemical nature, and is then called the "intercellular substance" or "middle lamella." This may or may not be as strong as the actual original cell-walls.

A simile which may be useful is the Flax, the fibres of which may be separated by maceration in water, and then provide us with a material which has very considerable tensile strength. Another vegetable fibre, which grows as isolated cells quite free from others of the same plant, is the Cotton-fibre, which is also a very resistant kind of cell. It is composed of nearly pure cellulose. The cells of wood are made of the same substance, but they are overlaid by cell-thickening or lignin. This lignin stiffens the cells and gives them rigidity and resistance to compression. Cellulose, on the contrary, may be extremely flexible, but I believe it to be the element which makes for longitudinal strength. The conclusion is, that the resistance of the compression-layer of wood to a load is in proportion to the amount of the lignin present, and the resistance to extension in the convex side of the test-piece is due to the amount of cellulose. A rope consists almost exclusively of cellulose, hence its immense tensile strength, and if we could estimate the proportionate amounts of both lignin and cellulose in a wood, we should have a "point d'appui" for estimating its strength. It may be said that there is as much cellulose in the weak White Pine (or Weymouth Pine) as in the particularly strong Silver Fir. I doubt it, but this is a subject that might be investigated with profit. Researches were made upon pulp woods by Schorger (1917, pp. 556–566) and Johnson and Hovey (1917 and 1918). The results of the last-mentioned throw some light on this proportion. The works of Cross and Bevan (1903) and Hubbard (1920) may also be consulted with advantage.

Parent (1707–8, p. 512) found that the resistance to a pull was greater in the Silver Fir than in the Oak in the proportion of 119 to 100. Poncelet (1870, p. 343) gives for the former 8–9 kilogrammes per sq. mm. and for the latter 6–8 kilogrammes, which results are not far from those of Parent.

Bauschinger (*ex* Fernow, 1892, p. 4) showed that the tensile strength of Pine was independent of the total width of the annual rings, but was dependent on the ratio between the amount of Spring and Summer wood.

Elasticity

Elasticity is that property which enables a body to regain its original form after a strain. It may be manifested in two ways that seem quite different, one when a piece of wood is bent and another when it is compressed. A piece of india-rubber springs back when it is stretched or bent or crushed, but a piece of wood will not stretch to any appreciable extent, and we may leave that part of the problem out of the question. Inasmuch as the resistance of a beam to a transverse load is really the resistance of the upper layers of wood to compression, the terms bending and crushing become synonymous. The converse of elasticity is rigidity. Roth (1895, p. 391) says that "stiffness (the converse of elasticity) decreases as the cube of the length." I do not think it more possible to formulate a law upon elasticity in respect to wood than upon its resistance to transverse strain. The problems seem to be precisely the same. The resistance to compression short of the crushing point of the upper layer of the beam is simply the resilience of that part of the wood, otherwise its elasticity, and so long as this layer remains uninjured, the wood will regain its original form. If it does not, then some of the fibres have been separated, *i.e.*, crushed and the so-called limit of elasticity is reached.

As a useful property, elasticity is a virtue possessed by wood in a form with which no other substance can compete. From a house-tree to the top joint of a fishing-rod there is no other substance that can adequately replace it.

The classical wood for beams, the Oak, may or may not be sufficiently elastic, according to its growth. Fast grown, solid Oak is comparatively rigid, whereas slowly-grown Oak, having little more than a succession of pore-rings, is very elastic. I must also make the reservation that the French consider the Silver Fir to be superior to the Oak for cross-beams, but here, again, it is elasticity that comes into play, for the wood of this species, being compressible without injury in the upper layers, returns to the horizontal after bending under a load. The bending moment of *Q. pedunculata* is given by Chevandier as 4·60 and by Morin as 12·0.

The alternations of soft and hard zones, the former acting as compressible cushions, is a general feature of the Coniferous woods related to the Pines, that contributes to making their use so general in house construction.

The pore-ring is not the only arrangement calculated to affect the elasticity of wood. If sections in a tangential direction, as shown by Figs. on Plates XXXII and XXXIII, be examined, it will be seen that there are two systems of fusiform cavities, both of which may act as springs in the same way as do those of a carriage. The smaller are those of the wood-fibres, the larger of the rays. The wood-fibres are usually empty when dry, but the thickness of their walls may vary and their resilience likewise. The rays in the meshes between the fibres may be either of empty, thin-walled cells, in which case little opposition to the closing of the mesh under stress will be offered, or the ray-cells may be hard and thick-walled and may be filled with starch. If so the wood will be inelastic and rigid.

The long-bow is another classical example of elasticity. Our forefathers knew as much, if not more, about woods than we do, and they were far more critical in their choice and patient in their treatment of them. The Romans used Laburnum amongst other species for bows according to Pliny, but we do not know which tree he meant by that name. It certainly was not the species so familiar to us, as he describes it as "materia candida," whereas our Laburnum is of a deep-brown colour, which Pliny would have called black. Nevertheless, a Laburnum was used in France from the time of the ancient Gauls and was still used in the Maconnais up to about 1817 (Loiseleur Deslongchamps). This was probably the Alpine species (*L. alpinus*), which still grows in those regions. These bows were reputed to maintain their elasticity for half a century. The Cornel was used by the Lyciens and the Sauromates. In England the Yew has always been first favourite and justly so, the Irish variety being preferred. In addition, we employed Maple, and in the sixteenth-century Wych Hazel (Wych Elm ?), and Ash also, as witness a law of Henry VIII, which obliged all London archers to make one bow of Yew and two of either of the other woods. The Yew bow was made from both sap-wood and heart-wood in such a manner as to include a few rings of the white sap-wood in the belly and a larger number of heart-wood in the back. By this means the elasticity of the heart-wood was combined with the greater flexibility of the sap-wood, the latter forming an easily-bent extension layer, and the former a highly-resistant compression layer. This brings us to the important fact that the sap-wood is more flexible than the heart, and that the outer portion of the heart is more elastic than the inner. Thus elasticity and flexibility do not follow Buffon's law that the desirable qualities of wood increase from without inwards; they are two notable exceptions.

Holzapfel (1902, p. 243) says that at the close of the sixteenth century the backing of bows with some other wood was introduced, and at the present day they are largely made of Lancewood (*Guatteria quitarensis*) and Hickory. As the former is a sap-wood tree and as the sap-wood of Hickory is of far better quality than the heart, I understand from this that it serves for the bellies, and that the backs are of some other wood. The practice of making the bows of two pieces, according to Stevenson (p. 146), was initiated by Kelsal, a bow-maker of Manchester, and in 1836 Yew was no longer used for bows, all being made from South American woods. One of these, Washiba at least, is used in the ancient manner, sap-wood and heart-wood being cut from the log in one piece. I have not been able to identify this Washiba: the name is a native one meaning "bow-wood," and several different species pass under it.

The singular wood of the Cactus (*Cereus giganteus*, Englm), has already been mentioned as being used for bows by the Indians of North America. As it is not much heavier than cork, there must be something very remarkable about this wood.

Beech, Maple and Cornel were used for the laths that actuated the old-fashioned lathes. Beech does not strike one as being so much an elastic, as a flexible wood when steamed, but Dupin (1815, p. 139) says that the best oars for the French navy were made of it. A great virtue of Maple is its flexibility under heat and its resistance to splitting. The Cornel was used for lance-shafts by the ancient Romans.

A practical application of elasticity that does not strike the casual observer is in the use of wood for ships. When crossing the waves, the ship "hogs" on the crests and "sags" in the hollows. On a length of sixty metres a ship will bend as much or more than half a metre (Herbin de Halle).

Tuzson (1903, p. 276) says that the spiral thickenings of the cells of the rays, which he discovered, may contribute to the resilience of wood.

I am told by Mr. Wilfred Gauler Wright, one of the Civil Engineers to the G.E.R. whose speciality is the maintenance of wooden bridges, that for the longitudinal timbers which bear the rails Willow is the best, and for the cross-heads that support them, Ash is preferred. Here we see that the different forms of elasticity of these two woods is well taken advantage of.

The most elastic wood commonly used (apart from Canes) is the Lancewood, already mentioned. It bends without injury to an extraordinary extent and no substitute for it has so far been found. The reason for this extreme capacity for bending is quite obscure. The structure gives us no clue whatever, as it does in the case of Conifers and ring-porous broad-leaved trees, on the contrary the wood is very dense and, in large pieces, certainly fails to give one the impression that it will prove elastic. It is evident that we are far from understanding the question. Greenheart is sometimes used for fishing-rods and is another instance where no clue to the cause of its elasticity is to be found in the structure.

A quality allied to that possessed by the Lancewood is characteristic of the woods used for violin-bows. These instruments demand a wood which is springy and at the same time sufficiently rigid to regain its form instantly. The best-known wood for this purpose is the Brazil (*Cæsalpinia sp.*), The best bows are made from the exterior heart-wood, the inferior from the inner, proving again that in point of elasticity the less ripe heart-wood is the better, indeed, according to Tolbecque (1903), the wood of the branches is much the best. Other exotic woods used at the present time, says the same author, are the Partridge-wood (Bois de perdrix, *Bocoa prouacensis*), the Grey Ironwood (Bois de fer gris, *Swartzia tomentosa*), which Tortini, the great violin-bow maker calls the "King of Woods," and the Bois d'Amourette (*Mimosa tenuifolia* and *M. tamarindifolia*). The sap-wood of the Ironwood and the Partridge-wood was used for common bows. The systematic names given above are supplied by M. Pecquin (*ex* Tolbecque), and it must not be assumed that our popular names correspond with those used by the French. There are many "Partridge-" and "Ironwoods" cited in English works, and those commonly met with on the English market do not accord with either *Swartzia* or *Bocoa*. Rosewood is mentioned as a bow-wood by Roussel. The only European species that I have heard of as being used for violin-bows, is the Service-tree (Sorbier, *Pyrus Sorbus*), which seems to be an excellent wood for the purpose.

Dumonteil, who made a long voyage in French Guiana and afterwards wrote a very useful *mémoire* upon the woods of that Colony, gives a list of tests in which the elasticity of each is compared with its weight, transverse resistance, etc. In point of elasticity, the Black Ebony heads the list (this does not, however, appear to be indigenous to F. Guiana). His figures prove once more that elasticity does not vary in harmony with the other physical qualities of wood, nor with the structure, as no series of woods could be so diverse in this last respect.

Another French observer who investigated the woods of the Île de la Réunion (Bourbon), mentions a wood, the Mapou (*Monimia rotundifolia*), as being "sans rupture," though, singularly enough, he gives the breaking coefficient as 0·375, that of the Oak being taken as unity, and the elasticity, compared in the same way, as 5·267.

In Noerdlinger's list of the moduli of elasticity (1859, p. 357 *et seq.*) Ebony and Teak head the list, with *Acer dasycarpum* and *Robinia Pseudacacia* coming next. In the list of trials upon Dumonteil's woods made by the Commission de Brest, the Green Ebony (Ébène verte) takes first place: modulus 35–45, as compared with Oak 15–25.

The wood of the Elder (*Sambucus nigra*), generally so badly grown in England, might well be made use of on account of its really extraordinary elasticity. I have seen French carpenters' rules of this wood that can be bent like those made of steel. It is the likeliest competitor of the Lancewood that I have so far met with.

The form of elasticity that has been called "resilience" is well exemplified in the use of wooden pegs or "trenails" instead of bolts in contact with water or with other woods such as the Oak that contain much tannin and hence corrode iron. The trenail is cut somewhat larger than the hole in which it is destined to fit and is driven therein through a metal ring somewhat smaller, by which it is forcibly compressed, hence it expands when home and holds with great tenacity. The Cornel was used for this purpose by the Romans. Other woods reputed good for trenails are the Nettle-tree, which holds first place, the Acacia, Oak, Ash and Bird-cherry, and one of the Australian Boxwoods (*Eucalyptus hemiphloia*) may be added.

Noerdlinger states (1859, p. 366) that the elasticity of wood harmonises with specific gravity and the width of the annual rings. This rule may hold good within the limits of the same species, but not between different species. A valuable property of woods is that of giving notice before rupture. There is a classical instance of an audience owing their lives to this virtue of the Chestnut. Warned by the cracking of the timbers of the edifice, they fled in time.

Flexibility

Flexibility is that property which permits a substance to be bent without breaking and without, of necessity, returning to its original form. Familiar instances are Withies and strips of wood used for the hooping of casks. In such woods the compression layer is plastic, and the fibres fold without rupture. A proof of this will be found by examining the structure of a wood that has been bent or compressed. I have a portion of a pit-prop which had lain for many years under the débris of a roof-fall and was flattened into an oval shape. The fibres of the two longer sides are to all appearances normal, but at the ends, where the reduction in size is greatest, the fibres are distinctly folded, much as they are in the well-known "rams-horn" or "fiddle-back" figure, but on a smaller scale.

Moisture causes the wood to become more plastic and is the reason why the moisture-content of wood so seriously affects the results of transverse tests, and in the above instance, why the pit-prop could be flattened without injury: it had lain in the wet ground until saturated. In the dry state, the Pine, from which the pit-prop was made, is not at all a flexible wood.

Heat, whether dry or moist, makes the wood more plastic as already stated. The celebrated Perpignan whip-stocks, which are so flexible that the whip can be "cracked" both forwards and backwards, and which no self-respecting French carter would be without, are first bent and then fixed by baking. In this case the bending probably compresses the fibres, which would normally regain their original form (the wood being extremely elastic), but the subsequent heating softens the fibres which rearrange themselves in a manner that they afterwards retain. In Germany, according to Gayer (1903, p. 502), whips on this principle are made from Ash, Maple, Sallow and Juniper.

Larger pieces may also be bent, as witness the manufacture of felloes for cart-wheels. In the north of Europe the Birch has long been used for this purpose. A sapling is bent into a circle and the rim entire made of one piece (Stevenson, p. 59).

Flexible woods, in the sense of being easily bent without preparation of any kind, are usually weak. Green wood is more flexible than dry and sap-wood more so than heart-wood. In both cases the difference is probably due to the greater water-content.

In the popular mind flexibility and elasticity are often confounded, whereas the one form of resistance is due to a quality which the other lacks, *i.e.* the reaction to compression.

Toughness, which is described by Exner (1902, p. 169) as being that quality which permits a wood to be strained past the breaking-point without the separation of the two parts, seems to be much akin to flexibility. It implies that the wood is so plastic that by ceding to the strain it provides no fulcrum, as it were, by means of which the tension layer can be ruptured. Resistance to shock owes much of its nature to the plasticity of the fibres. We see the two qualities combined in many woods. Exner (1903, p. 171) gives the following list as being both flexible and tough: Birch, Willow, Bird-cherry, Hickory, some species of *Pyrus* allied to the Service-tree (*Sorbus-arten*), Poplar, Hornbeam, Elm, Acacia, *Celtis* (Nettle-tree), Beech (only when steamed). Small strips used for hoops: Oak, Hazel, Cornel, and suppressed Spruce (grown under close shade). Young wood of Willow, Birch, Hornbeam, Aspen, Ash, Oak and Elm. The wood of the Chestnut is employed for the rings for masts.

Inasmuch as oil is used to render Canes more pliable, it would be interesting to know whether creosote has the same action on timber and by how much the strength is thereby diminished.

A wonderful example of the capacity of wood for bending is seen in the use of the Sitka or Silver Spruce for making of aeroplane spars. The McGruer spar is of two-ply wood, about $\frac{1}{4}$ inch thick, bent into a tube about 2 inches in diameter. The section is sometimes oval. The remarkable thing is that the wood is bent with the boundaries of the rings running the length of the tube, *i.e.*, it is made from quartered wood. Some of this is as slowly grown as twenty-six rings per inch.

There is not much to add as regards methods of testing the elasticity of wood to what has already been said on the head of resistance to transverse strain, besides which the methods are well known. I strongly recommend the use of a mirror to throw a reflected beam of light upon a scale to magnify the reading, as in some cases it is very small. As we know so little of the influence of the structure, the orientation of the test-piece is important, and I suggest that cylindrical pieces should be used in addition to the customary rectangular bars. The change in the radius of the curve should also be observed. Experiments on flexibility with gradually increasing quantities of moisture and of heat, both moist and dry, will be fruitful of practical results. The American investigators are already doing something in this direction.

Torsion

I am not conversant with the experiments which have been conducted of late upon the torsion of woods. The only work of which I have knowledge being that of Bevan (p. 129), who gives a long table of the moduli of different woods. Some of the results are surprising, the Horse Chestnut (modulus 22,205) being higher than the Walnut (19,784). When arranged in groups according to his figures, the most heterogeneous mixture of species is produced, which do not in any way agree with our impressions. Bevan says, however, "I have observed in a great number of experiments that the modulus of torsion bears a near relation to the weight of the wood when dry, whatever may be the species, and that for practical purposes we may obtain the deflection from the specific gravity." A study of his list when completed by the addition of the average weights per cubic foot, which he provides in a few cases only, will show that there is some relation between these two properties. (*See* H.S. in *Aeronautical Journal,* 1918, p. 263.) Of the 42 species enumerated, the 21 heavier woods contain only five which have a modulus less than 20,000, and the remaining 21 contain only four exceeding that figure, so that we may adopt his suggestion. One gathers from his figures that resistance to torsion does not vary as the strength, as the Oak, the Scented Cedar and the Pine come close together and the Cane falls into the same group with the Horse Chestnut. As regards the last-mentioned pair, I imagine that one would be ruptured while the other would not. Torsion does not accord with elasticity, as the Laburnum (used for long-bows) comes in close proximity to the Lime-tree and the Willows. It does not correspond with flexibility, as the Beech and the Apple are too near the Horse Chestnut.

I suggest that torsion will accord chiefly with the resistance to compression, modified by the fissibility, partly because in Bevan's list the resistance to cleavage (as far as my empirical knowledge permits me to say) seems to rise along with the modulus of torsion. Secondly, when a stick is twisted, the strain tends to separate the fibres in the direction of the length, as in splitting. Thirdly, as the fibres of the outer portion of the test-piece must take a spiral direction and hence tend to lengthen, while the centre of the stick tends to shorten, there is therefore a tensile strain acting upon the external fibres and compression upon the middle. The part that will give way first is the plane of adhesion between the annual rings.

Attention to the structure is here again necessary, but not so much as in transverse tests, because the strain is more equally distributed; still the wood having annual rings of greater radius which run as parallel as possible to one of the sides, will be the strongest. The cylindrical form of bar is preferable to the rectangular shape, as the corners of the latter are likely to be the least firmly attached and in taking the spiral direction they have so much farther to go. The strain in a cylinder will be evenly distributed at least, and, moreover, the orientation of the sections will be indifferent.

Resistance to Shearing.

The manner of carrying out shearing-tests as recommended by the Internationalen Verbaende fuer Materialpruefungen der Technik (*ex* Stamer, 1910, p. 379) by means of a machine recalling the clipping-machine used by blacksmiths, appears to me to be unsound, as if the iron edge which impinges upon the wood be a true right angle, it becomes a cutting instrument, and be the corner rounded ever so little, the weight required to shear the wood will bear no proper proportion to that needed when a rectangular plunger is used. This kind of test is somewhat frivolous, inasmuch as unless the investigator wishes to ascertain the resistance of the wood to edge-tools, he might set about it in other ways. If he wishes to find out how much the structural parts of buildings will stand, then the introduction of a square-edged iron resting upon wood is an absurdity. The only case in which it can serve any good purpose is in that of railway chairs resting upon sleepers, but even here the edges of the chairs are blunt, and the problem is one of crushing rather than shearing.

As already said, under the head of tensile strain, shearing is met with chiefly in the matter of bolt-holes, tenons and such-like expedients, where wooden rods are used as ties to support other wooden pieces. Hence, it will be either wood against wood (when wooden pegs or trenails are used), or against iron bolts, which will be round and not square. When strain is put upon these we shall have in the first case two possibilities :—Either the wood exterior to the hole will tend to be sheared out or the trenail will be sheared off. Secondly, in the case of the iron bolt the former alternative only is possible, but there will be no cutting, only pulling. Extreme care must be used in selecting wood for work for ties, both as to the orientation of the rings and to the species. The wood should have no pronounced lines of weakness such as pore-rings or large rays. A diffuse-porous wood with the bolt-hole bored at right angles to the rays is the ideal material.

Resistance to Friction

That there is a considerable difference amongst woods in their resistance to friction is common knowledge that dictates their use in many ways. Pliny (XVI, 76, 9) says that the rubbing-sticks employed in his day for the making of fire were of Ivy for the lower piece and Olive for the rubber, *i.e.*, a hard wood against a soft one. The choice of the Olive does not seem clear : I fail to observe any particular resistance of its surface. Theophrastus (V, 5, 1) mentions the little tablets made of the wood of the Wild Pear-tree, upon which cobblers whetted their knives. The wood of *Oreodoxa oleracea*, Mart., is used as a razor-strop (*see* the specimen in the Museum at the School of Botany, Cambridge), and Boulger (1902, p. 333) says that *Cecropia peltata* is put to the same use. This last species is one of the fire-producing woods, according to Laslett, who adds *Fusanus spicatus* (False Sandal-wood), *Hedycarya angustifolia*, and *Cordia myxa* (the Sebestan Plum). Willow and Poplar are used for brake-blocks, and the latter, according to Holtzapfel (p. 102), is utilized by glass-grinders for their wheels, discs about one inch thick being cut from the transverse section of the entire tree.

On the other hand, woods that are especially free from grit have their particular applications, *e.g.*, the Cornel is used by watchmakers for the removal of dust from pivot-holes, and the Alder for the polishing of clockwork.

Hornbeam and Pear were much employed in the past for mill-cogs, but this was probably on account of their toughness rather than their smoothness : the former is certainly a smooth wood, but as we have seen above, the Pear resists a sliding motion. For bevel-gearing, which is always noisy and troublesome, wooden cogs can be very well utilized to-day.

The most important application of the resistance to friction, though by no means the most obvious, is seen in the use of wooden spokes and felloes of wheels. As the spokes rise to the top of the wheel as it turns, the weight of the load forces them into their sockets in the felloes. This causes a wheezing noise. As they descend in their turn and approach the horizontal, where the pressure of the load forces the rim outwards, the spokes are drawn out of the sockets again, accompanied by another equally characteristic sound, like that of a cork when drawn from a bottle. By-the-way, one can tell a wheel made from Ash from one of Acacia by the difference in the " creak." Nearly the whole of the wear of a wheel comes between the spokes and the sockets, so the choice of wood for both these and the felloes must to some extent be dictated by their resistance to wear in these parts. Some woods become burnished by friction, *e.g.*, the Sycamore, of which small cotton-reels are often made, the edges of which are burnished by the contact of a smooth steel tool. Others burn, as witness the brown rings that form part of the rough decoration of cheap German toys (nine-pins and the like), produced by the contact of a harder piece of wood while revolving in the lathe. Others, again, offer so little friction that they may be employed for the bearings or journals of shafts. I remember the time when polishing spindles, that revolve with extreme velocity, ran in bearings of Lignum-vitæ (*Guaiacum*), and, according to Garraud (p. 189), the Boxwood was used in the same way. These polishing spindles showed no appreciable wear after many years' use, whereas those running in brasses are worn out comparatively quickly. Lignum-vitæ is used in Germany for the packing of power saws (Gayer). Sneezewood (*Pteroxylon utile*) is said by Boulger (1902, p. 314) to be even superior to Lignum-vitæ, brass or iron, for bearings.

Birch stands wear by friction better than any other European wood. The cross-bar in the turning mechanism of the rude waggons of the French country-side, takes, by means of a longitudinal piece, the weight of the shafts. At each movement of the latter these two pieces slide on each other. Only the most resistant woods could stand this. For waggon-building, Gayer (1903, p. 484) says the Birch is preferred before all other species. Besides this, it makes the best flooring for mills when used as battens and laid with the edges of the annual rings upwards. The Elm wears to a smooth surface, and is therefore employed for printers' and dyers' rollers, gunwales and dead-eyes (Stevenson, p. 34).

In the operation of turning, one end of the wood must often be supported by a centre, against which it revolves. The friction is severe in proportion as the speed of the lathe is great, and this in modern workshops is sometimes enormous, hence the question of the resistance of different woods is, in this way, of some technical significance. In preparing specimens of some 97 species of woods from British Guiana, I was struck by the great difference displayed by them in this respect. It is of course usual to lubricate with oil, but there are woods in which the centre-mark becomes burnished without burning even when run dry. Then, the oil may be quickly absorbed, it disfigures the wood, and may even be wasteful enough to be worth consideration in workshop practice.

Certain woods have a greasy surface, for example, the Tuart of Australia, and the West Indian Satin-woods. There is much oil in the latter woods. The Ash is somewhat unctuous to the touch, the Balata (*Mimusops globosa*) becomes slippery when used as flooring (Spon, p. 2013), and some hard woods become slippery from the usage of traffic, when employed as wood paving. On the contrary, Hemming says that the Kauri Pine (*Agathis australis*), under similar circumstances, does not.

Very few experiments have been performed to ascertain the resistance to a sliding motion displayed by wood. The only work that I have been able to find is that of Rennie (1829, p. 152), who gives some interesting figures. His conclusion that soft woods offer more resistance than hard ones will not be greatly disputed, but there will be so many exceptions that such a rule has but little value. His finding that the Red Teak offered the least resistance and the Yellow Pine the most, may be merely fortuitous, because the Teak has a greasy surface and the Pine may have been slightly resinous.

Rennie's method is vitiated like most others by neglect of the course of the grain, for it must be clear to all that the resistance of the transverse section must be vastly greater than that of the other cuts, and the radial would be more resistant than the tangential, because the rays which crop out as silver-grain must be drawn sideways along the surface in contact.

Rennie caused two pieces of wood to slide one upon another by means of, firstly, a weight suspended over a pulley, the test-pieces being held down by other weights. The amount of the latter required to cause the test-pieces to slip is the amount of the friction, otherwise its modulus. Secondly, he tilted his machine and caused the test-pieces to slip either by increasing the angle of inclination or the weights. So long as attention is paid to the sections this method may serve. I prefer, however, to adopt the lathe in which the tail-centre of a given size is pressed against the wood by a given weight and the number of revolutions at a known speed necessary to produce the first sign of burning be utilized as modulus.

CHAPTER XI

RESONANCE AND CONDUCTIVITY OF SOUND

THAT wood is an excellent conductor of sound is familiar to all on account of its application to the manufacture of instruments of music, sounding-boards and the like. No property of wood has been so thoroughly studied from a technical point of view as this, yet the literature of the subject contains but little information. I have searched in vain for any exhaustive treatise, and even the best books upon the violin, such as those of Hill and Tolbecque, leave one with a score of questions still unanswered.

The care with which the wood for violins is selected implies that there is something in the structure of the material which is all important, yet when each feature is examined, one by one, it is found to be indifferent.

Slowly-grown wood for the belly is insisted upon by all writers : the Italian masters did not, however, carry this to the same excess as the German makers. They endeavoured to obtain uniformity and straightness of grain rather than narrowness of the layers of wood. These layers (the boundaries of the annual rings) almost invariably run direct for the whole length of the belly, yet I have seen a violin by Costa (date 1754, Gauthier Collection, Nice, No. 1,073) which has the grain curved in a pronounced manner, and evidently expressly chosen, as the right- and left-hand sides balance each other.

Most instruments of European origin have the wood for both back and face cut on the quarter (radial section) ; still, Magnin, and even Stradivarius, occasionally employed it plankwise (slab-way or tangential section) (Tolbecque, p. 70).

The wood of the belly is of much greater significance than that of the back, as is proved by the greater diversity of species employed for the latter, whereas rarely more than two kinds are used for the front, not only for violins, but for guitars and mandolins also. For the violin only two species are used, the Spruce and the Silver Fir, the consensus of opinion being greatly in favour of the Spruce when of a special growth. This is known in Germany as "Resonanzholz" and in France as "Sapin de Galicie." The part from the exterior of the tree is the best which accords with our finding as regards elasticity (*see* p. 138). The Silver Fir (Vrai Sapin, *Abies pectinata*), according to Tolbecque, is not resinous enough, and is never employed except for violins "demi-fins" (compagnons) and contra-basses, but he adds that it was used by the old makers of Paris. Boulger (1912, p. 113) says the kind of Silver Fir known as "Swiss Pine" is now accounted the most resonant of all woods and is used for the bellies of violins. I have not been able to obtain confirmation of this. A species of Cedar is said by Tolbecque (p. 50) to have been used occasionally.

I have had the opportunity of examining the "Sapin de Galicie," supplied to me by M. Bovis, luthier, of Nice, and am able to confirm the determination as *Picea excelsa*, Link, the Common Spruce. It is by no means easy to identify the wood of the belly of a violin, as one cannot cut sections. All depends whether the very scarce vertical resin-canals (present in the Spruce) are shown. As these may be absent over as much as fifteen inches of ring, and as in the radial section they appear in their smallest numbers, one has to search the whole surface with great attention. If a resin-canal be found, then the diagnosis as Spruce is certain, but in the event of failure to do so, one cannot conclude that the wood is of Silver Fir; it is still possibly Spruce. When the wood is cut plankwise, where a greater number of canals may be expected to be exposed, the task is easier, but not certain. The canals in this section appear as minute scratches that run across the hard wood of the Autumn zones and sometimes stray a little into the softer wood adjacent. The largest number of these canals that I could find on the transverse section of a block of "Sapin de Galicie" was 6 per centimetre of arc, or, say, 20 per inch.

A variety of the Spruce known as "Hazel Pine, Haselfichte, Sapin coudrier, Sapin à chenilles," etc., shows a silver-grain that is apparently caused by a hypertrophy of the rays of a similar nature to those accompanying the pith-flecks of the Alder. According to Noerdlinger (1859, p. 25), this wood comes from Bohemia and is grown on swampy land. He mentions (p. 349) a fine board from an altitude of 2,900 (Vienna) feet above the sea. Its average width of ring was 0·72 mm., or about twenty-nine rings per inch.

The assumption of some makers (amongst them Tolbecque) that the grain is always widest at the centre of the tree and diminishes outwards, is true only according to circumstances. It may happen so, but it is not so of necessity. It is a question of the amount of light enjoyed by the crown of the tree.

Of two specimens given to me by M. Bovis from the outsides of very large trees, No. 1 shows 110 rings in a radial distance of 11·5 centimetres, the widest being at the rate of 6 per cm. and the narrowest 12. No. 2, in a distance of 11·0 cm., shows 78 rings, of which the widest are 6·5 per cm. and the narrowest 9·0. Taking the rings by groups of 10. Specimen No. 1 gives the width of certain selected groups, counting from the heart side to the back: First group, 8·25 mm.; fifth, 7 mm.; eleventh, 15 mm. The second group from the heart has the narrowest rings. Specimen No. 2: First group, 13 mm.; second, 18 mm.; fourth, 11·25 mm.; eighth, 14·5 mm. Here the fourth group has the narrowest rings, while the width of the groups rises and falls twice.

Next to the width of the layers comes their continuity. This is gained by using the wood in the radial section, yet we have seen that excellent instruments may be made from the tangential cut, where the layers are anything but continuous. Then the belly is made in two parts, right and left, with a wing on either side, making four parts in all, so that lateral continuity is not taken into account. This refers to the coarser structure only. As regards the minute structure, we find that it is of no moment whether the fibres be severed or not, as the belly is not bent into its somewhat swelling form, but is carved out of a thick piece, the underside being hollowed out. Certainly the German practice, according to Gayer (1903, p. 496), is to bend the belly by means of hot water, but this does not seem to be that of the best masters. Then, violins which develop bad places by decay or injury of any kind may be patched by having a piece taken out and replaced by another. In the case of guitars, the air-holes are sometimes so large that such strips of wood which remain continuous from end to end are very narrow indeed, compared with the width of the instrument.

The wood for the back of the violin is of less significance, as is indicated by a greater range of species, showing that the minute structure is of little influence, for no group of woods of more dissimilar structure could be found than those employed for this purpose. The Maple is most frequently met with, and may be regarded as the staple material; Poplar comes next (there are three examples in the Gauthier Collection at Nice); Walnut third (my friend, M. Bovis, has three); the Plane-tree exceptionally, and very rarely, the Lime, Beech, Cedar and Pear. The writer in the *Grand Encyclopédie* (XXII, p. 788) speaks of the Plane as being frequently used, and Varenne de Fenille says that the wood preferred above all others is the Sycamore. Red Walnut (*Noyer rouge*), a name which at the present time is not understood, is mentioned by Tolbecque, who also cites a Stradivarius (a bass belonging to O. Vaslin) that has both back and sides of Lime-tree.

The grain (the ring-boundaries understood) runs the whole length of the back direct, but the wood-fibres may be indifferently straight or undulating, or, as already mentioned in the case of the belly, even interrupted. The back is made in two parts from apparently æsthetic motives, to balance the figure of the wood. The material is cleft in the direction of the radius of the tree (quarter-cut), and in many instances it shows ripple-marks on the figure, known as "rams-horn." As this latter is caused by the undulating course of the fibres the crests of the waves of which are cut off in the planing, neither straightness nor continuity of the fibres can be of any moment.

M. Bovis tells me that the Maple more commonly used at the present time is from the Vosges, and possesses the rams-horn ripple; next comes the Hungarian Maple, which is plain. M. Pecquin, who is responsible for the determination of the species mentioned by Tolbecque, says that the Érable des Vosges is *Acer platanoides* and that other species used are the Sycamore (*A. pseudo-platanus*) and *A. opulifolium*, Villars (syn. *rotundifolium*, Lamk.; *A. neapolitanum*, Forsk). The wood that comes from Switzerland and the Tyrol is nearly exhausted. All are much of the same quality. The wood of the Sugar Maple (*A. saccharinum*) was tried, but abandoned, and the same may be said of the Bird's-eye Maple (a variety of the same species). The wood from the Vosges arrives in small pieces, that from Bohemia in large logs; still, the small pieces of the former indicate trees of considerable dimensions.

Hill (1902, p. 35 *et seq.*), whose opinion on this subject is worth quoting *in extenso*, says: "In choice of material it cannot be said that Stradivari was particularly happy. . . . The Maple is rather plain cut the slab-way of the grain, showing but little cross-figure and with veins running in a downward direction or in curves; or it is of another tree, marked by a small and weak curl, this time the right way of the grain. The Pine is of invariably good quality. . . . Only towards the end of Nicolo Amati's career do we begin here and there to see other woods than the ordinary native Maple used; it is easily distinguishable by the broader markings of the curl as contrasted with that of the small, close figure which we are so accustomed to see in the Amati instruments. All the members of the family showed a great preference for cutting the wood the slab-way of the grain." (*Ibid.*, p. 159), "Even with faulty, not to say absolutely bad material, if construction and dimensions are right and good varnish is successfully applied, a fairly good instrument will result, but though the wood and also construction and dimensions be perfect, the result will be astonishingly bad if the instrument be badly varnished. . . . The early Brescians used in the majority of cases for the backs, sides and heads of their instruments Poplar or wood of kindred nature, such as Lime, Pear and even Cedar; for the bellies, Pine, often of an exceptionally hard variety, cut the slab-way of the grain. . . ." (p. 165), "We may add a word as to the delusion that material taken from buildings, as, for instance, Swiss châlets—in some cases centuries old—is preferable to that cut and seasoned a less but still sufficient number of years . . .; in fact, our opinion is rather in favour of the more youthful woods. Our conclusions are that Stradivari's choice of material depended upon two circumstances: first, the remuneration he was to receive for a given instrument; second, the choice of wood he had at the time."

The opinion of another authority, who in this case is one possessing a profound knowledge of wood, is also worth quoting at length. Piccioli (*Technologo del Legno,* 1919, p. 24) says: "Stradivari used greater care in the selection of his wood in point of density than his predecessors: whilst the ancient violin-makers had adopted Pear, Cedar and Ash for the back and sides, he used Maple for the back, sides and neck, Spruce for the belly and White Poplar for the internal reinforcements and the four pegs. He insisted upon the radial section of the Spruce in order to obtain 'figured wood,' whilst Amati and the ancient Cremona makers cut it the slab-way (tangentially). The greater part of the Spruce at that time came from the South of Switzerland and the Trentino: the Maple from Istria and Dalmatia. The value of the ancient violins depends upon the selection of the wood, already carried out with great care by Nicolo Amati and with supreme skill by Stradivari, who did not make use of it until after prolonged seasoning. He arranged the single board (or the two halves) so that the narrowest rings were placed in the median line of the instrument, or alternatively, the narrowest rings under the bass and treble strings (*i.e.*, under the two feet of the bridge). From this arrangement the bass string acquired a tone that was noble, grandiose and enchanting, and the treble responded with a limpid and silvery sound sweet enough to compare with the trills of the nightingale. The wider the grain (annual rings) the duller becomes the tone, hence the choice of the width of the grain must be regulated by the 'timbre' of the instrument desired. For instruments constructed with particular care, it is the practice to choose only the wood from the side of the tree which was turned towards the South, easily recognizable even on rough logs by the absence of moss and lichen. It is a widespread opinion, not only amongst makers and violinists but also amongst physicists, that a potent factor in the excellence of the instrument is their age, that is to say, the work of time and the prolonged use by skilful artists, modifies their virtue. It is contended that the elasticity of the wood is tempered by the effect of harmonious and regular exercise, which gives force, uniformity, purity and sweetness to the tone. The effect of use, for example, is shown in the case of the violins of Guarnari del Gesu, that on account of the thickness of the belly have to be played for a long time before they produce high and vigorous notes, but subsequently acquire great security in passages needing agility and force."

Amongst the woods less employed is the Beech, by Bergonzi (Tolbecque, p. 55), and I have seen it mentioned elsewhere (*Dict. Petit Larousse*, p. 1051). Mangin and Mayne (p. 9) mention a wood from the South Tyrol called " Azarole " (possibly *Pyrus* [*Cratægus*] *azerolus*, l'Épine d'Espagne, known in France as the Azerolier), as being used by the Cremona makers. Hart mentions Pear, Ash and Lemon-woop.

Lupot (p. 4) objects to the rams-horn figure for the back, but says that we must excuse this little weakness in amateurs.

From all the foregoing we gather that neither the structure, as indicated by the species of wood, nor the fineness of the annual rings or the fibres, nor their course and continuity, nor the manner of cutting (slab-way or quarter-cut), are absolutely " de rigeur " ; in fact, we are compelled to endorse the opinion of the writer in the *Grand Ency.*, that many, if not the whole, of the details are insisted upon more from the fear of departing from the old models than because of their real significance.

A modern violin is quite an interesting collection of woods in its way. It consists as a rule of Spruce for the belly and the sound-post (a little peg inside which supports the bass leg of the bridge) and the bass-bar which is attached inside to the belly, running vertically the whole length and placed under the opposite leg of the bridge ; Maple for the neck, the volute, the bridge, the sides and the back ; Ebony for the touch, the keys, the button and the attachments of the strings, and Willow for the blocks which secure the neck to the body and for the linings.

The sound-post is generally supposed to convey the vibrations from the front to the back, but if this post be taken away and a weight placed upon the violin, there is no change in the effect. Stradivarius used Willow of a deep brown-red colour for the blocks and linings. The Amatis used Pine for the former (Hill, p. 187).

The wood for the sides is nearly always of Maple or at least some species of the same genus (*Acer*) ; still, one meets with Beech, especially in the large instruments. The choice of the wood in this case is dictated by the capacity for bending.

The backs of guitars and mandolins are more varied in the matter of wood, fancy being allowed more play. the Rosewood (*Dalbergia sp.*), both a resonant and ornamental wood, being a favourite for the latter.

In all the above instances it is the power of wood to augment sounds that is in view. This may be associated with the property of conducting it, as was well known to Pliny (Lib. XVI, 73, 1), who says that a blow with even so small an object as a stylet may be heard through the whole length of a log if the ear be applied to the opposite end. I may add that the tapping of the fingers, otherwise inaudible at a distance of six feet, can be heard quite well through the longest pole. An amusing application of this property was exhibited by Prof. Pepper at the Polytechnic, where he adapted an invention by Tyndall. Pepper placed four poles so that they passed from the basement up to the third floor, the lower ends being in contact with various instruments, while upon the upper ends harps were rested. In an illustration in one of Pepper's popular works the instruments shown are violin, violoncello, cornet and harp. The music played by the invisible band, and which was inaudible in the intervening stories of the building, was reproduced in the auditorium, *but in the harp sound.* When no instrument rested upon the upper ends of the poles no sound was heard.

The stethoscope formerly employed by medical men for auscultation was a solid stick of wood, which transmitted the sound of the heart-beat better than a tube would do.

A watch may often be heard ticking like an eight-day clock when suspended on a wooden partition and the ear applied to the woodwork of any other part of the room.

That knots and twisted grain can be detected in wood, as further stated by Pliny, cannot be accepted. In order to know for certain that the knots are there, the log must be cut up, and experience must be also obtained from knotless logs, with which to compare the difference in the amount of conduction, which Pliny was certainly never in the position to do. Tolbecque says that the sensibility of wood in conveying sound is in proportion to the straightness of the grain. This is a more reasonable proposition, but I have never met with any evidence in support of even this. Noerdlinger (p. 485) says that the sound given out by a log when struck with an axe-head is a very deceitful test of the soundness of the former.

Another familiar property of wood is the power to give out notes when struck, as illustrated by the harmonica. An instrument called the "Balafon," used by the Ouaddas of the Oubangui, consists of strips or tubes of wood fixed by fine cords over calabashes of various sizes. These when struck give out powerful and agreeable sounds like that of an organ. The Polynesians of the New Hebrides use a gong, made of the whole trunk of a tree hollowed out, that is audible for six to seven miles. Another gong, of the shape of a large bean, also hollowed, is another primitive instrument. A wooden drum is employed by the natives of the Cameroons for raising the alarm when threatened by the approach of an enemy, and, indeed, serves as a sort of telegraph.

