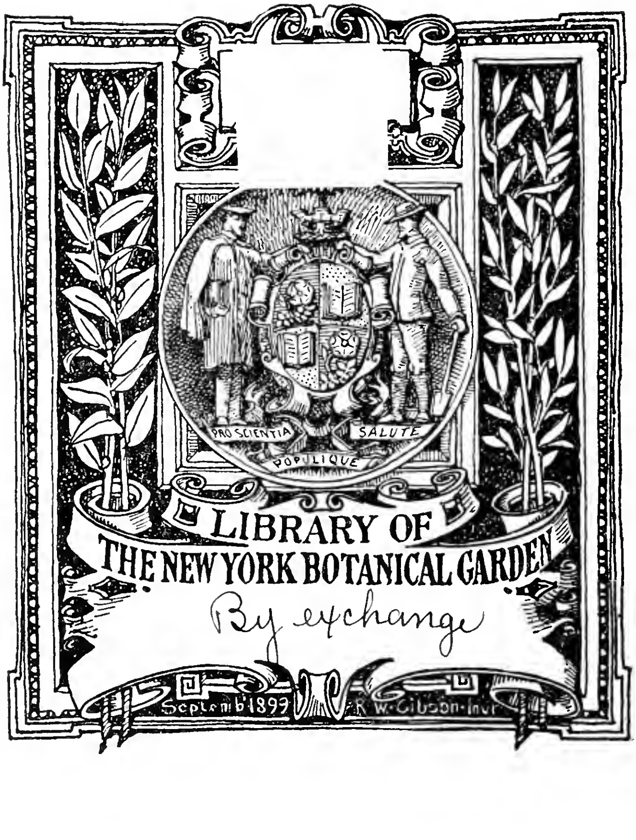

By exchange

BULLETIN No. 10.

U. S. DEPARTMENT OF AGRICULTURE.
DIVISION OF FORESTRY.

TIMBER:

AN ELEMENTARY DISCUSSION OF THE CHARACTERISTICS AND PROPERTIES OF WOOD.

BY

FILIBERT ROTH,
Special Agent in Charge of Timber Physics.

UNDER THE DIRECTION OF
B. E. FERNOW,
CHIEF OF THE DIVISION OF FORESTRY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Division of Forestry,
Washington, D. C., September 15, 1895.

Sir: I have the honor to transmit herewith for publication a brief but comprehensive discussion of the characteristics and properties of wood in general and of our American timbers in particular, which it is hoped may be useful to engineers, architects, carpenters, lumbermen, and all wood workers. The paper was prepared by Mr. Filibert Roth, in charge of the investigations in timber physics.

Although much of the information contained in this bulletin exists in the experience of practical woodworkers and in books in other languages, it has never before been published in English in systematic and accessible form and with special application to American timbers.

Such a publication can not, of course, exhaust any part of this great subject. It is desired that it may be followed by a more elaborate treatise when additional knowledge has been gained through the investigations now in progress. The information it contains is largely based on actual experiment and scientific observation, and will, it is hoped, not only explain the experiences of the practical worker with his material, but will remove erroneous notions, and thus aid in improving the practice and lead to a more rational use of our forest resources.

Respectfully,

B. E. Fernow,
Chief of Division of Forestry.

Hon. J. Sterling Morton,
Secretary.

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INTRODUCTION.

Wood is now, has ever been, and will continue to be, the most widely useful material of construction. It has been at the base of all material civilization. In spite of all the substitutes for it in the shape of metal, stone, and other materials, the consumption of wood in civilized countries has never decreased; nay, applications in new directions have increased its use beyond the saving effected by the substitutes. Thus, in England, the per capita consumption has increased in the last fifty years more than double, a fact which is especially notable, as the bulk of the timber used there must be imported, while iron and coal are plentiful in Great Britain.

In the United States we can only estimate from the partial data furnished by census returns. By these we find the per capita consumption to have increased for every decade since 1860 at the rate of from 20 to 25 per cent.

Although wood has been in use so long and so universally, there still exists a remarkable lack of knowledge regarding its nature in detail, not only among laymen, but among those who might be expected to know its properties. As a consequence, the practice is often faulty and wasteful in the manner of its use. Experience has been almost the only teacher, and notions—sometimes right, sometimes wrong—rather than well-substantiated facts lead the wood consumer. Iron, steel, and other metals are much better known in regard to their properties than wood. The reason for this imperfect knowledge lies in the fact that wood is not a homogeneous material, like the metals, but a complicated structure, and so variable that one stick will behave very differently from another stick, although cut from the same tree. Not only does the wood of one species differ from that of another, but the butt cut differs from the top log; the heartwood from the sapwood; the wood of the quickly grown sapling of the abandoned field from that of the slowly grown old monarch of the forest. Even the manner in which the tree was sawed and the condition in which the wood was cut and kept influence its behavior and quality. It is, therefore, extremely difficult to study the material for the purpose of establishing general laws, and it becomes necessary to make a specific inspection of the individual stick which is to be applied to a certain purpose. The selection, not only of the most suitable kinds, but of each stick, for the purpose for which it is fit will enter into that improved practice to which we may look both for greater economy and greater efficiency.

The object of this bulletin is to record more systematically than has been done hitherto the knowledge which exists and which will help the wood consumer in the choice of his material and in determining whether, and if so why, a given stick will answer his purpose. Such inspection requires, first, a knowledge of the gross structure and appearance, which give indications of quality and behavior, and then, for finer application, a knowledge of the minute anatomical or microscopic structure. The minute structure will often explain the difference in behavior of various kinds of wood, and a knowledge of it is almost indispensable in distinguishing the various kinds.

In the countries of Europe the kinds of wood used in construction and manufacture are so few that there is but little difficulty in distinguishing them. In our own country the great variety of woods, and of useful woods at that, often makes the mere distinction of the kind or species of tree most difficult. Thus there are at least eight pines (of the thirty-five native ones) in the market, some of which so closely resemble each other in their minute structure that they can hardly be told apart; and yet they differ in quality and should be used separately, although they are often mixed or confounded in the trade. Of the thirty-six oaks, of which probably not less than six or eight are marketed, we can readily recognize by means of their minute anatomy at least two tribes—the white and the black oaks. The distinction of the species is, however, as yet uncertain. The same is true as to the eight kinds of hickory, the six kinds of ash, etc. Before we shall be able to distinguish the wood of these species unfailingly, more study will be necessary. The key given in the present publication, therefore, is by necessity only provisional, requiring further elaboration. It unfortunately had to be based largely on external appearances, which are not always reliable. Sometimes, for general practical purposes, this mere appearance, with some minor attributes, such as color, taste, etc., are together sufficient, especially when the locality is known from which the species came, and in the log pile the determination may by these means be rendered possible when a single detached piece will leave us doubtful as to the species. In the market the distinctions are often most uncertain, and a promiscuous application of names adds to the confusion. To be sure, there is not much virtue in knowing the correct name, except that it assists us in describing the exact kind of material we desire to obtain. Nor is there always much gained in being able to identify the species of wood, but that it predicates certain qualities which are usually found in the species.

In selecting material, then, for special purposes we first determine what species to use as having either one quality which is foremost in our requirements, or several qualities in combination, as shown by actual experience or by experiment.

The uses of the various woods depend on a variety of conditions. The carpenter and builder, using large quantities of material and bestowing a minimum amount of labor on the greater part of the same, uses those kinds which are abundant, and hence cheap, to be had in large dimensions, light to ship, soft to work and to nail, and fairly stiff and insect proof—a combination represented in the conifers. They need not be handsome, hard, tough, or very strong, and may shrink even after they are in place. When it comes to finishing-woods, more stress is laid on color and grain and that the wood shall shrink as little as possible.

The furniture maker, who bestows a maximum amount of work on his material, needs a wood that combines strength, and sometimes toughness, with beauty and hardness, that takes a good polish, keeps joint, and does not easily indent. It must not warp or shrink when once in place, but it need not be light or soft or insect proof or abundant in any one kind, and in large dimensions, nor yet particularly cheap.

Toughness, strength, and hardness combined are sought by the wagon maker. The carriage builder, cooper, and shingle maker look for straight-grained, easy-splitting woods, and for a long fiber, the absence of disturbing resinous and coloring matter, knots, etc. Durability under exposure to the weather, resistance to indentation, and the holding of spikes are required for a good railroad tie; lasting qualities, elasticity, and proportionate dimensions of length and diameter, for telegraph poles.

Sometimes in practice it is immaterial whether the stick be of white oak or red oak, and many wood yards make no distinction, in fact do not know any, but the experienced cooper will quickly distinguish, not by name, perhaps, but by quality, the more porous red or black oak from the less porous white species. On the other hand, the very same white oak—*Quercus alba*, usually a superior article—may furnish so poor material for a handle or a plow beam that a stick of red oak would be preferable. The inspection, then, must be made not only for the species but for the quality, with reference to the purpose for which the stick is to be used.

That the inspection should have regard to defects [illegible] unhealthy condition (often indicated by color) goes without saying, and such inspection is usually practiced. That knots, even the smallest, are defects which for some uses condemn the material altogether needs hardly to be mentioned, but that season checks, even those that have closed by subsequent shrinkage, remain elements of weakness is not so readily appreciated. Yet there can not be any doubt of this, since the intimate connection of the wood fibers, once interrupted, is never reestablished. The careful wood user, therefore, is concerned as to the manner in which his material was treated after the felling, for according to the more or less careful seasoning of it the season checks, not altogether avoidable, are more or less abundant. This is practically recognized by splitting wagon and cooperage stock in the woods and seasoning it partly shaped, and also in making a distinction, often unnecessarily, between air-dried and kiln-dried material.

Where strength is required, the weight of the material will give good indications, for it is now pretty well established that weight and strength go more or less together. But since weight in the green wood is made up of at least three elements, namely, that of the wood fiber itself, that of the water in the cell spaces, and that of the water in the cell walls, the weight is deceptive unless we know also the moisture condition of the stick or else ascertain the specific weight of the dry wood. That the moisture contents influence considerably the strength of the material is now well proven, strength increasing with loss of moisture, and hence in practice allowance should be made according to whether the stick is to be used where it will be exposed to the weather or under cover and painted.

In some woods like the pines and the "ring porous" woods, such as oak, chestnut, and hickory, in which each annual layer or ring is made up of two distinct parts, the loose, porous spring wood and the dense and firm summer wood, the proportion of the latter per square inch of cross section—usually but not always depending on the width of the ring—furnishes a more direct criterion than the weight alone. The color effect of itself gives indications of the weight, since both weight and color effect depend on the same feature, namely, quantity of material; hence the larger quantity of dense summer wood on the cross section occasions darker color, which is usually indicative of strength. Color, too, must be consulted to detect incipient decay. Again, the difference in firmness and hardness of the summer wood itself, as tested by the knife or recognized in the difference of color effect by the practiced eye, furnishes another criterion in the selection of the stick.

Lastly, the manner in which the stick is sawed from the tree has a remarkable influence upon its qualities and behavior, and it should, therefore, either be specially sawed or selected with a view to its character and to the purpose for which it is to be used. This is a matter fully appreciated among only a few wood users, like the wheelwrights, piano makers, etc., but it needs to be observed much more than it is, even in building. Quarter or rift sawing, i. e., cutting sticks or boards out of the log in such a manner that the annual rings are cut through as nearly as possible radially, has lately been practiced largely for the sake of the beauty of the even grain thus obtained, and also for flooring on account of the better wear which the even exposure of the grain (hard bands of summer wood on edge) secures; but it should be much more widely applied to secure greater strength and more uniform seasoning and thus to reduce to some extent the one drawback to wood as a material of construction, that is, its liabilility to "working" (shrinking and swelling). The reason for the superiority of quarter-sawed pieces, as well as the general fact that the manner of sawing out a stick affects the general character and behavior of the same, will appear from the following considerations:

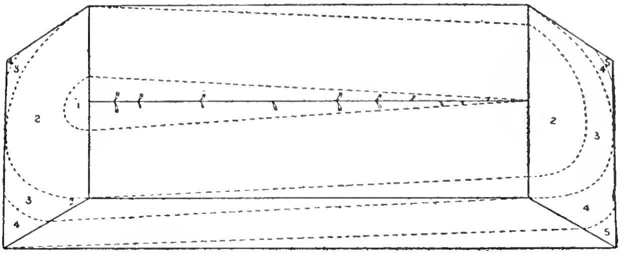

Fig. 1.—A piece of sawn timber cut through along the pith, illustrating its structural aggregates.

A square column or beam cut so as to contain the heart or pith of the tree in its center—which, by the way, is the weakest part on account of the many knots which it invariably and necessarily contains—consists in the main of five structural aggregates (see fig. 1), namely: (1) In the center a cone of wood fibers with the base in the butt end and the apex in the top end, the base representing the rings of as many years as it took the tree to attain the height of the column; none of the fibers belonging to these rings appear in the top section excepting those of the last ring which forms the apex of the cone; (2) a hollow cylinder of material surrounding the cone, all fibers of which are found in both sections and continuously through the whole length of the column; all the entire rings at the bottom belong in this cylinder, and undoubtedly form the strongest part of the column; (3) surrounding this cylinder a partial cylindrical envelope of wood fibers, all of which are represented in the top section, but only a part appear at the corners of the bottom; most of them, therefore, do not run through the whole length, but are cut through at varying lengths, thereby presenting the "bastard faces" on the sides of the column; (4) a partial envelope whose radial extent is limited by the corners of the basal section, imperfect at both ends; (5) the corners at the top, three-sided pyramids with the base in the top section, the fibers running out at varying lengths.

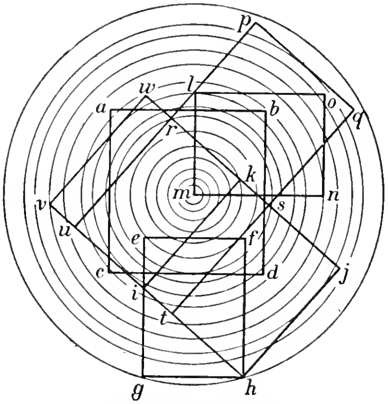

Fig. 2.—Possibilities of cutting timber from a log with reference to position of grain.

Now, it will be readily admitted that each of these "structural aggregates" has a different value in the combined strength of the whole. If the stick be cut with the center or pith in one side (see fig. 2) all these aggregates will be halved; if the stick be cut out differently, for instance, with the heart entirely out or if it be made longer or shorter, or rectangular instead of square, in each case the proportion of each of the aggregates changes, and hence it stands to reason that the strength of the column, or beam, or stick, changes according to the manner in which it is cut from the tree. This most evident and important fact has, it seems, escaped our best engineers and experimenters, who have tested beams without taking account of this disturbing element, and it is certainly overlooked most generally by builders and carpenters in their selection of material.

While it may perhaps not be expected that the sawing at the mill will be done with more care so as to secure the best results in application, or that the special advantage of quarter sawing will soon be sufficiently appreciated so as to extend its use in such a manner that the greater efficiency of the quarter-sawed material will compensate for the greater expense of the operation, wood users may at least be expected to make their selections from the sawed material in the yard, and shape it for their particular use with greater care.

There is no country in which wood is more lavishly used than in the United States, and none in which nature has more bountifully provided for all reasonable requirements. In the absence of proper efforts to secure reproduction, the most valuable kinds are rapidly being decimated, and the necessity of a more rational and careful use of what remains is clearly apparent. By greater care in selection, however, not only can the duration of the supply be extended, but more satisfactory results will accrue from its use.

B. E. FERNOW.

WASHINGTON, D. C., *September 15, 1895.*

TIMBER.

CHARACTERISTICS AND PROPERTIES OF WOOD.

I.—STRUCTURE AND APPEARANCE.

The structure of wood affords the only reliable means of distinguishing the different kinds. Color, weight, smell, and other appearances, which are often direct or indirect results of structure, may be helpful in this distinction but can not be relied upon entirely. In addition, structure underlies nearly all the technical properties of this important product and furnishes an explanation why one piece differs as to these properties from another.

Structure explains why oak is heavier, stronger, and tougher than pine; why it is harder to saw and plane, and why it is so much more difficult to season without injury. From its less porous structure alone, it is evident that a piece of a young and thrifty oak is stronger than the porous wood of an old or stunted tree; or that Georgia or longleaf pine excels white pine in weight and strength. Keeping especially in mind the arrangement and direction of the fibers of wood, it is clear at once why knots and "crossgrains" interfere with the strength of timber.

It is due to structural peculiarities that "honeycombing" occurs in rapid seasoning, that "checks" or cracks extend radially and follow pith rays, that tangent or "bastard" boards shrink and warp more than quartered lumber. These same peculiarities enable cherry and oak to take a better finish than basswood or coarse grained pine.

Moreover, structure, aided by color, determines the beauty of wood. All the pleasing figures, whether in a hard-pine ceiling, a desk of quartered oak, or in the beautiful panels of "curly" or "bird's-eye" maple decorating the saloon of a ship or a palace car, are due to differences in the structure of the wood. Knowing this, the appearance of any particular section can be foretold, and almost unlimited choice and combination are thereby suggested.

Thus a knowledge of structure not only enables us to distinguish the different woods, judge as to their qualities, and explain the causes of their beauty, but it also becomes an invaluable aid to the thoughtful worker, guiding him to a more careful selection and a more perfect use of his material.

CLASSES OF TREES.

The timber of the United States is furnished by three well-defined classes of trees: the needle-leaved, naked-seeded conifers (pine, cedar, etc.), the dicotyledonous (with two seed leaves), broad-leaved trees (oak, poplar, etc.), and to an inferior extent by the monocotyledonous (with one seed leaf), palms, yuccas, and their allies, which last are confined to the most southern parts of the country.

Broad-leaved trees are also known as deciduous trees, although especially in warm countries, many of them are evergreen,[1] while the conifers are commonly termed "evergreens," although the larch, bald cypress, and others shed their leaves every fall, and even the names "broad-leaved" and "coniferous," though perhaps the most satisfactory, are not at all exact, for the conifer ginkgo has broad leaves and bears no cones.

In the lumber trade, the woods of broad-leaved trees are known as "hardwoods," though poplar is as soft as pine, and the coniferous woods are "soft woods," notwithstanding that yew ranks high in hardness even when compared to "hardwoods."

Both in the number of different kinds of trees or species and still more in the importance of their product the conifers and broad-leaved trees far excel the palms and their relatives.

In the manner of growth both conifers and broad-leaved trees behave alike, adding each year a new layer of wood which covers the old wood in all parts of the stem and limbs. Thus the trunk continues to grow in thickness throughout the life of the tree by additions (annual rings) which in temperate climates are, barring accidents, accurate records of the tree. With the palms and their relatives the stem remains generally of the same diameter, the tree of a hundred years being as thick as it was at ten years, the growth of these being only at the top. Even where a peripheral increase takes place, as in the yuccas, the wood is not laid on in well-defined layers; the structure remains irregular throughout.

Though alike in their manner of growth, and therefore similar in their general make-up, conifers and broad-leaved trees differ markedly in the details of their structure and the character of their wood. The wood of all conifers is very simple in its structure, the fibers composing the main part of the wood being all alike and their arrangement regular. The wood of broad-leaved trees is complex in structure; it is made up of several different kinds of cells and fibers and lacks the regularity of arrangement so noticeable in the conifers. This difference is so great that in a study of wood structure it is best to consider the two kinds separately.

WOOD OF CONIFEROUS TREES.

Examining a smooth cross section or end face of a well-grown log of Georgia pine or Norway pine, we distinguish an envelope of reddish, scaly bark, a small whitish pith at the center, and between these the wood in a great number of concentric rings.

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[1] In Ceylon even the cultivated cherry has become an evergreen.

BARK AND PITH.

The bark of a pine stem is thickest and roughest near the base, decreases rapidly in thickness from 1½ inches at the stump to one-tenth inch near the top of the tree, and forms in general about 10 to 15 per cent of the entire trunk.

The pith is quite thick, usually one-eighth to one-fifth inch in Norway pine and in the southern species, though much less so in white pine, and is very thin, one-fifteenth to one twenty-fifth inch in cypress, cedar, and larch.

In woods with a thick pith, this latter is finest at the stump, grows rapidly thicker upward, and becomes thinner again in the crown and limbs, the first 1 to 5 rings adjoining it behaving similarly.

SAP AND HEART WOOD.

A zone of wood next to the bark, 1 to 3 or more inches wide, and containing 30 to 50 or more annual rings, is of lighter color; this is the sapwood, the inner, darker part of the log being the heartwood. In the former many cells are active and store up starch and otherwise assist in the life processes of the tree, although only the last or outer layer of cells the cambium, forms the growing part and the true life of the tree. In the heartwood all cells are lifeless cases, and serve only the mechanical function of keeping the tree from breaking under its own great weight, or from being laid low by the winds.

The darker color of the heartwood is due to infiltration of chemical substances into the cell walls, but the cavities of the cells in pine are not filled up, as is sometimes believed, nor do their walls grow thicker, nor is their wall any more lignified than in the sapwood. Sapwood varies in width and in the number of rings which it contains, even in different parts of the same tree; the same year's growth which is sapwood in one part of a disk may be heartwood in another. Sapwood is widest in the main part of the stem and varies often within considerable limits, and without apparent regularity. Generally it becomes narrower toward the top and in the limbs, its width varying with the diameter, and being least, in a given disk, on the side which has the shortest radius. Sapwood of old and stunted pines is composed of more rings than that of young and thrifty specimens. Thus in a pine 250 years old, a layer of wood or annual ring does not change from sapwood to heartwood until seventy or eighty years after it is formed, while in a tree 100 years old, or less, it remains sapwood only from thirty to sixty years. The width of the sapwood varies considerably for different kinds of pines; it is small for longleaf and white pine, and great for loblolly and Norway pines. Occupying the peripheral part of the trunk the proportion which it forms of the entire mass of the stem is always great. Thus even in old trees of longleaf pine the sapwood forms about 40 per cent of the merchantable log, while in the loblolly and in all young trees the bulk of the wood is sapwood.

THE ANNUAL OR YEARLY RING.

The concentric, annual, or yearly rings, which appear on the end face of a log are cross sections of so many thin layers of wood. Each such layer forms an envelope around its inner neighbor, and is in turn covered by the adjoining layer without, so that the whole stem is built up of a series of thin hollow cylinders, or rather cones. A new layer of wood is formed each season, covering the entire stem, as well as all the living branches. The thickness of this layer, or the width of the yearly ring, varies greatly in different trees and also in different parts of the same tree. In a normally grown, thrifty pine log the rings are widest near the pith, growing more and more narrow toward the bark. Thus the central 20 rings in a disk of an old longleaf pine may each be one-eighth to one-sixth inch (3 to 4 mm.) wide, while the 20 rings next to the bark may average only one-thirtieth inch (0.7 mm.). In our forest trees rings of one-half inch in width occur only near the center in disks of very thrifty trees of both conifers and hard woods; one-twelfth inch represents good thrifty growth, and the minimum width of about one two-hundredths inch (0.2 mm.) is often seen in stunted spruce and pine. The average width of rings in well-grown old white pine will vary from one-twelfth to one-eighteenth inch, while in the slower growing longleaf pine it may be one twenty-fifth to one-thirtieth of an inch. The same layer of wood is widest near the stump in very thrifty young trees, especially if grown in the open park, but in old forest trees the same year's growth is wider in the upper part of the tree, being narrowest near the stump and often also near the very tip of the stem. Generally the rings are widest near the center, growing narrower towards bark. In logs from stunted trees the order is often reversed, the interior rings being thin and the outer rings widest. Frequently, too, zones or bands of very narrow rings, representing unfavorable periods of growth, disturb the general regularity. Few trees, even among pines, furnish a log with truly circular cross section; usually it is an oval, and at the stump commonly quite an irregular figure. Moreover, even in very regular or circular disks the pith is rarely in the center, and frequently one radius is conspicuously longer than its opposite, the width of some of the rings, if not all, being greater on one side than on the other. This is nearly always so in the limbs, the lower radius exceeding the upper.

In extreme cases, especially in the limbs, a ring is frequently conspicuous on one side and almost or entirely lost to view on the other. Where the rings are extremely narrow, the dark portion of ring is often wanting, the color being quite uniform and light. The greater regularity or irregularity of the annual rings has much to do with the technical qualities of the timber.

SPRING AND SUMMER WOOD.

Examining the rings more closely, it is noticed that each ring is made up of an inner, softer, light-colored, and an outer, or peripheral, firmer and darker-colored portion. Being formed in the fore part of the season, the inner, light-colored part is termed spring wood, the outer, darker portion being the summer wood of the ring. Since the latter is very heavy and firm, it determines to a large extent the weight and strength of the wood, and as its darker color influences the shade of color of the entire piece of wood, this color effect becomes a valuable aid in distinguishing heavy and strong from light and soft pine wood. In most hard pines, like the longleaf, the dark summer wood appears as a distinct band, so that the yearly ring is composed of two sharply defined bands—an inner, the spring wood, and an outer, the summer wood. But in some cases, even in hard pines, and normally in the wood of white pines, the spring wood passes gradually into the darker summer wood, so that a sharply defined line occurs only where the spring wood of one ring abuts against the summer wood of its neighbor. It is this clearly defined line which enables the eye to distinguish even the very narrow rings in old pines and spruces. In some cases, especially in the trunks of Southern pines, and normally on the lower side of pine limbs, there occur dark bands of wood in the spring wood portion of the ring, giving rise to false rings which mislead in a superficial counting of rings. In the disks cut from limbs these dark bands often occupy the greater part of the ring and appear as "lunes" or sickle-shaped figures. The wood of these dark bands is similar to that of the true summer wood—the cells have thick walls, but usually lack the compressed or flattened form.

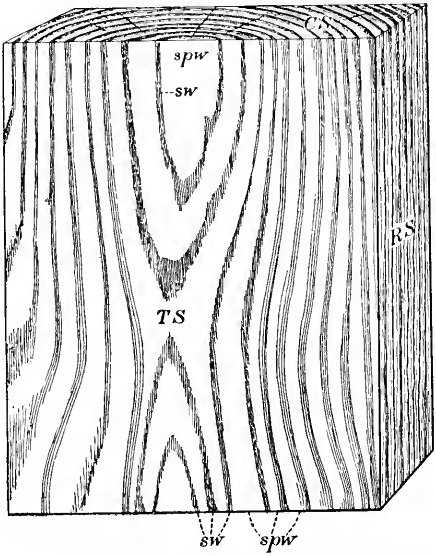

FIG. 3.—Board of pine. *CS*, cross section; *RS*, radial section; *TS*, tangential section; *sw*, summer wood; *spw*, spring wood.

Normally, the summer wood forms a greater proportion of the ring in the part of the tree formed during the period of thriftiest growth. In an old tree this proportion is very small in the first 2 to 5 rings about the pith, and also in the part next to the bark, the intermediate part showing a greater proportion of summer wood. It is also greatest in a disk taken from near the stump and decreases upward in the stem, thus fully accounting for the difference in weight and firmness of the wood of these different parts. In the longleaf pine the summer wood often forms scarcely 10 per cent of the wood in the central 5 rings; 40 to 50 per cent of the next 100 rings; about 30 per cent in the next 50, and only about 20 per cent in the 50 rings next to the bark. It averages 45 per cent of the wood of the stump and only 24 per cent of that of the top.

Sawing the log into boards, the yearly rings are represented on the board faces of the middle board (radial sections) by narrow, parallel stripes (see fig. 3), an inner, lighter stripe, and its outer, darker neighbor always corresponding to one annual ring.

On the faces of the boards nearest the slab (tangential or "bastard" boards) the several years' growth should also appear as parallel, but much broader stripes. This they do only if the log is short and very perfect. Usually a variety of pleasing patterns is displayed on the boards, depending on the position of the saw cut, and on the regularity of growth of the log. (See fig. 3.)

Where the cut passes through a prominence (bump or crook) of the log, irregular, concentric circlets and ovals are produced, and on almost all tangent boards, arrow, or V-shaped forms occur.

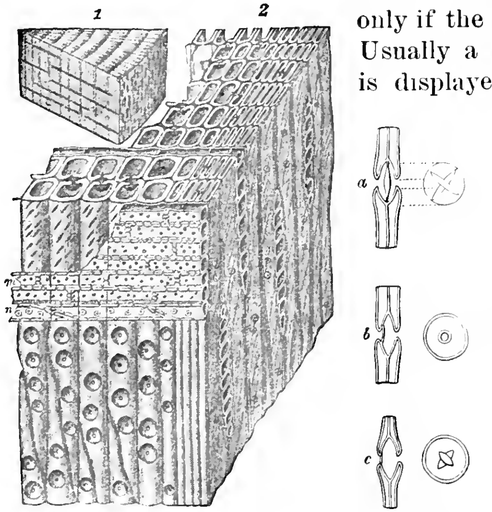

FIG. 4.—Wood of spruce. 1, natural size; 2, small part of one ring magnified 100 times. The vertical tubes are wood fibers, in this case all "tracheids." *m*, medullary or pith ray; *n*, transverse tracheids of pith ray; *a*, *b*, and *c*, bordered pits of the tracheids, more enlarged.

ANATOMICAL STRUCTURE.

Holding a well-smoothed disk, or cross section one-eighth inch thick toward the light, it is readily seen that pine wood is a very porous structure. If viewed with a strong magnifier, the little tubes, especially in the spring wood of the rings, are easily distinguished and their arrangement in regular straight radial rows is apparent. Scattered through the summer wood portion of the rings, numerous irregular grayish dots (the resin ducts) disturb the uniformity and regularity of the structure. Magnified 100 times, a piece of spruce, which is similar to pine, presents a picture like that shown in fig. 4. Only short pieces of the tubes or cells of which the wood is composed are represented in the picture.

The total length of these fibers is one-twentieth to one-fifth inch, being smallest near the pith, and is 50 to 100 times as great as their width (fig. 5). They are tapered and closed at their ends, polygonal, or rounded and thin walled, with large cavity, lumen or internal space in the spring wood, thick walled and flattened radially with the internal space or lumen much reduced in the summer wood. (See right-hand portion of fig. 4). This flattening, together with the thicker walls of the cells which reduces the lumen, causes the greater firmness and darker color of the summer wood—there is more material in the same volume. As shown in the figure, the tubes, cells, or "tracheids" are decorated on their walls by circlet-like structures, the "bordered pits," sections of which are seen more magnified at *a*, *b*, and *c*, fig. 4. These pits are in the nature of pores, covered by very thin membranes, and serve as waterways between the cells or tracheids.

The dark lines on the side of the smaller piece (1, fig. 4) appear when magnified (in 2, fig. 4) as tiers of 8 to 10 rows of cells, which run radially (parallel to the rows of tubes or tracheids) and are seen as bands on the radial face and as rows of pores on the tangential face. These bands or tiers of cell rows are the medullary rays or pith rays, and are common to all our lumber woods. In the pines and other conifers they are quite small, but they can readily be seen, even without a magnifier, if a radial surface of split wood (not smoothed) is examined. The entire radial face will be seen almost covered with these tiny structures, which appear as fine but conspicuous cross lines. As shown in fig. 4 the cells of the medullary or pith rays are smaller and very much shorter than the wood fibers or tracheids and their long axis is at right angles to that of the fibers. In pines and spruces the cells of the upper and lower rows of each tier or pith ray have "bordered" pits like those of the wood fibers or tracheids proper, but the cells of the intermediate rows, and of all rows in the rays of cedars, etc., have only "simple" pits, i. e., pits devoid of the saucer-like "border" or rim.

In pine, many of the pith rays are larger than the majority, each containing a whitish line, the horizontal resin duct, which, though much smaller, resembles the vertical ducts seen on the cross section. The larger vertical resin ducts are best observed on

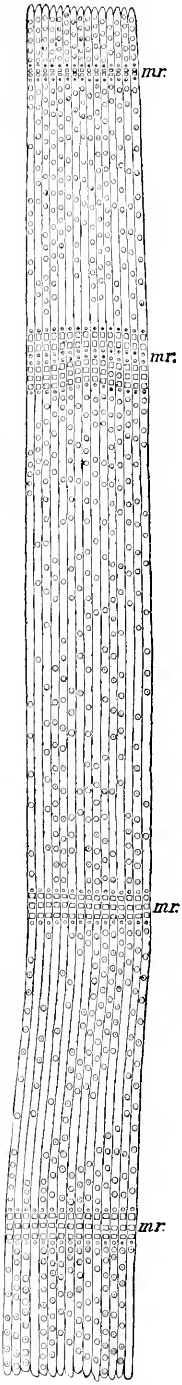

FIG. 5.—Group of fibers from pine wood. Partly schematic. The little circles are "border pits" (see fig. 4, *a–c*). The transverse rows of square pits indicate the places of contact of these fibers and the cells of the neighboring pith rays. Magnified about 50 times.

removal of the bark from a fresh piece of white pine, cut in winter, where they appear as conspicuous white lines, extending often for many inches up and down the stem.

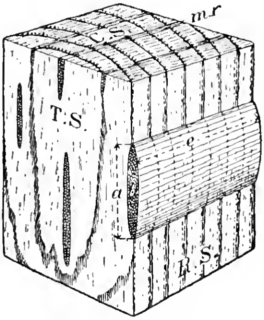

FIG. 6.—Block of oak. *C. S.*, cross section; *R. S.*, radial section; *T. S.*, tangential section; *m. r.*, medullary or pith ray; *a*, height, *b*, width, and *e*, length of a pith ray.

Neither the horizontal nor the vertical resin ducts are vessels or cells, but are openings between cells, i. e., intercellular spaces, in which the resin accumulates, freely oozing out when the ducts of a fresh piece of sapwood are cut. They are present only in our coniferous woods, and even here they are restricted to pine, spruce, and larch, and are normally absent in fir, cedar, cypress, and yew.

Altogether the structure of coniferous wood is very simple and regular, the bulk being made up of the small fibers called tracheids, the disturbing elements of pith rays and resin ducts being insignificant, and hence the great uniformity and great technical value of coniferous wood.

WOOD OF BROAD-LEAVED TREES.

On a cross section of oak, the same arrangement of pith and bark, of sapwood and heartwood, and the same disposition of the wood in well-defined concentric or annual rings occurs, but the rings are marked by lines, or rows, of conspicuous pores or openings which occupy the greater part of the spring wood of each ring (see fig. 6, also fig. 8) and are, in fact, the hollows of vessels through which the cut has been made. On the radial section, or quarter-sawed board, the several layers appear as so many parallel stripes (see fig. 7); on the tangential section or "bastard" face, patterns similar to those mentioned for pine wood are observed. But while the patterns in hard pine are marked by the darker summer wood and are composed of plain, alternating stripes of darker and lighter wood, the figures in oak (and other broad-leaved woods) are due chiefly to the vessels,

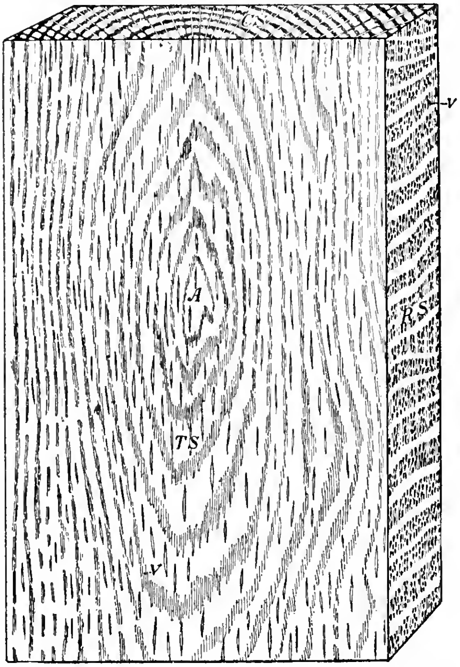

FIG. 7.—Board of oak. *CS*, cross section; *RS*, radial section; *TS*, tangential section; *v*, vessels or pores, cut through; *A*, slight curve in log which appears in section as an islet.

those of the spring wood in oak being the most conspicuous (see fig. 7); so that in an oak table the darker, shaded parts are the spring wood, the lighter, unicolored parts the summer wood.

On closer examination of the smoothed cross section of oak, the spring wood part of the ring is found to be formed, in great part, of pores: large, round, or oval openings made by the cut through long vessels. These are separated by a grayish and quite porous tissue (see fig. 8 A), which continues here and there in the form of radial, often branched, patches (not the pith rays) into and through the summer wood to the spring wood of the next ring. The large vessels of the spring wood, occupying 6 to 10 per cent of the volume of a log in very good oak, and 25 per cent or more in inferior and narrow-ringed lumber, are a very important feature, since it is evident that the greater their share in the volume, the lighter and weaker the wood. They are smallest near the pith, and grow wider outward; they are wider in the stem than limb and seem to be of indefinite length, forming open channels in some cases probably as long as the tree itself.

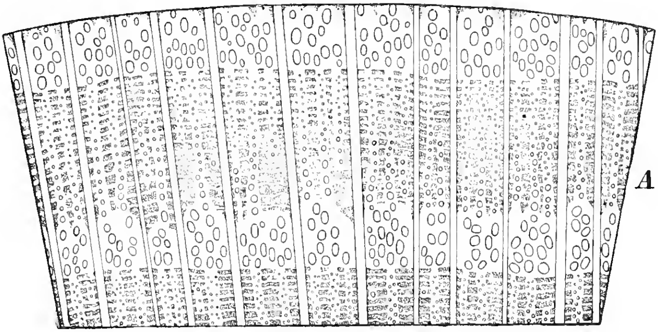

FIG. 8 A.—Cross section of oak magnified about 5 times.

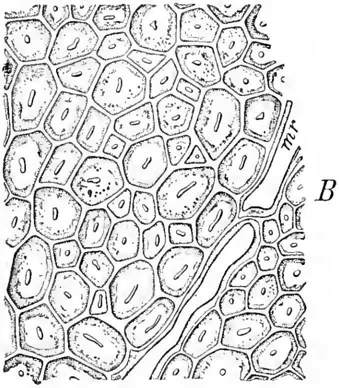

FIG. 8 B.—Portion of the firm bodies of fibers with two cells of a small pith ray *mr*. Highly magnified.

Scattered through the radiating gray patches of porous wood are vessels similar to those of the spring wood, but decidedly smaller. These vessels are usually fewer and larger near the spring wood, and smaller and more numerous in the outer portions of the ring. Their number and size can be utilized to distinguish the oaks classed as white oaks from those classed as black and red oaks; they are fewer and larger in red oaks, smaller but much more numerous in white oaks. The summer wood, except for these radial grayish patches, is dark colored and firm. This firm portion, divided into bodies or strands by these patches of porous wood and also by fine wavy concentric lines of short, thin-walled cells (see fig. 8 A), consists of thick-walled fibers (see fig. 8 B) and is the chief element of strength in oak wood. In good white oak it forms one-half and more of the wood; it cuts like horn, and the cut surface is shiny and of a deep chocolate-brown color. In very narrow-ringed wood and in inferior red oak it is usually much reduced in quantity as well as quality.

The pith rays of the oak, unlike those of coniferous woods, are at least in part very large and conspicuous (see fig. 6, their height indicated by the letter *a*, and their width by the letter *b*). The large medullary rays of oak are often twenty and more cells wide and several hundred cell rows in height, which amount commonly to one or more inches. These large rays are conspicuous on all sections. They appear as long, sharp, grayish lines on the cross section, as short, thick lines, tapering at each end, on the tangential or "bastard" face, and as broad, shiny bands, the "mirrors," on the radial section. In addition to these coarse rays, there is also a large number of small pith rays, which can be seen only when magnified. On the whole, the pith rays form a much larger part of the wood than might be supposed. In specimens of good white oak it has been found that they formed about 16 to 25 per cent of the wood.

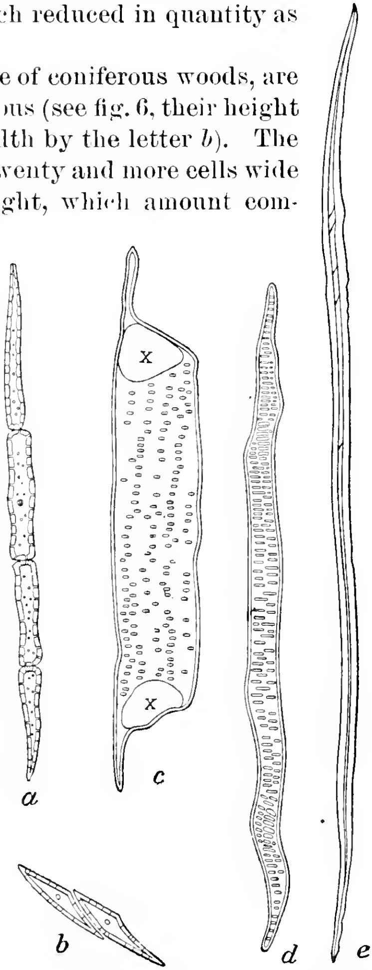

Fig. 9.—Isolated fibers and cells. *a*, four cells of wood parenchyma; *b*, two cells from a pith ray; *c*, a single joint or cell of a vessel, the openings *x* leading into its upper and lower neighbors; *d*, tracheid; *e*, wood fiber proper.

MINUTE STRUCTURE.

If a well-smoothed, thin disk, or cross section of oak (say one-sixteenth inch thick) is held up to the light, it looks very much like a sieve, the pores or vessels appearing as clean-cut holes; the spring wood and gray patches are seen to be quite porous, but the firm bodies of fibers between them are dense and opaque. Examined with the magnifier it will be noticed that there is no such regularity of arrangement in straight rows as is conspicuous in the pine; on the contrary, great irregularity prevails. At the same time, while the pores are as large as pin holes, the cells of the denser wood, unlike those of pine wood, are too small to be distinguished. Studied with the microscope, each vessel is found to be a vertical row of a great number of short, wide tubes, joined end to end (fig. 9, *c*). The porous spring wood and radial gray tracts are partly composed of smaller vessels, but chiefly of tracheids like those of pine, and of shorter cells, the "wood parenchyma," resembling the cells of the medullary rays. These latter, as well as the fine concentric lines mentioned as occurring in the summer wood, are composed entirely of short, tube-like parenchyma cells with square or oblique ends (fig. 9, *a* and *b*). The wood fibers proper, which form the dark, firm bodies referred to, are very fine, thread-like cells one twenty-fifth to one-tenth inch long, with a wall commonly so thick that scarcely any empty internal space or lumen remains (figs. 9, *e*, and 8, *B*).

If instead of oak a piece of poplar or basswood (fig. 10) had been used in this study, the structure would have been found to be quite different. The same kinds of cell-elements, vessels, etc., are, to be sure, present, but their combination and arrangement is different, and thus from the great variety of possible combinations results the great variety of structure and, in consequence, of the qualities which distinguish the wood of broad-leaved trees. The sharp distinction of sapwood and heartwood is wanting; the rings are not so clearly defined, the vessels of the wood are small, very numerous, and rather evenly scattered through the wood of the annual ring, so that the distinction of the ring almost vanishes and the medullary or pith rays, in poplar, can be seen, without being magnified, only on the radial section.

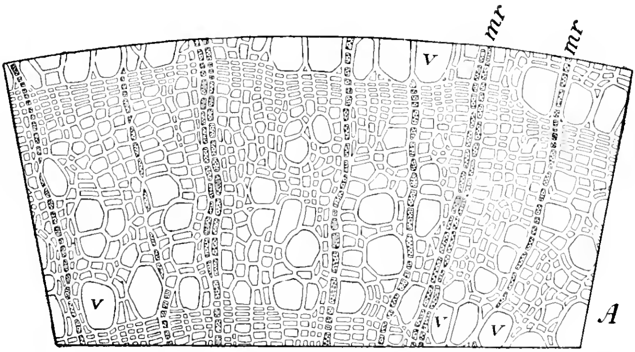

Fig. 10.—Cross section of basswood (magnified). *v*, vessels; *mr*, pith rays.

DIFFERENT GRAIN OF WOOD.

The terms "fine grained," "coarse grained," "straight grained" and "cross grained" are frequently applied in woodworking. In common usage, wood is "coarse grained" if its annual rings are wide, "fine grained" if they are narrow; in the finer wood industries a "fine-grained" wood is capable of high polish while a "coarse-grained" wood is not, so that in this latter case the distinction depends chiefly on hardness, and in the former on an accidental case of slow or rapid growth.

Generally the direction of the wood fibers is parallel to the axis of the stem or limb in which they occur, the wood is straight grained, but in many cases the course of the fibers is spiral or twisted around the tree as shown in fig. 11, and sometimes (commonly in butts of gum and cypress) the fibers of several layers are oblique in one direction, and those of the next series of layers are oblique in the opposite direction, as shown in fig. 12; the wood is cross or twisted grained. Wavy grain in a tangential plain as seen on the radial section is illustrated in fig. 13, which represents an extreme case observed in beech. This same form also occurs on the radial plain, causing the tangential section to appear wavy or in transverse folds. When wavy grain is fine, i. e., the folds or ridges small but numerous, it gives rise to the "curly" structure frequently seen in maple. Ordinarily, neither wavy, spiral, nor alternate grain is visible on the cross section; its existence often escapes the eye even on smooth, longitudinal faces in sawed material, so that the only safe guide to their discovery lies in splitting the wood in the two normal plains.

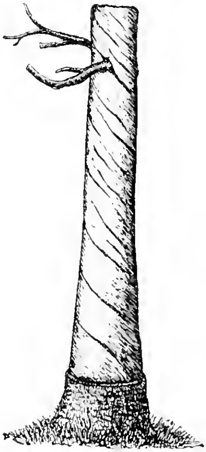

FIG. 11.—Spiral grain. Season checks, after removal of bark, indicate the direction of the fibers or grain.

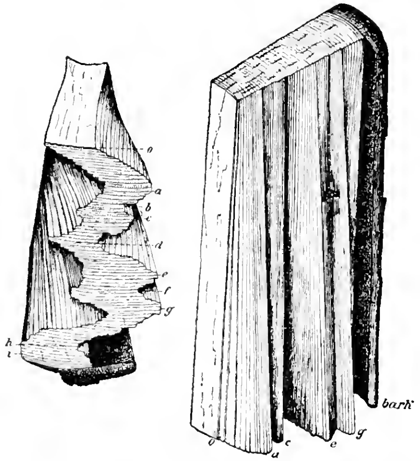

FIG. 12.—Alternating spiral grain in cypress. Side and end view of same piece. When the bark was at *o* the grain at this point was straight. From that time each year it grew more oblique in one direction, reaching a climax at *a*, and then turned back in the opposite direction. These alternations were repeated periodically, the bark sharing in these changes.

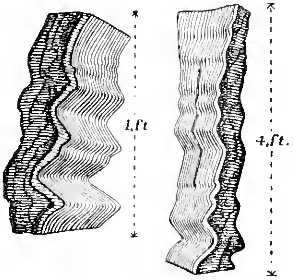

FIG. 13.—Wavy grain in beech; after Nördlinger.

Generally the surface of the wood under the bark, and therefore also that of any layer in the interior, is not uniform and smooth, but is channeled and pitted by numerous depressions which differ greatly in size and form. Usually, any one depression or elevation is restricted to one or few annual layers (i. e., seen only in one or few rings) and is then lost, being compensated (the surface at the particular spot evened up) by growth. In some woods, however, any depression or elevation once attained grows from year to year and reaches a maximum size which is maintained for many years, sometimes throughout life.

In maple, where this tendency to preserve any particular contour is very great, the depressions and elevations are usually small (commonly less than one-eighth inch), but very numerous. On tangent boards of such wood the sections of these pits and prominences appear as circlets and give rise to the beautiful "bird's-eye" or "landscape" structure. Similar structures in the burls of black ash, maple, etc., are frequently due to the presence of dormant buds, which cause the surface of all the layers through which they pass to be covered by small conical elevations, whose cross sections on the sawed board appear as irregular circlets or islets each with a dark speck, the section of the pith or "trace" of the dormant bud in the center.

In the wood of many broad-leaved trees the wood fibers are much longer when full grown than when they are first formed in the cambium or growing zone. This causes the tips of each fiber to crowd in between the fibers above and below, and leads to an irregular interlacement of these fibers, which adds to the toughness but reduces the cleavability of the wood.

At the junction of limb and stem the fibers on the upper and lower sides of the limb behave differently. On the lower side they run from the stem into the limb, forming an uninterrupted strand or tissue and a perfect union. On the upper side the fibers bend aside, are not continuous into the limb, and hence the connection is imperfect (fig. 14).