The vibrations of wood produced by wind is again familiar to all, but a curious adaptation of this property by the Chinese is worth mentioning. A thin strip of wood is fixed upon a kite, which when flown gives out intense but plaintive notes. Lastly, an instrument having a resemblance to a zither is made by the natives of Dahomey. The strings are of wood and the notes produced are wonderfully like those obtained from wires.

As already stated, the spokes of wheels will give out sounds characteristic of the species of wood used.

Wood is again employed in the manufacture of wind instruments, such as flutes, clarionets, etc., to which it gives a mellow tone. Amongst the species used may be mentioned the Ebony, Pomegranate, Service-tree and Boxwood. For the pipes of organs Cypress is used in many places, possibly because the organ came West from Constantinople, where Cypress-wood is much utilized. It is said that a celebrated organ-builder, Mittelburger, adopted the wood of the White Cedar after hearing the musical patter of rain-drops upon shingles made of it (Maxwell, 1918, p. 476). Powell-Jones and Walters (*Archives C.U.F.A.*, No. I, 1920) tell me that when sleeping in the open air in the Western Canadian forests, if by chance the head rests upon a tree-root, a sound like a full band is heard. This phenomenon is well known to the W. Canadian Railway Survey men, who call it the " Music of the Pines." Every one knows that the sound due to the vibration of the telegraph wires is heard in the posts, though that of the wires themselves is inaudible elsewhere.

I have already suggested elsewhere that pieces of wood of a given size when made to vibrate might produce notes that could be utilized in identification of species. I have made a rough melodeon by suspending the four-foot specimens at the School of Forestry on a rod and striking them with an ordinary gong stick. Another method is to sprinkle the upper surface of pieces of wood with iron filings and to observe the manner in which they arrange themselves in the so-called " dust-figures " when the wood is caused to vibrate.

Chladni performed experiments upon rods of wood held by the middle in a vice, a violin-bow being drawn across the end to cause them to vibrate. The note was repeated on a differential monochord and the number of vibrations calculated from the length of the wire of that instrument. Wood, however, unlike rods of homogeneous substances, gives a different note according to the section acted upon by the bow, hence the method is of no use for the estimation of the elasticity of woods.

The note given out by wood is or was put to practical use in the choice of logs destined to be employed in the making of violins. Piccioli (1919, p. 23) says that the method was originated by the Italian masters at the time when they enjoyed their highest reputation, and was practised on the Alps, where much of the timber is sent down the mountain-sides in " chutes " or slides called by the Italians " risine." As they shoot down, the most resonant logs may be recognized at a distance by the limpid, vibrant, singing sound that they give out as they strike the sides of the chute. It sufficed simply for the intending purchaser to take his place near a chute in action to appreciate the difference in tone of the various qualities of the logs. These " singers " (cantatori) that were eagerly sought for and bought at a high price were awaited by the merchants at the foot of the chute. The more prolonged the vibration after each shock and the higher the note, the greater was the price offered. Many hundreds of logs might descend without a " cantatoro " being detected.

CHAPTER XII

ABSORPTION AND SHRINKAGE

WOOD in its natural condition is more or less saturated with water, a certain proportion of which comes and goes with great freedom, so that the water-content of the tree may vary considerably from one season to another. Further, one part of a tree may contain less water than another, according to the demand for it made by the transpiring leaves.

R. Hartig (1882, II) has made a number of interesting researches upon this point, of which it will be well to make a few citations :—

(Page 8) Beech is poor in water in the heart, (page 40) and has two minima and maxima. First minimum in October before leaf-fall, maximum in December ; second minimum, February ; maximum, July. (Page 43) Pine has likewise two periods, the Oak and the Larch only one. (Page 5) Spruce is poor in water in the middle of old trees only. (Page 29) The inner wood of the Birch may be richer in water than the exterior, and may remain so throughout the year, except in October. It is the same with the Oak, but the minimum is reached in the beginning of July. (Page 38) In the Birch the transpiration in Summer outruns the water-supply so considerably that in October the water-content sinks to a minimum. (Page 28) Three 110-year old Pines (Kiefer) were sawn through the sap-wood and partly through the heart. One tree was cut so deeply as to be broken off by the wind. One of the others retained its green foliage from the Spring of 1871 to the Summer of the following year. (Page 29) All trees investigated contained more water in the top. (Page 6) A delay of even a few hours greatly disturbs the weighing of specimens, and is the source of great errors. (Page 4) The Birch, Maple and Hornbeam are bleeders (*i.e.*, they can be tapped for their fluid sap).

Again (1891, p. 203, table), he shows that a living Birch-tree may lose 46 out of 67·5 parts of water by natural transpiration between May 24th and December 28th. This proves not only how important it is to know the season of minimum-content of each species of tree, so as to be able to fell at the right season, but also that the great shrinkage which such a loss of water implies may proceed without the least injury to the wood by splitting.

From the above we may learn that the transference of the water from point to point varies in its rapidity according to the species. One tree, such as the Birch, which may be at one time equally rich in water throughout the trunk, may at another dry in the outer wood faster than it can be supplied from the inner, and at still another time water will run from it quite freely. Some of the American Birches will yield several gallons per day. Again, although the demand of the leaves during Summer will cause an ebb in the water of the exterior of the tree, yet, if by chance the tree be felled or girdled, there remains enough water in the trunk to keep life in it for twelve months and more. We learn also not to dogmatize upon wood or to generalize on the strength of experiments upon one or a few species, for each seems to have its own peculiarities and to be a law to itself.

The bleeding of trees is the most remarkable phenomenon. The water must travel in the wood as though there were no obstruction. Prodigious quantities are cited by Marsh as being drawn from single trees. Hence, the wood must not only be saturated throughout its tissues, but must be capable of carrying much surplus water in its cavities that may be set in movement by the mere wounding of the exterior of the woody body. The accumulation of this surplus water would seem to be independent of absorption, which term should be restricted to the attraction that the cell-walls and cell-contents have for water. This implies that what the cells have attracted they will hold until compelled to render it by some force greater than their attraction. The mere wounding of the tree cannot be regarded as a means of bringing such a force into play, so that the water which is free to flow in such cases must be surplus and quite aside from our present question of the power of absorption displayed by wood.

If the transverse surface of a piece of green wood be moistened, the water will sink into it, and if in a condition of complete saturation, an equal quantity of water will be seen to appear shortly afterwards on the lower surface. The water will sink more rapidly into the sap-wood than into the heart. The difference in the capacity of these two parts of the tree may be further demonstrated by floating a piece composed partly of both in water. At first the sap-wood end will float the higher, being less dense than the heart-wood, but the former, being the more bibulous, will absorb the water faster than the heart, and the two portions will eventually float more or less level.

Under ordinary atmospheric conditions wood is never really dry. According to Karmarsch (1841, II, p. 16), the proportion of water in air-dry wood is from 20 to 25 per cent., and never less than 10 per cent. The term air-dry is a very loose one, this condition depending upon weather and climate and fluctuating with every movement of the barometer. Mr. R. St. Barbe Baker tells me that Canadian timber when brought to England gains in weight. The hygroscopic capacity varies with the species. The Bird Cherry will swell and shrink in harmony with the weather. The Silver Fir when cut in a certain direction may be used to actuate a weather gauge. The Horse Chestnut is used for the making of shelves for the storage of fruit, as it will absorb the moisture at the points of contact with the fruit and thus prevent mould. Noerdlinger (1859, p. 510) notes this wood as "absorption rather difficult." The White Pine (*P. strobus*) is said to be a veritable hygrometer (Philadelphia Report). On the other hand, the Alder is employed for sabots on account of its resistance to the penetration of water. The True Boxwood (*Buxus* *sempervirens*) may be distinguished from the false West Indian Box by the difference in their respective affinities for water, that of the former being very low, while the latter is very absorbent. The rising and falling of the dead branches of the Spruce-trees, according to the amount of moisture in the air, is regarded by the inhabitants of Berchtesgaden (R. Hartig, 1901, p. 78) as a weather-gauge, thus demonstrating that the sides of the same branch may be sensible in different degrees. In this case the branch is composed of tissues of different nature, for which we have no proper term, but which are called by the Germans "Rothholz" and "Zugholz." The Rothholz is formed at such places as may be subject to strain, for instance, on the underside of branches and the leeward side of trees on mountains ; it is very bibulous, whereas the Zugholz is passive.

The action of the Rothholz is promoted no doubt by fluid water in the form of rain, as well as from moist air, but the hygroscopic power of woody tissue may be proved by placing thin transverse shavings of Oak in a damp cellar. Some, Hartig (1882, p. 38) says, took up 72 per cent. of their volume of water, while others gained 90 per cent. Woods may, again, vary in their capacity for the retention of water. A specimen of *Xylosma monospora* in my collection remained moist long after other species prepared at the same time had become air-dry, although kept under identical conditions.

As a general rule, wood will take up as much moisture as it originally gave up during drying (Dupont), but it must be added that Roth (1893, p. 32) avers that it will swell to more than its original size when soaked in water, implying that it will take up more. I incline to the view of Dupont, and doubt whether sufficient precaution was taken by Roth to obtain his measurements immediately after the wood was taken from the tree, which must also be done as soon as the tree is felled. It is common knowledge that a considerable quantity of the surplus water will run from the tree when it is severed from the stump, and Hartig has shown how quickly a further quantity may be lost between the time the wood is cut from the tree and that when it is weighed and measured in the laboratory. He went to the trouble of erecting small temporary laboratories in the forest for the purpose of avoiding the error in question. Further, we do not learn from Roth's experience at what time of the year the wood was taken, nor whether his species were subject to seasonal maxima and minima in their water-content.

The swelling that attends the absorption of water and the shrinkage consequent upon its withdrawal being two opposite phases of the same phenomenon, must be discussed together.

The rate of absorption is at first rapid, as is also the first loss of water. With large pieces saturation may take years. Petsch (1896, p. 166), whose excellent book on the use of wood as a paving material should be read by all students, says that paving-blocks of soft wood when immersed in water attain their maximum water-content in fifteen days, and a prolongation of the immersion to 115 days makes exceedingly little difference. For instance, a block of the Cluster Pine (*Pinus maritima*) took up ·267 kg. of water during the first period ; from fifteen to thirty days, ·069 kg., and from thirty to 115 days, only ·008 kg.

The enormous force exerted by wood during the process of swelling is exemplified in the splitting of millstones from the underlying rock. Holes are drilled in which cylinders of wood are inserted and water then thrown upon them. The slow and gentle but irresistible pressure exerted detaches the millstone without fear of injury. Strange as it may seem, the wood used for this purpose is a soft one, either Spruce or Pine.

This great attraction for water is ascribed to the imbibition of the cell walls, though the employment of this term does not make the process any clearer. The immediate effect appears to be the shortening of the fibres and the thickening of their walls, which at the same time become more plastic. Until this great force of imbibition is satisfied there can be neither water for the cell cavities nor free or surplus water. In what manner then is the swelling caused ? It cannot be simply the result of the thickening of the cell-walls, as, if the cavities be empty, the walls will close in upon them, just as a pneumatic tyre collapses when not supported from within by the air.

The woody-fibres which compose the bulk of the tissues are hollow, spindle-shaped bodies, the walls of which are extremely thin in comparison with their length. If the walls imbibe water and swell up, they must do so in all directions alike, so that the swelling should manifest itself vastly more in the direction of the length than transversely, which does not appear to be the case ; the increase in length of wood from this cause is infinitesimal. If the cell-walls are not supported by fluid in the interior of the cell, any thickening of the former should cause them to occupy more room or close in, so that the thickening should be balanced by a reduction in the space of the cell cavities. But this, again, does not appear to be the case, for we see that in a transverse direction the swelling is great ; nor would it solve the question of the non-extension in length, as the closing in of the sides of a spindle-shaped body should cause it to lengthen. It would seem fantastic to assume that a homogeneous substance like the cell-wall should on the absorption of water increase in thickness and decrease in length, yet such is the truth as regards the cotton-fibre when mercerized, as is known from actual observation. Cotton, and to a less degree flax, contracts with extreme violence when wetted, as is well known to the users of rope made of either material, so, inasmuch as the woody-fibres are of similar composition, can we accept this comparison as more than an analogy ? If this be good, then the apparently paradoxical case of the Silver Fir, which when cut in the direction of the radius is, as already said, used as a hygrometer, but if longitudinally, changes its length so little that compensating pendulums can be made of it, may be explained. There is an auxiliary cause for the swelling in a lateral direction, that is, the rays that traverse the wood. These are composed of thin-walled elements whose lumina become rapidly filled with water, and as thin sections show, have an extraordinary capacity for swelling. They are the first to absorb water and the first to give it up, and I believe that the most considerable share of the augmentation in bulk, as illustrated in the citation made from Petsch, is due to the rays. The rays are spindle-shaped in tangential section, and when their lumina are distended with water they tend to become wider and at the same time lower. Their action is to increase the swelling laterally by forcing out the fibres surrounding them, and so reduce the length of the wood. The position of the rays is also calculated to cause swelling. When seen on a transverse section (as the tree stands) they appear like the main strands of a spider's-web. Between them is a sector of wood which forms a very slender wedge. Now, when the rays gorge themselves with water and occupy more space, the wedge-shaped sectors of wood will be forced outwards and the periphery of the tree increased. Periodic and even diurnal changes in the diameter of trees have been observed by Kaiser and Friedrich, and Gayer (1903, p. 59) says that he has observed fluctuations in the height of trees, but it does not appear whether the increase in diameter is accompanied by a decrease in height, or the contrary.

Supposing, however, that the simile of the cotton-fibre does not apply and that the substance of the cell-walls shrinks equally in every direction, then the mass of the strands must become reduced in length. This will shorten the space occupied by the rays, but as the periphery of the stem is lessened by shrinkage, as already said, and the meshes of the net-work thereby closed in, thus lengthening the whole, the shortening due to the contraction of the cell-substance will be compensated more or less. This seems to agree better with the observed facts, for whether we regard the cells or the rays, the action of shortening from any cause is compensated by another, so that the apparent absence of change in the longitudinal direction in wood is accounted for.

The two systems (fibres and rays), being composed of hollow fusiform elements, act in the same way in the same direction as regards the tangential and longitudinal movements, and differ only in the fact that during the period of greatest change the fibres are not turgid while the rays are full of water. As soon as the ray-cells become flaccid they take no further part in the shrinkage, being too weak and too weakly attached to the fibres. During swelling, on the contrary, the ray-cells rapidly become turgid and must exert great pressure, tending to tear the wood apart in all directions as they outpace the swelling of the fibres. Hence the fact, but little known and appreciated, that wood splits even more easily when swelling than when drying. Discs of dry wood when placed in water will crack audibly and often become dished like saucers. A disc of *Diospyros lotus,* an inch and a half in thickness by about twelve inches in diameter, when soaked became dished as much as five-sixteenths of an inch by depth-gauge. It became flat again on drying (*Archiv. C.F.A.*, No. 1, 1920).

In order to gain a true idea of the action of the rays, let us for a moment imagine what would be the condition of things if they were absent. We should then have a plexus of fibrous strands resembling those of a net, the meshes of which are drawn tight in the form of narrow slots of fusiform section. The strands would be connected one with another at the upper and lower ends of the meshes, just as those of a net are by knots. There would be many concentric layers of the net, and here the simile will go no further, because each concentric layer would be soldered more or less firmly to those within and without. Instead of a true net-work we have really a mass of fibrous strands penetrated by slots arranged radially (*see* p. 75). If the fibres of the structure shrink, thus becoming thinner, there will not be of necessity any movement or shrinking of the whole mass in a tangential or peripheral direction, but in a radial direction, the strands being continuous, the shrinking would draw the whole towards the centre of the tree, so that the actual periphery of the tree and of every annual sheath of wood would be lessened.

During drying the rays (which are present in every species of wood that we have under consideration) must be affected by the thinning of the individual fibre-strands. The latter tend to leave the rays *more* room, but as the whole mass of the strands is drawn in towards the centre, where there is less space, they must have *less* room, so that one action may balance the other. Were it not so, the rays would be torn away from the strands surrounding them, the more so as the rays shrink more than any other tissue. Indeed, in unequal drying, the rays do so separate, and are the cause of checking or cracking and honey-combing, but in wood of uniform structure, when gradually and slowly dried, this checking is minimised.

The rays themselves may either be extremely fragile and easily ruptured, as is usually the case where they consist of a single series of cells, or they may be much the hardest of the tissues present, as in the Beech. Hence their mechanical resistance will vary, but in wet wood, when they are still full of water, the most delicate kinds of rays may offer great resistance. Wagner (p. 131) says that the rays pull against the woody-fibres, "thus the structure is subjected to two severe strains at right angles to each other. . . . This smaller shrinkage of the pith-rays along the radius of the log (the length of the pith-ray), opposing the shrinkage of the fibres in this direction, becomes one of the causes of the second great trouble in wood-seasoning, namely, the difference in the shrinkage along the radius and that along the rings or tangent."

The rays themselves can only resist a stress when they are turgid; when they are losing water faster than the rest of the tissues they must be flaccid, and it is inconceivable that such delicate structures can oppose any appreciable resistance. It is the collapse of the rays that facilitates, not opposes, the shrinkage, as it permits the sectors of wood between them to draw towards the centre of the tree, as already said. Rays having thick and hard cell-walls may take an active part in the shrinking but cannot oppose the action of the fibres because, as we have seen, the shrinkage of the latter must be greater in the radial direction, where they form an uninterrupted tissue. Jancka says (1915) that the higher the specific gravity of the wood the greater the shrinkage. If the latter equals the swelling on absorption, then Jancka's law is borne out by the instance of the Jarrah, but is belied by the Ebony. As a matter of fact, there is no such law between species, as stated in so many cases, but it will apply to the wood of different densities of the same species. It is quite true that, in general, dense wood shrinks more than lax wood.

The examination of the ends of dry logs and planks will show that the various zones shrink in different degrees. In some Coniferous timbers, such as the Douglas Fir, this is very marked, the hard Autumn wood standing up in ridges. In such woods the lesser shrinkage is due to their greater resin-content. The great shrinkage of the Spring wood would lead us to expect a much greater longitudinal contraction than is usually accepted as being possible. Hartig puts this down as only 1 per cent. Wagner (p. 138) says that the old tradition that woods do not shrink endwise has long been shattered, and cites instances of veneer, basket-stock and stave-bolts as evidence. In veneer he says (p. 139) that the Cottonwood has been observed to shrink full one-eighth inch in 36 inches and so has a cabbage-crate strip sawed from the log without boiling. As this amounts to one-third of 1 per cent., the instance somewhat lacks shattering force.

Rondelet gives for the shrinkage of the Silver Fir the figure of ·000091 of the total length, and for the Oak ·000152, both of which are practically inappreciable. Col. Lloyd (*ex* Holzapfel) found that Teak beams 38 feet in length shrank three-quarters of an inch in length (about 0·164 per cent.). The Eng. (*Dipterocarpus tuberculatus*) sometimes substituted for Teak, has been known to shrink as much in 40 inches.

The swelling varies, as may be expected, with the species. Thil (*ex* Boppe, p. 91) gives the following figures: Young Oak, ·400; old Oak, ·130; Ebony, ·010; Ash, ·821. These show important differences, which must be taken into consideration in all work where thrust has to be feared. This thrust has become a matter of moment in view of the extensive use of wood-paving, as the swelling of a large number of blocks in contact may be sufficient to cause the whole pavement to rise. If sufficient play be allowed or if the wood be green when laid, the blocks on drying will become loose and permit the road sweepings to fall between them, which is offensive. Petsch made many experiments to ascertain the amount of expansion of blocks when immersed. These have a practical application, but do not aid us in this discussion, because we do not learn in which direction the wood was cut in relation to the structure. He found, however, that of all the species tried up to his time in Paris, the Jarrah was the one that swelled the most. Wagner (p. 136) mentions a case where a roadway 40 feet wide expanded 8 inches, or 1·6 per cent.

An interesting experiment to test the amount of expansion in various directions can readily be made by placing a thin section of wood upon a glass slip and moistening it with water. The shaving will stretch so much as to buckle up in ridges parallel with the rays, showing at the same time that shrinkage and swelling takes place chiefly at right angles to these rays and that it is to their greater capacity for the absorption of water that the change is due. Such sections may be used to estimate, in a rough way, the amount of the shrinkage to be expected from a wood.

Swelling may affect various kinds of construction such as ships'-linings. Those made of Kauri Pine, according to Fincham (*ex* Holzapfel, p. 47), will expand and buckle. Ships made of Blue Gum (*Eucalyptus globulus*) are in like case, for the timbers of the bottom will swell up to such an extent that the seams are difficult to find when the ship is careened for coppering (Rankine, *ex* Maiden. *Select* E.-T. Pl., p. 449.)

Laves, *ex* Noerdlinger (1859, p. 336), says that the swelling occurs by the first water absorbed and that this stage may be reached by the aborption of moisture from damp air. Small test-pieces of dry Oak increased in weight by 13 per cent. in 48 hours in a damp cellar.

Saturation appears to take place in four phases: (*a*) the filling of all cavities exposed by the cut: this is exceedingly rapid and may take place in a few minutes, or a few hours at most, through capillarity; (*b*) the saturation of all the cell-walls and cavities of the parenchyma, especially that of the rays: this is slower and occupies, as we have seen from the experiments of Petsch, about fifteen days in the case of paving blocks or a few weeks if the piece be large; (*c*) the saturation of the lignified cell-walls of the woody-fibres, which may take months; and (*d*) the filling of the cavities of the fibres, which may take years. The variation according to species is immense. The process of drying is the converse of this.

H. S. Betts (1917, p. 2, *U.S. Bull.*, No. 552) says: "Water exists in wood in two conditions: (*a*) as free water contained in the cell-cavities, and (*b*) as water absorbed in the cell-walls. When wood contains just enough water to saturate the cell-walls, it is said to be at the 'fiber saturation point.' Any water in excess of this which the wood may contain is in the form of free water in the cell cavities. Removal of the free water has no apparent effect upon the properties of the wood except to reduce its weight, but as soon as any of the absorbed water is removed the wood begins to shrink. Since the free water is the first to be removed, shrinkage does not begin, as a general rule, until the fiber saturation point is reached. . . . For most woods the fiber saturation point corresponds with a moisture-content of from 25 to 30 per cent. of the dry weight of the wood."

In the foregoing the term "free" is used in a very ambiguous way and obscures the whole matter. The water in the cell cavities is in the fluid condition, but as regards its power to abandon the wood, it is anything but free. It is the water that is the last to leave the log, for it can do so only by way of the fibres which surround it with an entirely enclosed though permeable wall. It is perfectly obvious that until the fibres give up their own moisture, they cannot take any from the cell-lumina, so that when this so-called free water in its turn passes outwards by way of the fibres, it is the last, not the first water to leave. Further, the statement that shrinkage does not begin until the free water has disappeared (*i.e.*, until the water-content has been reduced to so low a percentage as 25–30 of the dry weight), is absolutely contrary to all the evidence so far accumulated. It will suffice only to take a disc of green wood, measure it and wait a few hours, when splitting will commence, showing that shrinking has begun. When at length cracking appears to have ceased, weigh again and re-measure, when a very considerable reduction in weight and water-content will be found. The latter must be finally ascertained by drying in the oven. It will be seen, firstly, that shrinkage commences as soon as the wood begins to lose water, and that the vast proportion of the reduction in bulk occurs long before the 25–30 per cent. stage is reached. After that point it is comparatively trifling.

I should not have occupied so much space with this criticism were it not for the wide circulation of the U.S. Dept. Agric. Bulletins, which have a well-earned reputation, and in consequence an error is all the more likely to stick.

Roth (1893, p. 32) says, "It makes no difference in the volume of a block of Pine-wood whether the cell-cavities are empty, as in the heart-wood, or three-quarters filled, as in the sap-wood. It is the saturation of the cell-walls only that influences the shrinking and swelling." I agree, except as to the filling of the cavities of the ray-cells, which certainly takes place before the saturation of the cell-walls of the fibres and which influences the first phase of swelling and shrinking materially, as we have seen. When sawing green wood, the fluid sap often bubbles out of the wood just in front of the saw, and in roughing-out cylinders with a high-speed turning machine, the sap flies out in a shower. This water is probably contained in the cell-cavities.

Laslett (1894, p. 81) says that it is almost impossible to drive coloured fluids into wood in a direction parallel to the rays. The reason of this may be that the walls of the ray-cells are not permeable to such colouring matters as have been tried; it does not prove in any way that water cannot travel readily in that direction. The experiments of C. H. Teesdale (1914, pp. 10 and 17) prove that the rays are resistant to the penetration of creosote, indeed the absorption in the radial and tangential directions worked out approximately equal and amounted to no more than $\frac{1}{20}$th to $\frac{1}{120}$th of that taken in a longitudinal direction. Further, it is not possible to predict the behaviour of one wood from another. While appreciating the value of this work I must warn the reader not to assume that results worked out with creosote are valid also for water.

Other tissues besides the rays are actively absorbent, namely the vertical parenchyma and the little bubble-like cells that choke the vessels of some woods. These are rarely sufficiently robust to have much influence upon the shrinking, but they are very bibulous and assist in the absorption of water to a considerable extent in the second phase. The rate of absorption and swelling of any wood may be roughly estimated by the quantity of these tissues present plus that of the ray parenchyma. The excessive sinking and twisting of the Red Gum (*Liquidambar styraciflua*) may be attributed to the presence of large quantities of these thin-walled tissues.

According to Duhamel, wood, when completely saturated and kept *under* water, will give up and absorb it in harmony with the barometer. In this case there may be more water in the wood than it originally contained in the tree.

During drying, wood may lose more than half its green-weight. The Silver Fir seems to hold the record in this respect. Thil (*ex* Boppe, p. 88) gives the following comparisons :—

Oak	wet 1·100	dry ·860	loss ·240
Hornbeam	,, 1·080	,, ·720	,, ·360
Larch	,, ·760	,, ·620	,, ·140
Silver Fir	,, 1·000	,, ·480	,, ·520

Tredgold (p. 25) gives an interesting comparison between the Oak and the Acacia, much in the favour of the latter from a practical point of view, the loss on drying being 29·8 per cent. in the former case, against only 9 per cent. in the latter.

The loss of water takes place in very different degrees from the various sections in which wood may be cut. If pieces of green wood cut in the Winter and trimmed to show transverse, radial and tangential sections, be placed near the pane of a window, the condensation upon the glass will demonstrate the fact that the transverse section exhales most moisture, the tangential next, but a long way behind, and the radial last. This is well known to the timber merchant, who, when he fears too rapid drying from the ends of his logs, will sometimes paint them over, to check undue evaporation and stop cracking. The transverse section exposes the cut ends of the vessels in broad-leaved trees. These vessels are minute but continuous tubes running the full length of each annual sheath. There is, therefore, a fair-way for the circulation of air, and under ideal conditions this should be the best channel for the exit of the water, inasmuch as the number of vessels is practically proportionate to the mass of the fibres, and a ring of small diameter in the centre of the log, having but a small number of vessels, would dry at the same rate as one of larger diameter at the exterior, because the latter has a larger number of vessels. In other words, the wood should dry equally in all parts, because the channels for the conveyance of the moisture are of approximately the same number per square centimetre everywhere. In such conditions the whole log would shrink uniformly and no tissue-tensions would be set up and no shakes nor cracks formed. We have, however, to think of the exterior of the log which is in contact with the air and dries from its surface as well as from its vessels. Moreover, the rays emerge on the surface, and as they readily give up their moisture, they convey water from within the log, not only by their intercellular passages, but by transferring the water from cell to cell by osmosis, which must result in unequal drying, the outermost ray-cells becoming much poorer in water than those within. Hence there is cracking in the radial direction. If, on the contrary, the bark has been preserved, the evaporation from the exterior is reduced to a minimum. Uhr (*ex* Petit, p. 5) says that barked trees lost four times as much water in three months as those on which the bark had been allowed to remain. The bark should certainly be retained until the second phase of the drying is completed, for we have seen that this is fairly rapid and that a great proportion of the shrinkage takes place during this phase. Little danger of too rapid drying need be feared afterwards, as the rays have then given up their moisture for the most part, and the more dangerous tissue-tensions (particularly those caused by the more rapid drying of the sap-wood) are relieved.

It is sometimes stated that the tyloses are an obstruction to the passage of water. This is true as regards a *free flow* of water, but not only do tyloses imbibe it very greedily, but inasmuch as they have no intimate connection with the vessels in which they lie, simply occupying them as so many little bladders, their surface-attraction would suffice to conduct water along the vessels. Their surfaces will hold the water against gravity and against a moderate pressure, but this force is nothing in comparison with the imbibition of the surrounding cell-walls, hence the tyloses will part with their water to the cellular substance and draw fresh supplies continually from elsewhere.

In the case of the Conifers, a fair-way for water, though proved by microscopical examination (Boehm, 1882, p. 233), is by no means so free. Even in those species having numerous vertical resin-canals little obstructed by resin, such as the less-resinous Pines, the canals are so few in comparison with the mass of the wood that they may be left out of consideration. With the Conifers, therefore, the drying must at first be almost entirely carried on by the rays which draw the water from the fibres.

The tangential and radial sections in *sawn* wood outweigh the transverse section so enormously in point of surface exposed, that the latter becomes negligible; in the plank form, therefore, it is chiefly by the rays that the moisture is exhaled in the tangential section (hence the tendency to warp), and mainly by the fibres in the radial section. If this is correct, then quartered wood should be longer in drying than planks cut by the through and through method, on which point I have no information.

The practice of keeping logs in water until needed for use seems to be justified by the fact that the heart-wood is drier than the sap-wood, hence tissue-tensions which can be supported by the wood in that condition may be reversed and become dangerous when the sap-wood becomes drier than the heart. By the prolonged soaking the water-content becomes equalized, then, when the heart is as moist as the sap-wood, drying may proceed with less risk.

According to Noerdlinger (1859, p. 125), Summer-felled wood is lighter than Winter-felled, as follows:—Heavy broad-leaved trees, 8 per cent. lighter; less heavy ditto, 8·6 per cent.; Evergreen Conifers, 5 per cent. On the contrary, the deciduous Larch is the heavier by 4 per cent. In view of Hartig's more recent investigations this statement has now little value, as the Beech has one of its maxima in July.

If the whole of the hygroscopic water be driven off by stoving, the wood will again rapidly imbibe moisture from the atmosphere, so that experiments performed upon pieces which have been dried artificially to a given percentage will not remain constant during the trial. On its return to the air-dry condition, stoved wood will be found to have lost some of its nature: nearly all observers agree, as already stated, that stoving impairs the strength of wood (Tiemann, 1906, p. 35). The excessive drying produces minute fissures, that, even if they disappear on the wood regaining its former bulk, are not healed thereby. The rays have but a feeble adherence to the fibres that surround them, and may easily become detached. This should not, however, cause brittleness so much as a tendency to split, whereas stoving appears to cause both. We must conclude that the substance of the cell-walls of the fibres is impaired when more than a due proportion of water is withdrawn from them. Coniferous woods lose turpentine during stoving and the resin remaining becomes more brittle, which may aid in lowering the resistance.

Some of the difference between air-dried and kiln-dried wood appears to be due to the different manner in which the water is distributed. In air-dried timber the water-content diminishes gradually from without inwards; the kiln-dried wood, on the contrary, is the moister on the outside, because it again absorbs water from the air. In large pieces, where the water of the centre of the kiln-dried wood is not disturbed, there will be a central core very wet, an outer layer with a small quantity of re-absorbed moisture, and an intermediate zone of very dry wood. This condition will not of course persist, but it is highly probable that in all experiments made on this wood, these conditions prevailed at the time of testing.

The distribution of water in green, air-dried and kiln-dried wood, already alluded to, is very well demonstrated by Hatt (1907, p. 10), who shows that the water-content may actually increase in the centre of large kiln-dried beams, while that of the exterior diminishes greatly. Taking the highest and lowest figures from his diagrams they appear as follows (the green wood was taken three days after leaving the saw: the air-dried after seasoning for three and a half months in the open, and the kiln-dried after three days in the kiln. The figures are for four corresponding points of the exterior of the beams and for the centre):—

	Green.	Air-dried.	Kiln.
Sides	66–51–71–40% .	23–17–22–19% .	11–13–13–9%
Centre	30% .	27% .	33%

Oak is a very slowly-drying wood. W. E. Graham (1904, p. 619) says that a seven-inch baulk will take seven years to dry, and a baulk of more than this size will never dry thoroughly. Elm is a very difficult wood to dry (Mathieu, p. 208), and so are the woods of the Blackthorn and Bullace (Garraud, p. 192).

The sap-wood dries much more rapidly than the heart-wood, notwithstanding the fact that it contains more water in the green state (Noerdlinger, 1859, p. 88). This inconvenience is borne in upon us daily.

The state of the dryness of wood may be known by the sound when struck (*ibid.*, p. 87). With a little practice the amount of moisture exceeding the air-dry conditions may be judged by the touch.

Apart from the question of seasoning without splitting, shrinkage affects the wood when cut up into small pieces in various ways, called warping, sinking, twisting, etc. Warping and twisting are manifestations of the same phenomenon and are caused by centripetal movement of the sectors of wood. If the transverse section of a board that has become warped (or bent into a slightly trough-shaped form) be examined, the rays will be found to run across the smaller diameter, *i.e.*, from face to face of the board. There the rays change their direction from point to point like the ribs of a fan, and in woods like the Oak, where they are broad, the rays are wider on the side of the wood corresponding to the bark-side of the log and taper towards the pith-side. When the board was cut it was flat, but during drying the rays have shrunk and appear to have drawn forward the corners of the plank, partly on account of the reduction in their thickness, but mostly by reason of their radial disposition. The fan has, as it were, slightly closed. This process is better seen in a log that has been halved by cutting it in the direction of the diameter. The two halves, at first meeting truly when placed face to face, will be found after drying to have drawn up their outer edges so that a space remains between them, otherwise they gape. Short drums of wood cut transversely from the tree when green nearly always split and gape, as may be seen in specimens exhibited in Museums. This gaping and warping are precisely the same thing. If one wishes to avoid the warping of planks, they must be cut "on the quarter" in the direction of the diameter of the tree. In this way the rays run more or less parallel with the faces of the boards; they will shrink as before, but being in vastly smaller numbers in this cut, their influence on the shape of the plank is negligible.

The opposite process may take place when a plank cut from a dry log is again moistened. The rays absorb the moisture, expand and push back the corners. Such a board may be again dried, but it will never come back quite to its original form, for though the rays have abundant strength to alter the form of the wood in expanding, they contract again with less force, more especially as it is the second time that they have done so. I ascribe this to the feeble adherence of the rays to the fibres which surround them, as by repeated contraction many become loosened. A drum of Pine of 23 cm. diameter by 5·5 cm. thick, being the entire section of a tree, had split in drying so much that it gaped on the outside no less than 2·3 cm. After three hours' immersion in the water, the gap not only closed, but the extra expansion of the sap-wood had split the drum almost into two pieces, and it now gaped at the centre to a width of 0·5 cm., while two small cracks had appeared in the heart. In this short time the wood had swelled enough to fill up a gap equal to 92 cubic centimetres and more, reckoning the opening at the heart (*Archiv. C.F.A.*, No. 1, 1920).

Sinking is, as already mentioned, a local phenomenon, and where it occurs in patches may be put down to the presence of parenchyma, but there is another kind which manifests itself in the formation of grooves. This has two different causes, firstly, when the Spring and Autumn wood are of different densities (as in many Conifers), and the former sinks because it contains so much less resin than the other. The grooves so formed may remain, but according to Noerdlinger (1859, p. 261, Fig. 41), those that are formed upon the faces of thick planks of Larch may again level up on complete drying.

The second kind of sinking is more especially characteristic of the Eucalypts or Australian Gum-trees, which show it in an astonishing degree. In this case it is due not to inequality in the density of the rings, but to the obliquity of the fibres, which have a spiral course round the stem. This spiral is reversed from time to time, so that the shrinking fibres pull against each other or rather retire in different directions, leaving grooves upon the face of the plank. All woods having a double-spiral grain exhibit this kind of sinking to some extent. In the Blue Gum, the tissue-tensions so set up will at times cause the wood to tear asunder, and in working it, one comes across cavities which are quite clean (*i.e.*, not gum-galls), and which appear to have been produced in this manner.

Freedom from the defects caused by excessive shrinking in certain woods dictates their use in the Arts. Floors made of Silver Fir remain permanently level (Spon, p. 2015). The sap-wood of the Lignum-vitæ shrinks so much that lawn-bowls made with a portion of it remaining upon the heart-wood will become flattened (Exner, 1903, p. 127). Hall (1911, p. 53), in his quaint English, says, "*Sequoia sempervirens*, the Giant Redwood, warps not at all, shrinks little, and disfiguration from swelling need not be feared." G. S. Perrin (1886, p. 7) states that the Celery Pine of New Zealand (*Phyllocladus rhomboidalis*) never shrinks, even when green. The Pear-wood is the classical material for set-squares, as it keeps its shape so well, but according to Holzapfel (p. 93), the Mangrove is also used for this purpose, and will stand better than Spanish Mahogany. This last-mentioned wood and others nearly related to it are used for foundry patterns, as the dampness of the moulding-sand does not affect them. Russian Larch, as tried by Laslett (1894, p. 347), exhibited a tendency to shrink far more than any other wood of which he had experience. Larch from other localities is by no means as bad, as is evident from the figures cited above in respect to the loss of water during drying, which is an indication at the same time of the amount of contraction.

R. Hartig (1882, II, p. 62) says that the Spring wood of narrow rings of the Spruce shrinks 15·3 per cent., while that of wide rings only 8·5 per cent., which enhances the quality of the former. Oak (p. 52) sap-wood shrinks 17 per cent. of its fresh-felled volume, the heart-wood only 12·8 per cent. In another article (1901, p. 9) he states that in wood in general the shrinkage from the green state to the dry pretty nearly equals the half of the bulk of the dry wood, and he arranges a formula for its calculation.

The disadvantage of undue shrinking is too well known to need comment, but a curious instance mentioned by Karmarsch (*ex* Exner, 1903, p. 127) is worth mentioning. Wooden measures of capacity such as are used by corn-dealers, when made of bent wood (*i.e.*, wood cut plankwise, where the shrinkage chiefly occurs in the breadth), lost on an average 2 per cent. of their holding capacity in eight days, whereas those made of staves (*i.e.*, like a tub) remained practically unchanged (loss one-third of 1 per cent. on an average).

The tests made to ascertain the rate and amount of absorption are usually upon small cubes, which are sometimes varnished to limit the contact of the water to one section at a time. In such cases the test-piece should be as long as possible, because if the transverse section be the one under consideration, the amount of vessels or fibres that are opened by the cut and which take up the water by capillarity will be less in proportion to the bulk of the wood. A disc of Birch, of the thickness of a quarter of an inch, when floated upon red ink will show how rapid this absorption is. The ink will appear upon the upper surface in a few seconds. If the piece is thicker (say half an inch) the ink will take much more than twice the time to come through.

To test the radial section, the wood should be cleft in sectors, so that the two sides will both expose the rays, the third side and the ends being varnished. This form will also serve for the tangential section, in this case the two radial sides and the ends being varnished. Any other forms but these will expose bastard cuts. For a general test, a cylindrical bar which shows the radial and tangential sections in their true proportions may be used. It must not, however, be overlooked that the varnish traps the air in the wood, and as the latter cannot find a natural exit, it will oppose the entrance of the water in some degree.

Much confusion arises from the difficulty of thinking in three dimensions. When the statement is made that wood shrinks more in the tangential than in the radial direction, we are really uttering a platitude and are saying in other words that the circumference is greater than the radius. Starting with a green log of a given size, we finish with a dry one that is smaller. If its substance shrinks equally in all directions, we have naturally more than three times the peripheral loss, compared with that shown by the measurement of the diameter. However, experiments on squared blocks, so far made, seem to show that the peripheral contraction is really the greater. Then the question arises, " How does a log ever dry without splitting ? "

There is much that is obscure in the problems of absorption and shrinkage. By no means the least is the following statement by Gilbert R. Keen (*Aeroplane Timbers*, p. 66), " However, many of the secretions contain a large percentage of moisture, of which water constitutes the greater portion, and as moisture has the particular duty of retarding rapid drying, the idea of extracting it by forced methods must be avoided."

Seasoning

The expression " seasoning " includes " drying," but it is more. Still, I have heard many people discuss the question as though drying only were meant, and others who seem to think that seasoning is desiccation by a natural process and " drying " the equivalent to stoving.

Wood may be seasoned without being dried, and conversely it may be dried without being seasoned. Drying is completed by removal of the moisture, but too rapid loss of the moisture is fatal to seasoning.

The difference is profound. Seasoning is a process by which the perishable contents of the wood (starch, sugar and nitrogenous matters) disappear, the starch and sugar being converted into resistant compounds of tannin, otherwise " heart-substance " (*see* p. 22). This conversion requires moisture, and the virtue of natural seasoning lies in the fact that the water is retained for sufficient time for the necessary changes to take place. If the process be carried out slowly, not only does the whole of the starch disappear, but the cell-walls are benefited by the addition of heart-substances which are resistant to decay, even if they cannot be regarded as an antiseptic. When starch is converted into tannin a solid passes into solution for which water is necessary, so that rapid drying must arrest the process. Hence rapid drying is pernicious in two respects—it fixes the starch in its primitive form and provides a welcome pabulum for the fungi of decay, and it deprives the wood of an additional dose of resistant material. On the other hand, in woods that have lost their starch, the soluble tannin may be likewise hindered in its change to the fixed form (heart-substance).

Seasoning under water derives its virtue from the prolongation of the period during which the wood may continue its changes, added to which, the external portion of the logs is prevented from drying too rapidly. It has one disadvantage, inasmuch as at one stage the tannin is fluid and may be leached out, a loss that may account for the inferiority of some floated timber. That the ash-content is adversely affected by floating seems to be proved by the fact that in the time of Duhamel de Monceau the laundry-women of Paris, who were accustomed to make their own ash for washing purposes, rejected floated wood because its yield of ash was inferior.

The merits of Winter and Summer seasoning may be summed up as follows:—In the former we have sometimes more water to commence with, but a low temperature and repeated recurrence of damp weather, which slows down the drying process, is, as we have seen, all to the advantage of the quality of the wood. Then, shakes are less liable to be caused, as the exterior of the log is not so likely to out-pace the inner in its shrinkage. In Summer seasoning we commence with less water sometimes, and it is more rapidly got rid of, but at the expense of true seasoning and at the risk of cracking. The wood is subject to fermentation of the sap, otherwise the inroads of bacteria which open the way for fungi, and insects are also to be feared.

Both Noerdlinger and R. Hartig (1901, p. 17) concur in the view that the difference between Summer- and Winter-felled wood does not arise from internal causes, but from the subsequent treatment. It appears to me that the fruiting-year has more influence than the season upon the quantity of the starch present in the wood. After fruiting the starch is practically exhausted, whereas in the non-fruiting year there is always much remaining, whatever the season. A crop of seeds will sometimes so exhaust a tree as to turn the leaves yellow prematurely. This circumstance should be considered more seriously.

This reservation must be made. Many sap-wood trees destined to be employed for temporary and indoor uses, should be dried quickly, indeed the sooner they are cut up the better, and kiln-drying may be permitted. Much of the Birch that arrives at our East Coast ports is already rotten after a voyage of but a few weeks. Birch and Alder coppice poles are scotched to hasten the drying, but for all timber for purposes demanding durability and strength and the other qualities associated with heart-substance, slow drying at a low temperature is the only process which is justified from the point of the user. From the point of the lumberman the various methods of kiln-drying are of great and increasing interest, and as far as the finishing of planks already partially dried there is not much to be said against kiln-drying, but I remain sceptical of the efficacy of kiln-drying green wood.

My method of drying by the "cold way" has the object of saving time without unduly hastening the process. It amounts to winter-seasoning all the year round, avoiding risks of injury by excessive heat, insects and fungi. In tropical countries where all these, and especially

White Ants, are to be feared, the process should be of service. The installation is simple and inexpensive and consists of a closed shed, furnished with a refrigerating apparatus such as is used by ham-curers, which will provide a cold spot where the moisture of the air will be condensed in the form of hoar-frost, without unduly lowering the temperature of the shed. The logs will then be continuously bathed in cool, dry air.

In the Report of the C.P.T. (1910, p. 16) we read, "Whether or not poles or cross-arms are to receive preservative treatment, there can be no doubt that it invariably pays to season them properly before putting them into service. Under ordinary conditions the life of a well-seasoned untreated pole should be 30 per cent. greater at least than that of an untreated green pole, and the life of cross-arms is increased in about the same proportion through proper seasoning."

Conductivity of Heat and Electricity

That the conductivity of wood for heat is low is exemplified in the use of handles for vessels destined to contain hot fluids, and in the case of tea and coffee-pots of metal, by the insertion of two small discs of Ebony or other wood at certain parts of the handle to prevent the heat passing those points. I have very little data on this subject, but it appears that the conductivity decreases as the density of the wood augments, hence the use of Ebony.

The moduli of the conductivity of heat, according to Havard, are for a few species as follows:—Walnut, 0·10; Silver Fir, 0·17; Oak, 0·21, in comparison with marble, 3·48; zinc, ·28; copper, ·64. I do not know how these figures were arrived at. A series of tests would be welcome, as it might be applied to the identification of certain species.

The specific heat of wood, otherwise its capacity for heat compared with an equal weight of water, has been determined by Dunlap (1912) for a large number of American species. It appears to range from ·3109 (lowest figure) for White Ash to ·3441 (highest) for Sugar Maple. The author in summing up says (p. 427), "The thermal expansion of wood is shown to be negative. This means that wood substance contracts and becomes denser on heating, instead of expanding and becoming lighter in weight. If this be true, wood substance differs from other substances, of which records are available. Moreover, it is difficult to reconcile this anomalous behaviour with the well-established fact that in the aggregate blocks of wood expand when heated."

The conductivity of wood for electricity, or rather its want of the same, is taken advantage of in the construction of electrical fittings. Pitch Pine is the most resistant species, Teak following next, but it is preferred to the former, on account of its better appearance.

Hiruma (1915, p. 62) says that "Woods having high specific gravity offer far less resistance than those having low specific gravity, so long as the amount of moisture remains the same. Also, the cross-section of wood has the least resistance and the radial the greatest. This is the more remarkable in the case of the broad-leaved trees than in the Conifers tried." Again, on p. 61, "The resistance to electricity decreases as the moisture of the wood increases, and since the moisture of the surface is constantly influenced by surrounding conditions, the resistance can hardly be determined and the figures given are only approximate." From this it would appear that a wood of light weight and low capacity for the absorption of moisture, used plankwise, will be the best non-conductor.

PART IV

The "Figure" of Wood—Callus—Defects—Durability and Decay—Laboratory Practice

CHAPTER XIII

FIGURE

THE word "Figure" is a trade term of somewhat loose application that appears to include any variation or contrast presented by the surface of wood, whether it be caused by the local exposure of different tissues or by bands or patches of colour. Anything which relieves the uniformity of the colour or reflection seems to fall under the head of figure. As we have no more precise word in the language to express the idea, we must use it, but it covers too much ground. Let us commence by splitting the conception into more convenient parts, *e.g.*, "Normal figure," or that which is seen on wood, the growth of which has taken a regular and undisturbed course, where the variations of the design are due to the manner in which the saw-cut has exposed the tissues. Secondly, "Abnormal figure," where external influences causing irregular growth have come into play. To the first category belong the characteristic "silver-grain or flower, clash, felt, or chink" of the Oak, and the "Roe" of Mahogany. Amongst the latter are Bird's-eye and Blister-figures, Ramshorn or Ripple and Burrs.

Normal Figure

We have already seen (p. 78) how the silver-grain is produced on the surface of quartered wood (radial section). To those who do not care to read that somewhat arid chapter, it may be said that the rays which run in the direction of a diameter of the tree, like the main strands of a spider's-web, are blade-shaped bodies, the flat sides of which are made visible in quartering the log when the saw has happened to run parallel with them. The slightest deviation from the radial direction will cause the saw to pass obliquely through the blade of tissue, so that an abrupt reduction in its length is produced. The more the cut departs from the radial line the narrower the rays will appear, until they reach their minimum width in the true tangential section (the slab-, slash- or plank-way). To realize this great reduction in width, it is only necessary to cut a strip of card at the smallest possible angle to the surface. The rays may often be thicker than card, so that their apparent width does not shrink from a broad ribbon to a mere line at a jump, still it falls immediately to a very narrow flake. (Figs. 4 and 5, Pl. XXXVIII.)

If the end of an inch board, cut from a quartered log, be examined the rays will be seen to be arranged in a fan-like manner radiating from the pith that will be found at one end, "a" (Fig. 4). On the sides a–b : a–e the rays will be exposed on the surface, producing "silver-grain." On the edge b–d, which is nearly a true tangential section (slab-cut), their ends only will be visible and that in their smallest dimensions. On the side d–c the ends are likewise exposed, but as the rays run out obliquely to the surface, these will be a trifle broader than on b–d, becoming narrower by degrees as they approach the point c, where the section is almost the same as at b–d, that is to say, tangential. The net result of all this is that the sides a–b : a–c will be showily figured and b–d : d–c will be plain.

Supposing that instead of the inch board, we choose to cut the wood only a quarter of an inch in thickness, then, as the rays towards the end b–d in Fig. 5 have not had space to change their direction very much, there will be figured wood on the face g–f, and inasmuch as the next board to be sawn off will partake of the same figure, we shall have two figured boards instead of one. If, again, the wood be sliced up into veneer, there will be a still greater quantity of showy pieces; hence, to make the most of a fine log, it must be cut up into thin boards or veneer.

There are several ways of cutting up a log that are well known, of which figures are given in most works on wood. One of these is the cutting of boards from the sides a–b and a–e alternately, during which the pieces become successively plainer, but in order to obtain figure in its full beauty on every board, the log must be split or sawn into sectors or wedge-shaped pieces. Our ancestors employed this method for making panels and from time to time old panelling comes to light which is made from feather-edged boards.

Our diagram (Fig. 5) explains why a radial section such as is found at the point g, on g–f, may change into a tangential one as it approaches the point f, a change that seems somewhat mysterious to the beginner who has not acquired the habit of consulting the cross-section. This surface may be called a "bastard-cut," as it partakes of both sections without truly showing either.

The best display of silver-grain is possible only when the rays run straight and true from pith to bark. This can happen only when the tree is symmetrical in its growth and the pith occupies its centre. If the tree be lop-sided, otherwise of unequal growth on opposite sides (*see* Frontispiece), the proportionately greater extension of the periphery on the fast-grown side causes the rays to diverge to right and to left, so that they become curved. Obviously, curved rays cannot be followed by the saw, which will expose them in small patches, as it will run tangentially to them. When choosing a log for fittings, select the one that has the most central pith.

It may happen that the rays take a serpentine course, though their trend may be in the main directly radial. In this case the saw will touch them on the crests of the waves and miss them across the troughs, so that little flakes will appear at more or less regular intervals. From the conical form of the layers, the edges of the rays will be cut alternately at different angles and the flakes will have the appearance of undulating on the quartered face as well as on the cross-section, but it will be an illusion in the former case. In a specimen of the Honey

Locust (*Gleditschia triacanthos*), shown in our figure No. 1, Pl. XII, the waves are due to unequal growth of the rings, which at some places are wide and at others narrow, and the rays belonging to each ring are thrown out of line first one way and then another. This instance should more properly belong to the section of abnormal figure, as indeed, strictly speaking, is that produced by curved rays also. Undulating rays in transverse section may be seen in our Fig. 1, Pl. XXVIII, of the Crab-wood of British Guiana.

It has been explained on p. 79 how the rays may be cut up or divided into two or more parts vertically, by having strands of fibres drawn across them (Fig. 3, Pl. XVI). This rarely happens in the Common Oak, the silver-grain consisting of broad flakes which may be occasionally as high as three or more inches, but, in practice, a flake of an inch is a large one. In the Turkey Oak (*Quercus cerris*), on the contrary, the rays are divided into several portions, so that the flakes resulting are interrupted and the silver-grain has somewhat the appearance of a mottle. In a bastard cut, where the rays are narrowed, the effect is of a row of beads, as is shown in our Fig. 2, Pl. XI (on the right). The quantity of the rays per inch in a transverse section will affect the silver-grain, for the closer they are the oftener they will be seen on the radial section and the more of the surface they will cover. In the Beech the rays are rather widely separated on the cross-section and hence appear wide apart on the quartered wood; in the Plane they are very numerous and close, hence, on a radial section, they occupy a large proportion of the surface (*see* Figs. 3 and 4, Pl. XII). Some of the Maples may be distinguished by this feature, the rays of *Acer dasycarpum* and *rubrum* being nearly twice as numerous as those in *Acer saccharinum*, though less beautiful; indeed, this is practically the only feature by which the two species can be distinguished.

Figure which results from the contrast in the coloration of the rays and fibres is very rare. Besides the Letter-wood (*see* p. 29) and the Plane-tree, I cannot recall any wood that is sufficiently remarkable to be used for this reason. Examples which are of no particular interest in this connection are the Alder, where the inconspicuous secondary silver-grain sometimes shows up (Fig. 2, Pl. XII), and the *Myristica Mouchigot* of French Guiana, where it is rather more evident still.

The difference in depth of colour of the two tissues, when seen in tangential section, may, nevertheless, be pronounced, because the cells of one tissue are seen in cross-section and appear deeper in shade than others which present their sides.

The so-called "Oyster figure," which much resembles the "sun-dial," is simply the cross section of the wood. It may be very beautiful, but is not much employed, as veneers cut in this way do not stand. This section is not often sufficiently displayed to enter much into the present discussion. It shows to best advantage on the tops of newels and other spherical or deeply under-cut fittings. In an ordinary piece of furniture it is difficult to find and may appear only on the edges of flat slabs or tables. Inasmuch as highly-figured wood is now-a-days rarely made up in the solid but is reserved for veneer, the student who wishes to learn from his domestic surroundings will often be astonished to find imposing vertical sections, accompanied by transverse ones of a very humble origin, the former being of veneer and the latter of the backing.

The second element in the normal figure is the ring-boundary. This is explained on p. 19, and may consist of a line of contrast in density or colour between the layers of the same or adjacent rings, as in most Coniferous woods, such as Deal, or it may be a line of a different tissue, as in the Mahogany, or, again, a ring of pores, as in the Oak, Elm, Ash, etc., or, lastly, it may be a very scanty pore-ring, packed with soft-tissue (parenchyma), as in the Walnut, False Acacia (Fig. 4, Pl. VIII) and the Teak.

The apparent boundary of the rings in *Celastrus acuminatus*, the Silk-bark-tree of the Cape, in most species of *Calophyllum*, and in certain varieties of West African Mahogany is of soft-tissue of a dark colour, which is rare. This has much to do with the beauty and lustre of these woods.

In all cases there is a contrast of some sort. Inasmuch as a tube cut in half vertically will expose its walls as parallel lines, the concentric sheaths of which the wood is built up will show many parallel lines on a radial section. Further, as the sheaths of wood in a tree are long-drawn-out cones, any other vertical cut made at a distance from the pith, but still parallel to it, will expose the ring-boundaries as loops, such as one may see on any deal floor. There being many cones one within the other, the path of the saw starting in an inner cone will soon leave it and pass through the next one external to it and then to the next and so on, each time exposing a fresh loop, so that many will appear astride of each other· The effect of these loops varies according to the nature of the boundary. If the latter be a line of striking contrast, as in the Pine, they are very prominent; if the contrast be slight, as in the Sycamore, the loops will appear as delicate hair-like lines; if, as in the Oak, a coarse pore-ring forms the boundary, the loops will appear as wide fringes; if, as in the Robinia, the pore-ring be feeble but packed with light-coloured soft-tissue, the latter will show up as hoary loops.

In the Elm and in many of the members of the same family, a repetition of the pore-ring on a small scale is seen in the Autumn wood (transverse section), indeed there may be many such secondary pore-rings which become successively smaller as they approach the outer limit of the ring, hence we may expect a series of small fringed loops within the larger loops. Here, however, a difference appears—the small pore-rings of the Summer-wood are *undulating* in their contour (Fig. 5, Pl. III), indicating a *fluted* cone or sheath of pores. As the saw-cut passes across these sheaths at different levels we get *wavy* and *zigzag* fringes between the coarser but *regular* fringed loops of the Spring-wood (Fig. 1, Pl. VII).

The parenchyma or soft-tissue is a very variable substance both as regards its colour and occurrence. In the case of the Walnut, the soft-tissue when well developed and light in shade, will appear as a broad hoary band following the rather scanty fringe composed of the pores of the Spring wood. At other times it may be practically absent.

Woods which have rings of a naturally or abnormally undulating contour will exhibit zigzags in tangential section (Fig. 3, Pl. VI), and even a notch in the ring, such as we are accustomed to look for in the Alder (Fig. 2, Pl. XXV), will cause a dip in the loops on the plank face. In this last species there is no contrast of colour to show up the result of the dip, and the same may be said for the truly undulating rings of the Hornbeam.

All these tangential figures may be modified by the greater or less visibility of the rays in that section. In the Beech they are dark and clear, forming an " ermine " figure, which comes more to the fore, because the boundary-loops are by no means prominent. On the other hand, the Plane, which has a very much more conspicuous silver-grain than the Beech, has rays that in the slab-way are obscure and have to be looked for with attention.

When minute, the ray-ends of most woods are almost invisible, but if the colour happens to be of a darker shade they may, by force of numbers, have an effect upon the eye, such as may be termed " half-tone." This imparts a very soft appearance to the tangential surface of the Common Elm, which the Wych Elm lacks, and much of the beauty of the Sycamore is derived therefrom. In the last-mentioned the ray-ends are very little darker in shade than the fibres and individually are scarcely distinguishable.

The large ray-ends of the Common Oak are not very readily seen, whereas the much shorter ones of the American Red Oak are, on account of their darker colour and greater distinctness, a very much more prominent feature of the figure.

Every one has noticed how the ring-boundaries change on an " ogee " moulding, one part of which has a convex surface which then runs into a concave one. The loops may point upwards on one and downwards on the other. In a less degree and in a simpler form, this reversal of the direction of the loops may be seen on almost any floor-board. If the tree from which the wood in question is cut is a true cone and the saw-cut is truly parallel with the pith, the loops will appear to turn their curved ends towards the top of the tree. If the trunk is bent, even in the slightest degree, the cones of wood composing it will be cut at a different angle and the loops will be upside down. If, again, the bend is a short one, the saw will slice off a rounded flake, as it were, from the bulge of the bend and a circle, ellipse or closed loop will be shown. This is difficult to understand from a description, but if the reader will take the trouble to make a cone of paper and snip it at various angles, he will readily appreciate the reason for the change of form and direction of the loops.

A similar change appears in the silver-grain on an ogee, but here the reason is quite different, as we are now dealing with plane surfaces, *i.e.*, ribbons of tissue and not with the boundaries of cones of wood. To understand this case it is necessary to examine the cross-section, that is nearly always the key to problems in wood. Figs. 1–3, Pl. XXXVIII, show that the re-entrant curve of the ogee exposes fragments of a number of rays which it invades in succession, leaving pairs of strips of ray-tissue on either side of the hollow, so that the loops are not simple ones, as in the case of the boundary-loops discussed above.

The change in direction has also a different origin. If we take a number of strips of paper and place them one upon another to imitate the rays, we shall see that if we attempt to cut a re-entrant curve or groove in them, we shall have pairs of edges exposed on the sides and at the bottom will be a single flake remaining uninjured. If we imitate a salient curve by cutting the sides of the paper strips away, we shall have the single flake on the top, with pairs of fragments on either side gradually receding from it. To complete the simile we must arrange our grooves and beading so that the cut is not parallel to the paper but at a slight angle to it, when we shall have open loops with widening sides in both cases, but the rounded curve will have the uninjured flake on the top and the groove will show it at the bottom.

It was pointed out in the chapter on "Lustre" (p. 36) that the silver-grain usually derives its beauty from the play of light and not from colour, but whenever the colour of the rays is actually different from that of the wood-fibres, it may be otherwise, as in the case of the Snake-wood (*Brosimum Aubletii*), the rays of which are black and show up, by a beautiful contrast, against the rich brown fibres. As these rays are exceedingly minute but abundant, and arranged in parallel (palisade), the effect is much the same in both radial and tangential sections. In the former cut a few rays are exposed, but *broadside on*: in the latter many ray-ends are seen *side by side*. The phenomenon called "fire" often owes its brilliance to this palisade arrangement of the rays.

As explained (p. 76), it is not unusual to meet with spiral-grain and that in many species double-spiral is quite normal. When even but slightly accentuated, the effect of the alternating obliquity of the fibres is to cause stripy wood that differs in shade, band by band, because the cut ends of the fibres differ in depth of colour from that of their sides (*see* p. 78). In any case there is always a considerable difference in the lustre, the sides of the fibres being bright and the cut-ends nearly always dull. Hence shining and dull bands of wood run side by side. The exotic Leguminosæ and Urticaceæ are notable amongst such woods, and the Spanish Mahogany is often characterized by the same play of light.

The inclination of the fibres may be so great that a true transverse section of a single ring, or a series of adjacent rings, may crop out on the radial surface. This implies a turn of direction through a right angle and would be difficult to believe were it not easy to observe in the brilliantly-figured East Indian Satin-wood. It may be that such specimens as I have seen were not cut vertically as the tree stood; perhaps they were intentionally cut obliquely, to show up the figure, but the fact remains that one series of fibres runs parallel with the face of the plank (showing their radial section), whilst others immediately alongside show a true transverse cut. I confess that at first I had much trouble to persuade myself of this. The transverse section of the Satin-wood is brighter than that of most species, the wood-fibres in longitudinal section are very brilliant, and the cells of the rays being equally bright, but reflecting the light at a different angle, add their lustre.

A very curious instance which came to light on making the examination of the fittings of the School of Forestry, Cambridge, is a panel in the Oak door of Room 5. An almost complete cross-section of about six inches in diameter (Fig. 3, Pl. VIII) passes abruptly into a perfect radial section. That a single ring, or a few rings, may change their orientation in such a manner can be understood, but that a whole cross-section should merge into a quarter-cut is very remarkable. I have seen planks cut from old, branchy trees, where the cross-section was parallel to the tangential (slab-cut), indeed this happens at the section of every knot, but for it to fade into the quarter is inexplicable, unless the tree was bent. We have also a plank of Alder which shows the transverse section on the end as is usual, and also on one of the edges at the corner.

The deviations from the figure which may arise at the point where branches and roots are given off from the trunk, are quite normal, inasmuch as the limbs are part of the economy of the tree, but here the structure is much disturbed.

The simplest form is the Knot, so familiar in Deal planking. This is no more than the inner or proximal end of a branch that by further growth of the trunk has gradually become buried. The burying process is accompanied by a certain amount of compression of the cambium (the wood of the branch endeavouring to increase in thickness while that of the trunk is growing up round it), hence the tissue of the former becomes small-celled and dense.

In the case of Conifers, the knots may be darker in colour and much harder and heavier than the wood surrounding them; indeed, they will sometimes sink in water. As a rule in the broad-leaved trees the difference in colour between the knot and the trunk is less. The tissue adjacent to knots is disturbed in proportion to the size of the latter and tends to resemble that of callus.

In large crotches or forks a very beautiful feather-like figure may be produced (Fig. 3, Pl. XV). As explained, p. 180, both branch and trunk compete in the filling up of the angle they make with each other. The upper angle is generally the smaller and there the disturbance of the growth is very marked. Sometimes the pressure of the bark is relieved by the buckling of the fibres, which become undulating and produce the figure known as "Ripple or Ramshorn" (Fig. 2, Pl. X), so much prized by amateurs of violins. It is most familiar in the Sycamore and the Maples, but may be met with in many woods. Our diagram (Fig. 2, Pl. XXXIX) explains the phenomenon.

Secondly, the pressure may be evaded by the more rapid filling up of the angle between the branch and the tree, when the wood, in addition to increasing the diameter of both, is piled up in the crotch. If Fig. 2, Pl. XV be examined and the layers of wood be traced from the angle up into both branch and trunk, it will be seen that the layers rapidly thin out. The reason of this is that the growing layers of the cylindrical portions of the trunk and branch are compressed or strangled by the bark and make wood slowly, whereas this pressure is absent in the angle, because the mutual increase in the diameter of the trunk and branch tends to lift the bark and to permit more rapid growth of the layer beneath. On the lower side of the branch (Fig. 1, Pl. XV) the ripple is shown in larger, parallel and regular waves and extends vertically for a considerable distance. I believe that the Maple wood used for violins comes from this lower side, and the reason why it disappears in the centre of large planks is explained. The same reasoning applies to the wood above the roots and it is quite possible that the buckling of the fibres from root and branch may meet in short, branchy trees. R. Hartig (1901, p. 52) claims to be the first to explain the cause of "ripple," but Kienitz, and, after him, Jost (1901, p. 2), dealt very fully with it, giving a diagram (*see* his Figs. 1 and 2). Jaccard (1910, p. 76) figures a piece of Spruce that shows the ripple in a remarkable way. None of the above authors make any distinction between the figure produced in the acute angle above the branch and that in the obtuse angle below it, though Jost seems to imply that the production of the ripple must be more intense in the upper angle. In our figure No. 1, Pl. XV, it will be seen that although it is more intense at first, no real ripple is produced, as it does not extend far enough, and expires an inch or two from the fork. (Compare Diagram Fig. 2, Pl. XXXIX.)

The angle at which a branch leaves the trunk varies very much and is characteristic of the species. My friend, V. K. Braid, has made a number of observations on this point for me, but comes to the conclusion that although, in a general way, the angle is a factor in the habit of the tree, yet the range of variation is too great for it to be possible to formulate any law. Trees that are spreading in their habit and have branches which are more or less horizontal, may produce ripple indifferently both above and below. The presence of a knot or crotch in a plank may occasionally afford means of identification by the angle that it makes with the pith.

The term "ripple" is used by Record (1919, p. 39) for the effect produced by the arrangement of the elements (especially the rays) in parallel or stages ("en palissade"), for which we use the term "fire" (Fig. 5, Pl. XXVIII). It is to be regretted that we have no common agreement upon technical terms. For this particular form I should prefer the term "dapple," which Record uses in connection with the Spruce.

The broader figure shown in Figs. 1 and 2, Pl. X, is called "roll." It may be caused in the same way as "ripple," but of this I have no evidence. It occurs in Sequoia, Birch and in the Huon Pine, etc., and is one of the most brilliant kinds of figure.

In abnormal figure we plunge into a maze of extraordinary phenomena which is almost unexplored, at least so far as their causes are concerned. The designs that may be met with are often fantastic and generally very beautiful.

The disturbance of the normal growth almost always arises from external injuries, that is to say, lesions of the tissues brought about by some agent foreign to the tree. The immediate cause may be an animal (man, quadruped, bird or insect), or vegetable (fungi, including Bacteria, or parasites such as the Mistletoe). The proximate cause is either a wound or an irritant, which stimulates the growing layer to the production of confused and irregular tissue.

The action of man may be accidental or deliberate and may range from the injury to the stump of a tree by the wheel of a passing cart to those resulting from the use of climbing-irons, by the strangling of the tree by wire or by pruning operations. All resemble each other in causing the formation of callus, but as this is rarely of an ornamental kind, most of them come more properly under the head of "Defects" (*see* p. 197).

Remarkable exceptions are the burrs of the Thuya-wood (*Callitris quadrivalvis*) from North Africa and the Briar-root used for pipes (*see* p. 194).

Deliberate action with a view to the production of figured wood is rare and sometimes doubtful. There is the now obsolete practice of beating Walnut trees, the memory of which is preserved in a time-honoured couplet in which it is associated with other equally obsolete customs. No accurate observations have been made on this process, but theoretically it is quite credible. The blows of the cudgels used to knock down the Walnuts, bruised the bark of the tree, thereby causing the growth of callus (*see* p. 186), otherwise "curly" wood. American Walnut, grown in the primæval forests of North America, is (apart from burrs and crotches) a very straight-grained wood, and the wood of European Walnut-trees grown of late years will be straight-grained also, from the lack of cudgelling.

Secondly, the method of producing walking-sticks with decussate (alternately opposite) pairs of "knots" or lumps throughout the length of the stick, as practised by the peasants in the neighbourhood of Perpignan, is quite a parallel case. The knots are caused by pinching the young saplings with a pair of specially-made pliers and the lumps arise under the bruised bark.

Thirdly, figured Boxwood is produced by the binding of the trees with iron bands, as practised in Italy (Piccioli, 1919, p. 13). The wood grows out between the bands and throws out many shoots, which are cropped annually, producing a combination of curly and burry wood. There is a specimen at Cambridge of the Japanese Ash which shows traces of having been dealt with in the same way. Three ropes had evidently been bound round the tree at intervals of about a foot, between which the wood had swelled. A section shows the effect upon the grain very clearly; it has become curly and very beautiful. I am told that the Japanese practise this art expressly, though this is denied by some. It can very easily be tried and the effect is rapidly obtained. The ropes should be removed as soon as the wood has visibly swelled, as it will retain its contour indefinitely afterwards. The nearer and smaller the ropes, the sooner should they be removed.

Warts play a very subordinate part in the matter of figure, as they are rare and generally small, but they may be very beautiful. We have at the School of Forestry a very fine one, weighing some 20 lb., from the

Ash, and another smaller wart from the Walnut, that are of exceedingly fine figure. The warts grow remarkably quickly, the first specimen cited being of but eighteen years' growth, yet, strange to say, the wood is much harder than that of the tree upon which it grew. This is quite the reverse of the wood produced by callus which occludes open wounds; the latter is nearly always softer and sinks more in drying than the wood of the parent tree. These warts are attributed to injury by gun-shot wounds.

Passing to the quadrupeds, we have nothing but conjecture to guide us, still, theoretically again, if wounds of any kind are covered over or "occluded" by callus (*see* p. 190), they must be the cause of curly grain. The long vertical grooves made in the bark of trees by the teeth of horses, cattle, and especially deer, voles and mice, must, when occluded, result in figured wood, so, without having any evidence upon the point, I predict that the "landscape-figure" of the Maples will be found to have its origin in the nibbling of deer. This figure appears as long loops and lines in tangential section and as notches or undulations in the contour of the ring in transverse section. In the latter cut the notches may be confused with similar indentations of the ring-boundary shown by the Bird's-eye figure, but on a tangential section these latter appear as circles only, as will be seen later.

If, as I understand, these figures are found only in the interior of large trees (Wagner, p. 96), this fact points to the attack of some animal that nibbles the bark of young trees and has no taste for the dry rhytidom of the old ones.

The nibbling of bark by cows, cattle or deer is quite characteristic (Pl. XVIII, Figs. 1 and 3). The grooves are very narrow, as though made by the corner of a tooth. Stripping of the bark is another and more serious matter, resulting in broad, vertical wounds with the ordinary callus-cushion that need years to occlude them. The tiny teeth of voles bear directly on the bark and leave pairs of equally tiny grooves. These latter will be rapidly covered with callus and should produce a figured wood, but up to the present I have not traced it. Rabbits do their work too thoroughly and will strip the stem entirely. The healing of such wounds in young trees will generally result in a condition as shown in our Fig. 5, Pl. XVIII.

Goats are the agents in the production of figured Olive-wood. Where these animals roam at liberty, the Olive-trees are sadly abused. I have seen trees upon the butts of which I could find no bark whatever, notwithstanding that the crown of the tree appeared none the worse. Young Olive-trees callus over when not entirely stripped, the curly wood produced being enhanced in beauty by the infiltration of blackish matter. I have seen the section of a stem thus variegated that was entirely surrounded by callus, thus appearing as a heart surrounded by its sap-wood.

I suspect an animal origin for some of the curious woods occasionally imported, that are apparently buttresses (*see* p. 17). These are beautifully curly and consist of slabs evidently split from the tree. Possibly injuries by deer may account for some of these arcabas. In stripping bark, the deer loosens a piece and backs away from the tree, tearing out a strip of considerable length which will probably run up to the branch next above. A wound of this kind will heal over after the manner of a frost-crack (*see* p. 192 and Fig. 20, Pl. V), and the more exuberant growth of the callus will account for the production of the buttress and also for its limited height.

That birds contribute to the production of figured wood appears possible from the statement of Record (1919, p. 66), who says that the reddish-brown streaks so common in *Hicoria* (*Carya*) are mostly the result of injury by birds, but he offers no explanation of the process nor does he mention the species of bird. The Bird's-eye figures of the Maple (Figs. 1 and 2, Pl. IX) might be very well caused by a woodpecker and not by an insect as currently reported, as the indentations in the bark are such as would be made by the beak of a bird. The dimple-like hollow by no means resembles the gallery of an insect, it is too local. All known insects that feed upon the cambium-layer of trees travel at least a little and form tunnels in their search of nourishment. It is hardly likely that an insect would bore directly through the bark to obtain so small a meal, just when it had reached abundance, nor is it likely that a bark-eating insect would feed upon such a heterogeneous pabulum as is presented by the various layers of the bark. It would prefer one layer to others and would tunnel in that only, after boring the shortest way through the less palatable corky exterior. Moreover the characteristic feature of the healed worm-gallery is the callus, as in the case of the so-called "pith-flecks" (*see* p. 187). In the Bird's-eye there is no callus, the wood which overlays the original dimple being quite normal, which seems to indicate that the cause is a blow hard enough to bruise and arrest the activity of the cambium for a short time without loosening the bark and without causing a true wound. Such a blow might be made by the beak of the woodpecker, to which the shape and size of the "Bird's-eye" would correspond. The Bird's-eye is by no means confined to the Maple. Our figure (No. 2, Pl. XIII) shows one from the Cedar (*Cedrus atlantica*). It is on so large a scale that it serves very well as a diagram. The invaginations of the boundary fit into each other so deeply that on a tangential section (left of figure) more than one dimple is cut across, hence more than one circle appears on the plank-face. In a specimen of the Japanese Ash (*Fraxinus mandshurica*) (Fig. 1, Pl. VI.), a wood of great beauty and lustre, we have a tangential section (middle of figure) passing into a radial section, hence we have both the circles and the notches shown on a still larger scale. Had we not the interpretation of the design by means of the previous examples, we should not so readily understand this last. This figure is also seen in Hungarian Ash. In the Japanese specimen we see that the figure depends also upon the pore-ring; the circles and notches are outlined in fringes instead of sharp, clear lines, as in the Cedar. We have no clue to the cause in the latter case. Boulger says that the "Bird's-eyes" of the Maple are sections of bud-axes, but that this is not the case may be proved on inspection.

The "blister-figure" of the Canary White-wood, shown in Fig. 3, Pl. X, is structurally of the same nature as the Bird's-eye, *i.e.*, it is due to invaginations or depressions in the boundaries of the annual sheaths. On a perfectly plain surface they appear to be raised in relief and have the effect of watered silk. So great is the illusion that one is irresistibly impelled to touch the surface to feel whether it be not really blistered. There does not seem to be any essential difference in structure between Blister and Bird's-eye, the immediate cause of both is the same, but in the former the ring-boundaries scarcely appear, whereas they are well outlined in the latter.

The term " blister " seems to be used in a different sense in the U.S.A., as Hough (7a, Part I) applies it to the parallel lines which result from a simple notch in the ring-boundary. As his specimen shows, the notch at first and for a great many years following, is not very evident, but becomes more pronounced as time goes on. The whole terminology of the subject needs revision. A notch such as seen on the cross-section of the Alder, where a ray crosses the boundary of a ring (Fig. 2, Pl. XXV), does not indicate a Bird's-eye, but rather the Blister in Hough's sense. The channel of which it is the section runs vertically up the stem for the whole height of the ray. In tangential section it will show pairs of lines something like the outline of the spindle-shaped grooves on the outside of a log of Oak from which the bark has been stripped (*comp.* Figs. 1 and 2, Pl. XVI, of *Stenocarpus*).

Passing to the insects, we have the "Pith-fleck" or Cambium-miner, though its work can only occasionally be classed as "figure," for the long strips of brown tissue so well known in the Birch (Fig. 9, Pl. XVIII) are scarcely ornamental. However, in Finland, where figured woods are rare, Birch when well sprinkled with flecks is highly prized. Of other insect injuries germane to our subject there are none, unless burrs are the result of the attacks by mites, which does not seem to be proven. I am of the opinion that any wound or wound-callus may give rise to a burr, because the latter has the property of producing buds and that is all that is necessary. This question is touched upon elsewhere (*see* p. 194). Although the burr is an important article of commerce, there is little that can be said about it that cannot be more readily appreciated by the inspection of our figures No. 17, Pl. V, of the Elm, exterior view after the removal of the bark; No. 4, Pl. XV, of the Spruce, radial section; and No. 4, Pl. VIII, of the False Acacia, radial section. Suffice it to say, that the photographs give little idea of the wonderful effect of colouring that may be seen in these burrs.

A writer in the *Timber Trades Journal* states that Walnut burrs have not been imported from European countries for twenty-five years: any that now reach this country come from North America and are the product of the Black Walnut (*Juglans nigra*). It is well to discriminate between the burrs of this tree and the curly wood of the English Walnut (*J. regia*). This latter wood is nearly always curly, whereas that of the American tree is usually straight-grained, but burrs may occur upon it. The European tree does not produce fine burrs in the colder countries: the Mediterranean region was formerly the source of supply.

The wood known as Hazel Pine, sometimes found in Spruce trees, and which consists of a kind of false silver-grain not normal to Conifers and appearing as tufts or brushes of rays, is probably due to a species of "Fleck" or to the so-called "bud-traces." As has been pointed out by several authors, rays are produced in abnormal quantities on the external (bark-side) of such flecks. I have not had the opportunity of investigating the details in the case of the Hazel Pine.

We have at the School of Forestry a very curious specimen of Oak, that shows prominent undulations or rather projections or swellings on the outside of the log. In consequence, the contour of the rings is much disturbed and a minute, dotted Bird's-eye figure is formed within. The dots are caused by the cross-section of the vessels that are exposed in small circles, but the effect is not sufficiently pronounced to be ornamental. This is exceptional, inasmuch as in most cases figure caused by the attacks of insects, etc., is produced by *hollows*, whereas here it is the contrary.

The dusky bands of pigment which are not in harmony with the contour of the rings, described on p. 29, are a very great and important element in the figure of many woods, indeed in the case of the so-called Satin Walnut they are the only feature of interest. The irregularity of these dark stripes has a very pleasing effect, something like that of marbling. As already stated, Hartig says that they are due to infiltration of humic matter, from wounds higher up in the tree. This we can readily believe as regards the Olive of Europe, but unless the commercial timber of many other kinds of wood is specially selected for this feature, the theory is not altogether satisfying. We may accept it for the Walnut, perhaps the most beautiful of all the woods which derive their variety of colouring from this abnormal staining. The bruising of the branches, already referred to, may account for the creation of the black pigment. Other woods prized for the same reason are the Brazilian and Indian Rosewoods (*Dalbergias*) and the Marble-wood of the Andamans (*Diospyros Kurzii*), and even the Ceylon Ebony and the Japanese Ebony or Marble-wood (*D. Kaki*) (Fig. 2, Pl. VII) may be included here, but perhaps the bands in the case of the Ebonies should be regarded as local stripes of heart-wood.

The early stages of decay frequently provide us with curious and beautiful displays of figure and colour, and inasmuch as decomposition naturally commences in the oldest wood, those parts in the centre near the root are most productive of showy effects. The remarkable series of hand-coloured plates in the "Icones lignorum" contain a very large proportion of woods variegated by decay. Makers of marquetry seek for timber of this kind, which comes from too many species for us to detail, and to illustrate them would necessitate a new edition of the "Icones," which has fairly well covered the whole ground.

CHAPTER XIV

CALLUS

CALLUS, as known to the Forester, is the woody substance which appears after the wounding of a tree and may under favourable circumstances cover or "occlude" the wound. It is not a question of healing, because there is no union between the old and new tissue (as in the case of a graft), though the edges of the callus-cushions coalesce when they meet. The cushions seem to grow from under the edges of the bark, gradually covering the wound. Our figures Nos. 7, 8, 9 and 20, Pl. V, and Fig. 2, Pl. XL, show the various stages of occlusion on wounds of various sorts.

The tissue of the callus consists of parenchyma-cells that are indistinguishable in structure from those of the rays and of the vertical wood-parenchyma, but instead of being arranged in a horizontal-radial direction, as in the former, or vertically, as in the wood-parenchyma, they are in confusion, being at first a tangled mass without order. The callus-cushion is provided with a cambium-mantle or growing layer that is continuous with and proceeds from the cambium of the tree trunk at the edges of the wound. When this growing layer eventually commences to make annual layers of wood, the latter are nearly normal in structure. They are never actually normal, however, as their tissues are usually laxer, as may easily be appreciated from the sinking and lack of quality of the callus-wood.

Hartig (1853, p. 513) says: "In the first stages of the development the callus-cushion has neither epidermis nor cortical tissue: the intercellular-spaces of the parenchyma open freely outwards. If one places together the callus-cushions of two cuttings that are in this condition, they will unite at the points of contact. It is not until later that a cork-layer arises under the outer layers of cells, which latter then die. Wide-walled cylindrical vessels that do not occur in normal tissues penetrate the callus-cushions."

If the progress of the callus be undisturbed, the cells of which it is composed gradually become "combed out," as it were, and assume a more or less radial direction. Eventually true vessels are formed, then wood-fibres, after which the tissues are to all appearances similar to those of the unwounded part of the tree. They are, however, out of harmony with the latter in respect to their orientation as they may lie in any direction, that is to say, the rays may be vertical and the wood-fibres horizontal, both having lost all relation to the axis of the tree. The callus has become an independent body, with laws of growth of its own, though still deriving its nourishment from the ancient sources.

Callus when not too far removed from the descending sap-stream has the advantage over normally-produced wood in its capacity for exuberant growth. We have specimens at the School of Forestry of callus (?) outgrowths that pass under the somewhat indefinite term of "warts," which attain the thickness of eight inches on a six-inch stem, the stem having increased but two and a half inches since the original wound was made (Fig. 15, Pl. V). Another, from the Walnut-tree, is a more or less spherical body, about nine inches in diameter, that has taken ten years to grow (Fig. 5). Both specimens are, however, exceptionally hard and dense, indeed much harder than ordinary wood of the same species. A third, formed round the base of the stem of a Pencil-cedar-tree, has the appearance of a huge onion, girthing 57 inches, whereas the stump of the tree girths only 14 inches (Fig. 24, Pl. V).

The origin of these "warts" is obscure, but from the absence of "inbarks" from the specimens that I have been able to examine in section, I believe them to be due to blows which have loosened the bark and separated it from the cambium, without greatly injuring the latter. The pressure of the bark being relieved (*see* page 19), growth at an accelerated rate is then possible. In the first of the instances cited above, the seat of the original wound from which the immense outgrowth has proceeded was less than an inch across, whereas the diameter of the wart, in a vertical direction, is nineteen inches.

Be it noted, that the bark was loosened only. Had it been removed, the callus would have provided itself with a bark of its own. This latter is different from that of the tree and can generally be recognised. It is a singular fact, that when the wound is not exposed to the light, no bark is formed, as is seen in cases of internal callus which sometimes forms from the edges of cracks in hollow trees and grows inside instead of out. We have specimens of a spherical shape which may more properly be classed under the name of "wood-balls," that have grown in the interior of a hollow tree and are quite naked. Their surfaces are curiously striated, just as in the case of the wood-balls to be described later, and the appearance of one of them suggests a human brain with very minute convolutions. The same thing happens with internal branches arising under similar circumstances, they also have no bark. The striations are caused by large vessels which are salient on the surface.