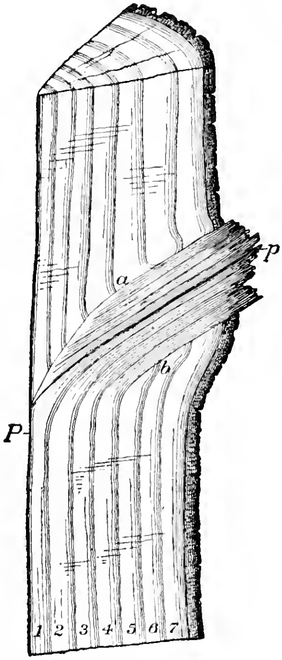

FIG. 14.—Section of wood showing position of the grain at base of a limb. *P*, pith of both stem and limb; 1-7, seven yearly layers of wood; *a*, *b*, knot or basal part of a limb which lived four years, then died and broke off near the stem, leaving the part to the left of *a*, *b*, a "sound" knot, the part to the right a "dead" knot, which would soon be entirely covered by the growing stem.

Owing to this arrangement of the fibers, the cleft made in splitting never runs into the knot, if started on the side above the limb, but is apt to enter the knot if started below, a fact well understood in wood craft. When limbs die, decay, and break off, the remaining stubs are surrounded and may finally be covered by the growth of the trunk, and thus give rise to the annoying "dead" or "loose" knots.

COLOR AND ODOR.

Color, like structure, lends beauty to the wood, aids in its identification, and is of great value in the determination of its quality. Considering only the heartwood, the black color of the persimmon, the dark brown of the walnut, the light brown of the white oaks, the reddish brown of the red oaks, the yellowish white of the tulip and poplar, the brownish red of the redwood and cedar, the yellow of the papaw and sumac, are all reliable marks of distinction; and color together with luster and weight are only too often the only features depended upon in practice. Newly formed wood, like that of the outer few rings, has but little color. The sapwood generally is light, and the wood of trees which form no heartwood changes but little, except when stained by forerunners of disease.

The different tints of colors, whether the brown of oak, the orange brown of pine, the blackish tint of walnut, or the reddish cast of cedar, are due to pigments, while the deeper shade of the summer-wood bands in pine and cedar, or in oak or walnut, is due to the fact that the wood being denser, more of the colored wood substance occurs on a given space, i. e., there is more colored matter per square inch.

Wood is translucent, a thin disk of pine permitting light to pass through quite freely. This translucency affects the luster and brightness of lumber. When wood is attacked by fungi it becomes more opaque, loses its brightness, and in practice is designated "dead" in distinction to "live" or bright timber. Exposure to air darkens all wood; direct sunlight and occasional moistening hasten this change and cause it to penetrate deeper. Prolonged immersion has the same effect, pine wood becoming a dark gray while oak changes to a blackish brown.

Odor, like color, depends on chemical compounds, forming no part of the wood substance itself. Exposure to weather reduces, and often changes the odor, but a piece of dry longleaf pine, cedar, or camphor wood exhales apparently as much odor as ever, when a new surface is exposed.

Heartwood is more odoriferous than sapwood. Many kinds of wood are distinguished by strong and peculiar odors. This is especially the case with camphor, cedar, pine, oak, and mahogany, and the list would comprise every kind of wood in use, were our sense of smell developed in keeping with its importance. Decomposition is usually accompanied by pronounced odors; decaying poplar emits a disagreeable odor, while red oak often becomes fragrant, its smell resembling that of heliotrope.

RESONANCE.

If a log or scantling is struck with the ax or hammer, a sound is emitted which varies in pitch and character with the shape and size of the stick, and also with the kind and condition of wood. Not only can sound be produced by a direct blow, but a thin board may be set vibrating and be made to give a tone by merely producing a suitable tone in its vicinity. The vibrations of the air, caused by the motion of the strings of the piano, communicate themselves to the board, which vibrates in the same intervals as the string and reenforces the note. The note which a given piece of wood may emit varies in pitch directly with the elasticity, and indirectly with the weight, of the wood. The ability of a properly shaped sounding board to respond freely to all the notes within the range of an instrument, as well as to reflect the character of the notes thus emitted (i. e., whether melodious or not), depends, first, on the structure of the wood and next on the uniformity of the same throughout the board. In the manufacture of musical instruments all wood containing defects, knots, cross grain, resinous tracts, alternations of wide and narrow rings, and all wood in which summer and spring wood are strongly contrasted in structure and variable in their proportions, is rejected, and only radial sections (quarter sawed, or split) of wood of uniform structure and growth are used.

The irregularity in structure, due to the presence of relatively large pores and pith rays, excludes almost all our broad-leaved woods from such use, while the number of eligible woods among conifers is limited by the necessity of combining sufficient strength with uniformity in structure, absence of too pronounced bands of summer wood, and relative freedom from resin.

Spruce is the favored resonance wood; it is used for sounding boards both in pianos and violins, while for the resistant back and sides of the latter, the highly elastic hard maple is used. Preferably resonance wood is not bent to assume the final form; the belly of the violin is shaped from a thicker piece, so that every fiber is in the original as nearly unstrained condition as possible, and therefore free to vibrate. All wood for musical instruments is, of course, well seasoned, the final drying in kiln or warm room being preceded by careful seasoning at ordinary temperatures often for as many as seven years or more. The improvement of violins, not by age but by long usage, is probably due, not only to the adjustment of the numerous component parts to each other, but also to a change in the wood itself; years of vibrating enabling any given part to vibrate much more readily.

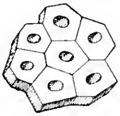

FIG. 15.—Cross section of a group of wood fibers.

II.—WEIGHT OF WOOD.

A small cross section of wood, as in fig. 15, dropped into water, sinks, showing that the substance of which wood fiber or wood is built up is heavier than water. By immersing the wood successively in heavier liquids, until we find a liquid in which it does not sink, and comparing the weight of the same with water, we find that wood substance is about 1.6 times as heavy as water, and that this is as true of poplar as of oak or pine.

Separating a single cell, as shown in fig. 16, *a*, drying and then dropping it into water, it floats. The air-filled cell cavity or interior reduces its weight, and, like a corked empty bottle, it weighs less than the water. Soon, however, water soaks into the cell, when it fills up and sinks.

Many such cells grown together, as in a block of wood, sink when all or most of them are filled with water, but will float as long as the majority are empty or only partly filled. This is why a green, sappy pine pole soon sinks in "driving" (floating). Its cells are largely filled before it is thrown in, and but little additional water suffices to make its weight greater than that of the water.

In a good-sized white pine log, composed chiefly of empty cells (heartwood), the water requires a very long time to fill up the cells (five years would not suffice to fill them all), and therefore the log may float for many months. When the wall of the wood fiber is very thick (five-eighths or more of the volume), as in fig. 16, *b*, the fiber sinks whether empty or filled. This applies to most of the fibers of the dark summerwood bands in pines, and to the compact fibers of oak or hickory, and many, especially tropical woods, have such thick-walled cells and so little empty or air space that they never float.

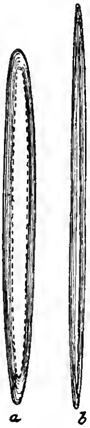

Fig. 16.—Isolated fibers.

Here, then, are the two main factors of weight in wood: The amount of cell wall, or wood substance, constant for any given piece, and the amount of water contained in the wood, variable even in the standing tree, and only in part eliminated in drying.

The weight of the green wood of any species varies chiefly as the second factor, and is entirely misleading if the relative weight of different kinds is sought. Thus some green sticks of the otherwise lighter cypress and gum sink more readily than fresh oak.

The weight of sapwood, or the sappy peripheral part of our common lumber woods, is always great, whether cut in winter or summer. It rarely falls much below 45 pounds and commonly exceeds 55 pounds to the cubic foot, even in our lighter wooded species.

It follows that the green wood of a sapling is heavier than that of an old tree, the fresh wood from a disk of the upper part of a tree often heavier than that of the lower part, and the wood near the bark heavier than that nearer the pith, and also that the advantage of drying the wood before shipping is most important in sappy and light kinds.

When kiln dried, the misleading moisture factor of weight is uniformly reduced and a fair comparison possible. For the sake of convenience in comparison the weight of wood is expressed either as the weight per cubic foot, or, what is still more convenient, as specific weight or density. If an old longleaf pine is cut up as shown in fig. 17, the wood of disk No. 1 is heavier than that of disk No. 2, the latter heavier than that of disk No. 3, and the wood of the top disk is found to be only about three-fourths as heavy as that of disk No. 1.

Similarly, if disk No. 2 is cut up as in the figure, the specific weight of the different pieces is:

a about 0.52
b about 0.64
c about 0.67
d, e, f about 0.65

showing that in this disk, at least, the wood formed during the many years' growth, represented in piece *a*, is much lighter than that of former years. It also shows that the best wood is the middle part, with its large proportion of dark summerwood bands.

Cutting up all disks in the same way, it will be found that the piece *a* of the first disk is heavier than piece *a* of the fifth, and that piece *c* of the first disk excels the piece *c* of all the other disks. This shows that the wood grown during the same number of years is lighter in the upper parts of the stem; and if the disks are smoothed on their radial surfaces and set up one on top of the other in their regular order for sake of comparison, this decrease in weight will be seen to be accompanied by a decrease in the amount of summer wood. The color effect of the upper disks is conspicuously lighter.

If our old pine had been cut one hundred and fifty years ago, before the outer, lighter wood was laid on, it is evident that the weight of the wood of any one disk would have been found to increase from the center outward, and no subsequent decrease could have been observed.

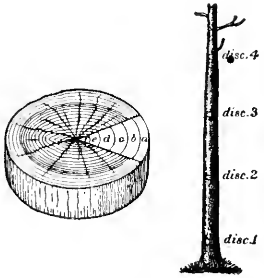

FIG. 17.—Orientation of wood samples.

In a thrifty young pine, then, the wood is heavier from the center outward, and lighter from below upward; only the wood laid on in old age falls in weight below the average. The number of brownish bands of summer wood are a direct indication of these differences.

If an old oak is cut up in the same manner, the butt cut is also found heaviest and the top lightest, but, unlike the disk of pine, the disk of oak has its firmest wood at the center and each successive piece from the center outward is lighter than its inner neighbor.

Examining the pieces, this difference is not as readily explained by the appearance of each piece as in the case of pine wood. Nevertheless, one conspicuous point appears at once, the pores, so very distinct in oak, are very minute in the wood near the center and thus the wood is far less porous. Studying different trees it is found that, in the pines, wood with narrow rings is just as heavy as, and often heavier than the wood with wider rings, but if the rings are unusually narrow in any part of the disk the wood has a lighter color; that is, there is less summer wood and therefore less weight.

In oak, ash, or elm trees of thrifty growth, the rings fairly wide (not less than one-twelfth inch), always form the heaviest wood, while any piece with very narrow rings is light. On the other hand, the weight of a piece of hard maple or birch is quite independent of the width of its rings.

The bases of limbs (knots) are usually heavy, very heavy in conifers, and also the wood which surrounds them, but generally the wood of the limbs is lighter than that of the stem, and the wood of the roots is the lightest.

In general, it may be said that none of the native woods in common use in this country are, when dry, as heavy as water, i. e., 62 pounds to the cubic foot. Few exceed 50 pounds, while most of them fall below 40 pounds, and much of the pine and other coniferous wood weighs less than 30 pounds per cubic foot.

The weight of the wood is, in itself, an important quality. Weight assists in distinguishing maple from poplar. Lightness, coupled with great strength and stiffness, recommends wood for a thousand different uses. To a large extent weight predicates the strength of the wood, at least in the same species, so that a heavy piece of oak will exceed in strength a light piece of the same species, and in pine it appears probable that, weight for weight, the strength of the wood of various pines is nearly equal.

Weight of kiln-dried wood of different species.

	Approximate.		
	Specific weight.	Weight of—	
		1 cubic foot.	1,000 feet of lumber.
(*a*) Very heavy woods:			
Hickory, oak, persimmon, osage orange, black locust, hackberry, blue beech, best of elm, and ash	0.70-0.80	*Pounds.* 42-48	*Pounds.* 3,700
(*b*) Heavy woods:			
Ash, elm, cherry, birch, maple, beech, walnut, sour gum, coffee tree, honey locust, best of Southern pine, and tamarack	.60- .70	36-42	3,200
(*c*) Woods of medium weight:			
Southern pine, pitch pine, tamarack, Douglas spruce, western hemlock, sweet gum, soft maple, sycamore, sassafras, mulberry, light grades of birch and cherry	.50- .60	30-36	2,700
(*d*) Light woods:			
Norway and bull pine, red cedar, cypress, hemlock, the heavier spruce and fir, redwood, basswood, chestnut, butternut, tulip, catalpa, buckeye, heavier grades of poplar	.40- .50	24-30	2,200
(*e*) Very light woods:			
White pine, spruce, fir, white cedar, poplar	.30- .40	18-24	1,800

For scientific names see list, p. 72.

Since ordinary lumber contains knots and also more water than is here assumed, and also since its dimensions either exceed or fall short of perfect measurement, the figures in the table are only approximate.

Thus, 1,000 feet, B. M., of longleaf pine weighs:

	Pounds.
Rough and green	4,500
Boards, rough but seasoned	3,500
Boards, dressed and seasoned	3,000
Flooring, matched, dressed and seasoned	2,500
Weatherboarding beveled and dressed	1,500

III.—MOISTURE IN WOOD.

Water may occur in wood in three conditions: (1) It forms the greater part (over 90 per cent) of the protoplasmic contents of the living cells; (2) it saturates the walls of all cells, and (3) it entirely or at least partly fills the cavities of the lifeless cells, fibers, and vessels. In the sapwood of pine it occurs in all three forms; in the heartwood only in the second form, it merely saturates the walls. Of 100 pounds of water associated with 100 pounds of dry wood substance in 200 pounds of fresh sapwood of white pine, about 35 pounds are needed to saturate the cell walls, less than 5 pounds are contained in living cells, and the remaining 60 pounds partly fill the cavities of the wood fibers. This latter forms the sap as ordinarily understood. It is water brought from the soil, containing small quantities of mineral salts, and in certain species (maple, birch, etc.) it also contains at certain times a small percentage of sugar and other organic matter. These organic substances are the dissolved reserve food, stored during winter in the pith rays, etc., of the wood and bark; generally but a mere trace of them is to be found. From this it appears that the solids contained in the sap, such as albumen, gum, sugar, etc., can not exercise the influence on the strength of the wood which is so commonly claimed for them.

The wood next to the bark contains the most water. In the species which do not form heartwood the decrease toward the pith is gradual, but where this is formed, the change from a more moist to a drier condition is usually quite abrupt at the sapwood limit. In longleaf pine, the wood of the outer 1 inch of a disk may contain 50 per cent of water, that of the next, or second inch, only 35 per cent, and that of the heartwood only 20 per cent. In such a tree the amount of water in any one section varies with the amount of sapwood, and is therefore greater for the upper than the lower cuts, greater for limbs than stems, and greatest of all in the roots.

Different trees, even of the same kind and from the same place, differ as to the amount of water they contain. A thrifty tree contains more water than a stunted one, and a young tree more than an old one, while the wood of all trees varies in its moisture relations with the season of the year.

Contrary to the general belief a tree contains about as much water in winter as in summer. The fact that the bark peels easily in the spring depends on the presence of incomplete, soft tissue found between wood and bark during this season and has little to do with the total amount of water contained in the wood of the stem.

Even in the living tree a flow of sap from a cut occurs only in certain kinds of trees and under special circumstances; from boards, timber, etc., the water does not flow out, as is sometimes believed, but must be evaporated.[1]

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[1] The seeming exceptions to this rule are mostly referable to two causes, namely: (*a*) Clefts or "shakes" will allow water contained in them to flow out. (*b*) From sound wood, if very sappy, water is forced out whenever the wood is warmed, just as water flows from green wood in the stove.

The rapidity with which water is evaporated, that is, the rate of drying, depends on the size and shape of the piece and on the structure of the wood. An inch board dries more than four times as fast as a 4-inch plank and more than twenty times as fast as a 10-inch timber. White pine dries faster than oak. A very moist piece of pine or oak will, during one hour, lose more than four times as much water per square inch from the cross section, but only one-half as much from the tangential, as from the radial section.

In a long timber, where the end or cross sections form but a small part of the drying surface, this difference is not so evident. Nevertheless, the ends dry and shrink first, and being opposed in this shrinking by the more moist adjoining parts, they check, the cracks largely disappearing as seasoning progresses.

High temperatures are very effective in evaporating the water from wood, no matter how humid the air. A fresh piece of sapwood may lose weight in boiling water, and can be dried to quite an extent in hot steam.

Kept on a shelf in an ordinary dwelling wood still retains 8 to 10 per cent of its weight of water, and always contains more water per pound than the surrounding air. Nor is this amount of water constant; the weight of a pan full of shavings varies with the time of day, being on a summer day greatest in the morning and least in the afternoon.

Desiccating the air with chemicals will cause the wood to dry, but wood thus dried at 80° F. will still lose water in the kiln. Wood dried at 120° F. loses water still if dried at 200° F., and this again will lose more water if the temperature is raised. So that absolutely dry wood can not be obtained, and chemical destruction sets in before all the water is driven off.

On removal from the kiln the wood at once takes up water from the air, even in the driest weather. At first the absorption is quite rapid; at the end of a week a short piece of pine, 1½ inches thick, has regained two-thirds of, and, in a few months, all the moisture which it had when air dry, 8 to 10 per cent, and also its former dimensions.

In thin boards all parts soon attain the same degree of dryness; in heavy timbers the interior remains moister for many months, and even years, than the exterior parts. Finally an equilibrium is reached, and then only the outer parts change with the weather.

With kiln-dried wood all parts are equally dry, and when exposed the moisture coming from the air must pass in through the outer parts, and thus the order is reversed. Ordinary timber requires months before it is at its best; kiln-dry timber, if properly handled, is prime at once.

Dry wood, when soaked in water, soon regains its original volume, and in the heartwood portion it may even surpass it; that is to say, swell to a larger dimension than it had when green. With the soaking it continues to increase in weight, the cell cavities filling with water, and if left many months all pieces sink. Yet even after a year's immersion a piece of oak 2 by 2 inches and only 6 inches long still contains air, i. e., it has not taken up all the water it can. By rafting, or prolonged immersion, wood loses some of its weight, soluble materials being leached out, but it is not impaired either as fuel or as building material. Immersion and, still more, boiling and steaming reduce the hygroscopicity of wood and, therefore, also the troublesome "working" or shrinking and swelling.

Exposure in dry air to a temperature of 300° F. for a short time reduces, but does not destroy, the hygroscopicity and with it the tendency to shrink and swell. A piece of red oak, which has been subjected to a temperature of over 300° F., still swells in hot water and shrinks in the kiln.

In artificial drying, temperatures of from 158° F. to 180° F. are usually employed. Pine, spruce, cypress, cedar, etc., are dried fresh from the saw, allowing four days for 1-inch boards; hard woods, especially oak, ash, maple, birch, sycamore, etc., are air-seasoned for three to six months, to allow the first shrinkage to take place more gradually, and are then exposed to the above temperatures in the kiln for about six to ten days for 1-inch lumber. Freshly cut poplar and cottonwood are often dried directly in kilns.

By employing lower temperatures, 100° to 120° F., green oak, ash, etc., can be seasoned in dry kilns without danger to the material. Steaming the lumber is commonly resorted to in order to prevent checking and "casehardening," but not, as has frequently been asserted, to enable the board to dry. Yard-dried lumber is not dry, and its moisture is too unevenly distributed to insure good behavior after manufacture. Careful piling of the lumber, both in the yard and kiln, is essential to good drying. Piling boards on edge or standing them on end is believed to hasten drying. This is true only because in either case the air can circulate more freely around them than when they are piled in the ordinary way. Boards on end dry unequally; the upper half dries much faster than the lower half and horizontal piling is, therefore, preferable.

Since the proportion of sap and heart wood varies with size, age, species, and individual, the following figures must be regarded as mere approximations:

Pounds of water lost in drying 100 pounds of green wood in the kiln.

	Sapwood or outer part.	Heartwood or interior.
(1) Pines, cedars, spruces, and firs	45–65	16–25
(2) Cypress, extremely variable	50–65	18–60
(3) Poplar, cottonwood, basswood	60–65	40–60
(4) Oak, beech, ash, elm, maple, birch, hickory, chestnut, walnut, and sycamore	40–50	30–40

The lighter kinds have the most water in the sapwood, thus sycamore has more than hickory.

IV.—SHRINKAGE OF WOOD.

When a short piece of wood fiber, such as that shown in fig. 18, *A*, is dried it shrinks, its wall grows thinner (as indicated by dotted lines), its width, *a b*, the thickness of the fiber, becomes smaller, and the cavity or opening larger, but, strange to say, the height or length, *b c*, remains the same. In a similar piece of fiber with a thinner wall (fig. 18, *B*) the effect is the same, but the wall being only half as thick the total change is only about half as great.[1]

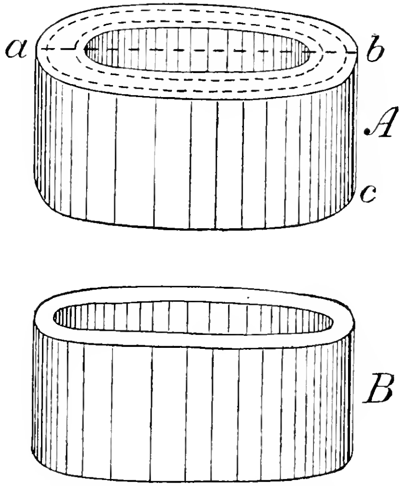

FIG. 18.—Short pieces of wood fibers, one thick, the other thin-walled; magnified.

If sections or pieces of fibers are dried and then placed on moist blotting paper, they will take up water and swell to their original size, though the water has been taken up only by their walls and none has entered into their openings or lumina. This indicates that the water in the cavity or lumen of a fiber has nothing to do with its dimensions, and that if the cell walls are saturated it makes no difference in the volume of a block of pine wood whether the cell cavities are empty as in the heartwood or three-fourths filled as in the sapwood.

FIG. 19.—Isolated cell.

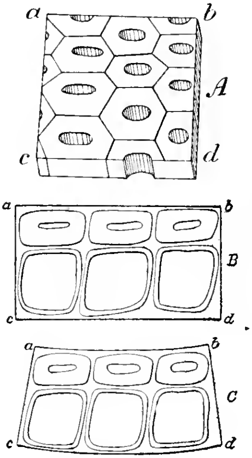

FIG. 20.—Warping of wood.

If an entire fiber, as shown in fig. 19, is dried, the wall at its ends *a* and *b*, like those of the sides, grow thinner, and thereby the length of the entire cell grows shorter. Since this length is often a hundred or more times as great as the diameter, the effect of this shrinkage is inappreciable; and if a long board shrinks lengthwise, it is largely due, as we shall see, to quite another cause.

A thin cross section of several fibers (see fig. 20, *A*) like the piece of a single fiber shrinks when dried, the wall of each fiber becomes thinner, and thus each piece smaller, and the piece on the whole necessarily

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[1] Though generally true, it must not be supposed that the fibers of all species, or even the fibers of the same tree, shrink exactly in proportion to the thickness of their walls.

shares this diminution of size, the distances, *a b* and *c d*, each becoming shorter. Where the cells are very similar in size and in the thickness of their walls, as in the case of piece *A*, fig. 20, *a b* and *c d* become shorter by about the same amount; but if the piece is made up of fibers, some of which have thin and others thick walls, as piece *B*, fig. 20, then the row of thick-walled cells shrinking much more than the row of thin-walled cells, the piece becomes unevenly shrunk or warped as shown in fig. 20, *C*. Not only is the piece warped, but the force which led to this warping continues to strain the interior parts of the piece in different directions.

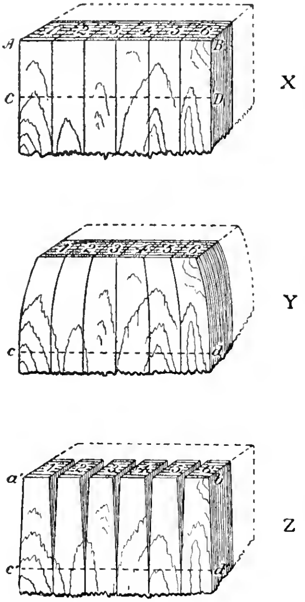

FIG. 21.—Formation of checks.

Since in all our woods cells with thick walls and cells with thin walls are more or less intermixed, and especially as the spring wood and summer wood nearly always differ from each other in this respect, strains and tendencies to warp are always active when wood dries out, because the summer wood shrinks more than the spring wood, heavier wood in general more than light wood of the same kind.

If the piece *A*, fig. 20, after drying, is placed edgewise on moist blotting paper, the cells on the underside, at *c d*, take up moisture from the paper and swell before the upper cells at *a b* receive any moisture. This causes the underside of the piece to become longer than the upper side and, as in the case of piece *C*, warping occurs. Soon, however, the moisture penetrates to all the cells and the piece straightens out. A thin board behaves exactly like this minute piece, only the process is slower and more easily observed. But while a thin board of pine curves laterally, it remains quite straight lengthwise, since in this direction both shrinkage and swelling are small. A thin disk or cross section swells, and when moistened on one side warps as readily in one direction as in another. If a green board is exposed to the sun with one side, warping is produced by removal of water and consequent shrinkage of the upper side, and the course of the process is simply reversed.

As already stated, wood loses water faster from the end than from the longitudinal faces. Hence the ends shrink at a different rate from the interior parts.

In a timber, the width *A B* (fig. 21, X) may have shortened (fig. 21, Y), while a short distance from the end *c d*, the original width is still preserved. This should produce a bending of the parts toward the center of the piece as shown in exaggeration at Y, but the rigidity of the several parts of the timber prevents such bending and the consequent strain leads to their separation as shown at Z, the end surface of the timber being "checked."

As the timber dries out, the line *c d* becomes shorter, the parts 1 to 6 are allowed to approach again, and the checks close up and are no longer visible.

The faster the drying at the surface, the greater is the difference in the moisture of the different parts, and hence the greater the strains and consequently also the amount of checking. This becomes very evident when fresh wood is placed in the sun, and still more in a hot kiln. While most of these smaller checks are thus only temporary, closing up again, some large radial checks remain and even grow larger as drying progresses. Their cause is a different one and will presently be explained.

The temporary checks not only occur at the ends, but are developed on the sides also, only to a much smaller degree. They become especially annoying on the surface of thick planks of hard woods, and also on peeled logs when exposed to the sun.

So far we have considered the wood as if made up only of parallel fibers all placed longitudinally in the log. This, however, is not the case. A large part of the wood is formed by the medullary or pith rays. In pine over 15,000 of these occur on a square inch of a tangential section, and even in oak the very large rays, which are readily visible to the eye, represent scarcely a hundredth part of the number which the microscope reveals.

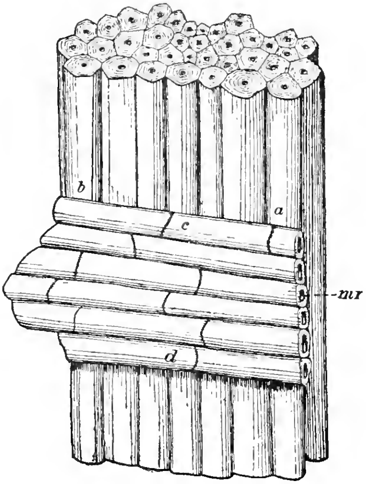

Fig. 22.—Small pith ray in oak. *a, b*, wood fibers; *c, d*, cells of pith ray.

As seen in fig. 22 the cells of these rays have their length at right angles to the direction of the wood fibers.

If a large pith ray of white oak is whittled out and allowed to dry it is found to shrink greatly in the direction from *c* to *d* (fig. 22), while, as we have stated, the fibers to which the ray is firmly grown in the wood do not shrink in the same direction. Therefore, in the wood, as the cells of the pith ray dry, they pull on the longitudinal fibers and try to shorten them, and, being opposed by the rigidity of the fibers, the pith ray is greatly strained. But this is not the only strain it has to bear. Since the fibers from *a* to *b* (fig. 22) shrink as much again as the pith ray in this, its longitudinal direction, the fibers tend to shorten the ray, and the latter, in opposing this, prevents the former from shrinking as much as they otherwise would. Thus the structure is subjected to two severe strains at right angles to each other, and herein lies the greatest difficulty of wood seasoning, for whenever the wood dries rapidly these fibers have not the chance to "give" or accommodate themselves, and hence fibers and pith rays separate and checks result which, whether visible or not, are detrimental in the use of the wood.

The contraction of the pith rays parallel to the length of the board is probably one of the causes of the small amount of longitudinal shrinkage which has been observed in boards.[1] The smaller shrinkage of the pith rays along the radius of the log (the length of the pith ray) opposing the shrinkage of the fibers in this direction becomes one of the causes of the second great trouble in wood seasoning, namely, the difference in the amount of the shrinkage along the radius and that along the rings or tangent.

This greater tangential shrinkage appears to be due, in part, to the cause just mentioned, but also to the fact that the greatly shrinking bands of summer wood are interrupted, along the radius, by as many bands of porous spring wood, while they are continuous in the tangential direction. In this direction, therefore, each such band tends to shrink, as if the entire piece were composed of summer wood, and since the summer wood represents the greater part of the wood substance, this tendency of greater tangential shrinkage prevails.

The effect of this greater tangential shrinkage affects every phase of woodworking. It leads to permanent checks, and causes the log to split open on drying.

Sawed in two, the flat sides of the log become convex, as in fig. 23; sawed into a timber, it checks along the median line of the four faces, and if converted into boards, the latter take on the forms shown in fig. 23, all owing to the greater tangential shrinkage of the wood.

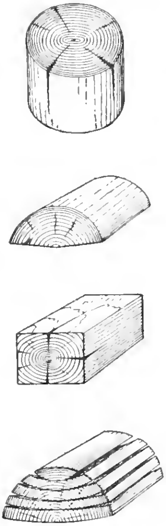

FIG. 23.—Effects of shrinkage.

Briefly, then, shrinkage of wood is due to the fact that the cell walls grow thinner on drying. The thicker cell walls and therefore the heavier wood shrinks most, while the water in the cell cavities does not influence the volume of the wood. Owing to the great difference of cells in shape, size, and thickness of walls, and still more in their arrangement, shrinkage is not uniform in any kind of wood. This irregularity produces strains, which grow with the difference between

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[1] In addition to this all fibers having an oblique position, as those at pith rays and knots, also the oblique, tapering ends of all fibers contribute to this longitudinal shrinkage, since one component of their normal shrinkage is longitudinal.

adjoining cells and are greatest at the pith rays. These strains cause warping and checking, but exist even where no outward signs are visible; they are greater if the wood is dried rapidly than if dried slowly, but can never be entirely avoided.

Temporary checks are caused by the more rapid drying of the outer parts of any stick; permanent checks are due to the greater shrinkage, tangentially, along the rings than that along the radius. This, too, is the cause of most of the ordinary phenomena of shrinkage, such as the difference in behavior of entire and quartered logs "bastard" (tangent) and "rift" (radial) boards, etc., and explains many of the phenomena erroneously attributed to the influence of bark, or of the greater shrinkage of outer and inner parts of any log.

Once dry, wood may be swelled again to its original size by soaking in water, boiling, or steaming. Soaked pieces, on drying, shrink again as before; boiled and steamed pieces do the same, but to a slightly less degree. Neither hygroscopicity, i. e., the capacity of taking up water, nor shrinkage of wood can be overcome by drying at temperatures below 200° F. Higher temperatures, however, reduce these qualities, but nothing short of a coaling heat robs wood of the capacity to shrink and swell. Rapidly dried in the kiln, the wood of oak and other hard woods "case-harden," that is, the outer part dries and shrinks before the interior has a chance to do the same, and thus forms a firm shell or case of shrunken, commonly checked wood around the interior. This shell does not prevent the interior from drying, but when this drying occurs, the interior is commonly checked along the medullary rays, as shown in fig. 24. In practice this occurrence can be prevented by steaming the lumber in the kiln, and still better by drying the wood in the open air or in a shed before placing in the kiln. Since only the first shrinking is apt to check the wood, any kind of lumber which has once been air dried (three to six months for 1-inch stuff) may be subjected to kiln heat without any danger. Kept in a bent or warped condition during the first shrinking, the wood retains the shape to which it was bent and firmly opposes any attempt at subsequent straightening.

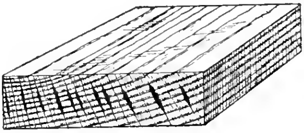

FIG. 24.—"Honeycombed" board. The checks or cracks form along the pith rays.

Sapwood, as a rule, shrinks more than heartwood of the same weight, but very heavy heartwood may shrink more than lighter sapwood. The amount of water in wood is no criterion of its shrinkage, since in wet wood most of the water is held in the cavities, where it has no effect on the volume.

The wood of pine, spruce, cypress, etc., with its very regular structure, dries and shrinks evenly and suffers much less in seasoning than the wood of broad-leafed trees. Among the latter, oak is the most difficult to dry without injury. Small-sized split ware and "rift" boards season better than ordinary boards and planks.

To avoid "working" or warping and checking, all high-grade stock is carefully seasoned, preferably in a kiln, before manufacture. Thicker pieces may be made of several parts glued together; larger surfaces are made in panels or of smaller pieces covered with veneer. Boring is sometimes resorted to to prevent the checking of wooden columns.

Since repeated swelling increases the injuries due to seasoning, wood should be protected against moisture when once it is dry.

Since the shrinkage of our woods has never been carefully studied, and since wood, even from the same tree, varies within considerable limits, the figures given in the following table are to be regarded as mere approximations. The shrinkage along the radius and that along the tangent (parallel to the rings) are not stated separately in the following table, and the figures represent an average of the shrinkage in the two directions. Thus, if the shrinkage of soft pine is given at 3 inches per hundred, it means that the sum of radial and tangential shrinkage is about 6 inches, of which about 4 inches fall to the tangent and 2 inches to the radius, the ratio between these varying from 3 to 2, a ratio which practically prevails in most of our woods.

Since only an insignificant longitudinal shrinkage takes place (being commonly less than 0.1 inch per hundred), the change in volume during drying is about equal to the sum of the radial and tangential shrinkage, or twice the amount of linear shrinkage indicated in the table.

Thus, if the linear average shrinkage of soft pine is 3 inches per hundred, the shrinkage in volume is about 6 cubic inches for each 100 cubic inches of fresh wood.

Approximate shrinkage of a board, or set of boards, 100 inches wide, drying in the open air.

	Shrinkage.
	Inches.
(1) All light conifers (soft pine, spruce, cedar, cypress)	3
(2) Heavy conifers (hard pine, tamarack, yew), honey locust, box elder, wood of old oaks	4
(3) Ash, elm, walnut, poplar, maple, beech, sycamore, cherry, black locust	5
(4) Basswood, birch, chestnut, horse chestnut, blue beech, young locust	6
(5) Hickory, young oak, especially red oak	Up to 10

V.—MECHANICAL PROPERTIES OF WOOD.

Every joist and studding, every rafter, sash, and door, the chair we sit on, the floor we walk on, the wood of the wagon or boat we ride in are all continually tested as to their stiffness and strength, their hardness and toughness. Every step from the simple splitting of a shingle or stave to the construction of the most elegant carriage or sideboard involves a knowledge, not only of one, but of several, of the mechanical properties of the material.

In the shop the fitness of the wood for a given purpose never depends on any one quality alone, but invariably upon a combination of several qualities. A spoke must not only be strong, it must be stiff to hold its shape, it must be tough to avoid shattering to pieces, and it must also be hard or else its tenons will become loose in their mortises.

Selecting wood in this way, the woodworker has learned almost all that is at present known about his material, but in many cases the great difficulty which always attends the judgment of complex phenomena has led to erroneous conclusions, and not a few well-established beliefs have their origin more in accidental error of observation than in fact.

The experimenter endeavors to avoid this complexity by testing the wood for each kind of resistance separately; when tested as to their stiffness, the pieces are all shaped, placed, and loaded alike. The wood is selected with a definite object in view; it is green or dry, clear or knotty, straight or crossgrained, according as he wishes to find out the influence of each of these conditions. If pine and oak are to be compared, the pieces are from the same position in the tree and are tried under exactly the same conditions, and thus the case is simplified.

But even results thus arrived at can not be used indiscriminately, and the figures on the strength of oak given in any book must not be supposed to apply to all oak, if tested in the given manner. This is due to the fact that a piece of wood is not simply a material but a structure, just as much as a railroad bridge or a balloon frame, and as such varies greatly even in the wood of the same tree, nay, more than that, even in the same year's growth of the same cross section of a log.

A scantling resists bending; it is stiff. On removal of the load it straightens; it is elastic. A column, a prop, or the spoke of a wagon wheel resists being crushed endwise. So does the upper side of a joist or beam when loaded, while the underside of the beam or of an ax handle suffers in tension. The tenons of a window sash or door tend to break out their mortises, the wood has to resist shearing along the fibers; the steel edge of the eye tends to cut into the hammer handle, it tries to shear it across the grain, and every nail, screw, bore hole, or mortise tends to split the board and tries the wood as to its cleavability, while all "bent" ware, from the wicker basket to the one-piece felly or ship's knee, involves its flexibility.

STIFFNESS.

If 100 pounds placed in the middle of a stick 2 by 2 inches and 4 feet long, supported at both ends, bend or "deflect" this stick one-eighth of an inch (in the middle), then 200 pounds will bend it about one-fourth inch, 300 pounds three-eighths inch, the deflection varying directly as the load. Soon, however, a point is reached where an additional 100 pounds adds more than one-eighth inch to the deflection—the limit of elasticity has been reached. Taking another piece from the straight grained and perfectly clear plank of the same depth and width, but 8 feet long, the load of 100 pounds will cause it to bend not only one-eighth inch, but will deflect it by about 1 inch. Doubling the length reduces the stiffness eightfold. Stiffness then decreases as the cube of the length.

Cutting out a piece 2 by 4 inches and 4 feet long, placing it flatwise so that it is double the width of the former stick and loading it with 100 pounds, we find it bending only one-sixteenth inch; doubling the width doubles the stiffness.

Setting the same 2 by 4 inch piece on edge, so that it is 2 inches wide and 4 inches deep, the load of 100 pounds bends it only about one sixty-fourth inch; doubling the thickness increases the stiffness about eightfold.

It follows that if we double the length and wish to retain the same stiffness we must also double the thickness of the piece.

A piece of wood is usually stiffer with the annual rings set vertically than if the rings are placed horizontally to the load.

Crossgrained and knotty wood, to be sure, is not as stiff as clear lumber; a knot on the upper side of a joist, which must resist in compression, is, however, not so detrimental as a knot on the lower side, where it is tried in tension.

Every large timber which comes from the central part of the tree contains knots, and much of its wood is cut more or less obliquely across the grain, both conditions rendering such material comparatively less stiff than small clear pieces.

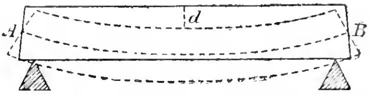

FIG. 25.—Bending a beam.

The same stick of pine, green or wet, is only about two-thirds as stiff as when dry. A heavy piece of longleaf pine is stiffer than a light piece; heavy pine in general is stiffer than light pine, but a piece of hickory, although heavier than the pine, may not be as stiff as the piece of longleaf pine, and a good piece of larch exceeds in stiffness any oak of the same weight.

In the same tree stiffness varies with the weight, the heavier wood being the stiffer; thus the heavier wood of the butt log is stiffer than that of the top; timber with much of the heavy summer wood is stiffer than timber of the same kind with less summer wood. In old trees (of pine) the center of the tree and the sap are the least stiff; in thrifty young pine the center is the least stiff, but in young second growth hard woods it is the stiffest.

Since it is desirable, and for many purposes essential, to know before hand that a given piece with a given load will bend only a given amount, the stiffness of wood is usually stated in a uniform manner and under the term "modulus (measure) of elasticity."

If AB, fig. 25, is a piece of wood, and d the deflection produced by a weight or load, the elasticity of the wood, as usually stated, is found by the formula:

$$\text{Modulus of elasticity} = \frac{W\,l^3}{4\,D\,bd^3}$$

where W is the weight, l the length, b and d the breadth and depth of the stick, and D the deflection for the load W. In the following table the woods are grouped according to their stiffness. The figures are only rough approximations which are based on the data given in Vol. IX of the Tenth Census. The first column contains the above modulus, the second shows how many pounds will produce a deflection of 1 inch in a stick 1 by 1 by 12 inches, assuming that it could endure such bending within the limits of elasticity, and the third column gives the number of pounds which will bend a stick 2 by 2 inches and 10 feet long through 1 inch.

The stick is assumed to rest on both ends; if it is a cantilever, i. e., fastened at one end and loaded at the other, it bears but half as much load at its end for the same deflection.

From the third column it is easy to find how many pounds would bend a piece of the same kind of other dimensions. A 2 by 4 inch bears eight, a 2 by 6 inch twenty-seven times as much as the 2 by 2 inch; a piece 8 feet long is about twice as stiff as a 10-foot piece; a piece 12 feet, only about three-fifths, 14 feet one-third, 16 feet two-ninths, 18 feet one-sixth, and 20 feet one-eighth as stiff.

The number of pounds which will bend any piece of sawed timber by 1 inch may be found by using the formula:

$$\text{Necessary weight} = \frac{4\ \text{E}\ bd^3}{l^3}$$

where E is the figure in the first column, b, d, l, breadth, depth, and length of the timber in inches. If the deflection is not to exceed one-half inch, only one-half the load, and if one-fourth inch, only one-fourth the load, is permissible.

To allow for normal irregularities in the structure of wood itself, as well as in the aggregate structure of timbers, an allowance is made on the numbers which have been found by experiment; this allowance is called the "factor of safety." Where the selection of the wood is not very perfect, the load is a variable one, and the safety of human life depends on the structure, the factor is usually taken quite high, as much as 6 or 10, i. e., only one-sixth or one-tenth of the figures given in the tables is considered safe, and the beam is made six to ten times as heavy as the calculation requires.

Table of stiffness (modulus of elasticity) of dry wood.—General averages.

Species.	Modulus of elasticity $E=\frac{W l^3}{4 D b d^3}$ per square inch.	Approximate weight which deflects by 1 inch a piece—	
		1 by 1 inch and 12 inches long.	2 by 2 inches and 10 feet long.
	Pounds.	*Pounds.*	*Pounds.*
(1) Live oak, good tamarack, longleaf, Cuban, and shortleaf pine, good Douglas spruce, western hemlock, yellow and cherry birch, hard maple, beech, locust, and the best of oak and hickory	1,680,000	3,900	62
(2) Birch, common oak, hickory, white and black spruce, loblolly and red pine, cypress, best of ash, elm, and poplar and black walnut	1,400,000	3,200	51
(3) Maples, cherry, ash, elm, sycamore, sweet gum, butternut, poplar, basswood, white, sugar and bull pine, cedars, scrub pine, hemlock, and fir	1,100,000	2,500	40
(4) Box elder, horse chestnut, a number of western soft pines, inferior grades of hard woods	1,100,000	[1]2,500	40

[1] Less than.

CROSS-BREAKING OR BENDING STRENGTH.

When the addition of 100 pounds to the load on our 2 by 2 inch piece begins to add more than one-eighth inch to the deflection, that is, when the stick has been bent beyond its "elastic limit," it still requires an increase of 30 to 50 per cent to the load before the stick breaks. The load which is borne before the limit of elasticity is reached indicates the strength of the wood up to this important point; the load which causes it to break represents its absolute strength, or the "cross-breaking or bending strength" as it is commonly called.

In longleaf pine the former (modulus of strength at the elastic limit),[1] is commonly about three-fourths of the latter. If left loaded for a considerable time, a load but little greater than that which brings the stick to its elastic limit will cause it to break, and this load should therefore not be exceeded.

Unlike the stiffness, the strength of a timber varies approximately with the squares of the thickness and decreases directly with increasing length and not with the cube of this latter dimension. Thus, if our piece 2 by 2 inches and 4 feet long can bear 1,000 pounds before it breaks, a 2 by 4 inch laid flat will break with about 2,000 pounds, and if set edgewise, it requires about 4,000 pounds to break it, while a piece of the same kind of 2 by 2 inches, and double the length (8 feet), breaks with half the original load, or only 500 pounds.

All conditions of the material which influence the stiffness also influence the bending strength. Seasoning increases, moisture decreases, the strength; knots and crossgrain depress it and both are more dangerous on the lower than on the upper side. But while the conifers with their simple cell structure excel in stiffness, the better hard woods

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[1] The elastic limit in this case is somewhat of an arbitrary quantity, namely, the point where 100 pounds produces a deflection 50 per cent greater than the preceding 100 pounds.

develop the greater strength in bending. Like elasticity and stiffness, the strength is expressed in a uniform manner by the so-called "modulus of rupture," to permit ready estimation of the strength of any given piece. This modulus refers to the resistance which the parts most strained, "the extreme fiber," offer. For reasons above stated, in practice a factor of safety is employed, as in all these calculations of resistance. The figures usually tabulated are obtained by the formula:

$$\text{Strength of extreme fiber} = \frac{3\,W\,l}{2bd^2}$$

where W is the breaking load, l the length, b and d the breadth and depth of the tested piece of wood.

The following table presents our common woods grouped as to their strength in bending. The load, as before, is supposed to act altogether in the middle. Column 1 gives the strength of the extreme fiber, as explained above; column 2, the number of pounds which will break a piece 1 by 1 inch and 12 inches long, and column 3, the strength of a stick 2 by 2 inches and 10 feet long, from which the strength of any given piece can readily be estimated, allowing, however, for defects, which increase with the size. Thus, if a good piece of pine 2 by 2 inches and 10 feet long breaks with 400 pounds, a 2 by 4 inch set on edge requires 1,600 pounds, a 2 by 6 inch, 3,600 pounds, a 2 by 8 inch piece 6,400 pounds to break it. If a piece 2 by 4 inches and 10 feet long breaks with 1,600 pounds, a 2 by 4 inch and 12 feet long piece breaks with about 1,300 pounds, one 16 feet with 1,000 pounds, etc., and if a factor of safety of 10 is allowed, only one-tenth of the above loads are permissible.

A board one-half inch by 12 inches and 10 feet long contains as much wood as a 2 by 3 inch of the same length, and if placed edgewise should offer four times as much resistance to breaking. Owing to its small breadth, however, it "twists" when loaded, and in most cases, therefore, bears less than the 2 by 3 inch. To prevent this twisting, joists are braced, and the depth of timbers is made not to exceed four times their thickness.

Short deep pieces shear out or split before their strength in bending can fully be called into play.

Strength in cross-breaking of well-seasoned, select pieces.

	Strength of the extreme fiber $f=\frac{3\ Wl}{2\ bd^2}$ per square inch.	Approximate weight which breaks a stick—	
		1 by 1 inch and 12 inches long.	2 by 2 inches and 10 feet long.
	Pounds.	*Pounds.*	*Pounds.*
(1) Robinia (locust), hard maple, hickory, oak, birch, best ash and elm, longleaf, shortleaf, and Cuban pines, tamarack	13,000	720	570
(2) Soft maple, cherry, ash, elm, walnut, inferior oak, and birch, best poplar, Norway, loblolly and pitch pines, black and white spruce, hemlock and good cedar	10,000	550	440
(3) Tulip, basswood, sycamore, butternut, poplars, white and other soft pines, firs, and cedars	6,500	350	280

TENSION AND COMPRESSION.

When a piece of wood is pulled lengthwise, in the manner shown in fig. 26, part of the fibers are torn asunder or broken, but many are merely pulled or shredded out from between their neighbors. Since failure in tension thus involves lateral adhesion as well as strength of fibers, it is affected not only by the nature and dimensions of the fibers but also by their arrangement. Owing to their transverse position the medullary rays (a large part of all woods) offer but one-tenth to one-twentieth as much resistance as the main body of fibers and moreover weaken the timber by disturbing the straight course of the fibers and the regularity of the entire structure. The resistance is also much affected by the position of the grain. The perfectly cross-grained piece *a* (fig. 27) sustains but about one-tenth to one-twentieth of the load which is supported by the straight-grained piece *c*, and it is evident that the piece *b*, which represents the ordinary case of crossgrain, is likewise weakened by the oblique position of the grain.

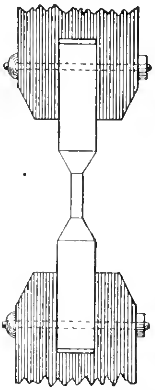

FIG. 26.—Specimen in tension test.