There are a variety of other forms of callus, which we will take in turn, beginning with the smallest, which are likewise internal. These are the so-called "pith-flecks." As they have nothing to do with the pith, I shall call them simply "flecks." They arise from the injury to the cambium by minute insects, that burrow under the bark and form little galleries in the most recently-produced wood only. These galleries are almost immediately filled up by callus, and on stripping the bark of a tree thus attacked, the flecks may be seen as narrow, salient lines, running vertically and sometimes anastomosing.

The insect in question is *Agromyza carbonaria*, discovered by J. C. Nielsen (1906, pp. 735–6, Pl. XXX). The miner commences to bore in the fork of a branch, forming a hair-like gallery, which gradually increases in diameter as the insect descends to the root. The larva has been known to travel a distance of forty feet. If it reaches the root before it is ready to pupate, it mounts again until the time arrives to descend once more. It emerges from the root at some distance from the stem and pupates a few inches away in the earth. *Agromyza pruinosa*, according to Greene (1914, pp. 471–4), is at least one of the insects which produce flecks in America, and is possibly the only one.

H. P. Brown (1913) has investigated the fleck itself and gives several excellent figures in which the "combing out" of the callus tissue into rays is well shown. Our illustration (Fig. 3, Pl. XXXVII) shows the same stage of a fleck in the Hornbeam. Brown is of the opinion that the rays produce the tissue of the fleck. My view is that the callus and rays are the same tissue and that it is rather that the fleck produces the rays. Either may be right, as the rays may proliferate and cause the flecks, which in their turn are combed-out into rays.

Thil (1900, p. 60) says that the cells of the flecks resemble those of the cortical parenchyma. Noerdlinger considers them to be tyloses. Ohmann (1905, *ex* Kuster, 1916, p. 367) says that the brush-like production of rays, long ago remarked by Noerdlinger as being frequently noticed on the distal side of the flecks, is due to mechanical influences. The last-mentioned author reported the presence of flecks in forty-one genera and an inspection of his 1,100 sections will reveal more. Brown reports forty-two species belonging to five families native of the U.S.A. They seem to be rare in tropical woods, but I have seen them in *Sentia Commersonii, Eugenia mespilioides, Mimusops globosa, Cordia sp., Lecythis sp., Dysoxylum sp., Buxus Macowani,* and the Manniballi of British Guiana. *Platonia insignis* is mentioned by Janssonius (1914, p. 16). In the East London Boxwood just mentioned, there are two kinds, differing in shape and size, as though caused by two different insects. The Ebony-like stripes sometimes seen in Lancewood may also be of this nature.

Wiegand (*ex* De Bary, p. 491) considers that the flecks seen in the Cherry-tree are the starting-points for the disorganization which produces the Cherry-gum. In one of the species of *Lecythis* above referred to (*L. Ollaria*), a similar degeneracy appears to take place, producing vertical tubes, sometimes arranged in arcs, which lead outwards. Flecks are very abundant in certain species of *Lecythis*, more particularly *L. lævifolia*, Grise., where they give a peculiar character to the wood. Brushes of rays on the outer side of the flecks may often be seen. They are larger in *L. Ollaria* and *grandifolia*, but very much less numerous.

The flecks of the Birch form brown patches on a transverse section and narrow brown stripes on a vertical section (Figs. 3, Pl. XIV, and 9, Pl. XVIII). They are more numerous in small trees and towards the centre of large ones, the insect evidently finding the old bark too tough to penetrate. Other species not already mentioned in which they are common are the Satin Walnut, Alder, Hazel, Elder, American Ash, the Kamassihout from the Cape (*Gonioma kamassi*) and the Maples. In all these they are brown. In the Hornbeam and the Poplars, where the rays are white, the flecks also are white.

The production of tufts of rays may give rise to a special feature on a radial section, as in the "Haselfichte," a variety of Spruce highly prized by German violin-makers, who call it also "resononzholz." In a less marked manner they may be seen, according to Noerdlinger, in *Prunus avium, Salix aurita* and *Populus monilifera,* and I have seen them well developed in *Pyrus aucuparia* and *Carpinus Betulus.* Mathieu

(1897, p. 548) demurs to the theory that the figure of the "Haselfichte" is due to insects. He, like Ohmann, asserts that they are of mechanical origin and due to the pressure upon the cambium of long resin-canals gorged with solidified resin and situated "en saillie" on the internal face of the bast, thus causing inflections in the contour of the annual rings. These channels are then faithfully overlaid year by year by the cambium, producing in transverse section the appearance of rays or traces of resting-buds.

Mathieu asserts (1 c., p. 158) that the Common Cherry may be distinguished from the Merisier Cherry (*Prunus Mahaleb*) by the presence of flecks; indeed, he says that the former is the only species of the Plum tribe in which they are to be found. Again, the Apple shows these flecks, whereas they are absent from *Cratægus*, *Mespilus*, *Cydonia*, *Sorbus* and *Amelanchier*. Inasmuch as the cambium-miner is widespread, the flecks are a good and valid aid to the identification of specimens in which they are present, but no conclusion can be drawn from their absence. I have seen quite large pieces of most of the above-mentioned woods in which there was no trace of flecks whatever, indeed none appear in any of the specimens of Birch of French origin that I have had the opportunity of examining.

Many trees amongst the Myrtaceæ, especially the Eucalypts, are frequently defective, on account of concentric arcs of tubes which may or may not be filled with Kino or other resin. When filled, they are termed "Gum-galls." Is it possible that they are originally due to the attacks of insects? Is it possible, also, that the traumatic, and even the normal resin-canals, of Conifers may have a like origin? The distribution of the latter is so casual and erratic that they strike one as being something outside normal tissue-production.

Hartig (1848, p. 126) found flecks in a fossil Conifer, not named.

Our figure No. 3, Pl. XXXVII, is from a piece of Hornbeam found in a bog in Ireland, where that species is not regarded as being indigenous.

Strange outgrowths from the branches of the "Bee-sucken" Ash and the Apple are occasionally seen (Figs. 1 and 10 Pl. V), which seem to have something in common. The wood of this callus is excessively hard, and in section shows irregular, often blackened chambers. Swanton (1912, Pl. XI) figures this phenomenon in the Apple, and in his description of the Plate, says: "An Aphis (*Myzozylus langier*) and a fungus (*Nectria ditissima*) occur in connection with these cankers, but it was thought that the latter caused them. It has been asserted recently, however, that a *Bacterium* (*B. mali*) initiates these overgrowths." In the canker produced by *Nectria ditissima* the wound gapes widely and remains superficial, whereas in the two cases cited above the wounds are quite enclosed and the fungus, or whatever it may be, works within: further, neither the tree nor the parts attacked seem any the worse, if one may judge from the solidity of their substance. The injury has also been ascribed to hornets.

A reaction to the irritation of a parasite, of a very remarkable nature, is that known as the "Rose of Hell" (Fig. 4, Pl. XVIII). It is the hypertrophied end of a branch, the growth of which has been perverted, and instead of growing in length, spreads out in a radial form, resembling that of a mushroom turned upside down, the gills, so to speak, are radial ridges of wood and the whole may attain a diameter of as much as a foot. The " Rose " may be the product of a single branch or of many, but in all cases the symmetry is retained. The parasitic plant that causes this phenomenon is a species of *Loranthus*, and the " Rose," while growing, is hidden by its base. It is only when a forest fire has killed the *Loranthus* that the " Roses " become visible, hence the superstitions which have gathered round this strange object. As it is the only flower-like thing that survives the fires, the natives of Guatemala have given it its expressive name. We have specimens of two kinds at the School of Forestry, Cambridge, one from Guatemala, produced on a kind of Lignum-vitæ-tree (*Guaiacum sanctum*), and the other from East Africa, on a tree which from its structure appears to be a species of *Pterocarpus*. The latter, from which our figure was taken, shows distinct evidence of scorching.

Birch and other trees when strangled by Honeysuckle form cushions which roll over the stem of the climber (chiefly on the upper side) and eventually bury it. It is well known that wires fastened round trees will become imbedded in the wood in the same way as the stem of the Honeysuckle; moreover, if a wire merely touches the tree without actually passing round it (as may happen when it is close up to a wire-fence), the callus will grow along the wire and form snout-like prolongations, which may be as much as five inches in length. The roots of an Elm-tree growing in the Birmingham Botanical Gardens in a very light soil, produced outgrowths which enveloped any pebble with which they came in contact. This covering in some cases is so complete that the pebbles with their integument of root resemble potatoes. Mr. H. A. Cox tells me of a " Tree of Heaven " (*Ailanthus glandulosus*) at Fulborne which has produced a large mass of callus on the top of a wall. After passing across the whole width of the wall (9 inches) the callus has commenced to flow, as it were, down the other side (Fig. 1, Pl. XL).

The most important manifestation of callus from the Forester's point of view is the ordinary cushion appearing after open wounds, the simplest form being that covering vertical incisions. These rapidly close, make a good mend and do not affect the timber beyond the spoiling of a small piece by an " in-bark," and the discoloration of some of the wood immediately adjacent. The cutting of initials on the bark of trees is also a small matter, and differs only in the fact that some of the incisions will be horizontal and will interrupt the descending sap-stream, so that the upper lip of the cross-marks will be nourished and grow, but the lower will scarcely react at all. Circular wounds made by the removal of branches in pruning are serious in proportion to their size and to the distance from the sap-stream, hence the cut should be made absolutely flush with the trunk. It must be borne in mind that the base of the branch was nourished from the lost branch and not from the trunk, so that a stump projecting even an inch can only depend upon such food-stuffs as can soak, as it were, laterally from the stem. When the edges of the wound are level with the trunk the wound is really a lesion of its bark, all the food descending on the same side of the tree will help to form callus, instead of passing downwards to the foot. Under such circumstances the callus-cushion will run across the wound in an amazingly short time. I have specimens of fairly good pruning (not so good as I should like to see) in which the cushion has made an advance of as much as half an inch in a year, but I have seen much faster progress on pruned trees near Geneva, where they take great care of them and understand the art of pruning to perfection: such wounds as they make, in removing a branch, are soon covered by an almost flat plate of callus. Mathey, however, strongly objects to close pruning.

The faster the cushions grow, the smoother is their bark, indeed in very good mends, the bark is shining with faint lines at intervals, indicating the yearly growth. Slowly-grown callus has a rough, wrinkled bark on which the year's growth is hardly to be discerned, so that good or bad pruning may be known by this feature alone. Our illustrations will show various cases of good and bad work, but of the former, none come up to the ideal. (Fig. 2, Pl. XL.)

The object to be attained in pruning is to leave the growing-layer in a condition to occlude the wound in the shortest possible time, for the mending must be done before decay of the stump sets in. Unless this be accomplished within a few years, the branch will rot and become a focus of infection, and water tainted by the results of decomposition will penetrate and stain the sound wood of the trunk. Even if the stump is eventually covered over, the rotting branch will be a serious defect in the timber and decay may proceed under the cover of the callus-cap. It cannot be too often insisted upon, that the greater the length of the stump that is left projecting from the trunk, the longer will occlusion be postponed and the less effective it will be. One of our specimens at Cambridge, which has apparently made a good mend and has produced a continuous plate of callus over the wound, shows a rotten branch within. Prael (1888, p. 80), in strongly recommending the air-tight closing of wounds by means of tar, etc., says, however, that this hinders the formation of wound-heart, which plugs the pores of the wood and forms a natural protection. He considers it well to wait for a year to give the wound-heart an opportunity to develop, and then to tar the exposed wood.

Regeneration of the tissues may occur on the surface of the wood exposed by bark-stripping providing the surface is not allowed to dry. This may occur naturally in wet seasons. Small patches of callus arise on the wound, and by spreading may ultimately cover the wound. N. J. C. Moeller gives good figures in his "Atlas," Plate I, Figs. 12–14, and ascribes the formation of star-shaped heart to this process. Wounds caused by the stripping of bark by deer may possibly be healed either by outgrowth from the surface or by callus-cushions from the edges. The injuries shown in our Fig. 3, Pl. VII, may have been produced in this way.

A common and serious form of vertical wound is that produced by the tearing of a branch from a young tree. Such injuries may kill the sapling through half its diameter. Callus-cushions grow together from the sides and meet at length. As the growth of the stem is arrested on the side of the wound, the callus takes up its work, and being the more vigorous, soon outpaces it, so that the final result may be a trunk, or section of a trunk, that is mostly of callus. Examples in which the new wood outweighs the old twice or thrice are not uncommon.

The extent to which these new growths may develop is illustrated by an instance cited by Pliny, who mentions an Olive-tree on which heroes were wont to hang their weapons as votive offerings. When this tree was cut up, these arms were found buried in the wood. Mr. Edmund Kett tells me of a case where the iron bracket of the sign of an inn was found on cutting up an Oak tree; indeed, every saw-yard has some story of the kind.

No doubt many of my readers have read Blackmore's *Lorna Doone*, and may remember that Jan Ridd relates that the trees burst with a sound like pistol-shots, from the extreme cold. I daresay that many a gamekeeper could tell the same story, and that of many Winters, for although I have never myself heard a tree explode, I have seen so many examples of frost-crack, that I consider it a common phenomenon (*see* p. 200). These cracks close quite tightly on returning warmth, and callus then forms and occludes the wound during the same season, but ever after, the rent is liable to open in by no means rigorous weather, so that the cushions are torn apart, time after time. Hence a series of parallel cushions become superposed one upon another, making but little progress to complete union; further, as fast as the cushions grow, they are parted by the increase in the periphery of the tree, which lags but a little behind. The explanation commonly accepted is that when the temperature falls below freezing point, ice is formed in the wood and the water thus withdrawn from the cell-walls. The result is practically a drying of the wood, which must be accompanied by contraction. The contraction being uneven, because only the outside of the tree is frozen, the wood of this portion must burst. Without denying the truth of this, I may say that it is by no means convincing, firstly because the bursting of trees is oftener heard after, than during, a frost, and secondly wood bursts, if anything, more easily when absorbing water than during the process of drying (*see* p. 157). To the first part of the theory I have no objection, there is that which amounts to a drying, but it is equally probable that such is caused by the natural loss of water from the wood, which is considerable during cold, dry weather, but whenever a tree loses moisture in a natural manner there is no cracking or bursting of the wood. However, when the thaw commences, there is a rush of water from the roots, and this moisture being unevenly distributed, causes severe tissue-tensions that result in frost-cracks. Again, a temperature such as will cause the freezing of wood to so great a depth in the trunk, would surely kill the living cells of the sap-wood, even if those of the cambium resisted, and double sap-wood would be formed; this is very rare in England, whereas the frost-cracks are common.

Vertical wounds of a formidable nature may be caused by lightning (*see* p. 200). In extreme cases the tree is split so badly as to be killed, but in milder ones a strip of bark and young wood, with approximately parallel sides, may be rent out of the tree, from top to foot. I have seen such pieces that were twisted like a cork-screw and thrown some distance from the tree. I have never seen the subsequent healing, but as the sap-stream is nowhere interrupted, there is no reason why occlusion should not take place.

A graft is a horizontal wound where precautions are taken by the gardener to preserve the life of the growing-layer and to cause the scion and stock to unite, as they will readily do. In this case the woody bodies are totally severed. As their tissues remain in the living condition, new wood is produced between the surfaces in contact, which coalesce. Hartig says that the new tissue arises from the proliferation from the rays, which points to the fact that any of the living cells of the plant may become meristematic or capable of reproducing themselves, or in other words of taking upon themselves the functions of the cambium. Penhallow says that in trees that have been tapped for resin, the heart-wood will resume the functions of the sap-wood and sometimes of the bark. All cells are daughter-cells of the cambium, and if they remain unlignified, as in the case of ray and wood-parenchyma and callus-cells, they may, as soon as a lesion sets them free from the restraint of the surrounding tissues, resume the function of the mother-cambium, *i.e.*, of reproduction by cell-division.

Some grafts are so perfect that it is only by the greatest attention that the point of union can be discerned on a section, though the bark permanently retains evidence of the junction. There is at Cambridge a graft of a scion of *Magnolia glauca* on an unknown stock (Fig. 3, Pl. V), and another of the Almond, both of which may be described as absolutely sound. In the former, the heart-wood of the scion has ripened to a greenish-yellow colour, but this descends no farther than the line of the graft, and does not enter the stock which is apparently of a species which does not form heart-wood. Figs. 25 and 26, Pl. V, show Weymouth Pine grafted on Scots Pine.

Pollarding and coppicing are both species of pruning, but here we have the whole of the upper part of the trunk removed, as in grafting, but there is no sap-stream from above to aid in the healing. Callus, as already said, has the property of giving birth to new buds, which in these cases develop into leafy branches, that are long-lived and may form considerable stems. The section of the parent tree which has been cut is seldom covered entirely in the case of coppice, but it may be nearly covered in the pollard (Fig. 2, Pl. V). Instances of the covering of the coppice-stool are recorded for the Silver Fir by Mathieu (1897, p. 529), in which cases the stools became occluded by caps of callus, but this seems to have been due to the inarching of the roots with those of neighbouring trees, which thus nourished the stools. In most other cases, especially amongst the broad-leaved trees, a small cushion of callus rolls over on to the edge of the upper surface of the stump, and that is all. The function of this callus is important, inasmuch as it throws up shoots which may become large poles. When these are situated near the ground on the " stool," they are called " coppice " (Fr. " coupé "), because it is the practice to cut them at short rotation. If the shoots spring from a trunk, cut off some distance from the ground, the tree is called a "pollard," but there is no difference in principle. By both processes, shoots which are of more rapid growth than the normal are obtained. Second-growth wood not only grows faster, but is of better quality than that which would have been produced from the uninjured tree. For certain purposes, such as the making of shuttles and of axe and hammer handles, second-growth woods of Persimmon, Hickory and Ash are preferred. Buffon maintains that young trees of a few years of age, if pollarded and trained with an upright leader, will outgrow those normally raised. This method is recommended for Oaks.

Burrs are swellings that appear upon the trunks of many kinds of trees, the most familiar being those on the Elm and the Oak. Their origin is ascribed variously to resting-buds, wounds, and to the irritation caused by the attacks of fungi or mites. Whatever be the nature of the stimulus, the great feature of burrs is the production of quantities of buds. Some of these develop into shoots, which are, however, short-lived as a rule, but the greater part fail to penetrate the bark, turn on themselves and form a mass of entangled fibres. Being endowed with a cambium-mantle or growing-layer, they continue to form wood on their sides, notwithstanding that their growing-points may have perished and they cannot increase in length.

The simplest form of burr has the appearance of a resting-bud-trace, and maintains the same diameter for many years, its growth in length just keeping pace with the increase in the thickness of the trunk of the tree (Fig. 4, Pl. VIII), by the annual production of a single bud which replaces the dead bud of the previous year. Later, more than one bud arises in the axils of the bud-scales, and the trace gradually enlarges in all directions, forming a semi-globular mass.

Burrs are often of great beauty when opened. The mass of tangled fibres assumes the most fantastic forms and varied shades of colour, hence they are much prized by the makers of veneers who give high prices for them, especially for those of the Walnut, Thuia-wood, Amboyna-wood and the Maple. The second kind mentioned, the Citrus of Pliny (XIII, 29, 2), commanded fabulous prices, according to that author. It should not be confused with the Thuia of Theophrastus (V, 5), as that was from a tree that "grew upon the mountains of cold countries," whereas the Citrus or Thyine-wood came from North Africa, and is most probably the burr of *Callitris quadrivalvis*, Baill. These burrs are caused by the destruction of the coppice by the Arabs, who to this day burn it in order to stimulate the growth of herbage for their flocks, hence the tree being unable to grow vertically, forms large masses of callus in the ground. This makes me think that whatever the mite (*Eriophyes*) may have to do with the production of "Witches'-brooms," it is not responsible for burrs, as Boulger (1902, p. 38) avers, and the fungus (*Exoascus*) may be exonerated also.

Burrs of Callitris, says Spon (p. 2012), are seldom 4 feet in diameter, still some big ones occasionally come to light, to witness one at the Paris Exhibition of 1885, which weighed 5,280 lb. Walnut burrs are also sometimes of great size, specimens being cited from Italy weighing 4 cwt. Spon adds (p. 2022) that the burrs do not occur on Walnut-trees grown in the colder latitudes. We have a very small one from an English source in our collection at Cambridge.

Certain species of Ash, more particularly *Fraxinus nana*, according to Kerner (II, p. 29), split their bark without any visible reason. Callus arises within and develops into burrs, which produce buds and shoots.

The Briar-root (Bruyère, *Erica arborea*, or Tree-Heath), used for the making of pipes, has its origin in a similar practice to that employed by the Arabs mentioned above. The Bruyère is burnt by gypsies to make room for the Bilberries that always occupy the ground after a moor-fire. The root-stock of the plant becomes thickened and produces burrs, the structure of which can be studied in any briar pipe of good quality.

A good example of a burr on a small scale, in section, cut in three directions, may be seen in Hough's *American Woods*, Vol. III, section-card 62A, of the Black Ash (*Fraxinus sambucifolia*).

Mer (1872, p. 235) observed a shoot spring from the surface of the solid wood of a cut branch at some distance from the cambium.

Many of the buds of a burr may be called "resting-buds," though I imagine that most of the shoots arise from the callus that solders the mass of the burr together. Many of the so-called resting-buds are really abnormal rays, which may sometimes be seen splitting up into smaller ones of normal size (*see* p. 80).

On some logs of the Plane-tree stripped of their bark, I noted large numbers of short conical projections, tapering to a fairly sharp point. Such, indeed, may be observed in many woods, but those in question were extended in a vertical direction, their bases being as long as one and a half inches, while their width did not exceed half inch. We have a log of the Willow which shows similar excrescences, but very much smaller, though equally long, and in vertical series like a tiny range of peaks arising from an elongated hill. To what class these belong is by no means clear. Our Fig. 3, Pl. V, shows these resting-buds in section.

A curious form of resting-bud that never wakes up is the wood-ball (sphæro-blast). I have made sections of many of these, and find a similarity in structure in all. They appear to originate in buds that cannot make their way through the bark, and, as said above, turn on themselves, but in this case only once, *i.e.*, they become folded so that their tips are directed towards their roots like an anatropous ovule. At this stage the growing-point perishes, but the cambium-mantle that clothes their sides continues to make wood each year, so that they become more or less bulky. We have one of these wood-balls that measures four inches long by three in diameter, but for the most part they are small egg-shaped bodies, that may be seen half sunken in the bark of many species of trees. (Fig. 6, Pl. XVIII.)

Callus has the property of giving rise to roots as well as branches, indeed it is this fact which makes it possible to propagate plants by means of cuttings. Callus forms on the surface of the cut portion, and were it not so, the cutting could not take root, hence, it is well to encourage callus-formation, and this is not done by keeping the wound damp, as is generally supposed; on the contrary, dryness is a favourable condition. Some gardeners let their cuttings wilt in the sun before putting them in the ground, and Hartig recommends varnishing the cuttings and letting them lie by until the tips of the roots appear. This is, however, a digression, except that it may be a hint to Foresters who may wish to increase their stock by using cuttings.

The Lebbek-tree (*Albizzia Lebbek*) can be propagated by means of pieces of the trunk as thick as a man's body (Schweinfurth).

CHAPTER XV

DEFECTS

AS it is possible to find logs so well grown and seasoned as to be without defects of any kind apart from small branches, we may commence by assuming that all defects are abnormal. Still, if defects arise during seasoning, we cannot leave out of consideration the question of growth.

The interior of a park or hedge-row tree will be very different in structure from that of one that is forest-grown. Not only will the former be full of large knots and branches, but the rings will be wide, becoming narrow only at an advanced age, when the growth slackens down. A forest-grown tree, on the contrary, will be broad-ringed in its early youth, but as its neighbours close in around, it will soon reduce the width of its rings. In the primitive or undisturbed forest this last condition may remain permanent, but in another under cultivation, the woods will be thinned periodically and the tree will recommence making wide rings until the canopy is formed again, and slow growth sets in once more. Here we shall have a rhythm of groups of fast- and slowly-grown rings alternating (Fig. 4, Pl. XVI). All the three foregoing cases may be regarded as normal, but the results, as far as defects are concerned, may be different.

As so often stated, wide rings imply dense wood in ring-porous broad-leaved trees, and lax wood in Conifers. In diffuse-porous broad-leaved trees the influence of growth is not marked. Now, as dense wood shrinks more than lax wood, there will be greater contraction in those parts where it is abundant, and the tensions thus set up may result in shakes, either in the living tree or in the log when felled.

We have very little information that will help us to predict as to what will happen in the many different cases which may present themselves, so each of the above categories should be dealt with separately. In the first a ring-porous broad-leaf will have a dense centre and a lax outer zone of wood, hence the shrinkage will be the greatest in the middle, but inasmuch as the sap-wood shrinks more than the heart-wood, quite apart from its density, the whole log may contract sufficiently uniformly to escape any disastrous tissue-tension. The heart-wood also becomes drier than the sap and exterior wood, and while living, has already shrunk to some extent. Excessive shrinking of the heart in this natural manner is, I believe, the cause of one kind of heart-shake, or cracks which have their wider openings towards the pith gradually narrowing and disappearing, before they reach the exterior of the log.

Secondly, in a Coniferous tree an opposite state of things prevails.

The centre will be laxer than the exterior. The outside will shrink and constrict the inner wood, but as the latter will be the drier, there will be a certain compensation, and tissue-tensions will here also be evaded. Hence there should be little risk of shakes.

Thirdly, when zones of dense and lax wood repeatedly alternate, we may have them pulling against each other from all directions, causing star-shake if a dense zone be on the outside. If this be in its turn surrounded by another lax zone, the wood may separate at the ring-boundaries (the line of greatest weakness), and ring-shake will be caused. In all specimens of ring-shake that I have examined, there is always a marked difference in the width of the rings (Fig. 11, Pl. V). Where the shake passes around a part of the tree only, the cause is excessive growth on one side of the tree, followed by a series of narrow rings. A defect of a precisely similar character, but manifested as horizontal shakes, is due to irregular growth in a vertical direction, where rings of great width thin away upwards or downwards (Fig. 4, Pl. XI). The pull which separates the tissues may come from a distance from the place of fracture, for, as we have seen in the chapter on "Shrinkage," a crack may open on the opposite side of the log to that where the actual contraction is taking place. I believe that the so-called "thunder-shake," which resembles that of the Elm just cited, arises in the same manner and may occur in the tree while still living.

Natural tissue-tensions may not always be severe enough to rupture the wood while the tree still lives, but subsequent separation from the stump may disturb the equilibrium and the trunk will either split at once, or the fracture may be postponed until a shock (*see* p. 113), or the shrinking of the outside of the log determines it.

Frothingham (1918, p. 835) says, "in falling Rock Elm the heart must be almost entirely cut through in notching, or the tree will split clear to the top : heart-planks would sometimes split through the centre from end to end when dropped from the saw."

The star-shake that results from the drying of the felled tree is a question of too rapid desiccation, and cannot be regarded as a defect in the timber itself, but in its subsequent treatment.

Other defects, such as the presence of knots and branches, are inconveniences or advantages, according to the purpose to which the wood is to be put. As burrs, warts, ripple, crotches, resting-buds, traces of mistletoe, etc., have their value as figure-producing causes, I relegate all these to the chapter dealing with that feature. Still, loose knots and buried stumps of branches are useless under all circumstances, and must always be considered defects. In a subject like that of wood, there must inevitably be much overlapping, so it may be said once for all that gum- and resin-galls (*see* p. 188), Bee-sucken wood (p. 189), the reddish-brown streaks so common in Hickory (p. 183), sinking, warping and twisting (p. 164), and pith-flecks (p. 187) may be looked for elsewhere. Defects due to Fungi are excluded from this work, as they belong to a part of the subject with which I do not pretend to be familiar and which will be treated, I understand, by a specialist in another text-book devoted to the fungoid enemies of trees.

I cannot refrain, however, from mentioning the remarkable defect known as "pumping" in Larch-trees. In some districts these trees commonly become hollow, in consequence of the attack of a fungus (*Dasyscypha calycina*) which leaves the sap-wood and inner ends of the branches intact. The whole trunk then forms a tube into which the proximal ends of the branches project, like so many pegs. In some cases the innermost sheath of wood is sufficiently indurated and dense to escape decay and remains attached like a core to the ends of the branches.

Many of the defects in standing timber may be read upon the bark or known by the presence of the fruit-bodies of fungi. In the former case, any irregularity of the bark should be carefully scanned and the presence of callus noted (*see* p. 191). On smooth-barked trees there are always marks and ridges which are the remains, greatly exaggerated by growth, of the leaf-scars and the cushions which arise around the branches. These are of a definite form for each species and their interpretation may be found by examining the leaf-scars left after the fall of the previous year's leaves. If these scars be traced from point to point down the twigs and branches, their immensely enlarged counter-parts will be seen on the trunk. These marks are normal and may be neglected, but all others must be regarded with suspicion.

The history of any particular wood or forest is a valuable detail, as the occurrence of any excessive thinning or the lack thereof may be responsible for defects arising from tissue-tensions that may affect the whole forest in question.

A peculiar defect known as "double-heart" or "double sap-wood," very rare in this country, is common enough in France, Belgium and Germany. It is supposed, with great probability, to be caused by a frost severe enough to kill the sap-wood and prevent it completing its metamorphosis into heart-wood, without killing the growing-layer or cambium. The contents of the latter, being more viscous, are able to resist the cold. The cambium can, therefore, continue to produce sap-wood, which in due time becomes heart-wood. The result is that we have an external sap-wood zone, followed by a heart-wood zone (Fig. 1, Pl. XVII), then sap-wood again and then heart-wood. The very excellent brochure upon this subject, by Mer (1897), should be read by those interested in this curious phenomenon. A good figure of this defect is given in the *Timber Trades Journal*, 1906, p. 912, and I have a section of Noerdlinger's of *Lonicera iberica* where the sap-wood and heart are thrice repeated.

Spiral-grain has already been touched upon (p. 76), but this can only be considered a defect when the wood is used as planking, it is no disadvantage when the tree is employed whole. Planks cut from twisted logs are liable to open in cracks which lead obliquely inwards and are very troublesome. Further, it is impossible to quarter the log in such a way as to follow the rays and show the silver-grain, because the rays on a transverse section run from the centre in a helicoid manner.

Any shake that may occur by the contraction of the wood during drying can have its counterpart in another caused by too rapid swelling following drought when the tree is living or in the log when seasoning. It is a matter of the unequal distribution of water. Parts of the trunk which are more easily supplied with water (the sap-wood, especially the outer portion, and the wood near the roots) may swell while others are still dry. After a time all parts obtain their share of moisture, and the fissures close up, but do not unite. I believe that ring-shake may be caused by the abundant supply of water during heavy rains succeeding a drought, more often than by the drought itself, during which the desiccation is gradual. The same may be said of any other form of shake. Frost-crack may be one in question, as they are usually in the lower part of the trunk, whereas if cold were the immediate cause, one would think that the upper parts of the tree, especially the branches, would suffer most. Evidence of frost-crack is readily found in the vertical and repeated parallel callus-cushions, and trees so marked should be rejected.

Heat-crack is not often met with in England. It was very prevalent on the Continent in August, 1911, when small trees of Spruce were so badly split that one could see through them. These have subsequently been attributed to frost, as pointed out in the *Forestry Quarterly* (Vol. XI, p. 420).

Bark-scorching is also rare in England. The growing-layer appears to be killed by the intense heat of the sun after exposure of woodland trees following thinning. The bark may curl up and serious wounds result (Hess, *ex* Schlich, p. 526).

Injury by lightning (Schlich, p. 659) may be serious enough to shatter the whole trunk and render it unfit for working up. In less extreme cases, when only a strip of bark and wood is ripped out, the timber may be useful if cut at once. If allowed to callus over, the subsequent growth will be too irregular to make good timber. The theory which is supposed to explain the tearing of the wood is that steam is generated in the cells by the passage of the electric current, and the outer wood is blown off. In this case every cell of the ruptured layer should be burst open. I have not had the opportunity of verifying this.

Traumatic resin-ducts (*see* p. 71) in Cedar and other Conifers may be so numerous as to form almost continuous rings or sheaths which separate one ring from another. A form of ring-shake may thus be caused. Small gum-galls in the Eucalypts, when in sufficient numbers, may have a like effect and are quite as bad as large, local galls.

Defects arising from advanced age and the excessive drying of the heart-wood and frequently accompanied by discoloration are frequent. The inner wood of old Gum-trees (Eucalypts) is generally brittle and useless.

Ring-shake may arise from the attacks of fungi or even from the results of a wound, but neither fall within the true meaning of the word "shake," as they are dead places in the wood and their causes are generally sufficiently evident. Transplanting is reputed to be one of the causes of such wounds.

Wind-shake is mentioned by Saxton (1918, p. 734). I do not know the precise nature of this defect, but the author says that on a slope with a north-east exposure, 42 per cent. of the Douglas Fir had this shake. It may occur at any point in the height of the tree, and sometimes it is present in the top and not in the butt.

Hartig (1889, p. 243) mentions and figures cases where wounds have been caused by the sudden increase in the growth of trees, which thus splits the bark that becomes partially detached. His figures Nos. 64 and 83 show, however, that the wood was exceptionally slowly grown, hence his explanation does not apply.

CHAPTER XVI

DECAY AND DURABILITY

DECAY may be defined as a disintegration of the tissues and a destruction of a portion of the cell-substance, during which the latter is converted from a solid into a gaseous form, the change being indicated by a considerable loss of weight.

A single tissue may escape decay, as in the instance cited by Sachs (1887, p. 160), where the rays of the Beech survived in the form of so many minute spokes, radiating from a centre from which the remainder of the tissue had fallen away in dust. In most cases the whole of the woody body falls into a state of dissolution.

Sometimes the decay runs in a radial direction, and on a transverse section can often be seen making progress in a star-shaped form. At others, as we have seen, the rays may be spared. H. A. Cox informs me that in the neighbourhood of Looe, in Cornwall, he saw the supports of a gate made of Oak, one end of which had lost the rays by decay and the other, on the contrary, had lost the tissue around the rays, which had become salient.

As we have already learnt, the cells of which the tissues are built up are little closed chambers, whose walls at first are composed of cellulose alone. The walls not only become thickened by the deposition of lignin, but the middle layer of the cell-wall undergoes a change in its composition, and acts as though it were a separate stratum of a different substance. This is called the middle-lamella or intercellular substance. We have, therefore, three different substances to consider that are susceptible to quite different influences which bring about their decay. Each in its turn is liable to be attacked and to disappear, with or without its neighbours.

A scientific explanation of the phenomena of decay is comparatively modern. Liebig (*ex* Justin, *Technologist*, II, p. 4), expressing the old view, says that the causes of decay are three :—that due to oxidation ; that due to contact with rotting substances, and, thirdly, that arising from the inner decomposition of the wood. The last two reasons are no explanation at all, and the first cannot be proved.

The modern view is, that all decay of vegetable matter is due to the action of lowly organisms such as fungi, including Bacteria. These invade the tissues and feed upon one or more of the layers of the cell-walls.

The middle-lamella contains much pectose (a substance which gives the character to Cherry gum). This pectose may be present in smaller quantity in the adjacent layers. It is a substance in which a bacillus

(*B. butyricus*, Cohn., syn. *B. amylobacter*, Van Tieghem; *Clostridium butyricum*, Prazmowsky) thrives exceedingly and which it eventually consumes. The result of the destruction of the middle-lamella is the separation of the cells, which fall apart.

Bersch says (p. 8): "If moist cellulose be exposed to the air, the originally white mass turns grey, becoming constantly darker and finally acquiring the appearance of the black-brown mould found in the core of rotten trees. It contains innumerable bacteria which in appearance closely resemble those found in wood-mould."

It is said that the bacillus prepares the way for fungi of a more robust nature, and as a matter of fact, decayed wood usually shows traces of the latter.

One of these fungi is, according to Th. Hartig (*Forst und Jagd Zeitung*, 1846, p. 14), *Nyctomyces candidus*, Hart., which also subsists upon the intercellular substance. It appears as a lax, silk-like mass in the wood of old Oaks. *Polyporus dryadeus* and *Merulius lacrymans* act in the same manner (Hartig, 1894, pp. 201, 219). *Nyctomyces fuscus*, Hart., on the contrary, feeds upon the thickening substance (cell-thickening or lignin) on the interior of the wood-fibres and vessels, leaving the intercellular substance untouched. Other fungi which have a similar habit are *Polyporus borealis* and *P. igniarius* (Hartig, 1894, pp. 197, 201). Here the cells are not isolated from one another and the tissues do not fall into dust, but remain structurally as before, but with a loss of much of their weight.

Tuzson (1903, p. 276) investigated a case of decay (agent unknown) where everything had disappeared from the wood of the Beech except the spiral thickenings of the rays. Here the cellulose of the walls and the intercellular substance had disappeared, leaving lignin only.

Buller (1905, p. 4), while investigating the decay of paving-blocks, detected two species of fungi, *Lentiscus lepideus* (Fr.), which was in abundance, and came from all parts of the area in which the paving-blocks were laid, and a species of *Corticium*. His examination showed that the tracheids of the wood (presumably Swedish Deal) appeared to have been left intact except for holes made in their walls by the hyphæ of the fungi. The middle-lamella was not destroyed, so that the cells had not separated one from another, and the secondary thickening had undergone no change. The rotten wood was much lighter than the sound wood.

In this case it is not clear what substance had disappeared.

Wiesner says that decay is the dissociation of the cells which are separated without the slightest alteration of their structure, implying that the cellulose remains.

The popular expressions of "red and white rot" correspond roughly to two opposite conditions brought about by the action of fungi which destroy one layer of the cell-walls only. If the fungus consumes the lignin, which is reddish or brownish in colour, the whitish cellulose remains. Conversely, if the fungus destroys the cellulose, the residue partakes of the reddish colour of the lignin.

From all the above it is evident that there are as many forms of decay as there are layers of substance in the cells, and, further, the disintegration may take place in different ways, according to the particular parasite, of which there may be several kinds, and more than one may be at work at the same time. Margell (1883, p. 198) says: "Every fungus calls forth a specific form of decay independently of external influences and of the species of the host plant." It is evident that we are not in a position to discuss the question of resistance to decay until we know what particular parasites have to be resisted.

Our knowledge on this point is extremely limited, and as I do not pretend to a knowledge of fungi, I shall confine myself to the external manifestations of decay.

The conditions under which wood may decompose are always those which favour the growth of fungi, *viz.*, a sufficient temperature, a certain amount of moisture and a small quantity of air. But little of the latter is necessary, and if stagnant, so much the more favourable for the fungus. The unfavourable conditions are the contrary of the foregoing, therefore, extreme cold, continued wetness or saturation, drought, and the exclusion of air are good for the preservation of wood, as the following examples will testify. It is, however, hardly necessary to call attention to the absence of fungi in cold climates and during the winter.

Saturation

Woods that are notoriously perishable in the open may be almost everlasting when immersed in water. The best instance is that of the piles of Alder which are found in the ancient pre-historic lake-dwellings. Those in the Lake of Geneva may still be seen under water. The ancient Roman war-vessel, the *Trajan*, discovered by Alberti in lake Riccio, where it had lain submerged for 1,300 years, had, when raised, not only the timbers of Cypress and Pine still in a good state of preservation, but the canvas caulking also. As a more modern instance, may be cited the experiments of Thelu on pit-props (1878). He found that they lasted much longer when watered.

Drought

As is well known, timber in dry, well-built houses may last indefinitely. The doors of St. Peter's at Rome, made by Adrian III, and removed by Eugene IV, 550 years after, were quite sound, according to Alberti (p. 26), who was present in Rome at the time of their removal. The woodwork of the Palace of the Dey of Algiers looks quite new at the present day, although it was put in more than 1,200 years ago. Violins made by the Cremona masters still exist in fair numbers, and although they are constructed of several kinds of wood, having very different reputations for durability, none appear to suffer from decay more than others. They are varnished on the exterior only, and there is sufficient means of access to the interior for the spores of fungi. In the desert climate of parts of Upper Egypt, we find the wood of the sarcophagi in the tombs perfectly well preserved; they show no signs of decay, because the air is too dry for the development of fungi.

Exclusion of Air

Wood buried in heavy clay will last three times as long as that buried in sand.

Conditions that may be favourable to the larger fungi may not suit the bacteria so well, for whereas the former require a certain amount of air (otherwise, of oxygen), the access of the latter immediately arrests all signs of vital activity in *Bacillus butyricus* (Wollny, p. 142). As regards the reaction of the wood, fungi are favoured by alkalinity, whereas the bacilli can support considerable acidity (*Ibid.*, p. 141).

The spores of fungi germinate best in enclosed spaces such as cracks in the wood or between boards, the faces of which, are in contact. Some can germinate in dry wood, others, for instance, our old enemy the dry rot, needs moisture at first, but when well established, can dispense with it, the fungus having the power of converting the substance of the wood into water.

As kiln-dried wood is generally more or less honey-combed (*i.e.*, contains small fissures), and retains the more perishable substances, it is in the most favourable condition for the germination of fungi.

In woods of submerged works there is sufficient oxygen in the water to serve for the oxidation of the substance of the wood, hence we cannot accept this element as an agent of decomposition.

Having seen that under certain circumstances, wood may be almost imperishable, we have to consider the fact of the undoubted difference in the amount of resistance displayed by various species. A few examples will aid the discussion :—

Larch.—A highly-resinous, rather heavy, heart-wood Conifer. The Swiss châlets are good examples. Many of these in the Canton of Valais still exist in habitable condition and bear the Bernese arms, showing that they date from the time of the Bernese domination (about 1798). They are built of squared logs and in many instances are actually soldered together by the resin. This is perhaps hardly a fair example, but the water-troughs with which the châlets are always provided, and through which a small rivulet has run for generations, are almost equally well preserved. This is a very severe test as the trough is dry on the outside and there must be an intermediate layer of wood which contains just sufficient moisture to invite fungus-parasites.

Silver Fir.—A very feebly-resinous, light-wooded, sap-wood Conifer. The trusses of the old part of the roof of the Basilica of St. Paul, at Rome, were framed in this wood in A.D. 816, and were good and sound in 1814 (Tredgold, p. 47).

Cypress (probably *Cupressus sempervirens*).—A soft, light Conifer, with little distinction between sap- and heart-wood ; no turpentine, but having a powerful aromatic resin. The doors of St. Peter's at Rome were made of this wood. Alberti (p. 26) cannot praise it too highly. He says : " What tree can you compare with it in point of fragrance, beauty, strength, dimensions, straightness and durability ? " Plato was of the opinion that the laws should be written on tables of Cypress in preference to those of copper and brass.

Oak.—A heavy, heart-wood, broad-leaved tree with perishable sap-wood. The reputation of this species is too well established to need comment.

Elm.—A heavy, heart-wood, broad-leaved tree, similar to the last, but having durable sap-wood. Its use for pump-bodies which are constantly between wet and dry, not only from the passage of water, but because the lower part of the pump is fixed in the soil, is the severest of all tests.

Red Gum or *Satin Walnut.*—A light, heart-wood, broad-leaved tree, of a notoriously perishable nature.

Beech.—A so-called " ripe-wood " broad-leaf, of medium weight, and bad reputation for durability.

Hornbeam.—A sap-wood broad-leaf, of an equally bad reputation. Thelu (p. 26) says that when used as pit-props it will rot in a few weeks, and sooner than the Birch. It is one of the heaviest of our indigenous woods.

Boxwood.—A sap-wood broad-leaf, heavier than the Hornbeam. Its reputation is, however, good. I have never heard of a piece of decayed Boxwood.

Canary Whitewood (*Liriodendron tulipifera*).—A light, sap-wood broad-leaf, having the reputation of being imputrescible.

Birch.—A rather light, sap-wood broad-leaf, perhaps the most perishable of all the commercial woods. Poles sent from Norway are frequently already rotten on arrival. According to Powell, the Red Birch makes very good hop-poles, whereas the White Birch is quite useless. The bark of this tree is everlasting. It is used in Russia for the damp-courses of houses as we use slate, and in Norway houses are sometimes roofed with it, and upon this bark covering earth is placed, in which to grow flowers (Stevenson, p. 65). Both wood and bark are well preserved in peat, though the latter is more frequently found as an empty cylinder (Noerdlinger, 1859, p. 471). An analysis of both bark and wood might reveal some substance present in the former and not in the latter, which may afford a clue to the reason of the great difference in their behaviour.

Amongst the above species we have representatives of all kinds of sap-, ripe-, and heart-wood trees of very different weights and composition. The difficulty with which we are faced is that we cannot fix upon any one character to which we may attribute durability, for there are nearly always other woods that can be cited in contradiction.

Dumonteil (1823–26) went so far as to say that " other things equal, the durability increases as the density." This when applied, as he did, to the woods of French Guiana may work very well, but amongst those of another country may be inapplicable. Conifers of considerable density, like the Larch, highly charged with resin, are durable, and others, like the Maritime Pine, are perishable. The Giant Redwood (*Sequoia*) is one of the lightest of all commercial woods, has no aromatic, essential oil such as is supposed to preserve the Cypress, yet it is remarkably lasting. The wood of the Spruce and Silver Fir that have no heart-wood are fairly durable. To sum up, we have few data to teach us to what the resistance to decay of any particular species can be ascribed, and no information as to the value of the resistance conferred by any substance contained in any wood. It is easy to say that the essential oil of the Cypress acts as an antiseptic, but it is quite a gratuitous assumption. Pliny says that the oil extracted from the Cedar was used as a preservative for other woods, while the Gurjun and Carapa oils and Gambier are used for the same purpose in India, Burmah and British Guiana respectively. Are these the only facts which we have to rely upon?

In the chapter on "Heart-substance," I have adopted the view that as far as the non-aromatic woods are concerned, durability is due to the Phlobaphene, but this conclusion is arrived at by a process of reasoning, for which there is, after all, no proof. We know that in some woods the heart-wood is very much more durable than the sap-wood, and as the difference in composition is chiefly brought about by the addition of permanent or altered tannin, we are to that extent justified in ascribing the difference in the resistance to decomposition to that substance. But sap-wood, as we have seen in the case of the Elm, is not always perishable. We have at Cambridge a portion of a water-main made of the trunk of an Elm that lay in the Marylebone Road, London, for about eighty years. The trunk was whole and the sap-wood is still in good preservation. The sap-wood of the False Acacia is equally durable. Daltenau-Bosc (p. 9) says that poles of this wood are as good as new after ten years' exposure as vine-poles.

A critic in the *Journal of Forestry* (1919, p. 876) demurs on two points to the conclusion expressed in an article of mine in the *Timber Trades Journal* dealing with this subject. He says that it is generally accepted that something is taken from the wood during the passage of the sap-wood into heart-wood. To this it is sufficient to reply that the heart-wood is the heavier, hence something must be added. Secondly, he states that Phlobaphene is not an oxidation-product. I am not a chemist, and I expressly avoided committing myself to any view concerning this compound by adopting the general term of "heart-substance," but to show that I was not writing at random, I cite the following opinion.

Husemann, I, p. 262: "The Phlobaphene met with in the bark of other plants shows the greatest similarity with the brownish-red product of decomposition, which affords much tannic-acid and also other glucosides by the action of oxidizing agents. It is therefore highly probable that the naturally-produced Phlobaphene in the external clothing of plants in contact with the air is a product of the oxidation of the wide-spread tannic-acids."

Having considered the conditions of decay, the agents, and the susceptibilities of various species, let us review the substances contained in the wood.

Cellulose, lignin (cell-thickening), and pectose are found in all woods, forming the original walls of the cells and their subsequent thickening. We have seen that each substance in its turn may be attacked by fungi or bacteria. Then there are the contents of the cells—nitrogenous matters composing the protoplasm or living part of the cell, starch, oil, and sugar. In seasoned woods the whole of these should have been absorbed, and in any case they do not persist in the heart-wood, such parts as retain them being classed for that reason as sap-wood. The protoplasm is the most perishable of all organic substances, and woods that retain much may be more susceptible to decay than others which do not. The quantity is not, however, great, and it is not readily accessible to the fungi, as they must first penetrate the cell-walls to reach the protoplasm.

The starch comes next in importance. This substance is frequently present in quantity, often filling the cells of the wood-parenchyma and the rays. It is more abundant at the beginning of Winter and disappears to a great extent when the tree breaks into leaf in the Spring. It is not readily attacked by fungi, but is so easily changed into substances which may be a welcome food for those parasites, that the presence of starch must be always regarded as a bad point. There is, however, little or none in the heart of heart-wood trees, but in ripe-wood trees, such as the Beech, there may be a considerable amount even as far in the interior of the tree as the sixtieth ring from the bark. Hartig (1894, p. 52) says: "It not infrequently happens that starch resists the destructive influence of wood-parasites longer than the lignified walls of the cells." This depends upon the species of fungus.

Sugar, dextrine and glucose are a very banquet for the enemies of wood, but under favourable conditions of seasoning become in their turn converted into tannin. This latter substance, as we have already learnt, has its soluble and insoluble forms, the former being a transitory condition and the latter a permanent one. The Hornbeam is a very hard sap-wood tree and contains much tannin (Thenius, p. 40), yet it is very perishable. Hartig (1894, p. 51) says: "The tannin which is dissolved in the cell-sap offers excellent food for the mycelium of *Polyporus ingiarius*. This accounts for the change of smell in woods attacked by this fungus." Hiley (1919, p. 28) says that during the attack on the wood of the Larch by the fungus *Dasyscypha calycina* (the Larch-canker) the actual tannin-content is increased by the action of the parasite.

Only fixed tannin can favourably affect the resistance of wood to decay. The soluble tannin is found in the perishable sap-wood of the Oak and other trees, as well as in the durable heart-wood. It can be leached out by water. On the contrary, Noerdlinger says (1859, p. 451): "Sugar, dextrine, gum and starch do not appear to be much more liable to decay than the wood-fibres themselves. The tannin is a substance whose resistance to decay cannot be doubted. Resin affords a mechanical protection to the wood that is quite saturated with it; it is, however, not a resistant substance. On the transverse section of the wood of the White Pine (*P. Strobus*) we often see much mould appear in the saturated parts around the openings of the resin-canals, out of which it may be seen growing. Without exception it is upon the zones of the rings which are richest in resin that the most mould is found, even when there is none whatever on the remaining portion of the surface." Again (p. 44): "In the neighbourhood of Bordeaux, the stem of the richly-resinous Maritime Pine (Cluster Pine, *Pinus Pinaster*) may be seen completely rotten, whilst the narrow-ringed wood of tapped trees will last six years under the same conditions. This author was apparently unaware of the fact that in tapped trees the top is drained of resin while the latter becomes concentrated in the butt. Mignard (p. 12) expressly excludes tapped Fir (*Abies pectinata*) from building operations, as being perishable. Misconception on this point has led to the view that trees that have been tapped must of necessity be poor in resin. Young trees that have been tapped to death furnish very inferior timber.

Sugar, dextrine, glucose and gums, and any wood containing them, will be durable only in the dry. When moistened, these substances will ferment, otherwise be attacked by the bacteria of fermentation. Duhamel (*Exploit.*, p. 566) says, " the fermentation of sugar into alcohol causes the wine-like or acid smell that is remarked in damp wood-stores." Chevandier (*Recherches*, 1844, p. 8) perceived this same smell in damp saw-dust kept in closed glass vessels, where he found a small quantity of a colourless fluid smelling strongly of alcohol. Various kinds of saw-dust that had been kept in barrels in a warm cellar for three weeks passed into a condition of spirituous fermentation, and the water was replaced by another compound.

The popular impression that the fluid sap is injurious and should be promptly got rid of is not justified. It may contain matters which attract parasites, but it must not be forgotten that these same susceptible substances are the material from which the resistant ones may be derived. This can only be done during a slow process of seasoning, preceding the death of the cells. Kiln-dried wood fixes these substances, and any subsequent moistening may bring the wood into a state calculated to produce fermentation.

Phlobaphenes, says Dragendorff (p. 143), present a great analogy with certain resins, from the point of view of their insolubility in water and their solubility in alcohol. They are soluble in ammonia-water also. If during fermentation, alcohol, which is a solvent of Phlobaphene, be produced, we shall have a loss of the latter which may be leached out. Resins which are similarly soluble may also be lost when wood is exposed to the weather, as ammonia is always present in rain-water.

Other alkalies may have a pernicious effect upon wood. Planat (II, p. 370) says that " timbers fixed in plaster made with lime that has become nitrous through bad mixing, decay rapidly." Chevreuil (*ex* Noerdlinger, 1859, p. 457) says that " gallic acid, which is closely related to the tannins in its chemical composition, will take up oxygen if the smallest quantity of free alkali be present, and become converted into a brown, humus-like substance." Planat also advises the careful separation of all woodwork from sanitary conduits which may give off ammonia, but inasmuch as large quantities of ammonia are generated in stables without any appreciable injury to the woodwork, I do not think this point worth too much attention.

A reputation for resistance to decay may be based on quite insufficient grounds. As a rule, the whole of the circumstances do not transpire, the history is incomplete, and the testimony is that of persons unaccustomed to the sifting of evidence. For instance, the Giant Fir of Canada (*Thuia gigantea*) is greatly praised by many authors on account of its durability. Hough is amongst these. He mentions (IX, No. 220) a case where a fallen tree of this Fir had lain so long upon the ground, that a Hemlock of 130 years of age had grown upon it. Mr. Hough kindly sent me a photograph of these trees *in situ*, accompanied by a piece of the wood of the Fir. This latter is quite sound. Two of my students, Messrs. Powell-Jones and Walters, who have both worked this wood at mills in Western Canada, assure me that the lumber-men by no means share this opinion of the great durability of the wood of the Giant Fir. What conclusion can we draw? I feel that many of the reports on other timbers can hardly be regarded as impeccable.

The season of felling is credited with much influence on the durability of wood and in respect of the risks the timber may run on account of the warmth of the Summer, which encourages parasites and also dries the wood unevenly and too quickly, it is obvious that this is not the season for felling. Hartig (1894, p. 215) says of the Spruce, felled in the Alps, where Winter work is impossible, "Summer-felled wood cracks and admits the spores of fungi. It is then floated to the mill, the cracks close, the spores germinate, and 33 per cent. of the logs are lost the following year by 'red-stripe.'"

The "old-wives' tale" concerning felling at certain phases of the moon turns up even now-a-days. The men who fell the trees are rarely in the position to follow the logs through their subsequent vicissitudes. The durability of perishable species may possibly be judged, but the history of long-lasting woods may stretch over more than one generation of woodmen, none of whom have put the facts on record, the whole being hearsay.

We need more tests carried out on rigorously exact lines. When possible the commercial test, such as may be made on pit-props and railway sleepers, is the best. The quantities of the test-pieces is large and money depends upon the result. Amongst the best may be cited those of Roth (1895), upon railway-sleepers, and of Thelu, on pit-props.

The results of the former may be stated briefly as follows, the species being arranged in the order of their life on the track :—Redwood, 12 years; Black Locust, Cypress and Red Cedar, 10; White and Chestnut Oaks, 8; Tamarack, 7–8; Cherry, Black Walnut, Locust, 7; Longleaf Pine, 6; Hemlock, 4–6; Spruce, 5; Red and Black Oaks, 4–5; Beech, Maple, 4 years.

Thelu (p. 261) gives the order of durability for his pit-props, commencing with the most durable, as follows :—Oak and Pine (*P. sylvestris*), Alder, Cluster Pine (*P. Pinaster*), False Acacia (*Robinia*), Willow, Maple, Elm and Aspen Poplar. He says that Willow and Alder have the special property of lasting a long time in hot, damp situations, such as mines.

If we had a sufficiency of tests of this kind (especially if the investigators would add the systematic names of the woods, to enable us to identify the species more precisely), they would be of inestimable value. By the way, it is rather a surprise to find the Alder so high in Thelu's list, and the Elm so low. Both lists disprove Dumonteil's (or was it Buffon's) theory, that the durability varies as the density. The single example of the Redwood, found at the top of Roth's list, will convince anyone to the contrary.

A test of another kind, which we may call a laboratory-test, is that of Lapparent. He employed two methods. Firstly, he packed woods of various species in a case, with layers of horse-manure between them, and then buried the whole. Secondly, he stuck pieces half their length in the ground. The extent of decay was ascertained by weighing before and after, the loss being expressed in percentages. His results were remarkable and showed how much superior were some of the woods of Guiana to the European Oak (see *Revue Maritime*, VII, p. 57). As this work is accessible with difficulty, I give a selection of Lapparent's results :—

			Per cent.
Oak (French, forest-grown). Loss in weight by decay			30
Teak (superior quality)			16
Soft Teak (from an English source)			25
Angelique,	(probably	*Dicorynia parœnse* (Guiana)	5
Coupi	,,	*Goupia glabra* (Guiana)	nil
Bois violet	,,	*Peltogyne paniculata* (Guiana)	nil
Wacapou	,,	*Vouacapoua americana* (Guiana)	10
Balata	,,	*Mimusops Kauki* (*globosa*) (Guiana)	10
Courbaril	,,	*Hymenœa sp.* (Guiana)	12
Beech (French, injected)			30
Poplar (,, ,,)			10

It is interesting to note the superiority of the Angelique, Coupi and Bois violet to the injected Beech and Poplar. The first-mentioned wood is a particular favourite of mine : about the same weight as the Oak, it is equally elastic, much stronger and works equally well. I do not know if it grows in British Guiana, but if so, it should be worth attention. Lapparent placed 18 pieces of Oak along with two pieces of Angelique in the framework of two ships. When the whole of the pieces of Oak had become quite rotten, the Angelique was found in a perfect state of preservation. The loss of weight found by Lapparent's second method was added to that of the first series, and an average struck. This is unfortunate, as the author himself states that the results of the two series were not parallel, from which it was evident that different fungi were concerned with the same species of wood in the two methods. No test can be satisfactory which does not include a cultivation of the fungus to which the decay may be due. Inoculation tests will no doubt in time enlighten us very much on this subject, but so far we have insufficient data. The resistance of a series of woods to any one particular fungus is scientifically interesting, but as under ordinary conditions the spores of many species may be present and even taking part simultaneously in the attack on the wood, it does not go far enough to permit us to announce the relative durability of woods on the strength of such experiments.

According to Pfeil (*ex* Noerdlinger, 1859, p. 469), woods buried in sand last but a quarter of the time those buried in clay endure. Heavy clays preserve the wood the best, sand if saturated, the next, then dry sand, and lastly, chalk-sand.

The Alder is found amongst Noerdlinger's list of very perishable woods (1859, p. 438), and along with it the Bird-cherry, Hazel and Plane.

The depredations of insects (wood-borers and white ants), the ship-borers (*Teredo navalis* and *Limnoria terebrans*), do not concern us here beyond the fact that galleries of insects are likely to induce the appearance of fungi. In quite a number of cases, a wood reputed resistant to decay has the same reputation in regard to animal parasites. This applies more particularly to the aromatic woods. Insects are certainly kept at bay by certain aromas, which extend their protection to the contents of chests made of scented woods. In a few instances, the repelling influence must be ascribed to the taste, for the scentless sap-wood of the Sandal-wood (*Santalum album*) is eaten right down to the heart by white ants. The smell of the heart, which is very powerful indeed when fresh, does not keep the insects at a distance. Pencil Cedar (*Juniperus virginiana*), supposed to be useful for making drawers for objects needing protection of this kind, may occasionally be seen riddled with the galleries of a large borer. We cannot generalize on this matter "Chacun à son gôut," even amongst insects.

The *Teredo* is said to have an aversion to iron, which is the reason why piles are sometimes studded with iron nails (Holzapfel, p. 460). Bethell used pyrolignite of iron in his anticipation of the Boucherie-process, as a preservative solution. It might be tried against *Teredo*.

Of the species which resist *Teredo*, says Hamilton (1918, p. 4), *Fagrœa fragrans*, the Anan of Burma, stands first. At Tavoy there are posts which have stood in water from two to three hundred years unattacked. He suggests that ships should be overlaid or sheathed with about an inch of this wood, as it is known that the animal will never pass from one plank to another, however close may be the contact.

We have a pile of Oak from the foundations of the Lady Chapel of Winchester Cathedral (thirteenth century) that is bored by *Pholas dactylus*, one of the shells being still *in situ*. How did it get there? Could we base any geological theory upon the presence of this small beast at Winchester, as at the Temple of Serapis? By the way, our specimens of both Oak and Beech from the same foundations are in quite good condition, though somewhat cracked on the surface. The one cited was from a place where the water in the foundations was 20 feet deep.

The preservation of wood by artificial means is not one which concerns us here. Our subject is the wood itself and not what may be made of it. Readers interested in this matter will do well to read the several very excellent brochures published by the Department of Forestry of the U.S.A. It is, however, interesting to record the fact that the first known case of artificial preservation, apart from that mentioned by Pliny, is that of carbonizing the exterior of the piles used for the foundations of the locks of the Martesano Canal, constructed by Leonardo da Vinci, somewhere about the end of the fifteenth century.

A natural form of carbonization is taken advantage of by the inhabitants of St. Malo, where there is a submerged forest, the wood from which is as black as Ebony, as though it had been burnt, and has a density of 1·09. The collecting of this wood at neap tide is a local industry, vine-props which last indefinitely, being made of it.

It has already been pointed out that small cracks are most suitable for the growth of fungi and also (p. 165) that dry wood may crack when wetted as wet wood does when drying, so that even a seasoned block may open and furnish cracks through which fungus-spores may gain access to the untreated interior. All treatment that is superficial is quite unavailing as soon as the preserved layer is penetrated, hence all holes and trimming should be done before, and not after, the preservative is applied.

CHAPTER XVII

LABORATORY PRACTICE

BEFORE dressing a piece of wood it is well to examine it in the rough, as it may afford information that will otherwise be missed. The external appearance of the log after removal of the bark, the sinking and shrinking of some tissues more than others, the greater prominence of the silver-grain where the wood happens to be rent and the colour due to weathering are important. The bark, though beyond our present purview, should not be neglected, but it is the part that generally fails to be preserved. It is frequently characteristic of the species. The colour of the cross-section of a freshly-cut log differs not only when it is weathered, but also when dressed and when dry. The nature of the sap-wood if any, its width and number of rings should be noted, as any observation on these points will, perhaps, add to our somewhat meagre knowledge of the relation of early heart-production to soil, aspect, etc.

A whole chapter might be filled with a simple enumeration of the points to be observed in a piece of wood in its various stages of manufacture, but the reader will find most of these indicated in the " Prompter " on page 220.

The wood should be dressed by the student himself, and not left to an assistant, as the working-qualities, the aroma, the crispness, or silkiness of the shavings and borings, and the effect of the wood on the sense of touch, all unite to teach him, and perhaps there is more to be discovered in this way than we suspect.

Fracture should be examined with a lens, because when the fibres happen to be broken off short, as in " biscuit " fracture, the structure of the woods comes out quite clearly.

On a cross-section a clean cut with a sharp knife or plane will expose the pores as holes, or as light-coloured points when cut with a dull blade, because some of the surrounding soft-tissue is carried into the holes and stops them up. The same effect results with glass-papering, and may even be an advantage, as the pores are made more evident thereby. So long as one is on one's guard, this is good and glass-paper becomes one of the best aids that we have. Do not use both coarse and fine paper, as the former will only make deep scratches that are more trouble to get out than when one does the work with fine paper alone. Rub down the surface with new " 00 " glass-paper and finish with some of the same number that is nearly worn out. Worn glass-paper is sometimes worth more than new. A particularly useful tool is a strip of wood around which a whole sheet of glass-paper is wrapped, and held in place by rubber-bands or drawing-pins. If the wrapping is carefully done without creasing the paper, the whole sheet may be used to the last fragment without tearing. Other means of smoothing are the scraper, pumice-stone, whetstones both natural and corundum, and even the grindstone for very hard woods. The keen edge of glass is particularly useful (the photograph from which our Frontispiece was taken, is of a solid block prepared in this way. Although the small rays do not come out in the reproduction, some of them are clearly visible in the photograph itself).

When planing a cross-section, the block must be firmly held in a vice, but the ordinary pattern provided with a carpenter's bench is very unsatisfactory, as the block is rarely held immovably. An iron vice is as bad in another way, because it crushes the wood too much. Some benches have a special vice designed for cramping, at the left-hand, in which a block can be placed and is there closed in on three sides and cannot move laterally, but even with this the block may descend under the pressure on its surface, so some provision must be made to prevent this. A good make-shift is a recess cut in the side of the bench or thick plank, in which the block can be secured by wedges, or, again, a hole may be cut or bored in the plank to fit the block, which is fixed in flush with the surface and both plank and block are planed together. This last expedient amounts to imbedding, such as is employed on a very small scale in cutting sections with a microtome.

When the piece to be planed on the cross-section is in the form of a board, a bevel should be chiselled off from the far edge, otherwise a piece will be torn away by the plane. Whenever possible, plane in a direction parallel to the rays, as woods having delicate rays will be less liable to separate into shreds.

The student should first familiarize himself thoroughly with the wood in "the lump," not only with the unaided eye, but with a hand-lens, and then with a hand-microscope, the latter giving a magnification of about ten diameters (*see* below). Afterwards, thin sections for use with higher powers may be made, but in no case should the order be reversed. The use of the microscope, unless taken in conjunction with the solid wood, is fatal to a proper comprehension of the material. A student accustomed to nothing but thin sections, is harder to teach than a beginner. A piece of wood examined with a lens or hand-microscope falls constantly under the observation of the naked eye: when thin sections are used alone, there is no such control, and the learner is likely to make a mental picture of a piece of wood with a transverse section magnified fifty diameters, tacked on to a tangential one of twenty, as more experienced observers have done.

The hand-microscope is invaluable for the examination of specimens that must not be cut or damaged. The best form is that of an ordinary microscope-tube with eye piece and objective, fitted with an external sliding tube, to regulate the focal distance. A gap is cut in the side of this latter tube, to admit the light to the specimen. The slide can readily be made from a piece of tin, indeed a very good microscope can be made of brown paper, rolled and pasted into a tube, the only metal part being an adapter in one end to take the objective. The adapter will adhere quite well to the paper tube if gummed.

Any reagent that will bring out the contrast of the tissues will help, and under this latter term we may class water, which makes the rays clearer, and oil, this being more useful on the radial section when the latter is to be photographed. Our figures of planks are taken in this way. Polish acts similarly, but it should not be a spirit-shellac varnish, as the pores will then be filled up and frequently the colour of the wood will be altered. In every case, the surface must be well examined before anything is applied.

We are surrounded with a variety of polished objects in the form of our domestic furniture, indeed, we have a Museum of prepared specimens ready to hand, and many deceptions in colour and veneer will probably be unmasked. By the way, whence comes our love of polish? Such as we see now-a-days is purely "fake." The public do not realize that unstained and unpolished wood is a beautiful thing. We are far behind the Japanese in the matter of taste in wood, and even our ancestors were our superiors in this respect. The brilliance of the surface that the latter produced on wood was obtained by smoothing it to perfection by the use of *Equisetum* (Horsetail), a plant of the marshes. At most they used a little oil, or wax.

Pieces of wood should be reserved for rough tests of elasticity, fracture, etc., and shavings for the making of extracts, to ascertain what colouring matters, etc., may be present.

If your specimen be in the form of a plank, consult the transverse section, to ascertain the course of the rays, then plane corners from two opposite edges, one in the plane of the rays and the other at right angles to it, and then the former will expose the radial, and the latter the tangential section. If preferred and the material permits, it may be turned into a cylinder, which will show the gradual transition of one section into another (Fig. 2, Pl. XXXV). This form is better than any, except a ball, which is, however, difficult to make. In either case the silver-grain will come out rather poorly, so a flat may be planed off parallel with the rays. This will show it up and will prevent the cylinder rolling about. Turning is undoubtedly the best method with very hard exotic woods, and even if pieces chip out, as they generally do, this defect will appear less in a turned article than in a flat one, and the exasperating process of planing down a flat surface to eliminate continually recurring holes, will be avoided. When cutting the transverse surface with a knife, the wood should be held in a vice, an uneven and unsatisfactory surface will always be obtained if the wood be held simply in the hand.

The cutting of thin sections from hard wood is so troublesome a matter, that it is usually shirked, hence we have a plethora of information gained from herbaceous stems and the softer Conifers, but very little from the harder woods. The latter are too hard for the delicate edge of the microtome-razor.

I have a quantity of preparations for use with the microtome (inherited from my predecessor, E. Russell Burdon) which have been some five and a half years in glycerine-alcohol after the following treatment: Boiling and cold water alternately till the wood sank; hydrofluoric acid and water, equal parts, eighteen days; washed in water, nine days; glycerine and water, equal parts, for keeping. Specimens of the Oak (this species being the hardest of the series) cut quite sweetly and apparently did so shortly after the treatment, as very good sections were then cut from them. The hydrofluoric acid is very corrosive, and must be kept in vulcanite or rubber bottles, and these should be examined frequently, as they are liable to be attacked, as I know to my cost. The specimens in the dilute solution may be kept in glass bottles lined with paraffin wax.

All that is necessary in the macroscopic study of wood is to obtain sections which will show the relation of one tissue to another and this can be done with a plane. Where the sculpture of the cells and vessels is important, a macerated preparation is better than a thin section. Let it be borne in mind that vegetable cells are comparatively large and that sections can be *too* thin, indeed vertical sections of woods with vessels, unless cut obliquely, will fall into strips because the section is thinner than the width of a vessel.

Maceration.—Potassium chloride with enough nitric acid to cover the wood. When the latter has turned white, wash, tease out the cells and stain. If heat be employed, the process should be carried on in a fume-cupboard.

There is a range of hardness quite beyond that of the microtome. but which can be dealt with by the plane. There is another category that is beyond the plane, where thin sections cannot be thought of, and this contains a vast number of useful and interesting woods.

Grinding has been recommended by Sydenham. A thin piece of wood is glued to a cork and ground with glass-paper, a grindstone or whetstone until very thin. It is said to be good for both soft and hard woods. I take it for granted that the reduced piece of wood will be afterwards cemented to a glass slip and the grinding of the other side completed on a whetstone.

If a lathe is at one's disposition, a flat circular " bob," covered with fine glass-paper, is a good appliance not only for grinding, but for the finishing of the transverse sections of solid specimens. It cuts very quickly and care must be taken not to touch it with the fingers while it is revolving, as bad wounds can be produced by it in an instant.

An iron plane of the Stanley type with adjustable iron is virtually a microtome, and excellent sections can be made with it by any careful carpenter. A quantity of shavings is made from any section, examined with a lens and the thinnest portions chosen for use with the microscope. The transverse or cross-section is usually the most difficult to cut, but if the piece of wood be long enough to permit of a steady stroke, and the width does not exceed half an inch, good results are possible. Always plane in a direction parallel to the rays, for if these are fragile they may be ruptured by a cut at any other angle. If the specimen be an old one, that has lain on the shelf for a long time, it is likely to crumble and to be full of minute shakes, hence it will be well to remove a strip, to get down to sound wood. Moistening with water or glycerine between each stroke will cause the wood to cut more sweetly, but green (freshly-felled) wood cuts the best. Foxworthy (1920) holds the contrary opinion and insists upon dry wood. His woods are, however, of the Philippines, and no doubt he knows the best practice for these. Dupont recommends stearic acid (commonly found in candles), applied to the surface of the wood and melted in with a hot iron. The stearic acid can afterwards be cleared with alcohol.

The shaving which sometimes curls very strongly will usually unroll if laid on a glass slip and moistened below only, the water being allowed to mount gradually upwards. Otherwise, if wetted too suddenly, it will give trouble.

In cutting the radial section it must not be forgotten that the direction of the rays changes continually and the cross-section must be examined after each cut, to see that the tool is cutting parallel with the rays. In microtome cutting this is a difficulty unless the machine be fitted with an attachment for slewing over the specimens into the right plane. Wood taken from the outsides of large trees where the divergence of the rays is less, is perferable.

The tangential section is the easiest to deal with, but it must be truly tangential, or the ends of the rays will appear spread and distorted.

The shavings, when straightened out and dried between blotting-paper, may be examined dry or in water or glycerine. Balsam mounts add very little to the detail that can be seen with low powers and most of the colouring matters, gums, resins, etc., are lost or altered. The air-bubbles may be driven off with alcohol or boiling water, but care must be exercised with the latter, as delicate woods may be macerated and fall to pieces.

Permanent mounts are desirable, and for class work are essential, but they are then best left to the professional *préparateur*. They are not indispensable for the study of wood and there is no necessity to compel students to acquire the skill in making them, as their time may be better employed.

Structures that are visible when the section is examined in water may be almost invisible in glycerine or balsam mounts, as pointed out by Piccioli (1919, p. 196) in reference to the spirals in the tracheids of *Taxus*, *Cephalotaxus*, *Torreya* and *Pseudo-Tsuga*.

The rays are best seen in the solid on a cross-section, when they are held in a direct line between the eye and the light. Resin-canals, on the contrary, are more easily detected by looking along the plank with one's back to the light. Sap-wood, as a rule, shows the structure more clearly than heart-wood. If two pieces of wood are to be compared one with another, they should be held side by side in a vice with their cross-surfaces quite level, so that a portion of each shall come into the field of the lens at the same time. If a bench microscope be used so much the better. A swing holder for a hand microscope can easily be fitted to the carpenter's bench and will be found of great utility. Transparent sections can be compared by placing them on the same slide. For this purpose the lantern is very useful and is indeed indispensable both for study and demonstration, as minute details can be pointed out to a second person. It is always some satisfaction to a teacher to feel certain that the students have really seen that which has been described to them and have not been admiring air-bubbles and dust-particles instead.

Hough supplies some superb lantern-slides of American woods in his "Stereopticon" series. English buyers will do well to ask him for the thin sections only, as his slides are "quarter-plate" and do not fit ordinary English lanterns. The sections need nothing more than placing between glass plates and binding. The section-cards of Hough and Burckhardt are also fine productions, but are of infinitely less use than solid blocks. They are not transparent, and one does not quite know why so much trouble should be taken to produce them. Thil's small sections are thin and good, but are put up in such a cumbrous form that they are of little use. Noerdlinger's are also thin, and being in paper folds, are also troublesome to examine and so liable to damage as to preclude their use in a class. In addition, his synonymy is antiquated, and few people would care to take the trouble to check the whole of his 1,100 sections, without which precaution they are of comparatively little use.

I am convinced that the extract obtained from the wood will sooner or later become one of the most important means of identifying species which in many cases may be run down by this method alone. The process is exceedingly simple and needs no previous knowledge of chemistry. A few shavings are first extracted by placing them in sufficient water to cover them and bringing the water to the boiling point. Prolonged boiling is not recommended. The water may be distilled, in which case a drop of an alkaline solution must be added to bring out the colour of pigments: if potable water is used, sufficient lime will already be present. The colour, etc. (*see* Prompter, p. 220), should be noted and the infusion divided into some twelve parts, each of which should then be tested by the addition of a single drop of the various reagents enumerated. Others may be added as desired, but so far I have found that the series sufficiently covers the ground.

There is no better way of becoming thoroughly acquainted with the structure of a wood than by describing it point by point, and when teaching advanced students, I require them to do so after the following method:

The whole of the particulars which should be noted are read out by an assistant, who also writes down the details, thus leaving the student free to use his lens or microscope. The student has merely to reply to the question put. The schedules which result can be used as descriptions for publication if needed, and have the inestimable advantage of being easily comparable. Each point falls approximately in the same place in all schedules and can be found instantly. For the making of Keys this system is indispensable, as a dozen schedules can be scanned to compare any tissue in a few moments.

The model "Prompter" which follows may be thought by some to be redundant, but I have found when constructing Keys, that unless every detail has been rigorously described, it is always the critical one that has been missed.

When a workable Key is provided in a book, long descriptions of each species may be dispensed with, only the salient features needing to be printed. This advantage will become the more evident as descriptions multiply. To wade through long lists of details which must recur in many allied species, is a soul-destroying task to a reader who wishes to arrive at the name of a wood. It is an exercise that is salutary to the learner and valuable to the specialist, but it is a misery to the technologist. I am aware that I have myself been a sinner in this respect, but I have grown out of it by hard experience. In future my descriptions, apart from formal matter, will consist of the exclusive characters of the wood in hand and those points by which it may be distinguished from others resembling it, and *no more.* These will be confronted with each other in parallel columns.

Prompter for the Description of Woods

Formal matter. Number of specimen and generic number (Durand). Location and origin: determined by . . .

Popular and systematic names: Family: Tribe: Synonyms. Figures, Plates.

References to, and illustrations by other authors. Specimens that have been compared with Type and their location.

GENERAL CHARACTERS. Weight, hardness, colour (distribution of: deepens?). Resembles or may be confused with other species. Surface; lustre, and to what due. Grain (fine, open, straight, zigzag). Touch (warmth, stickiness, both dry and wet). Shade of sections. Smell. Soiling. Weathering.

USES that may assist in identification.

PHYSICAL CHARACTERS. Weight and hardness ascertained by experiment: equal to (such and such a species). Elasticity. Flexibility. Strength. Toughness. Cuts like . . . Fracture. Absorption; shrinkage. Burning (smell, crepitation, smoke, juices expelled). Smell (when dry, when wetted, worked, warmed or freshly-felled); if sap-wood also, is aromatic? Taste. Extract with water, alcohol, etc. Reactions.

STRUCTURE. Resembles that of . . . , compare figure No. . . . Specimen, how prepared? (planed, glass-papered, etc.).

TRANSVERSE SECTION.

Parenchyma. If of one or more kinds.

(a). Visibility of (with unaided eye; with lens × 3; with macro., × 10). Colour (compared also with that of the rays, etc.); change of colour on exposure. Arrangement; if in lines, then their continuity, width, number per mm., width of intervals, where most abundant, where lacking, if simulating the ring-boundaries, if branching or anastomosing. If not in lines, then in what arrangement? If swelling up with water: if retiring when drying. If of different colour in transparent sections (direct or oblique light). If different in young (early) wood and in the old (late) wood. Proportion of the mass of the wood occupied by the P.

Parenchyma (b). Repeat details given above for P (a), if in lines. If in minute bars, their colour, continuity, and direction.

Vessels. Visibility (eye: × 3 and × 10), and if appearing as holes or coloured points. Bleeding. Size; diminution from the inside to the outside of the ring and diminution in size as the tree ages (*i.e.*, from the early to the late wood). Diminution in number from inside to outside of the ring: number per square mm. in both Spring and Autumn wood. Arrangement (lines, arcs, angles, etc.). Isolated or in groups (m-and-d). If in contact with the rays. Shape. Contents. Proportion of the mass of the wood.

Vertical Resin-canals. Visibility; size; number.

Rays. Visibility (eye : × 3 : × 10) both when dry, and after moistening. If of two kinds. Colour. Size. Regularity and intervals between them. Course (straight or undulating). Proportion of thin ends to thick middles. If tapering or forking. If widening outwards, fusiform or nodose. Number per mm. Hardness. Density. If swelling with water : if retiring on drying. If shrinking more than the fibres. Contents. Proportion of the mass of the wood.

Ground-tissue (wood-fibres). Visibility of the cells, × 10. Proportion of the mass.

Rings. Clearness of the boundary. If a pore-ring, a line of contrast or line of different tissue. Difference in colour of various zones. If dusky bands are present. Contour (regular, etc.). Gum-galls. Flecks.

RADIAL SECTION. Colour (distribution of : surface, lustre and to what due). Grain (coarseness, straightness, if filled or open). If bright and dull stripes alternate. Nature of P (a) and P (b). Vessels (visibility, colour, lustre and if the visibility be due to either) : coarseness : if twinned. Contents. Rays (visibility, colour, lustre, visibility due to either : if double silver-grain be present). Rings (visibility, definition of limits : dusky bands : boundaries).

TANGENTIAL SECTION. To be treated as the radial but differences in the P (a), P (b), vessels and rings if any, to be stated. The rays if visible as spindle-shaped lines of . . . mm. in height (or so many cells high by so many wide). If uniseriate or multiseriate or both. If in palisade or in échelon and the effect of that arrangement on the eye. Colour, shape, and if of two kinds of cells.

PITH. Size, colour, shape, texture, hardness, structure : contour, and whether the early rings follow the same.

SAP-WOOD. If present : colour, width (by count of rings and by measure). If defined from the heart-wood (sharply or vaguely). Contour. If any tissue becomes coloured before another.

HEART-WOOD. If excentric.

BARK. *Exterior.* If entire or fissured and in what manner : depth and course of fissures. Excrescences ; scales. Colour of cuticle and of the subjacent layers if exposed or cut. If the cuticle is persistent on the ridges. Width and shape of the ridges. Lenticels (shape, grouping, orientation). In which direction does the bark peel ? Texture, fracture. Smell when broken. Shrinkage. Adhesion to the trunk. Taste. Extract. Gums, resins.

Bark in section. Colour, thickness. If in layers, then their number, colour, nature, and texture of each layer. Cortical rays (if converging in pencils). Scales (how marked off). Scleroses.

Bark, inner surface. Colour, change on exposure, sculpture, bast.

Appearance of the log before cutting up. Colour of the ends. Shrinkage of the various tissues.

THE EXTRACT. With potable water (hot) : Colour, limpidity, fluorescence, smell, taste, presence of froth or pellicle. With alcohol (same details). Both extracts after addition of the following reagents : Perchloride and sulphate of iron, Bichromate of potash, Sulphate of copper, Sulphate of alumina with ammonia, Lime-water, Protochloride of tin, Gelatine, Acetate of lead.

In Laboratory Practice a few words concerning the *Index Kewensis* will not be out of place. This important work was undertaken by Joseph D. Hooker and B. D. Jackson, and later by Th. Durand, at the request of Charles Darwin, who bequeathed the necessary funds. Its object is to weed out all synonyms of plants and to refer them to the correct species.

The species which, according to the authors, are good, are printed in Roman characters and the synonyms or obsolete names, in italics. Unfortunately, the authors did not think it necessary to explain their method and the student has to find it out.

First look out the name, which will be found in its alphabetical order under genus and then species. If it is in Roman type, an abbreviated title of the work in which it was first described, the name of the author and of the country of origin of the plant will be found, and the search is finished. If, on the contrary, the name is in italics, an alternative name, that of the good species will follow. If this is a specific name only, the plant is of the same genus given at the head of the column or chapter. If both a generic and specific name are given, then the new genus must be looked up, to find the name of the author, etc., as the same names have often been used by different authors for different plants. This is rather tiresome, and it is a pity that the authors of the *I.K.* did not think fit to add at least the abbreviated name of the author of the species, and so save readers the trouble of referring to find this detail.

In many cases there is more than one name in Roman. These are printers' errors, and it is then impossible to decide which to choose. In such a compendious work, such things must happen.

When the presumably correct name is found, the reader must consult the supplements, of which there are more than one, and the " Addenda, Corrigenda and Emmendanda," of which there are also several. None of these can safely be ignored, more particularly as revisions of genera become more frequent. All this seems a very laborious affair, but compared with the difficulties of the Botanist before this book was published, it is a trifle.

Many Botanists, especially those of the Continent, do not recognize the *I.K.*, hence we must be on our guard when using foreign books. Further, there is the man who delights to unearth some long-forgotten name, for which he claims priority, so that we never reach finality, but let us leave these silly disputes to those who have nothing better to do, and take the stand that we refuse to recognize any change of name from those in the *I.K.*, unless it be the correction of an actual error.