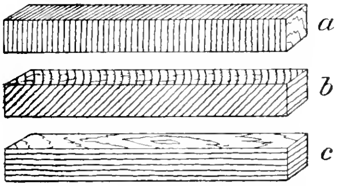

FIG. 27.—Straight and cross grained wood.

This explains the detrimental influence of a knot on the underside of a board, as in fig. 28. Since the lower side of the board, in bending, is stretched, the upper side being compressed, the fibers of the lower side are subjected to tension and the wood of the knot, like the piece of crossgrained wood, offers but little resistance. Commonly the defect is greatly increased by a season check in the knot itself, so that the knot affects the strength of the board like a saw cut of equal depth.

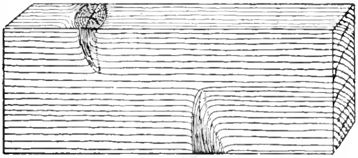

FIG. 28.—Effect of knots and their position.

Tested in compression endwise (fig. 29), the fibers act as so many hollow columns firmly grown together, and when the load becomes too great the piece fails in the manner illustrated in fig. 31. This failure is a very complex phenomenon; in wood like pine the fibers of the plain in which failure occurs become separated into small bodies; they tear apart and cease to behave as one solid body but act as a large number of very small independent pieces. Like the strands of a rope these small bodies offer but little resistance to compression; they bend over, and the piece "buckles."

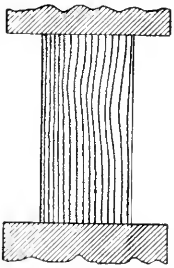

FIG. 29.—Compression endwise.

It is evident that a vertical position and a regular arrangement of the fibers increase the resistance, and that therefore the medullary rays and oblique position of fibers in crossgrained and knotty timber tend to reduce the strength in compression.

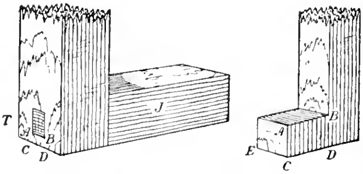

FIG. 30.—Longitudinal shearing.

From the following table of strength in tension and compression it will be seen that these two are not always proportional, the stiffer conifers excelling in the latter, the tougher hard woods in the former:

Ratio of strength in tension and compression, showing the difference between rigid conifers and tough hard woods.

	Ratio: $R=\frac{\text{Tensile strength.}}{\text{compressive strength.}}$	A stick 1 square inch in cross section. Weight required to—	
		Pull apart.	Crush endwise.
		Pounds.	*Pounds.*
Hickory	3.7	32,000	8,500
Elm	3.8	29,000	7,500
Larch	2.3	19,400	8,600
Longleaf pine	2.2	17,300	7,400

Strength in compression of common American woods in well-seasoned select pieces.

[Approximate weight per square inch of cross section requisite to crush a piece of wood endwise.]

	Pounds.
(1) Black locust, yellow and cherry birch, hard maple, best hickory, longleaf and Cuban pines, and tamarack	9,000+
(2) Common hickory, oak, birch, soft maple, walnut, good elm, best ash, shortleaf and loblolly pines, western hemlock, and Douglas fir	7,000+
(3) Ash, sycamore, beech, inferior oak, Pacific white cedar, canoe cedar, Lawson's cypress, common red cedar, cypress, Norway and superior spruces, and fir	6,000+
(4) Tulip, basswood, butternut, chestnut, good poplar, white and other common soft pines, hemlock, spruce, and fir	5,000+
(5) Soft poplar, white cedar, and some western soft pines, and firs	4,000+

SHEARING.

When, in a structure like that shown in fig. 30, a weight is placed on *J* and the tenon *T* by downward pressure breaks out the piece *A B C D*,

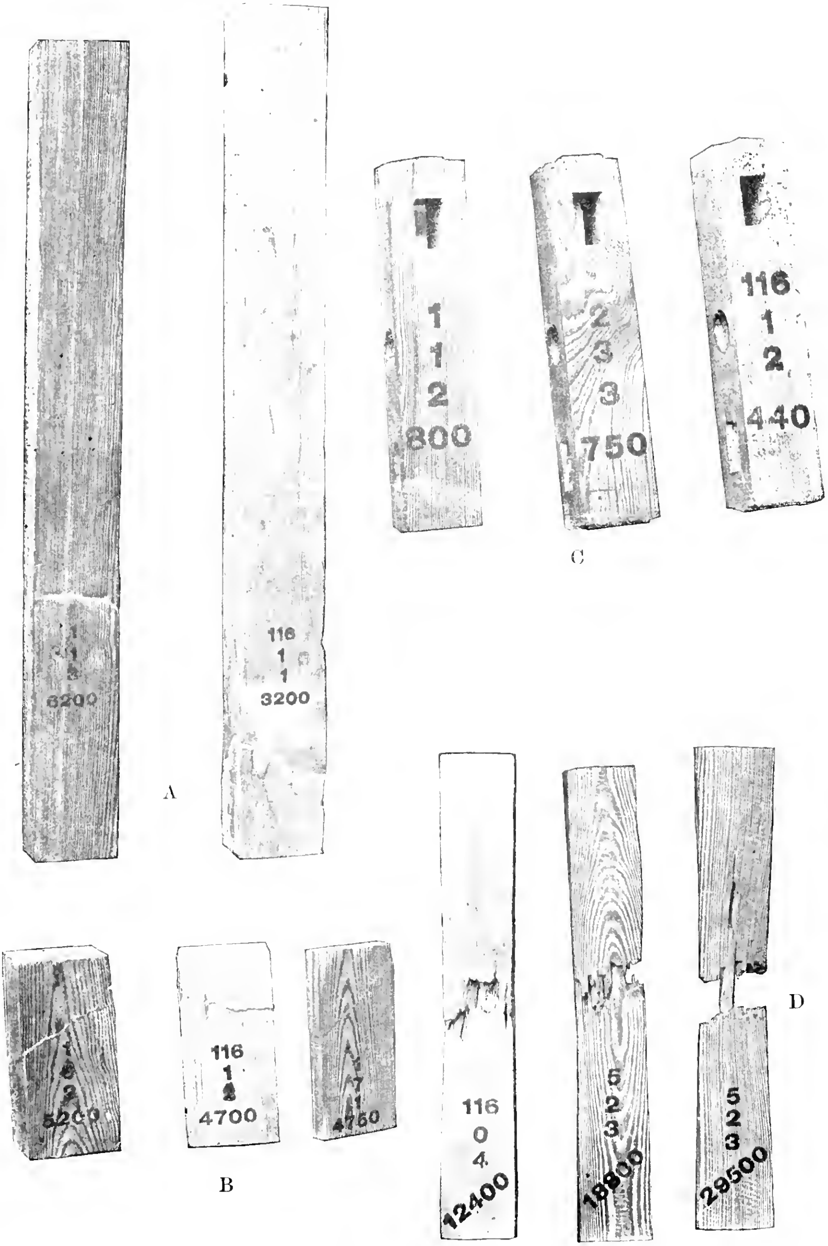

FIG. 31.—Various forms of failure. A and B, compression endwise; C, shearing (the bolt of a stirup passed through the mortise and sheared out the end). D, tension. The lower figure indicates the number of pounds per square inch which produced the failure in tests by the Division of Forestry. No. 116 (upper figure on each piece) is white pine, Nos. 1, 2, and 5 are longleaf pine, about one-fifth natural size.

this is said to shear out along the fiber. In the same manner, if the shoulder *A B C D* in fig. 30, is pushed off along *B D*, it is sheared, and if *B D* and *C E* are each 1 inch, the surface thus sheared off is 1 square inch, and the weight necessary to do this represents the shearing strength per square inch of the particular kind of wood. This resistance is small when compared to that of tension and compression.

In general wet or green wood shears about one-third more easily than dry wood; a surface parallel to the rings (tangent) shears more easily than one parallel to the medullary rays. The lighter conifers and hard woods offer less resistance than the heavier kinds, but the best of pine shears one-third to one-half more readily than oak or hickory, indicating that great shearing strength is characteristic of "tough" woods.

Resistance to shearing along the fiber.

	Per square inch.
	Pounds.
(1) Locust, oak, hickory, elm, maple, ash, birch	[1] 1,000
(2) Sycamore, longleaf, Cuban, and shortleaf pine, and tamarack	600
(3) Tulip, basswood, better class of poplar, Norway, loblolly and white pine, spruce, red cedar.	400
(4) Softer poplar, hemlock, white cedar, fir	[2] 400

[1] Over. [2] Less than.

NOTE.—Resistance to shearing, although a most important quality in wood, has not been satisfactorily studied. The values in the above table, taken from various authors, lack a reliable experimental basis and can be considered as only a little better than guesswork.

INFLUENCE OF WEIGHT AND MOISTURE ON STRENGTH.

It has been stated that heavy wood is stronger than lighter wood of the same kind, and that seasoning increases all forms of resistance. Let us examine why this is so.

Since the weight of dry wood depends on the number of fibers and the thickness of their walls, there must be more fibers per square inch of cross section in the heavy than in the light piece of the same kind,[1] and it is but natural that the greater number of fibers should also offer greater resistance, i. e., have the greater strength.

The beneficial influence of drying and consequent shrinking is twofold: (1) In dry wood a greater number of fibers occur per square inch, and (2) the wood substance itself, i. e., the cell walls, become firmer. A piece of green longleaf pine, 1 by 1 inch and 2 inches long, is only about 0.94 by 0.96 inch and 2 inches long when dry; its cross section is 10 per cent smaller than before, but it still contains the same number of fibers. A dry piece 1 by 1 inch, therefore, contains 10 per cent more fibers than a green piece of the same size, and it is but fair to suppose that its resistance or strength is also about 10 per cent greater.

The influence of the second factor, though unquestionably the more important one, is less readily measured. In 100 cubic inches of wood

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[1] This imperfect assumption is used only for comparison.

substance the material of the cell walls takes up about 50 cubic inches of water and thereby swells up, becoming about 150 cubic inches in volume. In keeping with this swelling the substance becomes softer and less resistant. In pine wood this diminution of resistance, according to experiments, seems to be about 50 per cent, and the strength of the substance therefore is inversely as the degree of saturation or solution.

HARDNESS AND SHEARING ACROSS THE GRAIN.

When the solid steel plunger P in fig. 32 descends on the piece of wood *w*, the first effect is to press it into the wood of the upper surface without affecting the interior or lower part. The wood is thus tried with regard to its hardness. If a perforated steel plate is substituted for the solid plate the effect of the plunger is at first the same, but soon the fibers some distance from the steel are seen to bend, and finally the piece of wood fails in shearing across the grain. Hardness and shearing across the grain are closely related. The former is the more important quality, however, since abrasion and indentation, the two failures in hardness, are the common cause of loosening of tenons in the mortise, of the handle in the ax, etc.

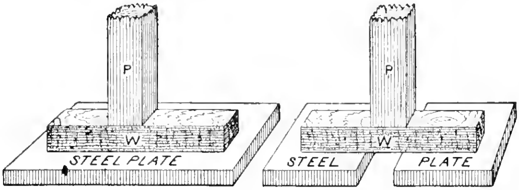

FIG. 32.—Test in hardness and shearing across the grain.

Heavy wood is harder than lighter wood; the wood of the butt, therefore, is harder than that of the top; the darker summer wood harder than the light-colored spring wood. Moisture softens, and seasoning, therefore, hardens wood.

Placing the rings vertical helps the wood to resist indentation. Though harder wood resists saw and chisel more than softer wood, the working quality of the wood is not always a safe criterion of its hardness.

The following indicates the hardness of our common woods:

1. Very hard woods requiring over 3,200 pounds per square inch to produce an indentation of one-twentieth inch: Hickory, hard maple, osage orange, black locust, persimmon, and the best of oak, elm, and hackberry.

2. Hard woods requiring over 2,400 pounds per square inch to produce an indentation of one-twentieth inch: Oak, elm, ash, cherry, birch, black walnut, beech, blue beech, mulberry, soft maple, holly, sour gum, honey locust, coffee tree, and sycamore.

3. Middling hard woods, requiring over 1,600 pounds per square inch to produce an indentation of one-twentieth inch: The better qualities of Southern and Western hard pine, tamarack and Douglas spruce, sweet gum, and the lighter qualities of birch.

4. Soft woods requiring less than 1,600 pounds per square inch to produce an indentation of one-twentieth inch: The greater mass of coniferous wood; pine, spruce, fir, hemlock, cedar, cypress, and redwood; poplar, tulip, basswood, butternut, chestnut, buckeye, and catalpa.

CLEAVABILITY.

When an ax is struck into a piece of wood as shown in fig. 33 the cleft projects beyond the blade of the ax and the process is not one of cutting, but of tension across the grain. The ax presses on a lever, *a b*, while the surface in which the transverse tension takes place is reduced almost to a line across the stick at *b*. If the wood is very elastic, the cleft runs far ahead of the ax, the lever arm *a b* is long, and the resistance to splitting proportionately small. Elasticity, therefore, helps splitting, while great shearing strength, a good measure for transverse tension and hardness hinder it.

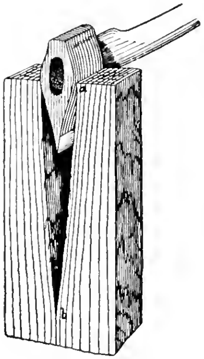

FIG. 33.—Cleavage.

Wood splits naturally along two normal planes, the most readily along the radius, because the arrangement of fibers and pith rays is radial, and next along the tangent, or with the annual rings, because the softer spring wood forms continuous planes in this direction. Cleavage along the radius, however, is from 50 to 100 per cent easier, and only in case of cross grain, etc., the cleavage along the ring becomes the easier. In the wood of conifers, wood fibers and pith rays are very regular, the former in perfect radial series or rows, and cleavage is, therefore, very easy in this direction. The same is brought about in the oak by the very high pith rays, but where they are thick and low, as in sycamore, and generally in the butt cuts and about knots, they impede cleavage by causing a greater irregularity in the course of the wood fibers. The greater the contrast of spring and summer wood, the easier the cleavage tangentially or in the direction of the rings. This is especially marked in conifers and also in woods like oak, ash, and elm, where the spring wood appears as a continuous series of large pores. Very slow growth influences tangential cleavage, narrow-ringed oak breaks out and splits less regularly even in a radial direction; in conifers, however, this difference scarcely exists. Weight of wood affects the cleavage but little; in heavy wood the entrance of the ax, to be sure, is resisted with more force, but the greater elasticity of the wood, on the other hand, counterbalances this resistance. Irregularities in the course of the fibers, whether spiral growth, crossgrain, or in form of knots, all aid in resisting cleavage. Knotty bolts are split more easily from the upper end, since the cleft then runs around the knots (see p. 23). Moisture softens the wood and reduces lateral adhesion, and therefore wood splits more easily when green than when dry.

FLEXIBILITY.

Pine is brittle, hickory is flexible; the former breaks, the latter bends. Being the opposite of stiffness, want of stiffness would seem to indicate flexibility. This, however, is only partly true; hickory and ash are stiff and yet among the most flexible of woods. Their small dimensions cause shavings and thin strands of most woods to appear pliable. For this reason the pliable, twisted wicker willow is not a fair measure of the flexibility of the wood of this species. Generally hard woods are more flexible than conifers, wood of the butt surpassing in this respect that of the main part of the stem, the latter being usually superior to that of the limbs. Moisture softens wood and thereby increases its flexibility. Knots and crossgrain diminish flexibility, but the irregular structure of elm, ash, etc. (particularly the arrangement of bodies of extremely firm fibers, like so many strands, among the softer tissue, as well as the interlacement of fibers, due to post-cambial growth), favorably influences the flexibility of these woods.

TOUGHNESS.

So far the load by which the exhibition of the various kinds of strength in compression, tension, cross bending, etc., was produced has always been assumed as applied slowly and gradually. When a wagon goes lumbering along a cobble pavement the load on the spokes is not thus applied. Every stone deals the wheel a blow, and a mile's journey means many thousand blows to every wheel rim and spoke. In chopping, the ax handle is jarred and a handle made of pine wood, which shears easily along the fiber, would soon be shattered to pieces. Loads thus applied are "shocks," and resistance to this form of loading requires a combination of various kinds of strength possessed only by "tough" woods. Toughness is a familiar word to woodworkers, and yet is rarely defined. Tough wood must be both strong and pliable. Thus a willow is not tough when dry; it is weak and brittle, and requires, notwithstanding its small lateral dimensions, to be moistened and twisted or sheared into still smaller strands so that its fibers are subjected almost exclusively to tension, if great deflection and great strength are to be combined (handles of wicker baskets). Hickory is both strong and pliable; in the dimensions of a willow twig it can be used almost like a rope. The term "tough," therefore, is properly applied to woods like hickory and elm and improperly to willow.

Judging from the behavior of elm and hickory, wood may be pronounced "tough" if it offers great resistance to—

(1) Longitudinal shearing over 1,000 pounds per square inch,
(2) Tension over 16,000 pounds per square inch,

and permits, when tested dry, of an aggregate distortion in compression and tension amounting to not less than 3 per cent.

For instance, of a piece of dry hickory (*H. alba*) we may expect—

Strength in shearing	pounds	1,200
Strength in tension	do	25,000
Distortion in tension	per cent	2.03
Distortion in compression	do	1.55
Total distortion	do	3.58

PRACTICAL CONCLUSIONS.

From the foregoing considerations a few valuable facts, mostly familiar to the thoughtful woodworker, may be deduced:

In *framing*, where light and stiff timber is wanted, the conifers excel; where heavy but steady loads are to be supported, the heavier conifers, hard pine, spruce, Douglas spruce, etc., answer as well as hard woods, which are costlier and heavier for the same amount of stiffness. On the other hand, if small dimensions must be used, and especially if moving loads are to be sustained, hard woods are safest, and in all cases where the load is applied in form of "shocks" or jars, only the tougher hard woods should be employed. The heavier wood surpasses the lighter of the same species in all kinds of strength, so that the weight of dry wood and the structural features indicative of weight may be used as safe signs in selecting timber for strength.

In *shaping* wood it is better, though more wasteful, to split than to saw, because it insures straight grain and enables a more perfect seasoning.

For *sawed stock* the method of "rift" or "quarter" sawing, which has so rapidly gained favor during the last decade, deserves every encouragement. It permits of better selection and of more advantageous disposition of the wood; rift-sawed lumber is stronger, wears better, seasons well, and is least subject to "working" or warping.

All hardwood material which *checks or warps* badly during seasoning should be reduced to the smallest practicable size before drying, to avoid the injuries involved in this process; and wood once seasoned should never again be exposed to the weather, since all injuries due to seasoning are thereby aggravated. Seasoning increases the strength of wood in every respect, and it is therefore of great importance to protect wooden structures, bearing heavy weights, against moisture.

Knots, like crossgrain and other defects, reduce the strength of timber. Where choice exists, the knotty side of the joist should be placed uppermost, i. e., should be used in compression.

Season checks in timber are always a source of weakness; they are more injurious on the vertical than on the horizontal faces of a stringer or joist, and their effect continues even when they have closed up, as many do, and are no longer visible.

Rafted timber, kiln-dried or steamed lumber are, as far as our present knowledge extends, as strong as other kinds, and wherever any of these processes aids in a more uniform or perfect seasoning, it increases the strength of the material.

Pine "bled" for turpentine is as strong as "unbled."

Time of felling, whether season of the year or phase of the moon, does not influence strength, except that summer-felled hard wood rarely seasons as perfectly as that felled in the fall, and to this extent an indirect influence may be observed, as well as by the fact that fungi and insects have a better opportunity for developing.

Warm countries and sunny exposures generally produce heavier and stronger timber, and conditions favorable to the growth of the species also improve its quality. But exceptions occur; neither fast nor slow growth is an infallible sign of strong wood, and it is the character of the annual ring, rather than its width, and particularly the proportion of summer wood, which determines the quality of the material.

VI.—CHEMICAL PROPERTIES OF WOOD.

Wood dried at 300° F. is composed of over 99 per cent of organic and less than 1 per cent of inorganic matter; the latter remains as ashes when wood is burned.

Wood consists of a skeleton of cellulose, permeated by a mixture of other organic substances, collectively designated by the name of lignin, and particles of mineral matter or ashes.

Cellulose is the common substance of which plant cells form their cases or walls; in flax, the entire fiber is almost pure cellulose, but the amount of cellulose obtained from wood, by the common processes, rarely exceeds one-half of its dry weight. Cellulose is identical in composition with starch, but unlike the latter it resists alcoholic fermentation, though the plants themselves, as well as decay-producing fungi, are able to reconvert it into starch, from which it seems originally derived, and also to change it into various forms of sugar.[1] Lignin is as yet a chemical puzzle. The substances forming it are carbohydrates like cellulose itself, but of slightly different proportions and distinguished by greater solubility in acids, and by other chemical properties.

In 100 pounds of wood (dried at 300° F.) and of cellulose the following proportions are found:

	Wood.	Cellulose.
	Pounds.	*Pounds.*
Carbon	49	44.4
Hydrogen	6	6.1
Oxygen	44	49.3

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[1] Chemists have succeeded in producing reconversion into grape sugar, and though the methods thus far employed are expensive, it is to be expected that in the near future wood will become the principal source of both vinegar and alcohol.

This composition of wood is fairly uniform for different species.

At ordinary temperatures wood is a very stable compound; both in air and under water it remains the same for centuries, and only when living organisms attack it with their strong solvents and convertants do change and decay set in.

Heated to 300° F. wood gives off only water, though some slight chemical changes are noticeable even at this temperature. If the heat is increased, gases of pungent odor and taste are evolved, and if the temperature is sufficiently raised, the gases are ignited, forming the flame of the fire, while the remaining solid part glows like an ignited charcoal, giving much heat, but no flame. The amount of heat produced by wood varies. If first dried at 300° F., 100 pounds of poplar wood should give as much heat as 100 pounds of hickory. In the natural state, however, this is not the case.

The beneficial effect of thorough seasoning for firewood appears from the following consideration:

One hundred pounds of wood as sold in the wood yards contains in round numbers 25 pounds of water, 74 pounds of wood, and 1 pound of ashes.

The 74 pounds of wood are composed of 37 pounds of carbon, 4.4 pounds of hydrogen, and 32 pounds of oxygen.

In burning (which is a process of oxidation) 4 pounds of hydrogen are already combined with 32 pounds of oxygen and there are only the 37 pounds of carbon and 0.4 pounds of hydrogen available in heat production. Thus only about one-half the weight of the wood substance itself is heat producing while every pound of water combined in the wood requires about 600 units of heat to evaporate it, and thus diminishes the value of the wood as fuel. Hence under the most favorable circumstances 100 pounds of green wood (50 per cent moisture) furnishes about 150,000 units[1] of heat; 100 pounds of half dry (30 per cent moisture) about 230,000 units; 100 pounds of air dry (20 per cent moisture) about 280,000 units; 100 hundred pounds of air dry (10 per cent moisture) about 320,000 units; 100 pounds of kiln-dry (2 per cent moisture) about 350,000 units.

In the ordinary stove or other small apparatus the evil effect of moisture in the wood is very much increased since combustion is materially interfered with.

One hundred pounds of ordinary charcoal furnishes 700,000 units of heat but the same quantity of charcoal produced at a temperature of 2,000° F. furnishes nearly 800,000 units of heat.

Conifers and the lighter hard woods produce more flame, while the heavy hard woods furnish a good bed of live coal and exceed the former by 25 to 30 per cent in production of heat with ordinary appliances.

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[1] A unit of heat in this case is the amount of heat which raises the temperature of 1 pound of water by 1.8° F. or 1° C.

Heated in a closed chamber or covered with earth, as in charcoal pits, the wood is prevented from burning and a variety of changes occur, depending on the rate of heating. If the temperature is raised gradually so that the wood is heated several hours before a temperature of 600° F. is reached the process is called dry distillation. In this process the wood is destroyed. It forms at first "red" or "brown" coal, still resembling wood, and finally charcoal proper. This coal is darker, heavier, conducts heat and electricity better, requires a greater heat to ignite, and produces more heat in burning the higher the temperature under which it is formed.

One hundred pounds of wood (dried at 300° F.) leaves only about 30 pounds of charcoal. In common practice much less charcoal (18 to 20 per cent) is produced. In this change from wood to coal the volume is diminished by about one-half, so that a cord of wood which contains about 100 cubic feet of wood solid would be converted into 50 cubic feet at best.

Of the 70 pounds of gaseous products which 100 pounds of wood lose, during coaling, in being heated up to 700° F., about 63 pounds become volatile before the temperature of 550° F. is reached.

If condensed in a cooler, about three-fourths of the 63 pounds of volatile matter first evolved is found to be wood-vinegar, from which about 4 pounds of pure acetic acid, the only source of perfectly pure vinegar, is obtained. Besides acetic acid, the liquid contains wood spirits and a quantity of various allied substances.

After the first stage of dry distillation, a large part of the products developed can not be liquefied in the ordinary cooler. They are gases like the illuminating gas, mostly belonging to the marsh gas series; they lack oxygen and thus show that the available oxygen has been nearly exhausted in the preceding part of the process. Products of the later stages are tars and heavy oils, volatile only at high temperatures. Here also belong the substances known collectively as wood creosote, employed as antiseptics in wood impregnation.

Warmed in dilute nitric acid with a little chlorate of potash, the cells of a piece of wood may be separated, each cell remains intact, but its wall is reduced in thickness and material; the lignin substances being dissolved out, only the cellulose is left. In commercial cellulose manufacture, soda, sulphates, and of late chiefly sulphites are substituted for the nitric acid. The wood is chipped, boiled in the respective solution under high pressures, the residue is washed, and the remaining cellulose bleached and ready for use. As a matter of economy the residual liquid is evaporated and the soda used over again.

When resinous wood, "fat pine," "lightwood," such as the knots and stumps of longleaf, pitch, and other pines, is heated in a kiln or retort, the resins ooze out, are collected, and in distillation with steam yield turpentine and rosin. The resins and their components vary with the species; the balsam of fir is limpid, its turpentine remains clear on exposure; the resin of pines is very viscid, their turpentines readily oxidize and darken when brought in contact with air. Resins are gathered more commonly either from cracks, such as "wind" and "ring shakes," as in the case of larch and fir (Venetian turpentine), or else from wounds made especially for this purpose, as in the case of naval stores gathered from pines. This latter process is known as "bleeding," "tapping," or "orcharding," and is at present the principal method of obtaining turpentines and rosins.

On burning resinous wood, wood tar, etc., in a smoldering fire, soot is deposited on the walls and partitions of the specially constructed soot pit. It is then collected, but must be freed of various products of dry distillation, by carefully heating to red heat before it becomes the lampblack used in printers' ink and otherwise much employed in the arts.

Many kinds of wood and the bark of most trees contain tannin. To serve in tanning the bark must contain at least 3 per cent of tannin; the kinds mostly used vary from 5 to 15 per cent, and even the best probably never furnish over 20 per cent in the average. The use of tan bark involves considerable disadvantages. It is difficult to dry and preserve, very liable to mold, bulky, and therefore expensive to ship and store, and very variable in the amount of tannin which it contains.

To avoid these difficulties the tannic compounds are, in recent times, leached out of the finely ground bark and wood, condensed by evaporation, and shipped as extracts containing 80 to 90 per cent of tannin.

The manufacture of pulp as well as the production of fiber capable of being spun and woven, are also technological uses of wood, which rely partly upon chemical reactions.

VII.—DURABILITY AND DECAY.

All wood is equally durable under certain conditions. Kept dry or submerged, it lasts indefinitely. Pieces of pine have been unearthed in Illinois which have lain buried 60 or more feet deep for many centuries. Deposits of sound logs of oak, buried for unknown ages, have been unearthed in Bavaria; parts of the piles of the lake dwellers, driven more than two thousand years ago, are still intact.

On the radial section of a piece of pine timber, with one of the shelf-like, fungus growths, as shown in fig. 34, both bark and wood are seen to be affected. A small particle of the half-decayed wood presents pictures like that of fig. 35. Slender, branching threads are seen to attach themselves closely to the walls of the cells, and to pierce these in all directions. Thus these little threads of fungus mycelium soon form a perfect network in the wood, and as they increase in number they dissolve the walls, and convert the wood substance and cell contents into sugar-like food for their own consumption. In some cases it is the woody cell wall alone that is attacked. In other cases they confine themselves to eating up the starch found in the cells, as shown in fig. 36, and merely leave a stain (bluing of lumber). In all cases of decay we find the vegetative bodies, these slender threads of fungi, responsible for the mischief. These fine threads are the vegetative body of the fungus, the little shelf is its fruiting body, on which it produces myriads of little spores (the seeds of fungi). Some fungi attack only conifers, others hard woods; many are confined to one species of tree and perhaps no one attacks all kinds of wood. One kind produces "red rot," others "bluing." In one case the decayed tracts are tubular, and in the direction of the fibers the wood is "peggy." In other cases no particular shapes are discernible.

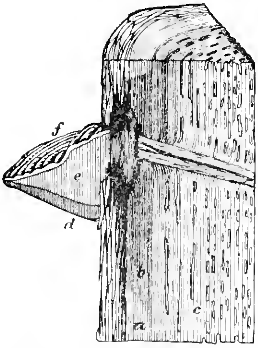

FIG. 34.—"Shelf" fungus on the stem of a pine. (Hartig.) *a*, sound wood; *b*, resinous "light" wood; *c*, partly decayed wood or punk; *d*, layer of living spore tubes; *e*, old filled up spore tubes; *f*, fluted upper surface of the fruiting body of the fungus, which gets its food through a great number of fine threads (the mycelium), its vegetative tissue penetrating the wood and causing its decay.

Cutting off a disk of loblolly pine, washing it, and then laying it in a clean, shady place in the sawmill, its sapwood will be found stained in a few days. Nor is this mischief confined to the surface; it penetrates the sapwood of the entire disk. From this it appears that the spores must have been in the air about the mill, and also that their germination and the growth of the threads or mycelium is exceedingly rapid. (Watching the progress of mold on a piece of bread teaches the same thing.) Placing a fresh piece of sapwood on ice, another into a dry kiln, and soaking a few others in solutions of corrosive sublimate (mercuric chloride) and other similar salts, we learn that the fungus growth is retarded by cold, prevented and killed by temperatures over 150° F., and that salts of mercury, etc., have the same effect. The fact that seasoned pieces if exposed are not so readily attacked by fungi shows that the moisture in air-dry wood is insufficient for fungus growth.

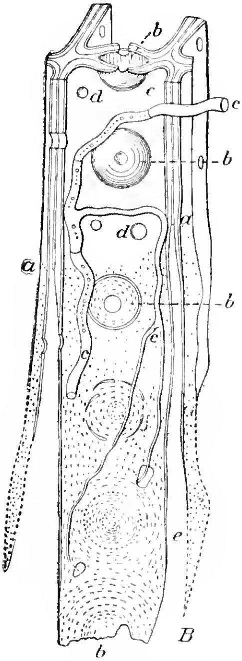

FIG. 35.—Fungus threads in pine wood. (Hartig.) *a*, cell wall of the wood fibers; *b*, bordered pits of these fibers; *c*, thread of mycelium of the fungus; *d*, holes in the cell walls made by the fungus threads, which gradually dissolve the walls as shown at *e*, and thus break down the wood structure.

From this it appears that warmth, preferably between 60° and 100° F., combined with abundance of moisture (but not immersion), is the most important condition favoring decay, and that the defense lies in the proper regulation or avoidance of these conditions, or else in the use of poisonous salts, which prevent the propagation of fungi.

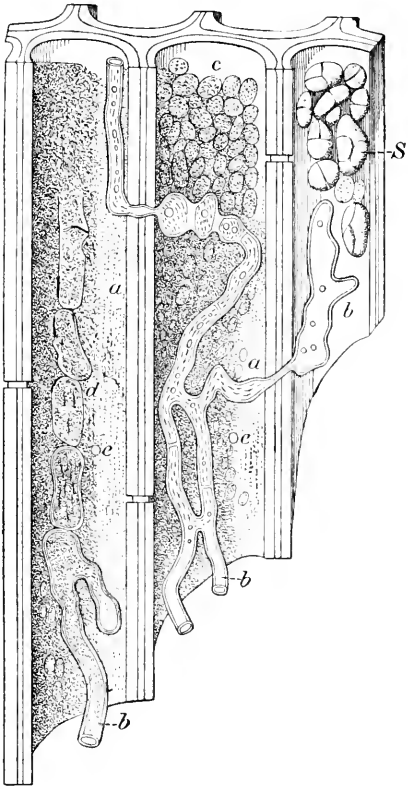

FIG. 36.—Cells of maple wood attacked by fungus threads (*Nectria cinnabarina* Mayer). Section of three wood fibers showing the threads of the fungus branching in their cavities and consuming the starch stored in these cells. *a*, interior or cavity of cells; *b*, threads of the fungus; *c*, partly destroyed starch grains; *d*, dead portions of the fungus thread together with débris; *e*, holes bored by the fungus through the cell walls; *S*, starch grains just being attacked.

It is also apparent, therefore, why wood decays faster in Alabama than in Wisconsin, faster in the swamps than on the plains, and why the presence of large quantities of decaying wood about the yard, constantly producing fresh supplies of spores, stimulates decay. Covering with tar or impregnating with creosote, salts of mercury, copper, etc., enables even sapwood to last under the most trying conditions. Contact with the ground assures most favorable moisture conditions for fungus growth, and the higher temperatures near the surface of the ground, together with the ever-present supply of spores, cause rot in a post to start at the surface more readily than 30 inches below.

The use of means to prevent decay is therefore desirable where timber is placed in positions favorable to fungus growth, as in railway ties; and all joists and timber in contact with damp brick walls, as also all building material whose perfect seasoning is prevented by the absence of proper circulation of air, should be specially protected. In the former cases it is economy to apply preservative processes; in the latter a sanitary necessity. Wood covered with paint, etc., before it is perfectly seasoned, falls a prey to "dry rot;" the fungus finds abundance of moisture, and the protection intended for the wood protects its enemy, the fungus. Since charcoal resists the solvents of fungi, charring the outer parts of posts makes, if well done, namely, so as not to open checks into the interior of the wood, a very fine protection.

Under ordinary circumstances, only the second great factor of decay, i. e., the moisture condition, can be controlled.

Perfect seasoning, preferably kiln-drying, before using, and protection against the entrance of moisture by tar, paints, and other covers, when put in place, prolong the life of wooden structures. Where such a covering is too expensive, good ventilation at least is necessary. Contact surfaces, where timber rests on timber or brick, should in all cases be especially protected.

Different species differ in their resistance to decay. Cedar is more durable than pine and oak better than beech, but in most cases the conditions of warmth and moisture in particular locations have so much to do with durability that often an oak post outlasts one of cedar, even in the same line of fence, and predictions of durability become mere guesswork.

Containing more ready-made food, and in forms acceptable to a great number of different kinds of fungi, the sapwood is more subject to decay than the heartwood, doubly so where the latter is protected by resinous substances, as in pine and cedar. Several months of immersion improves the durability of sapwood, but only impregnation with preservative salts seems to render it perfectly secure. Once attacked by fungi, wood becomes predisposed to further decay.

Wood cut in the fall is more durable than that cut in summer, only because the low temperature of the winter season prevents the attack of the fungi, and the wood is thus given a fair chance to dry. Usually summer-felled wood, on account of prevalent high temperature and exposure to sun, checks more than winter-felled wood, and since all season checks favor the entrance of both moisture and fungus, they facilitate destruction. Where summer-felled wood is worked up at once and protected by kiln-drying no difference exists. The phases of the moon have no influence whatever on durability.

In sawing timber much of the wood is bastard cut; at these places water enters much more readily, and for this reason split and hewn timber and ties generally resist decay perhaps better than if sawed.

The attacks of beetles, as well as those of the shipworm, can not here be considered; like chisel or saw they are mechanical injuries against which none of our woods are proof.

Range of durability in railroad ties.

	Years.		Years.
White oak and chestnut oak	8	Redwood	12
Chestnut	8	Cypress and red cedar	10
Black locust	10	Tamarack	7 to 8
Cherry, black walnut, locust	7	Longleaf pine	6
Elm	6 to 7	Hemlock	4 to 6
Red and black oaks	4 to 5	Spruce	5
Ash, beech, maple	4		

The durability of wood, exposed to the changes of the weather, and where painting, after thorough seasoning, is impracticable, is increased by impregnating it with various salts or other chemicals, which prevent the fungus from feeding on the wood. The wood is first steamed, to open the pores and remove the hardened surface coating of sap and dirt, and a liquid solution of the preservative material is then injected with the assistance of heat and pressure.

The most efficient fluids used on a large scale are bichloride of zinc and creosote, or both combined. The "life" of railroad ties is thereby increased to twice and three times its natural duration.

HOW TO DISTINGUISH THE DIFFERENT KINDS OF WOOD.

By B. E. FERNOW and FILIBERT ROTH.

The carpenter or other artisan who handles different woods becomes familiar with those he employs frequently, and learns to distinguish them through this familiarity, without usually being able to state the points of distinction. If a wood comes before him with which he is not familiar, he has, of course, no means of determining what it is, and it is possible to select pieces even of those with which he is well acquainted, different in appearance from the general run, that will make him doubtful as to their identification. Furthermore, he may distinguish between hard and soft pines, between oak and ash, or between maple and birch, which are characteristically different; but when it comes to distinguishing between the several species of pine or oak or ash or birch, the absence of readily recognizable characters is such that but few practitioners can be relied upon to do it. Hence, in the market we find many species mixed and sold indiscriminately.

To identify the different woods it is necessary to have a knowledge of the definite, invariable differences in their structure, besides that of the often variable differences in their appearance. These structural differences may either be readily visible to the naked eye or with a magnifier, or they may require a microscopical examination. In some cases such an examination can not be dispensed with, if we would make absolutely sure. There are instances, as in the pines, where even our knowledge of the minute anatomical structure is not yet sufficient to make a sure identification.

In the following key an attempt has been made—the first, so far as we know, in English literature—to give a synoptical view of the distinctive features of the commoner woods of the United States, which are found in the markets or are used in the arts. It will be observed that the distinction has been carried in most instances no further than to genera or classes of woods, since the distinction of species can hardly be accomplished without elaborate microscopic study, and also that, as far as possible, reliance has been placed only on such characteristics as can be distinguished with the naked eye or a simple magnifying glass, in order to make the key useful to the largest number. Recourse has also been taken for the same reason to the less reliable and more variable general external appearance, color, taste, smell, weight, etc.

The user of the key must, however, realize that external appearance, such, for example, as color, is not only very variable but also very difficult to describe, individual observers differing especially in seeing and describing shades of color. The same is true of statements of size, when relative, and not accurately measured, while weight and hardness can perhaps be more readily approximated. Whether any feature is distinctly or only indistinctly seen will also depend somewhat on individual eyesight, opinion, or practice. In some cases the resemblance of different species is so close that only one other expedient will make distinction possible, namely, a knowledge of the region from which the wood has come. We know, for instance, that no longleaf pine grows in Arkansas and that no white pine can come from Alabama, and we can separate the white cedar, giant arbor vitæ of the West and the arbor vitæ of the Northeast, only by the difference of the locality from which the specimen comes. With all these limitations properly appreciated, the key will be found helpful toward greater familiarity with the woods which are more commonly met with.

The features which have been utilized in the key and with which—their names as well as their appearance—therefore, the reader must familiarize himself before attempting to use the key, are mostly described as they appear in cross section. They are:

(1) Sapwood and heartwood (see p. 13), the former being the wood from the outer and the latter from the inner part of the tree. In some cases they differ only in shade, and in others in kind of color, the heartwood exhibiting either a darker shade or a pronounced color. Since one can not always have the two together, or be certain whether he has sapwood or heartwood, reliance upon this feature is, to be sure, unsatisfactory, yet sometimes it is the only general characteristic that can be relied upon. If further assurance is desired, microscopic structure must be examined; in such cases reference has been made to the presence or absence of tracheids in pith rays and the structure of their walls, especially projections and spirals.

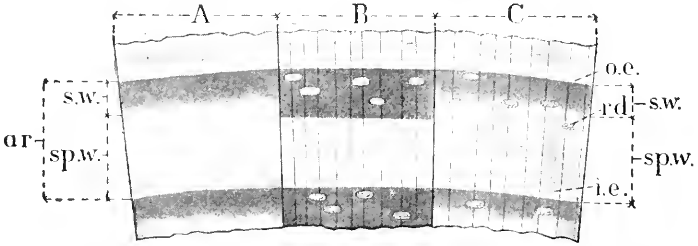

FIG. 37.—"Non-porous" woods. *A*, fir; *B*, "hard" pine; *C*, soft pine; *ar*, annual ring; *o. e.*, outer edge of ring; *i. e*, inner edge of ring; *s. w.*, summer wood; *sp. w*, spring wood; *rd*, resin ducts.

(2) Annual rings, their formation having been described on page 14. (See also figs. 37–39.) They are more or less distinctly marked, and by means of such marking a classification of three great groups of wood is possible.

(3) Spring wood and summer wood, the former being the interior (first formed wood of the year), the latter the exterior (last formed) part

of the ring. The proportion of each and the manner in which the one merges into the other are sometimes used, but more frequently the manner in which the pores appear distributed in either.

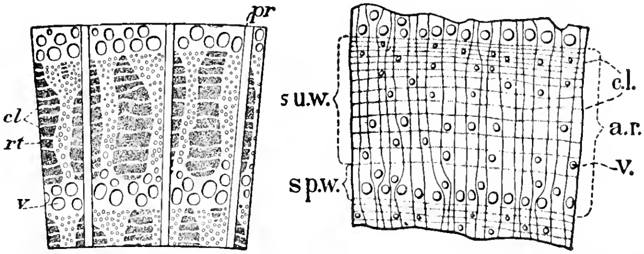

FIG. 38.—"Ring-porous" woods—white oak and hickory. *a. r.*, annual ring; *su. w.*, summer wood; *sp. w.*, spring wood; *v*, vessels or pores; *c. l.*, "concentric" lines; *rt*, darker tracts of hard fibers forming the firm part of oak wood; *pr*, pith rays.

(4) Pores, which are vessels cut through, appearing as holes in cross section, in longitudinal section as channels, scratches, or indentations. (See p. 19 and figs. 38 and 39.) They appear only in the broad-leaved, so called, hard woods; their relative size (large, medium, small, minute, and indistinct, when they cease to be visible individually by the naked eye) and manner of distribution in the ring being of much importance, and especially in the summer wood, where they appear singly, in groups, or short broken lines, in continuous concentric, often wavy, lines, or in radial branching lines.

(5) Resin ducts (see p. 16 and fig. 37), which appear very much like pores in cross section, namely, as holes or lighter or darker colored dots, but much more scattered. They occur only in coniferous woods, and their presence or absence, size, number, and distribution are an important distinction in these woods.

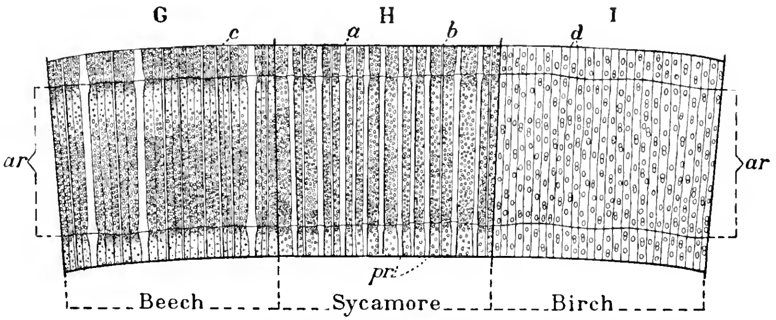

FIG. 39.—"Diffuse-porous" woods. *ar*, annual ring; *pr*, pith rays which are "broad" at *a*, "fine" at *b*, "indistinct" at *d*.

(6) Pith rays (see p. 17 and figs. 38 and 39), which in cross section appear as radial lines, and in radial section as interrupted bands of varying breadth, impart a peculiar luster to that section in some woods. They are most readily visible with the naked eye or with a magnifier in the

broad-leaved woods. In coniferous woods they are usually so fine and closely packed that to the casual observer they do not appear. Their breadth and their greater or less distinctness are used as distinguishing marks, being styled fine, broad, distinct, very distinct, conspicuous, and indistinct when no longer visible by the naked (strong) eye.

(7) Concentric lines, appearing in the summer wood of certain species more or less distinct, resembling distantly the lines of pores but much finer and not consisting of pores. (See fig. 38.)

Of microscopic features, the following only have been referred to:

(8) Tracheids, a description of which is to be found on page 20.

(9) Pits, simple and bordered, especially the number of simple pits in the cells of the pith rays, which lead into each of the adjoining tracheids.

For standards of weight, consult table on page 28; for standards of hardness, table on page 47.

Unless otherwise stated the color refers always to the fresh cross section of a piece of dry wood; sometimes distinct kinds of color, sometimes only shades, and often only general color effects appear.

HOW TO USE THE KEY.

Nobody need expect to be able to use successfully any key for the distinction of woods or of any other class of natural objects without some practice. This is especially true with regard to woods, which are apt to vary much, and when the key is based on such meager general data as the present. The best course to adopt is to supply one's self with a small sample collection of woods, accurately named. Small, polished tablets are of little use for this purpose. The pieces should be large enough, if possible, to include pith and bark, and of sufficient width to permit ready inspection of the cross section. By examining these with the aid of the key, beginning with the better-known woods, one will soon learn to see the features described and to form an idea of the relative standards which the maker of the key had in mind. To aid in this, the accompanying illustrations will be of advantage. When the reader becomes familiar with the key, the work of identifying any given piece will be comparatively easy. The material to be examined must, of course, be suitably prepared. It should be moistened; all cuts should be made with a very sharp knife or razor and be clean and smooth, for a bruised surface reveals but little structure. The most useful cut may be made along one of the edges. Instructive, thin, small sections may be made with a sharp penknife or razor, and when placed on a piece of thin glass, moistened and covered with another piece of glass, they may be examined by holding them toward the light.

Finding, on examination with the magnifier, that it contains pores, we know it is not coniferous or nonporous. Finding no pores collected in the spring-wood portion of the annual ring, but all scattered (diffused) through the ring, we turn at once to the class of "Diffuse-porous woods." We now note the size and manner in which the pores are distributed through the ring. Finding them very small and neither conspicuously grouped, nor larger nor more abundant in the spring wood, we turn to the third group of this class. We now note the pith rays, and finding them neither broad nor conspicuous, but difficult to distinguish, even with the magnifier, we at once exclude the wood from the first two sections of this group and place it in the third, which is represented by only one kind, cottonwood. Finding the wood very soft, white, and on the longitudinal section with a silky luster, we are further assured that our determination is correct. We may now turn to the list of woods and obtain further information regarding the occurrence, qualities, and uses of the wood.

Sometimes our progress is not so easy; we may waver in what group or section to place the wood before us. In such cases we may try each of the doubtful roads until we reach a point where we find ourselves entirely wrong and then return and take up another line; or we may anticipate some of the later-mentioned features and finding them apply to our specimen, gain additional assurance of the direction we ought to travel. Color will often help us to arrive at a speedy decision. In many cases, especially with conifers, which are rather difficult to distinguish, a knowledge of the locality from which the specimen comes is at once decisive. Thus, northern white cedar, and bald cypress, and the cedar of the Pacific will be identified, even without the somewhat indefinite criteria given in the key.

KEY TO THE MORE IMPORTANT WOODS OF NORTH AMERICA.

[The numbers preceding names refer to the List of Woods following the Key.]

I Non-porous woods—Pores not visible or conspicuous on cross section, even with magnifier. Annual rings distinct by denser (dark colored) bands of summer wood (fig. 37).

II. Ring-porous woods.—Pores numerous, usually visible on cross section without magnifier. Annual rings distinct by a zone of large pores collected in the spring wood, alternating with the denser summer wood (fig. 38).

III. Diffuse-porous woods.—Pores numerous, usually not plainly visible on cross section without magnifier. Annual rings distinct by a fine line of denser summer wood cells, often quite indistinct; pores scattered through annual ring, no zone of collected pores in spring wood (fig. 39).

NOTE.—The above described three groups are exogenous, i. e., they grow by adding annually wood on their circumference. A fourth group is formed by the endogenous woods, like yuccas and palms, which do not grow by such additions.

I.—NON-POROUS WOODS.

(Includes all coniferous woods.)