Collections

In a large collection great waste of time is caused by the lack of easy means of finding specimens. If arranged, as is usually the case, according to families and tribes, only those who are thoroughly conversant with systematic Botany can find them. I recommend most strongly that the specimens be numbered according to Bentham and Hooker's "Genera Plantarum," as regards the genus, and afterwards the species in alphabetical order. Systems change and at the present time Engler is in favour, but there is no finality, and the student of wood or of any technical branch of Botany will be wise not to follow the caprices of systematists too closely, or he will have little time for his own work.

Bentham and Hooker's numbers are condensed in a very convenient form in Durand's "Index Generum Phanerogamorum," and the index to this book will form a catalogue to your collection. When a specimen is required, the number of the genus is looked out in this index, and the specimen can be found immediately.

A large collection will consist of (*a*) fine planks or logs that can be accommodated only in a large hall; (*b*) small planks that can be stored in any ordinary room; (*c*) hand specimens that will go on shelves; (*d*) specimens of irregular form that must be kept in cases; (*e*) small fragments that must be stored in boxes; (*f*) veneers, drawings, photos, etc., that may be put in flat boxes or drawers; (*g*) lantern-slides; (*h*) microscope slides, *i.e.*, eight different sets at least, kept in as many places. When classified by numbers any inexperienced assistant can find and replace specimens, but failing this the time of an expert must be wasted in what is, after all, a menial occupation. The card-catalogue, containing an enumeration of everything in the collection, is arranged alphabetically according to genera and then as to species. Each slip bears the number, according to Durand, and a short description of the specimen sufficient to indicate in which category (plank, hand-specimen, etc.) it is to be looked for.

Specimens which are accompanied only by the native or trade name may be classified according to countries, each country being allotted a number following on the last given in Durand. If the country be unknown, the specimens are relegated to a section and number terminating the series.

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PLATES

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As regards the assistance that I have received from my colleagues and students, I have marked the various photographs, etc., with abbreviations, indicating the artist, as follows :—

E.A.K.	Mr. E. A. Ketteringham	Photos.
A.D.	Mr. Arthur Deane	,,
R.J.	Mr. Roger Jesson	,,
N.M S.	Miss N. M. Simmonds	Drawings.
H.A.C.	Mr. H. A. Cox	,,
M.F.	Monsieur Faucheron, Fac. Sci., Lyons	Photos.

A few of the transverse sections have been taken by Messrs. Deane & Ketteringham from Noerdlinger's series of wood sections and a few others from material of unknown origin, but apparently from professional sources.

PLATE I. Cross-sections, Natural Size, taken from the Wood direct by E. A. K.

Fig. 1. Sycamore. Pores fine and uniformly distributed ; rays visible by lustre rather than by contrast of colour ; ring-boundaries very fine. (Pith-side below.)

Fig. 2. Canary Whitewood (*Liriodendron*) or Tulip-tree. Structure much as that of Sycamore, but the rays are as a rule more distinct, owing to the deepening of the colour of the fibres by exposure to light. (Pith-side up.)

Fig. 3. Honduras Mahogany. Pores visible, few, widely isolated ; boundary a very fine but clear line ; rays just visible. (Pith-side to left.)

Fig. 4. Pear-tree. Much as Sycamore, but the rays are red and the wood is brownish red.

Fig. 5. False Acacia (*Robinia*). Type "a." Pores few and widely isolated, surrounded by light-coloured parenchyma, which is also very abundant and prominent in the boundary, where it composes the bulk of the apparent pore-ring ; rays light-coloured also, fine. (Pith-side to right, above.)

Fig. 6. False Acacia. Type "b." The parenchyma in the Summer wood is largely developed and unites the Summer pores into concentric lines which, when undulating, resemble those of the Elm, from which it may be distinguished by the colour of the rays. (Pith-side to right, below.)

PLATE I.

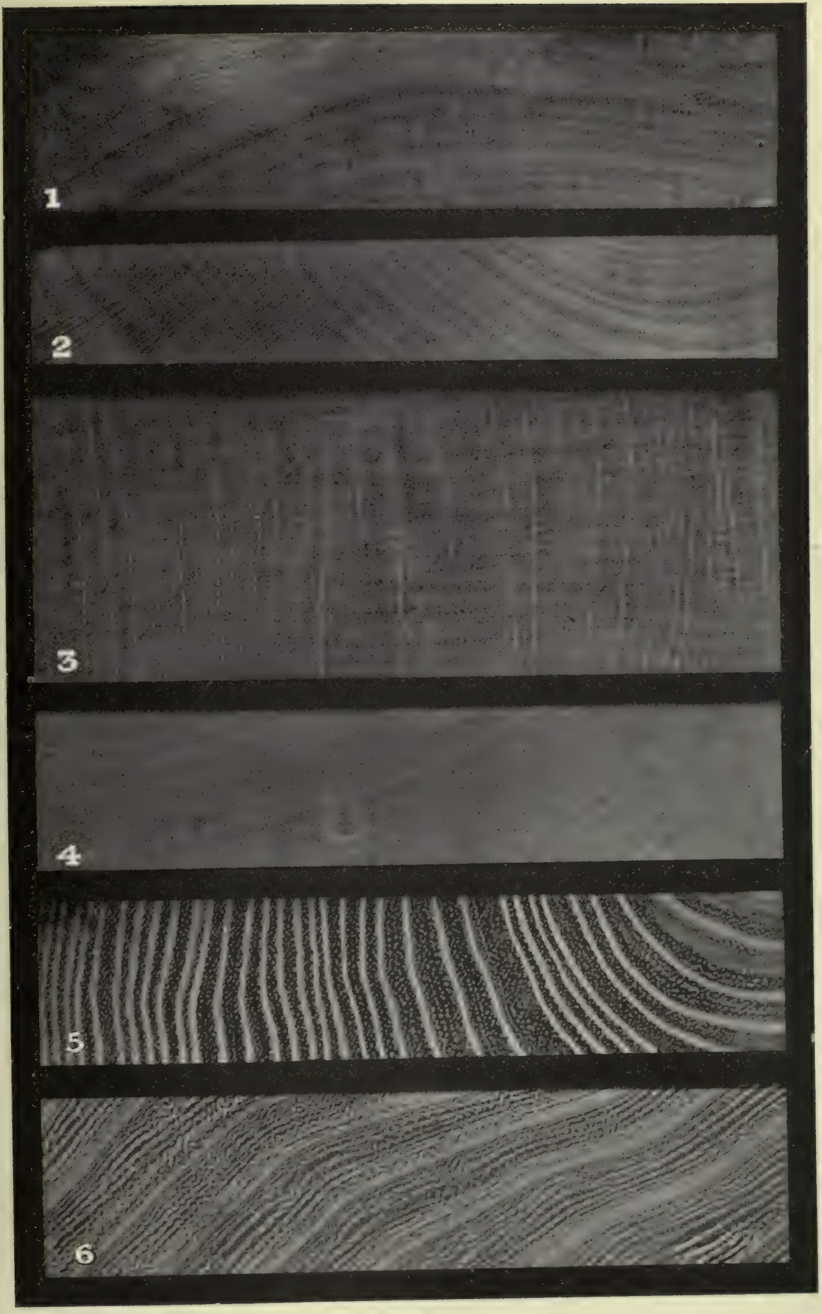

PLATE II. Cross-sections, Natural Size, taken from the Wood direct by E. A. K.

Fig. 1. Alder (pith-side to the right). The structure is not well shown, owing to lack in contrast of colour. The notches at the point where large rays cross the boundaries may vaguely be seen.

Fig. 2. Evergreen Oak (*Quercus Ilex*, pith-side to the right). The pores are in long straggling, radial streams that are made more visible by the light-coloured parenchyma in which they are imbedded. The rays are larger than in any other European wood. The concentric lines just discernible in the Summer wood, are of parenchyma.

Fig. 3. Sweet Chestnut (pith-side to the left below). A ring-porous wood with Summer pores arranged in radial streams as in the Oak, which the wood much resembles; the rays, however, are invisible to the naked eye.

Fig. 4. American Red Oak (*Q. rubra*, pith-side upwards). As the Sweet Chestnut, but the rays are large. This is a typical example of all the deciduous Oaks, and differs from the Evergreen Oaks in having a strongly-marked pore-ring. The concentric parenchyma is generally more visible than in the Common Oak.

Fig. 5. Beech (pith-side to the right). In all respects similar to the Plane (Plate III, Fig. 2), but the rays are less numerous and crowded and in the solid wood are bright.

PLATE II.

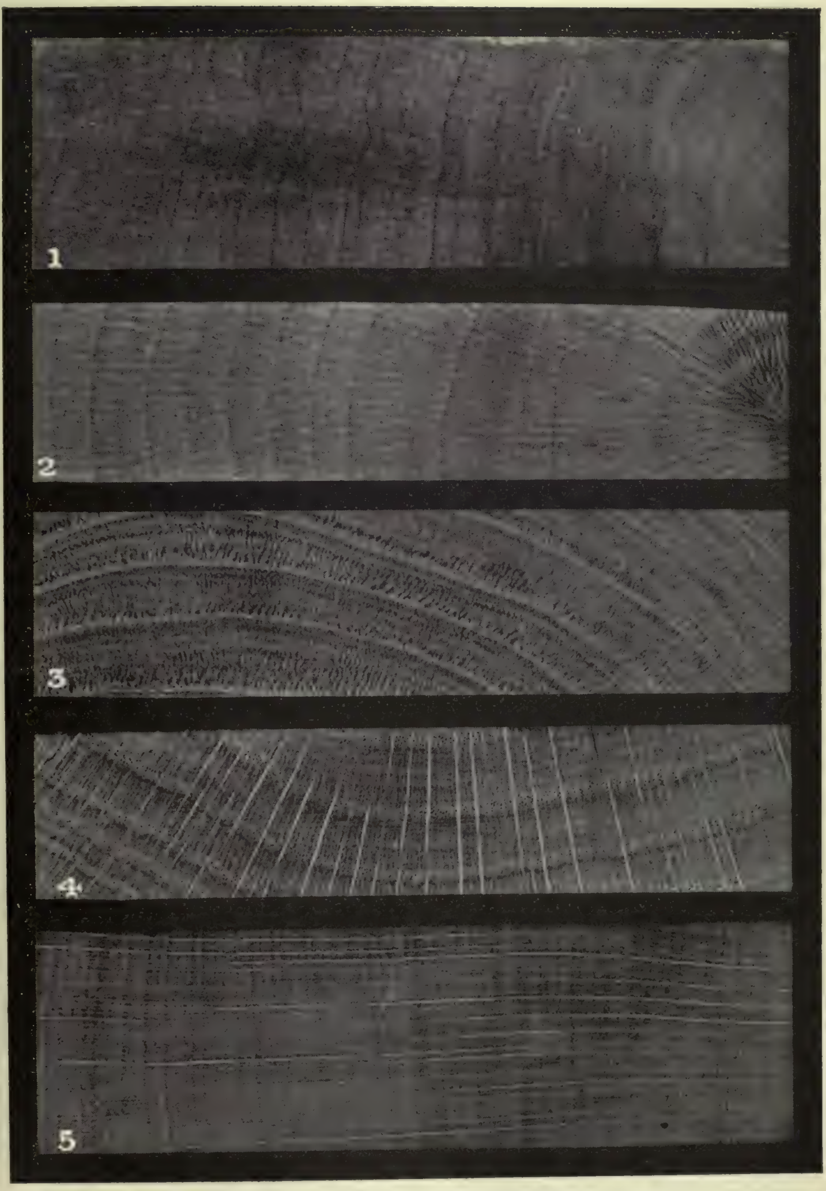

PLATE III. CROSS-SECTIONS, NATURAL SIZE, TAKEN FROM THE WOOD DIRECT BY E. A. K.

FIG. 1.—Hickory (*Carya alba*, pith-side downwards). The specimen is very slowly-grown and shows only a succession of pore-rings, conveying the impression that it is a diffuse-porous wood. On the contrary, it is really a very strongly ring-porous species, and when the Summer wood is properly developed the Summer pores are seen to be very few and widely isolated. The concentric parenchyma is then so clear as to be visible to the naked eye. This specimen is typical of most of the commercial Hickory. The darker portion represents the heart-wood.

FIG. 2. Plane-tree (*Platanus orientalis*, pith-side to the left). Pores uniformly crowded throughout the section; rays large and very numerous, occupying about half the section. In the solid wood they are dull. Ring-boundaries vaguely indicated.

FIG. 3. American Elm (*Ulmus racemosa*, very slowly grown, pith-side to the left, below). The boundaries are of light-coloured parenchyma, imbedding a single row of pores. The structure is hardly discernible to the unaided eye, except when an occasional broad ring is present (comp. Fig. 6, Plate XXII.).

FIG. 4. Poplar (*Populus sp.*, pith-side to the left below). Pores minute and occupying whole section; rays invisible to the naked eye.

FIG. 5. English Elm (*Ulmus campestris*, fast grown, pith-side to the right, above). A ring-porous wood. The pores of the Summer wood are united by parenchyma into undulating festoon-like lines; rays small and not appearing in the figure, but are quite visible, though small, and in the solid wood are brown in colour and darker than the wood-fibres.

FIG. 6.—Teak (*Tectona grandis*, pith side to left, below). The boundaries of the rings which are so conspicuous in the solid wood are composed of light-coloured parenchyma imbedding a scanty ring of pores. It is the same parenchyma which makes the pores of the Autumn wood visible in the solid, but in a transparent section this tissue does not appear.

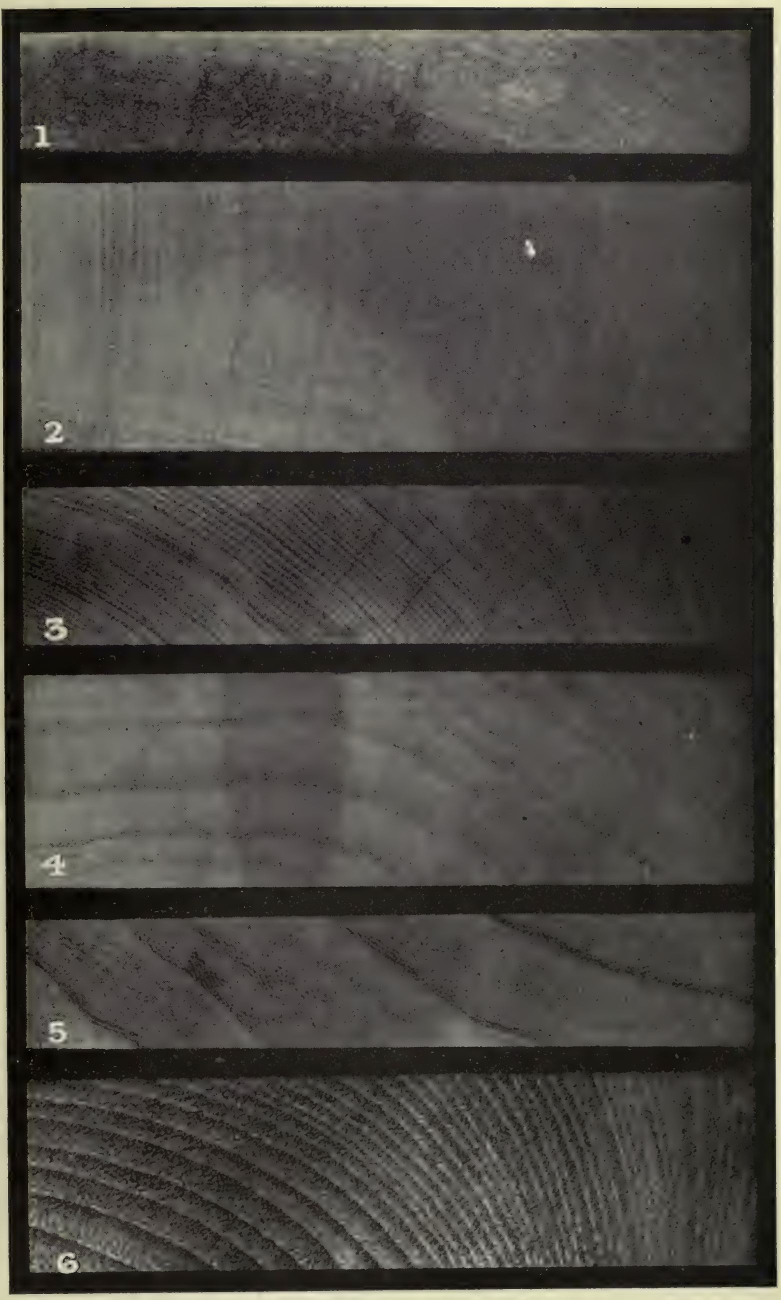
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PLATE IV. CROSS-SECTIONS, NATURAL SIZE, TAKEN FROM THE WOOD DIRECT BY E. A. K.

FIG. 1. Pitch Pine (*Pinus palustris*, pith-side to the right, below). The darker Summer zones contrast strongly with the lighter Spring wood. Rays fine, but visible here and there. The vertical resin-canals appear as light-coloured spots, chiefly in the dark Summer zones.

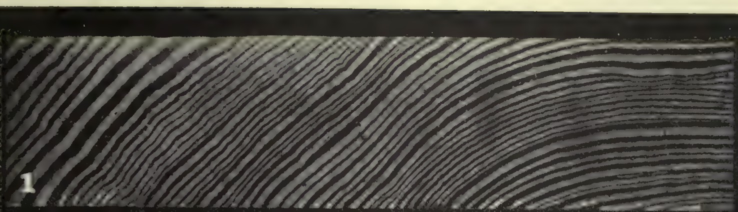
FIG. 2. Scots Pine. The Summer zones appear narrower here than in the previous figure, but in other specimens may be much broader ; still, the proportion of Spring wood is always greater. The resin-canals are visible and often stray into the middle of the ring, but never into its innermost zone. One or two " false starts " may be discerned in the younger rings, and sometimes affect only a portion of the periphery of the ring.

FIG. 3. Sitka or Silver Spruce (*Picea sitchensis*, English fast-grown wood, pith-side to the left). Resin-canals extremely scarce. Summer wood scanty and hardly indicated (comp. Fig. 5).

FIG. 4. New Zealand White Pine (*Podocarpus dacrydioides*, pith-side to right, above). Ring-boundaries indefinite ; no resin-canals.

FIG. 5. Sitka Spruce, from British Columbia, as imported for aeroplane work. Resin-canals visible here and there. This specimen showed 35 rings per inch. The Summer zones are better developed than in Fig. 3, but the great difference consists in the reduction of the Spring wood. (Pith-side to the left.)

PLATE IV.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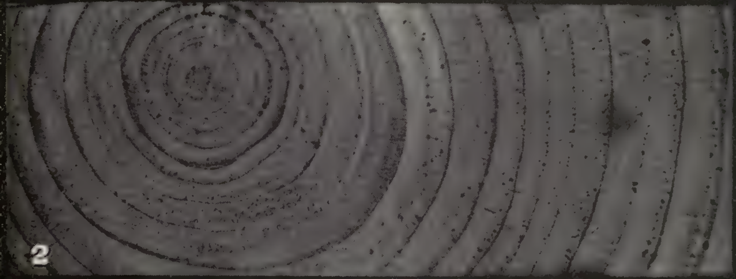
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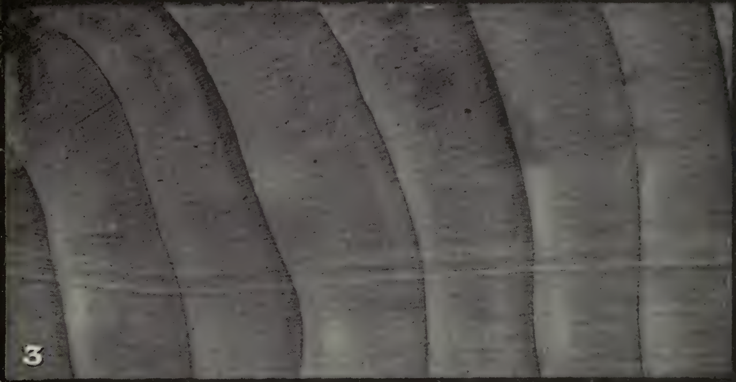
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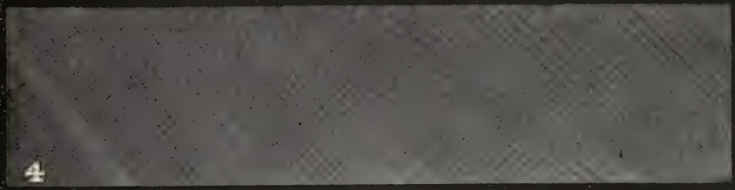
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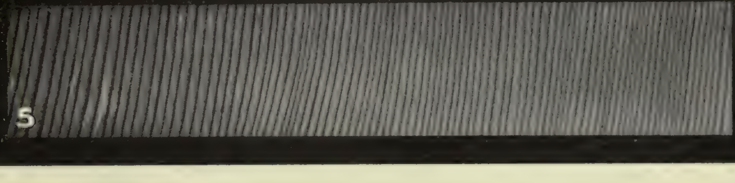
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PLATE V. ALL FIGURES ABOUT $\frac{1}{20}$TH NATURAL SIZE. PHOTO BY E. A. K.

FIG. 1. "Bee-sucken Ash." The swellings are of exceedingly hard substance (see p. 189), and conceal black cavities.

FIG. 2. Vertical section of a Pollard Willow, showing the overgrown stubs of the branches

FIG. 3. Cross-section of *Diospyros Kaki*, the Japanese Marble-wood. The conical points projecting from the exterior under the bark are the so-called resting-buds.

FIGS. 4 and 5. Warts from Pine and Walnut-trees respectively. They are supposed to have arisen from wounds such as those produced by gun-shot. Note the rapid growth in Fig. 5 in about 7–8 years (see p. 187).

FIG. 6. Board of English Walnut, showing "ripple."

FIG. 7.—Example of good pruning. The branch was cut vertically in the course of the sap-stream, and the mend is as nearly perfect as possible.

FIG. 8. Indifferent pruning. A stub has been left which has split, and the callus had to advance considerably before the wound was covered.

FIG. 9. Good pruning; occlusion in progress.

FIG. 10. Crab-tree, affected in a similar manner to the Bee-sucken Ash in Fig. 1.

FIG. 11. Cross-section of Pine, showing ring-shake, due to a wound which has killed the growing layer, in a concentric direction.

FIG. 12. Cross-section of Elm of very eccentric growth. The pith is to the left. The growth was very rapid on the right side and very slow on the left, but there are as many rings on the one side as the other, notwithstanding.

FIG. 13. Grafted Magnolia.

FIG. 14. Lower part of the trunk of a Logwood-tree with the characteristic buttresses (see p. 17).

FIG. 15. Wart on Ash. Note the enormous size compared with the stem from which it has arisen (see p. 187).

FIG. 16. Cross-section of Logwood-tree, showing the deeply re-entering channels which occasionally become closed.

FIG. 17. Burr of Elm, exposed by removal of the bark. The bristling points are the so-called resting-buds.

FIG. 18. Piece of kiln-dried Oak, showing "honey-combing," i.e. concealed cracks which do not appear on the surface.

FIG. 19. Cross-section of Elm with ring-shake (to left of centre), due to the unequal shrinkage of laxer and denser zones of wood (cf. Fig. 4, Plate XI.).

FIG. 20. Portion of trunk of Oak with two frost-cracks, the larger indicated by the projecting ridge of callus to the right, the smaller by a fissure just to the left.

FIG. 21. Small stem of Logwood, deeply channelled.

FIG. 22. Plank of Sweet Chestnut taken from the butt, showing ring-shake in vertical section. (The plank is lying on its edge, with the butt-end to the left.) Note how the shake curves outwards with the grain.

FIG. 23. Trunk of Poplar, infested by Mistletoe. The holes were occupied by the "sinkers" or roots of the parasite, which have subsequently decayed.

FIG. 24. Large globular wart surrounding the butt of a small Pencil Cedar-tree. The latter is only four inches in diameter, whereas the wart measures fifteen inches and is, moreover, excessively hard.

FIG. 25. A plank from a grafted tree (Weymouth Pine on Scots Pine, see fig. 26) showing the line of the graft. Note the difference in the appearance of the wood of the two species.

FIG. 26. Trunk of grafted Pine planted about 1840, from a tree planted at the same time as that from which the plank shown in Fig. 25 was cut. Note the difference in the bark of the two species (Weymouth above the graft, Scots Pine below).

PLATE V.

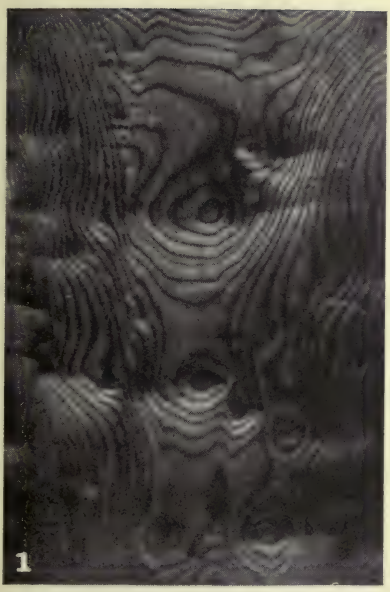
PLATE VI. ALL FIGURES ABOUT ONE-HALF NATURAL SIZE. PHOTO BY E. A. K.

FIG. 1. Plank showing partly radial and partly tangential section, and a form of Bird's-eye figure outlined in fringes (pores). The circles are the cross-sections of the salient parts, similar to those seen at the left of the figure.

FIG. 2. Plank of Taiwan Sugi, a Japanese Conifer. The figure is outlined by sharply-cut bands of Summer wood. The circles are produced in the same way as in Fig. 1.

FIG. 3. American Red Oak. Plank in tangential section, showing zigzag tracery, due to the cutting of the (abnormally) undulating ring-boundaries.

FIG. 4. Plank of Keaki (*Zelkowa acuminata*), a Japanese tree. The outline of the figure is in very fine fringes and the Bird's-eye circles are more delicate than in previous examples.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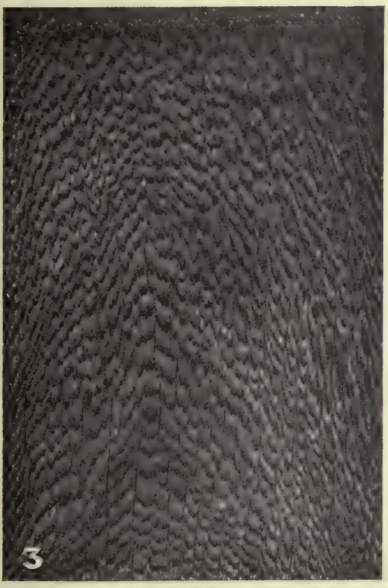
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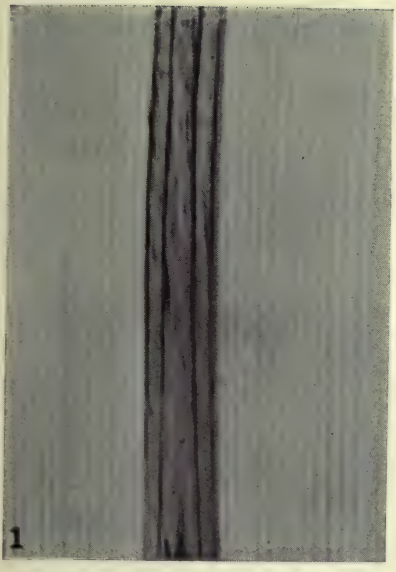
PLATE VIII. PHOTO BY E. A. K.

FIG. 1. Plank of Corsican Pine in radial section, showing the outline of the tree at an early age (scale about ⅕th natural size). The difference in colour in this case is due to incipient decay. Note the spots in oblique lines, indicating the insertions of the short shoots.

FIG. 2. Block of New Zealand Silky Oak (*Stenocarpus salignus*), showing transverse, radial and tangential sections. Scale about ¼.

FIG. 3. Portion of a panel in the door of Room 5 at the School of Forestry, Cambridge. At the top left-hand corner is a perfect transverse section; this passes below into an equally perfect radial section. Scale about ⅕th.

FIG. 4. Plank of False Acacia, with burr projecting from the edge in true radial section Note that the burr commences in a point, remains narrow for some years and then increases in a geometrical manner; also that there is a certain amount of order in the tissue even of a burr. Scale about ⅕th.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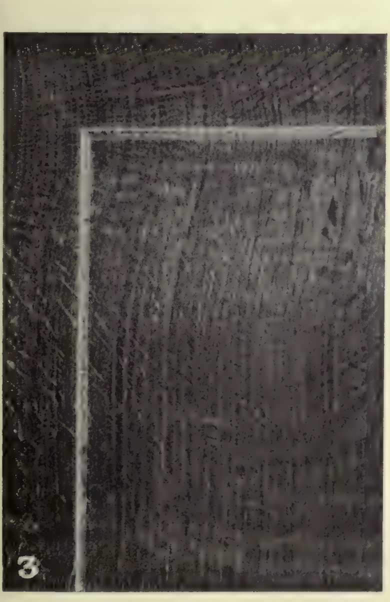
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PLATE IX. Scale Natural Size. Photo by E. A. K.

Fig. 1. Bird's-eye Maple as seen on the outside of the trunk. The holes or dimples are overlaid by regular thicknesses of new wood year by year, but are not filled up.

Fig. 2. The same seen from within, in tangential section. The roughly-circular lines are the sections of the layers of wood occupying the dimples.

Fig. 3. An ogee moulding of American White Oak, showing the reversal of the loops produced by the cutting of the rays by alternate salient and re-entrant grooves.

Fig. 4. Lignum-vitæ split to show the extraordinary irregularity in the course of the grain.

PLATE IX.

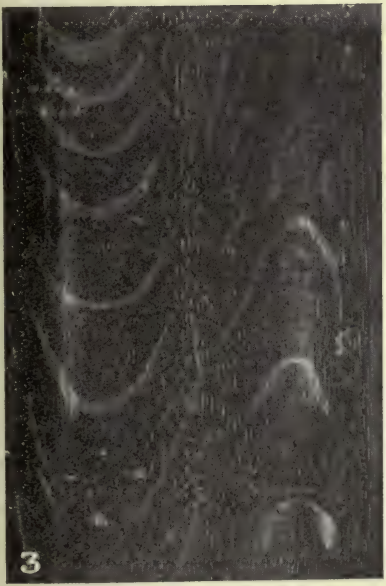


PLATE X. Photo by E. A. K.

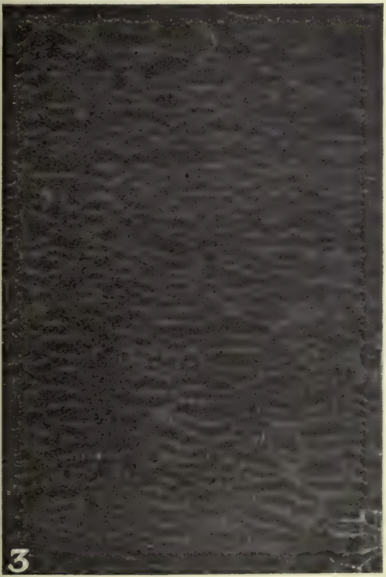
Fig. 1. Plank of Huon Pine (*Dacrydium Franklinii*), with "roll" or "ripple" figure, due to the undulation of the fibres; the plank-face is, however, perfectly flat. Scale $\frac{1}{5}$th.

Fig. 2. Plank of the Giant Redwood (*Sequoia sempervirens*), with "roll." Scale $\frac{1}{5}$th.

Fig. 3. Veneer of Canary Whitewood (*Liriodendron*), with "blister" figure. Scale $\frac{1}{5}$th.

Fig. 4. Board of the same with "blister" figure on a smaller scale. Both are caused by the cutting of swellings, but as the boundaries are not very readily seen, it does not produce the Bird's-eye effect, though the cause is the same. Scale $\frac{1}{5}$th.

PLATE X.



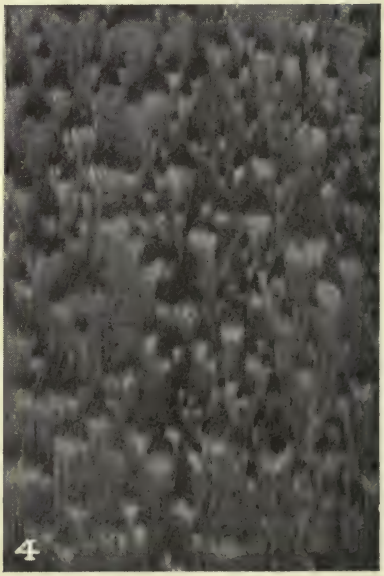


PLATE XI. PHOTO BY E. A. K.

FIG. 1. Quartered board of Common Oak, showing normal silver-grain, i.e. the rays in radial section (indicated by the light-coloured bands in the photo). The vertical lines are the large pores of the pore-rings, which in this cut appear as parallel lines of fine scratches. Scale $\frac{1}{5}$th.

FIG. 2. Quartered board of Turkey Oak (*Quercus cerris*), normal figure, but in this case the rays are cut up by strands of fibres obliquely drawn across them, hence they do not form broad bands, but are subdivided into small flakes. On the right of the photo they thin out to a sort of necklace pattern. Scale $\frac{1}{5}$th.

FIG. 3. Board of American Red Oak (*Q. rubra*) in nearly radial section. The plane of the cut has just touched the pith at one point from which the rays spread out, thus producing a sort of "sun-dial" figure. Scale $\frac{1}{5}$th

FIG. 4. Elm, showing "thunder-shake," due to the contraction of unequally broad layers (i.e. of wood of unequal density of substance), which sets up tissue-tensions. It is to be understood that the point where the greatest tension exists may be distant from the point of rupture (see p. 198; compare Fig. 19, Plate V). Scale $\frac{1}{2}$ natural size.

PLATE XI.

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PLATE XII. All Figures taken from the Planks, Scale about $\frac{1}{5}$th. Photo by E. A. K.

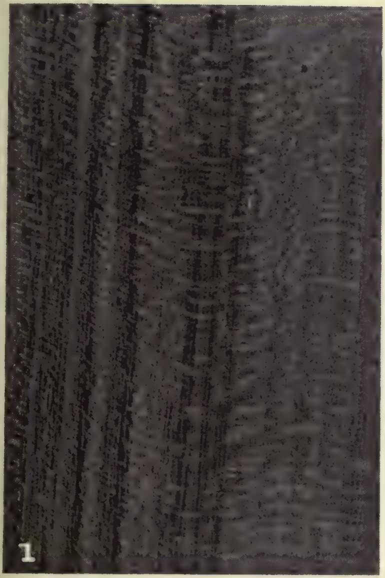
Fig. 1. Quartered plank of Honey Locust (*Gleditschia triacanthos*), showing wavy silver-grain, due to the undulations in the course of the rays seen on the cross-section.

Fig. 2.—Alder (*Alnus glutinosa*), radial section, natural size, photo from the solid wood. The very faint smoky streaks are the large rays. The minute horizontal lines are the small rays (secondary silver-grain).

Fig. 3. Oriental Plane, quarter-cut. Note the proportion of the surface occupied by the silver-grain.

Fig. 4. Beech, quarter-cut, showing the small proportion of the surface occupied by the silver-grain. The latter is bright, whereas that of the Plane is dull and hence show more distinctly in the photograph.

PLATE XII.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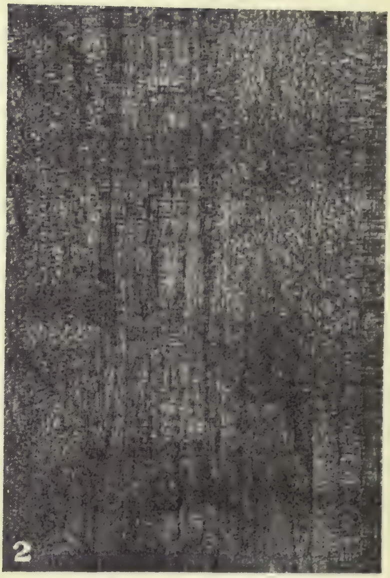
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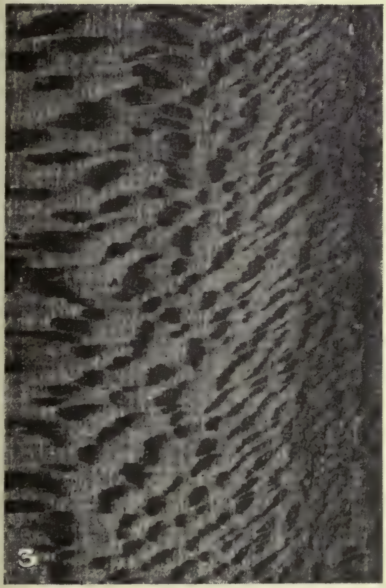
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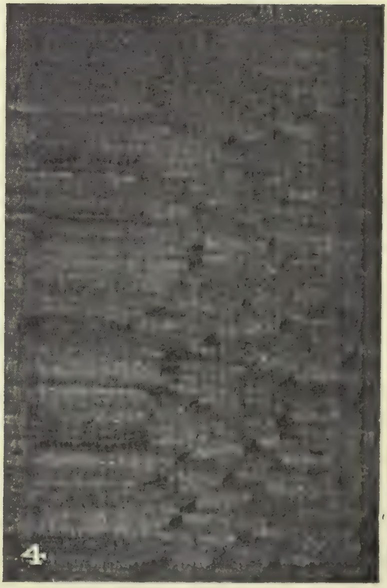
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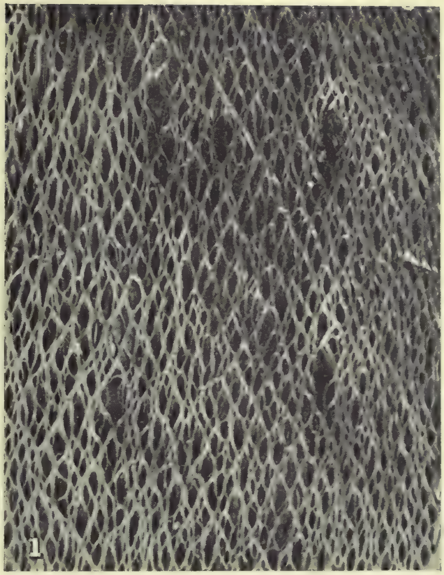
PLATE XIII. Scale about ⅛th Natural Size.

Fig. 1. Wood from a Cactus (*Cereus peruvianus*), from which the rays have disappeared by decay. This is a good illustration of the structure of exogenous wood and represents that which wood would be without rays, i.e. a mesh-work. The strength will therefore depend firstly upon the tensile resistance of the fibre-strands, and secondly upon the amount of cohesion at the points where the strands are joined one to another. Photo by M. F.

Fig. 2. Cedar of Lebanon, showing abnormal dimple-like invaginations of the ring-boundaries which fit, as it were, into each other. A vertical section at any point will cut more than one of the layers in the dimple, hence concentric circles will be produced on a tangential section, as shown on the front of the block. This affords the explanation of the well-known Bird's-eye figure. Natural size. Photo by E. A. K.



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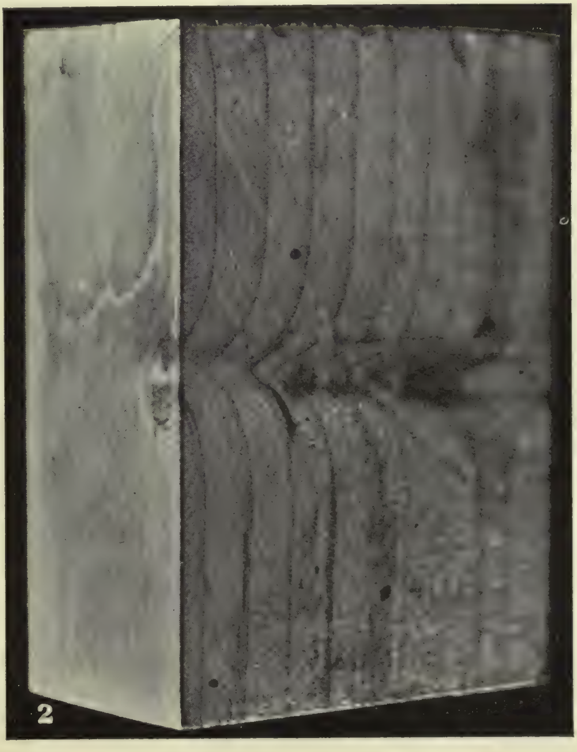

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PLATE XIV.

FIG. 1. Portion of the branch of the Evergreen Oak (*Q. Ilex*), from which our frontispiece was taken. The side here shown corresponds with that on which the larger rays come out on the surface under the bark. The rays are indicated by the coarse spindle-shaped grooves. Scale ½ natural size. Photo by M. F.

FIG. 2. The same block seen from the opposite side, where the smaller rays crop out, as indicated by the much smaller spindle-shaped grooves. Photo by M. F.

FIG. 3. Cross-section of young Birch, showing "flecks," otherwise the filling by dark-coloured callus of the galleries of the larvæ of a fly (*Agromyza carbonaria*). Scale ½ natural size. Photo by E. A. K.

FIG. 4. Block of Mahogany riddled by the Ship-worm (*Teredo navalis*). The white patches in the galleries are the fragments of nacre with which the worm lines the hole. Scale about ⅓rd natural size. Photo by E. A. K.

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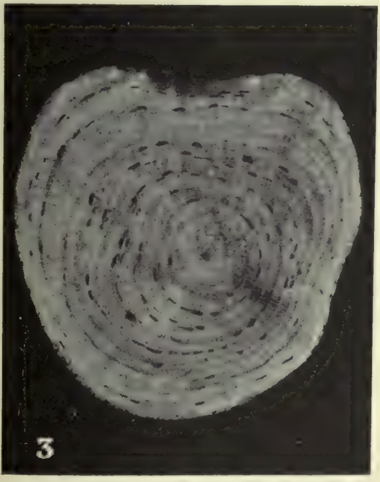

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PLATE XV. ALL FIGURES ABOUT $\frac{1}{5}$TH NATURAL SIZE.