A. Resin ducts wanting.[1]

1. No distinct heartwood.
   - *a.* Color effect yellowish white; summer wood darker yellowish (under microscope pith ray without tracheids)..................(Nos. 9–13) FIRS.
   - *b.* Color effect reddish (roseate) (under microscope pith ray with tracheids), (Nos. 14 and 15) HEMLOCK.
2. Heartwood present, color decidedly different in kind from sapwood.
   - *a.* Heartwood light orange red; sapwood, pale lemon; wood, heavy and hard..(No. 38) YEW.

ADDITIONAL NOTES FOR DISTINCTIONS IN THE GROUP.

Spruce is hardly distinguishable from fir, except by the existence of the resin ducts, and microscopically by the presence of tracheids in the medullary rays. Spruce may also be confounded with soft pine, except for the heartwood color of the latter and the larger, more frequent, and more readily visible resin ducts.

In the lumber yard, hemlock is usually recognized by color and the slivery character of its surface. Western hemlocks partake of this last character to a less degree

Microscopically the white pine can be distinguished by having usually only one large pit, while spruce shows three to five very small pits in the parenchyma cells of the pith ray communicating with the tracheid.

The distinction of the pines is possible only by microscopic examination. The following distinctive features may assist in recognizing, when in the log or lumber pile, those usually found in the market:

The light, straw color, combined with great lightness and softness, distinguishes the white pines (white pine and sugar pine) from the hard pines (all others in the market), which may also be recognized by the gradual change of spring wood into summer wood. This change in hard pines is abrupt, making the summer wood appear as a sharply defined and more or less broad band.

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[1] To discover the resin ducts a very smooth surface is necessary, since resin ducts are frequently seen only with difficulty, appearing on the cross section as fine whiter or darker spots normally scattered singly, rarely in groups, usually in the summer wood of the annual ring. They are often much more easily seen on radial, and still more so on tangential sections, appearing there as fine lines or dots of open structure of different color or as indentations or pin scratches in a longitudinal direction.

b. Heartwood purplish to brownish red; sapwood yellowish white; wood soft to medium hard light, usually with aromatic odor . (No. 6) RED CEDAR.

c. Heartwood maroon to terra cotta or deep brownish red; sapwood light orange to dark amber, very soft and light, no odor; pith rays very distinct, specially pronounced on radial section........... (No. 7) REDWOOD.

3. Heartwood present, color only different in shade from sapwood, dingy-yellowish brown.

a. Odorless and tasteless........................... (No. 8) BALD CYPRESS.

b. Wood with mild resinous odor, but tasteless.... (Nos. 1-4) WHITE CEDAR.

c. Wood with strong resinous odor and peppery taste when freshly cut.. (No. 5) INCENSE CEDAR.

B. Resin ducts present.

1. No distinct heartwood; color white, resin ducts very small, not numerous, (Nos. 33-36) SPRUCE.

2. Distinct heartwood present.

a. Resin ducts numerous, evenly scattered through the ring.

a'. Transition from spring wood to summer wood gradual; annual ring distinguished by a fine line of dense summer-wood cells; color, white to yellowish red; wood soft and light....... (Nos. 18-21) SOFT PINES.[1]

b'. Transition from spring wood to summer wood more or less abrupt; broad bands of dark-colored summer wood; color from light to deep orange; wood medium hard and heavy .... (Nos. 22-32) HARD PINES.[1]

b. Resin ducts not numerous nor evenly distributed.

a'. Color of heartwood orange-reddish, sapwood yellowish (same as hard pine); resin ducts frequently combined in groups of 8 to 30, forming lines on the cross section (tracheids with spirals), (No. 37) DOUGLAS SPRUCE.

b'. Color of heartwood light russet brown; of sapwood yellowish brown; resin ducts very few, irregularly scattered (tracheids without spirals)............................. (Nos. 16 and 17) TAMARACK.

The Norway pine, which may be confounded with the shortleaf pine, can be distinguished by being much lighter and softer. It may also, but more rarely, be confounded with heavier white pine, but for the sharper definition of the annual ring, weight, and hardness.

The longleaf pine is strikingly heavy, hard, and resinous, and usually very regular and narrow ringed, showing little sapwood, and differing in this respect from the shortleaf pine and loblolly pine, which usually have wider rings and more sapwood, the latter excelling in that respect.

The following convenient and useful classification of pines into four groups, proposed by Dr. H. Mayr, is based on the appearance of the pith ray as seen in a radial section of the spring wood of any ring:

Section I. Walls of the tracheids of the pith ray with dentate projections.

a. One to two large, simple pits to each tracheid on the radial walls of the cells of the pith ray.—Group 1. Represented in this country only by *P. resinosa*.

b. Three to six simple pits to each tracheid, on the walls of the cells of the pith ray.—Group 2. *P. taeda*, *palustris*, etc., including most of our "hard" and "yellow" pines.

Section II. Walls of tracheids of pith ray smooth, without dentate projections.

a. One or two large pits to each tracheid on the radial walls of each cell of the pith ray.—Group 3. *P. strobus*, *lambertiana*, and other true white pines.

b. Three to six small pits on the radial walls of each cell of the pith ray. Group 4. *P. parryana*, and other nut pines, including also *P. balfouriana*.

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[1] Soft and hard pines are arbitrary distinctions and the two not distinguishable at the limit.

II.—RING-POROUS WOODS.

[Some of Group D and cedar elm imperfectly ring-porous.]

A. Pores in the summer wood minute, scattered singly or in groups, or in short broken lines, the course of which is never radial.
  1. Pith rays minute, scarcely distinct.
    a. Wood heavy and hard; pores in the summer wood not in clusters.
      a′ Color of radial section not yellow..................(Nos. 39–44) ASH.
      b.′ Color of radial section light yellow; by which, together with its hardness and weight, this species is easily recognized..(No. 103) OSAGE ORANGE.
    b. Wood light and soft; pores in the summer wood in clusters of 10 to 30, (No. 56) CATALPA.
  2. Pith rays very fine, yet distinct; pores in summer wood usually single or in short lines; color of heartwood reddish brown; of sapwood yellowish white; peculiar odor on fresh section ....(No. 111) SASSAFRAS.
  3. Pith rays fine, but distinct.
    a. Very heavy and hard; heartwood yellowish brown.(No. 77) BLACK LOCUST.
    b. Heavy; medium hard to hard.
      a.′ Pores in summer wood very minute, usually in small clusters of 3 to 8; heartwood light orange brown .... (No. 83) RED MULBERRY.
      b.′ Pores in summer wood small to minute, usually isolated; heartwood cherry red...................................(No. 61) COFFEE TREE.

ADDITIONAL NOTES FOR DISTINCTIONS IN THE GROUP.

Sassafras and mulberry may be confounded but for the greater weight and hardness and the absence of odor in the mulberry; the radial section of mulberry also shows the pith rays conspicuously.

Honey locust, coffee tree, and black locust are also very similar in appearance. The honey locust stands out by the conspicuousness of the pith rays, especially on radial sections, on account of their height, while the black locust is distinguished by the extremely great weight and hardness, together with its darker brown color.

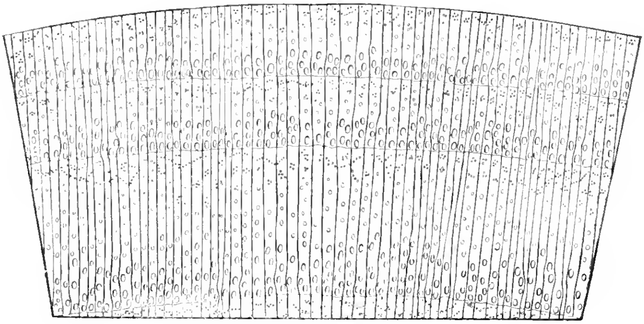

FIG. 40.—Wood of coffee tree.

The ashes, elms, hickories, and oaks may, on casual observation, appear to resemble one another on account of the pronounced zone of porous spring wood. The sharply defined large pith rays of the oak exclude these at once; the wavy lines of pores in the summer wood, appearing as conspicuous finely-feathered hatchings on tangential section, distinguish the elms; while the ashes differ from the hickory by the very conspicuously defined zone of spring-wood pores, which in hickory appear more or less interrupted. The reddish hue of the hickory and the more or less brown hue of the ash may also aid in ready recognition. The smooth, radial surface of split hickory will readily separate it from the rest.

4. Pith rays fine but very conspicuous, even without magnifier. Color of heartwood red; of sapwood pale lemon .... (No. 78) HONEY LOCUST.

B. Pores of summer wood minute or small, in concentric wavy and sometimes branching lines, appearing as finely-feathered hatchings on tangential section.
 1. Pith rays fine, but very distinct; color greenish white. Heartwood absent or imperfectly developed.............................(No. 70) HACKBERRY.
 2. Pith rays indistinct; color of heartwood reddish brown; sapwood grayish to reddish white .. ..(Nos. 62–66) ELMS.

C. Pores of summer wood arranged in radial branching lines (when very crowded radial arrangement somewhat obscured).
 1. Pith rays very minute, hardly visible..................(Nos. 58–60) CHESTNUT.
 2. Pith rays very broad and conspicuous.....................(Nos. 84–102) OAK.

D. Pores of summer wood mostly but little smaller than those of the spring wood, isolated and scattered; very heavy and hard woods. The pores of the spring wood sometimes form but an imperfect zone. (Some diffuse-porous woods of groups A and B may seem to belong here.)
 1. Fine concentric lines (not of pores) as distinct, or nearly so, as the very fine pith rays; outer summer wood with a tinge of red; heartwood light reddish brown ....(Nos. 71–75) HICKORY.
 2. Fine concentric lines, much finer than the pith rays; no reddish tinge in summer wood; sapwood white; heartwood blackish.
 (No. 105) PERSIMMON.

ADDITIONAL NOTES FOR DISTINCTIONS IN THE GROUP.

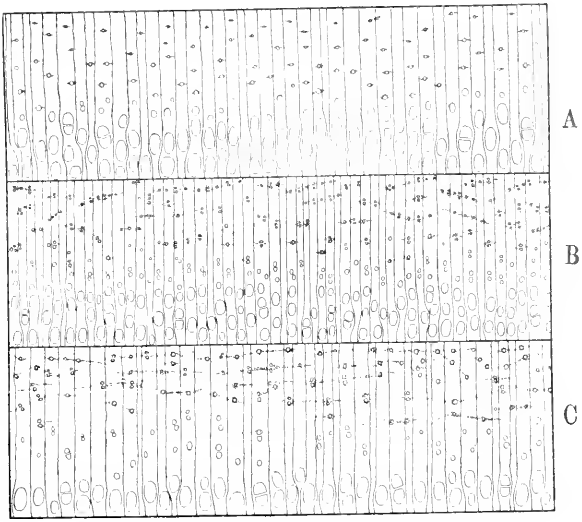

FIG. 41.—*A*, black ash; *B*, white ash; *C*, green ash.

The different species of ash may be identified as follows:
1. Pores in the summer wood more or less united into lines.
 a. The lines short and broken, occurring mostly near the limit of the ring .... (No 39) WHITE ASH.
 b. The lines quite long and conspicuous in most parts of the summer wood ....(No. 43) GREEN ASH.
2. Pores in the summer wood not united into lines, or rarely so.
 a. Heartwood reddish brown and very firm .... (No. 40) RED ASH.
 b. Heartwood grayish brown, and much more porous.. (No. 41) BLACK ASH.

ADDITIONAL NOTES—continued.

In the oaks, two groups can be readily distinguished by the manner in which the pores are distributed in the summer wood. In the white oaks the pores are very fine and numerous and crowded in the outer part of the summer wood, while in the black or red oaks the pores are larger, few in number, and mostly isolated. The live oaks, as far as structure is concerned, belong to the black oaks, but are much less porous, and are exceedingly heavy and hard.

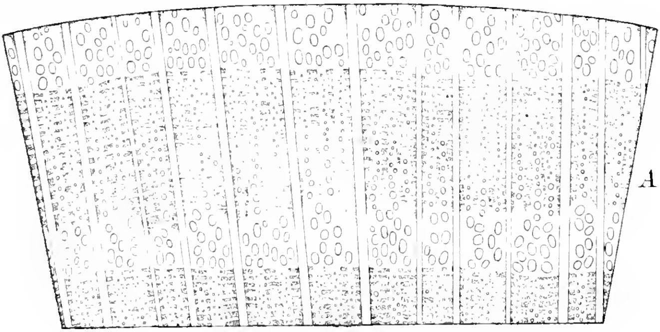

FIG. 42.—Wood of red oak. (For white oak see fig. 38.)

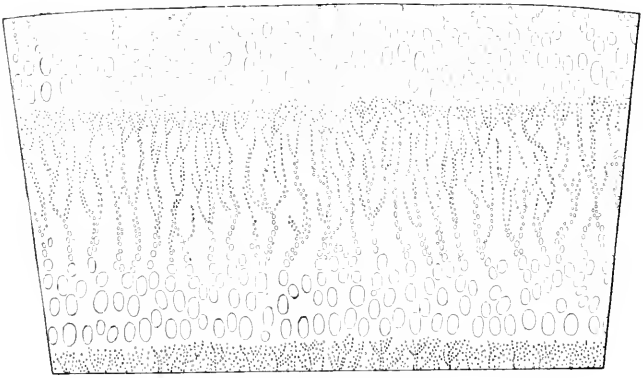

FIG. 43.—Wood of chestnut.

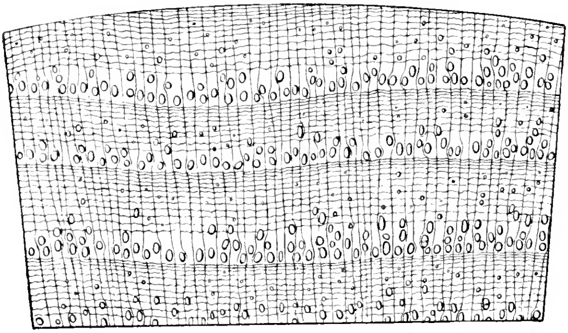

FIG. 44.—Wood of hickory.

III.—DIFFUSE-POROUS WOODS.

[A few indistinctly ring-porous woods of Group II, D, and cedar elm may seem to belong here.]

A. Pores varying in size from large to minute; largest in spring wood, thereby giving sometimes the appearance of a ring-porous arrangement.

- 1. Heavy and hard; color of heartwood (especially on longitudinal section) chocolate brown .... (No. 116) Black walnut.
- 2. Light and soft; color of heartwood light reddish brown . (No. 55) Butternut.

B. Pores all minute and indistinct; most numerous in spring wood, giving rise to a lighter colored zone or line (especially on longitudinal section), thereby appearing sometimes ring porous; wood hard, heartwood vinous reddish; pith rays very fine, but very distinct. (See also the sometimes indistinct ring-porous cedar elm, and occasionally winged elm, which are readily distinguished by the concentric wavy lines of pores in the summer wood) .... (No. 57) Cherry.

C. Pores minute or indistinct, neither conspicuously larger nor more numerous in the spring wood and evenly distributed.

- 1. Broad pith rays present.
  - *a*. All or most pith rays broad, numerous, and crowded, especially on tangential sections, medium heavy and hard, difficult to split. (Nos. 112 and 113) Sycamore.
  - *b*. Only part of the pith rays broad.
    - *a′*. Broad pith rays well defined, quite numerous; wood reddish-white to reddish .... (No. 47) Beech.
    - *b′*. Broad pith rays not sharply defined, made up of many small rays, not numerous. Stem furrowed, and therefore the periphery of section, and with it the annual rings sinuous, bending in and out, and the large pith rays generally limited to the furrows or concave portions. Wood white, not reddish .... (No. 52) Blue beech.
- 2. No broad pith rays present.
  - *a*. Pith rays small to very small, but quite distinct.
    - *a′*. Wood hard.
      - *a″*. Color reddish white, with dark reddish tinge in outer summer wood .... (Nos. 79–82) Maple.
      - *b″*. Color white, without reddish tinge .... (No. 76) Holly.
    - *b′*. Wood soft to very soft.
      - *a″*. Pores crowded, occupying nearly all the space between pith rays.
        - *a‴*. Color yellowish white, often a with greenish tinge in heartwood .... (No. 115) Tulip poplar, (No. 116) Cucumber tree,
        - *b‴*. Color of sapwood grayish, of heartwood light to dark reddish brown .... (No. 69) Sweet gum.
      - *b″*. Pores not crowded, occupying not over one-third the space between pith rays; heartwood brownish white to very light brown, (Nos. 45 and 46) Basswood.
  - *b*. Pith rays scarcely distinct, yet if viewed with ordinary magnifier, plainly visible.
    - *a′*. Pores indistinct to the naked eye.
      - *a″*. Color uniform pale yellow; pith rays not conspicuous even on the radial section .... (Nos. 53 and 54) Buckeye.
      - *b″*. Sapwood yellowish gray, heartwood grayish brown; pith rays conspicuous on the radial section .... (Nos. 67–68) Sour gum.
    - *b′*. Pores scarcely distinct, but mostly visible as grayish specks on the cross section; sapwood whitish, heartwood reddish .... (Nos. 48–51) Birch.

D. Pith rays not visible or else indistinct, even if viewed with magnifier.

- 1. Wood very soft, white, or in shades of brown, usually with a silky luster, (Nos. 105–110) Cottonwood (poplar.)

ADDITIONAL NOTES FOR DISTINCTIONS IN THE GROUP.

Cherry and birch are sometimes confounded, the high pith rays on the cherry on radial sections readily distinguishes it; distinct pores on birch and spring-wood zone in cherry as well as the darker vinous-brown color of the latter will prove helpful.

Two groups of birches can be readily distinguished, though specific distinction is not always possible.

1. Pith rays fairly distinct, the pores rather few and not more abundant in the spring wood; wood heavy, usually darker,
   (No. 48) CHERRY BIRCH and (No. 49) YELLOW BIRCH.
2. Pith rays barely distinct, pores more numerous and commonly forming a more porous spring-wood zone; wood of medium weight,
   (No. 51) CANOE OR PAPER BIRCH.

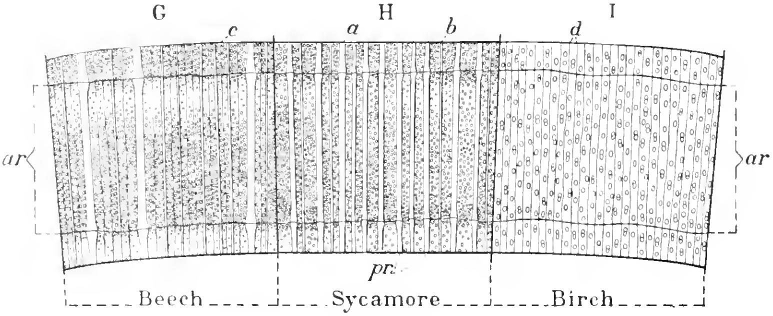

FIG. 45.—Wood of beech, sycamore, and birch.

The species of maple may be distinguished as follows:

1. Most of the pith rays broader than the pores and very conspicuous,
   (No. 79) SUGAR MAPLE.
2. Pith rays not or rarely broader than the pores, fine but conspicuous.
   - *a.* Wood heavy and hard, usually of darker reddish color and commonly spotted on cross section.............................. (No. 80) RED MAPLE.
   - *b.* Wood of medium weight and hardness, usually light colored,
     (No. 82) SILVER MAPLE.

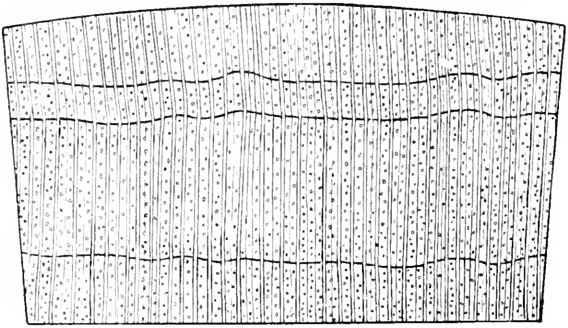

FIG. 46.—Wood of maple.

Red maple is not always safely distinguished from soft maple. In box elder the pores are finer and more numerous than in soft maple.

ADDITIONAL NOTES—continued.

The various species of elm may be distinguished as follows.

1. Pores of spring wood form a broad band of several rows; easy splitting, dark brown heart .... (No. 64) RED ELM.
2. Pores of spring wood usually in a single row, or nearly so.
   - *a.* Pores of spring wood large, conspicuously so ...... (No. 62) WHITE ELM.
   - *b.* Pores of spring wood small to minute.
     - *a′.* Lines of pores in summer wood fine, not as wide as the intermediate spaces, giving rise to very compact grain......... (No. 63) ROCK ELM.
     - *b′.* Lines of pores broad, commonly as wide as the intermediate spaces, (No. 66) WINGED ELM.
   - *c.* Pores in spring wood indistinct, and therefore hardly a ring-porous wood .... (No. 65) CEDAR ELM.

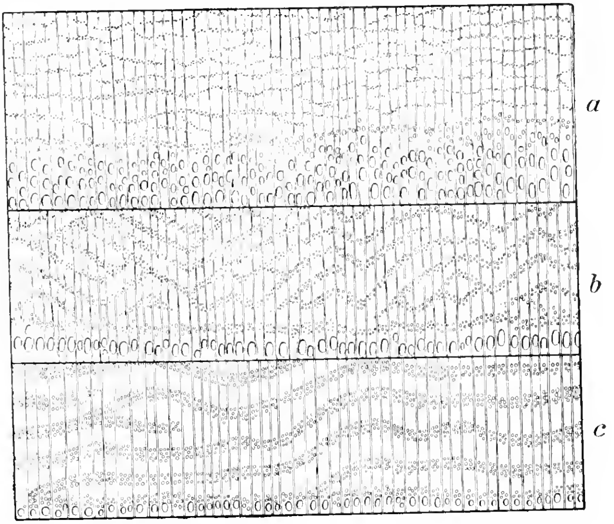

FIG. 47.—Wood of elm. *a*, red elm; *b*, white elm; *c*, winged elm.

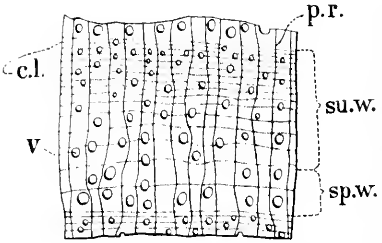

FIG. 48.—Walnut. *p. r.*, pith rays; *c. l.*, concentric lines; *v*, vessels or pores; *su. w.*, summer wood; *sp. w.*, spring wood.

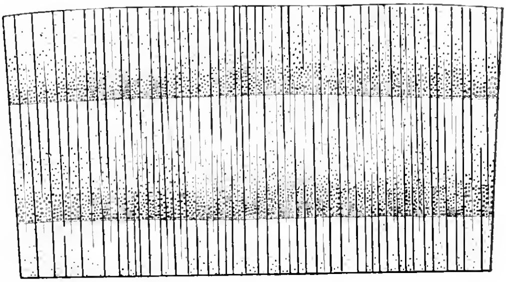

FIG. 49.—Wood of cherry.

LIST OF THE MORE IMPORTANT WOODS OF THE UNITED STATES.

[Arranged alphabetically.]

A.—CONIFEROUS WOODS.

Woods of simple and uniform structure, generally light, soft but stiff; abundant in suitable dimensions and forming by far the greatest part of all the lumber used

CEDAR.—Light, soft, stiff, not strong, of fine texture; sap and heartwood distinct, the former lighter, the latter a dull, grayish brown, or red. The wood seasons rapidly, shrinks and checks but little, and is very durable. Used like soft pine, but owing to its great durability preferred for shingles, etc. Small sizes used for posts, ties, etc.[1] Cedars usually occur scattered, but they form, in certain localities, forests of considerable extent.

a. **White cedars.**—Heartwood a light grayish brown.

1. White cedar (*Thuya occidentalis*) (Arborvitæ): Scattered along streams and lakes, frequently covering extensive swamps; rarely large enough for lumber, but commonly used for posts, ties, etc. Maine to Minnesota and northward.
2. Canoe cedar (*Thuya gigantea*)(red cedar of the West): In Oregon and Washington a very large tree, covering extensive swamps; in the mountains much smaller, skirting the water courses; an important lumber tree. Washington to northern California and eastward to Montana.
3. White cedar(*Chamæcyparis thyoides*): Medium-sized tree, wood very light and soft. Along the coast from Maine to Mississippi.
4. White cedar (*Chamæcyparis lawsoniana*) (Port Orford cedar, Oregon cedar, Lawson's cypress, ginger pine): A very large tree, extensively cut for lumber; heavier and stronger than the preceding. Along the coast line of Oregon.
5. White cedar (*Libocedrus decurrens*) (incense cedar): A large tree, abundantly scattered among pine and fir; wood fine grained. Cascades and Sierra Nevada of Oregon and California.

b. **Red cedars.**—Heartwood red.

6. Red cedar (*Juniperus virginiana*) (Savin juniper): Similar to white cedar, but of somewhat finer texture. Used in cabinetwork in cooperage, for veneers, and especially for lead pencils, for which purpose alone several million feet are cut each year. A small to medium sized tree scattered through the forests, or, in the West, sparsely covering extensive areas (cedar brakes). The red cedar is the most widely distributed conifer of the United States, occurring from the Atlantic to the Pacific and from Florida to Minnesota, but attains a suitable size for lumber only in the Southern, and more especially the Gulf, States.
7. Redwood (*Sequoia sempervirens*): Wood in its quality and uses like white cedar; the narrow sapwood whitish; the heartwood light red, soon turning to brownish red when exposed. A very large tree, limited to the coast ranges of California, and forming considerable forests, which are rapidly being converted into lumber.

CYPRESS.

8. Cypress (*Taxodium distichum*) (bald cypress; black, white, and red cypress): Wood in appearance, quality, and uses similar to white cedar. "Black

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[1] Since almost all kinds of woods are used for fuel and charcoal, and in the construction of fences, sheds, barns, etc., the enumeration of these uses has been omitted in this list.

cypress" and "white cypress" are heavy and light forms of the same species. The cypress is a large deciduous tree, occupying much of the swamp and overflow land along the coast and rivers of the Southern States.

FIR.—This name is frequently applied to wood and to trees which are not fir; most commonly to spruce, but also, especially in English markets, to pine. It resembles spruce, but is easily distinguished from it, as well as from pine and larch, by the absence of resin ducts. Quality, uses, and habits similar to spruce.

9. BALSAM fir (*Abies balsamea*): A medium-sized tree scattered throughout the northern pineries; cut, in lumber operations whenever of sufficient size, and sold with pine or spruce. Minnesota to Maine and northward.

10. WHITE FIR (*Abies grandis* and *Abies concolor*): Medium to very large sized tree, forming an important part of most of the Western mountain forests, and furnishing much of the lumber of the respective regions. The former occurs from Vancouver to central California and eastward to Montana; the latter from Oregon to Arizona and eastward to Colorado and New Mexico.

11. WHITE FIR (*Abies amabilis*): Good-sized tree, often forming extensive mountain forests. Cascade Mountains of Washington and Oregon.

12. RED FIR (*Abies nobilis*) (not to be confounded with Douglas fir; see No. 37): Large to very large tree, forming with *A. amabilis* extensive forests on the slope of the mountains between 3,000 and 4,000 feet elevation. Cascade Mountains of Oregon.

13. RED FIR (*Abies magnifica*): Very large tree, forming forests about the base of Mount Shasta. Sierra Nevada of California, from Mount Shasta southward.

HEMLOCK.—Light to medium weight, soft, stiff but brittle, commonly crossgrained, rough and splintery; sapwood and heartwood not well defined; the wood of a light, reddish-gray color, free from resin ducts, moderately durable, shrinks and warps considerably, wears rough, retains nails firmly. Used principally for dimension stuff and timbers. Hemlocks are medium to large sized trees, commonly scattered among broad-leaved trees and conifers, but often forming forests of almost pure growth.

14. HEMLOCK (*Tsuga canadensis*): Medium-sized tree, furnishes almost all the hemlock of the Eastern market. Maine to Wisconsin; also following the Alleghanies southward to Georgia and Alabama.

15. HEMLOCK (*Tsuga mertensiana*): Large-sized tree, wood claimed to be heavier and harder than the Eastern form and of superior quality. Washington to California and eastward to Montana.

LARCH OR TAMARACK.—Wood like the best of hard pine, both in appearance, quality, and uses, and owing to its great durability, somewhat preferred in shipbuilding, for telegraph poles, and railroad ties. In its structure it resembles spruce. The larches are deciduous trees, occasionally covering considerable areas, but usually scattered among other conifers.

16. TAMARACK (*Larix americana*) (Hackmatack): Medium-sized tree, often covering swamps, in which case it is smaller and of poor quality. Maine to Minnesota, and southward to Pennsylvania.

17. TAMARACK (*L. occidentalis*): Large-sized trees, scattered, locally abundant. Washington and Oregon to Montana.

PINE.—Very variable, very light and soft in "soft" pine, such as white pine; of medium weight to heavy and quite hard in "hard" pine, of which longleaf or Georgia pine is the extreme form. Usually it is stiff, quite strong, of even texture, and more or less resinous. The sapwood is yellowish white; the heartwood, orange brown. Pine shrinks moderately, seasons rapidly and without much injury; it works easily; is never too hard to nail (unlike oak or hickory); it is mostly quite durable, and if well seasoned is not subject to the attacks of boring insects. The heavier the wood, the darker, stronger, and harder it is, and the more it shrinks and checks. Pine is used more extensively than any other kind of wood. It is the principal wood in common carpentry, as well as in all heavy construction, bridges, trestles, etc. It is also used in almost every other wood industry, for spars, masts, planks, and timbers in shipbuilding, in car and wagon construction, in cooperage, for crates and boxes, in furniture work, for toys and patterns, railway ties, water pipes, excelsior, etc. Pines are usually large trees with few branches, the straight, cylindrical, useful stem forming by far the greatest part of the tree; they occur gregariously, forming vast forests, a fact which greatly facilitates their exploitation. Of the many special terms applied to pine as lumber, denoting sometimes differences in quality, the following deserve attention:

"White pine," "pumpkin pine," "soft pine," in the Eastern markets refer to the wood of the white pine (*Pinus strobus*), and on the Pacific Coast to that of the sugar pine (*Pinus lambertiana*).

"Yellow pine" is applied in the trade to all the Southern lumber pines; in the Northeast it is also applied to the pitch pine (*P. rigida*); in the West it refers mostly to bull pine (*P. ponderosa*).

"Yellow longleaf pine," "Georgia pine," chiefly used in advertisement, refers to longleaf pine (*P. palustris*).

"Hard pine" is a common term in carpentry, and applies to everything except white pine.

"Pitch pine" includes all Southern pines and also the true pitch pine (*P. rigida*), but is mostly applied, especially in foreign markets, to the wood of the longleaf pine (*P. palustris*).

For the great variety of confusing local names applied to the Southern pines in their homes, part of which have been adopted in the markets of the Atlantic seaboard, see report of Chief of Division of Forestry for 1891, page 212, etc., and also the list below:

a. **Soft pines.**

18. WHITE PINE (*Pinus strobus*): Large to very large sized tree; for the last fifty years the most important timber tree of the Union, furnishing the best quality of soft pine. Minnesota, Wisconsin, Michigan, New England, along the Alleghanies to Georgia.

19. SUGAR PINE (*Pinus lambertiana*): A very large tree, together with *Abies concolor*, forming extensive forests; important lumber tree. Oregon and California.

20. WHITE PINE (*Pinus monticola*): A large tree, at home in Montana, Idaho, and the Pacific States; most common and locally used in northern Idaho.

21. WHITE PINE (*Pinus flexilis*): A small tree, forming mountain forests of considerable extent and locally used; Eastern Rocky Mountain slopes; Montana to New Mexico.

b. **Hard pines.**

22. LONGLEAF PINE (*Pinus palustris*) (Georgia pine, yellow pine, long straw pine, etc.): Large tree; forms extensive forests and furnishes the hardest and strongest pine lumber in the market. Coast region from North Carolina to Texas.

23. BULL PINE (*Pinus ponderosa*) (yellow pine): Medium to very large sized tree, forming extensive forests in Pacific and Rocky Mountain regions; furnishes most of the hard pine of the West; sapwood wide; wood very variable.

24. LOBLOLLY PINE (*Pinus tæda*) (slash pine, old field pine, rosemary pine, sap pine, short straw pine, etc.): Large-sized tree, forms extensive forests; wider-ringed, coarser, lighter, softer, with more sapwood than the longleaf pine, but the two often confounded. This is the common lumber pine from Virginia to South Carolina, and is found extensively in Arkansas and Texas. Southern States; Virginia to Texas and Arkansas.

25. NORWAY PINE (*Pinus resinosa*): Large-sized tree, never forming forests, usually scattered or in small groves, together with white pine; largely sapwood and hence not durable. Minnesota to Michigan; also in New England to Pennsylvania.

26. SHORTLEAF PINE (*Pinus echinata*) (slash pine, Carolina pine, yellow pine, old field pine, etc.): Resembles loblolly pine; often approaches in its wood the Norway pine. The common lumber pine of Missouri and Arkansas. North Carolina to Texas and Missouri.

27. CUBAN PINE (*Pinus cubensis*) (slash pine, swamp pine, bastard pine, meadow pine): Resembles longleaf pine, but commonly has wider sapwood and coarser grain; does not enter the markets to any great extent. Along the coast from South Carolina to Louisiana.

28. BULL PINE (*Pinus jeffreyi*) (black pine): Large-sized tree, wood resembling bull pine (*P. ponderosa*); used locally in California, replacing *P. ponderosa* at high altitudes.

The following are small to medium sized pines, not commonly offered as lumber in the market; used locally for timber, ties, etc.:

29. BLACK PINE (*Pinus murrayana*) (lodge-pole pine, tamarack): Rocky Mountains and Pacific regions.

30. PITCH PINE (*Pinus rigida*): Along the coast from New York to Georgia and along the mountains to Kentucky.

31. JERSEY PINE (*Pinus inops*) (scrub pine): As before.

32. GRAY PINE (*Pinus banksiana*) (scrub pine): Maine, Vermont, and Michigan to Minnesota.

REDWOOD. (*See* CEDAR.)

SPRUCE.—Resembles soft pine, is light, very soft, stiff, moderately strong, less resinous than pine; has no distinct heartwood, and is of whitish color. Used like soft pine, but also employed as resonance wood and preferred for paper pulp. Spruces, like pines, form extensive forests; they are more frugal, thrive on thinner soils, and bear more shade, but usually require a more humid climate. "Black" and "white spruce," as applied by lumbermen, usually refer to narrow and wide ringed forms of the black spruce (*Picea nigra*).

33. BLACK SPRUCE (*Picea nigra*): Medium-sized tree, forms extensive forests in northeastern United States and in British America; occurs scattered or in groves, especially in low lands throughout the Northern pineries. Important lumber tree in Eastern United States. Maine to Minnesota, British America, and on the Alleghanies to North Carolina.

34. WHITE SPRUCE (*Picea alba*): Generally associated with the preceding; most abundant along streams and lakes, grows largest in Montana and forms the most important tree of the subarctic forest of British America. Northern United States, from Maine to Minnesota, also from Montana to Pacific, British America.

35. WHITE SPRUCE (*Picea engelmanni*): Medium to large sized tree, forming extensive forests at elevations from 5,000 to 10,000 feet above sea level; resembles the preceding, but occupies a different station. A very important timber tree in the central and southern parts of the Rocky Mountains. Rocky Mountains from Mexico to Montana.

36. TIDE-LAND SPRUCE (*Picea sitchensis*): A large-sized tree, forming an extensive coast-belt forest. Along the seacoast from Alaska to Central California.

BASTARD SPRUCE.—Spruce or fir in name but resembling hard pine or larch in the appearance, quality, and uses of its wood.

37. DOUGLAS SPRUCE (*Pseudotsuga douglasii*) (yellow fir, red fir, Oregon pine): One of the most important trees of the Western United States; grows very large in the Pacific States, to fair size in all parts of the mountains, in Colorado up to about 10,000 feet above sea level; forms extensive forests, often of pure growth. Wood very variable, usually coarsegrained and heavy, with very pronounced summer wood, hard and strong ("red" fir), but often fine-grained and light ("yellow" fir). It replaces hard pine and is especially suited to heavy construction. From the plains to the Pacific Ocean; from Mexico to British America.

TAMARACK. (*See* LARCH.)

YEW.—Wood heavy, hard, extremely stiff and strong, of fine texture with a pale yellow sapwood, and an orange red heart; seasons well and is quite durable. Yew is extensively used for archery, bows, turner's ware, etc. The yews form no forests, but occur scattered with other conifers.

38. YEW (*Taxus brevifolia*): A small to medium sized tree of the Pacific region.

B.—BROAD-LEAVED WOODS (HARDWOODS).

Woods of complex and very variable structure and therefore differing widely in quality, behavior, and consequently in applicability to the arts.

ASH.—Wood heavy, hard, strong, stiff, quite tough, not durable in contact with soil, straight grained, rough on the split surface and coarse in texture. The wood shrinks moderately, seasons with little injury, stands well and takes a good polish. In carpentry ash is used for finishing lumber, stairways, panels, etc.; it is used in shipbuilding, in the construction of cars, wagons, carriages, etc., in the manufacture of farm implements, machinery, and especially of furniture of all kinds, and also for harness work; for barrels, baskets, oars, tool handles, hoops, clothespins, and toys. The trees of the several species of ash are rapid growers, of small to medium height with stout trunks; they form no forests, but occur scattered in almost all our broad-leaved forests.

39. WHITE ASH (*Fraxinus americana*): Medium, sometimes large sized tree. Basin of the Ohio, but found from Maine to Minnesota and Texas.

40. RED ASH (*Fraxinus pubescens*): Small-sized tree. North Atlantic States, but extends to the Mississippi.

41. BLACK ASH (*Fraxinus sambucifolia*) (hoop ash, ground ash): Medium-sized tree, very common. Maine to Minnesota, and southward to Virginia and Arkansas.

42. BLUE ASH (*Fraxinus quadrangulata*): Small to medium sized. Indiana and Illinois; occurs from Michigan to Minnesota and southward to Alabama.

43. GREEN ASH (*Fraxinus viridis*): Small-sized tree. New York to the Rocky Mountains, and southward to Florida and Arizona.

44. OREGON ASH (*Fraxinus oregana*): Medium-sized tree. Western Washington to California.

ASPEN. (*See* POPLAR.)

BASSWOOD.

45. BASSWOOD (*Tilia americana*) (lime tree, American linden, lin, bee tree): Wood light, soft, stiff but not strong, of fine texture, and white to light brown color. The wood shrinks considerably in drying, works and stands well; it is used in carpentry, in the manufacture of furniture and woodenware, both turned and carved, in cooperage, for toys, also for paneling of car and carriage bodies. Medium to large sized tree, common in all Northern broad-leaved forests; found throughout the Eastern United States.

46. WHITE BASSWOOD (*Tilia heterophylla*): A small-sized tree most abundant in the Alleghany region.

BEECH.

47. BEECH (*Fagus ferruginea*): Wood heavy, hard, stiff, strong, of rather coarse texture, white to light brown, not durable in the ground, and subject to the inroads of boring insects; it shrinks and checks considerably in drying, works and stands well and takes a good polish. Used for furniture, in turnery, for handles, lasts, etc. Abroad it is very extensively employed by the carpenter, millwright, and wagon maker, in turnery as well as wood carving. The beech is a medium-sized tree, common, sometimes forming forest; most abundant in the Ohio and Mississippi basin, but found from Maine to Wisconsin and southward to Florida.

BIRCH.—Wood heavy, hard, strong, of fine texture; sapwood whitish, heartwood in shades of brown with red and yellow; very handsome, with satiny luster, equaling cherry. The wood shrinks considerably in drying, works and stands well and takes a good polish, but is not durable, if exposed. Birch is used for finishing lumber in building, in the manufacture of furniture, in wood turnery for spools, boxes, wooden shoes, etc., for shoe lasts and pegs, for wagon hubs, ox yokes, etc., also in wood carving. The birches are medium-sized trees, form extensive forests northward and occur scattered in all broad-leaved forests of the Eastern United States.

48. CHERRY BIRCH (*Betula lenta*) (black birch, sweet birch, mahogany birch): Medium-sized tree; very common. Maine to Michigan and to Tennessee.

49. YELLOW BIRCH (*Betula lutea*) (gray birch): Medium-sized tree; common. Maine to Minnesota and southward to Tennessee.

50. RED BIRCH (*Betula nigra*) (river birch): Small to medium sized tree; very common; lighter and less valuable than the preceding. New England to Texas and Missouri.

51. CANOE BIRCH (*Betula papyrifera*) (white birch, paper birch): Generally a small tree; common, forming forests; wood of good quality but lighter. All along the northern boundary of United States and northward, from the Atlantic to the Pacific.

BLACK WALNUT. (*See* WALNUT.)

BLUE BEECH.

52. BLUE BEECH (*Carpinus caroliniana*) (hornbeam, water beech, ironwood): Wood very heavy, hard, strong, very stiff, of rather fine texture and white color; not durable in the ground; shrinks and checks greatly, but works and stands well. Used chiefly in turnery for tool handles, etc. Abroad, much used by mill and wheel wrights. A small tree, largest in the Southwest, but found in nearly all parts of the Eastern United States.

BOIS D'ARC. (*See* OSAGE ORANGE.)

BUCKEYE—HORSE CHESTNUT.—Wood light, soft, not strong, often quite tough, of fine and uniform texture and creamy white color. It shrinks considerably, but works and stands well. Used for wooden ware, artificial limbs, paper pulp, and locally also for building lumber. Small-sized trees, scattered.

53. OHIO BUCKEYE (*Æsculus glabra*) (fetid buckeye): Alleghanies, Pennsylvania to Indian Territory.

54. SWEET BUCKEYE (*Æsculus flava*): Alleghanies, Pennsylvania to Texas.

BUTTERNUT.

55. BUTTERNUT (*Juglans cinerea*) (white walnut): Wood very similar to black walnut, but light, quite soft, not strong and of light brown color. Used chiefly for finishing lumber, cabinetwork, and cooperage. Medium-sized tree, largest and most common in the Ohio basin; Maine to Minnesota and southward to Georgia and Alabama.

CATALPA.

56. CATALPA (*Catalpa speciosa*): Wood light, soft, not strong, brittle, durable, of coarse texture and brown color; used for ties and posts, but well suited for a great variety of uses. Medium-sized tree; lower basin of the Ohio River, locally common. Extensively planted, and therefore promising to become of some importance.

CHERRY.

57. CHERRY (*Prunus serotina*): Wood heavy, hard, strong, of fine texture; sapwood yellowish white, heartwood reddish to brown. The wood shrinks considerably in drying, works and stands well, takes a good polish, and is much esteemed for its beauty. Cherry is chiefly used as a decorative finishing lumber for buildings, cars, and boats, also for furniture and in turnery. It is becoming too costly for many purposes for which it is naturally well suited. The lumber-furnishing cherry of this country, the wild black cherry (*Prunus serotina*), is a small to medium sized tree, scattered through many of the broad-leaved woods of the western slope of the Alleghanies, but found from Michigan to Florida and west to Texas. Other species of this genus as well

as the hawthorns (*Cratægus*) and wild apple (*Pyrus*) are not commonly offered in the market. Their wood is of the same character as cherry, often even finer, but in small dimensions.

CHESTNUT.

58. CHESTNUT (*Castanea vulgaris* var. *americana*): Wood light, moderately soft, stiff, not strong, of coarse texture; the sapwood light, the heartwood darker brown. It shrinks and checks considerably in drying, works easily, stands well, and is very durable. Used in cabinetwork, cooperage, for railway ties, telegraph poles, and locally in heavy construction. Medium-sized tree, very common in the Alleghanies, occurs from Maine to Michigan and southward to Alabama.

59. CHINQUAPIN (*Castanea pumila*): A small-sized tree, with wood slightly heavier but otherwise similar to the preceding; most common in Arkansas, but with nearly the same range as the chestnut.

60. CHINQUAPIN (*Castanopsis chrysophylla*): A medium-sized tree of the western ranges of California and Oregon.

COFFEE TREE.

61. COFFEE TREE (*Gymnocladus canadensis*) (coffee nut): Wood heavy, hard, strong, very stiff, of coarse texture, durable; the sapwood yellow, the heartwood reddish brown; shrinks and checks considerably in drying; works and stands well and takes a good polish. It is used to a limited extent in cabinetwork. A medium to large sized tree; not common. Pennsylvania to Minnesota and Arkansas.

COTTONWOOD. (*See* POPLAR.)

CUCUMBER TREE. (*See* TULIP.)

ELM.—Wood heavy, hard, strong, very tough; moderately durable in contact with the soil; commonly crossgrained, difficult to split and shape, warps, and checks considerably in drying, but stands well if properly handled. The broad sapwood whitish, heart brown, both with shades of gray and red; on split surface rough; texture coarse to fine; capable of high polish. Elm is used in the construction of cars, wagons, etc., in boat and ship building, for agricultural implements and machinery; in rough cooperage, saddlery and harness work, but particularly in the manufacture of all kinds of furniture, where the beautiful figures, especially those of the tangential or bastard section, are just beginning to be duly appreciated. The elms are medium to large sized trees, of fairly rapid growth, with stout trunk, form no forests of pure growth, but are found scattered in all the broad-leaved woods of our country, sometimes forming a considerable portion of the arborescent growth.

62. WHITE ELM (*Ulmus americana*) (American elm, water elm): Medium to large sized tree, common. Maine to Minnesota, southward to Florida and Texas.

63. ROCK ELM (*Ulmus racemosa*) (cork elm, hickory elm, white elm, cliff elm): Medium to large sized tree. Michigan, Ohio, from Vermont to Iowa, southward to Kentucky.

64. RED ELM (*Ulmus fulva*) (slippery elm, moose elm): Small-sized tree, found chiefly along water courses. New York to Minnesota, and southward to Florida and Texas.

65. CEDAR ELM (*Ulmus crassifolia*): Small-sized tree, quite common. Arkansas and Texas.

66. WINGED ELM (*Ulmus alata*) (Wahoo): Small-sized tree, locally quite common. Arkansas, Missouri, and eastern Virginia.

GUM.—This general term refers to two kinds of wood usually distinguished as sweet or red gum, and sour, black, or tupelo gum, the former being a relative of the witch-hazel, the latter belonging to the dogwood family.

67. TUPELO (*Nyssa sylvatica*) (sour gum, black gum): Maine to Michigan, and southward to Florida and Texas. Wood heavy, hard, strong, tough, of fine texture,

frequently crossgrained, of yellowish or grayish white color, hard to split and work, troublesome in seasoning, warps and checks considerably, and is not durable if exposed; used for wagon hubs, wooden ware, handles, wooden shoes, etc. Medium to large sized trees, with straight, clear trunks; locally quite abundant, but never forming forests of pure growth.

68. TUPELO GUM (*Nyssa uniflora*) (cotton gum): Lower Mississippi basin, northward to Illinois and eastward to Virginia, otherwise like preceding species.

69. SWEET GUM (*Liquidambar styraciflua*) (red gum, liquidambar, bilsted): Wood rather heavy, rather soft, quite stiff and strong, tough, commonly crossgrained, of fine texture; the broad sapwood whitish, the heartwood reddish brown; the wood shrinks and warps considerably, but does not check badly, stands well when fully seasoned, and takes good polish. Sweet gum is used in carpentry, in the manufacture of furniture, for cut veneer, for wooden plates, plaques, baskets, etc., also for wagon hubs, hat blocks, etc. A large-sized tree, very abundant, often the principal tree in the swampy parts of the bottoms of the Lower Mississippi Valley; occurs from New York to Texas and from Indiana to Florida.

HACKBERRY.

70. HACKBERRY (*Celtis occidentalis*) (sugar berry): The handsome wood heavy, hard, strong, quite tough, of moderately fine texture, and greenish or yellowish white color; shrinks moderately, works well, and takes a good polish. So far but little used in the manufacture of furniture. Medium to large sized tree, locally quite common, largest in the Lower Mississippi Valley; occurs in nearly all parts of the Eastern United States.

HICKORY.—Wood very heavy, hard, and strong, proverbially tough, of rather coarse texture, smooth and of straight grain. The broad sapwood white, the heart reddish nut brown. It dries slowly, shrinks and checks considerably; is not durable in the ground, or if exposed, and, especially the sapwood, is always subject to the inroads of boring insects. Hickory excels as carriage and wagon stock, but is also extensively used in the manufacture of implements and machinery, for tool handles, timber pins, for harness work, and cooperage. The hickories are tall trees with slender stems, never form forests, occasionally small groves, but usually occur scattered among other broad-leaved trees in suitable localities. The following species all contribute more or less to the hickory of the markets:

71. SHAGBARK HICKORY (*Hicoria ovata*) (shellbark hickory): A medium to large sized tree, quite common; the favorite among hickories; best developed in the Ohio and Mississippi basins; from Lake Ontario to Texas, Minnesota to Florida.

72. MOCKERNUT HICKORY (*Hicoria alba*) (black hickory, bull and black nut, big bud, and white-heart hickory): A medium to large sized tree, with the same range as the foregoing; common, especially in the South.

73. PIGNUT HICKORY (*Hicoria glabra*) (brown hickory, black hickory, switch-bud hickory): Medium to large sized tree, abundant: all Eastern United States.

71. BITTER NUT HICKORY (*Hicoria minima*) (swamp hickory): A medium-sized tree, favoring wet localities, with the same range as the preceding.

75. PECAN (*Hicoria pecan*) (Illinois nut): A large tree, very common in the fertile bottoms of the Western streams. Indiana to Nebraska and southward to Lousiana and Texas.

HOLLY.

76. HOLLY (*Ilex opaca*): Wood of medium weight, hard, strong, tough, of fine texture and white color; works and stands well, used for cabinetwork and turnery. A small tree, most abundant in the Lower Mississippi Valley and Gulf States, but occurring eastward to Massachusetts and north to Indiana.

HORSE-CHESTNUT. (*See* BUCKEYE.)

IRONWOOD. (*See* BLUE BEECH.)

LOCUST.—This name applies to both of the following:

77. Black locust (*Robinia pseudacacia*) (black locust, yellow locust): Wood very heavy, hard, strong, and tough, of coarse texture, very durable in contact with the soil, shrinks considerably and suffers in seasoning; the very narrow sapwood yellowish, the heartwood brown, with shades of red and green. Used for wagon hubs, tree nails or pins, but especially for ties, posts, etc. Abroad it is much used for furniture and farm implements and also in turnery. Small to medium sized tree, at home in the Alleghanies, extensively planted, especially in the West.

78. Honey locust (*Gleditschia triacanthos*) (black locust, sweet locust, three-thorned acacia): Wood heavy, hard, strong, tough, of coarse texture, susceptible of a good polish, the narrow sapwood yellow, the heartwood brownish red. So far, but little appreciated except for fencing and fuel; used to some extent for wagon hubs and in rough construction. A medium-sized tree, found from Pennsylvania to Nebraska, and southward to Florida and Texas; locally quite abundant.

MAGNOLIA (*See* Tulip.)

MAPLE.—Wood heavy, hard, strong, stiff, and tough, of fine texture, frequently wavy-grained, this giving rise to "curly" and "blister" figures; not durable in the ground or otherwise exposed. Maple is creamy white, with shades of light brown in the heart; shrinks moderately, seasons, works and stands well, wears smoothly, and takes a fine polish. The wood is used for ceiling, flooring, paneling, stairway, and other finishing lumber in house, ship, and car construction; it is used for the keels of boats and ships, in the manufacture of implements and machinery, but especially for furniture, where entire chamber sets of maple rival those of oak. Maple is also used for shoe lasts and other form blocks, for shoe pegs, for piano actions, school apparatus, for wood type in show bill printing, tool handles, in wood carving, turnery, and scroll work. The maples are medium-sized trees, of fairly rapid growth; sometimes form forests and frequently constitute a large proportion of the arborescent growth.

79. Sugar maple (*Acer saccharum*) (hard maple, rock maple): Medium to large sized tree, very common, forms considerable forests. Maine to Minnesota, abundant, with birch, in parts of the pineries; southward to northern Florida; most abundant in the region of the Great Lakes.

80. Red maple (*Acer rubrum*) (swamp or water maple): Medium-sized tree. Like the preceding, but scattered along water courses and other moist localities

81. Silver maple (*Acer saccharinum*) (soft maple, silver maple): Medium-sized, common; wood lighter, softer, inferior to hard maple, and usually offered in small quantities and held separate in the market. Valley of the Ohio, but occurs from Maine to Dakota and southward to Florida.

82. Broad-leafed maple (*Acer macrophyllum*): Medium-sized tree, forms considerable forests, and like the preceding has a lighter, softer, and less valuable wood. Pacific Coast.

MULBERRY.

83. Red mulberry (*Morus rubra*): Wood moderately heavy, hard, strong, rather tough, of coarse texture, durable; sapwood whitish, heart yellow to orange brown; shrinks and checks considerably in drying; works and stands well. Used in cooperage and locally in shipbuilding and in the manufacture of farm implements. A small-sized tree, common in the Ohio and Mississippi valleys, but widely distributed in the Eastern United States.

OAK.—Wood very variable, usually very heavy and hard, very strong and tough, porous, and of coarse texture; the sapwood whitish, the heart "oak" brown to reddish brown. It shrinks and checks badly, giving trouble in seasoning, but stands well, is durable, and little subject to attacks of insects. Oak is used for many purposes: in shipbuilding, for heavy construction, in common carpentry, in furniture, car, and wagon work, cooperage, turnery, and even in wood carving; also in the manufacture of all kinds of farm implements, wooden mill machinery, for piles and wharves, railway ties, etc. The oaks are medium to large sized trees, forming the predominant part of a large portion of our broad-leaved forests, so that these are generally "oak forests" though they always contain a considerable proportion of other kinds of trees. Three well-marked kinds, white, red, and live oak, are distinguished and kept separate in the market. Of the two principal kinds white oak is the stronger, tougher, less porous, and more durable. Red oak, is usually of coarser texture, more porous, often brittle, less durable, and even more troublesome in seasoning than white oak. In carpentry and furniture work, red oak brings about the same price at present as whi . oak. The red oaks everywhere accompany the white oaks, and, like the latter, are usually represented by several species in any given locality. Live oak, once largely employed in shipbuilding, possesses all the good qualities (except that of size) of white oak, even to a greater degree. It is one of the heaviest, hardest, and most durable building timbers of this country; in structure it resembles the red oaks, but is much less porous.

84. WHITE OAK (*Quercus alba*): Medium to large sized tree, common in the Eastern States, Ohio and Mississippi valleys; occurs throughout Eastern United States.

85. BUR OAK (*Quercus macrocarpa*) (mossy-cup oak, over-cup oak): Large-sized tree, locally abundant, common. Bottoms west of Mississippi; range farther west than preceding.

86. SWAMP WHITE OAK (*Quercus bicolor*): Large-sized tree, common. Most abundant in the Lake States, but with range as in white oak.

87. YELLOW OAK (*Quercus prinoides*) (chestnut oak, chinquapin oak): Medium-sized tree. Southern Alleghanies, eastward to Massachusetts.

88. BASKET OAK (*Quercus michauxii*) (cow oak): Large-sized tree, locally abundant; lower Mississippi and eastward to Delaware.

89. OVER-CUP OAK (*Quercus lyrata*) (swamp white oak, swamp post oak): Medium to large sized tree, rather restricted; ranges as in the preceding.

90. POST OAK (*Quercus obtusiloba*) (iron oak): Medium to large sized tree. Arkansas to Texas, eastward to New England and northward to Michigan.

91. WHITE OAK (*Quercus durandii*): Medium to small sized tree. Texas, eastward to Alabama.

92. WHITE OAK (*Quercus garryana*): Medium to large sized tree. Washington to California.

93. WHITE OAK (*Quercus lobata*): Medium to large-sized tree; largest oak on the Pacific Coast; California.

94. RED OAK (*Quercus rubra*) (black oak): Medium to large sized tree; common in all parts of its range. Maine to Minnesota, and southward to the Gulf.

95. BLACK OAK (*Quercus tinctoria*), (yellow oak): Medium to large sized tree; very common in the Southern States, but occurring north as far as Minnesota, and eastward to Maine.

96. SPANISH OAK (*Quercus falcata*), (red oak): Medium sized tree, common in the South Atlantic and Gulf region, but found from Texas to New York, and north to Missouri and Kentucky.

97. SCARLET OAK (*Quercus coccinea*): Medium to large sized tree; best developed in the lower basin of the Ohio, but found from Maine to Missouri, and from Minnesota to Florida.

98. PIN OAK (*Quercus palustris*) (swamp spanish oak, water oak): Medium to large sized tree, common along borders of streams and swamps. Arkansas to Wisconsin, and eastward to the Alleghanies.

99. WILLOW OAK (*Quercus phellos*) (peach oak): Small to medium sized tree. New York to Texas, and northward to Kentucky.

100. WATER OAK (*Quercus aquatica*) (duck oak, possum oak, punk oak): Medium to large sized tree, of extremely rapid growth. Eastern Gulf States, eastward to Delaware, and northward to Missouri and Kentucky.

101. LIVE OAK (*Quercus virens*): Small-sized tree, scattered along the coast from Virginia to Texas.

102. LIVE OAK (*Quercus chrysolepis*). (maul oak, Valparaiso oak): Medium-sized tree; California.

OSAGE ORANGE.

103. OSAGE ORANGE (*Maclura aurantiaca*) (Bois d'Arc): Wood very heavy, exceedingly hard, strong, not tough, of moderately coarse texture, and very durable; sapwood yellow, heart brown on the end, yellow on longitudinal faces, soon turning grayish brown if exposed; it shrinks considerably in drying, but once dry it stands unusually well. Formerly much used for wheel stock in the dry regions of Texas; otherwise employed for posts, railway ties, etc. Seems too little appreciated; it is well suited for turned ware and especially for wood carving. A small-sized tree, of fairly rapid growth, scattered through the rich bottoms of Arkansas and Texas.

PERSIMMON.

104. PERSIMMON (*Diospyros virginiana*): Wood very heavy and hard, strong and tough; resembles hickory, but is of finer texture; the broad sapwood cream color, the heart black; used in turnery for shuttles, plane stocks, shoe lasts, etc. Small to medium sized tree, common and best developed in the Lower Ohio Valley, but occurs from New York to Texas and Missouri.

POPLAR AND COTTONWOOD (*See also* TULIP WOOD).—Wood light, very soft, not strong, of fine texture and whitish, grayish to yellowish color, usually with a satiny luster. The wood shrinks moderately (some crossgrained forms warp excessively), but checks little; is easily worked, but is not durable. Used as building and furniture lumber, in cooperage for sugar and flour barrels, for crates and boxes (especially cracker boxes), for wooden ware and paper pulp.

105. COTTONWOOD (*Populus monilifera*): Large sized tree; forms considerable forests along many of the Western streams, and furnishes most of the cottonwood of the market. Mississippi Valley and west; New England to the Rocky Mountains.

106. BALSAM (*Populus balsamifera*) (balm of Gilead): Medium to large sized tree; common all along the northern boundary of the United States.

107. BLACK COTTONWOOD (*Populus trichocarpa*): The largest deciduous tree of Washington; very common. Northern Rocky Mountains and Pacific region.

108. COTTONWOOD (*Populus fremontii* var. *wislizeni*): Medium to large sized tree, common Texas to California.

109. POPLAR (*Populus grandidentata*): Medium-sized tree, chiefly used for pulp. Maine to Minnesota and southward along the Alleghanies.

110. ASPEN (*Populus tremuloides*): Small to medium sized tree, often forming extensive forests and covering burned areas. Maine to Washington and northward, south in the Western mountains to California and New Mexico.

SOUR GUM. (*See* GUM.)

RED GUM. (*See* GUM.)

SASSAFRAS.

111. SASSAFRAS (*Sassafras sassafras*): Wood light, soft, not strong, brittle, of coarse texture, durable; sapwood yellow, heart orange brown. Used in cooperage, for skiffs, fencing, etc. Medium-sized tree, largest in the Lower Mississippi Valley, from New England to Texas and from Michigan to Florida.

SWEET GUM. (*See* GUM.)

SYCAMORE.

112. SYCAMORE (*Platanus occidentalis*) (button wood, button-ball tree, water beech): Wood moderately heavy, quite hard, stiff, strong, tough, usually crossgrained, of coarse texture, and white to light brown color; the wood is

hard to split and work, shrinks moderately, warps and checks considerably, but stands well. It is used extensively for drawers, backs, bottoms, etc., in cabinet-work, for tobacco boxes, in cooperage, and also for finishing lumber, where it has too long been underrated. A large tree, of rapid growth, common and largest in the Ohio and Mississippi valleys, at home in nearly all parts of the Eastern United States. The California species—

113. *Platanus racemosa* resembles in its wood the Eastern form.

TULIP WOOD.

114. Tulip tree (*Liriodendron tulipifera*) (yellow poplar, white wood): Wood quite variable in weight, usually light, soft, stiff but not strong, of fine texture, and yellowish color; the wood shrinks considerably, but seasons without much injury; works and stands remarkably well. Used for siding, for paneling and finishing lumber in house, car, and ship building, for sideboards and panels of wagons and carriages; also in the manufacture of furniture, implements and machinery, for pump logs, and almost every kind of common wooden ware, boxes, shelving, drawers, etc. An ideal wood for the carver and toy man. A large tree, does not form forests, but is quite common, especially in the Ohio Basin; occurs from New England to Missouri and southward to Florida.

115. Cucumber tree (*Magnolia acuminata*): A medium-sized tree, most common in the Southern Alleghanies, but distributed from New York to Arkansas, southward to Alabama and northward to Illinois. Resembling, and probably confounded with, tulip wood in the markets.

TUPELO. (*See* Gum.)

WALNUT.

116. Black walnut (*Juglans nigra*): Wood heavy, hard, strong, of coarse texture; the narrow sapwood whitish, the heartwood chocolate brown. The wood shrinks moderately in drying, works and stands well, takes a good polish, is quite handsome, and has been for a long time the favorite cabinet wood in this country. Walnut, formerly used even for fencing, has become too costly for ordinary uses, and is to-day employed largely as a veneer, for inside finish and cabinetwork; also in turnery, for gunstocks, etc. Black walnut is a large tree, with stout trunk, of rapid growth, and was formerly quite abundant throughout the Alleghany region, occurring from New England to Texas, and from Michigan to Florida.

WHITE WALNUT. (*See* Butternut.)

WHITE WOOD. (*See* Tulip, and also Basswood.)

YELLOW POPLAR. (*See* Tulip.)

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BULLETIN No. 11.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF FORESTRY.

SOME FOREIGN TREES

FOR THE

SOUTHERN STATES.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Division of Forestry,
Washington, D. C., August 15, 1895.

Sir: I have the honor to submit herewith for publication a bulletin containing accounts of the value and method of cultivation of some exotic trees of economic value, which may be cultivated with advantage in some parts of the Southern States, with a view to the enrichment of the forest flora and to give rise to new and valuable industries.

Respectfully,

B. E. Fernow,
Chief of Division of Forestry.

Hon. J. Sterling Morton,
Secretary of Agriculture.

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ILLUSTRATIONS.

INTRODUCTION.

This bulletin has been prepared with a view to calling attention to a few economic trees of the highest importance which are believed to be worthy of extended trial in the Gulf region of the Southern States and in California.

The cork oak offers a new industry to the South, and one which, properly fostered, will prove of no small value to the people. Experiments so far made, as a result of a distribution of seeds and plants of this species, show that the cork oak can be successfully grown over a large range of territory as far north as the thirty-third degree of latitude in Georgia.

The rapidly decreasing supply of tan bark makes the cultivation of any tree rich in tannin a subject of practical importance. The Australian wattle trees are among the richest in tannin. Their culture in California, begun under such favorable auspices a number of years ago, received a severe check, however, by the attack of the cottony cushion scale, one of the worst insect pests which has ever visited this country. The wattles were the favorite host plants of the scale, which spread thence to the citrus fruit trees, threatening the destruction of one of California's most important industries. With the advent of the parasite of this scale it is no longer feared, and it is hoped the culture of the wattle will be resumed and greatly enlarged.

The great variety in form, habit, and value of wood which the genus Eucalyptus offers makes it one of the greatest interest, not only to economic botanists, but to planters as well. The wonderful rapidity with which these trees develop suggests their usefulness, not only for wood supplies, but for shelter-belt planting. In California these trees are well established and grown for economic purposes. Although probably not many localities in the South are adapted to their cultivation, experiments are still needed to show the adaptability of some of the species, the large number of these with different habitats in their native country suggesting the possibility of adaptation.

The bamboo, a grass rather than a tree, but of such dimensions and character as to serve for the purposes for which trees are grown, has so far also been grown only or mainly for ornamental purposes. The incredibly rapid growth and the usefulness of the material for many purposes, together with the ease of propagation when once established, suggest an extension of its use also for shelter planting in more southern latitudes.

While it is true that the natural forest resources of the South are rich and varied and by no means near exhaustion, the addition of these species of foreign origin, in special localities and under special conditions, will not be found devoid of interest and usefulness.

B. E. Fernow.

Washington, D. C., *September 15, 1895.*

SOME FOREIGN TREES OF ECONOMIC VALUE ADAPTED TO PLANTING IN SOUTHERN STATES.

CORK OAK.

By Dr. J. D. Jones,
Formerly Assistant Chief of Division of Forestry.

Among the minor products of the forest, cork is one of the most widely used, though the area of its production is extremely limited. With the rapid development of the wine industry of California, the home production of cork has become a matter of increased importance. Attention has been attracted to the possibilities of cork growing in America by the rapid development of a few trees from acorns imported by the Department of Agriculture and planted in California in 1860. The following notes are based principally on a French publication—Le Chêne-Liège, sa culture et son exploitation par A. Lamey, Paris, 1893:

HISTORY AND STATISTICS.

Among the more ancient writers, Theophrastus, 288 B. C., mentions cork, and the elder Pliny, 23–79 A. D., in his natural history (Liv. XVI, Chap. VIII), speaks of the tree, its growth, acorns, and the use made of its bark. The Greeks and Romans were familiar with many of the uses to which cork is put at the present time. They knew that the cork tree produced a new bark after the old had been detached, and they have recorded that in certain parts of northern Africa the natives used cork bark to cover their houses. Theophrastus mentions the cork oak of the Pyrenees, and all that Pliny says of it is true, except that the cork oak did not exist in Gaul.

The uses of cork were restricted, though knowledge of it had existed so long, until the seventeenth century, when the development of glass manufacture and the general use of bottles made it a necessity. At first only the native cork was used, and not until the eighteenth century do we find traces of the culture of the cork oak noted in Spain. Dr. Primitiro Artigas, professor of the School of Forestry at the Escorial, reports in 1760 a German—called by the people of the country Don Jose Rumez, director of the Royal Cannon Ball Foundry at San

Lorenzo de la Muga, a little village in the Pyrenees in the Province of the Girone—as having undertaken, with an associate, the farming of cork forests. After gathering the cork they burned the refuse and shipped the product to their own country. From this time cork forests commenced to be rented. In 1796 the proprietors were paid 6 reals (75 cents) per hundredweight. At the same time the culture of the cork oak was extended; workshops were established for the cutting of corks in this region; the product was sent to the principal cities in Europe, and the reputation of the quality, which was merited, is still retained.

Catalonia has a right to be considered as the cradle of the cork industry. In Portugal cork culture made the most rapid strides. Although of recent introduction, it became so extended that the production of Portuguese cork not only equaled but surpassed in quantity all the produce of other countries. The cultivation of the cork oak extended from Catalonia to other slopes of the Pyrenees and into the Province of Gascony, where its cultivation was seriously commenced in 1820. The first efforts in this direction for governmental forests date back to 1827.

There exists at the present time the following amount of cork-forest lands:

	Hectares.
Portugal	300,000
Spain	255,000
Italy	80,000
France	148,500
Algiers	459,000
Tunis	116,000
	1,358,500
	(3,488,250 acres.)

It appears that France, Algiers, and Tunis possess more than one-half of the total cork forests known. The Morocco forests are not mentioned, being still unexplored.

The cork oak industry, then, is of modern origin, but has increased in a most extraordinary manner. Already in a half century the production has more than doubled without a notable reduction in price, and with an extensively increasing market. The amount of prepared cork sold during 1892 equaled 587,000 hundredweight, which represents a value of $7,630,000.

Portugal occupies the first place as a producer, while the United States, with an annual importation of $400,000 to $500,000 worth, and England and Germany are the principal consumers. Spain exports to all countries, the principal exportation being manufactured corks for bottles. In this industry, and in the quality of the product, she surpasses all other countries. Italy exports her product principally to Spain, France, and Germany. In France almost the entire production is consumed by the home manufacturers.

The quantity of corks that are manufactured and used each year by the world is enormous; 500,000 hundredweight of cork bark, allowing for loss, will give about 175,000 hundredweight of manufactured corks (there being about 1,000 corks to 3 kilograms of weight, which equals 5,833,333,000 cut corks). There are about 150 models, by which the various sizes and forms are regulated.

BOTANICAL.

The Swiss botanist J. Jay first presented the specific characteristics which distinguish the veritable cork oak (*Quercus suber* L.) from the cork of Gascony, which was named by Jay *Q. occidentalis.* The separation of these species made by him is of scientific interest rather than of practical benefit.

The two species of cork oak belong to the evergreen oaks; leaves oval-oblong, entire or more frequently toothed, and the teeth jagged; 1¼ to 2 inches long, width about 1 inch; branches rather scant, shade slight; the root system is strong and extensive, and roots are frequently seen on the surface; the growth varies as to locality, but is in general slow. The most suitable exposure is on southern slopes, as offering more free circulation of air and admission of light, rather than on plains. Care must be taken in the selection of soil. It is said that the tree in its wild state is found only on the older geological formations, such as granite, clay, and slate. The experience of cultivators is that the best cork and the most rapid growth is produced on granitic, siliceous, and slate (Silurian) soils. It succeeds but poorly, if at all, in calcareous soils. Moreover, it requires abundant moisture combined with good drainage.

The true cork oak appears spontaneously in the southern regions of Europe and on the northern shores of Africa. It grows alone or mixed with other trees, principally the maritime pine (*Pinus maritima*) and holm oak (*Quercus ilex*). The principal stations are Portugal (in the basin of the Tagus), Spain (Andalusia, Catalonia, Estramadura), France (Southern Pyrenees, Var, Maritime Alps, Corsica), Italy (Sardinia, Sicily, Tuscany), Istria, and Greece. It constitutes vast forests in Morocco, Algiers, and Tunis. It is not established in European Turkey, and is unknown in Syria and Asia Minor. With this range it is seen that the species is almost exclusively found in the basin of the Mediterranean. Its habitat is from about the thirty-fourth to the forty-fourth degree of north latitude, the region having an average temperature of about 59° F. It grows on the plains, but prefers slightly undulating ground, such as that of hills or mountains of slight elevation. In France it does not grow in a higher altitude than the grape vine, namely, an elevation of from 1,900 to 2,200 feet, but in Algeria it is found at an altitude of 4,000 feet.

CULTIVATION AND YIELD.

The tree is usually raised from seed, the large sweet acorns producing trees of full and regular growth and yielding the finest cork, while the small bitter acorns produce trees of a coarse and inferior nature.

The most approved method of planting, which is otherwise carried on like other nut planting, appears to be in furrows or belts, 5 to 7 feet apart, between rows of grapevines, which afford shelter. Two or more acorns are placed 20 to 40 inches apart in the furrows. No further cultivation is necessary, excepting the usual thinning as circumstances require. The first harvest usually takes place at the age of 40 years, at which time the plantation should contain about 700 trees per acre. The yield of this first crop is about 7 pounds per tree, worth about 30 cents, so that the first crop may be estimated at about $200 per acre. At 50 years the plantation should contain about 200 trees per acre, which is reduced to 100 trees at 75 years, and 40 trees at 120 years, when thinning ceases or replanting begins. The average yield per harvest for the period from the age of 40 to the age of 120 years may be considered a little more than 50 pounds per tree, and the gross income about $225 per acre.

The yield of cork steadily increases with the age and size of the tree. At the age of 120 years over 100 pounds per tree is expected, and exceptional cases are on record where a single tree furnished 500 and even 1,000 pounds of cork bark at a single harvest.

Since manufactured cork costs in France 9 cents per pound, its value is almost doubled by the manufacture.

HARVEST.

The cork of commerce is by no means the natural product of the tree, but an abnormal development of the bark layers under certain treatment. The natural cork is entirely useless for the purposes of manufacture, being too coarse, deeply furrowed, full of siliceous deposits and very irregular, and sometimes so woody and dense that it does not float. This "wild" cork, which the French call liege mâle is developed as the tree grows until it attains a diameter of from 6 to 10 inches. It should then be removed, leaving the interior denser, darker, and softer cork layer, which is called the liber, or mother layer, from which the cork of commerce develops more or less evenly. (See Pls. I and II.)

There is no difficulty in removing the bark while in sap—an operation which can be also facilitated by beating with a mallet around the trunk; but in its removal it is necessary to be careful of the inner layer, or bast, for, if injured, no cork would be produced at that place. For the same reason it is also necessary to clear the liber, or bast, entirely of the "wild" bark, making a smooth, uninjured surface of the mother layer.

The first harvest is made when the trees are from 12 to 18 inches in circumference, and takes place usually from six to ten years after the first removal of the rough bark, which prepares the way for the development of the commercial article. The season for taking the bark is from the middle of June to the end of August. Operating earlier than the time of full sap should be avoided, also rainy days and violent and dry winds, in order that the tender bast may not suffer from the exposure. In gathering the bark a circular cut is made, taking care not to penetrate the layer subjacent to the mother layer; a similar circular cut should be made at the bottom of the tree, after which a vertical cut connects the two circular cuts, using the same precaution as before. (See Pl. III.) Commencing at the upper portion to open the incision with the edge of the hatchet, the layer of commercial cork is detached from the mother layer with the handle of the hatchet, the end of which is cut on a bevel for this purpose. (See Pl. I.) On arriving at the bottom of the tree the cork is detached by a sharp cut of the hatchet, the break being made at the level of the ground. When the trees are not more than 19 to 24 inches in circumference, the cork is taken off in one piece called a "cannon;" and when the trees are larger, in place of one longitudinal cut, two or three vertical incisions are made, so that the cork may be taken off in slabs; the portion of cork remaining on the bottom of the tree is called a sleeper, or heel; the presence on the stump of a certain number of these marks serves as a record of the number of gatherings of cork realized from the tree.

The mother layer develops new cork by annual layers, and its age is therefore discernible, just as in the barks of other trees. (See Pl. II.) It is allowed to grow until it has reached the thickness required in commerce, namely, about 1 inch, a thickness which in France takes at least six to ten years. The barking is a very simple operation in principle, but nevertheless requires great care and should never be intrusted to inexperienced workmen, for faults committed by them frequently cause the death of the tree. The barking can only take place when the tree is in sap, as at this time the separation of the layers is more easily effected, and when the vegetation is not in full vigor there is great danger of detaching the mother cork. It is very necessary not to commence the operation of barking too early, the best period being when the first mounting of the sap has somewhat slackened and when the new leaves have achieved their development. The end of May is considered the proper time in Algeria for the harvesting of the cork product, while in France, where vegetation is less forward, it is necessary to wait three or four weeks later. By the 23d of June the woods are full of activity, as when the work commences it is pushed forward in order to avoid the dry seasons and drying winds, which render the operation more difficult by retarding the flow of sap. This process of taking the commercial cork and removing part of the wild cork is repeated every six to ten years, until the heavy branches are reached.

If the branches are of good size they are treated in the same manner as the trunk. Care must be taken not to denude too much of the trunk at once, as that will endanger its life. Therefore each tree is managed so as not to expose in the same year more than one zone of mother layer, alternating the harvest among the trees. (See Pl. III.) The mother layer is liable to damage from exposure as well as from insect enemies, among which are the red ant (*Formica liguiperda*), the larva of *Corœbus undatus* (Corch), and also from various fungi.

Notwithstanding the care that is taken, there occurs from the unavoidable exposure of the mother cork a loss of trees amounting to 2 per cent after each decortication. Besides, there is a loss of 15 to 18 per cent of cork by the furrowing of the cork layer, due to dryness and also sand and dust blown against it and embedded, a considerable layer thus becoming useless. To avoid these losses it is proposed to cover the mother layer, using for the purpose the cylinders of "wild" cork attached by wire, closing their open sides with tar paper. This method is claimed by the originator (Capgrand-Mothe) to double the yield, but its practicability is doubted by others.

The question as to the age a cork oak must attain before the first barking is difficult to answer, as during the early years the cork oak is capricious as to its development; often a tree can be barked at 20 years, while another growing by its side would be 30 years of age before being sufficiently mature. Size is the only true guide. Many cork workers advise the first cutting to be made when the tree has attained a measurement of 12 inches in circumference 3 feet from the ground; others think it better to wait until the tree is 20 inches in circumference. These are extreme opinions.

The following progress may occur in a cork plantation regulated for a series of annual harvests (see Pl. III):

First period. Take a tree 14 to 16 inches in circumference that has been barked to a height of 30 inches. At the expiration of a period of from six to eight years the tree will measure from 18 to 21 inches in circumference, and will furnish the first harvest of cork to a height of 30 inches; at the time of gathering the cork the outer bark should be removed to a height of 18 inches above the last cut.

Second period. Six years after the first harvest the outer barking should again be extended 24 inches above the last cleared portion. At the expiration of the period for ripening, the tree will measure from 24 to 30 inches in circumference at the last barked portion. The cork may be gathered up to 48 inches from the ground.

Third period. Six years after the second harvest it is possible to detach the cork from the surface that was prepared during the second period, and at the same time another surface 24 inches higher should be barked. At the expiration of the period of development the new cork can be harvested from a surface 48 inches from the bottom of the tree upward; the measurement will be from 30 to 36 inches in circumference.

Fourth period. Six years after the expiration of the third period the harvest of cork may be taken from the surface measuring 48 inches on the upper portion. At the end of the period of development the harvest will be produced as before from the surface measuring 48 inches on the lower portion of the tree, which at this time will measure 34 to 39 inches in circumference. A surface of 24 inches in length situated above the last barked surface should now be prepared for a future harvest.

Fifth period. Six years after, the harvest will be taken from the surface having a dimension of 48 inches situated in the central part of the trunk. At the expiration of the period of development the cork can be taken from the 48 inches of surface on the lower part of the tree and the 24 inches situated on the upper part of the trunk. The measurements of various portions of the trunk will vary from 39 to 48 inches in circumference.

At the end of the fifth period the barking of the wild bark is not extended further unless the vigor of the tree well permits an increase of the barked area, and thereafter only the commercial cork is gathered twice during each period, alternating the harvest from the surface having a measurement of 48 inches situated in the center of the trunk with that of the surfaces having a measurement of 48 inches situated at the base and top of the trunk.

PREPARATION FOR MARKET.

The cork, having been stripped from the trees in the form of slabs or cylinders, is first placed in long rectangular vessels and boiled for the purpose of swelling the bark. The boiling closes the pores, increases its elasticity, and renders it more supple and compact. The efficacy of this treatment is incontestable; its specific weight is reduced, but the volume is increased about 20 per cent.

The vessels used are about 6 feet square and will hold from 3 to 5 hundredweight of bark, which is flattened and held in position by means of heavily weighted planks. The cork is boiled about one-half to three-quarters of an hour. After boiling, the cork slabs are allowed to cool. They are then scraped with an instrument, either by hand or machinery, by which means all the wood fiber is removed. The loss in weight is greater when treated by machinery than by hand. After the operation of scraping, the cork slabs go to the cutter, who trims them in proper shape, removes the defective parts, and sorts them into grades suitable for different purposes. The various qualities are placed in five classes, namely, thick, ordinary, bastard or fair, thin, and refuse. having measurements as follows:

1. Thick, measuring 31 millimeters or above.
2. Ordinary, measuring 26 to 30 millimeters.
3. Bastard or fair, 23 to 25 millimeters.
4. Thin, 22 millimeters.

Each quality is subdivided again into various grades of superiority:

Thick into superfine, superior, ordinary, and inferior.
Ordinary into superfine, first, second, third, and fourth qualities.
Bastard or thin into good, ordinary, inferior, and refuse.

These grades are again divided into classes, "champagne cork" being the highest quality.

USES.

Cork was not generally used for stopping bottles until toward the end of the seventeenth century, though the Greeks and Romans used it for their wine vessels to a limited extent.

The importance of the cork crop has been appreciated in Spain only since 1850. The uses are numerous, each country having its own peculiar manner of utilizing this bark. The bottle cork is of course the article most largely manufactured and most universally used. In Spain are manufactured beehives, pails, pillows, window lights; in Portugal, roofing, linings for garden walls, fences, etc.; in Italy, images, paving for footpaths, sometimes used in buttresses of village churches; in Turkey, cabins and coffins; in Morocco, drinking vessels, plates, tubs, house conduits; in Algeria, shoes, wearing apparel, saddles, horseshoes, armor, common boats, landmarks, fortifications, furniture, etc. The possibilities and usefulness of this bark are seemingly unlimited, and it is as great a necessity to the Algerian as the agave is to the Mexican or the palm to the Arab.

In France cork is used for insulating boilers, and being a bad conductor of heat and cold it is frequently used in situations where protection from either is necessary. Of the waste cork from the cutting of bottle stoppers, about 30 per cent is utilized for filling cushions, horse collars, hats, mattresses, also for the manufacture of cork-dust bricks, which are used where excessive dryness is required, and for wheels having small diameters. Pasteboard of a high grade is manufactured from French cork. The ground cork is thoroughly mixed with paper pulp by means of a machine, and the water is expressed by heavy Holland presses and the material dried. Cork waste is also used in the manufacture of linoleum, in lifeboats, buoys, etc., in insoles for shoes, artificial limbs, cork concrete, and many other articles where lightness and elasticity are required.

THE CORK OAK IN AMERICA.

The following notes were kindly furnished for this Bulletin by Prof. Charles H. Shinn, of the University of California:

> There are twelve or fourteen cork oak trees growing on the farm of Mr. S. Richardson, Alhambra post-office, San Gabriel Valley, California, about 4 miles from Pasadena. The soil is a sandy loam, irrigated as required. The site is near a creek bank and is occupied mainly by an orange grove.

In 1860 the Commissioner of Agriculture sent a number of cork oak acorns to Don Benito Wilson (now dead). He gave two acorns to Mr. Carpenter, a neighbor who owned what is now the S. Richardson farm, and planted the remainder, perhaps 100, in his own nursery. They grew fast, but were all destroyed the next year by an ignorant workman, who took them for weeds; consequently the two Carpenter acorns, both of which grew, furnished the only stock in the valley. One made a tall, shapely tree, and grew well until 1892, when it died, probably owing to too much water and injury by visitors. The trunk of this tree was 21 inches in diameter in 1892; height to first branch about 15 feet; total height, 40 to 45 feet.

The second of the original oaks still remains. A windstorm broke the top, but it is recovering from the injury; it is smaller than the tree above mentioned, having been moved when 5 years old. It is now about 14 inches in diameter 3 feet from the ground, and 28 feet high, the trunk having a height of 12 feet to the lowest branch.

The finest cork oak on the Richardson farm is 13 years old. It is from the first crop of acorns produced by the original larger tree. It has made a remarkable growth, although, standing on a bank or bluff, it gets less water than the others. It is now 16 inches in diameter and 30 to 35 feet high, with a spread of branches of 25 feet. The trunk is 7 feet to the lowest branch.

The remaining trees range in size from 4 to 12 inches in diameter of trunk. Thousands of acorns have been distributed from these trees in fruiting years. The University of California has sent out several bushels at different times, and Mr. Richardson has given so many away that it is said there are now not less than 1,000 cork oak trees of small size in the San Gabriel Valley alone. Nurserymen in several places have also grown and sold them. The acorns germinate readily if planted in the fall and let alone. When potted and petted they usually fail.

Cylinders of the cork from the largest trees are on exhibition in San Francisco and Los Angeles.

It will be observed that Mr. Shinn's measurements indicate a much more rapid growth of the cork oak in California than is usual in France, which may be considered the best possible evidence of the adaptability of the species to the soil and climate of that part of California in which it has been tested.

The first distribution of acorns of cork oak was made by the Department of Agriculture in 1858. These seeds were distributed in the Southern States and California, and the trees resulting from them are occasionally met with.

Bark from one of these trees planted at Sandersville, Ga., is now on exhibition at the Cotton States and International Exposition in Atlanta. Sandersville is near the thirty-third degree of latitude, and while the tree has lost its foliage several times during severe winters it has always leafed out vigorously in the spring, seeming to entirely recover from the winter's injury.

In 1892 the Division of Forestry secured through Thomas Meehan & Sons, Germantown, Pa., two barrels of cork oak acorns, which were grown at the Maryland Experiment Station. Through lack of proper care comparatively few of the seed germinated, and many of the seedlings were badly damaged by grub worms. Sixteen packages of seedlings were distributed in the States suitable for their growth, in most cases to experiment stations.

The excellent showing reported by Professor Shinn and the few trees occasionally met with in the South indicate that the tree can be successfully grown on sandy clay soils throughout the southern part of the Gulf States and South Carolina.

Whether the cork industry will flourish in the United States can only be proved by time; the probabilities are that it will be successful and be of immense value. The official statistics show that the United States has imported cork during the year 1892 to the value of $1,689,724, and during 1893 to the value of $1,993,025. Cork is now at eleven times the price that was paid for it in 1790. This is certainly inducement enough for us to try to protect ourselves by entering into the production of cork.

NOTE.—For Plates I, II, and III, referred to in the foregoing article, see after p. 20.

WATTLE TREE.

By CHARLES A. KEFFER,
Assistant Chief of Division of Forestry.

Among the economic trees introduced in the Southern States by the Department of Agriculture the Australian wattles (*Acacia pycnantha* and *A. decurrens*) have a peculiar value as affording one of the richest tanning barks known. Many analyses of *A. pycnantha*, the broad-leafed, or golden, wattle, show a range of from 28.5 to 46.47 per cent tannic acid, and the range in *A. decurrens*, the black wattle, is from 15.08 to 36.3 per cent. These analyses were made in Australia, and the reports of the Australian Government on wattle culture contain quite complete records of them. Wattle bark grown in California has been analyzed by Professor Woodbridge with the following results for the species named: *A. pycnantha* 31.9 per cent tannic acid; *A. decurrens* 36.3 per cent tannic acid. These results are contrary to the average of the Australian analyses, which indicate a higher percentage of tannic acid in *A. pycnantha* than in *A. decurrens*. The average oak bark contains 12 per cent of tannic acid and the hemlock 13 per cent.

It will thus be seen that the wattle barks are very rich in tannin, and their successful cultivation in this country becomes a matter of increasing economic interest as our own supply of tanning bark decreases.

The acacias belong to the natural order Leguminosæ, represented in our country by the black locust, the honey locust, the Kentucky coffee tree, and the redbud. All of the species (312 are natives of Australia) contain more or less tannin, but only three are sufficiently rich to be worthy of cultivation, and of these *A. pycnantha* and *A. decurrens* much exceed *A. dealbata* in the percentage of tannic acid contained.

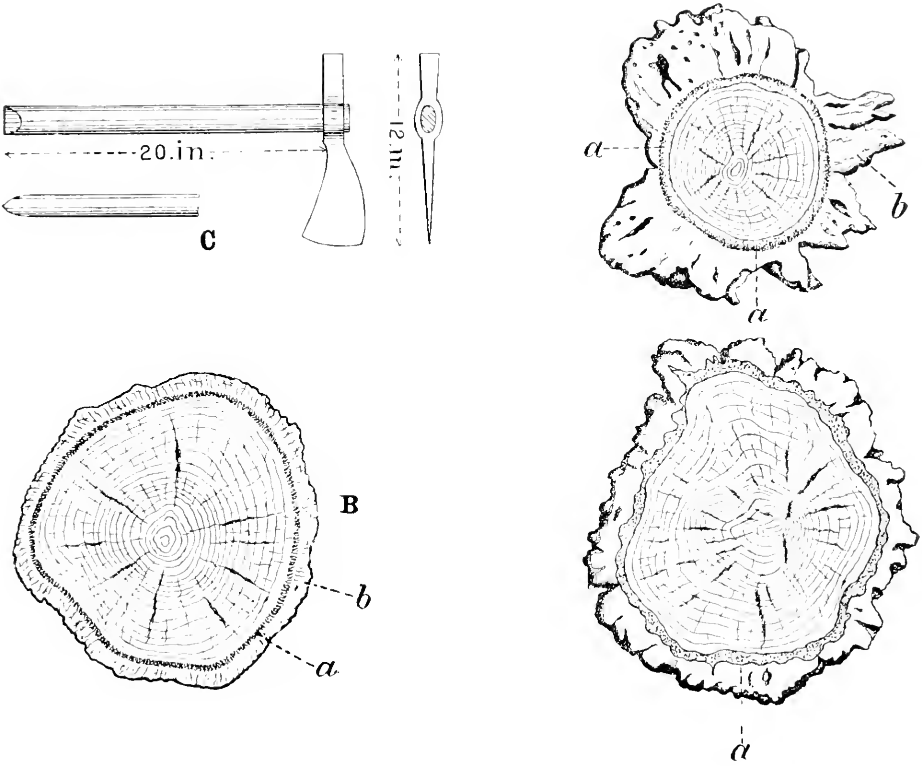
The acacias do best on a sandy soil with clay subsoil. On limestone formations the bark of trees is greatly inferior in tannin to those grown on any other formation, though wattles grow exceedingly well in limestone soil in South Australia and in California. The seed are hard and very small, there being 30,000 to 40,000 to the pound. If planted dry, they lie dormant several years, there being well-authenticated instances of seed germinating after being over thirty years in the soil. To hasten germination boiling water should be poured over them and left until the seed are soft. Thus prepared they will germinate in about three weeks. The soaked seed may be mixed with dry sand, to prevent their sticking together, and planted in drills, as is usual in nursery practice, the seedlings to be transplanted when one year old to their permanent places; or, where only a few are grown, the seed may be planted in short section of cane, open at both ends, and the seedlings set in their permanent places without removing the cane. In India and Australia both bamboo and *Arundo donax* are used for this purpose. The cane decays during the first season in the ground, and the young plant receives no check in transplanting. The principal advantage of this method is that it admits of planting out the young acacia plants at any convenient time, while if grown in nursery rows the seedlings can only be safely set while dormant.

In Australia the trees succeed well under an annual rainfall of from 16 to 20 inches, and it is thought that an unlimited supply of water makes the bark deficient in tannic acid. They grow rapidly, increasing in diameter at the rate of an inch per year. The practice is to have the trees stand about 4 by 6 feet when the first bark is removed. When the seed is sown broadcast the proper distance is secured by two or three thinnings; and when planted in place the greater amount of cultivation required probably offsets the cost of thinning, making the expense of the two methods approximately the same. Doubtless the method recommended for general planting of forest trees in the prairies would be most satisfactory; that is, plant the seedlings 3 by 3 feet, with a view to shading the ground quickly, and thin as required.

The first harvest is gathered in from five to seven years from planting, when the trees are from 4 to 5 inches in diameter. The bark of the trunk is somewhat richer in tannin than that of the branches, but in stripping all of the larger limbs should be bared. The amount of tannin contained in the bark varies considerably during the time when the bark will peel, and Australian experiments indicate that the best season is when the bark will first peel readily, as when the buds are swelling.

When the trees are stripped they should be removed, and seedlings set in their place, or the sprouts permitted to grow. By this means a succession is obtained. The trees are at their best in Australia about the tenth year. Thereafter they are much more subject to injury from fungi and insects. The harvest is usually arranged on a system of thinnings, and covers a period sufficiently long to permit the stripping of the first trees of the second planting when the initial planting is exhausted, making a rotation of about ten years.

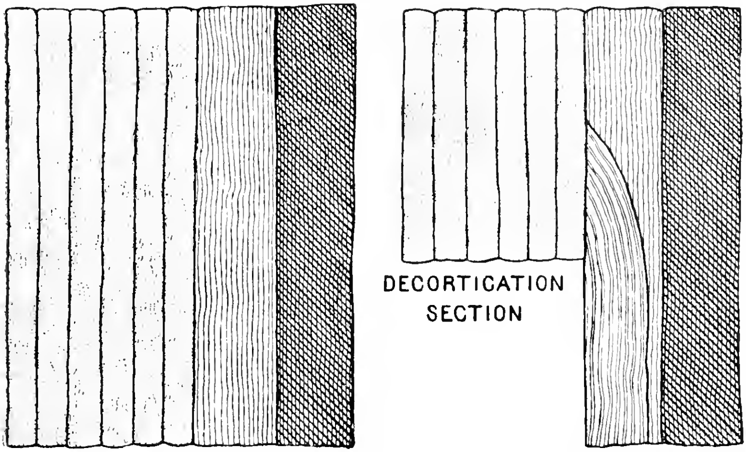
Of the two species the seeds of which were disseminated by the Department of Agriculture several years ago, *Acacia decurrens*, the black wattle, is the more rapid grower in Australia, but *A. pycnantha* is considered hardier, will endure on drier soils, and is richer in tannin. From the standpoint of the producer, however, in regions where the temperature will permit the cultivation of both species, the black wattle will probably be the more profitable, as it attains larger size and



A. CROSS SECTION OF WILD TREE.
a, mother bark layer.
b, wild cork.

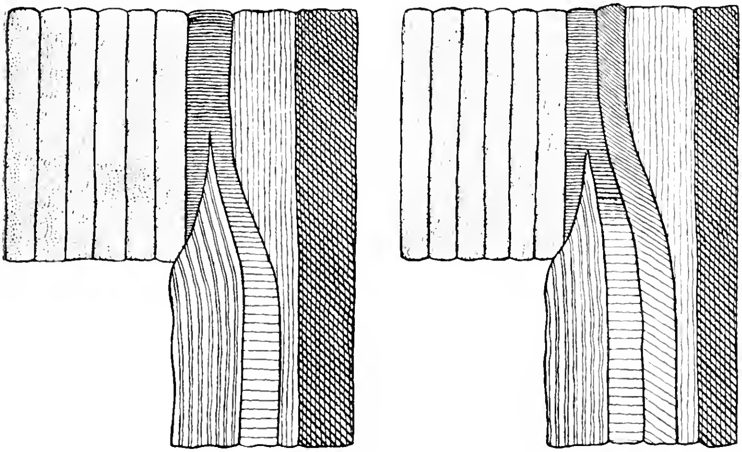
B.—CROSS SECTION OF DECORTICATED TREE.
a, mother bark layer.
b, commercial cork.

C.—HATCHET USED IN DECORTICATING.



BEFORE DECORTICATION

AFTER DECORTICATION



ONE YEAR AFTER DECORTICATION FIRST LAYER OF COMMERCIAL CORK FORMED.

TWO YEARS AFTER DECORTICATION SECOND LAYER OF COMMERCIAL CORK FORMED.

▩ WOOD OF TREE.

▥ MOTHER BARK.

▥ HARDENED MOTHER BARK.

☐ WILD CORK OF SIX ANNUAL LAYERS

▤ FIRST LAYER OF COMMERCIAL CORK.