FIG. 1. Portion of the trunk and branch of the False Acacia. As they increase in thickness, both parts compete for space in the angles. Above the branch where the competition is severest, the fibres are at first sharply buckled, but afterwards the slackening of the bark-pressure changes the buckling to "piling-up," as in Fig. 2. Below the branch, the competition for space is less, but the bark-pressure is maintained, hence the buckling is perpetuated and "ripple," "fiddle-back" or "ramshorn" figure is produced (see diagram, Plate XXXIX. Fig. 2). Photo by E. A. K.

FIG. 2. Fork of Elm, split to show the structure of a "curl or crotch." Note that the annual layers at the bottom of the fork are much broader than the corresponding layers in the branches. This arises from the freer growth consequent on the relaxing of the pressure of the bark in the fork, whereas the growing-layer of the branches continues to be strangled; the bark acts like the hoops of a barrel, when intact, but at a fork it is lifted or drawn away to some extent. Photo by R. J.

FIG. 3. Crotch of Padauk, showing the appearance when cut and planed. Photo by E. A. K.

FIG. 4. Plank of Spruce with burr in radial section. Note the small beginning of the burr. Photo. by E. A. K.

PLATE XV.

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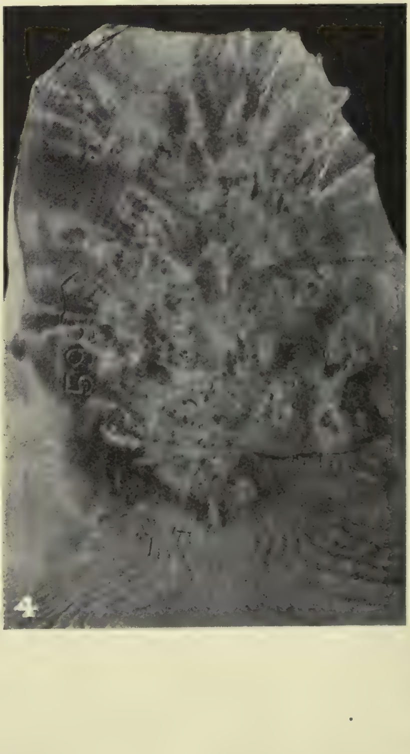

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PLATE XVI. PHOTO BY E. A. K.

FIG. 1. Cross-section of the New Zealand Silky Oak (*Stenocarpus salignus*), showing wonderfully large rays, with the notches subtending them in the outside of the stem. There is little indication of the boundaries of the layers of growth. Scale about ½ natural size.

FIG. 2.—Block of *Stenocarpus salignus*, exterior of the log with a portion of the bark removed to show the spindle-shaped grooves in the mesh-work, at the bottom of which the rays terminate.

FIG. 3. Cross-section of a Palm, *Rhopalostylis Baueri*, an endogenous tree (Monocotyledon). The vascular-bundles are scattered throughout the stem. Scale about natural size.

FIG. 4. Cross-section of a pile of Pitch Pine. The interior rings produced when the tree was young and had plenty of light and root-space, are wide. They diminish gradually as it becomes crowded by its neighbours, forming "canopy." A second series of wide rings indicates a thinning of the forest when the tree again became free, but canopy being gradually re-formed, a series of narrow rings follows and so on.

PLATE XVI.

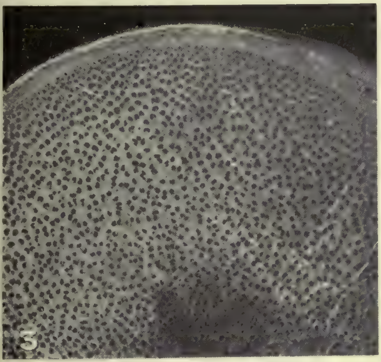


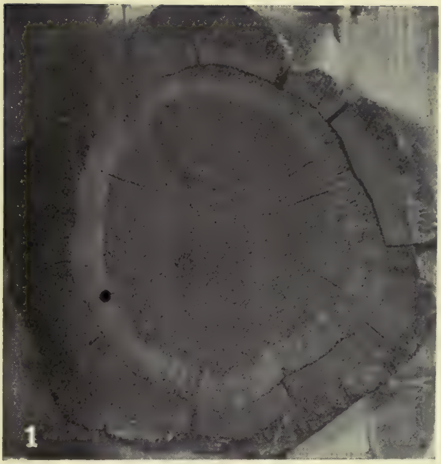
PLATE XVII.

Fig. 1. Cross-section of Oak with a defect known as "double-sap" (see p. 199). Scale $\frac{1}{5}$th.

Fig. 2. "a." Poplar infested by Mistletoe. "b." A similar specimen cut open to show the holes left by the "sinkers" of the parasite. The outer, lighter-coloured wood is that of the Mistletoe. Scale $\frac{1}{5}$th. Photo R. J.

Fig. 3. *Acantholinum* (Plumbaginaceæ), natural size, after Krueger. This is a ray-less wood, having apparently no provision for filling up the ray-clefts.

PLATE XVII.



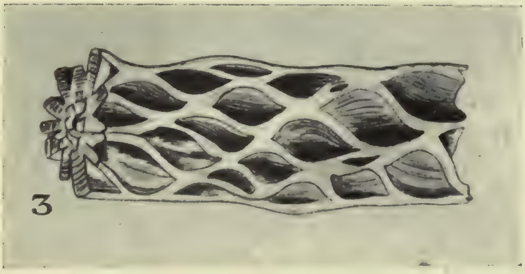


PLATE XVIII. Photo by E. A. K.

Fig. 1. Branch stripped by deer. Scale about $\frac{1}{5}$th natural size.

Fig. 2. Branch stripped by voles. Scale about $\frac{1}{5}$th natural size.

Fig. 3. Branch stripped by cattle. Scale about $\frac{1}{5}$th natural size.

Fig. 4. The "Rose of Hell," or the branch of a tree stimulated to abnormal growth by a parasite (*Loranthus*) similar to the Mistletoe. During forest fires the parasite is killed and falls off, exposing the "Rose." The present specimen is from a species of *Pterocarpus* and shows distinct traces of scorching. Scale about $\frac{1}{5}$th natural size.

Fig. 5. Hazel after wounding by the stripping off of a branch. The callus is now larger than the original stem. Scale about $\frac{1}{5}$th natural size.

Fig. 6. A wood-ball (see p. 195). Scale $\frac{1}{5}$th.

Fig. 7. Stem of Hazel, partially healed after nibbling by voles. Scale about $\frac{1}{5}$th natural size.

Fig. 8a. Cross-section of a plank of Beech cut the "slab-way," showing the influence of the rays in warping. 8b. Another plank cut on the quarter which has not warped. Scale $\frac{1}{5}$th natural size.

Fig. 9. Birch stem, vertical section, showing "flecks" (cf. Plate XIV., Fig. 3). Scale about $\frac{1}{5}$th natural size.

PLATE XVIII.

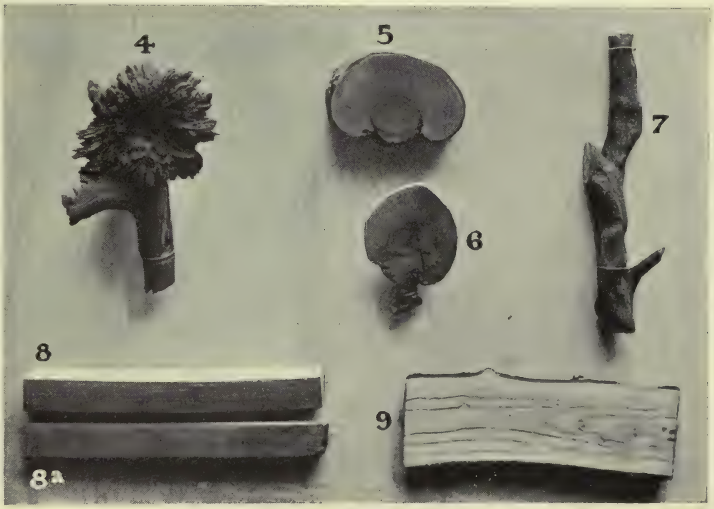


PLATE XIX. CROSS-SECTIONS TAKEN FROM THIN, TRANSPARENT SECTIONS BY A. D.

FIG. 1. Cluster Pine (*Pinus Pinaster*), showing large resin-canals. (× 3.)

FIG. 2. Silver Fir (*Abies pectinata*), showing the great regularity in the radial rows of cells. No resin-canals. (× 3.)

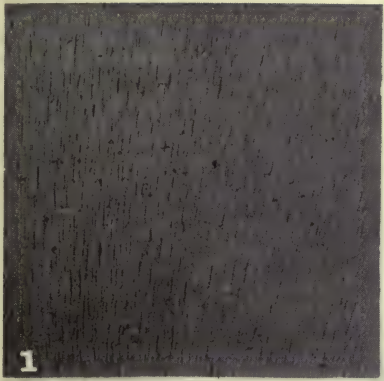
FIG. 3. The same, × 20.

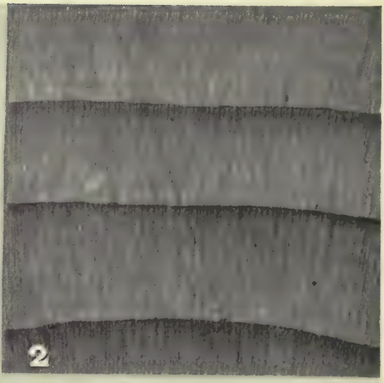
FIG. 4. New Zealand White Pine (*Podocarpus dacrydioides*). The limits of the annual rings are very vague. No resin-canals. (× 3.)

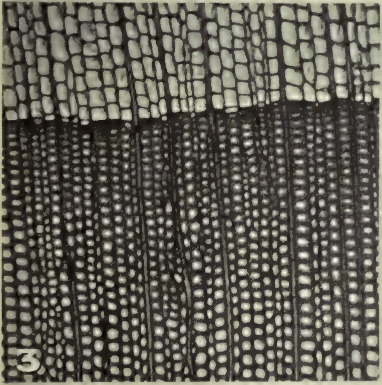
FIG. 5. Pencil Cedar (*Juniperus virginiana*). Ring-boundaries clear ; no resin-canals but occasional zones of resin-cell which simulate the boundaries. (× 3.)

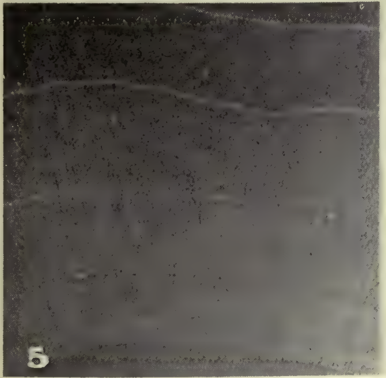
FIG. 6. The Giant Redwood or Wellingtonia (*Sequoia gigantea*) from an exceedingly slowly-grown specimen. Some of the rings are no more than two rows of cells wide, but many are probably nothing but "false starts." (× 3.)

PLATE XIX.









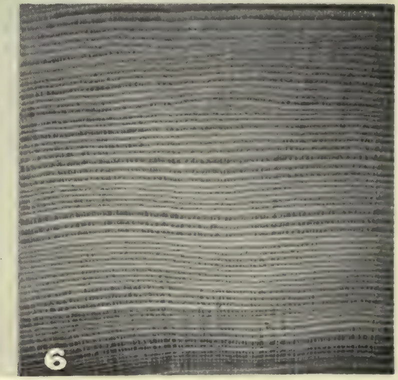


PLATE XX. CROSS-SECTIONS TAKEN FROM THIN, TRANSPARENT SECTIONS BY A. D.

FIG. 1. Hornbeam. The large rays are "aggregate," or composed of many small ones. The ring-boundary is notched, indicating a deep, spindle-shaped groove on the exterior of the trunk. This, though filled up year by year with new wood, is always perpetuated. The pores are in radial files. (× 3.)

FIG. 2. Common Oak, well-grown, with very broad pore-rings, which thin out in the Summer wood to radial streams. The small rays are discernible between the large ones, as is also the parenchyma surrounding the pores. The concentric parenchyma does not show up. (× 3.)

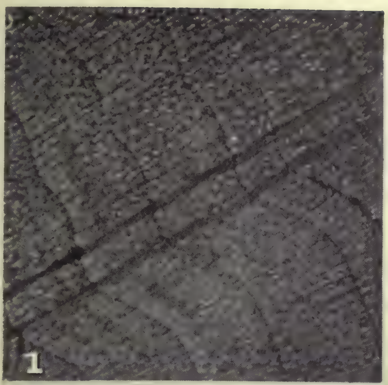
FIG. 3. Beech. The pores occupy the major portion of the section, but are very small. The rays appear to taper at each end, but this is due to the obliquity of the cutting (cf. Plate II., Fig. 5).

FIG. 4. Oriental Plane. This resembles the Beech, but the ring-boundaries are vague and the large rays more numerous. (× 3.)

FIG 5. Western Plane. As Fig. 5, but the boundaries are much more distinct (this is slightly exaggerated, the section being thicker). (× 3.)

FIG. 6. *Bignonia sp.*, showing the failure of the rays which have caused the stem to crack vertically. (× 20.)

PLATE XX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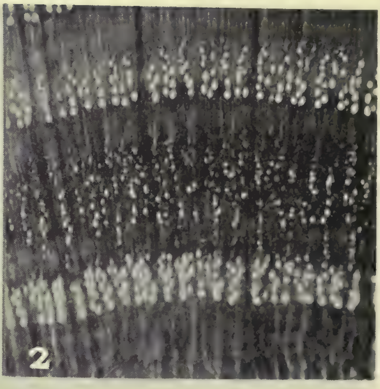
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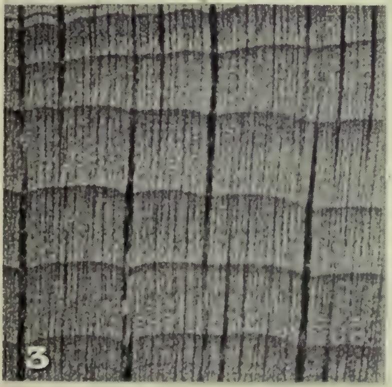
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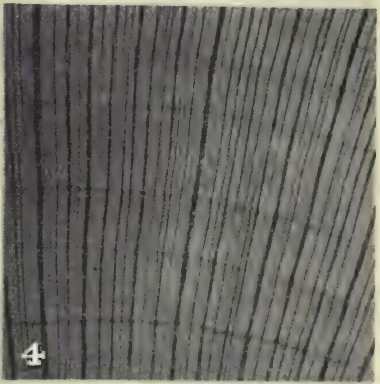
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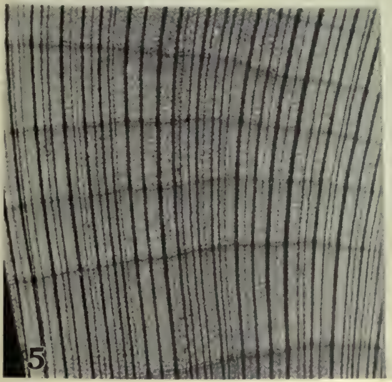
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PLATE XXI. CROSS-SECTIONS, × 3, TAKEN FROM THIN SECTIONS. PHOTO BY A. D.

FIG. 1. *Casuarina Fraseriana*, one of the She-Oaks of New Zealand, remarkable for its very large compound rays. The patchy appearance of these is caused by the presence of pigment in some of the cells only. The relationship of the Casuarinas to the Oaks is strongly evidenced by the structure of the wood.

FIG. 2. *Grevillea robusta*, one of the Silky Oaks of New Zealand (family Proteaceæ), in no way related to the foregoing. All the woods of this family have large and showy rays.

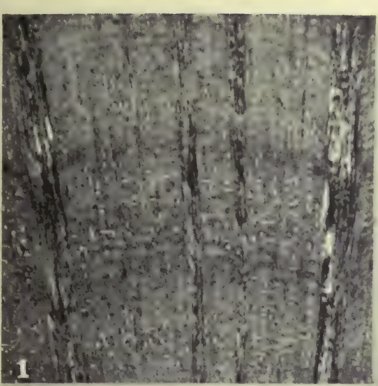
FIG. 3.—Oak slowly grown, with narrow rings (cf. Fig. 2, Pl. XX.).

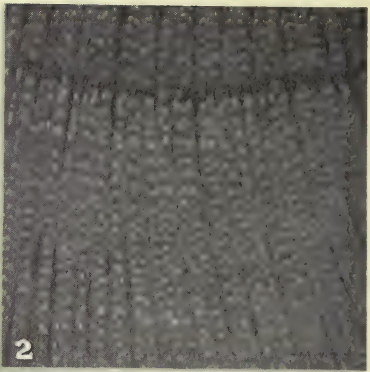
FIG. 4. *Carallia integerrima*, a wood from Ceylon.

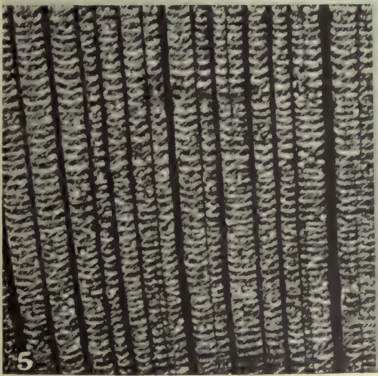
FIG. 5. *Plagianthus betulinus*, the Lace-bark of New Zealand, a wood of the Mallow family which recalls the structure of the Proteaceæ very strongly (cf. Fig. 2).

FIG. 6. *Stenocarpus salignus*, the Silky Oak of New Zealand, another wood of the Proteaceæ and one of the showiest known woods. It differs from most of the same family in the absence of the tendency for the pores to group themselves into narrow zones. Several of the large rays in the figure are seen to be in the process of splitting up. The ring-boundaries are not perceptible.

PLATE XXI.







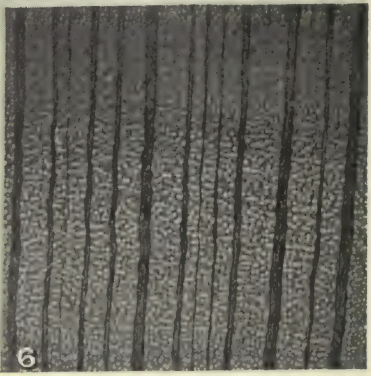


PLATE XXII. CROSS-SECTIONS, × 3, TAKEN FROM THIN SECTIONS. PHOTO BY A. D.

FIG. 1. *Prunus Cerasus*, the Cherry, a wood of very uniform character. The specimen shows a marked increase in the average size of the pores from year to year.

FIG. 2. *Pyrus malus*, the Crab-apple. Structure similar to the preceding, although the woods differ considerably in the solid.

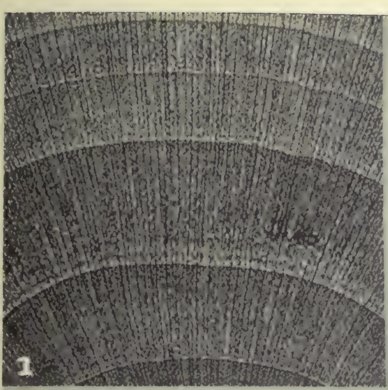
FIG. 3. *Eucalyptus globulus*, the Blue Gum of Tasmania. The pores are seen here and there to be arranged in curved, radial lines ; ring-boundaries very vague ; rays extremely fine, numerous and closely crowded.

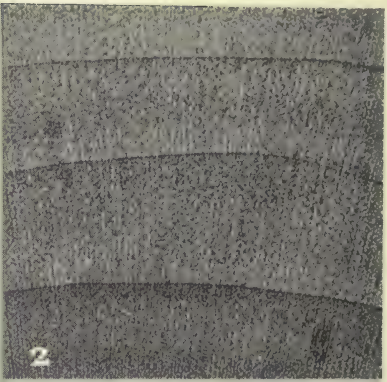
FIG. 4. *Eucalyptus salubris*, the Gimlet Gum of Queensland, a rather aberrant type of this genus.

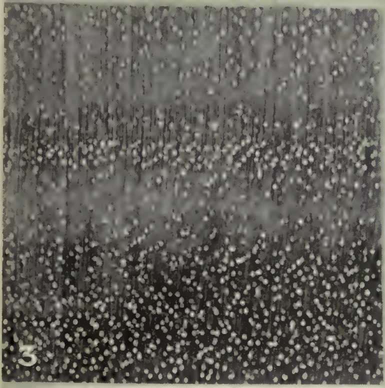
FIG. 5. *Populus alba*, the Hoary Poplar, another wood of a uniform structure identical with that of the Willows. The pores occupy practically the whole of the section, being simply separated by numerous and exceedingly fine rays, one for each file of pores. The ring-boundary consists of one or two rows of flattened parenchyma-cells.

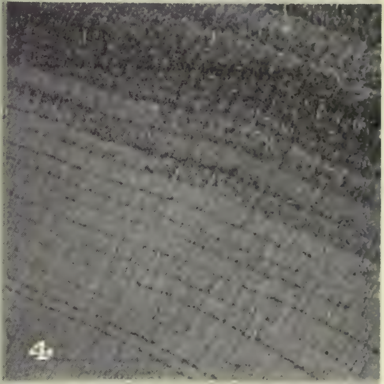
FIG. 6. *Ulmus racemosa*, the Rock Elm of North America. Only here and there are the rings sufficiently wide to show the undulating lines of parenchyma which unite the pores into festoons. As a rule, the wood is a mere succession of one-rowed pore-rings. These are compacted by light-coloured parenchyma which is sufficiently abundant to give a yellow tone to the section in the solid wood. (Pith side to the left above.)

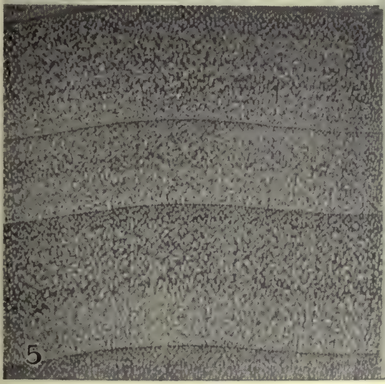
PLATE XXII.











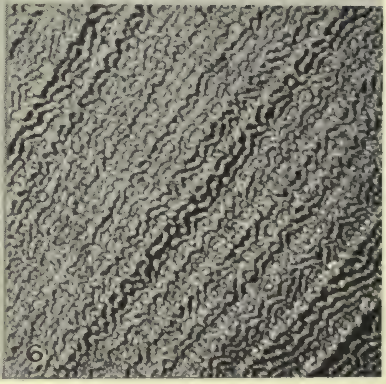


PLATE XXIII. CROSS-SECTIONS, × 3, TAKEN FROM THIN SECTIONS. PHOTO BY A. D.

FIG. 1. *Zanthoxylum flavum*, the West Indian Satinwood, from San Domingo. The pores are few and often arranged in radial strings lying between the rays. The ring-boundaries are of white parenchyma (not shown). These two characters are typical of all the woods of this family (Rutaceæ).

FIG. 2. *Actinidia arguta*, a climber with large pores and fine undulating rays, which compose most of the solid wood. The width of the rings is hardly greater than the longer diameter of a large pore.

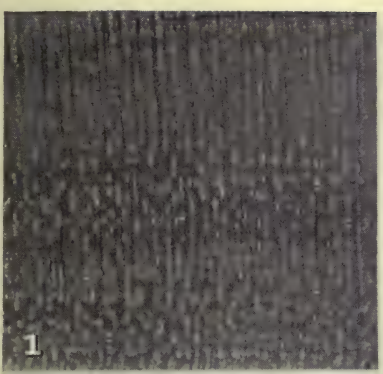
FIG. 3. *Schinus molle* (Terebinthaceæ), a wood of very irregular growth, apparently making repeated "false starts."

FIG. 4. *Robinia Pseud-Acacia*, the False Acacia. The specimen is of a type intermediate between those shown on Plate I., Figs. 5 and 6, having isolated pores in the inner zone of the ring and festooned pores in the outer.

FIG. 5. *Passiflora emarginata*, a Passion-flower, showing pores in long radial strings which extend continuously over many rings.

FIG. 6. *Tectona grandis*, the Teak. This shows the pores rather more crowded in the inner zone of the ring. The prominent, light-coloured parenchyma so characteristic of this wood, does not appear in the transparent section; in the solid wood the ring of pores is practically obscured by it (cf. Fig. 6, Plate III.).

PLATE XXIII.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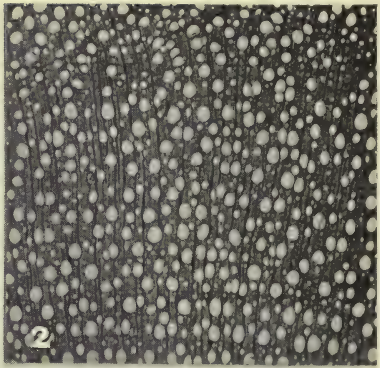
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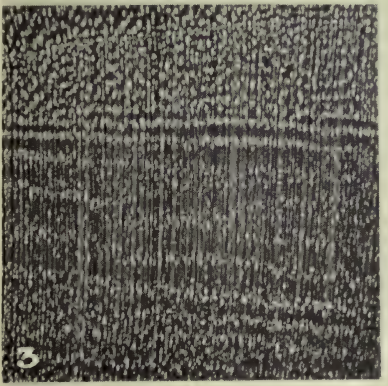
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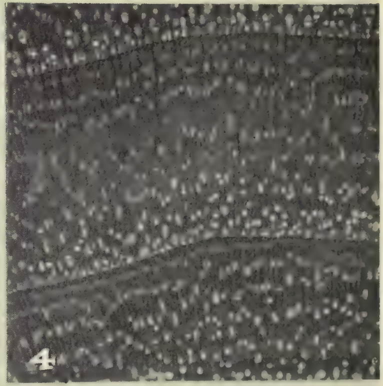
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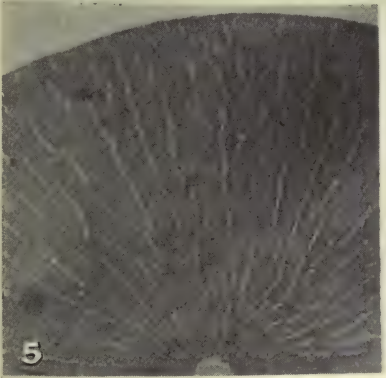
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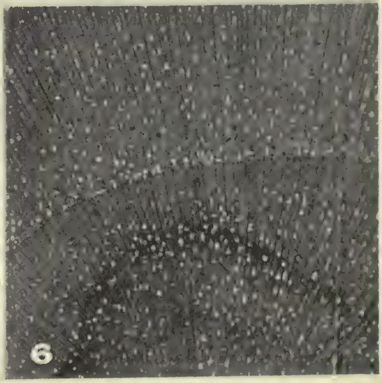
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PLATE XXIV. CROSS-SECTIONS FROM THIN SECTIONS.

FIG. 1. *Pyrus. aria*, the Whitebeam-tree, × 50; the cells of the rays and wood fibres are visible with this magnification. The former are seen to be elongated in a radial direction, the latter present their narrowest diameter.

FIG. 2. *Crataegus oxyacantha*, the Hawthorn, × 50; the pores are evenly distributed and diminish but little in size, the cells of the ground-tissue (wood-fibres) are thick-walled.

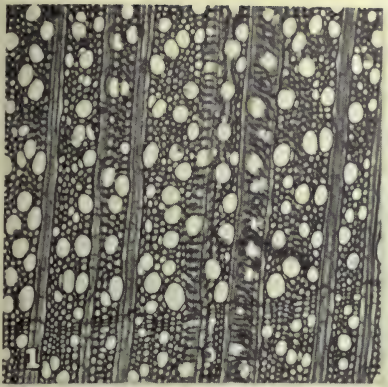
FIG. 3. *Dimorphandra Mora*, a Leguminous wood from British Guiana, × 3, from the solid wood (sap-wood to left, heartwood to right). The pores are sheathed with parenchyma; the ring-boundaries are not indicated.

FIG. 4. *Ilex Aquifolium*, the Holly, × 50, showing large compound rays and widely-scattered mother-and-daughter pore-groups. The Holly may be confused with the Hornbeam, which it resembles in colour and hardness. It is best distinguished by the height of the rays in tangential section.

FIG. 5. *Carpinus Betulus*, the Hornbeam, × 50, showing wide poreless spaces in which there is a large "aggregate" ray (i.e. composed of many small ones, as in a bundle).

FIG. 6. *Æsculus Hippocastanum*, the Horse Chestnut, × 50. The rays are exceedingly fine, and are about the width of a large pore apart. The boundary-line below is of flattened parenchyma cells.

PLATE XXIV.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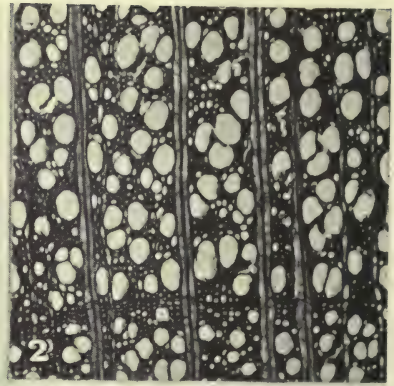
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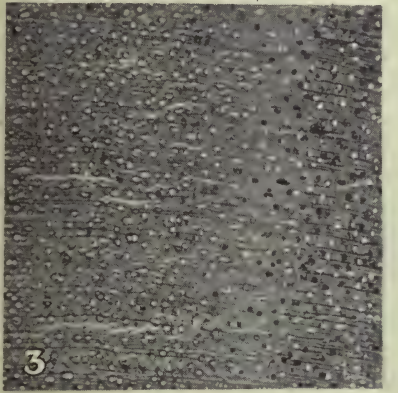
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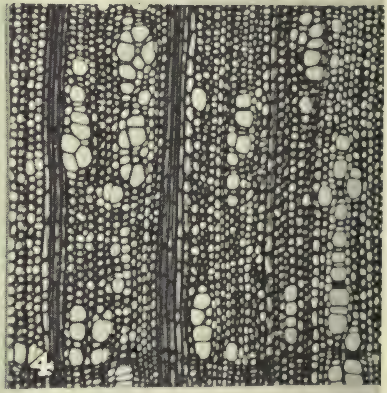
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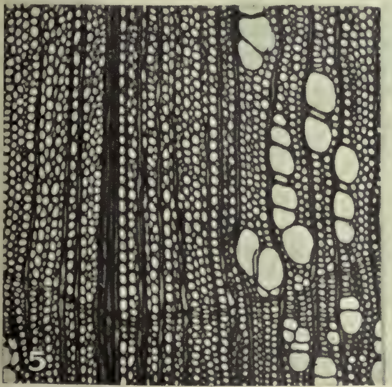
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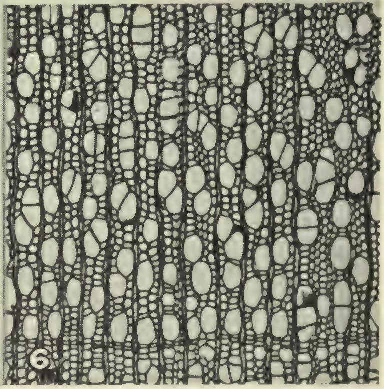
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PLATE XXV. Cross-sections, × 25, taken from Thin Sections; Pith-side Downwards. Photo by E. A. K.

Fig. 1. *Lomatia obliqua*, a wood of the family Proteaceæ. The pores are restricted to narrow concentric bands of a few rows of small pores. The rays are swelled or nodose at the point where they cross the boundary-line (below).

Fig. 2. *Alnus maritima*, an Alder. The boundaries of the rings are sharply notched where the rays cross them, indicating deep grooves on the outside of the log under the bark.

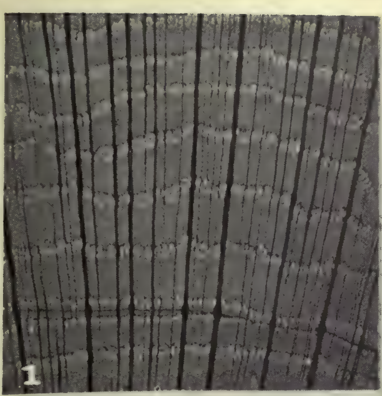
Fig. 3. *Saccopetalum tomentosum* (Anonaceæ), from the East Indies, showing minute, concentric lines of parenchyma which is somewhat characteristic of this order.

Fig. 4. *Sideroxylon borbonicum* (Sapotaceæ), from Réunion. The pores are in radial groups which link up to other groups a little to one side, thus forming long straggling strings by which woods of this family can easily be recognized even by the unaided eye, on the end of a hewn log. The concentric bands of parenchyma are also characteristic; they do not indicate the limits of the season's growth, the latter not being certain.

Fig. 5. *Rhamnus virgatus*, one of the Buckthorns, showing the pores arranged in a beautiful flame-shaped or cruciform manner.

Fig. 6. *Betula lenta*, the American Birch of commerce. The attenuated ends of the rays are seen to be occupying the greater part of the space left by the pores (they are more distinctly visible in the second and third ring from the top).

PLATE XXV.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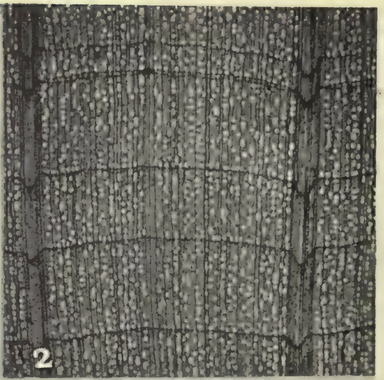
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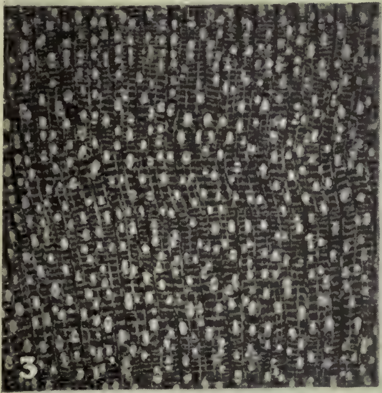
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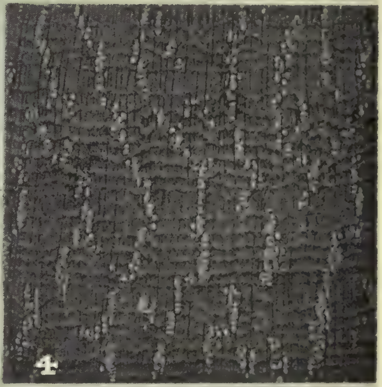
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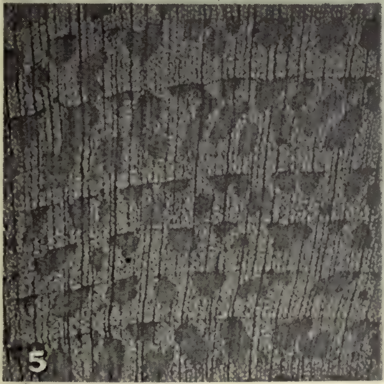
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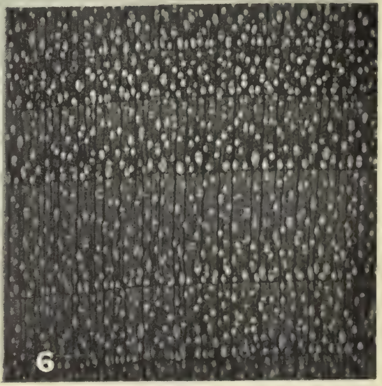
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PLATE XXVI. CROSS-SECTIONS, × 20, FROM THIN SECTIONS; PITH-SIDE DOWNWARDS.

PHOTO BY E. A. K.

FIG. 1. *Albizzia procera*, a Leguminous wood from Australia, having large and widely isolated pores sheathed by parenchyma, which appears as aureoles around them. Some of the pores are subdivided by septa, and may be in series of several "mother-and-daughter" pores. The rays are fine and appear to run round or avoid the pores. The ring-boundary appears quite distinct, but in the solid wood is by no means pronounced.

FIG. 2. *Cassia fistula*, a Leguminous wood from the West Indies, of similar structure to that of Fig. 1, differing only in the excessive development of the parenchyma, which here unites the pores into strongly-undulating, festoon-like bands.

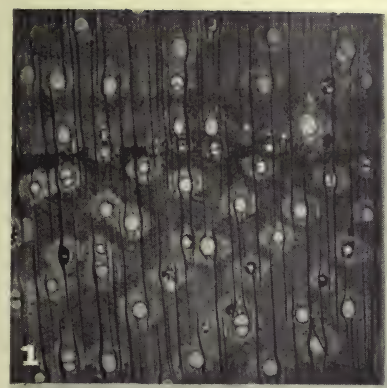
FIG. 3. *Calophyllum Tacamahaca*, from Madagascar. The pores are arranged in straggling, radial lines which, however, appear better unmagnified. There are two kinds of parenchyma, that sheathing the pores and another in interrupted concentric lines. The latter is brown and darker than the surrounding fibres, a rare case.

FIG. 4. *Diospyros virginiana*, the Persimmon of North America, a wood of the Ebony family, but differing from the real Ebonies in having a fairly well-marked pore-ring, which perhaps corresponds with its temperate habitat. The parenchyma is scanty round the pores, but abundant in concentric lines or bars (just visible in the figure).

FIG. 5. *Ficus macrophylla*, a species of Fig-tree, another case where the parenchyma is largely developed. The lines are less undulating than in Fig. 2.

FIG. 6. *Hippophœ rhamnoides*, the Sea Buckthorn (family Elæagnaceæ), a curious case, where the annual growth is commenced by a zone of small pores, then follow large and small ones alternately, and lastly a very broad zone containing small pores only.

PLATE XXVI.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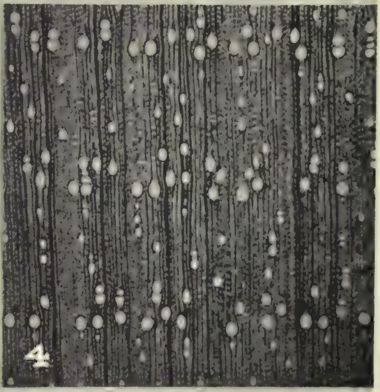
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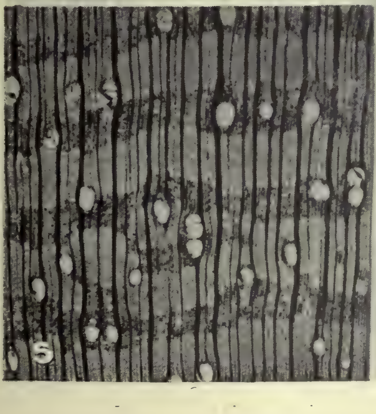
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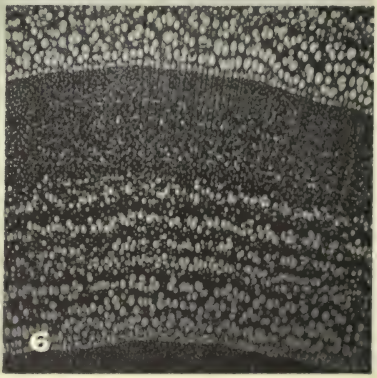
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PLATE XXVII. CROSS-SECTIONS, × 3, FROM THIN TRANSPARENT SECTIONS ; PITH-SIDE DOWNWARDS. PHOTO BY A. D.

FIG. 1. *Celastrus acuminatus,* the Silk-bark-tree of the Cape. This is one of the exceptional woods in which the parenchyma (the concentric bands in the figure) is of darker colour than the fibres. It imparts a beautiful appearance to the wood in tangential section. These bands may or may not indicate the limits of the season's growth.

FIG. 2. *Berria ammonilla,* the Trincomalee-wood from India. The pores are united tangentially by small bars of parenchyma, which in this case are simply the lateral extensions or wings of that which sheathes the pores.

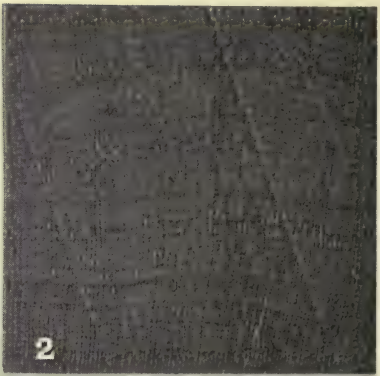
FIG. 3. *Dysoxylon Muelleri,* the Australian Mahogany. The concentric lines of parenchyma are dark in this case also.

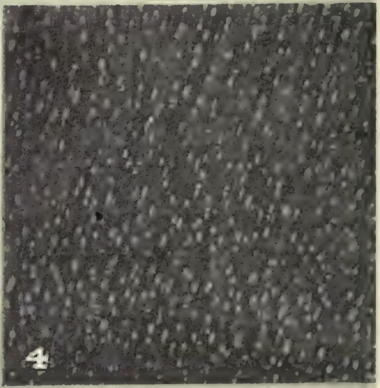
FIG. 4. *Dalbergia latifolia,* the Indian Rosewood or Blackwood. The rays are excessively fine, occupying the major part of the section. The concentric bars of parenchyma are doubtfully discernible in the photo.

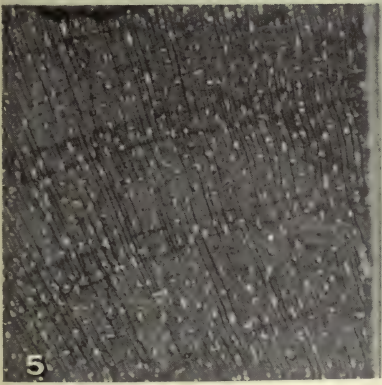
FIG. 5. *Picræna excelsa,* the Quassia of commerce. The concentric parenchyma is white in the solid wood, but owing to its peculiar optical properties, shows dark in a transparent section and hence on the photograph.