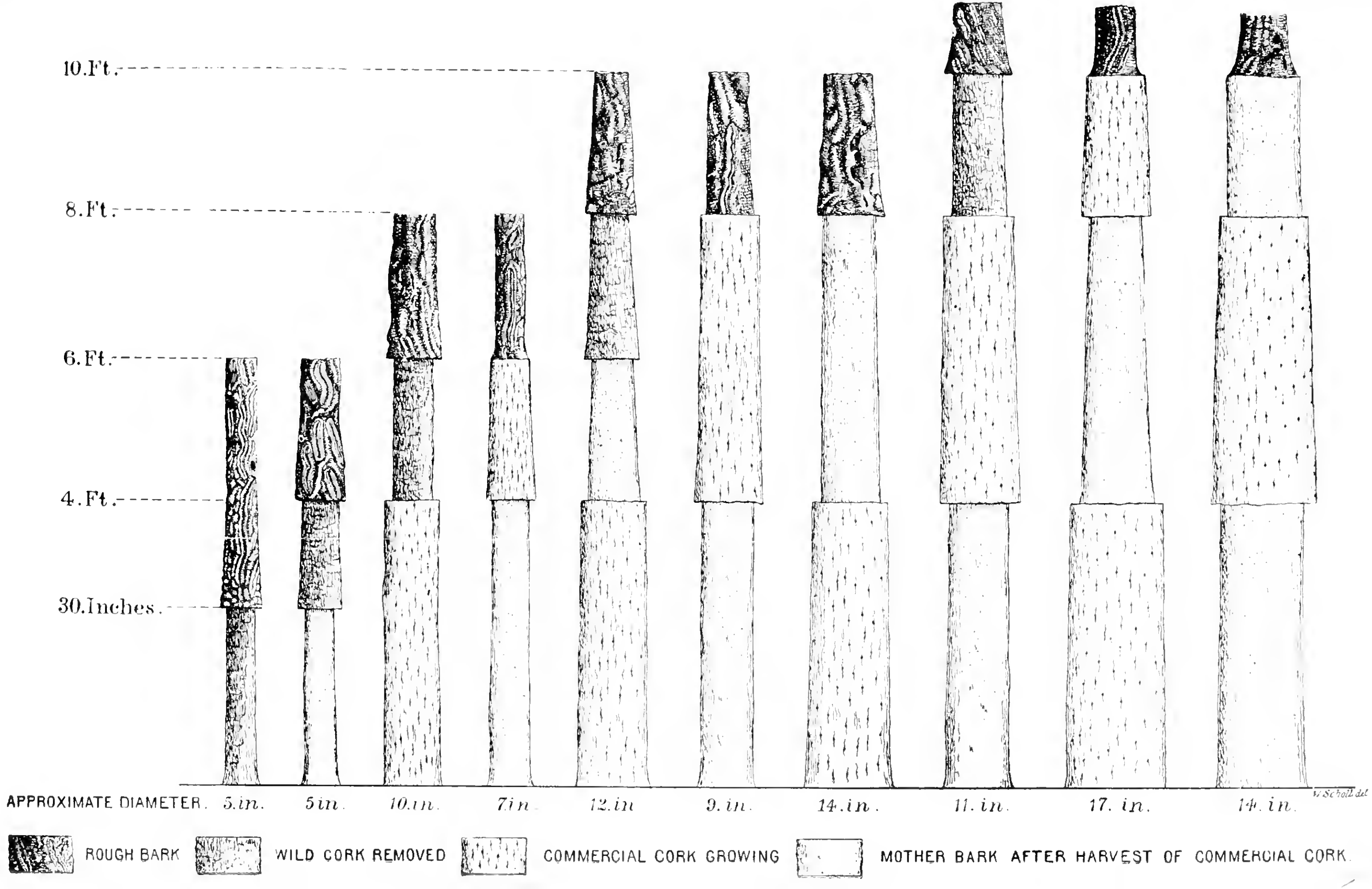
▤ LAYER OF WILD CORK FORMED AT SAME TIME.

▧ SECOND LAYER OF COMMERCIAL CORK.

▧ LAYER OF WILD CORK FORMED AT SAME TIME.

W SCHOLL DEL

PROGRESS IN THE FORMATION OF CORK.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W. Scholl del.
ROUGH BARK
WILD CORK REMOVED
COMMERCIAL CORK GROWING
MOTHER BARK AFTER HARVEST OF COMMERCIAL CORK.

yields more bark than the broad-leafed. Professor Maiden claims that the two species will "supplement one another, the black wattle flourishing in situations too damp and cold for the broad-leafed." Baron von Mueller recommends the planting of the black wattle on worn-out lands in Victoria.

The Australian reports give remarkable estimates of the profits to be made in wattle cultivation in New South Wales and Victoria. Prof. J. H. Maiden, in his Wattles and Wattle Barks, quotes one estimate in which 100 acres of wattles would yield a net profit of $12,763 in eight years from planting, after making full allowances for rent, interest, and all possible expenses. This would be at the rate of almost $16 per acre per year. By another estimate, in which the purchase price of the land at $14.50 per acre is included in the expense account, 100 acres of wattles is made to yield in seven years a net profit of $5,362.72, or $7.66 per acre per year. In the expense account is also included fencing, fire breaks, and interest, and the yield is put at 10 pounds of bark per tree, an admittedly low estimate.

Wattles have been cultivated in California for a number of years with varying success. Specimens of the hardiest species known in California (*A. melanoxylon*) were killed by a temperature of 14° F. at Chico, one tree being 18 inches in diameter at the stump. The tanning wattles will not stand more than 6° or 8° of frost, and if, as claimed by the Australians, a limited rainfall insures their best development, the only part of the Southern States adapted to their growth is southern Texas.

In California the cottony cushion scale threatened the complete destruction of all the acacias a few years ago, but with the introduction of its parasite its ravages have been so reduced that it is now considered practically harmless, and the renewed cultivation of the wattle trees is beginning.

An important purpose is served by the acacias in the vicinity of San Francisco, where they have been found especially adapted to planting on the sand dunes. They thrive in the desolate sands and cold sea breezes of that vicinity, and will prove an effective means of fixing the shifting sands. Their bright yellow flowers, which appear in great profusion, and their fine foliage make them highly ornamental, and thus far they have been more used for lawn planting in California than for any other purpose. The wood of the acacias makes a superior fuel, and in southern Texas this use alone would warrant their cultivation.

Both the black and golden, or broad-leafed, wattle are grown throughout the coast region of California, from San Francisco south, and in the more southern valleys, and there is little doubt that in that region at least the wattles rich in tannin can be grown with profit. It is to be hoped that they will be extensively tested throughout the warmer regions of the Southern States, especially in southern Texas, where there is need of forest planting.

Wattle seeds have been distributed by the Division of Forestry at various times, the first being sent out in 1886. While California has received the major part of these seeds, they have also been sent to Florida, Texas, New Mexico, and Arizona. Owing to a lack of knowledge of methods of germinating the seeds, and transplanting the seedlings, few favorable reports have been received from these Government distributions outside of California, but it is believed that both the golden and black wattles can be grown successfully in the extreme southern part of Texas and in Florida.

EUCALYPTUS.

By Abbot Kinney, *Lamanda Park, Cal.*

Among the foreign trees that may be grown in the warmest parts of the United States none are of higher economic value than several species of eucalyptus. The eucalyptus was introduced in California a number of years ago, and the most common form, *Eucalyptus globulus*, is now extensively grown in the southern part of that State. Comparatively few of the 150 species have been tested in the Gulf States, and it is yet an open question if any will be a complete success in the Gulf region, while in southern Florida several have become well acclimated.

GENERAL CHARACTERISTICS.

The eucalyptus is a genus of woody plants varying in height from a few feet to over 400 feet, and affording great variety in foliage and flower. The genus is one of the largest among tree forms, and all the species are natives of the Australian continent and adjacent islands. None have been found in New Zealand, on the one side, nor in Asia on the other. The foliage of all the species is persistent; i. e., is evergreen, and of many shades, running through grays, blues, and greens. The foliage as a whole may be fairly described as generally gray or dull green, of similar color on both sides of the leaf, hanging edgewise to the sky, and sickle-shaped. The blue color is almost entirely due to a bloom which when rubbed off leaves the leaf or fruit a dull green.

One striking characteristic of the eucalypts is the extraordinary difference of the foliage in both shape and color of young and old trees. The leaves of the young blue gum, for instance, are opposite, sessile or stemless, roundish to oval in shape upon a sharply quadrangular stem, and a bright gendarme blue in color. The leaves on mature trees are scattered, long-stalked, sickle-shaped, on a round stem, and a saturated green in color.

The color of the new growth of the mature trees varies greatly in the different species. In the blue gum, *E. globulus*, the new growth is green with a yellow shading, often changing to a red brown; in *E. rostrata*, red gum, it is a bright willow green; in *E. stewartiana* it is blue, while the main foliage is green; in *polyanthema*, it is blue; in *E. viminalis*, manna gum, and in *E. corynocalyx*, sugar gum, it is red.

The peculiarly strong eucalyptus smell of the leaves is absolutely the only apparent point in common between the yearling and the mature tree of *E. globulus*. Nearly all the species have a yearling condition quite dissimilar from the grown form.

There are a few of the eucalypts that retain their early form throughout life. One of these is *E. risdoni*, which is a bluish gray in color of its foliage and has nearly all its leaves opposite and sessile. Another is *E. gamophylla*, which has a similar coloring, with the leaves all opposite and united, whence the name *gamophylla*, or married leaves. The flower consists of a cup-like persistent calyx, on which the numerous stamens are inserted surrounding the pistil. There is no corolla. In some forms the flowers are brilliantly colored and of large size, while in others they are greenish hued and comparatively inconspicuous.

The eucalypts are valuable for the rapidity of their growth, the excellence of their timber, and the oils contained in their leaves. Add to these the great beauty of many of the species, and we have qualities which make these trees worthy of extensive trial wherever the climate will admit of their growth.

All the eucalypts must be transplanted when very young. The extraordinary rapidity of their growth makes this essential. This quality of the ability of the young to get an immediate possession of a prepared soil is doubtless one, if not the main, cause of their extensive popularity in all climates in which they can thrive. The economy of setting small trees, the short time that care is required, and the small cost of the trees on account of the short nursery handling are due to this feature of their rapid growth.

The genus has several groups of species that when mature are difficult to differentiate, largely on account of a tendency to vary according to the climate and soil in which the tree is found. The bark, the color of the leaves, as well as the general appearance of the tree, are consequently often deceptive. From this or some other cause great trouble has been experienced in obtaining seed and trees true to name. *E. viminalis*, for instance, was introduced into California as the very valuable timber tree *E. rostrata*. It was extensively planted, and though a valuable timber tree in its own line, did not equal the real red gum in any way. This costly and disappointing work was done through a seedman's error. Both seeds and trees can now be obtained in California true to name. Doubtless many nurseries can furnish reliable stock.

USES.

The use of eucalyptus wood is being constantly extended. It is now, for instance, the exclusive source of rollers for moving buildings, an extensive business in southern California on account of the rapid growth of the towns, making land too valuable in the business centers for the early built buildings. George W. Bell has just written a pamphlet on the advantages of eucalyptus wood for paving.

An important by-product of the genus is eucalyptus oil, which is extracted from the leaves. Many of the species contain oils of the same general character, called eucalyptol, cuminol, citronellon, geraniol, phellandrene, etc. Of these eucalyptol is best known, and possesses antiseptic qualities of a high order. The eucalyptus oils from Australia are from the native mixed forests, and are generally of mixed origin. The oils made in California are all extracted from *E. globulus*, and are consequently standard and reliable in their contents of eucalyptol, containing about 60 per cent.

Eucalyptus trees are said to be great absorbents of air moisture, as they are of soil moisture, and for this reason, coupled with the antiseptic oils contained, have been extensively planted in malarial districts. While the evidence of good resulting from such planting varies greatly, although it is generally assumed that several of the species have a beneficial effect, the improvement of sanitary conditions claimed due to extensive planting of eucalyptus in the Campagna Romana was, however, by a commission of investigation instituted by the Italian Government, declared to be largely due to other causes.

ABILITY TO WITHSTAND COLD.

Most of the species are very tender, enduring but a few degrees of frost. The most hardy can not resist a lower temperature than 25°, and prolonged cold periods, even though less extreme, are fatal. It will be seen from this that the extreme southern parts of Georgia and the Gulf States and California are the only localities in the United States where the temperature is adapted to the genus, and occasionally, as last winter during the exceptional freeze even in Florida, the trees are killed. They are peculiarly free from insect pests, being protected, doubtless, by the essential oils contained in their foliage.

The species that stand frost the best, and which are also fast growers and good trees, are the following:

Eucalyptus viminalis, the manna gum. This is a iall, graceful tree, reaching in damp gorges a height exceeding 300 feet. The timber is not very good, nor is there a large amount of essential oil in the foliage. It is a rapid grower. The common name is derived from a manna-like exudation from the leaves due to the action of certain Australian cicadæ. I have never seen the manna here, nor been able to make it appear by wounding the foliage. This tree, in the high Mojave plateau of southern California, has resisted temperature down to 10° F. It stands the English climate.

E. coccifera, a handsome tree closely allied to the *E. amygdalina*, reported as hardy in England. We have only opened trials with it in California.

E. urnigera, a handsome tree with dark-green leaves, hardy in England, and commencing its trial here.

E. gunnii. Very rapid grower; in fact, the fastest grower for the first two years we have ever tried. The first year's growth of an *E. gunnii* has exceeded 2 feet a month, or 26 feet for the year. The tree does not continue its rapid growth as long as the blue gum does. The blue gum grows in its phenomenal rapidity for about ten years, more or less, according to soil and climate. It has frequently measured over 300 feet in height. *E. gunnii* is of a greener foliage than the gums in general, has a wavy or fluted leaf, and is a free bloomer, with small white flowers. Hardy in England. It has at times a tendency to irregular and fantastic forms of growth.

E. amygdalina. This giant has been noted in the damp Victorian gorges to reach a height of 480 feet, but it does not attain the cubic contents of timber of the Sequoia. Its extreme height is due to long, delicate branches very different from those of our big tree. In California we have been disappointed in this tree because probably we expected too much. It has not grown as fast as several other species nor finally made so large a tree. *E. globulus*, for instance, exceeds it here in every way. There are several varieties of *E. amygdalina* or of closely allied species. These are *E. amygdalina*, *E. coccifera*, *E. risdoni*, *E. regnans*, and *E. linnea*.

Besides *E. coccifera*, the *E. risdoni* stands low temperature. In California the narrow-leafed variety, or perhaps a sport, has withstood uninjured a temperature of 9° and perhaps even a short exposure of a lower temperature. The leaf has a pungent odor resembling a mixture of eucalyptus and peppermint, and the tree is commonly called peppermint gum.

E. hemiphloia, with a large percentage of oil containing eucalyptol, is reported as growing well in sandy places. It might, therefore, succeed better in such soils than the blue gum, which likes a rich soil.

SPECIES IN SOUTHERN CALIFORNIA.

The species of eucalyptus most popular in southern California at the present time are in about the order named as follows:

E. globulus, the blue gum, is first on account of its continued rapid growth, sanitary and medicinal effects, good fuel, fine piling, and general hardiness and vigor in all our valleys opening to or not far from the ocean. It makes new crops of fuel rapidly when pollarded, being in this respect like a willow. The blue gum plantations far exceed in importance those of all other forest trees whatever. In California when the eucalyptus is spoken of—as "a row of eucalyptus," "a grove of eucalyptus," "eucalyptus leaves," etc.—*E. globulus* is meant and taken for granted. This is the species which has been almost exclusively used for its attributed ameliorating or inhibitory effects upon malarial disease. This antimalarial influence of certain eucalypts may interest sections in our Southern States. The blue gum when young will not stand frosts below 25° F. The mature trees have, however, withstood temporary temperatures down to 18°, with some frost burn.

E. corynocalyx, sugar gum, largely planted as a roadside tree in the warm and dry interior, makes a good head with dark-green, shining leaves. The timber in Australia is highly valued. Does not resist severe frost.

E. robusta, a very handsome tree, with large, dark-green, shining leaves. It is particularly attractive when in bud. The buds are a delicate cream pink and quite large. The timber of this tree is very durable and especially resistant in earth or water. It contains the largest percentage of kino yet measured. For ornamental road or street planting it is now the most sought of any of the eucalypts.

E. rostrata, red gum. This tree contains a considerable proportion of oil in the foliage and of fine kino in the timber. It is a highly valued timber in Australia. It is a good grower and is particularly adapted to very hot, dry climates. It also does well in our mild valley climates. I have just successfully introduced the tree in Arizona, where a number of other eucalypts have failed. It is with us nearly all the time covered with new growth. This is a vivid willow-green in color. The particularly agreeable odor of the leaves is an additional attraction.

E. leucoxylon, var. *rosea*. This tree has two distinct forms—one with green foliage and pink flowers and the other with silver-gray foliage and pink flowers. Both have a deep-red persistent bark. The silver-gray is far the more striking. The timber of this tree is exceedingly durable and is stronger than English oak (Laslett).

We have two other forms of *E. leucoxylon* here. One has rough red bark, green foliage, and white flowers. This is a very shy bloomer, while the others are all free flowering. The other form has a white, smooth bark, from decortication; green foliage; and, besides, grows differently. The first three are strong, single-stem trees, while the last, or white bark one, grows larger, but tends to branch low and make several stems. I feel sure that some of these varieties should have specific rank. The silver-leafed *E. leucoxylon* with pink flowers is extensively planted for ornament.

E. polyanthema is also planted for ornament. It has round leaves of silvery blue color.

E. fissifolia is extensively sought for its dark-green leaves and magnificent crimson flowers. It is to be noted that our seedling *E. fissifolias*, vary sometimes in flower color, the range being pink, orange, crimson, and magenta.

E. maculata, var. *citriodora*, is planted for the delicate fragrance of its foliage. The timber of this tree is valuable.

The most successful of these trees in California are *E. corymbosa*, bloodwood; *E. resinifera*, red mahogany; *E. diversicolor*, karri; *E. calophylla*, South Australian red gum; *E. botryoides*, bastard mahogany; the scarlet-flowered *E. fissifolia*, for ornament only; *E. corynocalyx*, sugar gum, for dry soils; and *E. robusta*, swamp mahogany, for heavy, damp soils and as an ornamental shade tree for streets.

Reports from the Exotic Nurseries of Seven Oaks, Florida, speak of *E. robusta* and *E. resinifera* as growing the fastest there. It is reasonable to presume that this type of foliage would be more favorable to the climate of Florida than that of the equally green group, doubtless evolved to resist prolonged periods of drought characteristic of so much of Australia.

E. marginata has leaves somewhat paler beneath. Under the name of jarrah its timber has become renowned as a desirable, strong wood, capable of resisting the teredo, and consequently particularly adapted to piling. It is a tree well worth trying in southern Florida. It lives, but does not succeed for commercial promise, in the climate of California.

Another valuable timber tree of this unequally green leaf is *E. gomphocephala*, tooart gum. This tree grows well in California and makes a thick, symmetrical head, but is not a phenomenal grower. None of this type resist temperatures much below freezing; nor, with the exception of the *E. corynocalyx*, do they withstand dry air with long continued high temperatures such as those occurring in central Australia, southern Algiers, Arizona, etc.

SPECIES IN SOUTHERN FLORIDA.

Mr. Alex. Bauer, of Wauchula, Fla., reports to the Division of Forestry, under date of April 18, that the past severe winter had killed or badly injured all his eucalypts. Among the growths reported by Mr. Bauer are the following:

Eucalyptus (species unknown), planted October 7, 1890, height 52½ feet, circumference at base 3 feet 10 inches.

E. raniculata, planted same date, height 42 feet, circumference at base 29 inches.

E. lanceolata, planted same date, trunk branched at surface, height 27 feet, circumference at base 27 inches.

Mr. Bauer is not discouraged by the damage of last winter, but has already sent to Australia for a supply of seed for renewed experiments.

I should think that in middle and southern Florida the very handsome *E. calophylla* would do well. It has cream-white flowers, dark-green, shining foliage, and its timber is valuable. The fruit of this timber is large. A company here is polishing these fruits and making them into pipe bowls.

A large and important group of the eucalypts has leaves dark shining green above and pale beneath. This group has less or none of the sickle-shaped foliage, makes a better head and gives more shade, as the leaves are not generally, if at all, turned edgewise to the sun. The species in this group generally contain a large amount of kino.

This kino is a gum something similar to the resin of our pines and more or less permeates the timber of these trees. It is usually red or reddish brown in color, has a powerful preservative effect on the timber, antagonizing insect life, and has an antiseptic action. This latter property is availed of in medicine for the treatment of indolent ulcers, gangrenous tendencies, and is a deodorizer in external cancer. The foliage of this group is poor in the oil to which the therapeutic and hygienic reputation of the eucalypts is due.

BAMBOO.

By Henry G. Hubbard.

[Note.—The following article, kindly written for this Bulletin by Mr. Henry G. Hubbard, of Crescent City, Fla., is valuable, not only for the facts it contains, but because they are based upon the practical experience of the writer in the cultivation of the plant.

The tribe Bambusæ (bamboos), the giants of the great grass family of plants, numbers about 20 genera and 200 species, of which the one Mr. Hubbard describes is at once the most common and the most useful. In addition to the genus Bambusa, the genera Arundinaria, Arundo, Dendrocalamus, and Guadua are the most important. The canes which grow in swampy places throughout the Southern States from Missouri to Florida belong to this tribe, and are its most hardy representatives. Several species of Arundinaria and Arundo can be grown for ornament and for the binding of sand dunes as far north as New York, while the bamboo itself is worthy of extended trial throughout the Gulf region.—B. E. F.]

A species of arundo closely allied to or identical with *Arundo donax* is widely distributed in the Southern States, where a variety beautifully variegated with white has long been grown in gardens as an ornamental plant. It attains a height of 12 or 15 feet, but has little economic importance. A similarly variegated variety of the larger European plant was introduced into Florida in 1884. It thrives wonderfully in moist, rich land and sends up canes annually 25 or 30 feet long. The stalks of this reed, however, have little strength and no durability, and are greatly inferior in this and other respects to the native cane of the canebrakes.

One of the so-called flat-stemmed bamboos was introduced in the city of Savannah, Ga., several years ago. It was obtained from a sailor who brought it from either China or Japan. It may be seen in one of the city parks, where, however, it is grown under adverse circumstances and is kept down by the surrounding shade trees. It is one of those bamboos that require moist land. In the outskirts of the town, in the gardens where it was first introduced, it has taken full possession, growing as high as the telegraph poles, and making culms $2\frac{1}{2}$ inches in diameter at the base. It is, however, a pestiferous plant, and has the bad habit of spreading underground and sending up suckers at a great distance from the parent plant. It is this uncontrollable nature that makes most of the introduced species of bamboo and the native canes very undesirable neighbors in a garden. For this reason care should be exercised in transplanting from hothouse collections and importations of ornamental plants the various species of these giant grasses to the open ground in semitropical countries like Florida and southern California. Many of the smaller species—for example that known in nurserymen's catalogues as *Bambusa violacea*—may be grown in a climate as mild as that of Washington, and form very attractive clumps in summer. But the same plant transferred to moist ground in Florida runs riot and becomes a veritable pest. Its subterranean stems penetrate even into quicksand, and at a depth of 3 or 4 feet below the surface soil, and send up shoots many yards away from the parent, often breaking forth in the very midst of other shrubbery, which is soon overgrown and destroyed.

The unarmed bamboo of Bengal, *Bambusa vulgaris*, has none of the bad qualities of the intractable species which spread in leaps and bounds by underground stems. It forms symmetrical clusters, which increase regularly by the addition of new stems on the outside.

The experience of the past fifteen years proves that it is admirably adapted to the soil and climate of Florida, and that it grows there under suitable conditions to a greater height than is recorded for this bamboo in any other country. In Florida its culms rise to a height of 72 feet in a single season, growing at the average rate of more than a foot a day.

Seed has never been produced in Florida. In its native home, also, it is said to bloom and set seed only at intervals of many years. Propagation of the plant is readily made either by roots or by cuttings of the stem. Offsets from the roots may be taken in early summer, when one of the large buds, with its surrounding rootlets, may be separated from the mass. Such a young plant will weigh from 40 to 50 pounds. When transplanted it will send up the first year, not the giant culm of maximum size, but several smaller canes of the size of fishing poles. These will be followed by larger and larger canes. The crop of each successive season will exceed their predecessors about 1 inch in diameter and 10 feet in height for five years, provided no exceptionally severe frost retards their development.

Plants of more manageable size may be obtained from cuttings. The readiest method of securing a strong plant in this way is to cut in May or June from a one year-old stalk one of the nodes, or divisions of the stem, with its wand-like branch, and place this in water in a cool, shady place. During the summer roots will be produced at the node, and it may be planted in moist, shady ground in the fall. Later on, when it has made stronger roots, it may be transplanted to open ground. This species of bamboo will not thrive in saturated soil, although it requires a constant supply of moisture. If cared for when young, mulched with leaves and watered carefully, it may be grown anywhere in Florida, and even on sandy hills will attain a large size. Its powerful roots will after a few years reach water even at a depth of 30 or 40 feet, after which the plant will ask for nothing of the cultivator.

There is no grander landscape decoration than the gigantic fountain of verdure produced by a well-grown clump of bamboo. At ten years of age a plant should consist of fifty or sixty stalks, the yearlings rising erect above the mass to their full height of over 70 feet, their tops for 20 feet or more lightly branched and tracing against the sky a delicate network. Below, the older culms, fully feathered out and heavy with leaves, bend outward on all sides in graceful curves like great ostrich feathers. The outer rows almost sweep the ground with their tips, and swaying in the wind give glimpses of the ascending columns, standing in close ranks, polished and as green as emerald.

About the first week in July the new shoots of the year make their appearance. A dozen or more of the mighty buds, sheathed in hairy scales, push their way out of the ground. They resemble gigantic asparagus shoots, and, like them, grow only at the tip, having attained their full diameter of 4 or 5 inches before they leave the ground, and only diminish in girth very gradually as they ascend. Each joint of the young stalk is protected by a broad scale of creamy white, which is thrown off as the culm matures, and these litter the ground in late summer as shingles are scattered about in the building of a roof. At the start and until they have risen 15 or 20 feet from the ground, the shoots grow in length at the rate of 8 inches in twenty-four hours, but during the heat of August and as the tapering stalks decrease in girth they rush on toward completion at the rate of 12 to 18 inches each day.

By the middle of September, or in nine or ten weeks from the starting of their growth, the July brood of culms will have reached their full height of 70 feet and upward. Another crop of buds appears after the first are nearly full grown, but these in Florida never make culms; the cool nights of September chill them to death. During the first season the new stalks produce branches only at the top, and these are scantily supplied with tufts of leaves. The second summer the development of branches extends downward along the stem and the tops feather out and bend under the weight of foliage. A third season of active branch growth brings the culm to full maturity, after which it has passed its prime and enters upon a period of decadence which ends in the fifth or sixth year with the snapping off of the dead and brittle stalk in some high wind.

The culms of *Bambusa vulgaris* have moderately thin walls, the hollow joints somewhat over a foot long and the partitions which divide them rather strong and thick, but brittle enough when dry to be broken out by a sharp blow. By means of an iron rod it is easy to convert the stalks into tubes, which may be used as water pipes, or they may be split in half and converted into troughs. They are easily put to numerous uses in a Southern garden. Cut into convenient lengths and the partitions removed, they make excellent and durable subsoil drains. Split and converted into troughs they make the best of roofs, being laid like tile, the alternate pieces inverted and covering the edges of the upturned gutters. Flower pots and utensils for holding liquids are very simply made by sawing apart the joints. For light trellises and open sheds bamboo posts, poles, and rafters have no equal.

The proper manipulation of bamboo in constructive work is of course unfamiliar to our people, but is easily learned and would soon be acquired if the material was fairly abundant. There is also much to be learned as to the proper methods of curing and seasoning the timber. If cut too young or in the growing season the tubular stems check or split, which destroys their value for holding liquids and somewhat impairs their strength. In Florida the proper season to cut bamboo is during the winter before growth begins. In the West Indies, where there is less winter rest, it is said bamboo will not check if cut "in the dark of the moon." Water seasoning is practiced by the Chinese and Japanese, but it will not avail with young or sappy stalks in Florida, at least.

Bambusa vulgaris will stand 8° or 10° of frost in Florida, if of short duration, and is certainly destined to become more hardy with time.

The stalks at Crescent City, which is situated in Putnam County, and about the middle of the peninsula, have been cut down by cold three times since 1882. However, even the most disastrous frosts, like those of the past winter, can not materially injure the roots of well-established plants.

BULLETIN No. 12.

U. S. DEPARTMENT OF AGRICULTURE.
DIVISION OF FORESTRY.

TIMBER PHYSICS SERIES.

ECONOMICAL DESIGNING
OF
TIMBER TRESTLE BRIDGES,

BY

A. L. JOHNSON, C. E.

PREPARED UNDER THE DIRECTION OF
B. E. FERNOW,
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1862 1889

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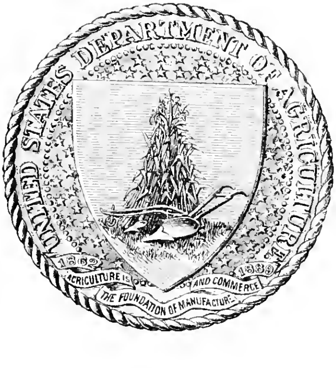

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ECONOMICAL DESIGNING OF TIMBER TRESTLE BRIDGES.

INTRODUCTION.

There are in the United States at least 2,000 miles of timber trestle, representing an expenditure of more than $60,000,000. These have to be entirely replaced every nine years, on the average, making an annual expenditure of about $7,000,000, which, capitalized at 4 per cent, gives an invested capital of $175,000,000 necessary to maintain these structures, consuming annually about 260,000,000 feet, B. M., of timber, nearly all of it being in large sizes, very valuable for other purposes.

Any economy effected, upon however small a margin it is based, is therefore, when multiplied so enormously, of great benefit not only to the railroad companies but to our national forestry interests.

The capital invested in timber structures is greatly in excess (probably twice as much) of that invested in structures of iron and steel. Every piece in these latter structures is thoroughly inspected, both chemically and physically, and carefully designed to carry the imposed load. Timber structures, on the other hand, have been designed according to the general principal that the Lord takes care of His own, as the great number of fatalities resulting from failures of these structures will attest. Experience is not only a dear teacher, but requires endless time to tell what he knows. That this time has not yet expired is evidenced by the anachronisms of design existing in the present practice.

It is a well-known principle that a chain is no stronger than its weakest link, and therefore, having one weak link, it is unnecessary that the others should be any stronger. Yet there are thousands of timber structures throughout this country to-day that have, in some parts, barely sufficient strength to carry their working load (with a factor of safety of only 1—see table on pages 9 and 10), while other portions of the same structure have from twenty to thirty times this strength. The engineer who would design an iron structure in such a manner would be the laughing stock of the most ignorant man in the profession.

There are now about 800 miles of timber trestle bridges in this country so designed. What is the cause of this almost universal disregard of the laws of economy? One reason is that timber has been in the past very cheap, and it was not necessary to consider sizes so carefully as is done in iron and steel structures. The principal reason, probably, is that material even of the same species was found to give strength factors of such a wide range of values that scientific investigation was discouraged. The elements affecting the strength were not known, and there was no assurance that the piece to be used would develop a strength within narrow limits comparable with that shown by the test piece. To-day the elements affecting the strength of wood are much better known. While we still obtain the same wide range of values we are able to assign causes therefor.

It is safe to say that the time is coming when, by ocular inspection, an expert will be able to predict the strength of a piece of wood more accurately than can be done by the same method with iron or steel. Rules of inspection may then be formulated which, if carefully followed, will yield timber of comparatively uniform strength. But even with the knowledge we now have it is possible to improve greatly upon the present practice.

With this object in view a query sheet was sent to about thirty of the principal railroad companies of the United States for the purpose of determining what the prevailing practice now is. Answers were received from twenty of these companies, and serviceable information from fifteen, ten of which represented 500 miles of trestle. The other five did not report mileage. This information has been compiled in Tables I and II.

DATA FOR TRESTLE CONSTRUCTION.

PRESENT PRACTICE.

Table I gives the different species now employed in the various parts of these structures and a mean estimate of the length of life of each. These separate estimates, however, were very erratic, in many cases being little better than a guess, so that the mean given in the table is by no means reliable.

This lack of information is scarcely less remarkable than it is unfortunate. Although for more than fifty years railroad companies have been using timber, no accurate, classified knowledge exists as to its length of life; yet this could be easily obtained if each member of a trestle were given a number, as is done in iron structures. The length of life of timber is, of course, not an exact quantity, being a function not only of the various conditions of use, but also those of growth and treatment previous to use. For a given locality and treatment the length of life of originally sound timber of a given species should not exhibit such a remarkable difference in durability as indicated on the separate returns from the railroad companies.

From an examination of the mean value given at the bottom of Table I we see that, in general, the piles and posts outlast the stringers and caps by from one to two years. This is reasonable and undoubtedly correct in kind; probably an underestimate in degree.

TABLE I.—*Species of timber employed in the construction of wooden trestle bridges.*

[Compiled from reports from fifteen railroads of the United States.]

Species used.	Mean length of life.	Per cent of reported roads using this species.
PILES.	*Years.*	
White oak	10	70
Burr oak	...	12
Red cedar	16	31
Redwood	12	6
Longleaf pine	9	25
Oregon or Douglas fir	8-9	12
Red cypress	7	6
White pine	7	6
Norway pine	7	6
Sugar pine	...	6
Red spruce	...	6
Mean	9.6	...
STRINGERS.		
Douglas or Oregon fir	10	41
Longleaf pine	8	56
Shortleaf pine	6	6
White pine	8	41
Norway pine	8	6
Red cypress	7	6
Mean	7.8	...
CAPS.	*Years.*	
Douglas or Oregon fir	10	25
Longleaf pine	8	41
Shortleaf pine	6	6
White pine	8	38
Norway pine	8	12
Colorado pine	8	6
Red cypress	10	19
Red cedar	11	6
White oak	8	19
Redwood	12	6
Mean	8.9	...
POSTS.		
Douglas or Oregon fir	12	25
Longleaf pine	10	56
Shortleaf pine	6	6
White pine	10	38
Norway pine	9	12
Red cypress	9	12
Red cedar	11	6
White oak	9	19
Redwood	12	6
Mean	9.8	...

TABLE II.—*Showing the range in values of safe unit stresses as reported by fifteen railroad companies of the United States.*

[The "factor of safety" given below is not what was reported by these companies, their values ranging from five to twelve, but what actually exists according to values based on the tests of the Forestry Division as given in Table IV.]

Species.	Modulus of strength at rupture per square inch.	Modulus of elasticity per square inch.	Crushing strength endwise per square inch.	Crushing strength across the grain per square inch.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Longleaf pine (*Pinus palustris*)	1,000–5,000	...	830–1,700	650–1,000
Shortleaf pine (*Pinus echinata*)	...	...	...	...
White pine (*Pinus strobus*)	500–1,000	...	600–1,000	400– 120
Norway pine (*Pinus resinosa*)	...	...	650–2,100	350
Colorado pine (*Pinus ponderosa*)	1,360	...	...	...
Douglas fir (*Pseudotsuga douglasii*)	500–2,160	...	600–1,000	120– 420
Redwood (*Sequoia sempervirens*)	600	...	300	60
Red cedar (*Juniperus virginiana*)	1,750	...	1,000	530
Bald cypress (*Taxodium distichum*)	1,600	...	1,000	260
White oak (*Quercus alba*)	3,300	...	1,400	600
Factor of safety	1.5–13.0	...	2.6–25.0	0.6–5.7

* The reporter of this value gave 10,000 pounds per square inch as the modulus of rupture, and said in designing he was accustomed to use one-half the amount.

TABLE II shows the range in values for the safe unit stresses as reported by these railroad companies. This range is best appreciated by an inspection of the range in value of the factor of safety for the different factors of strength, given at the bottom of the table, which is based upon the safe-load values given in Table IV. Supposing these latter values to be correct, we find that where a factor of safety of say 5 to 12 was supposed to exist, this quantity has a range of from 0.6 to 25. The former value occurs for the crushing strength across the grain by which the bearing area on the cap of a trestle bent should be proportioned. Less seems to be known about this quality of timber than any of the others, though very little is known of any of them. Two companies reported equal values for the crushing strength endwise and across the grain.

Most of the safe loads assumed by these companies for this latter factor would, if actually employed, be dangerously unsafe. Fortunately, perhaps, trestles have not been designed according to these or any other safe loads, but according to standard sizes which have proved themselves capable of doing the required duty—at least for a time. But even these furnish an altogether insufficient factor of safety in many cases, while in others it becomes five times as large as necessary. No values whatever were given for the modulus of elasticity.

Table III.—*Showing the great range in value of the factor of safety for the different portions of timber trestles, according to the practice now prevailing.*

[Span=14 feet; length post=12 feet; posts, caps, and sills, all 12 inches square. Load=100-ton consolidation engine of the P. R. R. Maximum moment=98,600 foot-pounds on one rail; maximum shear=36,000 pounds on one rail; maximum bent load=91,800 pounds on both rails.]

Species.	Stringers, all 16 inches high.		Caps.								Factor of safety for posts.
	Factor of safety.		Factor of safety for bearing value under stringers of—							Factor of safety for bearing value under post.	
	In cross breaking.	For bearing on cap.	Longleaf pine.	Shortleaf pine.	White pine.	Norway pine.	Colorado pine.	Douglas fir.	Cypress.		
Longleaf pine	5	1.92	1.92	2.28	3.38	2.74	3.04	2.25	2.97	3.03	24.4
Shortleaf pine	5	2.30	1.92	2.28	3.38	2.74	3.04	2.25	2.97	3.03	20.5
White pine	5	2.32	1.32	1.56	2.32	1.87	2.08	1.54	2.01	2.07	17.1
Norway pine	5	1.82	1.28	1.52	2.25	1.82	2.02	1.50	1.98	2.02	18.4
Colorado pine	5	2.55	1.61	1.92	2.83	2.30	2.55	1.89	2.49	2.54	15.3
Douglas fir	5	1.76	1.50	1.78	2.63	2.13	2.37	1.75	2.32	2.35	21.4
Redwood	......	......	1.03	1.23	1.81	1.46	1.63	1.21	1.59	1.62	15.8
Cedar.	......	......	2.21	2.67	3.94	3.18	3.54	2.62	3.46	3.52	17.1
Cypress	5	1.66	1.07	1.28	1.89	1.53	1.70	1.26	1.66	1.69	16.4
White oak	......	......	3.58	4.26	6.30	5.10	5.66	4.20	5.51	5.63	19.5

This table gives, for a set of conditions representative of the present practice, the factors of safety obtaining for the posts and for the bearing value of stringers on caps and caps on posts, using the safe loads given in Table IV and a uniform height of stringer of 16 inches. That is to say, the load assumed and the dimensions of caps and posts and height of stringer are supposed to represent the average conditions in practice. The necessary width of stringer, however, has been determined by using the safe loads recommended in Table IV. While in some cases this resulting width, from which the bearing area is computed, will be too small to represent the average practice, in other cases it will be too large, so that it is thought to be fairly representative thereof. It is also assumed that the stringers are butting, each having but 6 inches bearing at each end on the cap.

A factor of safety of 3 (see discussion of Table IV) is necessary and sufficient for the proportioning of areas subject to load across the grain.

From an inspection of Table III, under the head of "Stringers"—the latter being correctly designed to resist the bending moment—we see that stringers of none of these species would have sufficient bearing area upon a 12 by 12 inch cap. Colorado pine comes nearest, with a factor of safety of 2.55. The resistance of the cap under the stringer depends upon the kind of stringer used. For example, with a white-pine cap and Douglas-fir stringers, the cap has a factor of safety of 1.54. The last column but one in the table gives the factor of safety for the bearing value of cap on the post.

There are only four species, i. e., longleaf and shortleaf pine, cedar, and oak, that have sufficient strength in crushing across the grain to enable the cap to resist the thrust of the post. Oak is the only species that has sufficient strength to enable the cap to resist the pressure of all kinds of stringers.

There has been no such parsimony exercised in the design of the posts, however. The factors of safety here range from 15.8 to 24.4.

Now, although the stringers in cross breaking have a factor of safety of 5, and the posts have a factor of safety of 20, the structure as a whole has a factor of safety of only 2, approximately.* Since these values are intended to represent only the average condition in practice, they are very unlikely to represent any actual condition, being functions of such variable quantities as the proof load, length and height of span, height of stringer, etc.

They serve to show, however, the wholly inefficient allowance that has been made in the bearing area, and it is probable that in nine out of ten cases no attempt has been made to proportion this surface according to conditions in hand.

RECOMMENDED PRACTICE.

Since the strength of timber varies very greatly with the moisture contents (see Bulletin 8 of the Forestry Division), the economical designing of such structures will necessitate their being separated into groups according to the maximum moisture contents in use.

MOISTURE CLASSIFICATION.

Class A (moisture contents, 18 per cent).—Structures freely exposed to the weather, such as railway trestles, uncovered bridges, etc.

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*This is based upon the assumption that it is dangerous to strain a cap or stringer in crushing across the grain more than 3 per cent of the height. (See page 14.) While this amount of crushing is not a failure in the sense of collapse of the structure, yet unless the piece is soon taken out and replaced, the structure as a whole will be in danger.

Class B (moisture contents, 15 per cent).—Structures under roof but without side shelter, freely exposed to outside air, but protected from rain, such as roof trusses of open shops and sheds, covered bridges over streams, etc.

Class C (moisture contents, 12 per cent).—Structures in buildings unheated, but more or less protected from outside air, such as roof trusses or barns, inclosed shops and sheds, etc.

Class D (moisture contents, 10 per cent).—Structures in buildings at all times protected from the outside air, heated in the winter, such as roof trusses in houses, halls, churches, etc.

The following tables of safe loads have all been made out for Class A, with the intention of making them applicable to bridge-trestle construction. To make these applicable to the other classes make the following modifications:

For longleaf pine add to all the values given in the tables, except those for moduli of elasticity, tension, and shearing, for Class B, 15 per cent; for Class C, 40 per cent, and for Class D, 55 per cent. For the other species add to these values, for Class B, 8 per cent; for Class C, 18 per cent, and for Class D, 25 per cent.

For the modulus of elasticity add only one-half of the above percentages. For tension and shearing use the tabular values— whatever the percentage of moisture.

For longleaf and shortleaf pine these modifications are quite correct, the percentage of increase of strength of the former being about twice as great as that for the latter between the green and dry condition. This percentage of increase is not so well known for the other species, but tests that have been made indicate a percentage of increase at least as large as for shortleaf pine. Until further tests have been made, therefore, the modifications given above may safely be used.

NOTE.—The reductions for moisture as given above in the case of longleaf pine appear somewhat at variance with results obtained since. In the case of other species they rest on assumption, for which experimental data are still largely lacking; it will, therefore, be proper to use the same with caution.

The moisture condition at 18 per cent is one difficult to obtain under natural conditions; it would, therefore, have been more desirable if the author had started from the green condition, which is fixed. The following values for green condition are here added for the four Southern pines, on which alone the Forestry Division has reliable data:

	Moisture condition.	Cuban pine.	Longleaf.	Loblolly.	Shortleaf.	Average change.
	Per cent.					
Transverse strength or modulus of rupture, green	33	6,150	6,200	5,830	5,230	....
Compression endwise, green	33	4,150	3,660	3,430	3,360	....
Relative strength as a mean of transverse and compression:						
Green	33	100	100	100	100	100
Half dry	20	125	119	122	120	122
Yard dry	15	149	148	147	138	146
Room dry	10	182	191	187	165	182

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Table IV is a table of safe unit stresses* of the various kinds for the materials employed in the construction of timber trestles. The "safe unit stress" is equal to the ultimate strength, as determined from the test, divided by a quantity which is called the factor of safety.

SAFE UNIT STRESSES.

TABLE IV.—*Safe unit stresses at 18 per cent moisture.*

[The values marked "D" were obtained from experiments made by the Forestry Division. The other values were obtained from various sources, chiefly the Tenth Census report, but so modified as to give results comparable with Forestry Division values. To arrive at true average values of strength, multiply safe loads by factor of safety given in each column. The values for resilience and tensile strength are the *ultimate* values. The former is practically never used in designing. The latter is a factor impossible to develop in practice, since the piece will always fail in some other way, usually by shearing. (See descriptive text.)]

Species.	Modulus of strength at rupture per square inch.	Modulus of elasticity per square inch.	Elastic resilience per cubic inch.	Crushing strength endwise per square inch.	Crushing strength across the grain per square inch.	Tensile strength per square inch.	Shearing strength per square inch.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Longleaf pine (*Pinus palustris*), D....	1,550	720,000	1.30	1,000	215	12,000	125
Shortleaf pine (*Pinus echinata*), D....	1,300	600,000	1.30	840	215	9,000	100
White pine (*Pinus strobus*)...........	880	435,000	1.00	700	117	7,000	75
Norway pine (*Pinus resinosa*)........	1,090	566,000	....	760	113	....	....
Colorado pine (*Pinus ponderosa*).....	980	444,000	....	630	180	....	....
Douglas fir (*Pseudolsuga douglasii*)...	1,320	690,000	....	880	167	....	....
Redwood (*Sequoia sempervirens*)......	1,140	226,000	....	650	115	....	....
Red cedar (*Juniperus virginiana*).....	1,000	335,000	....	700	250	....	....
Bald cypress (*Taxodium distichum*), D	1,000	450,000	1.10	675	120	6,000	60
White oak (*Quercus alba*), D..........	1,200	550,000	1.25	800	100	10,000	200
Factor of safety......................	5	2	1	5	3	1	1

In designing add one-half inch to each dimension obtained by use of above table to allow for weathering.

The values marked "D" in the table were obtained from tests made by the Forestry Division and are considered quite reliable, especially those for longleaf and shortleaf pine. These are, as indicated above, for a moisture of 18 per cent, representing a half dry condition, and were taken from a minimum moisture curve† which represented the average strength of the lowest 10 per cent of the nondefective pieces tested. This curve gives values from 15 to 20 per cent less than the mean values obtained for the species, and material of this strength can readily be obtained even for full-sized beams and columns by an inspector of average intelligence.

The other values were obtained from various sources, chief of which was the Tenth Census report. They were not taken as there given, however, but modified in the following manner to make them comparable with the Forestry Division values: The mean of the values given in the census report for the "D" timbers in Table IV were compared with the mean of these same values there given; the ratio of these two was

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* For a description of these stresses see page 29.

† See Bulletin 8.

used as a factor of reduction for applying to the census report values for the species upon which the Forestry Division has so far made no tests.

The information for these species is very meager, but the values given are considered safe, though probably not as economical as they might be if more extensive tests had been made.

As will be seen from an inspection of Table IV, the factor of safety is not a constant quantity, but ranges from 2 to 5.

In general, any composite structure should be of equal strength in all of its parts. This does not mean that they should all have the same factor of safety.

This factor is a function of three things:

(1) The importance of the piece in the structure.

(2) The amount of ignorance as to the strength of the material.

(3) The amount of ignorance as to the amount of the imposed load.

In many cases the failure of one piece will not endanger the structure as a whole. In other cases, even if the whole structure is wrecked, no serious calamity results. In these cases a small factor of safety may be used.

The values given for the modulus of elasticity for all the species except redwood and cedar will give, for the average condition,* a deflection equal to about one two-hundredths of the span, which has been assumed as the maximum allowable. This is about equal to a factor of safety of 5 on the total deflection at rupture. The exceptions to this are the two species above mentioned, but these are not used for beams.

The crushing strength across the grain in Table IV is based upon a crushing of 3 per cent of the cross-sectional height of the piece. This point may be compared to the elastic limit † in the cross-breaking tests. While absolute failure does not occur at this point, yet it is a point beyond which it is unsafe to go. The point of absolute failure in this test is, more or less, an imaginary point, and the above percentage of crushing has been selected as an arbitrary representative thereof. As failure does not occur here, however, a factor of safety of 3 is deemed necessary and sufficient for this kind of a load.

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* See page 13.

† See Bulletin 8, page 23.

TABLE V.—*Safe loads, in pounds, for longleaf-pine (Pinus palustris) beams uniformly loaded, and 1 inch in width.*

[For other species multiply these loads by the ratio of the safe modulus of rupture for the species as given in Table IV, divided by 1,550. Thus, for shortleaf pine these loads should be multiplied by $\frac{1,300}{1,550}$. For other widths, multiply by the width. For single load in middle of beam, divide these loads by 2. To avoid danger of shearing along the neutral plane, the ratio of length to height of uniformly loaded beam should be at least 10; for beam with single load in middle, not less than 8.]

Length of beam.	Height of beam in inches.												
	6	7	8	9	10	11	12	13	14	15	16	17	18
Feet.													
4	1,550	......	......	......	......	......	......	......	......	......	......	......	......
5	1,240	1,687	......	......	......	......	......	......	......	......	......	......	......
6	1,033	1,406	1,837	2,325	......	......	......	......	......	......	......	......	......
7	885	1,206	2,574	1,992	2,460	......	......	......	......	......	......	......	......
8	775	1,054	1,376	1,742	2,150	2,603	3,100	......	......	......	......	......	......
9	688	935	1,224	1,550	1,914	2,316	2,755	3,235	......	......	......	......	......
10	620	844	1,101	1,394	1,720	2,083	2,480	2,910	3,370	3,875	......	......	......
11	562	768	1,000	1,267	1,564	1,893	2,253	2,645	3,068	3,520	1,010	......	......
12	517	702	917	1,160	1,434	1,736	2,067	2,426	2,812	3,226	3,673	4,150	4,650
13	477	649	847	1,072	1,322	1,601	1,906	2,238	2,595	2,980	3,390	3,825	4,285
14	442	603	787	995	1,230	1,188	1,770	2,077	2,408	2,763	3,145	3,550	3,980
15	413	562	733	930	1,147	1,387	1,653	1,940	2,250	2,580	2,940	3,320	3,720
16	386	527	688	872	1,074	1,302	1,550	1,818	2,109	2,420	2,753	3,108	3,485
17	364	496	647	820	1,013	1,226	1,459	1,711	1,984	2,278	2,590	2,925	3,280
18	343	469	612	775	956	1,157	1,379	1,619	1,878	2,152	2,450	2,762	3,100
19	327	445	580	733	905	1,097	1,305	1,533	1,777	2,039	2,320	2,618	2,933
20	310	422	550	696	860	1,041	1,240	1,455	1,689	1,940	2,206	2,490	2,790
21	296	401	525	663	820	992	1,181	1,387	1,609	1,845	2,100	2,370	2,656
22	281	384	500	635	783	946	1,129	1,325	1,536	1,762	2,005	2,260	2,535
23	269	366	479	607	748	905	1,079	1,264	1,467	1,684	1,919	2,161	2,424
24	258	352	458	581	717	868	1,033	1,212	1,408	1,616	1,837	2,072	2,321
25	248	337	440	558	688	833	992	1,164	1,350	1,550	1,762	1,990	2,231
26	238	324	424	535	662	802	954	1,120	1,299	1,191	1,697	1,913	2,142
27	230	312	407	517	637	773	920	1,079	1,250	1,431	1,635	1,842	2,066
28	221	302	393	498	613	745	885	1,040	1,206	1,384	1,575	1,777	1,992
29	213	292	380	482	593	718	855	1,005	1,163	1,338	1,521	1,718	1,925
30	203	281	368	465	575	694	827	968	1,127	1,292	1,470	1,660	1,860

Safe-load formula.

Uniform load, $S=\frac{4\,R\,b\,h^2}{3\,l}$

Single load in middle, $S=\frac{2\,R\,b\,h^2}{3\,l}$

where

R = modulus of rupture. (See Table IV.)
S = safe load in pounds.
b = breadth of beam in inches.
h = height of beam in inches.
l = length of beam in inches.

Deflection formula.

Uniform load, $\Delta=\frac{5\,R\,l^2}{24\,E\,h}$

Single load in middle, $\Delta=\frac{R\,l^2}{6\,E\,h}$

Δ = deflection at center in inches.
E = modulus of elasticity. (See Table IV.)
Other quantities same as for safe-load formula.

Table V gives the safe load on longleaf-pine beams, uniformly loaded and 1 inch thick. By a uniform load is meant a constant load per running foot of beam.

TABLE VI.—*Safe load on square columns of longleaf pine* (*Pinus palustris*).

[Load given in tons of 2,000 pounds.]

Length in feet.	Side in inches.											
	4	5	6	7	8	9	10	11	12	13	14	15
2	7.65	12.2	17.7	24.2	31.7	......	......	......	......	......	......	......
4	6.90	11.2	16.7	23.2	30.6	38.2	48.6	58.9	70.5	......	......	......
6	5.99	10.2	15.5	21.8	29.3	37.6	47	57.4	68.8	81.1	94.9	109.2
8	5.18	9.4	14.1	20.3	27.5	35.7	45	55.2	66.9	79.4	92.7	107
10	4.50	8.08	12.9	18.7	25.8	34	43	53.2	64.4	77	90	101.5
12	3.90	7.21	11.7	17.3	23.9	31.8	40.8	50.7	62	74	86.9	101.4
14	3.43	6.46	10.6	15.8	22.3	29.7	38.6	48.3	59.3	71	84.3	98.4
16	3.05	5.81	9.6	14.6	20.7	28.2	36.5	46	56.6	68.4	81.3	95.1
18	......	5.22	8.81	13.8	19.3	26.2	34.3	43.6	53.5	65.1	78.4	91.6
20	......	4.75	8.10	12.4	18	24.7	32.3	41.2	51.1	62.6	75.1	88.4
22	......	......	7.41	11.6	16.8	23.4	30.6	39.4	49	59.9	72	85.2
24	......	......	6.84	10.7	15.6	21.8	28.9	37.1	46.6	57.2	69	82
26	......	......	......	10	14.6	20.4	27.3	35.3	44.4	54.5	66.2	78.7
28	......	......	......	9.33	13.7	19.4	25.9	33.7	42.3	52.3	63.4	75.5
30	......	......	......	......	12.9	18.2	24.4	31.7	40.6	50.3	60.8	72.6
32	......	......	......	......	12.2	17.1	23.3	30.3	38.4	48	58.6	70.1
34	......	......	......	......	......	16.3	22	29	36.9	45.8	56	67.5
36	......	......	......	......	......	15.4	20.9	27.6	35.2	44	54	65
38	......	......	......	......	......	14.8	20	26.1	33.7	42	52.3	62.7
40	......	......	......	......	......	......	19	25	32.3	40.6	49.7	60.4
42	......	......	......	......	......	......	18.1	24	30.8	38.6	47.9	58.3
44	......	......	......	......	......	......	......	23	29.6	37.4	46.2	56
46	......	......	......	......	......	......	......	22	28.6	36	44.5	54
48	......	......	......	......	......	......	......	......	27.4	34.6	52.8	52.5
50	......	......	......	......	......	......	......	......	26.3	33.4	41.6	50.6

Table VI gives the total safe load for square columns of longleaf pine in tons of 2,000 pounds per square inch.

In designing, one-half inch is to be added to each cross-sectional dimension obtained from these two tables to allow for weathering.

The ordinary column formulæ take this form:

$$f = \frac{F}{1 + \frac{1}{a}\left(\frac{l}{d}\right)^2}$$

f = allowable working stress per square inch for the long column.
F = allowable working stress per square inch for the short column.
a = constant, for square-ended columns, usually taken at from 500 to 550.
l = length in inches.
d = least cross-sectional dimension in inches.

From experiments made upon about 50 columns by this division, the following formula may be deduced, which closely coincides with the mean of the plotted points as shown on fig. 1.

$$f = \frac{F}{1 + \dfrac{1}{700 + 15\left(\dfrac{l}{d}\right)}\left(\dfrac{l}{d}\right)^2}$$

That is to say, that a, instead of being a constant, as usually assumed, has been found to be a rectilinear function of $\frac{l}{d}$

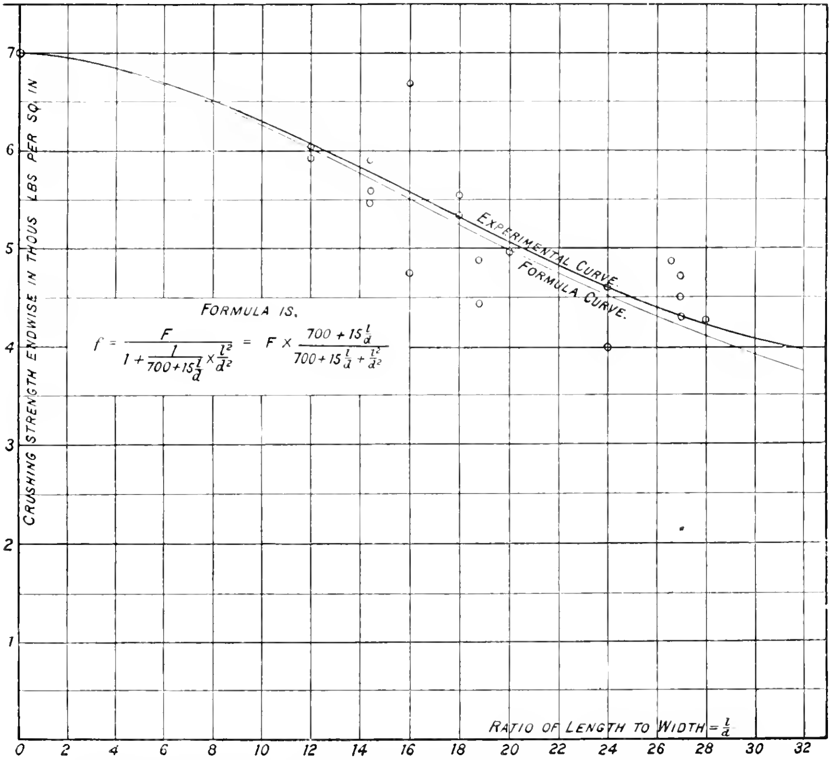


FIG. 1.—Diagram showing the relation between the coefficient of crushing endwise strength and the ratio of length to least width of solid timber columns of longleaf pine.

This equation, transformed, becomes

$$f = \mathrm{F} + \frac{700+15e}{700+15e+e^2}, \text{ where } e = \frac{l}{d}$$

The values in Table VI have been computed by this formula.

TABLE VII.—*Giving length of grip at end bearing required for uniformly loaded longleaf-pine (Pinus palustris) beams of varying heights and lengths of span.*

Formula: $c = \frac{2 R h^2}{3 S l}$ or for given species $c = K\frac{h^2}{l}$

where

c = required length of grip in inches.
R = safe modulus of rupture. (See Table IV.)
S = safe crushing strength across the grain. (See Table IV.)
h = height of beam in inches.
l = length of span in inches.
K = a constant, depending upon the material used.

For longleaf pine K=4.8; shortleaf, 4.0; white pine, 4.0; Norway pine, 5.0; Douglas fir, 5.28; bald cypress, 5.55.

To obtain the tabular values for other species multiply the value for the longleaf pine given in the table by the ratio of $\frac{K' \text{ (for the species)}}{K \text{ (for longleaf pine)}}$.

Height of beam in inches.	Length of span in feet.											
	6	7	8	9	10	11	12	13	14	15	16	17
6	2.4	2.1	1.8	1.6	1.4	1.3	1.2	1.1	1.0	1	0.9	0.8
7	3.3	2.8	2.4	2.2	2	1.8	1.6	1.5	1.4	1.3	1.2	1.2
8	4.3	3.7	3.2	2.8	2.6	2.3	2.1	2	1.8	1.7	1.6	1.5
9	5.4	4.6	4.4	3.6	3.2	2.9	2.7	2.5	2.3	2.2	2	1.9
10	6.7	5.7	5	4.4	4	3.6	3.4	3.1	2.9	2.7	2.5	2.4
11	8.1	6.9	6.1	5.4	4.8	4.4	4	3.7	3.5	3.2	3	2.8
12	9.6	8.2	7.2	6.4	5.8	5.2	4.8	4.4	4.1	3.8	3.6	3.4
13	11.3	9.7	8.4	7.5	6.8	6.1	5.6	5.2	4.8	4.5	4.2	4
14	13.1	11.2	9.8	8.7	7.8	7.1	6.5	6	5.6	5.2	4.9	4.6
15	15	12.8	11.2	10	9	8.2	7.5	6.9	6.4	6	5.6	5.3
16	17.1	14.6	12.8	11.4	10.2	9.3	8.5	7.9	7.3	6.8	6.4	6
17	19.6	16.5	14.4	12.8	11.6	10.5	9.6	8.9	8.3	7.7	7.2	6.8
18	21.6	18.5	16.2	14.4	13	11.8	10.8	10	9.3	8.6	8.1	7.6

Height of beam in inches.	Length of span in feet.										
	18	19	20	21	22	23	24	25	26	27	28
6	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5
7	1.1	1	1	.9	.9	.9	.8	.8	.8	.7	.7
8	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1	1	.9	.9
9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2
10	2.2	2.1	2	1.9	1.8	1.7	1.7	1.6	1.5	1.5	1.4
11	2.7	2.5	2.4	2.3	2.2	2.1	2	1.9	1.9	1.8	1.7
12	3.2	3	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.1
13	3.8	3.6	3.4	3.2	3.1	2.9	2.8	2.7	2.6	2.5	2.4
14	4.4	4.1	3.9	3.7	3.6	3.4	3.3	3.1	3	2.9	2.8
15	5	4.7	4.5	4.3	4.1	3.9	3.7	3.6	3.5	3.3	3.2
16	5.7	5.4	5.1	4.9	4.6	4.4	4.3	4.1	3.9	3.8	3.7
17	6.4	6.1	5.8	5.5	5.3	5	4.8	4.6	4.4	4.3	4.1
18	7.2	6.8	6.5	6.2	5.9	5.6	5.4	5.2	5	4.8	4.6

For beams under concentrated loads, such as trestle stringers, add 30 per cent to above values.
For single concentrated load in middle of beam divide these values by 2.

Table VII gives the length of grip at end bearing required for uniformly loaded longleaf-pine beams of varying heights and lengths of span.

The formula $c = \frac{2 R h^2}{3 S l}$ has been obtained in the following manner:

$S = \frac{W'}{2 c b}$ or $W' = 2 S c b$ (see Table VII for definition of quantities)

and R for uniform load $= \frac{3 W'' l}{4 b h^2}$ or $W'' = \frac{4 R b h^2}{3 l}$.

Where W′ = total load on beam at time the end bearing has its proof load.

W″ = total load on beam at time the extreme fiber has its proof load.

Making $W' = W''$ we have

$$2\,S\,c\,b = \frac{4\,R\,b\,h^2}{3\,l}$$

or

$$c = \frac{2\,R\,h^2}{3\,S\,l} \text{ for uniformly loaded beams, or}$$

$$c = \frac{R\,h^2}{3\,S\,l} \text{ for concentrated loads at middle.}$$

Problem: What is the length of grip necessary at the end of a white-pine stringer 14 feet long and 16 inches high?

The table gives for these dimensions 7.3 inches as the grip required for a longleaf-pine beam uniformly loaded.

The value of $\frac{K'}{K}$ in this case is equal to $\frac{4.0}{4.8} = \frac{1}{1.2}$

Also we must add 30 per cent on account of the difference in the character of the load. Hence we have $7.3 \times \frac{1}{1.2} \times 1.3 = 7.9$ inches.

INSPECTION.

Scientific inspection of timber requires a knowledge of the elements affecting the strength thereof.

The following are the principal elements: Moisture condition; weight per cubic foot; size of piece: position in tree; defects, such as knots, cross-graining, ring shakes, and season checks; anatomical structure; character of the secretions, such as resin, etc.; method of treatment previous to use.

Moisture condition.—This is the chief element affecting the strength of timber. The strength of a thoroughly seasoned piece is from 50 to 100 per cent more than that of a green piece. To say that a certain piece of timber has a strength of a certain amount is of no service whatever in determining its relative strength unless the moisture condition is specified.

Weight.—In material of the same species, having practically the same anatomical structure and character of secretions, the strength varies directly as the weight for the same condition of moisture.

Size of piece.—This has some effect, but it is much less than has been generally supposed. The chief difficulty is in the seasoning of large pieces. If this is done carefully no allowance need be made in the safe loads given on account of size, except for more frequent defects.

Position in tree.—The strength varies with the position in tree. In old trees of pine, from 150 to 200 years of age, the strongest portion of the butt log will be at about one-half the radius from the center. As we go higher in the tree, the central part, though weaker than in the butt log, becomes the strongest portion of the cross section.

Defects.—Large knots should not be allowed to come at the middle of a beam, either on top or bottom, as they are a source of weakness in compression as well as in tension, though not quite to the same extent.

The fibers around a knot run nearly at right angles to the axis of the tree, so that in a compression test these fibers are subject to a crushing strength across the grain, in which direction they are very weak.

Season cracks on top of a beam have little effect upon the strength, except as they may collect water and start rot. Those, however, on the side of a beam near the neutral plane, which for timber is usually a little below the middle, are very injurious, as they greatly increase the liability to shear along this plane.

Wooden beams, as ordinarily employed, are more apt to fail in this manner than in any other way. By putting a bolt in each end of large beams, thus firmly holding the top and bottom portions together, this danger could be largely avoided. Ring shakes are also prime causes of shearing along the neutral plane.

Anatomical structure.—This has, of course, great influence upon the strength of timber, and to it is largely due the difference in strength between the different species.

But little is known about this subject as yet, except in a general way, as, for example, regarding pine and oak.

The present time is a little premature for the formulation of full rules for scientific inspection of timber. We only know that for strength we require dry timber, and for a given species the heavier the stronger.

For the present it is impossible to evaluate the effect of knots and other defects, but we should guard against them as far as possible.

The safe loads given in the tables herein will then be perfectly safe, and apply to all sizes.

METHODS OF DESIGNING.

PRESENT PRACTICE.

Many of the railroad companies now use a safe load of 1,000 pounds per square inch for the modulus of rupture for longleaf-pine stringers. The caps, sills, and posts are usually 12 by 12 inches, irrespective of load.

Fig. 2 represents a common type of construction designed by the above considerations and for the same conditions given in Table III.

The formula for bending is*

$$M = \frac{R b h^2}{6}$$

M=bending moment in pounds per square inch.
R=safe load on extreme fiber in pounds per square inch.
b=breadth of beam in inches.
h=height of beam in inches.

Transformed, this becomes

$$b = \frac{6 M}{R h^2}$$

---

*See Appendix 1.

Substituting the values for these quantities, we have

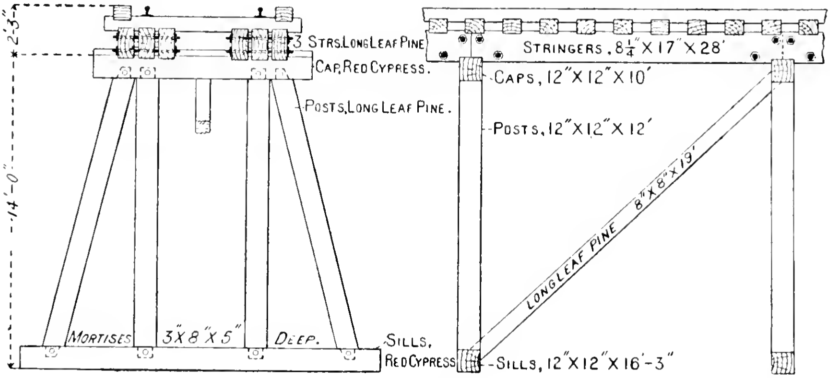
$$b = \frac{6 \times 98,600 \times 12}{1,000 \times 289}$$

where the height is assumed for trial.

This will make three stringers under each rail, 8¼ by 17 inches in cross section, posts, caps, and sills all being 12 by 12 inches in cross section.

The following factors of safety are indicated by their practice:

Stringers in cross breaking	7.6
Stringers in deflection $\frac{1}{200}$ span	3.1
Stringers in bearing value	2.7
Cap, bearing value under stringers	1.5
Cap, bearing value under posts	1.9
Posts crushing endwise	21.6



Scale: $\frac{1}{8}$ Inch = 1 Foot.

FIG. 2.—Example of present practice of designing.

Bill of material.

TIMBER, EXCLUSIVE OF TIES AND GUARD RAIL.

Species.	Used for—	Size.	Number feet, B.M.	Cost per thousand.	Total cost.
Longleaf pine	Stringers	6 pieces, 8¼"×17"×14' in 28' lengths	982	$13.00	$12.80
Red cypress	Caps	1 piece, 12"×12"×10'	120	11.00	1.32
Longleaf pine	Posts	4 pieces, 12"×12"×13' 6"	648	8.00	5.18
Red cypress	Sills	1 piece, 12"×12"×16' 3"	195	11.00	2.14
Longleaf pine	S. braces	1 piece, 8"×8"×19'	101	8.00	.81
			2,046		22.25
		Cost of iron			2.86
		Total cost of panel			25.11

IRON.

Size.	Number of pounds.	Cost per pound.	Total cost.
		Cents.	
Bolts, 8 pieces, ¾"×32½", at 5.20	41.6	4	$1.66
Driftbolts, 2 pieces, 1"×23", at 7.5	15	4	.60
Washers, O. G., 16 pieces, 3" diameter, at 1.25	21	2½	.60
Total	80.6		2.86

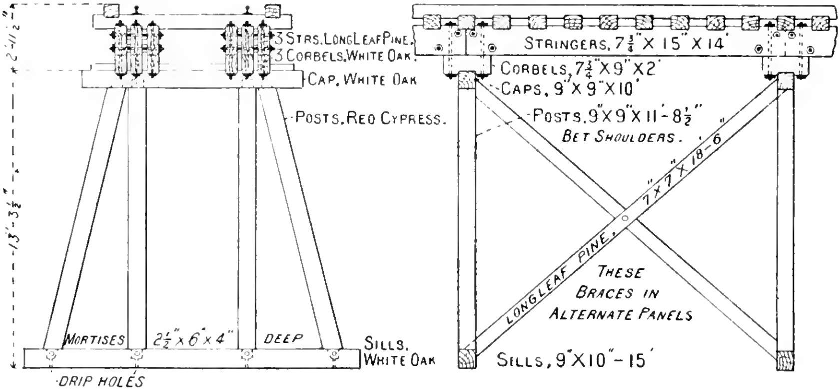
Figs. 3 and 4 show designs recommended by the Forestry Division, that in fig. 3 being preferred, though slightly more expensive than that in fig. 4. These diagrams illustrate an important point, i. e., that the economical design of timber structures requires the *judicious employment of different species as well as different sizes*, in the same.

RECOMMENDED PRACTICE.

With corbels:

Factors of safety.

Stringers in cross breaking	5 +
Stringers in deflection $\frac{1}{200}$ span	2 +
Stringers in end bearing	1 +
Cap in bearing value	3 +
Posts in endwise crushing	7.1+



SCALE: $\frac{1}{8}$ INCH = 1 FOOT.

FIG. 3.—Example of proposed practice with corbels.

Bill of material.

TIMBER, EXCLUSIVE OF TIES AND GUARD RAIL.

Species.	Used for—	Size.	Number feet, B.M.	Cost per thousand.	Total cost.
Longleaf pine	Stringers	6 pieces, 7¾″×15″×14′, in 14′ lengths.	815	$11.00	$8.96
White oak	Caps	1 piece, 9″×9″×10	68	11.00	.75
Red cypress	Posts	4 pieces, 9″×9″×13′	351	8.00	2.81
White oak	Sills	1 piece, 9″×10″×15′	112	11.00	1.23
Longleaf pine	S. braces	1 piece, 9″×7″×18′ 6″	76	8.00	.61
White oak	Corbels	6 pieces, 7¾″×9″×2′	58	8.00	.46
			1,480	....	14.82
		Cost of iron			5.31
		Total cost of panel			20.13

IRON.

Size.	Number of pounds.	Cost per pound.	Total cost.
		Cents.	
Bolts (stringers), 8 pieces, ¾″×31″, at 4.96	39.7	4	$1.59
Bolts (corbels), 12 pieces, ¾″×28″ at 4.48	53.8	4	2.15
Driftbolts, 2 pieces, 1″×12″ at 4.00	8	4	.32
Washers, O. G., 40 pieces, 3″ diameter, 1.25	50	2½	1.25
Total	151.5	....	5.31

Without corbels:

Factors of safety.

Stringers in cross breaking	5 +
Stringers in deflection $\frac{1}{200}$ span	2 +
Stringers in end bearing	3 +
Cap in bearing value	3 +
Posts in endwise crushing	7.1 +

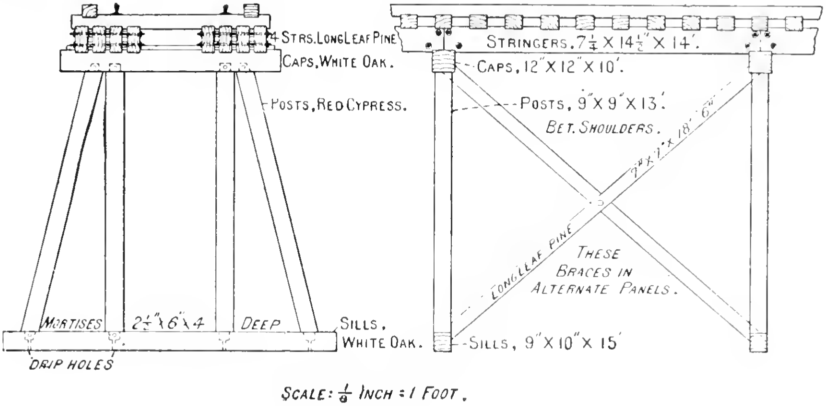


FIG. 4.—Example of proposed practice without corbels.

Bill of material.

TIMBER, EXCLUSIVE OF TIES AND GUARD RAIL.

Species.	Used for—	Size.	Number feet, B.M.	Cost per thousand.	Total cost.
Longleaf pine	Stringers	8 pieces, 7¼″×14.5″×14′ long	982	$10.50	$10.31
White oak	Caps	1 piece, 12″×12″×10′	120	11.00	1.32
Red cypress	Posts	4 pieces, 9″×9″×13′	351	8.00	2.81
White oak	Sills	1 piece, 9″×10″×15′	112	11.00	1.23
Longleaf pine	S. braces	1 piece, 7″×7″×18′ 6″	76	8.00	.61
			1,641		16.28
		Cost of iron			3.17
		Total cost of panel			19.45

IRON.

Size.	Number of pounds.	Cost per pound.	Total cost.
		Cents.	
Bolts (stringers), 8 pieces, ¾″×38½″, at 6.15	49.2	4	$1.97
Drift bolts, 2 pieces, 1″×23″, at 7.5	15	1	.60
Washers, O.G., 16 pieces, 3″ diameter, at 1.25	24	2½	.60
Total			3.17

STRINGERS.

The stringer is the first thing to be considered in the design of timber trestles. It is the most important member of the structure and the most difficult to design economically. The cost of a stringer is a function of not only the number of feet, B. M., contained therein, but also of the height or maximum cross-sectional dimension.

The Atlanta Lumber Company, of Atlanta, Ga., quote the following relative prices for longleaf-pine timber such as would be used for stringers: For sizes 12 inches or under, $8 per 1,000 feet, B. M. For sizes over 12 inches add $1 per inch per 1,000 feet, B. M.

Assuming that these prices represent the average conditions, fig. 5 shows the relative cost of stringers of different heights but of equal cross-bending strength and stiffness.

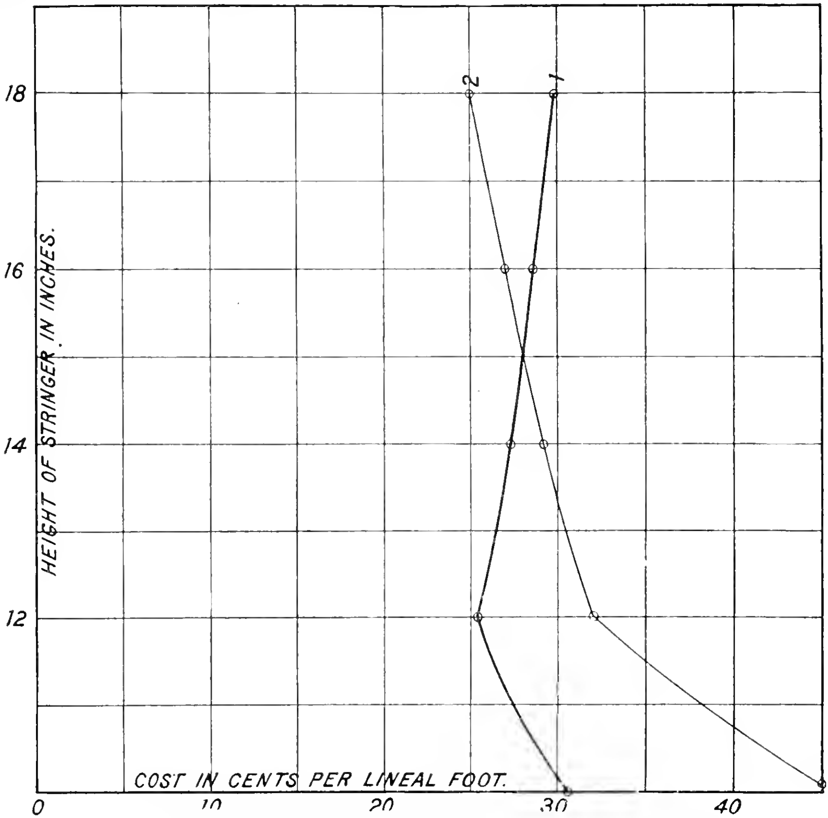


Fig. 5.—Diagram showing relative cost of stringers of different heights.

The heavy line shows the relative cost of stringers of different heights, but designed to develop the same safe unit stress in the extreme fiber, while the light line shows their cost when designed to develop the same maximum allowable deflection of one two-hundredth of the span.

COST OF STRINGERS OF EQUAL STRENGTH.

For uniform load in cross bending:

$$R^{*} = \frac{3\,W\,l}{4\,b\,h^{2}}$$

$$\text{or } b = \frac{3\,W\,l}{4\,R\,h^{2}} \text{ from which } b\,h = A = \frac{3\,W\,l}{4\,R\,h}$$

---

*See Appendix 1.

where A = area of cross section in square inches, and $\frac{A}{12} = \frac{W\,l}{16\,R\,h}$ = number of feet, B. M., per linear foot of stringer.

Let c equal the cost per foot, B. M., for height, h; then

$$\frac{Ac}{12} = \frac{W\,l\,c}{16\,R\,h} \tag{1}$$

equals the cost per linear foot of this height of stringer.

For any other height we have, as the cost per linear foot of stringer of equal strength

$$\frac{A'c'}{12} = \frac{W\,l\,c'}{16\,R\,h'} \tag{2}$$

Dividing (1) by (2) we have

$$\frac{\frac{Ac}{12}}{\frac{A'c'}{12}} = \frac{c\,h'}{c'\,h} \tag{3}$$

For example, the cost per linear foot of a 12-inch stringer is to the cost per linear foot of a 14-inch stringer of equal strength as 8 times 14 is to 10 times 12, equal to $\frac{14}{15}$.

Having, therefore, computed the cost per linear foot for the given conditions of span and load by equation (1), the cost for other heights may be found by equation (3).

COST OF STRINGERS OF EQUAL STIFFNESS.

The modulus of elasticity*

$$E = \frac{5\,W\,l^3}{32\,\Delta\,b\,h^3}$$

for uniformly distributed load.

W = total load on stringer in pounds.
b = breadth in inches.
h = height in inches.
l = length of stringer in inches.
Δ = deflection at middle in inches.

$$\text{Then } b = \frac{5\,W\,l^3}{32\,E\,\Delta\,h^3} \text{ or since } \Delta = \frac{l}{200} \quad b = \frac{1{,}000\,W\,l^2}{32\,E\,h^3}$$

or

$$b\,h = A = \frac{1{,}000\,W\,l^2}{32\,E\,h^2}$$

---

* See Appendix 1.

or, as before,

$$\frac{Ac}{12} = \frac{125\ W\ l^2\ c}{48\ E\ h^2} \tag{4}$$

equals the cost per linear foot of stringer of height h.

For any other height we have

$$\frac{A_1c_1}{12} = \frac{125\ W\ l^2\ c^1}{48\ E\ h_1{}^2} \tag{5}$$

Dividing (4) by (5)

$$\frac{\frac{Ac}{12}}{\frac{A_1c_1}{12}} = \frac{c\ h_1{}^2}{c_1 h^2} \tag{6}$$

That is to say, the cost per linear foot of stringers designed to give a maximum deflection of one two-hundredths of the span decreases as the square of the height, and increases with the first power only of the cost per foot, B. M. The cost, therefore, will be a decreasing quantity according to the present method of fixing the prices.

These two curves necessarily intersect. The point of intersection is a very important point and may be found for the general conditions of species and length of span by solving equations (1) and (4) as simultaneous equations thus:

$$\frac{W\ l\ c}{16\ R\ h} = \frac{125\ W l^2\ c}{48\ E\ h^2}$$

from which we get

$$\frac{h}{l} = \frac{2{,}000\ R}{48\ E} \tag{7}$$

For the case under consideration the span was 14 feet and the material longleaf pine, for which (see Table IV) R = 1,550 and E = 720,000.

Hence, $\frac{h}{l}$ for this case is equal to $\frac{1}{11.1}$ and $h = \frac{168}{11.1} = 15.1''$, as shown in the diagram.

For heights below that of the point of intersection stringers should be designed by the deflection formula; for greater heights, by the cross-breaking formula. The most economical height is that at the point of intersection and for longleaf-pine stringers is $\frac{1}{11.1}$ of the span.

Assuming a height of 14.5 inches for stringers, the necessary width under each rail is equal to 21.8 inches, making three pieces $7\frac{1}{4}$ by $14\frac{1}{2}$ inches by 14 feet long. From Table VII we see that the length of end bearing or grip on the cap necessary for these stringers is $6'' + 30$ per cent $= 6'' \times 1.3 = 7.8''$. To provide for weathering the stringers are increased one-half inch on each cross-sectional dimension, making three pieces under each rail $7\frac{3}{4}$ by 15 inches by 14 feet long. Now, since 7.8 inches grip are required for the grip on the cap, either a corbel must be used or the stringers given a full bearing on the cap.

CORBELS.

A corbel is deemed best for this case, as it has several advantages, among which are the following:

(1) It not only supports but unites the abutting stringers, forming a portion of the bond between them.

(2) It stiffens the joint, materially decreasing the strain in the stringers.

(3) When employed single-span lengths of stringers may be used, these being cheaper and more readily furnished than the double-span length. The double-span length is of course better.

(4) Large beams, which stringers usually are, are particularly liable to shear along their neutral axis. They will fail in this manner at less than half the shearing strength per square inch, as indicated on a small test. The reasons for this are: (1) That a large beam is apt to contain a portion of the heart center of a log, which is likely to be ring shaken; (2) with old trees—and the trees from which such sizes are cut are usually old—the heart center is much below the average quality of the cross section; (3) large pieces are particularly liable to check in seasoning. Now, the bolt through the corbel and stringer does excellent service in increasing the resistance to failure by shearing. In fact, even when corbels are not used, a bolt through the ends of the stringers would be a wise precaution. It would be necessary, however, to tighten these occasionally until the timber had thoroughly seasoned.

(5) Corbels in many cases furnish the only means of obtaining sufficient bearing value for the stringers.

Many companies will not use corbels, claiming—

(1) That they increase the cost in labor, lumber, and iron.

(2) That they increase the number of joints and hence the number of places for the beginning of decay.

(3) That they do not, after all, increase the bearing area of the stringer, since, as the latter deflects, the whole load is brought upon the ends of the corbel.

With regard to the first item, by comparing the cost of designs shown on figs. 2 and 3, we see that the corbel design costs in material 68 cents more per bent. The additional cost in labor would be very nearly offset, probably, by the greater facility in handling smaller and fewer pieces. Perhaps 75 cents would be a fair estimate of the extra cost of corbel construction. It gives, however, much better structure, and would undoubtedly secure enough additional length of life to more than pay for the extra original cost.

The second objection is of no more force than the assertion that a chain containing eleven links is not so strong as one containing but ten.

The third claim, in a corbel not exceeding 3 or 4 feet in length, is of no moment. The deflection of a well-designed stringer at the end of a 4-foot corbel will not exceed a quarter of an inch for the proof load.

Even if the stringer crushed all this amount, it would still be able to crush as much more before being in danger. This would not happen, however. The corbels may be beveled toward the ends an eighth of an inch if desired, but it is scarcely necessary.

In the last design, by using four stringers $7\frac{1}{4}$ by $14\frac{1}{2}$ inches each, with a 12-inch cap, the corbels are avoided, sufficient bearing area being obtained without them.

POSTS AND CAPS.

The posts in these last two designs are much lighter than those in the first, but, before weathering begins, have a factor of safety of about 9. Taking off one-half inch from the cross-sectional dimension to allow for weathering, after being in service for some years they still have a factor of safety of $7\frac{1}{2}$. The dimensions were obtained as follows:

Assuming four posts in the bent, we have $\frac{91,800}{4}$ (22,950 pounds), to be carried by each post, or 11.48 tons. These posts will be about 11 feet 8 inches long and have a ratio of $\frac{l}{d}$ = about 20, probably. From an inspection of Table IV we find that for this ratio a 7 by 7 inch longleaf-pine post will suffice.

With an oak cap, the safe bearing value of which is 400 pounds per square inch, we will require an area of cap and sill at the end of each post of $\frac{22,950}{400} = 57.4$ square inches. Adding to this the mortise area, we have 72.4 square inches which will require a post a trifle over 8.5 inches square. Then adding a half inch to each dimension to allow for weathering, we have a 9 by 9 inch post, requiring caps and sills of the same size. But with posts of this size we may use cypress or any of the weak, cheap, but durable timbers.

The designs in figs. 3 and 4, though capable of carrying twice as much load as that shown in fig. 2, show a saving of \$5 per span, equal to 36 cents per linear foot of track, and 28 per cent less timber.

Assuming that this would be representative of one-half the total mileage of timber trestle bridges, i. e., 1,000 miles, we have a total saving every nine years of \$1,900,000, which is equal to an annual expenditure of \$211,000. This capitalized at 4 per cent gives a capital of \$5,275,000. These 1,000 miles of trestle use annually about 120,000,000 feet, B. M., of valuable timber, 35,000,000 feet of which might readily be saved.

The tables of cost accompanying these designs upon which the above figures have been based are, of course, subject to great modification, depending upon the location, condition of the market, etc. It is thought, however, that they give a fair representation of the average conditions.

APPENDIX I.

EXPLANATION OF FACTORS OF STRENGTH.

Cross breaking.—From the cross-breaking test are obtained the modulus of strength at rupture (R), the modulus of elasticity (E), and the elastic resilience per cubic inch (r).

The modulus of strength at rupture is the intensity (in pounds per square inch) of the stress upon the extreme fibers of a beam at the point where, and at the time when rupture begins.

For example, take a longleaf-pine beam of any length and height and 10 inches wide, loaded to the point of failure. The value of the modulus of rupture for this species is 5 by 1,550 (see Table IV)=7,650 pounds per square inch. Now, if we conceive a layer of extreme fiber a tenth of an inch in thickness and running the full width of the beam, then the actual load on this square inch of material, tending to pull the fibers apart or crush them together—depending upon whether this layer was taken from the convex or concave side of the beam—is 7,650 pounds.

The stress on the extreme fiber (f) is a function of the size of the load, the method of loading, and shape of the piece.

For rectangular beams of uniform cross section

$$f=\frac{3\,W\,l}{4\,b\,h^2}, \text{ for beam uniformly loaded,}$$

$$\text{and } f=\frac{3\,W\,l}{2\,b\,h^2}, \text{ for concentrated load in middle;}$$

where

W=total load on beam in pounds,
l=length of beam in inches,
b=breadth of beam in inches,
h=height of beam in inches,

the latter dimension being measured parallel to the direction of the load.

If W is the proof load on the beam, then f becomes equal to R, the modulus of strength at rupture.

The modulus of elasticity is the ratio of

$$\frac{\text{Unit stress (in pounds per square inch)}}{\text{Unit distortion (expressed as fractional part of length)}}$$

Thus, if 30,000 pounds will stretch a bar of iron 1 inch square one one-thousandth of its length, the modulus of elasticity for that iron is

30,000 × 1,000 = 30,000,000 pounds per square inch. Or, in cross bending, if a bar be bent so that the stress per square inch on the extreme fiber directly under the load is 30,000 pounds, and the elongation of this fiber in a length of 1 inch be one one-thousandth of an inch, then will the modulus of elasticity be again 30,000,000 pounds per square inch. For the different species of wood this factor varies from about 300,000 to 3,000,000. It is independent of the size and shape of the piece, as also of the method of loading.

For uniformly loaded beam,

$$E = \frac{5 f l^2}{24 \Delta h} = \frac{5 W l^3}{32 \Delta b h}$$

and for beam with concentrated load in the middle,

$$E = \frac{f l^2}{6 \Delta h} = \frac{W l^3}{4 \Delta b h^3}$$

where f is stress on the extreme fiber for the given condition of loading and Δ is the deflection in inches, the other quantities being as before.

The elastic resilience of a beam is the product of one-half the load into the deflection at the loaded point. For a beam loaded with numerous concentrated loads the resilience is one-half the total sum of each load into the deflection of beam at that point. This quantity is a function of the volume of the beam.

The elastic resilience per cubic inch, as given in Table IV, is the above quantity for rectangular beams, divided by the volume. It is a measure of the amount of shock that may be absorbed, without injury, by rectangular wooden beams loaded in the middle.

The other factors of strength are very simple and do not require explanation.*

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* For the method of making the experiments, etc., see Bulletin 8, pp. 4–8.

APPENDIX II.

REVIEW OF THE FOREGOING PAPER BY MR. G. LINDENTHAL,* CHIEF ENGINEER OF THE NORTH RIVER BRIDGE COMPANY.

The designing of trestle structures has only in recent years been undertaken by engineers; formerly it was left entirely to the practical judgment of bridge carpenters, aided by a few general rules as to strength and section of timbers issued to them by railroad managers. Usually the sizes of timber most readily handled were employed, and variation of section was avoided, as likely to lead to delay in getting the material from the sawmills. Timber being cheap and labor dear have sometimes led to constructions far from economical in an engineering sense.

Trestle bridges on almost all railroads are regarded as temporary structures, to be replaced with stone or iron structures and with filling. If the financial condition of the railroad does not permit the permanent work to be done before the timber structure becomes unsafe from wear or rottenness, it must be replaced with a new timber structure, as being the cheaper; yet it never loses its temporary character. It is true, however, that much money can be saved in the correct designing of trestles.

The proposition to classify timber structures according to the moisture they contain and to use different values for dimensioning for different moisture classifications would, I think, unnecessarily complicate the designing. It is better and simpler, as well as safer, to assume that all timber going into trestles is green and that only the unit stresses for green timber should be used in dimensioning it.† According to location and use, the timber will either remain green or will get seasoned; in the latter case there is no harm done—the timber simply gets stronger. Simplicity will always remain a valuable rule in designing such structures.

Insistence on selecting good timber, free of knots and wind shakes, is justified, and the inspection of the timber in that regard should be very rigid.

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*As explained in the letter of transmittal, the paper by Mr. A. L. Johnson, C. E., was submitted to two leading bridge engineers for review, and extracts from the expression of their views thus elicited are appended, believing that they will add to the value of Mr. Johnson's paper and to its appreciation by the public.—B. E. F.

†This is practically what the author of the paper has assumed. The moisture for all timber in trestles has been taken at 18 per cent, which is called "half-dry." The increase in strength from the green to this condition is so slight as to be immaterial.

Regarding the details of construction, it is quite proper to call attention to the stupid disproportion in strength of the columns, caps, and sills, and particularly to the inadequate bearing areas of stringers upon caps and of columns against caps and sills.

The use of mortises for joining the columns to the caps and sills, however, should be discouraged. It reduces the bearing areas, increases the amount of work in the fitting, provides places in the lumber for the accumulation of moisture, and is in every respect an unsuitable construction, borrowed from ancient roof building, where it may do less harm, being all the time under cover and absolutely dry.

I inclose a sketch, showing a much cheaper and better construction (fig. 6). In place of two vertical and two slanting legs, use four vertical legs. It is obvious that the fit of the outside slanting legs requires accurate work, consequently takes more time and money, whereas the four vertical legs being of the same length, require no special fitting.

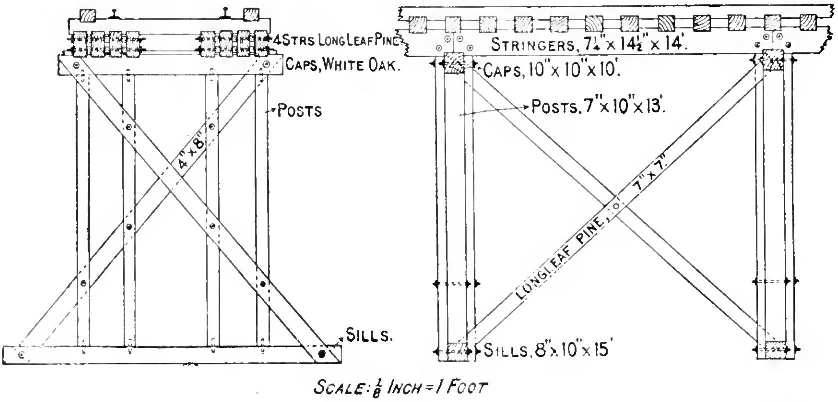

FIG. 6.—Showing construction with four vertical legs.

Next, use three-quarter-inch iron dowel pins to connect columns to caps and sills, and further use diagonal braces bolted through with three-quarter-inch bolts and large 2-inch washers, so that the trestle bent will be a compact, rigid structure which, if necessary, can be lifted with a hoist and set up in place.

I inclose another sketch, showing two vertical legs and two slanting, outside legs, using dowel pins, wooden splice pieces, and bolts for connecting the whole in the one rigid frame (fig. 7).

By using dowel pins the bearing of post on caps and sills is not impaired. The posts can be proportioned without making additions for mortises. The work of fitting is very much reduced. The larger amount of ironwork in the form of bolts and washers is *not* a disadvantage, since these can be used again in the renewal of the structure.

The detail of corbel bearings, as provided in Mr. Johnson's design, is to be commended; but I would not commend using short stringers the length of only one panel. The stringers should always be the length of two panels, with alternating joints in the two, three, or four stringers under each rail, as may be found necessary.

One point to be watched in trestle construction is to prevent the lodgment of cinders in the structure, which would set it on fire. The cinders will usually lodge between the ties on top of the stringers or between the stringers on top of the cap. For this reason it is a good practice to cover the top of the stringers, from end to end, with a galvanized-iron sheet bent down over the edges. It will not only protect the stringers against the weather, but it will also largely protect the structure against fire, on account of which a large amount of wooden trestlework each year has to be renewed. Another method used with success against fire is planking over the stringers and gravel between the ties, used by Mr. Bouscaren on a long trestle near New Orleans.

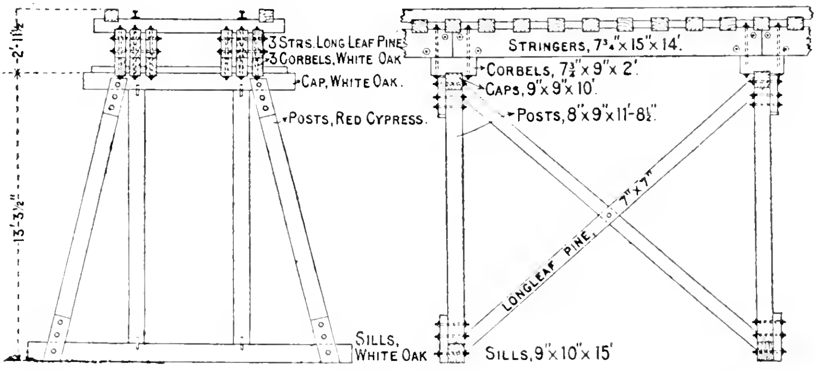

FIG. 7.—Showing construction with two vertical and two standing legs.

As regards longitudinal bracings between trestle bents, no general rules would be applicable. It will always depend upon the local conditions. Where the trestle is high or on a curve or on uncertain bottom, special provisions of bracings will have to be made.

It may not be amiss to say—although not directly connected with the subject under discussion—that no better way of economizing timber in the construction of railroads could be devised than doing away with trestles altogether.

APPENDIX III.

NOTES BY MR. WALTER G. BERG, PRINCIPAL ASSISTANT ENGINEER OF THE LEHIGH VALLEY RAILROAD.

The first section of the paper contains pertinent criticisms of the existing practice, and presents valuable suggestions and exceedingly interesting tables. The demonstration of the necessity for a more regular and uniform theoretical practice, based upon scientific research, in place of the chaotic conditions, as exhibited by Table III, is certainly apparent after a perusal of this part of the paper.

The most valuable information for the profession at large is contained in Table IV, which represents the data obtained to date from the very extensive series of timber tests of the United States Forestry Division, supplemented by the best information available in regard to other authenticated tests. This table can be considered in the nature of an advance sheet, giving the grand averages of the results of the tests mentioned up to date, and deserves to be well circulated and regarded as the latest authentic information till supplemented by future publications of the Forestry Division.

The fact, mentioned by the author of the paper, that structural iron and steel is invariably tested with the greatest degree of care, while timber for structural work is seldom given more than a cursory eye inspection for visible defects, is traceable to the fact that very little reliable data have thus far been available on which to base the strength of timber. The great variations existing in the coefficients of strength for the different parts of a timber trestle, as assumed in practice, brought out so clearly in Tables II and III, is a silent but potent argument in favor of timber tests on a large scale, as being conducted by the United States Forestry Division. These investigations, extended to include all the principal varieties of timber in use, and especially tests of large size timber struts, will have a greater tendency to effect a decided economy in the use of timber throughout the country than the presentation of individual views as to how to improve on existing practice in particular cases. With reliable knowledge of the proper coefficients of strength that can be allowed for the various parts of a timber structure, it will be perfectly safe and consistent to expect that the parties interested in the economical construction of a structure will be only too glad to avail themselves of any reasonable economy that can be effected without assuming any undue risks.