FIG. 6. *Sophora tetraptera,* from New Zealand. The concentric parenchyma imbeds the very fine pores and unites them into oblique lines and festoons, which anastomose here and there. The sap-wood (above) shows the rays more clearly than does the heart-wood (below).

PLATE XXVII.







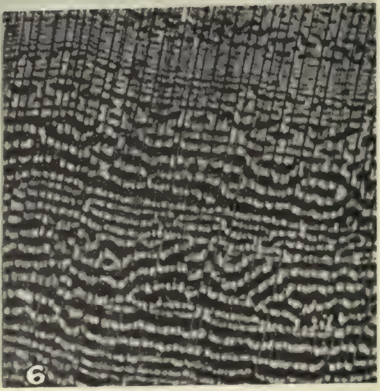


PLATE XXVIII.

FIG. 1. *Carapa guianensis*, the Crabwood of British Guiana and Trinidad, from transparent transverse section, × 3, showing undulating rays. Pith-side downwards. Photo by A. D.

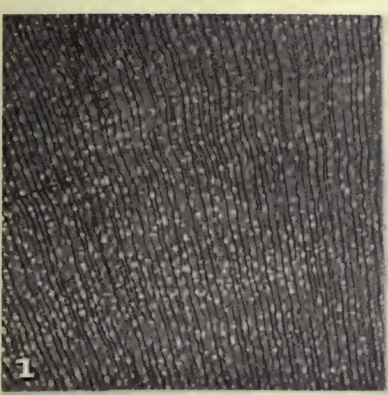
FIG. 2. *Picea excelsa*, the Common Spruce, showing "traumatic" resin-canals, said to be due to wounding. The boundary is formed by a "line of contrast" between lax and dense tissue. × 10 from a transparent section. Photo by A. D.

FIG. 3. *Nectandra Rodioei*, the Greenheart of British Guiana. The pores are large and distributed with remarkable regularity, and there is no indication of the boundaries of the rings. In the solid wood the yellow parenchyma is quite visible to the naked eye. × 3, from the solid. Pith-side to the right. Photo by E. A. K.

FIG. 4. *Gnetum sp.*, one of the Gymnosperms which have vessels. Each segment of the ring remains unconnected with those produced during the following year. The rays are not continuous, being mere plates of parenchyma separating the segments. The pores are *smaller* on the inner side of the ring, the contrary of nearly all the woods of the broad-leaved trees. Natural size, from the solid. Photo by M. F.

FIG. 5. *Paradaniella Olivierii*, a tree of Nigeria, tangential section, × 3. Photo from the solid wood by E. A. K. The vertical lines on the figure are the ends of the rays arranged in parallel rows. This produces the effect of stippling. The stronger horizontal lines are vessels.

PLATE XXVIII.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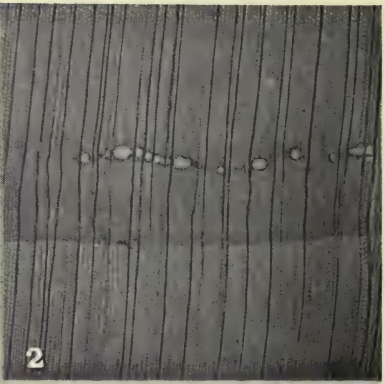
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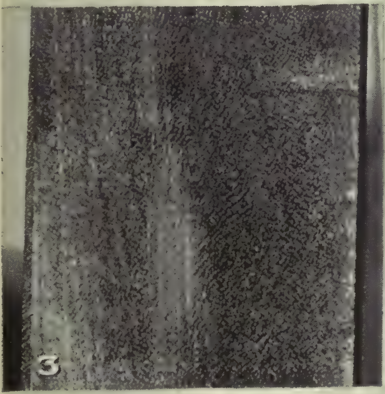
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PLATE XXIX. CROSS-SECTIONS, × 3, FROM THIN TRANSPARENT SECTIONS. PHOTO BY A. D.

FIG. 1. *Quercus pedunculata*, English Oak. A young stem of ten years' growth. The pith is five-lobed, and for a few years the rings maintain the same contour. Note the radial streams of Summer pores in the denser wood and the general increase in their size from within outwards (cf. Fig. 2, Plate XX., of the Oak at a later stage). The rays are few and seem to arise from the hollows in the contour of the pith. The segment between two of them (leading obliquely downwards) seems to be let in the wood, as it were; being cut off from the surrounding wood from the beginning, by the rays, it has not "kept step." The concentric parenchyma is seen in the dense wood of some of the rings; that sheathing the pores does not come out well.

FIG. 2. *Drymis chilensis*, a tree of the Magnolia family which has many characters of the Conifers. The wood contains no vessels, and is composed of tracheids and rays only. The latter are swelled at the point where they cross the boundaries of the rings, which are hardly traceable.

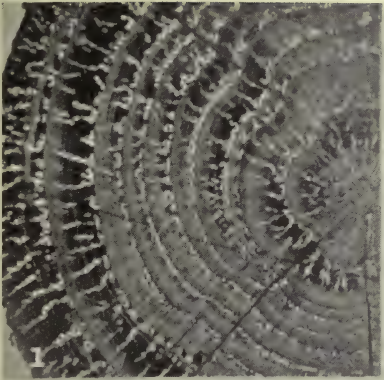
FIG. 3. *Glycine chinensis*, the Wistaria, a climber.

FIG. 4. *Cadaba glandulosa*, a climber showing long, radial files of pores, but no traceable ring-boundaries.

FIG. 5. *Cadaba farinosa*, another climber, related to the foregoing, but of abnormal structure. The rings are not only all to one side of the pith, but they are frequently incomplete, i.e. cut off in segments. This is probably due to the pressure of the stem upon which the plant clings.

FIG. 6. *Acacia juniperina*, an aberrant Leguminous wood of the Mimosa tribe. Apart from the genus *Drymis*, this Acacia has fewer pores than any known wood.

PLATE XXIX.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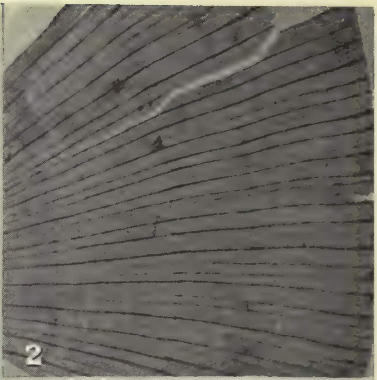
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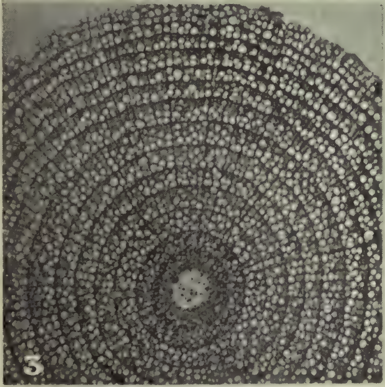
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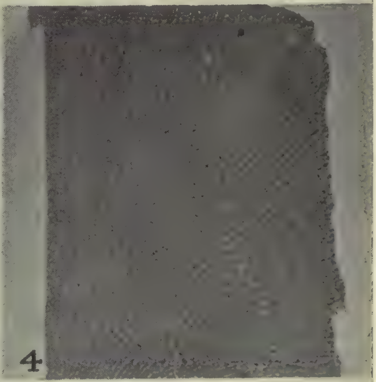
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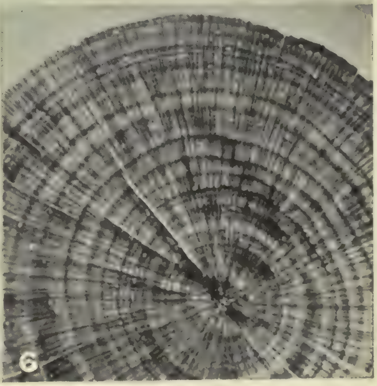
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PLATE XXX. Radial Sections, × 50, taken from Transparent Sections.
Photo by E. A. K.

Fig. 1. *Robinia Pseud-Acacia,* the False Acacia. The larger white spaces indicate pores or vessels filled with angular tyloses. The horizontal cells are the parenchyma-cells of the rays. Some pointed, vertical parenchyma in parallel rows, sheathing the vessels, is seen. The mass of the tissue is of long, tapering wood-fibres.

Fig. 2. *Juglans regia,* the European Walnut. Details as above, but the vertical (concentric) parenchyma is seen in files of square-ended cells, at intervals. These latter are really chambers in long, tapering thin-walled cells.

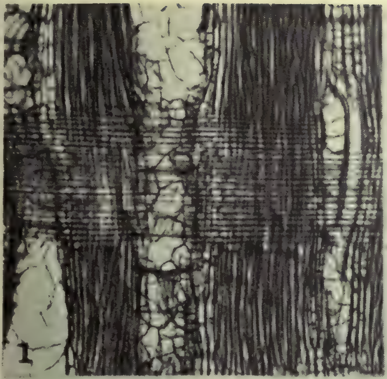
Fig. 3. *Carpinus Betulus.* The Hornbeam, details as for preceding figure. The concentric parenchyma is invisible in the solid wood, but appears in a thin section.

Fig. 4. *Castanea sativa,* the Sweet Chestnut. Details as for Fig. 1, but the wood-fibres are twisted and in parallel groups, recalling the disposition of the parenchyma in Fig. 1; the latter tissue in this case is in file, as in Fig. 2.

Fig. 5. *Quercus pedunculata,* the English Oak. The grain is strongly twisted in this specimen, but is not usually so. Note the abundant tyloses in the vessel and the vertical (concentric) wood-parenchyma in files at regular intervals, as in Figs. 2 and 3.

Fig. 6. *Liriodendron tulipifera,* the Canary Whitewood or Tulip-tree. The little grid faintly seen in the second vessel from right, is the remains of the septum or partition which originally divided the vessel into separate cells. A fragment of such a grid resembling a rake is seen in the adjacent vessel.

PLATE XXX.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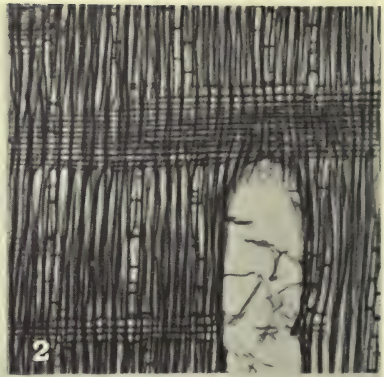
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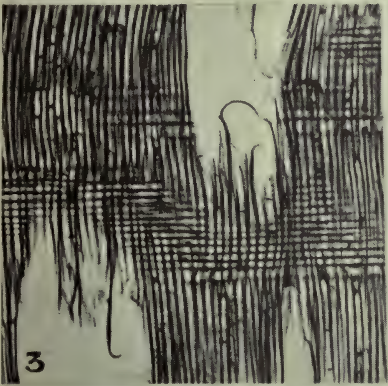
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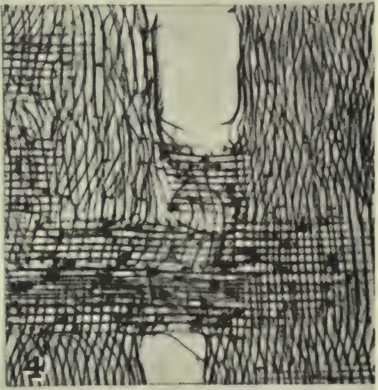
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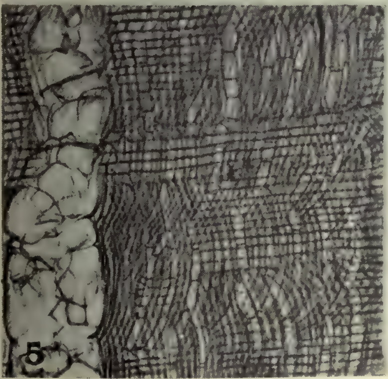
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PLATE XXXI. VERTICAL SECTIONS, × 50, FROM THIN, TRANSPARENT SECTIONS.

FIG. 1. *Æsculus Hippocastanum,* the Horse Chestnut. The white spaces are pores or vessels; the horizontal cells are the parenchyma of the rays. The simple or rounded perforations of the chambers of the vessels may be traced.

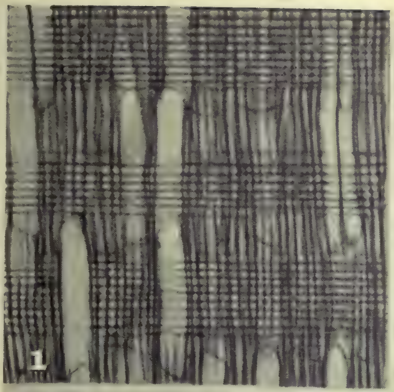
FIG. 2. *Betula alba,* the Birch, radial section. The figure shows a predominance of wood-fibres. Grids may be seen in the vessels.

FIG. 3. *Sequoia sempervirens,* the Giant Redwood, showing the limit of the season's growth (dense Summer wood to left, lax Spring wood to right). The mass of the tissue is of tapering tracheids, the ends of which interlock.

FIG. 4. *Pseudo-Tsuga Douglasii,* the Douglas or Oregon Pine. Details as in Fig. 3.

FIG. 5. *Fagus sylvatica,* tangential section, showing large and small rays.

FIG. 6. *Prunus Padus,* the Bird Cherry, tangential section.



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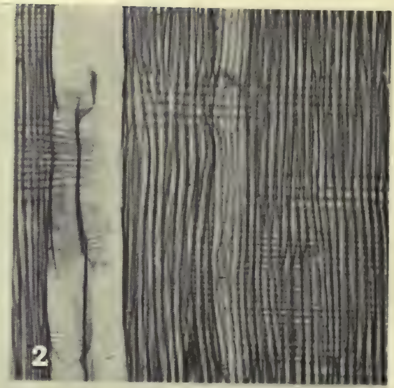

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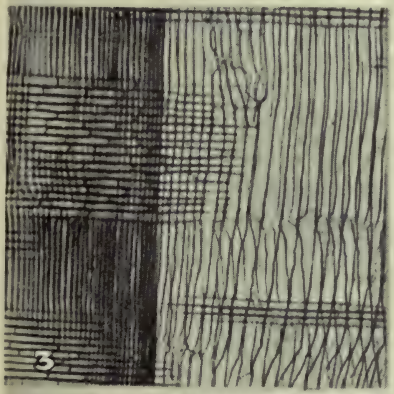

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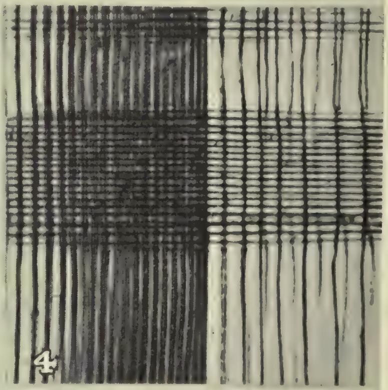

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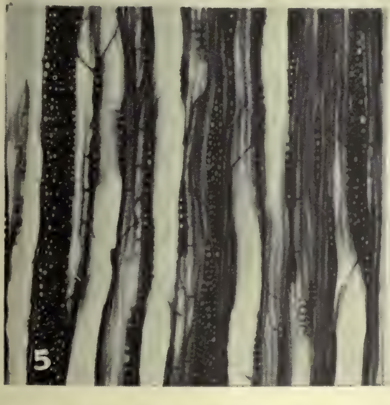

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PLATE XXXII. VERTICAL SECTIONS, × 50, FROM TRANSPARENT SECTIONS.

FIG. 1. *Sequoia sempervirens*, the Giant Redwood. The vertical files of round cells are the rays seen endwise. There is one string of wood-parenchyma (resin-cells) running the full height of the figure (about one-third of the width from the right); it may be recognized by its square-ended chambers. Tangential section.

FIG. 2. *Carpinus Betulus*, the Hornbeam. The aggregate rays are not shown. The horizontal lines indicate the smaller rays. Radial section.

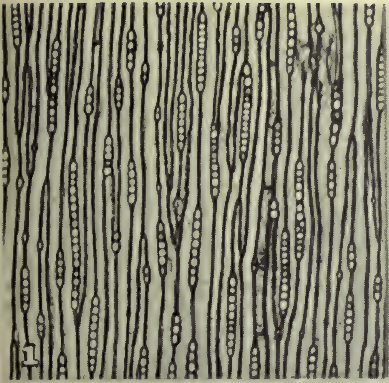
FIG. 3. *Ulmus montana*, the Wych Elm, showing slender compound rays, also a few very small rays of one or two rows of cells and a little parenchyma. Tangential section.

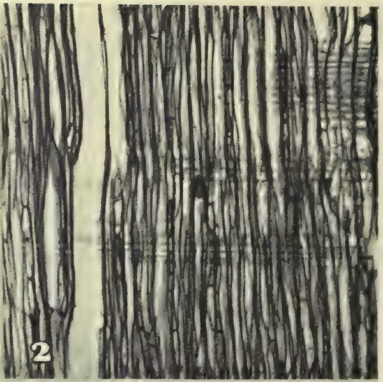
FIG. 4. *Larix europea*, the Common Larch. Details as in Fig. 1, but here in the centre is a large ray with a horizontal resin-canal within it. Tangential section.

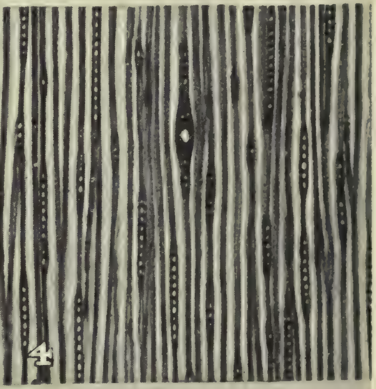
FIG. 5. *Betula alba*, the Common Birch. Note the (fragmentary) grids or perforated septa in the vessels, as in *Liriodendron* (Plate XXX., Fig. 6). The rays are simple (uni-seriate or one-rowed) and compound. Tangential section.

FIG. 6. *Æsculus Hippocastanum*, the Horse Chestnut. The rays in this species are all one-rowed. Tangential section.

PLATE XXXII.







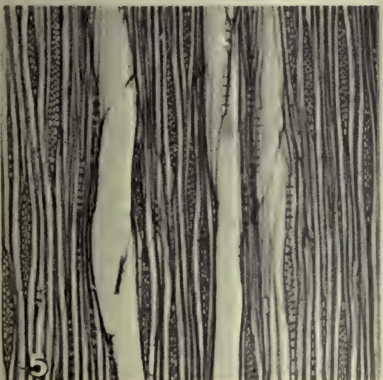


PLATE XXXIII. VERTICAL SECTIONS, × 50, FROM TRANSPARENT SECTIONS.

FIG. 1. *Fagus sylvatica*, the Beech, showing both one-rowed and compound rays, the latter in various sizes. The ray in the centre is splitting up (see Plate XXXV., Fig. 1); there are a few vertical parenchyma-cells adjacent to it.

FIG. 2. *Fraxinus excelsior*, the Ash, showing both one-rowed and compound rays and much short- and wide-celled parenchyma.

FIG. 3. *Laburnum vulgare*, the Common Laburnum, showing large compound rays and one or two small rays. There is much pointed wood-parenchyma arranged in parallel rows, a feature of many Leguminous woods.

FIG. 4. *Castanea sativa*, the Sweet Chestnut, showing a large short-chambered vessel and rays of one or two rows of cells, and mostly of irregular form. Some twisted wood-parenchyma masks a portion of the smaller vessel (to left).

FIG. 5. *Liriodendron tulipifera*, the Canary Whitewood or Tulip-tree, showing 2–3-rowed compound rays (one-rowed rays occur, but are rare). Note the rake-like fragments of the grids or septa of the vessels.

FIG. 6. *Quercus pedunculata*, the Common Oak, showing a portion of one large compound ray and many one-rowed simple rays. There is a little wood-parenchyma with square-ended chambers to be seen. The thin-walled tyloses in the vessel in centre scarcely appear.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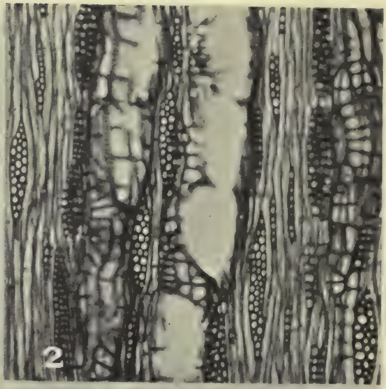
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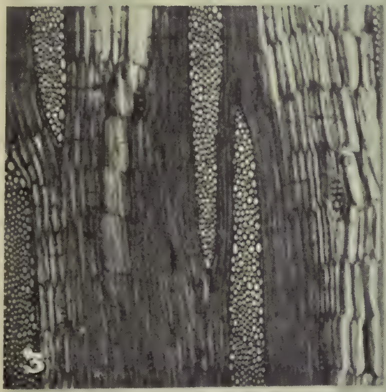
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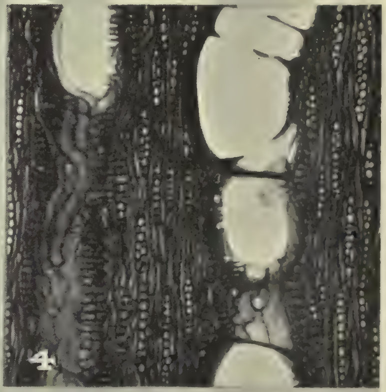
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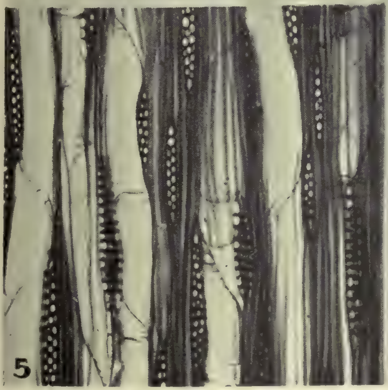
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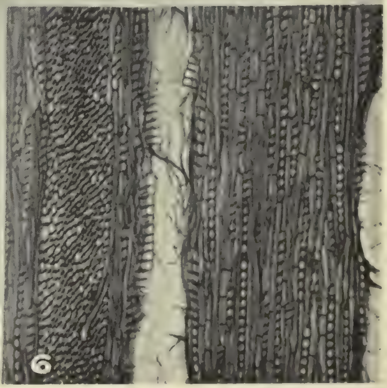
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PLATE XXXIV. Photo by E. A. K.

Tangential section, natural size, of the wood of a species of Live Oak (probably *Quercus virens*), showing prodigious rays (the darker areas). Note their fantastic shapes and the manner in which they are subdivided by strands of fibres formed across them.

PLATE XXXV. Photo by M. F.

Fig. 1. Beech, natural size, turned to show how the rays become broken up and dispersed. Trace the prominent rays on the rounded top, over the edge and down the front of figure. One or two, though split up, maintain their identity. They may be traced sometimes for a height of 6–7 inches, otherwise for a distance much greater than that corresponding to the length of an internode of the original twig from which they run.

Fig. 2. Beech, natural size, turned above and left square below to show the effect of the cut on the silver-grain. The rays on the lower part appear as parallel flakes and as loops on the cylindrical portion. The "loop-effect" is an illusion, as the curve is made up of portions of more than one.


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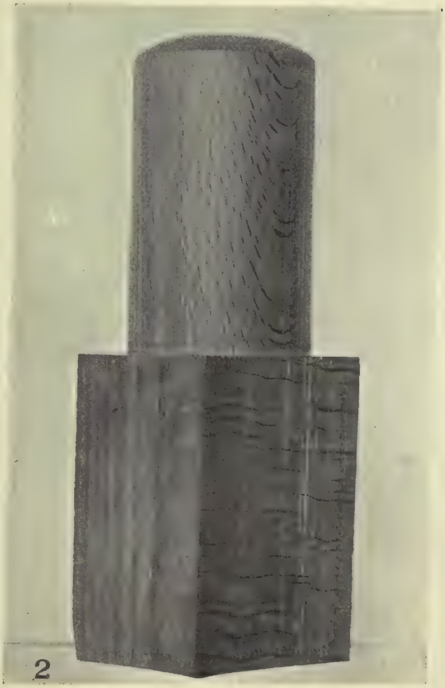
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PLATE XXXVI. Photo by E. A. K.

Fig. 1 (*a* to *f*). Sections of wooden bars, showing the disposition of the annual rings, according to cut and position.

(*g*) Suggested form of toggle for testing resistance to crushing. As the wood yields, the upper part of the block is more severely pinched than the lower, thus reproducing the action which takes place in a loaded beam.

(*h*) Diagram illustrating the spindle-shaped form of both fibres and rays.

(*i*) Crushed block with central rays running at right angles to the front surface.

(*j*) The same, but with the central rays running from corner to corner.

(*k*) Diagram of Duhamel's "barreau armé."

Fig. 2. Charcoal of Evergreen Oak. The rays-spaces have gaped with the heat, and show the strands of fibres that subdivided the ray. Natural size.

Fig. 3. *Larix europea*, radial section, × 700, showing the cross-fields at the points where the ray-cells (horizontal) cross the tracheids (vertical). Note the small eye-shaped pits in the cross-fields (there are as many as seven in one of the fields near the top of figure). The rows of serrations on the oblique septa of the ray-cells are "pits" in section. There is a "bordered pit" in the third tracheid from the left in the uppermost cross-field.

Fig. 4. *Casuarina torulosa*, one of the Australian She-Oaks, tangential section, natural size, showing the manner in which the rays are split up. The spaces are filled up by subsequent growth, hence the portion of the ray occupying the slit is not contemporaneous in its origin with the wood surrounding it.

PLATE XXXVI.

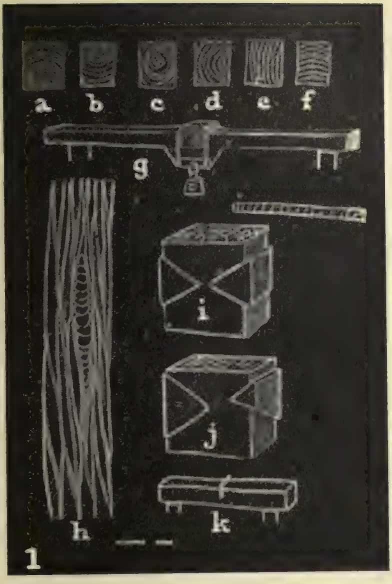

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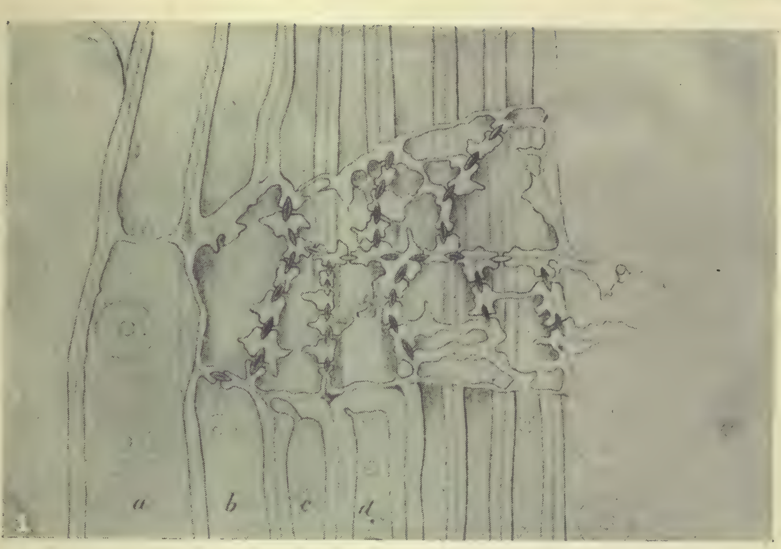
PLATE XXXVII. Reproductions from Other Authors.

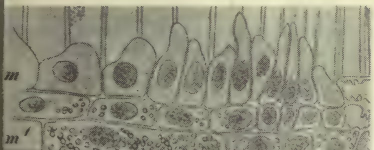
Fig. 1. After Erich Schmidt. Proximal end or the beginning of a ray, showing the irregular shape of the ray-cells before they have attained their usual prismatic shape. Note that the tracheids (the vertical cells) at the commencement are also distorted. All this indicates that the ray-space is a fissure, and the ray-cells stop-gap tissue.

Fig. 2. After Strasburger. Radial section of the bast of *Pinus sylvestris*. Note that here, also, the edge-cells are irregular and distorted, as they would be if filling a fissure. This occurs along the whole length of rays having edge-cells (otherwise vertical ray-cells or "palissaden"), but to a less extent in the wood-rays.

Fig 3. *Carpinus Betulus*, showing a "fleck" in transverse section, × 50. Note how the tissue of the fleck, which is of the same kind as wood and ray-parenchyma, becomes "combed out" into rays on the distal side of the fleck (to right).

PLATE XXXVII.





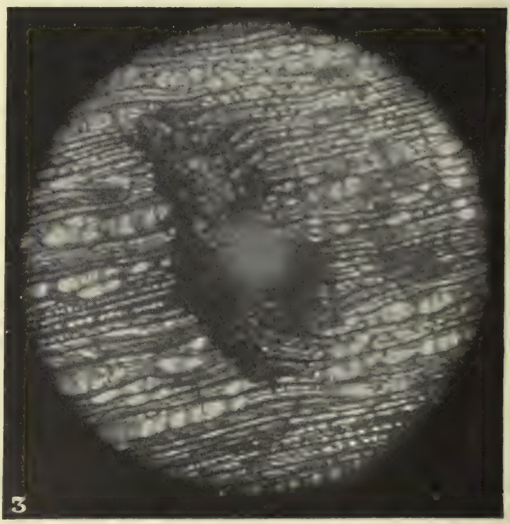


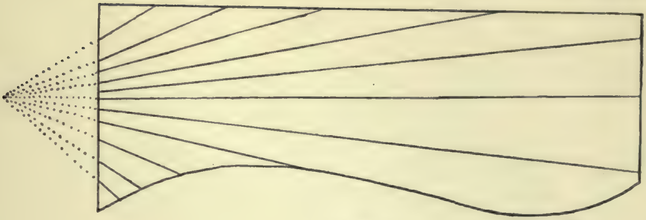
PLATE XXXVIII. Diagrams from Drawings by N. M. S.

Figs. 1–3. Ideal sections of ogee moulding, showing the relations of the curved surfaces to the rays. The pith is supposed to be placed at different points which are quite arbitrary, but practically cover any alternative. Fig. 2 will afford no figure ; Fig. 1 will show some on the top of the salient curved surface, while Fig. 3, taken from the outside edge of a large, quartered tree, will be figured on both hollow and crest.

Fig. 4. Quartered log, showing the course of the rays and their relation to planks cut from the quartered face.

Fig. 5. A plank from the foregoing, showing the angle at which the rays will emerge on the upper face. The thinner the board the more parallel to the surface will be the rays. The face of the succeeding plank will be well figured also, and will match the reverse side of the first board. Pieces from the outside of wide boards taken from large trees will be better figured than those from small logs, for the same reason It is, of course, understood that at the same distance from the pith the effect must be the same in both.

Fig. 6. Diagram showing that the radial and tangential sections may be found in a board by bevelling two opposite corners.



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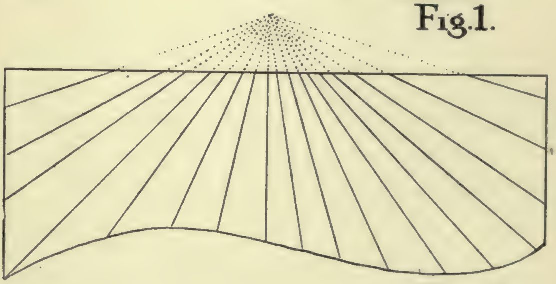


Fig. 2.

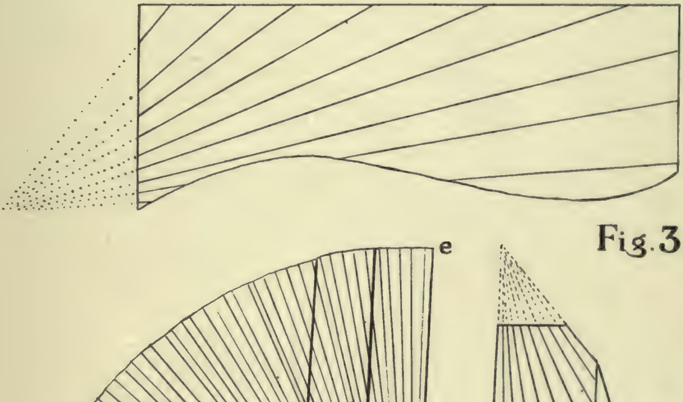
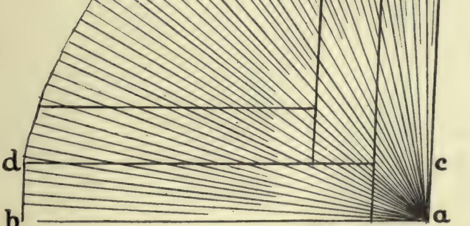


Fig.3.



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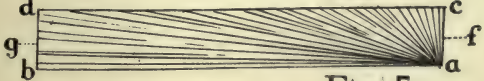

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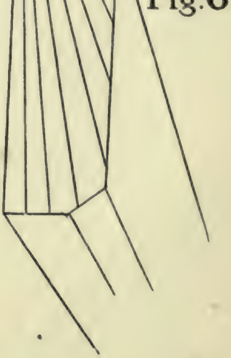


Fig.6.

PLATE XXXIX. Diagrams.

Fig. 1. Imaginary case of the development of the lines of pores on a transverse section when they are produced by the cambium at regular intervals. From "a" to "e" the pores are in a straight line; this gradually becomes more oblique. Supposing that there are two points of generation, *a–e*, *b–e*, working towards each other. As they meet in the middle they form angles, and finally flatten out near the outer boundary of the ring. This arrangement of the pores is very common in woods. From a drawing by N. M. S.

Fig. 2. Diagram showing how the increase in the diameter of the trunk on the one hand and of the branches and roots on the other tend to fill the angles twice over. The crowding of the fibres is compensated in two ways. In the acute angles sharp buckling occurs and then the wood commences to be piled up in the fork (cf. Fig. 2, Pl. XV.). In the obtuse angles the buckling is less severe but is perpetuated indefinitely, producing "rams-horn" or "ripple" (cf. Fig. 1, Pl. XV.).

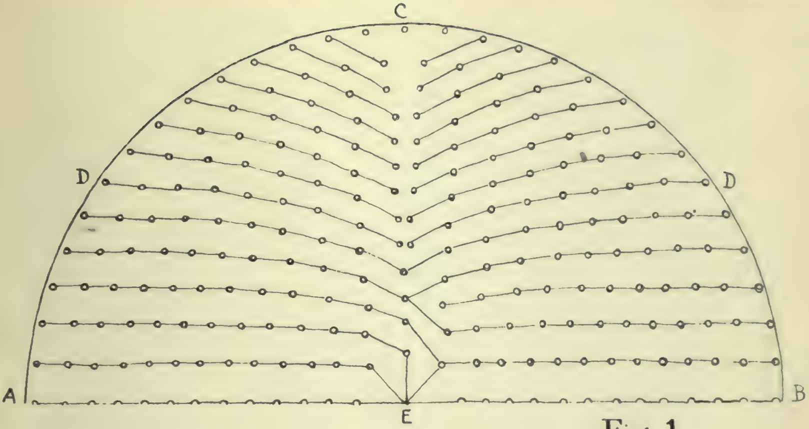


Fig. 1

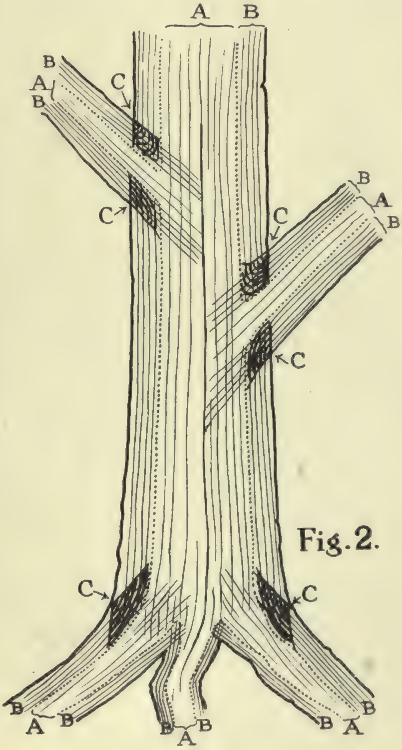


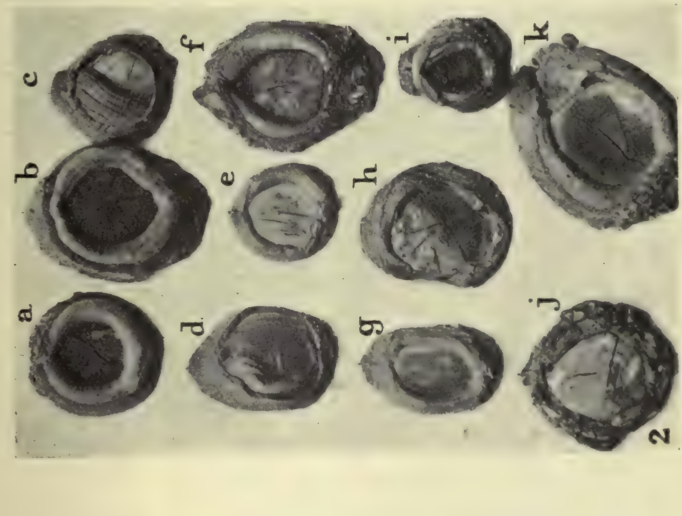
Fig. 2.

PLATE XL.

Fig. 1. A tree (*Ailanthus glandulosa*, the "Tree of Heaven") growing against a wall upon which it has formed a mass of callus which has even commenced to descend the face of the wall. Photo by H. A. C.

Fig. 2. Specimens showing the effect of various ways of pruning. "a" and "b" are examples of good pruning, the callus-cushions (of three years' growth) are smooth and regular. In "c" the callus has grown very well on the left side, but, as on the right, the bark was loosened from the stump, there is no sign of callus on that side. In "d" a good covering has been made, but as the bark was left projecting on the left, the callus has made only a third of the progress as that of the opposite cushion. In "e" the rough edges of the wound have caused the growth of the callus to be irregular, and in "f" the callus has "sulked" because the bark was loosened. Specimens "g" to "k" are examples of bad chipping or of the loosening of the bark.

1



2

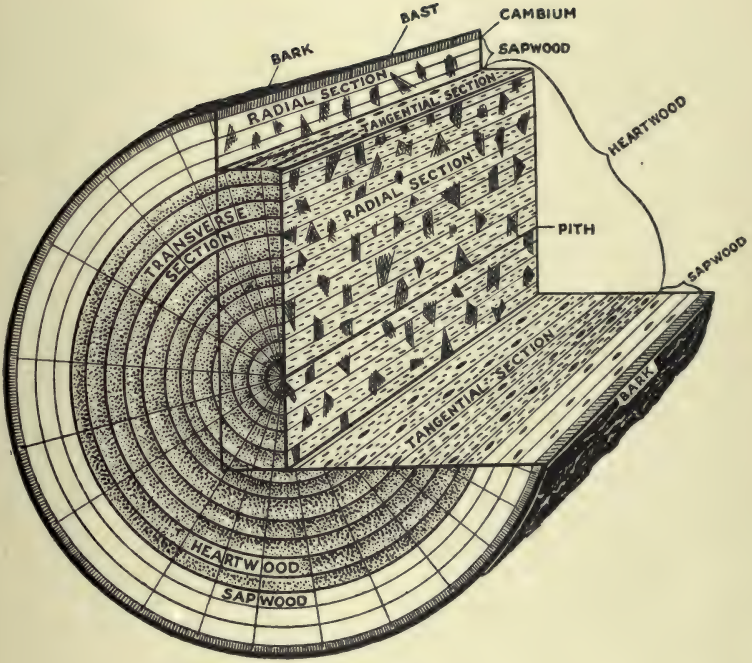
PLATE XLI. Diagram of a Log in Section from a Drawing by A. D.

The rectangular area represents a plank cut from the log in a radial direction as regards its right-hand side, and in a tangential direction as regards its left side. The former, as its name implies, is in the plane of the rays and hence shows fragments or flakes of them on its surface. The rings which represent the annual growth of the tree become converted into nearly parallel lines on the face of this section. This section is called the "quarter" cut or "rift-sawn."

The left-hand side of the plank (not visible) has its counterpart in the horizontal surface marked "tangential section," and also on the upper edge of the plank (similarly marked). A comparison of the relations between the rings on all these surfaces will show that they are the same. This section is called the slab- or slash-cut, and the method of cutting planks tangentially to the rings is termed "through-and-through" or "plankwise.".

Note that in all cases the boundaries of the rings may be traced from one surface over the edge into another, and that the difference in the appearance of the "cuts" is due entirely to the manner in which the sheaths of wood (represented by the rings) are opened to view. All the tissues that are present in one section must be present in every other, but the "cut" will produce great differences in appearance, which must be reconciled. A pore in cross-section (transverse) becomes a little groove or scratch on the radial and tangential sections, a circle becomes a pair of parallel lines which, in tangential section, will end in a loop (not shown in the figure); a ray becomes a flake in radial section, and a fine spindle-shaped line on the other. By the examination of one section it is possible to predict what the appearance of any other section will be.

PLATE XLI.


BAST
CAMBIUM
BARK
SAPWOOD
RADIAL SECTION
TANGENTIAL SECTION
HEARTWOOD
RADIAL SECTION
TRANSVERSE SECTION
PITH
SAPWOOD
TANGENTIAL SECTION
BARK
HEARTWOOD
SAPWOOD