Table III illustrates, in general, that the railroad practice of the day is working with approximately correct units of strength as far as the cross breaking of stringers is concerned, but that the proper units for shearing and for bearing values across grain are either not known or entirely disregarded in a great many cases. Similarly the posts are apparently designed out of reason, but it will be noted that they are invariably too heavy, which fact is traceable in part to certain practical reasons to be mentioned later.

The statement of the author of the paper that "although the stringers in cross breaking have a factor of safety of 5, and the posts have a factor of safety of 20, the structure as a whole has a factor of safety of only 2 approximately" is not warranted as to the conclusion reached, with the whole meaning apparently thereby conveyed. The meaning would seem to be that some vital part of the structure has a factor of safety of 2 only, and hence the structure would be dangerous if loaded to twice the assumed load. As mentioned above, the low factors of safety, according to Table III, are invariably for bearing values. Timber may indent badly, due to an excessive bearing strain across grain, but this would not necessarily prove disastrous. It is more a serious question of maintenance expenses than of absolute danger to the structure.

It is hardly correct, therefore, to conclude, owing to the small bearing surfaces at the ends of stringers or of the caps on the posts, that the prevailing practice of timber-trestle construction is subject to as low a factor of safety as 2 in one of its principal parts absolutely affecting the safety of the structure.

As mentioned above, Table IV contains the most valuable information to the profession at large presented in the paper. It gives the results of the very valuable United States Government tests, mentioned above, corrected, adjusted, and supplemented by the author of the paper, whose professional standing and work in connection with these Government tests qualify him to present this information in the most authentic manner. The profession owes thanks to Mr. Johnson for compiling this table with the accompanying explanatory remarks. It would have, perhaps, made the table more valuable to have given extreme breaking unit stresses in place of safe unit stresses, leaving it to each individual designer to select his own factors of safety, while a general recommendation as to the desirable factors of safety could have been added.*

Table V is also of great practical benefit, as it is based on the latest and most reliable coefficients for the cross-breaking stress of timber.

Table VI would be of even more value to the profession than Table V, provided more information were presented relative to the new formula for columns presented in the paper upon which the table is based. It would be desirable to know the actual number and kind of tests from the results of which the new formula was developed. Presumably the information will be supplied in a future publication of the Forestry

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* They can be obtained by multiplying the safe values by the factors of safety given.

Division. A formula for large timber columns, the correctness of which can not be questioned, is a great desideratum, and would be a boon to engineers, architects, and in fact all designers of structural work.*

Table VII is indicative of the importance attributed by the author of the paper to the proper proportioning of timber structures for bearing of timber on timber across grain. The point at which an indentation due to the bearing of timber on timber across grain becomes dangerous or objectionable depends upon individual views and local conditions. The units for crushing strength across the grain are assumed by the author of the paper as being the stresses at which an indentation of 3 per cent of the height of the stick would take place.

In regard to inspection of timber, the author of the paper outlines the principal points affecting the strength of timber, which points form the basis of the investigations and tests now being conducted by the Forestry Division. There is no doubt that, with additional systematic and reliable information furnished on these different questions, the proper inspection of timber will be greatly assisted and benefited, but, as the author of the paper states, the present time is premature for the formulation of rules for scientific inspection of timber.

Referring now to the second division of the paper, in which the present practice of trestle construction is compared with designs proposed by the author of the paper, it should be said, in a general way, that it is to be regretted that, in selecting a structure from everyday practice to illustrate the actual practical economies that can be introduced, owing to our present better information on the subject of strength of timber, the author did not select some other timber structure in place of a trestle. The different parts of a railroad trestle can not always be designed so as to be subject to or to correspond to mathematical calculations, as there are certain conditions in the actual construction or erection work and subsequent use of the structure which predominate in establishing the design and the dimensions far more than theoretical calculations of the strength of individual parts.

The principal features of the proposed new designs, as compared with the present practice, consist in the recommendation for the introduction of corbels, in which case the caps are reduced to 9 inches; the scaling down of the posts to correspond to the new formula for wooden columns; the proper designing of stringers, not only to be safe for cross breaking and deflection under load, but especially for bearing value at end of stringer, and a corresponding general scaling down of all other parts, such as sills, braces, etc., although no attempt is made to warrant these last reductions of sizes by calculations.†

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*The data for the development of such a formula are being collected, but are not yet sufficient to warrant conclusions.—B. E. F.

† Not true as far as caps and sills are concerned. (See p. 28.) The braces have not been computed in the paper; in fact, they are not mentioned. There is a radical change in them, however, and I computed them before putting them in.

On the design in fig. 2, present practice, it will be noticed that there is one brace in each panel, while in the new designs there are two braces in every other panel.

The writer agrees with the author of the paper that the bearing surfaces at the ends of stringers and of caps in railroad trestles are usually too small, and that in consequence indentations of the timber take place, which means a destroying of the fiber and, in connection with moisture and constant working, subsequent speedy decay. But it will be impossible to follow the author of the paper to the extent of recommending the introduction of corbels under the ends of stringers. This may be due in part to the individual objections that the writer has always had against the use of corbels. These objections have not been overcome by a perusal of the points presented by the author of the paper in favor of corbels, and an examination of the design recommended, showing corbels, fails to reveal wherein the bearing surface on top of the cap is improved by the introduction of a corbel under each stringer, considering that the corbels as proposed are of the exact width as the stringers. The author of the paper must either assume that the corbels reduce the clear span or else that only the panel on one side of the bent is loaded. Both assumptions are wrong from a practical standpoint. As above stated, it is impossible for the writer to see how a 7¾-inch corbel resting on a 9-inch cap, giving about 70 square inches of bearing surface on top of the cap, can be an improvement over a stringer of the same width as the corbel, resting on a 12-inch cap, giving 93 square inches of bearing surface, or, according to the "example of present practice," over an 8¼-inch stringer resting on a 12-inch cap, giving 99 square inches of section.

The introduction of corbels is objectionable on account of the extra cost, without any commensurate improvement of the design, and owing to the undesirable feature of bringing more timber against timber, especially on horizontal and boxed surfaces, increasing the liability of decay. The recommendation (?) of the author of the paper to use short stringers in place of double-length stringers is a disadvantage; while a screw bolt through the corbel and stringer, tending to increase the resistance of the beam to failure by shearing, would prove, if introduced solely for this purpose, a foolish precaution in place of a wise one, for the reason that with the seasoning of the timber the grip of the bolt would be lost unless kept regularly tightened up. To do this to such an extent as to be of practical benefit would be impracticable. There are cases where corbels laid flat, i. e., made wider than the stringers, will increase the bearing value on the cap. There are also cases where the elevation of the rails on curves on trestlework can be best accomplished by the introduction of corbels, giving an opportunity to vary the elevation according to the thickness of the corbel. But as a steady,

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This latter arrangement allows the braces to be attached at their intersection by means of a bolt. Hence, instead of computing a strut large enough to transmit the thrust along the full length of the diagonal, about 18 feet, we need only determine the area necessary to transmit it half that distance. That is, in the first case we have a column 18 feet long, and in the latter case columns only 9 feet long, so that they do not need to be so large.—A. L. Johnson.

everyday practice, corbels can not be considered as desirable, and as designed and recommended by the author of the paper there is a decrease in bearing value on the cap in place of an increase.*

In relation to the posts, the aim of the author of the paper would be evidently to scale down the posts of the different bents to such odd sizes as would correspond with the mathematical calculations of strength. For the example presented of a post about 12 feet high, the author recommends a 9 by 9 inch stick in place of a 12 by 12 inch stick, or, in other words, the actual size in use is about 75 per cent larger than the theoretical requirements. This might seem to indicate that a similar disproportion prevails for all lengths of posts. Attention should be called, however, to the fact that even theoreticians would hardly desire to call for a post much less than 9 by 9 inches on a trestle for supporting heavy locomotives, even for very short posts, while the longer the post gets the more nearly the theoretical size will correspond to current practice, which is to use practically 12 by 12 inch sticks throughout. The comparatively low height of trestle assumed by the author of the paper for demonstrating the case does not really represent a fair average of the trestles in the country as far as the proportion of theoretical to actual sizes of posts is concerned. In other words, the grand average of actual current work would show that the timber used for posts is closer to the theoretical requirements than in the example assumed for illustration.

The use of 12 by 12 inch stuff indiscriminately, while wasteful of timber in certain cases, is warranted by a great many practical features which absolutely control the situation and predominate far above theo-

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* The reviewer here and elsewhere has missed the main point made for the use of corbels as proposed, namely, that they as well as caps and sills be of oak or some similar hard wood, so that a smaller bearing area will yield twice the strength. The bearing areas have been made sufficient to give a factor of safety of 3 for oak. The corbels were used to give the stringers sufficient bearing area.—A. L. J.

To this rejoinder Mr. Berg had an opportunity of replying, the reply being as follows:

"If corbels and caps of a trestle are made of a timber like oak, with a relatively high unit resistance to crushing across grain, as suggested by Mr. Johnson, then the deficient bearing at the ends of the usual stringers in practice will be obviated. It is a question, however, whether in practice it would be feasible to make such a distinction and to utilize several species of timber. For special work the proposition is all right, but for the general run of railroad work it would be difficult to introduce this innovation, especially in sections of the country where hard timber for the corbels and caps would be more costly or difficult to obtain. Practical men also claim (although how correctly I am unable to say) that different species of timber in contact with each other will rot quicker than if only one kind of timber is used, and this statement has especially been made frequently in connection with bringing oak timber and soft pine timber in contact with each other."—W. G. B.

[The last objection has no physiological basis. The former illustrates the penny-wise pound-foolish policy which unfortunately prevails with many if not most railroad companies, to the detriment of the public and the stockholders, and the necessity for competent demonstration of the financial superiority of stable, lasting structures on permanent roads.—B. E. F.]

retical calculations. Space is here too brief to enumerate all possible reasons for this apparently wanton use of 12 by 12 inch lumber, but the mention of a few will suffice to indicate the general trend of the practical questions which the writer has in mind. A railroad corporation has to keep a large stock of lumber on hand for emergencies, sudden calls for new work not allowing time to obtain lumber from the mills, and for other reasons. The uncertainty as to where the timber is to be eventually used makes it impossible to have the timber cut to specific sizes, and, again, to attempt to run a large lot of sizes would be more wasteful in the end than to maintain a few stock sizes only. Lumber can be bought more cheaply by giving a general order for "the run of the mill for the season" or "a cargo lot," specifying approximate percentages of standard stringer size, of 12 by 12 inch stuff, 10 by 10 inch stuff, etc., and a liberal proportion of 3 or 4 inch plank, all lengths thrown in. The 12 by 12 inch stuff, etc., is ordered all lengths, from a certain specified length up. In case of a wreck, washout, burn out, or sudden call for a trestle to be completed in a stated time, it is much more economical and practical to order a certain number of carloads of "trestle stuff" to the ground and there to select piece after piece as fast as needed, dependent only upon the length of stick required. When there is time to make the necessary surveys of the ground and calculations of strength and to wait for a special bill of timber to be cut and delivered, the use of different sizes for posts in a structure would be warranted to a certain extent.

The reasons presented indicate, therefore, that while it is not true economy as far as the general timber consumption of the country is concerned to use 12 by 12 inch sticks indiscriminately for posts, caps, and sills of trestles, still, in the majority of cases, it is true practical economy as far as the interest of the party who is paying for the work is concerned.

Another very important feature to consider in the designing of trestles is not only to give a proper factor of safety as established from timber tests, but to design those parts the failure of which would prove absolutely disastrous in such a way as to give an additional guaranty of safety against the racking of the structure from the unknown strains and peculiar conditions resulting from the impact of fast-moving trains with heavy concentrated wheel loads passing over the trestle, the centrifugal force caused by high-speed trains upon curved trestles, the lateral swaying induced by wind or the wobbling of the train back and forth within the play of the gauge even on a straight track, and other similar features.*

There are also other practical points to consider, such as, for instance, the possible shifting of the bearing caused by the undermining of some mudsills, or the loosening or breaking of one of the posts, in which

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*The factor of safety of 5 was an average value reported by the engineers of the railroad companies and is by the author considered sufficient only if applied to the "minima" values of strength.—A. L. J.

case a greater strain than originally contemplated is thrown on another part of the trestle. In some trestles the batter posts are spaced so far from the main posts that the main posts have to be considered as practically carrying all the load, and no one would desire to trust a 9 by 9 inch stick in that case. If the stringer is three-ply, or especially four-ply, as shown by the author of the paper in one of the recommended designs, the strain on all the stringers would not be perfectly equal and the bearing on the cap would not fall over the post in every case, which would produce certain cross strains in the cap, requiring consideration.* In addition, the fact that the cap receives a terrible punishment in the shape of direct blows from the passing rolling stock has caused actual experience to demonstrate that frequently even 12-inch sticks, especially when made of brittle timber,† will not stand, but break off.

Another practical reason for the employing of larger sizes than theoretically required in certain parts of a trestle is that certain sticks, even with the best inspection and light on the subject that we now have, will rot before others, or certain bearings will become defective long prior to others. The very best bridge inspection and supervision can not pretend to discover and repair immediately every defect as soon as it appears. Therefore an excess of strength is required to allow for the premature decaying of certain parts until such time as repairs to the structure are feasible.

In the writer's opinion, the proper method to pursue to cause true economy in the designing of trestle bridges is to circulate and spread widely the knowledge of the results obtained from the very valuable series of timber tests made by the Government, which data should be carefully studied by the designers of structures. The more economical use of timber, with due regard to the true safety of the structure, will surely and gradually follow in direct ratio as the number, reliability, and value of the Government tests increase.

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* But the responsibility is divided, should any one prove defective.—A. L. J.

† The oak cap will stand better.—A. L. J.

APPENDIX IV.

REPORT OF A COMMITTEE OF THE AMERICAN INTERNATIONAL ASSOCIATION OF RAILWAY SUPERINTENDENTS OF BRIDGES AND BUILDINGS ON "STRENGTH OF BRIDGE AND TRESTLE TIMBERS."*

Your committee appointed to report on "Strength of bridge and trestle timbers, with special reference to Southern yellow pine, white pine, fir, and oak," desire to present herewith, as part of their report, the very valuable data, compiled by the chairman of the committee, relative to tests of the principal American bridge and trestle timbers and the recommendations of the leading authorities on the subject of strength of timber during the last twenty-five years, embodied in the appendix to this report and tabulated for easy reference in the accompanying tables (I to IV).

The uncertainty of our knowledge relative to the strength of timber is clearly demonstrated after a perusal of this information, and emphasizes, better than long dissertations on the subject, the necessity for more extensive, thorough, and reliable series of tests, conducted on a truly scientific basis, approximating as nearly as possible actual conditions encountered in practice.

The wide range of values recommended by the various recognized authorities is to be regretted, especially so when undue influence has been attributed by them in their deductions to isolated tests of small-size specimens, not only limited in number, but especially defective in not having noted and recorded properly the exact species of each specimen tested, its origin, condition, quality, degree of seasoning, method of testing, etc.

The fact has been proved beyond dispute that small-size specimen tests give much larger average results than full-size tests, owing to the greater freedom of small selected test pieces from blemishes and imperfections and their being, as a rule, comparatively drier and better seasoned than full-sized sticks. The exact increase, as shown by tests and by statements of different authorities, is from 10 to over 100 per cent.

Great credit is due to such investigators and experimenters as Profs. G. Lanza, J. B. Johnson, H. T. Bovey, C. B. Wing, and Messrs. Onward Bates, W. H. Finley, C. B. Talbot, and others, for their experimental work and agitation in favor of full-size tests. Profs. G. Lanza, R. H. Thurston, and William H. Burr have contributed valuable treatises on the subject of strength of timber. The extensive series of small and full size United States Government tests, conducted in 1880 to 1882 at the Watertown Arsenal, under Col. T. T. S. Laidley, and more recently the very elaborate and thorough timber tests being conducted by the United States Forestry Division under Dr. B. E. Fernow, chief, and Prof. J. B. Johnson, of Washington

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[*] Mr. Berg also kindly supplied in time for insertion in this publication the above report on "Strength of bridge and trestle timbers," to be read before the convention at New Orleans on October 16, 1895. As this comes in the shape of a recommendation from an international body regarding the future practice, it was considered desirable to make it a part of this bulletin.—B. E. F.

University, St. Louis, afford us to-day, in connection with the work of the abovementioned experimenters, our most reliable data from a practical standpoint.

The test data at hand and the summary of criticisms of leading authorities seem to indicate the general correctness of the following conclusions:

(1) Of all structural materials used for bridges and trestles timber is the most variable as to the properties and strength of the different pieces classed as belonging to the same species; hence it is impossible to establish close and reliable limits for each species.

(2) The various names applied to one and the same species in different parts of the country lead to great confusion in classifying or applying results of tests.

(3) Variations in strength are generally directly proportional to the density or weight of timber.

(4) As a rule, a reduction of moisture is accompanied by an increase in strength; in other words, seasoned lumber is stronger than green lumber.

(5) Structures should be, in general, designed for the strength of green or moderately seasoned lumber of average quality and not for a high grade of well-seasoned material.

(6) Age and use do not destroy the strength of timber unless decay or season checking takes place.

(7) Timber, unlike materials of a more homogeneous nature, as iron and steel, has no well-defined limit of elasticity. As a rule, it can be strained very near to the breaking point without serious injury, which accounts for the continuous use of many timber structures with the material strained far beyond the usually accepted safe limits. On the other hand, sudden and frequently inexplicable failures of individual sticks at very low limits are liable to occur.

(8) Knots, even when sound and tight, are one of the most objectionable features of timber, both for beams and struts. The full-size tests of every experimenter have demonstrated not only that beams break at knots, but that invariably timber struts will fail at a knot or owing to the proximity of a knot, by reducing the effective area of the stick and causing curly and cross-grained fibers, thus exploding the old practical view that sound and tight knots are not detrimental to timber in compression.

(9) Excepting in top logs of a tree or very small and young timber, the heart wood is, as a rule, not as strong as the material farther away from the heart. This becomes more generally apparent, in practice, in large sticks with considerable heart wood cut from old trees in which the heart has begun to decay or been wind shaken. Beams cut from such material frequently season check along middle of beam and fail by longitudinal shearing.

(10) Top logs are not as strong as butt logs, provided the latter have sound timber.

(11) The results of compression tests are more uniform and vary less for one species of timber than any other kind of test; hence, if only one kind of test can be made, it would seem that a compressive test will furnish the most reliable comparative results.

(12) Long timber columns generally fail by lateral deflection or "buckling" when the length exceeds the least cross-sectional dimension of the stick by 20; in other words, when the column is longer than 20 diameters. In practice the unit stress for all columns over 15 diameters should be reduced in accordance with the various rules and formulæ established for long columns.

(13) Uneven end bearings and eccentric loading of columns produce more serious disturbances than are usually assumed.

(14) The tests of full-size long compound columns, composed of several sticks bolted and fastened together at intervals, show essentially the same ultimate unit resistance for the compound column as each component stick would have if considered as a column by itself.

(15) More attention should be given in practice to the proper proportioning of bearing areas; in other words, the compressive bearing resistance of timber with and

across grain, especially the latter, owing to the tendency of an excessive crushing stress across grain to indent the timber, thereby destroying the fiber and increasing the liability to speedy decay, especially when exposed to the weather and the continual working produced by moving loads.

The aim of your committee has been to examine the conflicting test data at hand, attributing the proper degree of importance to the various results and recommendations, and then to establish a set of units that can be accepted as fair average values, as far as known to-day, for the ordinary quality of each species of timber and corresponding to the usual conditions and sizes of timbers encountered in practice. The difficulties of executing such a task successfully can not be overrated, owing to the meagerness and frequently the indefiniteness of the available test data, and especially the great range of physical properties in different sticks of the same general species, not only due to the locality where it is grown, but also to the condition of the timber as regards the percentage of moisture, degree of seasoning, physical characteristics, grain, texture, proportion of hard and soft fibers, presence of knots, etc., all of which affect the question of strength.

Your committee recommends, upon the basis of the test data at hand at the present time, the average units for the ultimate breaking stresses of the principal timbers used in bridge and trestle constructions shown in the accompanying table.

In addition to the units given in the table, attention should be called to the latest formulæ for long timber columns, mentioned more particularly in the appendix to this report, which formulæ are based upon the results of the more recent full-size timber column tests, and hence should be considered more valuable than the older formulæ derived from a limited number of small-size tests. These new formulæ are Professor Burr's, Appendix I; Professor Ely's, Appendix J; Professor Stanwood's, Appendix K, and A. L. Johnson's, Appendix V; while C. Shaler Smith's formulæ will be better understood after examining the explanatory notes contained in Appendix L.

Attention should also be called to the necessity of examining the resistance of a beam to longitudinal shearing along the neutral axis, as beams under transverse loading frequently fail by longitudinal shearing in the place of transverse rupture.

In addition to the ultimate breaking unit stress the designer of a timber structure has to establish the safe allowable unit stress for the species of timber to be used. This will vary for each particular class of structures and individual conditions. The selection of the proper "factor of safety" is largely a question of personal judgment and experience, and offers the best opportunity for the display of analytical and practical ability on the part of the designer. It is difficult to give specific rules. The following are some of the controlling questions to be considered:

The class of structure, whether temporary or permanent, and the nature of the loading, whether dead or live. If live, then whether the application of the load is accompanied by severe dynamic shocks and pounding of the structure. Whether the assumed loading for calculations is the absolute maximum, rarely to be applied in practice, or a possibility that may frequently take place. Prolonged heavy, steady loading and also alternate tensile and compressive stresses in the same place will call for lower averages. Information as to whether the assumed breaking stresses are based on full-size or small-size tests or only on interpolated values, averaged from tests of similar species of timber, is valuable in order to attribute the proper degree of importance to recommended average values. The class of timber to be used and its condition and quality. Finally, the particular kind of strain the stick is to be subjected to and its position in the structure with regard to its importance and the possible damage that might be caused by its failure.

In order to present something definite on this subject, your committee presents the accompanying table, showing the average safe allowable working unit stresses for the principal bridge and trestle timbers, prepared to meet the average conditions existing in railroad timber structures, the units being based upon the ultimate breaking unit stresses recommended by your committee and the following factors of safety, viz:

Tension with and across grain	10
Compression with grain	5
Compression across grain	4
Transverse rupture, extreme fiber stress	6
Transverse rupture, modulus of elasticity	2
Shearing with and cross grain	4

In conclusion, your committee desires to emphasize the importance and great value to the railroad companies of the country of the experimental work on the strength of American timbers being conducted by the Forestry Division of the United States Department of Agriculture, and to suggest that the American Association of Railway Superintendents of Bridges and Buildings indorse this view by official action and lend its aid in every way possible to encourage the vigorous continuance of this series of Government tests, which bids fair to become the most reliable and useful work on the subject of strength of American timbers ever undertaken. With additional and reliable information on this subject far-reaching economies in the designing of timber structures can be introduced, resulting not only in a great pecuniary saving to the railroad companies, but also offering a partial check to the enormous consumption of timber and the gradual diminution of our structural timber supply.

WALTER G. BERG, *Chairman.*
J. H. CUMMIN.
JOHN FOREMAN.
H. L. FRY.

Average safe allowable working unit stresses in pounds per square inch recommended by the committee on "strength of bridge and trestle timbers," American Association of Railway Superintendents of Bridges and Buildings, fifth annual convention, New Orleans, October, 1895.

Kind of timber.	Tension.		Compression.			Transverse rupture.		Shearing.	
			With grain.						
	With grain.	Across grain.	End bearing.	Columns under 15 diameters.	Across grain.	Extreme fiber stress.	Modulus of elasticity.	With grain.	Across grain.
Factor of safety	10	10	5	5	4	6	2	4	4
White oak	1,000	200	1,400	900	500	1,000	550,000	200	1,000
White pine	700	50	1,100	700	200	700	500,000	100	500
Southern, longleaf, or Georgia yellow pine	1,200	60	1,600	1,000	350	1,200	850,000	150	1,250
Douglas, Oregon, and Washington fir or pine:									
Yellow fir	1,200	....	1,600	1,200	300	1,100	700,000	150	....
Red fir	1,000	....	....	....	....	800	....	....	....
Northern or shortleaf yellow pine	900	50	1,200	800	250	1,000	600,000	100	1,000
Red pine	900	50	1,200	800	200	800	600,000	....	....
Norway pine	800	....	1,200	800	200	700	600,000	....	....
Canadian (Ottawa) white pine	1,000	....	....	1,000	....	....	....	100	....
Canadian (Ontario) red pine	1,000	....	....	1,000	....	800	700,000	100	....
Spruce and Eastern fir	800	50	1,200	800	200	700	600,000	100	750
Hemlock	600	....	....	800	150	600	450,000	100	600
Cypress	600	....	1,200	800	200	800	450,000	....	....
Cedar	800	....	1,200	800	200	800	350,000	....	400
Chestnut	900	....	....	1,000	250	800	500,000	150	400
California redwood	700	....	....	800	200	750	350,000	100	....
California spruce	....	....	....	800	....	800	600,000	....	....

Average ultimate breaking unit stresses in pounds per square inch recommended by the committee on "strength of bridge and trestle timbers," American Association of Railway Superintendents of Bridges and Buildings, fifth annual convention, New Orleans, October, 1895.

Kind of timber.	Tension.		Compression.			Transverse rupture.		Shearing.	
			With grain.						
	With grain.	Across grain.	End bearing.	Columns under 15 diameters.	Across grain.	Extreme fiber stress.	Modulus of elasticity.	With grain.	Across grain.
White oak	10,000	2,000	7,000	4,500	2,000	6,000	1,100,000	800	4,000
White pine	7,000	500	5,500	3,500	800	4,000	1,100,000	400	2,000
Southern, longleaf, or Georgia yellow pine	12,000	600	8,000	5,000	1,400	7,000	1,700,000	600	5,000
Douglas, Oregon, and Washington fir or pine:									
Yellow fir	12,000	....	8,000	6,000	1,200	6,500	1,400,000	600	....
Red fir	10,000	....	....	....	....	5,000	....	....	....
Northern or shortleaf yellow pine	9,000	500	6,000	4,000	1,000	6,000	1,200,000	400	4,000
Red pine	9,000	500	6,000	4,000	800	5,000	1,200,000	....	....
Norway pine	8,000	....	6,000	4,000	800	4,000	1,200,000	....	....
Canadian (Ottawa) white pine	10,000	....	....	5,000	....	....	....	350	....
Canadian (Ontario) red pine	10,000	....	....	5,000	....	5,000	1,400,000	400	....
Spruce and Eastern fir	8,000	500	6,000	4,000	700	4,000	1,200,000	400	3,000
Hemlock	6,000	....	....	4,000	600	3,500	900,000	350	2,500
Cypress	6,000	....	6,000	4,000	700	5,000	900,000	....	....
Cedar	8,000	....	6,000	4,000	700	5,000	700,000	....	1,500
Chestnut	9,000	....	....	5,000	900	5,000	1,000,000	600	1,500
California redwood	7,000	....	....	4,000	800	4,500	700,000	400	....
California spruce	....	....	....	4,000	....	5,000	1,200,000	....	....

NOTE.—These and the following tables are printed here as part of the preceding report. In doing so the Forestry Division disclaims any apparent indorsement of the data contained therein, except as far as its own results are recorded; the other data having been probably obtained from a small number of tests without reference to and allowance for the conditions of the material as to state of seasoning, etc., believed to be an essential requisite.
B. E. F.

STRENGTH OF BRIDGE

TABLE I.—

[Ultimate breaking stress

RECOMMENDED

Authority.	Appendix reference.	Description.	Tension.				Compression.	
			With grain.		Across grain.		With grain.	
			Limits.	Average.	Limits.	Average.	Limits.	Average.
W. J. M. Rankine	A	Red oak		10,250				6,000
		English oak	10,000–19,800					10,000
Chas. H. Haswell	A	Oak				2,300		
		White oak		16,500				7,500
		Live oak		16,380				6,850
		Canadian white oak.						5,982
		Red oak		10,250				
		Pennsylvania oak, seasoned.		20,333				
John C. Trautwine	A	Oak				2,300	5,000–7,000	6,000
		White oak		10,000				
		Live oak		10,000				
		Basket, black, and red oak.		10,000				
Robert H. Thurston	A	Oak						
		White oak		10,000			5,500–8,000	
		Live oak		10,000			8,000–10,000	
		Canadian oak						
Louis De C. Berg	A	White oak		11,000		2,300		7,200
		Red oak		8,000				6,000
		Live oak		11,000				6,850
		Canadian oak		7,500				6,000
F. E. Kidder	A	White oak		16,000			3,150–7,000	
Malverd A. Howe	A	White oak		10,000				7,000
		Live oak		10,000				7,000
William Kent	A	Oak						
A. L. Johnson	W	White oak		10,000				4,000

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*Compiled for the Fifth Annual Convention of the American Association of Railway

RESULTS OF

U. S. Ordnance Department. Capt. T. J. Rodman.	B i	White oak, well seasoned.	13,333–25,222				4,691–10,058	
Thomas Laslett	B b	White oak		7,021				6,964
	B b	Baltimore oak		3,832				5,891
R. G. Hatfield	B a	Oaks, average						
		White oak		19,500			6,531–9,775	8,000
		Canadian oak						
		Live oak						11,100
U. S. Tenth Census	B h	White oak					5,810–9,070	
		White, post, iron, red, and black oak.						7,000
		Scrub and basket oak.						6,000
		Chestnut and live oak.						7,500
		Pin oak						6,500
Robert H. Thurston	B e	White oak		13,210				7,140
		Live oak		10,310				10,410
St. Louis Bridge	B d	White oak:						
		Blocks					3,200–3,778	3,505
		Round columns					6,000–12,200	7,812
		Black oak:						
		Blocks						
		Round columns					5,400–6,980	6,101
U. S. Ordnance Department. Watertown Arsenal.	B f	White oak	12,670–22,703	17,410				7,192
		Red oak	7,600–12,133	10,124				
		Yellow oak	20,260–20,520	20,390				

AND TRESTLE TIMBERS.*

Oak.

in pounds per square inch.]

VALUES.

Compression.			Transverse rupture.				Shearing.			
Across grain.			Extreme fiber stress.		Modulus of elasticity.		With grain.		Across grain.	
Limits.	Indentation.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.
				10,600						
			10,000-13,600		1,200,000-1,750,000			2,300		4,000
		2,300				1,710,000		780		4,032
				10,800						
				11,520						
				10,512						
				9,720						
					1,000,000-2,000,000	1,500,000	400-700			
				10,800						4,425
				10,800						8,180
				15,300						
								780		4,000
				11,000						
				12,000						
				10,000						
		2,400		7,200		900,000		800		4,100
				6,500		1,200,000		750		
		4,500		7,300				700		8,500
				7,000						
				5,670		1,240,000		780		4,400
	$\frac{1}{10}$″	1,600				1,500,000		850		4,400
	$\frac{1}{10}$″	1,600				1,500,000				
					971,000-2,283,000					
	3(	1,200		6,000		1,100,000		800		

Superintendents of Bridges and Buildings, October, 1895, by Walter G. Berg.

SMALL-SIZE TESTS.

			8,160-17,340							
				10,900		1,330,000				
				9,800		1,770,000				
				8,550		1,114,560				
	$\frac{1}{20}$″	2,650		11,700		1,339,200	1,076-1,474	1,250		
				10,600		1,929,312				
	$\frac{1}{20}$″	6,800								
	$\frac{1}{100}$″ $\frac{1}{10}$″	1,600 4,000	7,010-18,360		879,000-2,103,000					
	$\frac{1}{10}$″	4,000								
	$\frac{1}{10}$″	4,200								
	$\frac{1}{10}$″	4,500								
	$\frac{1}{10}$″	3,000								
				9,840		1,620,000				
				11,280		1,851,428				
1,300-2,200		1,750								
1,600-2,000		1,800								
	$\frac{1}{20}$″	2,850						842		
								803		

TABLE I.—

[Ultimate breaking stress

RESULTS OF

Authority.	Appendix reference.	Description.	Tension.				Compression.	
			With grain.		Across grain.		With grain.	
			Limits.	Average.	Limits.	Average.	Limits.	Average.
G. Lanza......	......	White oak:						
	D e	36 beams	......	......	......	......	......	......
	G a	10 posts and blocks.	......	......	......	......	3,132–4,450	3,470
	G a	18 old posts	......	......	......	......	2,943–6,147	3,957
D. Kirkaldy & son......	E b	White oak:						
		5 beams, 5 feet span.	......	......	......	......	......	......
		5 beams, 11 feet span.	......	......	......	......	......	......
		5 posts, about 6 diameters.	......	......	......	......	......	3,285
		5 posts, about 11 diameters.	......	......	......	......	......	3,418
		5 posts, about 23 diameters.	......	......	......	......	......	2,891

Oak—Continued.

in pounds per square inch.]

FULL-SIZE TESTS.

Compression.			Transverse rupture.				Shearing.			
Across grain.			Extreme fiber stress.		Modulus of elasticity.		With grain.		Across grain.	
Limits.	Indentation.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.
......	......	......	3,535–7,834	5,863	744,774–1,777,500	1,131,100	......	......	......	......
......	......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......	......
......	......	......	......	6,890	......	......	......	......	......	......
......	......	......	......	8,550	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......	......

TABLE II.—

[Ultimate breaking stress

RECOMMENDED

Authority.	Appendix reference.	Description.	Tension.				Compression.	
			With grain.		Across grain.		With grain.	
			Limits.	Average.	Limits.	Average.	Limits.	Average.
Chas. H. Haswell	A	White pine		11,800		550		5,775
John C. Trautwine	A	White pine		10,000		550	5,000–7,000	6,000
Robert H. Thurston	A	White pine	3,000–7,500				3,000–6,000	
Louis De C. Berg	A	White pine		9,000		550		5,500
F. E. Kidder	A	White pine		7,000			2,800–4,500	
Malverd A. Howe	A	White pine		10,000				5,400
H. T. Bovey	M	Canadian (Ottawa) white pine.						5,000
A. L. Johnson	W	White pine		7,000				3,500
W. M. Patton	A	White pine		7,000				9,500

RESULTS OF

Authority.	Appendix reference.	Description.	Tension, with grain, Limits.	Tension, with grain, Average.	Tension, across grain, Limits.	Tension, across grain, Average.	Compression, with grain, Limits.	Compression, with grain, Average.
U. S. Ordnance Department, Capt. T. J. Rodman.	B i	White pine, well seasoned.	11,433–11,960				5,017–5,775	
R. G. Hatfield	B a	White pine		12,000			5,579–7,502	6,650
U. S. Tenth Census	B h	White pine					3,750–5,600	5,400
Robert H. Thurston	B c	White pine		6,880				9,590
St. Louis Bridge	B d	White pine:						
		Blocks					3,083–3,694	3,261
		Columns					3,580–3,900	3,727
F. E. Kidder	B e	White pine						
U. S. Ordnance Department, Watertown Arsenal.	B f	White pine	5,300–11,299	8,916				5,617
	Q	White pine, resistance to keys tearing out.						
H. T. Bovey	M	Canadian (Ottawa) white pine.	8,503–14,273	11,396				

RESULTS OF

Authority.	Appendix reference.	Description.	Tension, with grain, Limits.	Tension, with grain, Average.	Tension, across grain, Limits.	Tension, across grain, Average.	Compression, with grain, Limits.	Compression, with grain, Average.
H. T. Bovey		Canadian (Ottawa) white pine.						
	M i	15 beams						
	M ii	68 posts						3,843
U. S. Ordnance Department, Watertown Arsenal.	H a	White pine:						
		Posts under 32 diameters.					1,687–3,700	2,414
		Posts 32–62 diameters.					1,000–2,000	
G. Lanza	D d	White pine, 37 beams.						
		Western white pine, kiln dried, 8 beams.						
Onward Bates		White pine:						
	R a	New and old, 30 beams.						
	R b	New, 14 beams						
W. H. Finley	S	White pine:						
		31 years in use, 12 beams.						
		New, 2 beams						

White pine.

in pounds per square inch.]

VALUES.

Compression.			Transverse rupture.				Shearing.			
Across grain.			Extreme fiber stress.		Modulus of elasticity.		With grain.		Across grain.	
Limits.	Indentation.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.
		550		9,000		1,830,000		490		
				8,100		1,600,000	250–500			2,480
						1,000,000		490		
		700		4,000		850,000		450		2,500
				4,320		1,073,000		490		2,480
	$\frac{1}{10}''$	600				1,750,000		325		2,480
	3/8	140		4,400		870,000		300		
				9,000				482		2,480

SMALL-SIZE TESTS.

Limits.	Indentation.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.
			6,798–7,092							
	$\frac{1}{20}''$	800		9,000		1,252,800	433–530	480		
	$\frac{1}{100}''$ $\frac{1}{10}''$	600 1,200	5,610–11,530		868,000–1,478,000					
				5,280		883,636				
555–722		611								
			7,578–9,140	8,297	1,251,252–1,461,728	1,388,497				
	$\frac{1}{20}''$	1,045						370		
							236–611	421		
							273–382			

FULL-SIZE TESTS.

Limits.	Indentation.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.
			2,500–4,936	3,388	433,250–1,181,240	754–265				
			2,456–7,251	4,151	727,200–1,565,000	1,222,000				
				5,482		1,183,037				
			2,350–5,376	3,872	712,500–1,430,900	1,098,000				
			2,160–5,131	3,694						
			5,139–10,616	7,051	715,000–1,900,000	1,208,250				
				5,402		982,500				

TABLE III.—*Southern yellow pine, longleaf yellow*

[Ultimate breaking stress

RECOMMENDED

Authority.	Appendix reference.	Description.	Tension.				Compression.	
			With grain.		Across grain.		With grain.	
			Limits.	Average.	Limits.	Average.	Limits.	Average.
W. J. M. Rankine	A	Yellow pine						5,400
Chas. H. Haswell	A	Pitch pine				550		8,947
		Yellow pine		13,000		550		
		Virginia pine		19,200		550		8,200
		Georgia pine				550		
John C. Trautwine	A	Yellow pine		10,000		550		
		Georgia yellow pine.						
		Pitch pine		10,000				
Robert H. Thurston	A	Yellow pine	5,000-12,000				6,500-10,000	
		Pitch pine	8,000-10,000					
Louis De C. Berg	A	Yellow pine		9,000				5,400
		Georgia yellow pine.		12,000				7,400
		Pitch pine		10,000				8,900
F. E. Kidder	A	Yellow pine		16,000			4,400-6,000	
Malverd A. Howe	A	Southern yellow pine.		10,000				8,500
G. Lanza	D b	Yellow pine						
A. L. Johnson	W	Longleaf pine		12,000				5,000
W. M. Patton	A	Yellow pine		20,700				11,500

RESULTS OF

U. S. Ordnance Department, Capt. T. J. Rodman.	B i	Yellow pine, well seasoned.	12,600-19,200				7,836-8,350	
Thomas Laslett	B b	Pitch pine		4,666				6,462
R. G. Hatfield	B a	Georgia pine		16,000			8,170-11,503	9,500
		Pitch pine						
U. S. Tenth Census	B h	Longleaf Georgia pine.					1,010-10,600	8,500
Robert H. Thurston	B c	Yellow pine		20,700				11,950
St. Louis Bridge		Yellow pine:						
	B d	Blocks					4,500-4,917	4,722
		Columns					4,650-4,820	4,735
F. E. Kidder	B e	Yellow pine						
U. S. Ordnance Department, Watertown Arsenal.	B f	Yellow pine	12,066-17,922	15,478				
	Q	Yellow pine, resistance to keys tearing out.						
U. S. Forestry Division, Bulletin No. 8.	C	Longleaf pine, from Alabama.	4,170-31,890	16,029			4,587-9,850	7,228

RESULTS OF

U. S. Forestry Division, Bulletin No. 8.	C	Longleaf pine, from Alabama.						
G. Lanza		Yellow pine:						
	D b	51 beams						
	G a	18 posts and blocks.					3,604-5,452	4,544
U. S. Ordnance Department, Watertown Arsenal.		Yellow pine:						
	H a	Posts under 22 diameters.					3,430-5,677	4,412
	H a	Posts 22 to 62 diameters.					1,700-3,500	
	H c	Straight grained, well seasoned, 12 posts.					5,593-8,644	7,386
		Very slow growth, 3 posts.					7,820-10,250	9,339
		Very green and wet, 3 posts.					2,795-3,180	3,015

pine, Georgia yellow pine, or Southern pitch pine.

in pounds per square inch.]

VALUES.

Compression.			Transverse rupture.				Shearing.			
Across grain.			Extreme fiber stress.		Modulus of elasticity.		With grain.		Across grain.	
Limits.	Indentation.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.
		550		9,861		2,430,000		510		
		550		9,360						
		550								
		550		14,400						
				9,600		1,600,000			4,340–5,735	
				15,300						5,735
				9,900						5,053
				7,000		1,600,000		510		
				8,000		1,900,000				
				6,000		1,100,000				4,800
		1,850		7,200		1,200,000		500		5,700
				6,600		1,225,000		510		5,000
				6,750		1,780,000		510		5,700
	$\frac{1}{10}$″	1,300				1,600,000		325		5,700
				5,000						
	3%	645		7,750		1,440,000		500		
				15,000				843		5,735

SMALL-SIZE TESTS.

			8,796–11,676	9,972						
				11,900		1,900,000				
	$\frac{1}{20}$″	2,250	9,000–21,168	15,300		2,468,800	713–931	840		
				9,792		1,225,152				
	$\frac{1}{100}$″ $\frac{1}{10}$″	1,300 2,600	9,220–21,060		879,000–2,878,000					
				16,740		3,534,727				
1,000–1,222		1,092								
			12,280–14,654	13,048	1,707,282–1,926,160	1,821,630				
	$\frac{1}{20}$″	1,900						352		
							337–720	512		
584–2,094	15	1,517					464–1,299	852		

FULL-SIZE TESTS.

			4,268–16,200	12,250	842,000–3,117,370	2,069,650				
			3,963–11,360	7,486	1,162,467–2,386,096	1,757,900				

TABLE IV.—*Douglas, Oregon, Washington,*

[Ultimate breaking stress

RECOMMENDED

Authority.	Appendix reference.	Description.	Tension.				Compression.	
			With grain.		Across grain		With grain.	
			Limits.	Average.	Limits.	Average.	Limits.	Average.
Robert H. Thurston	A	Oregon pine	9,000-14,000				9,200-11,500	
		California spruce	12,000-14,000				9,200-12,800	
F. E. Kidder	A	Oregon pine		13,800				
		Oregon spruce						
H. T. Bovey	M	Douglas fir						6,000
		Douglas fir, specially selected.						
		Douglas fir, ordinary first quality.						
Arthur Brown, Southern Pacific Ry.	O b	Pacific Northwest (Douglas) fir.		15,900				6,000
A. L. Johnson	W	Douglas fir						4,400
								RESULTS OF
U. S. Ordnance Department, Capt. T. J. Rodman.	B i	Oregon yellow fir	13,633-16,833				7,488-9,217	
		Oregon red fir		12,867				7,083
		Oregon white fir		14,533				6,644
U. S. Tenth Census	B h	Red and yellow Douglas fir.					4,880-9,800	
W. B. Wright	O d	Red fir		10,872				6,099
		Yellow fir		11,550				6,132
Oregon and California R. R.	O e	Douglas fir		16,600				3,085
		Oregon sugar pine.		11,000				3,391
Robert H. Thurston	O c	Oregon pine					9,200-11,500	
		California spruce.					9,200-12,800	
U. S. Ordnance Department, Watertown Arsenal.	B f	Oregon pine		13,810				8,597
		Oregon spruce		16,160				5,772
H. T. Bovey	M III	Douglas fir, 71 tests.	2,485-18,856	11,612				
	M IV	Douglas fir						
John D. Isaacs, Southern Pacific Ry.	T	Douglas fir		15,900				6,000
								RESULTS OF
Onward Bates		Douglas fir:						
	B i	12 beams						
		10 beams (omitting 2 bad sticks).						
H. T. Bovey		Douglas fir:						
	M I	Specially selected, 4 beams.						
	M I	Ordinary first quality, 15 beams.						
	M II	122 posts						5,974
		British Columbia spruce:						
	M I	3 beams						
	M II	69 posts						3,617
C. B. Talbot, Northern Pacific R. R.	N a	Washington yellow fir, 5 small beams.						
	N e	Washington yellow fir, hard fine grain, 1 small beam.						
	N e	Washington pine, fine grain, 1 small beam.						

and California fir, pine, and spruce.

in pounds per square inch.]

VALUES.

Compression.			Transverse rupture.				Shearing.			
Across grain.			Extreme fiber stress.		Modulus of elasticity.		With grain.		Across grain.	
Limits.	Indentation.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.
				11,071						
				12,228						
								810		
								310		
								400		
				9,000		2,000,000				
				6,000		1,430,000				
				13,630		1,272,000		600		
	3%	500		6,600		1,380,000				

SMALL-SIZE TESTS.

			7,740-10,944							
				6,728						
				4,194						
			8,220-17,920		1,308,000-2,579,000					
				15,894						
				15,030						
	$\frac{2}{100}''$	1,000		8,658			515-833	689		
	$\frac{1}{100}''$	1,000		8,370						
				11,071						
				12,228						
	$\frac{1}{20}''$	1,150		17,223				786		
	$\frac{1}{20}''$	695						311		
							377-411	103		
						1,272,000		600		

FULL-SIZE TESTS.

			3,597-7,544	5,791						
			5,268-7,544	6,214						
			8,020-10,441	9,054	1,931,500-2,178,100	2,036,529				
			4,027-8,382	6,081	926,500-1,770,563	1,431,209				
			4,614-5,908	5,120	1,011,450-1,528,499	1,203,633				
			6,890-9,720	7,847						
				9,720						
				5,116						

TABLE IV.—*Douglas, Oregon, Washington, and*

[Ultimate breaking stress

RESULTS OF FULL-

Authority.	Appendix reference.	Description.	Tension.				Compression.	
			With grain.		Across grain.		With grain.	
			Limits.	Average.	Limits.	Average.	Limits.	Average.
A. J. Hart, Chic., Milw. and St. Paul R. R.	N b	Washington yellow fir:						
		green, 4 beams.	....	......	......	......	....	......
		6 years seasoned, 2 beams.	....	......	......	......	....	......
A. J. Hart and C. B. Talbot.	N c	Washington fir, 9 beams.	....	......	......	......	....	......
S. Kedzie Smith	N d	Washington yellow fir, close grain, 2 beams.	....	......	......	......	....	......
	N d	Washington red fir, 8 beams.	....	......	......	......	....	......
	O a	Washington yellow and red fir, 19 beams.	....	......	......	......	....	......
Report Washington Chapter Amer. Inst. Architects.	N f	Douglas fir, 11 beams.	....	......	......	......	....	......
		Washington yellow fir, 13 beams.	....	......	......	......	....	......
		Washington red fir, 11 beams.	....	......	......	......	....	......
		Average of all tests.	....	......	......	......	....	......
Charles B. Wing	U	Douglas fir, ordinary No. 1 merchantable:						
		10 beams.	....	......	......	......	....	......
		10 small beams.	....	......	......	......	....	......

California fir, pine, and spruce—Continued.

in pounds per square inch.]

SIZE TESTS—Continued.

Compression.			Transverse rupture.				Shearing.			
Across grain.			Extreme fiber stress.		Modulus of elasticity.		With grain.		Across grain.	
Limits.	Indentation.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.	Limits.	Average.
....	....	....	6,143–7,982	7,323	....	....	....	......	......	......
....	....	....	5,935–6,088	6,020	....	....	....	......	......	......
....	....	....	5,263–7,561	6,273	....	....	....	......	......	......
....	....	....	7,500–8,160	7,830	....	....	....	......	......	......
....	....	....	1,255–6,138	5,186	....	....	....	......	......	......
....	....	....	3,530–8,160	5,420	....	....	....	......	......	......
....	....	....	....	5,979	....	....	....	......	......	......
....	....	....	....	7,402	....	....	....	......	......	......
....	....	....	....	5,186	....	....	....	......	......	......
....	....	....	....	6,359	....	....	....	......	......	......
....	....	....	5,580–7,951	6,482	....	....	....	......	......	......
....	....	....	6,438–12,056	9,257	....	....	....	......	......	......

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